Master thesis on Cognitive Systems and Interactive Media

Universitat Pompeu Fabra

Augmented Reality through a Heritage Experience: From Individual to group Interaction

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Abstract

Cultural Heritage experiences have been improved through times. New technologies like augmented and mixed reality have allowed many stakeholders to improve the offer and also its impact over users; transferring knowledge with informal learning methodologies. However, the traditional augmentative approach is commonly based on the Window-on-the-World (WoW) paradigm; which may isolate the user when a group experience is expected. Therefore, this proposal is based on the new paradigm World-as-Support; which was declared a few years ago, exposing the "Magic Lantern" as a tool for projective augmentation and extended reality.

Keywords: Interactive experiences; Augmented reality; Cultural Heritage

Chapter 1

Introduction

1.1 Problem Statement

Augmented and Mixed Reality (AR/MX) offer the potential to turn the invisible visible [1, 2], exposing virtual content on physical world elements, but also allowing the interaction with them. It has been usually implemented with mobile or tablet displays; generating the "Window on the World" (WoW) paradigm. However, that solution may limit the impact over subjects around it or even reduce the attention that they pay to the physical environment during the experience.

As a response, new approaches have appeared; which is the case of the so-called "World-as-Support" (WaS) interaction paradigm, grounded in the tradition of projective augmentation, extended reality, embodied interaction, tangible interaction and Full-Body interaction [3, 2, 4]. Some recent studies have implemented functional WaS prototypes, in fact, we are developing the “Magic Lantern”, which is a projective AR-based handheld device consisting of a smartphone connected to a pico-projector; it dynamically recognizes the surrounding physical world and projects the context-aware digital information directly on it. Also, we have carried out multiple experiments aimed to identify its influence on child learning and on their relationships within a group. Despite those reflected positive results about the WaS and WoW comparison, we expose the necessity of comparing the paradigms within dif-

ferent contexts in order to validate their findings.

The current investigation proposes the integration of the "Magic Lantern" as a WaS tool to improve the group and explorative experience within the Museu d'Història de Barcelona (MUHBA). Considering the environment and technology involved, two roles for the subjects can be defined: (1) "Magic lantern" holder and (2) non-holder; nevertheless, in order to avoid possible biases, the experience will limit users to hold the same role throughout the visit. Therefore, the analysis aims to identify differences between each kind of role for WaS and WoW situations from three key indicators: (1) learning, (2) usability and (3) user engagement.

Aimed to find specific insights for both kinds of subjects, the experiments will be focused on the impact of the augmented heritage experience by measuring the subject's knowledge about clearly defined elements or keywords related to Barcino's culture. Additionally, it will allow us to test the users' capability to hold information after a while; taking into account the power of a memorable experience to generate valuable knowledge. It is also relevant to highlight that learning experiences for spaces such as archaeological sites have become an important field for the design of virtual cultural heritage [2].

Furthermore, the usability test will take as first priority the "Magic Lantern"-based experience capability to intuitively expose how to play throughout the visit; including multiple interaction points for the holder and non-holder users. Measures such as reaction time, the time between points of interaction and the number of interest points found will be analyzed.

Finally, the user engagement indicator aims to identify the interest of the subjects about the proposed WaS-based technology; considering the motivation of the non-holder user to change the role or the motivation of the holder subjects to find all hidden points of interest throughout the experience.

1.2 Context

As mentioned before, this research project is a continuation of previous studies from the Full-Body Interaction Lab in the Universitat Pompeu Fabra; therefore, a collaboration between the lab and the Museu d'Història de Barcelona (MUHBA) has been imperative to provide access to the cultural heritage site as well as to expose the history behind it. Then, the research process was influenced by many people, taking into account the personnel from the museum and the partners in the lab; especially the supervisor Narcís Parés, classmate Paul Hine and two undergraduate students: Santiago Gonzalez and Danae Costa.

1.3 State of the art

1.3.1 Digital technologies for cultural heritage

The inclusion of digital technologies in museum and heritage settings suggests a new phase of our relationship with the digital world, it includes a wide range of advanced interfaces and interaction techniques [5]; from 360-degree panoramas to tell stories and simulate time travel, to stereoscopic displays to dazzle with 3D views of historic locations. Furthermore, the integration of audio guides, video mapping, and immersive visualization has led to complex interactions between users, machine, designer, site, and heritage experience. That complexity is represented in new ways based on storytelling guidelines or even procedurally generated narratives [6]. Although Interactive narrative (IN) technologies have not yet been solidified and it is still a topic of research, some scholars place emphasis on the promise of the medium to evoke empathy. They present the necessity of an IN rather than a non-interactive one to generate a successful experience. Even if, at first glance, it may seem an unlikely fit to combine interaction and history because we cannot change what has happened in the past, when it is acknowledged that the act of storytelling is constructivist (i.e. It allows the students to construct their own learning experiences), we can notice that the storytelling of history has always been interactive. For instance, the Rensselaer Polytechnic Institute has been working over the past six years in a course mainly

focused on Augmented Reality and Design for Cultural Heritage (CH). Applying a collaborative, co-design approach with stakeholders, they have built seven projects, starting from prototypes up to its implementation for the public, most of them made with Unity and Vuforia or Apple ARkit. All of those are WoW-based applications where the user scans some code or pattern at specific points through the visit to expose virtual content in the screen-based device [6].

Additionally, augmented reality has been splitted into marker-based AR and markerless AR; the first one, as mentioned before, uses markers that are often made with distinct patterns like QR codes or other unique designs such as fiducials, which act as anchors for the technology. When a marker in the physical world is recognized by an augmented reality application, the digital content is placed on top of it. On the other hand, markerless AR does not require artificial patterns to expose virtual content, in fact, the implemented algorithm has the capability to recognize features in the environment, such as planes or edges and determine them as new anchors that trigger elements or actions within the augmented reality application. For instance, in 2012, the CHESS project (Cultural Heritage Experiences through Socio-personal Interaction and Storytelling) implemented interactive exhibitions that enabled audiences to enhance their experiences by re-injecting the sense of discovery and wonder. AR is used as an extension of the presentation form: when pointing the screen-based device towards a statue triggers its original bright colors, along with superimposed text and audio annotations [7, 8, 9]. Outdoor AR experiences have also been explored, but those are limited by factors such as variable lighting (and shadows) conditions, caused by changes in the environment (objects height and orientation, obstructions, occlusions), the weather, and the time of day. A case study focused on the Parliament Buildings National Historic Site in Ottawa, Canada has been conducted based on a markerless multi-image approach, which is characterized by using a set of images taken at different times of the day and from the same position. The experiment presented an effective result in an outdoor experience by implementing the Vuforia library for image tracking; however, the researchers aim to compare the performance against a model-based tracking [10].

However, one could argue that by using the device's camera to perceive the world

isn't the fact of augmenting the reality, but virtualizing it instead. Therefore, virtual heritage (VH) experiences have been designed in order to avoid "digital dividers" such as screen-based devices and also considering the heritage conservation policies (e.g. restrictions of modifications to the physical space), poor lighting conditions and the high degree of humidity in shelters, which limit the possibilities to permanently install multimedia content in situ [11]. A research was carried in the context of the "Refugi 307", one of the 1.402 bomb shelters that were built by civilians during the Spanish Civil War in Barcelona, considered as a CH site, nowadays part of the History Museum of Barcelona. The project was aimed to define the requirements for the design of a full-body interactive VH learning experience based on the WaS interaction paradigm, also integrating "Magic Lantern" prototypes [4, 11]. Ethnographic study and participatory design were carried out to achieve a prototype that complements the guided tour within a learning experience. The researchers suggest the augmentation of "invisible" aspects of the environment and also the promotion of specific actions to support the learning process, the integration of context-aware AR activities through location-based projections by presenting content from different perspectives to allow comparison, environment-aware AR to represent missing content, and finally, social-aware AR activities through multiple pieces of content and a common task to incite empathy in the users [2, 4, 12].

The video mapping made in Sant Climent de Taüll (Leida, Spain) is another example of the use of new technologies to expose the artistic heritage. The original handmade pieces, also considered world heritage, were moved from the places they were created to the National Museum of Art of Cataluña with the aim to preserve them; however, the curators of these places have requested these artworks to be returned. Therefore, the project Taüll 1123 recreated the Romanesque frescoes of the San Clemente's church through an audiovisual projection; allowing the spectators to travel in time and see how it was in 1920 at the time when the originals were moved, and how it was in 1123, year of consecration of the paintings. The technology implemented offers the potential to expose the past in situ and compare it with current status without physically modifying the heritage space. The video-mapping technique also known as projection mapping or spatial augmented reality is based on a digital scanning

of the space in order to reproduce its edges and shapes, then it can be virtually modified through a projection [13, 14]. At the final stage of the video-mapping experience, it shows a lantern effect to help people identify the difference between past and present, which is a similar behavior presented by the “Magic Lantern” in the “Refugi 307” project; the results can be noticed in Figure 1.

(a) Current state. (b) Digital reconstruction.

Figure 1: Comparison between the current state of the Sant Clement art heritage piece and digital reconstruction made with video mapping technique.

1.3.2 Embodied Interaction in Cultural Heritage

To identify the impact of a WaS-based and explorative experience over different users (“holders” and "non-holders”) through a museum visit, it is important to describe our understanding of embodied interaction. Initially defined as “the creation, manipulation, and sharing of meaning through engaged interaction with artifacts”, afterwards it included space, place, and technology as core elements that influence the whole body movement and physical actions in general [2]. Then, as mentioned by Bonini in 2008 and recalled by Marie Schaper in 2019, knowledge is unfolded through movement and experiences [2, 15]. In fact, learning has been considered a body-anchored experience and embedded in action; a clear example is the case of sports training, where awareness about one’s own body movement can affect performance, safety and even motivation for an activity [16, 17]. Moreover, it is known that people interact with the world based on perception, which is obtained by touching, looking at, listening to, tasting and smelling. Therefore, we are in constant exploration of the environment, trying to identify opportunities and dangers

but we investigate and try to understand our surroundings as well; in other words, we are constantly interacting with everything around us [18]. Furthermore, we consider it convenient to mention the origins of our "Full-body interaction" definition, which has been built from a merge between Varela's and Dourish's statements. It is based on how we understand the world through our bodies and the actions they enable, focused on human-product interaction rather than the product experience itself exposed by Rompay et al. in 2015 [19]. Thereby, we included the Dourish's embodiment definition which denotes the property of "being manifest in" and of "the everyday world", implying a participative status but also presenting interaction as an embodied phenomenon that happens in the physical and social world as well; consequently, his declaration also involves the concept of tangibility aimed to present the evolution of Human-Computer Interaction (HCI) and influenced by what he called "Tangible Computing" [20, 21]. However, that general definition could only embrace the embodied interaction concept, then we integrated the Varella definition which holds that cognition is what living systems do in interaction with their environment, in fact, he argues that knowledge depends on being in a world that is inseparable from our bodies, our language, and our social history. Taking that into account, we concluded with the term "Full-body Interaction" as a participative status within a constantly evolving environment, which is waiting to be explored through embodied actions [22, 23].

CH experiences usually integrate navigation and exploration to generate meaning in historical contexts, thus, users can feel immersed and so their memories may be linked to a specific location or stimuli. However, as mentioned before, the traditional augmentative approach for these spaces is commonly based on the Window-on-the-World paradigm; which may lead to a significant degree of isolation from other visitors and turn a group experience to an individual one [11]. Then, we propose the Window-as-Support paradigm approach, but it must also include particular experiences that allow the "holder" and "non-holder" users to interact not only with the virtual content but also with each other. In that way, the CH experience becomes an entertainment visit with AR game-based learning (ARGBL), and cooperative situations [24].

1.3.3 User Engagement

Through time, it has been proved that good user experience and engagement lead to better performance, understanding, and remembrance. An engaged student may learn more than those who are not [25]. Hence, many strategies to enhance user experience and engagement have been exposed, including the one called "Gamification" i.e., the use of game design elements in nongame contexts [26]; however, a "gamified" experience cannot be interpreted as a complete game, because its focus always remains on some specific task that must be done [27].

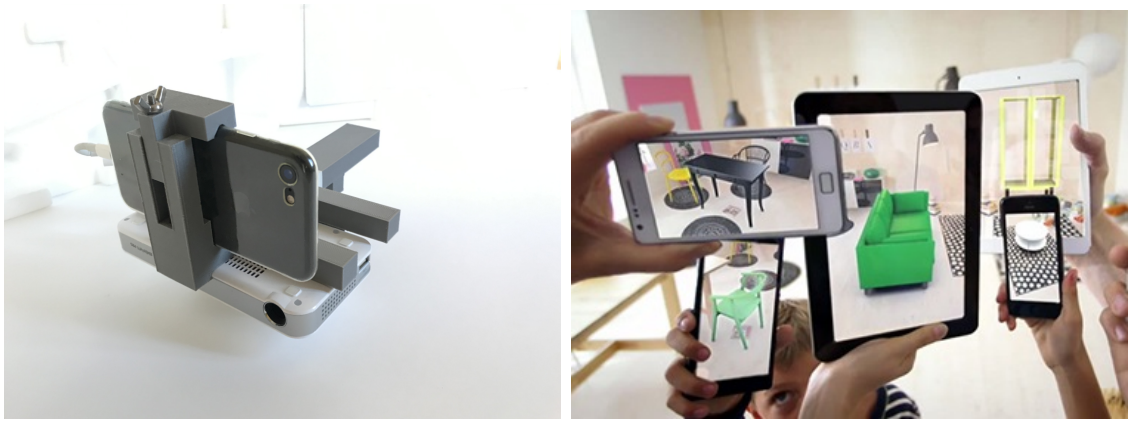
Therefore, researchers and game developers integrated educational content within game-based contexts, creating the so-called "Serious Games", which are aimed to transfer knowledge, teach skills and raise awareness. Some related reports have exposed significant improvements in subject understanding, diligence, and motivation [24, 27].

Chapter 2

Methods

2.1 Research Approach & Study

This survey is focused on the influence of the emergent augmented reality paradigms within a Cultural Heritage experience and it aims to compare the World-as-Support (WaS) based "Magic Lantern" tool versus the traditional Window-on-the-World (WoW) smartphone 2. Punctually, we argue that a WaS approach would improve the group experience more than the usual case of integrating a WoW digital divider such as a screen-based device.



(a) World-as-Support device. (b) Window-on-the-World devices.

Figure 2: Tools based on the emergent Augmented reality paradigms.

Therefore, from a scenery with a group of subjects and only one WaS device, two kinds of interactors have been defined: holder and non-holder; each one represents the role assigned to the participants and it will greatly influence their experience. Since the role cannot be changed during the experiment, we expect to obtain declarative and behavioral data to posteriorly compare the results between both WaS and WoW approaches and for each interactor's type.

2.1.1 Research Question & Hypotheses

In relation to the above described, the following research question is defined: World-as-Support based device can influence positively a Cultural Heritage group experience more than a traditional Window-on-the-world approach?. Thereby, a couple of hypotheses are in concern,

- Learning: The Full-body Interaction provided by integrating a WaS device would increase the user's capabilities to remember the experience as well as the core elements of the culture
- Usability: Since each paradigm offers a different way to interact with the digital content, there will be a significant difference between WoW and WaS based experiences
- User Engagement: It would motivate the whole group to interact with the experience and with each other

2.1.2 Original Plan

The following Gantt chart 3 exposes the original plan for the project, including all the design and development process, also internal testing in the lab and testing in situ were planned in order to proceed with official trials. However, at the beginning of March, an exceptional situation occurred and so the rest of the process was modified as shown in the "Covid-19 and lockdown: adaptation of project" subsection 2.1.3.

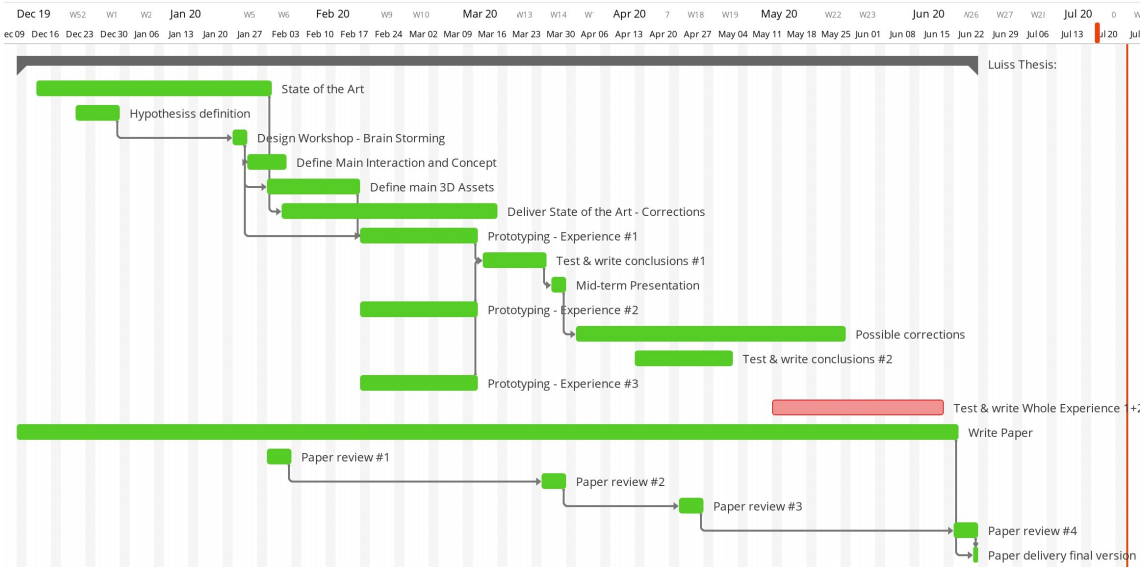


Figure 3: Gantt Chart that describes the original plan for the project.

2.1.3 Covid-19 and lockdown: adaptation of project

Every research implies a degree of uncertainty and it is known that many external factors may influence the results; as researchers, we are concerned about the experiment's validity and so its replicability. However, the probability of facing an exceptional situation is always present; this probability came true this time with the shape of the world-wide COVID-19 crisis.

The COVID-19 has had a huge impact on the world and the government's response to close all non-essential businesses has made unachievable the normal execution of the experiments as planned. Firstly, the deployment process requires the calibration and execution of technical proofs on-site at the Barcelona Museum of History (MUHBA); additionally, as mentioned above, the main objective is to present a full-body interaction experience and compare the behavior of a group of subjects with at least two people. Each person has a specific role that would highly influence his/her behavior throughout the visit. One of the roles must hold the device that guides the travel across the remains inside the Barcino excavation and also the device is responsible for triggering the multiple experiences that we have designed.

Hence, the original plan has been modified in order to proceed as smoothly as possible. The changes can be noticed in the new gantt chart below 4

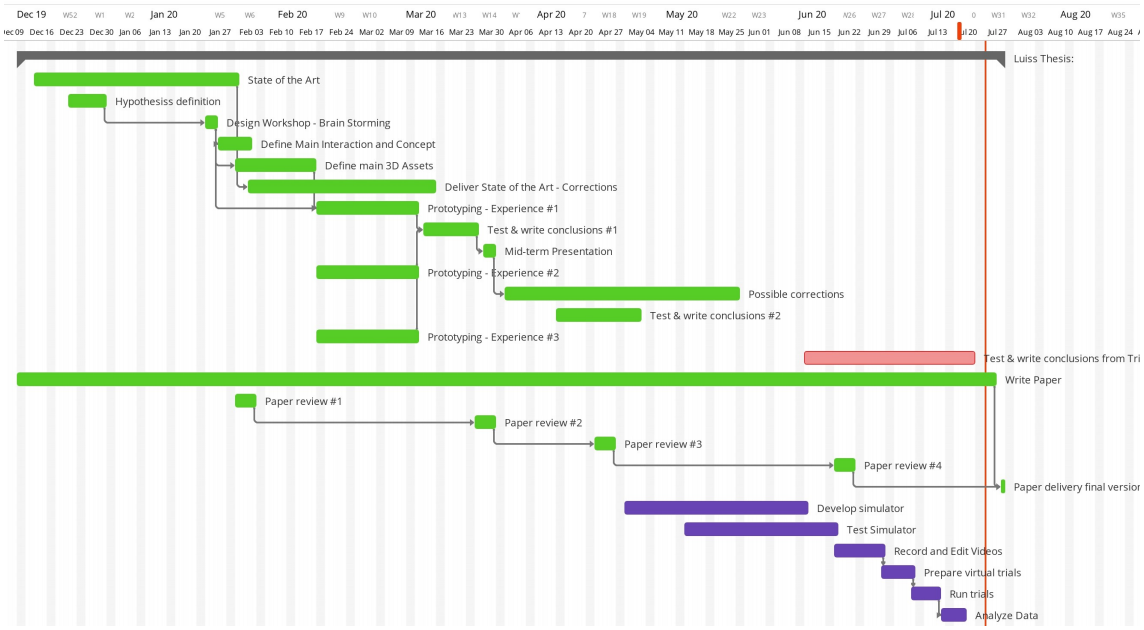


Figure 4: Gantt Chart that describes the adaptation plan for the project.

2.2 Design of AR Interactive Experiences

2.2.1 Design & Development criteria

Firstly, it is imperative to mention that we faced the declared research question by applying a design thinking approach and the objectives tree is attached in the appendix A; so we managed to empathize with the problem through a preliminary investigation about the Barcino culture along with a tour-guided visit to the Museu d'Història de Barcelona. By speaking directly with the experts about the ruins of Barcino, the team was allowed to identify the key elements to lead the experience design and put all potential points of in situ interaction into consideration.

So, we have been focusing on the remains placed in the MUHBA on La Plaça del Rei; which was the first nucleus of the museum since its opening to the public in 1943. It exposes items from Roman Barcino in the 1st century B.C. to the Barcelona of the 13th century A.D. and to the early middle ages. Visitors to this underground

area can walk along the streets of Roman Barcelona, past the city wall; they can look around a laundry from the 2nd century A.D. and see the remains of the city's first Christian community, as well as other spaces. This site also features some important medieval buildings at its surroundings, such as Palau Reial, the Chapel of Santa Àgata and Saló del Tinell, in addition to the Gothic mansion of Casa Padellàs, originally located in another part of the city. The latter building is now used for temporary exhibitions on modern and contemporary Barcelona. The visit to the Monumental Site of Plaça del Rei involves a journey through an area stretching over 4,000 m2, much of which is located beneath the actual square. By revealing Roman Barcelona's urban structure, the remains allow the visitor to take a close look at the commercial life of the city, some of its craft production centers, and the everyday life of Barcelona's first Christian community. As well as the underground area, MUHBA Plaça del Rei includes the buildings that make up the old Palau Comtal, later renamed Palau Reial. They are fascinating examples of Romanesque and Gothic architecture, and they were also important sites for the expansion of Barcelona in medieval times.

Experience Design

The experience design was leaned on the elements that have been considered as the most iconic of Barcino's culture: water, wine, and garum, as well as representative places such as the laundry, garum factory, and forum. Afterward, a brainstorming workshop was executed and the proposals have been implemented within the Unity3D environment; those are described in the Final Experiences subsection 2.2.3.

Interaction Design

The main interaction was defined based on the interests of the research as well as considering the advantages and limitations of the technology and scenery. Therefore, we argued that an explorative experience would fit the requirements of the cultural heritage tour and also bring valuable conclusions about the group and individual behavior; however, the embodied exploration should be executed without being in direct contact with the remains because of their historical value. Despite that, as an

advantage, the "Magic Lantern" allows the users to interact with the ancient surfaces without touching them or modifying their state; the tool projects content over the remains and presents the potential to explore virtual portals and travel across the history. Additionally, the user can interact with specific augmented reality elements by pointing at them with the light of the "Magic Lantern" and hold the aim for a few seconds so the radial progress bar presented in the figure 5 is shown to subsequently trigger the action after the load is completed; it has been developed by integrating a ray cast from the camera viewpoint.

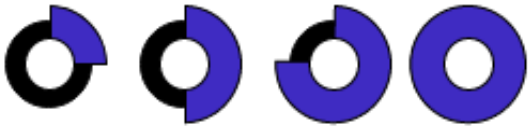


Figure 5: Progress Bar implemented as visual feedback to enable the interaction with virutal elements within the AR Application.

Each element is placed in relation to punctual sites into the museum and the application has been developed to identify the features presented in that particular scenario; their location is exposed in figure 6.

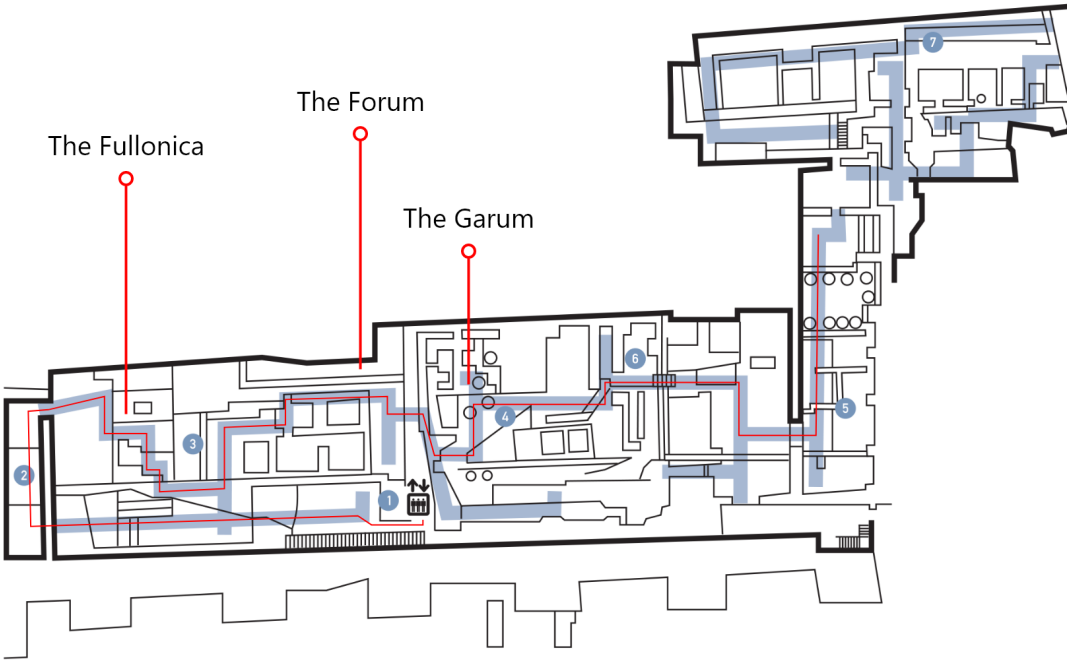


Figure 6: Progress Bar implemented as visual feedback to enable the interaction with virutal elements within the AR Application.

2.2.2 Tools & technology

Most of the development has been built in Unity3D, however, it is relevant to mention the main external source included into the project, the ARFoundation SDK. This open-source package allows the developer to create Augmented Reality applications within an easy-to-use and well documented escene. We have focused on the ARKit XR Plugin for iOS, however, it supports many other features from ARCore, Magic Leap and HoloLens.

As an extra effort, an editor mode has been developed in order to create AR scenes in real-time; storing key points from the environment and establishing a relation between them and the virtual content in order to hold their positions. Most of it was developed before starting with the experience design aimed to facilitate the creative process. See the figure 7.

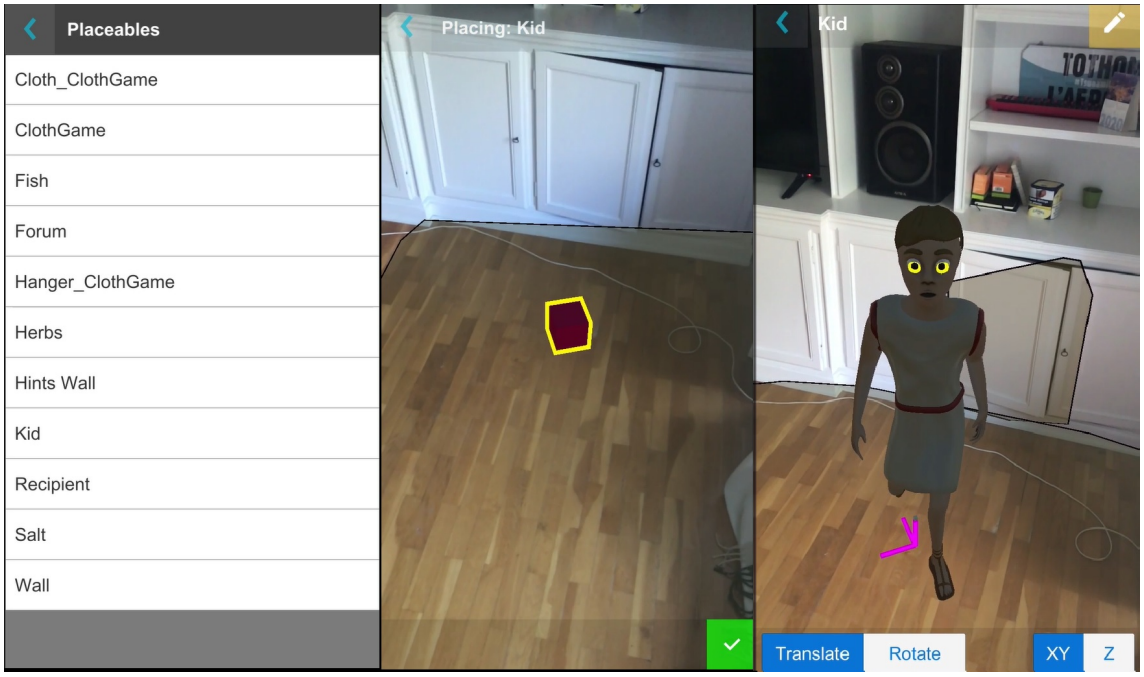


Figure 7: Editor Mode used to create the virtual worlds in Augmented Reality..

2.2.3 Final Experiences

The Forum

The experience is aimed to expose the external structure of the Barcino's Forum, which was a representative building located in the middle of the city. We found that inside the museum we can access a gray wall that presents low light conditions so it is perfect to achieve a very good projection and it is also positioned in the right direction to where the forum was, thereby we designed the experience in a way that the subject can perceive the past through a projected portal on the wall.

Additionally, the 3D model that we integrated in the AR application was created in the Full-Body Interaction Lab and we considered as the main reference the Barcino3D web application exposed in the Ajuntament website, see figure 8.

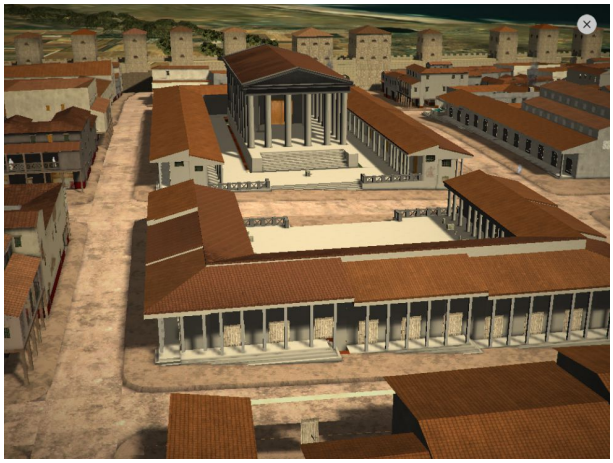


Figure 8: Visualization of the Forum's 3D-Model from the Barcino3D web application.

Therefore, as part of the iterative design process, many technical proofs have been executed in order to achieve a stable projection. Despite the fact that the low light conditions are positive to increase the resolution of the projection, the fidelity of the tracking system that identifies the features on the environment has been compromised but good results were still achieved, see figure 9.

Figure 9: Projection of the Forum in situ.

The Fullonica

The workshops dedicated to laundry and dyeing were located near the entry of the city that was also close to the Cardo Maximus. Some analysis found that they used to hang the clothes on large sticks of wood and so let the sun dry those off [28].

Thereby, we defined an experience that allows the users to grab some cloth on the ground by aiming at it with the flashlight and so move it around until they find an available hanger to place it, as exposed in the figure 10.

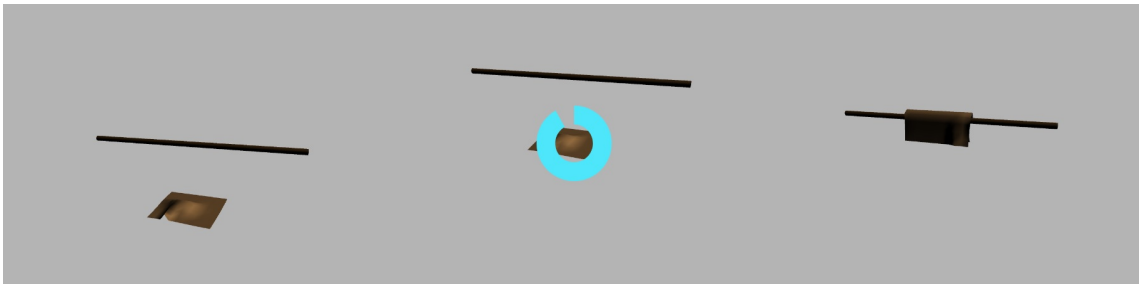


Figure 10: Interaction with the cloth at the laundry. Explore until find the object (1), aim to the interactable object (2), wait for the progress bar to trigger the grab action (3), move the object to the hanger (4).

Furthermore, the experience has been designed and tested in situ, which helped to identify that the color of the projected content must be brighter in order to improve the perception and avoid a low contrast against the real-world elements; see figure 11.

Figure 11: Interaction with the cloth at the laundry. Explore until find the object (1), aim to the interactable object (2), wait for the progress bar to trigger the grab action (3), move the object to the hanger (4).

The Garum Factory

From the guided visit, we found that another representative element from Barcino's culture is the garum or fish sauce, which was very popular in the Roman ages; to the point of becoming imperative for many foods. It was based on fish offal, salt, and herbs (see figure 12); however, the process of fabrication requires at least 6 months to ferment [29]. Actually, the remains of the Barcino factory are still in the museum and because of that, we decided to develop an experience to present the core elements of the sauce and suggest the challenge of collecting all the ingredients to make the sauce and sequentially mix them into a recipient or dolia.

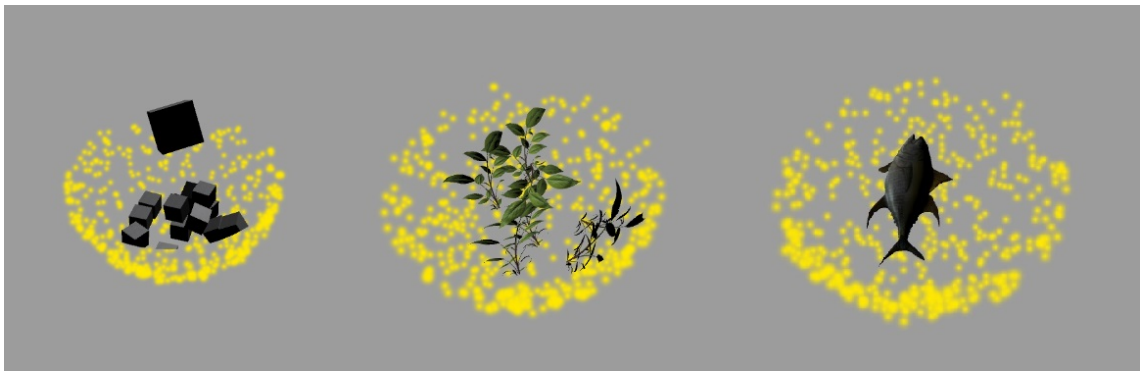


Figure 12: Ingredients required to produce garum. Salt, herbs, and fish.

The interaction procedure is similar to the one presented in the Fullonica, but with the difference that all ingredients must be dropped into the dolia one by one and so the sauce making process will start. The following figure describes the procedure 13.

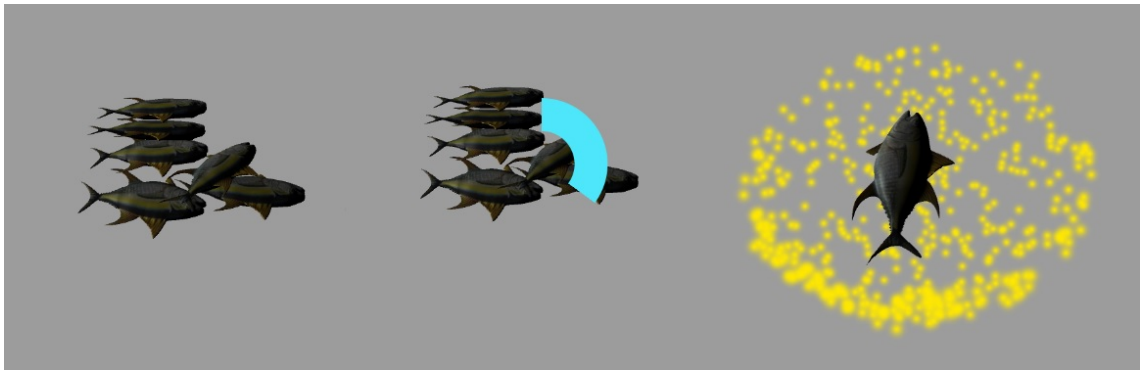
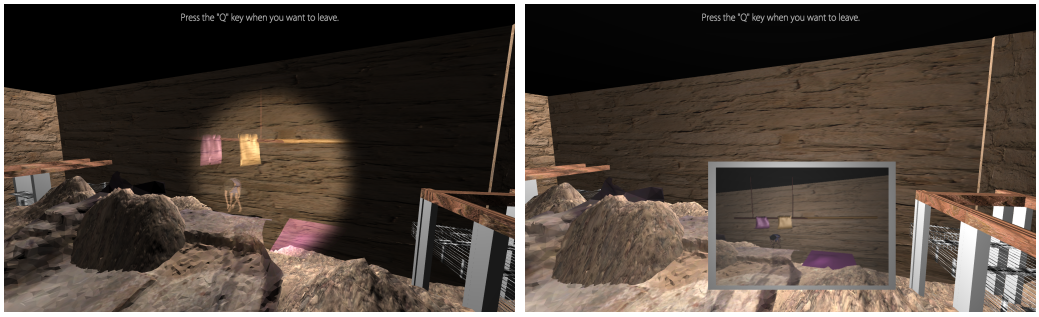


Figure 13: Procedure to collect the fish.

2.2.4 Virtualization of experiences due to Covid-19

The circumstances do not allow the improvement of the technology nor its integration in real trials because those require observing users interacting and holding the prototype at MUBHA. Despite that, an alternative solution has been presented in order to replicate the heritage scenario as a virtual guided tour. However, that ignores the full-embodied and physical/group interaction. To mitigate that, we have leaned on some videos aimed to give the subjects an idea of how the real project would be.

Therefore, a simulator has been developed with Unity3D; taking into account the core elements exposed within the real museum. The subjects were allowed to walk throughout a digital version of the Barcino remains and interact with the "augmented" content. The experiment involved two groups, ones were exposed to the World-As-Support simulated experience, meanwhile, the others faced a Window-on-the-World situation 14.



(a) Group 1: World-As-Support. (b) Group 2: Window-on-the-World.

Figure 14: Perspective by groups within the simulator.

Additionally, the team made an effort to make the experience as immersive as possible, thereby most of the 3D environment was created by scanning some parts of the real museum with the Display.land AR tool; which is able to extract features from the real world and generate a relatively accurate 3D model. However, these models were still noisy and a clean up in Blender was required 15 16.

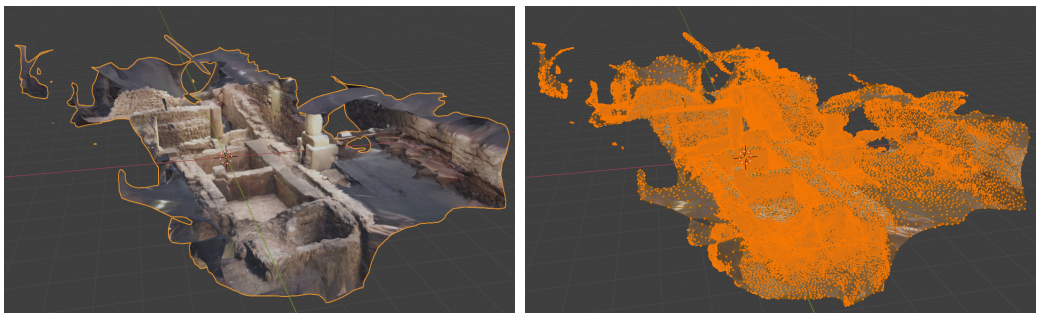


Figure 15: Noisy model scanned with Display.land.

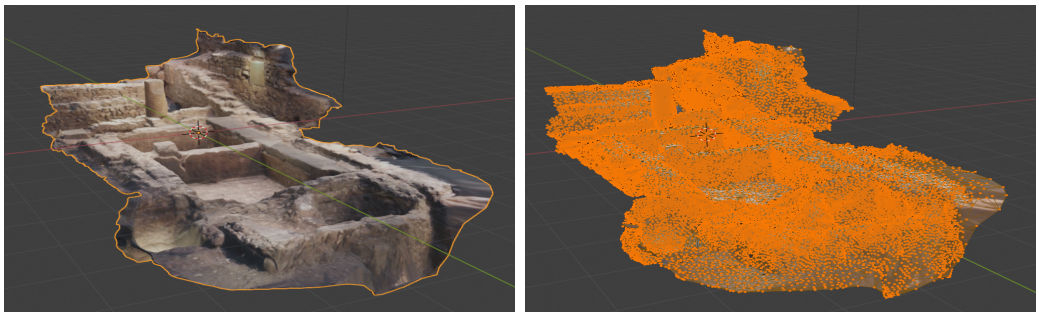


Figure 16: Cleaned model edited in Blender.

Detailed flow can be found in the Anexo B.B.

2.3 Experimental design and set-up

Due to external limitations, the experimental design has been compromised and so the design improvements below described are the result of an iterative development process with constant proofs in the Full-Body Interaction Lab.

At first, we identified that the Forum experience had issues with the depth perception, which could decrease the visual impact of the exploration process; so we decided to integrate a border in the portal to emphasize the parallax effect. Thereby, the forum would feel far from the wall in which it has been projected, simulating its location in the past.

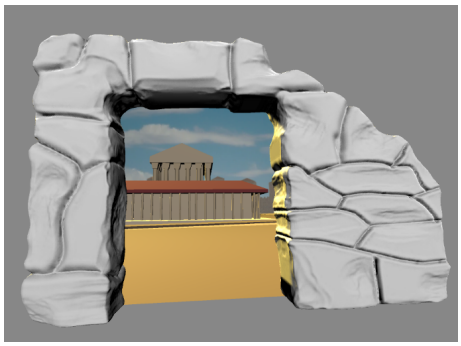


Figure 17: Portal with parallax effect, integrated in Unity3D and aimed to expose the Forum of the ancient Barcino at the distance.

Furthermore, the Fullonica experience was likely not very intuitive, so we suggested introducing a character executing the task as an explicit affordance for the user; as shown in the figure 18.

Figure 18: Animation integrated as affordance to guide users into the action of hanging the clothes at the Fullonica.

Finally, we decided to improve the physical structure of the “Magic Lantern”; this would highly influence the user experience because the subject could interact in a better way with the proposed technology by being more confident at every action, it would also decrease the probability of any physical damage to the involved elements. The work in progress is shown in the figure 19.

Figure 19: Work in progress of the new "Magic Lantern" case.

2.3.1 Experimental Set-Up

In order to successfully execute the trials in situ, the hardware may vary depending on the paradigm in concern. Thereby, the following table describes the elements 1

Table 1: Elements required for in situ trials.

World-As-Support Trial	**Window-on-the-World Trial**
Magic Lantern	AR Device
BarcinoXR application	BarcinoXR application
Questionnaire, printed or digital	Questionnaire, printed or digital

Additionally, it is highly recommended to fully charge all the devices before each trial to avoid tracking issues or interruptions. The defined flow can be found in the appendix C.A.1.

2.3.2 Virtualization of the experimental Set-Up

On the other hand, the virtual version of the trial planned due to the Covid-19 contingency, it only requires a compatible device for running the simulator; which can be either Windows or macOS system but in both cases, it may require administrator rights to unzip the file and execute the game. The invitation letter is presented as a notion webpage and can be shared through social media or any other digital service such as email. Furthermore, the videos presented have been posted as private in Vimeo and only the participants are allowed to watch them. The flow with detailed information is presented in the appendix C.A.2.

2.4 Data Gathering

The experiment proposed has the potential to ensure a significant difference between the experience faced by holders and non-holder users in comparison with both WaS and WoW paradigms. That dissimilarity can be exposed by analyzing behavioral data and declarative survey data. However, due to an exceptional situation, the procedures have been influenced to only focus on the main exposed paradigms and their overall impact throughout the heritage experience. Unfortunately, the unavailability of presence in situ at the museum within a group experience, forced the trials to be executed via simulation and individually from each subject's home. Details on methodology are described above 2.2.4.

2.4.1 Behavioral Data

While interacting with the virtual environment that we have built, the user's position and rotation are being tracked; thereby, we can replicate the movement he/she does throughout the experiment. That data is stored locally in the device within a JSON structure, also including demographic data such as gender and age; after the trials, the file is extracted manually and prepared to be analyzed. The format is exposed in the appendix B.A.

2.4.2 Declarative Survey Data

A multimodal survey has been designed with the objective to measure the learning rate and remembrance. Therefore, the questions allow us to identify if there is a significant difference with respect to the impact over the user's memory between each experience by the WaS and WoW users. It can be found in the appendix C.B.

Furthermore, another one is also presented and it is based on the Game Experience Questionnaire (GEQ); holding a scale from "not at all" to "extremely". This one is aimed to measure User Engagement levels [30].

Chapter 3

Results

Below are exposed both behavioral and declarative data obtained from the executed trials. Dataset consists of three different groups of information, data captured by the system is behavioral data stored during the virtual visit to the simulated museum, then data from questionnaires is composed of 41 Likert scale questions, and finally, a couple of memory tasks were executed within a multimodal survey.

3.1 Data captured by system

The following graphs correspond to the behavioral data and they represent the movement of the user within the simulation of the cultural heritage experience and the general points of interactions for all the subjects that presented the trial 20 21.

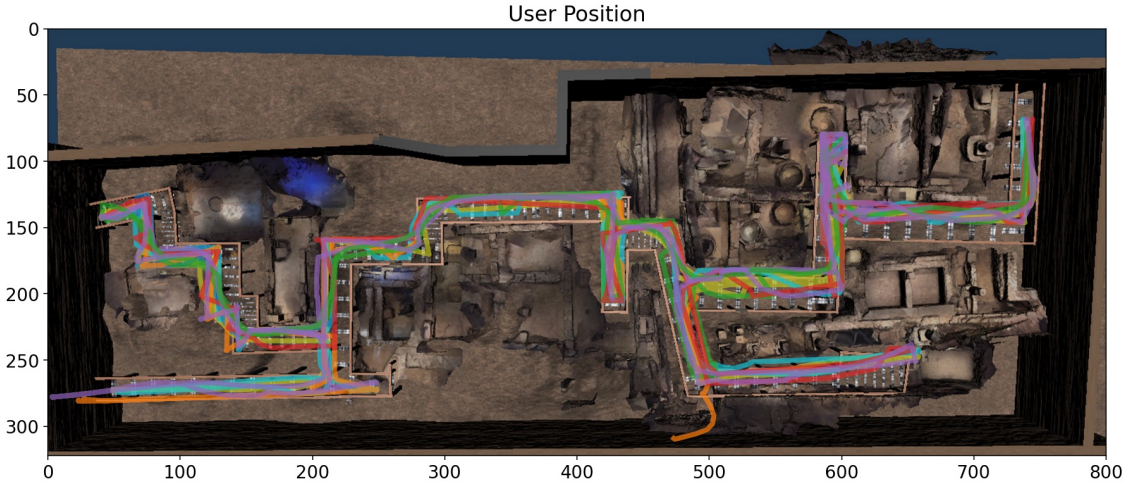


Figure 20: Describes the route followed by users throughout the visit.

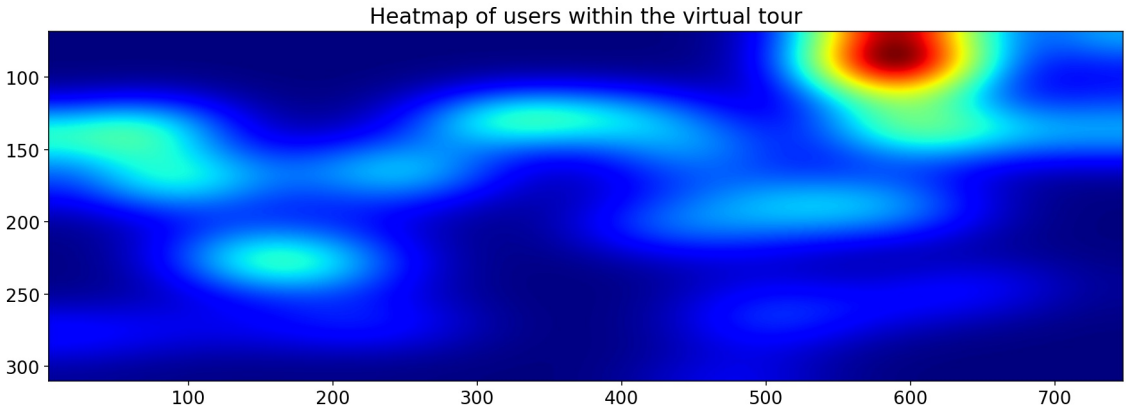


Figure 21: Describes the zone with major users presence over time.

In addition to the movement of the users through the experience, the interaction with augmented content has been logged as well. The following graphs expose the interaction points by users for each group 22 23.

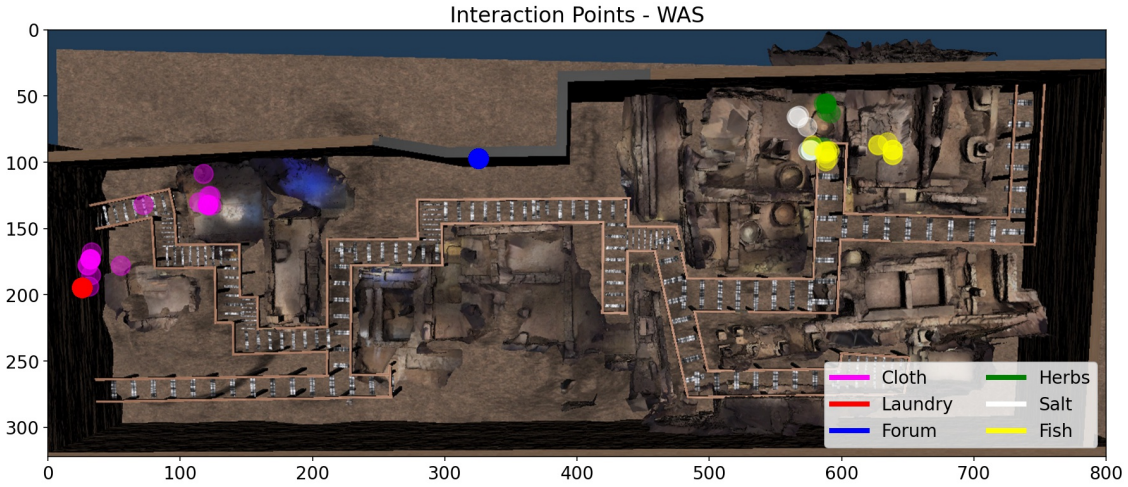


Figure 22: Interaction with augmented content for all users in World-As-Support group.

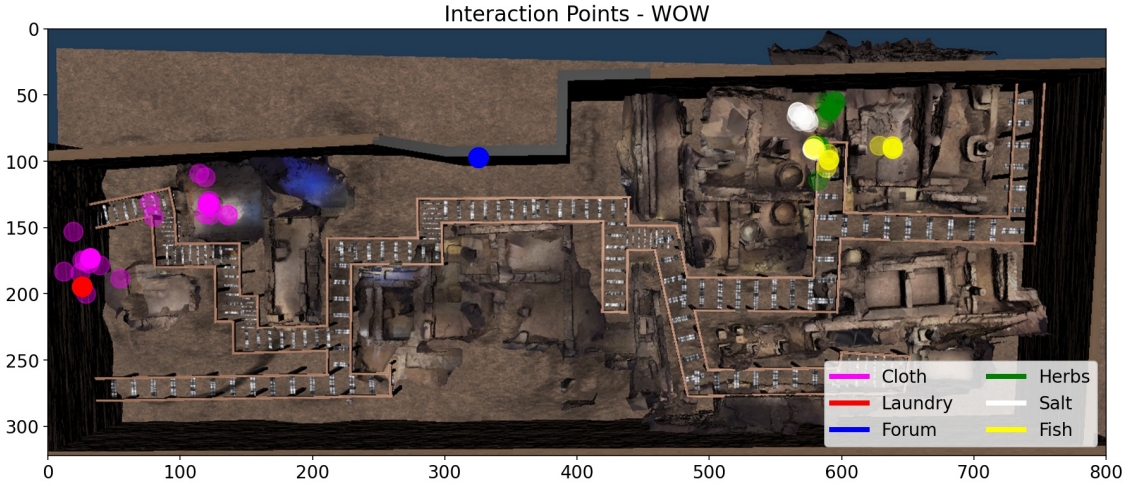


Figure 23: Interaction with augmented content for all users in Window-on-the-World group.

3.1.1 Data from questionnaires

In relation to the declarative data, 41 Likert-based questions were presented to the subjects; these are focused on Usability and User Engagement matters on a scale from 0 to 5; being 0 strongly disagree and 5 equals to strongly agree. The full questionnaire can be found in the appendix C.A. Therefore, the results for each question were analyzed according to the Shapiro-Wilk test to identify if the data follows a normal distribution as shown in the Figure 24.

	WOW MEAN	WOW STD	WAS MEAN	WAS STD	WAS SHAPIRO	WOW SHAPIRO	WAS NORMAL	WOW NORMAL	ALL NORMAL
EX05_01	4.200000	1.549193	3.900000	1.595131	0.002738	0.000031	False	False	False
EX05_02	3.200000	0.918937	2.900000	1.728840	0.259707	0.148798	True	True	True
EX05_03	4.100000	0.875595	3.500000	1.581139	0.083165	0.016694	True	False	False
EX05_04	4.800000	0.421637	3.900000	1.523884	0.001311	0.000005	False	False	False
EX05_05	5.000000	0.000000	3.700000	1.494434	0.007892	1.000000	False	True	False
EX05_06	4.800000	0.632456	4.100000	1.595131	0.000231	0.000000	False	False	False
EX05_07	4.000000	1.563472	3.600000	1.646545	0.045274	0.000718	False	False	False
EX05_08	4.900000	0.316228	4.000000	1.563472	0.000718	0.000000	False	False	False
EX05_09	4.200000	0.788811	3.200000	1.316561	0.000742	0.025134	False	False	False
EX05_10	3.200000	1.032796	2.600000	1.349897	0.197747	0.011390	True	False	False
EX05_11	3.000000	1.414214	2.800000	1.475730	0.514116	0.002999	True	False	False
EX06_01	4.400000	0.699206	3.500000	1.649916	0.062016	0.008489	True	False	False
EX06_02	4.200000	1.032796	3.200000	1.475730	0.055710	0.011390	True	False	False
EX06_03	4.200000	0.918937	2.900000	1.286684	0.028454	0.004219	False	False	False
EX06_04	3.900000	1.523884	3.100000	1.370320	0.142367	0.001311	True	False	False
EX06_05	3.500000	1.581139	2.500000	1.900292	0.207801	0.083165	True	True	True
EX06_06	4.900000	0.316228	4.000000	1.490712	0.000109	0.000000	False	False	False
EX06_07	4.800000	0.632456	4.100000	1.523884	0.000076	0.000000	False	False	False
EX06_08	3.100000	1.728840	2.800000	1.619328	0.098470	0.018158	True	False	False
EX06_09	4.800000	0.421637	3.900000	1.449138	0.000086	0.000005	False	False	False
EX06_10	3.900000	1.663330	3.600000	1.577621	0.024912	0.001519	False	False	False
EX06_11	4.900000	0.316228	4.200000	1.549193	0.000031	0.000000	False	False	False
EX06_12	4.700000	0.483046	4.100000	1.595131	0.000231	0.000047	False	False	False
CQ02_01	4.200000	0.788811	3.700000	0.948683	0.286870	0.025134	True	False	False
CQ02_02	3.500000	0.707107	3.500000	0.707107	0.002088	0.002088	False	False	False
CQ02_03	4.300000	0.674949	3.400000	1.429841	0.268272	0.015409	True	False	False
CQ02_04	3.400000	1.577621	2.800000	1.619328	0.108805	0.042069	True	False	False
CQ03_01	4.600000	0.516398	3.700000	1.494434	0.007892	0.000169	False	False	False
CQ03_02	4.300000	0.674949	3.000000	1.825742	0.096539	0.015409	True	False	False
CQ03_03	4.500000	0.527046	3.700000	1.494434	0.007892	0.000254	False	False	False
CQ03_04	4.000000	0.816497	3.500000	1.957890	0.002980	0.035215	False	False	False
CQ03_05	3.400000	1.837873	3.100000	1.728840	0.004728	0.052893	False	True	False
CQ03_06	4.800000	0.421637	3.800000	1.475730	0.001302	0.000005	False	False	False
CQ03_07	4.400000	1.577621	4.200000	1.619328	0.000046	0.000001	False	False	False
CQ04_01	4.700000	0.674949	3.800000	1.475730	0.001302	0.000009	False	False	False
CQ04_02	3.100000	0.994429	2.500000	1.509231	0.086880	0.152012	True	True	True
CQ04_03	4.600000	0.516398	3.600000	1.429841	0.004797	0.000169	False	False	False
CQ04_04	3.100000	1.197219	2.400000	1.429841	0.268272	0.691488	True	True	True
CQ04_05	2.600000	1.776388	3.000000	1.247219	0.006826	0.076350	False	True	False
CQ04_06	3.500000	1.080123	3.100000	1.286684	0.003036	0.258241	False	True	False
CQ04_07	3.900000	1.523884	3.100000	1.595131	0.294621	0.001311	True	False	False
CQ04_08	4.600000	0.516398	3.800000	1.619328	0.003088	0.000169	False	False	False

Figure 24: Exposes the normality test for each question. Yellow cells from the 'ALL NORMAL' column represent a normal distribution for each question respectively.

Consequently, T-Test or Mann-Whiney Test was run for each question in order to identify any differences between the groups 25 26.

	WOW MEAN	WOW STD	WAS MEAN	WAS STD	WAS SHAPIRO	WOW SHAPIRO	WAS NORMAL	WOW NORMAL	ALL NORMAL	ttest
EX05_02	3.200000	0.918937	2.900000	1.728840	0.259707	0.148798	True	True	True	0.633844
EX06_05	3.500000	1.581139	2.500000	1.900292	0.207801	0.083165	True	True	True	0.217070
CQ04_02	3.100000	0.994429	2.500000	1.509231	0.086880	0.152012	True	True	True	0.307710
CQ04_04	3.100000	1.197219	2.400000	1.429841	0.268272	0.691488	True	True	True	0.250661

Figure 25: Exposes t-test for the questions with normal distribution according to the Shapiro-Wilk Test.

From the above-exposed table it's relevant to mention the questions in concern:

- When I didn't see any augmented content, I was bored
- It was easy to walk between one point of interaction to another one
- I think I found all of the artifacts in the historical site
- It was easy to find the artifacts

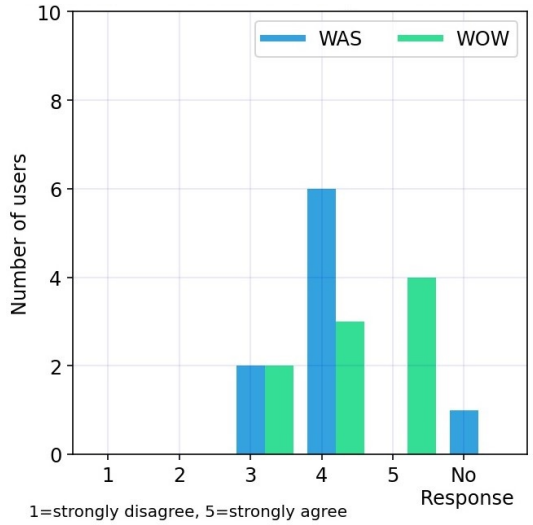
	WOW MEAN	WOW STD	WAS MEAN	WAS STD	WAS SHAPIRO	WOW SHAPIRO	WAS NORMAL	WOW NORMAL	ALL NORMAL	mannwhitneyu
EX05_01	4.200000	1.549193	3.900000	1.595131	0.002738	0.000031	False	False	False	0.279258
EX05_03	4.100000	0.875595	3.500000	1.581139	0.083165	0.016694	True	False	False	0.238655
EX05_04	4.800000	0.421637	3.900000	1.523884	0.001311	0.000005	False	False	False	0.031024
EX05_05	5.000000	0.000000	3.700000	1.494434	0.007892	1.000000	False	True	False	0.001043
EX05_06	4.800000	0.632456	4.100000	1.595131	0.000231	0.000000	False	False	False	0.081857
EX05_07	4.000000	1.563472	3.600000	1.646545	0.045274	0.000718	False	False	False	0.260867
EX05_08	4.900000	0.316228	4.000000	1.563472	0.000718	0.000000	False	False	False	0.027331
EX05_09	4.200000	0.788811	3.200000	1.316561	0.000742	0.025134	False	False	False	0.027773
EX05_10	3.200000	1.032796	2.600000	1.349897	0.197747	0.011390	True	False	False	0.151038
EX05_11	3.000000	1.414214	2.800000	1.475730	0.514116	0.002999	True	False	False	0.303671
EX06_01	4.400000	0.699206	3.500000	1.649916	0.062016	0.008489	True	False	False	0.114332
EX06_02	4.200000	1.032796	3.200000	1.475730	0.055710	0.011390	True	False	False	0.040367
EX06_03	4.200000	0.918937	2.900000	1.286684	0.028454	0.004219	False	False	False	0.011565
EX06_04	3.900000	1.523884	3.100000	1.370320	0.142367	0.001311	True	False	False	0.042064
EX06_06	4.900000	0.316228	4.000000	1.490712	0.000109	0.000000	False	False	False	0.011949
EX06_07	4.800000	0.632456	4.100000	1.523884	0.000076	0.000000	False	False	False	0.045781
EX06_08	3.100000	1.728840	2.800000	1.619328	0.098470	0.018158	True	False	False	0.375568
EX06_09	4.800000	0.421637	3.900000	1.449138	0.000086	0.000005	False	False	False	0.014093
EX06_10	3.900000	1.663330	3.600000	1.577621	0.024912	0.001519	False	False	False	0.235809
EX06_11	4.900000	0.316228	4.200000	1.549193	0.000031	0.000000	False	False	False	0.066807
EX06_12	4.700000	0.483046	4.100000	1.595131	0.000231	0.000047	False	False	False	0.250716
CQ02_01	4.200000	0.788811	3.700000	0.948683	0.286870	0.025134	True	False	False	0.123372
CQ02_02	3.500000	0.707107	3.500000	0.707107	0.002088	0.002088	False	False	False	0.385046
CQ02_03	4.300000	0.674949	3.400000	1.429841	0.268272	0.015409	True	False	False	0.082995
CQ02_04	3.400000	1.577621	2.800000	1.619328	0.108805	0.042069	True	False	False	0.185891
CQ03_01	4.600000	0.516398	3.700000	1.494434	0.007892	0.000169	False	False	False	0.046000
CQ03_02	4.300000	0.674949	3.000000	1.825742	0.096539	0.015409	True	False	False	0.040367
CQ03_03	4.500000	0.527046	3.700000	1.494434	0.007892	0.000254	False	False	False	0.081167
CQ03_04	4.000000	0.816497	3.500000	1.957890	0.002980	0.035215	False	False	False	0.500000
CQ03_05	3.400000	1.837873	3.100000	1.728840	0.004728	0.052893	False	True	False	0.253395
CQ03_06	4.800000	0.421637	3.800000	1.475730	0.001302	0.000005	False	False	False	0.012216
CQ03_07	4.400000	1.577621	4.200000	1.619328	0.000046	0.000001	False	False	False	0.327203
CQ04_01	4.700000	0.674949	3.800000	1.475730	0.001302	0.000009	False	False	False	0.024030
CQ04_03	4.600000	0.516398	3.600000	1.429841	0.004797	0.000169	False	False	False	0.018045
CQ04_05	2.600000	1.776388	3.000000	1.247219	0.006826	0.076350	False	True	False	0.274882
CQ04_06	3.500000	1.080123	3.100000	1.286684	0.003036	0.258241	False	True	False	0.331196
CQ04_07	3.900000	1.523884	3.100000	1.595131	0.294621	0.001311	True	False	False	0.097588
CQ04_08	4.600000	0.516398	3.800000	1.619328	0.003088	0.000169	False	False	False	0.128827

Figure 26: Exposes Mann-Whitenay Test for the questions with a non normal distribution according to the Shapiro-Wilk Test. Green cells represent a significant difference between groups.

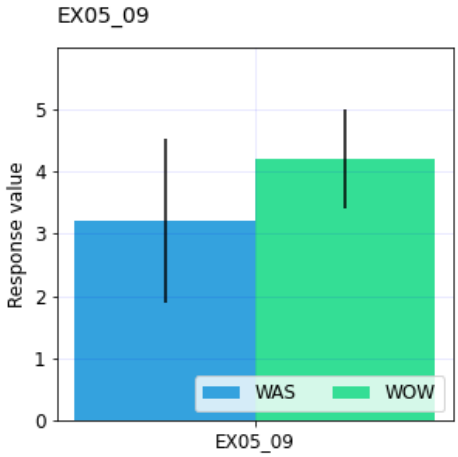
Then, below are presented the 15 highlighted questions from the Mann-Whitney significance table.

- I like the idea of using some kind of device like this that adds augmented imagery to a historical site during a visit
- I like the idea of using the device for visits to the Barcino heritage site
- I found the idea of holding a device to be adequate in the exploration activities
- I found natural the interaction between the augmented content and the environment
- It was easy to identify how to interact with the augmented elements
- I liked the timing of the progress bar to execute the actions related to the augmented content
- The speed of the animations was clear enough to understand what was happening
- The augmented elements made the experience more valuable
- Augmented content made the visit more interesting
- I think that the device helped me to explore the past
- I liked exploring the remains of Barcino
- I liked the layout and presentation of the virtual visit to Barcino
- I would recommend that others visit ancient Barcino, physically or virtually
- I liked finding and examining or interacting with the artifacts of the past
- I liked the paths available to explore Barcino

Afterward, we focused the analysis on the four following questions. See Figures 27 28 29 30.

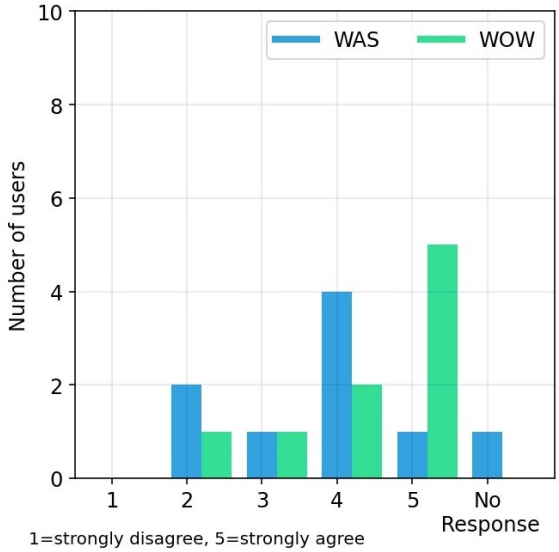


(a) Number of users for each answer in the Likert scale.

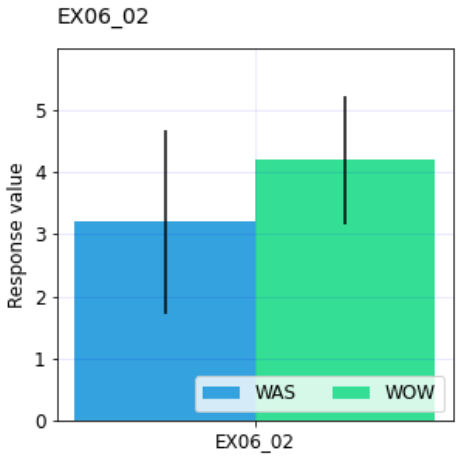


(b) Mean of answers in Likert scale.

Figure 27: I found natural the interaction between the augmented content and the environment.

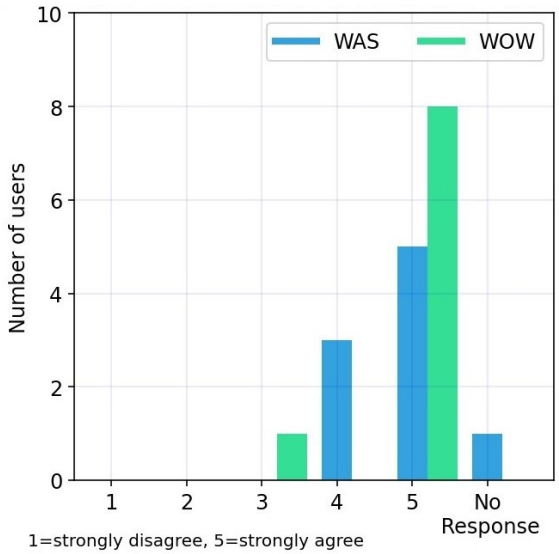


(a) Number of users for each answer in the Likert scale.

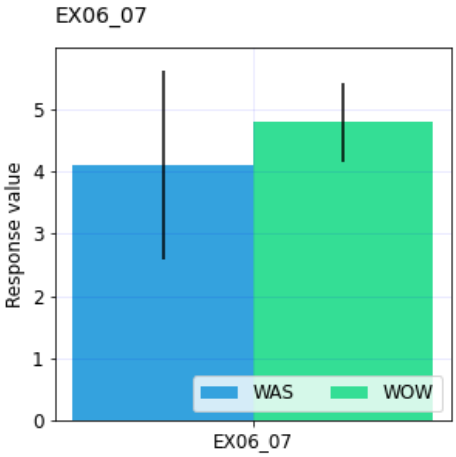


(b) Mean of answers in Likert scale.

Figure 28: It was easy to identify how to interact with the augmented elements..

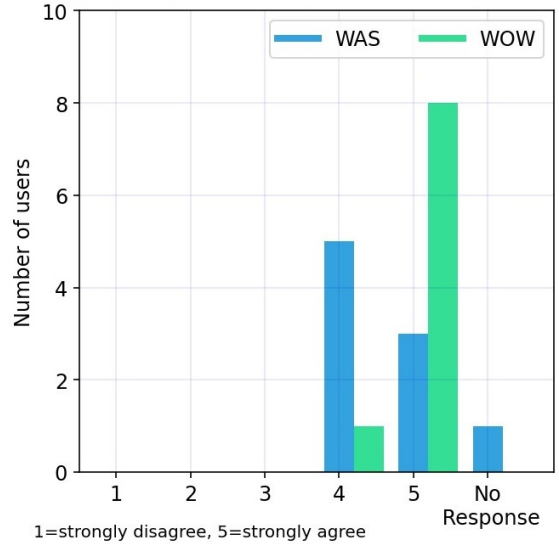


(a) Number of users for each answer in the Likert scale.

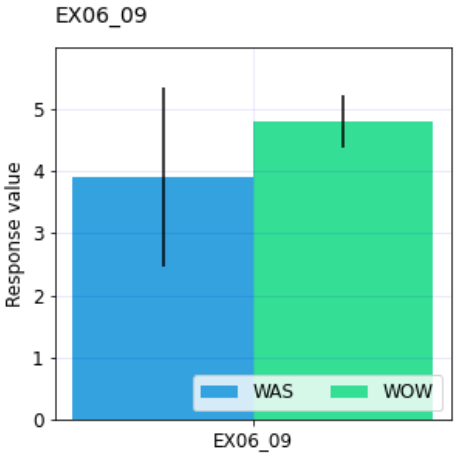


(b) Mean of answers in Likert scale.

Figure 29: Augmented content made the visit more interesting.



(a) Number of users for each answer in the Likert scale.



(b) Mean of answers in Likert scale.

Figure 30: I think that the device helped me to explore the past.

3.1.2 Data from recall tests

The multi-modal questionnaires provided valuable data about the user's capabilities to retain certain information such as the position of each interaction point and its respective action; also generating a contrast against behavioral data and highlighting the impact of interaction overall user's memory 31 32 33 34.

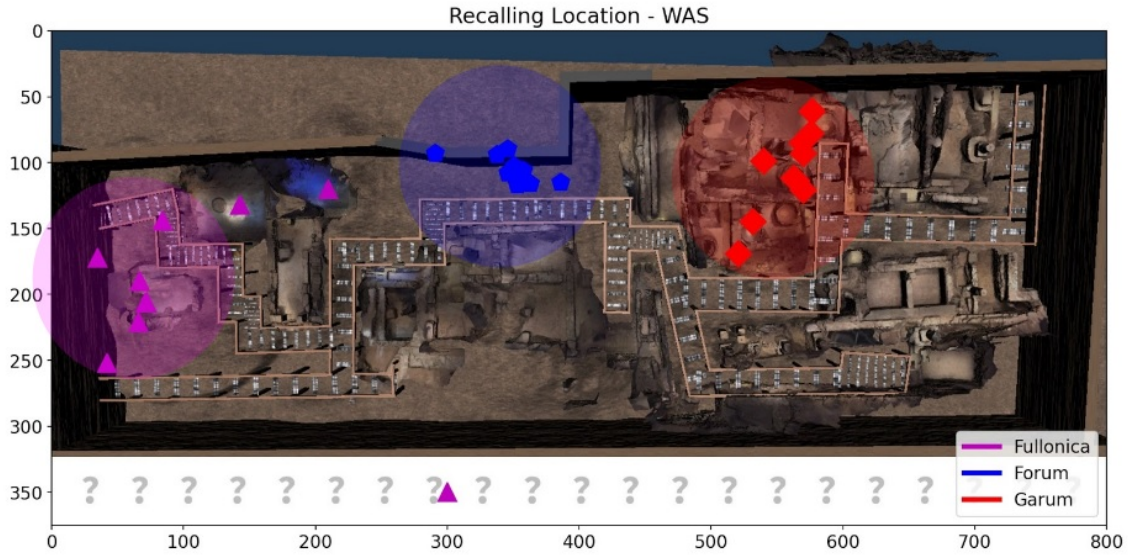


Figure 31: Interaction points recalled for all users in World-As-Support group.

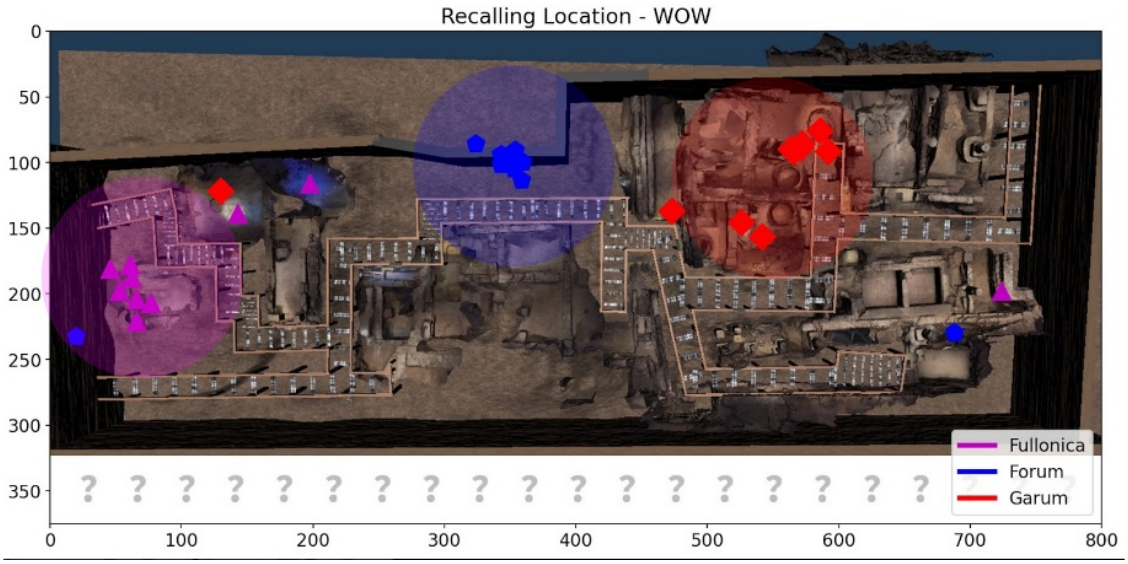


Figure 32: Interaction points recalled for all users in Window-on-the-World group.

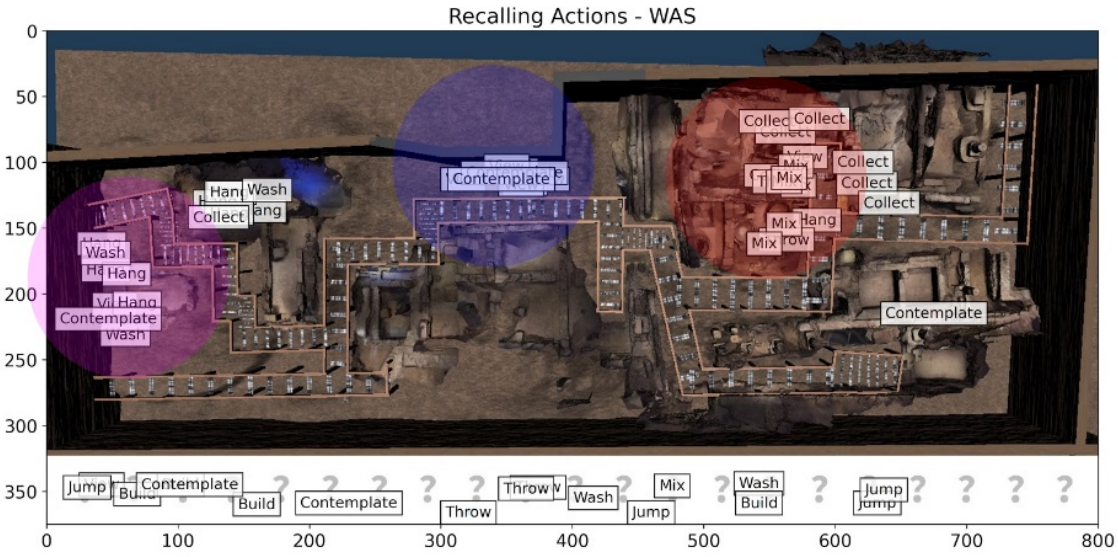


Figure 33: Actions recalled by all users in World-As-Support.

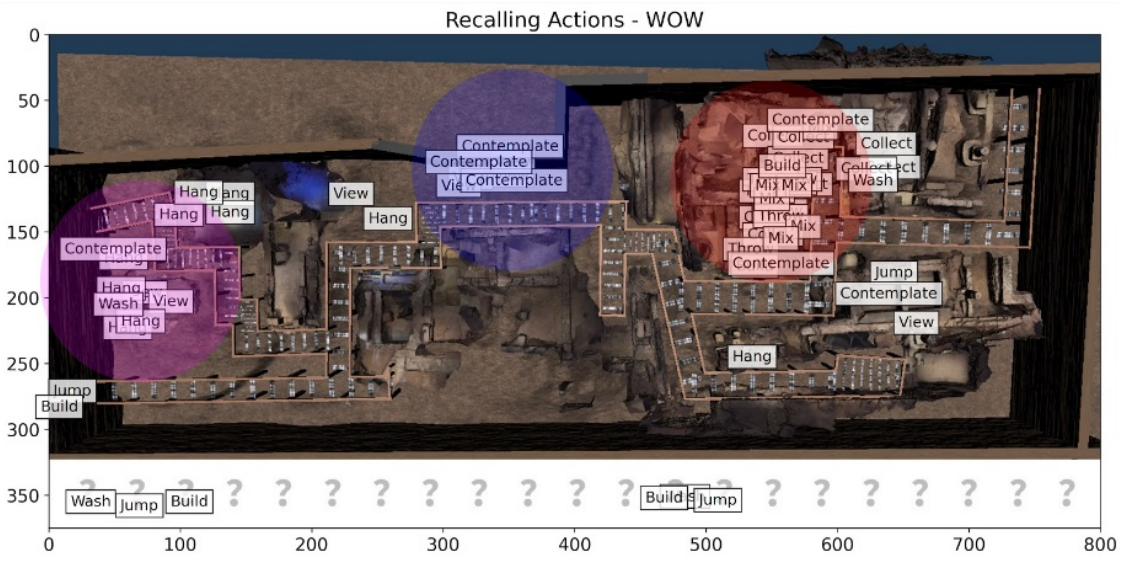
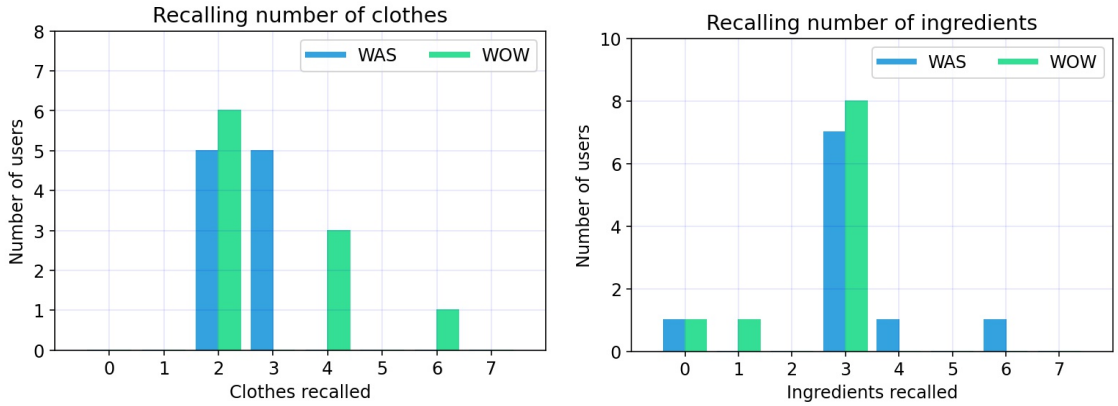


Figure 34: Actions recalled by all users in Window-on-the-World group.

Additionally, we dove into details to expose whether the experience also helps the users to retain even more specific information about the Barcino culture; so we asked about the clothes within the Fullonica but also about the number of ingredients required to make the Garum sauce. See results in Figure 35.



(a) Mann-Whitney test p-value: 0.353292 (b) Mann-Whitney test p-value: 0.116443

Figure 35: Recalling details. During your visit to the museum, you were presented some representative elements from the Barcino culture; can you remember them?.

Chapter 4

Discussion & Conclusions

Continuously, the respective data analysis has been carried out in order to identify any possible differences between the previously mentioned paradigms World-As-Support and Window-on-the-World.

4.1 Discussion

Firstly, as exposed in the "Data captured by system" section 3.1, even in lack of a Full-Body Interactive experience due to the Covid-19 exceptional situation (see details in 2.2.4), it's evident that the users present an internal motivation to explore the full path within the museum 20; this motivation has been potentially incentivized by the augmented reality device and the fact of new digital content anchored to the reality. Indeed, the heatmap 21 suggests that the most elaborate experience catches more attention in relation to the other interaction points.

Thereby, we can compare the stored data from the real interactions made by the users for each of the paradigms in concern to find no significant difference between them 22 23; however, this behavior is also present in other comparisons and this may suggest a possible bias within the general experience due to the simulator. We assume that the feeling of holding the device wasn't clear enough for the participants since both paradigms were experienced through a computer screen.

Then, if we take a look at the declarative data obtained from the 41 Likert-based questions, some answers become relevant in contrast to the research hypotheses. The first group is composed of those that followed a normal distribution according to the Shapiro-Wilk test 25, this group of questions has its meaning from the usability perspective and they represent a non-significant difference between WaS and WoW; again potentially influenced by the simulator. However, most of them are highly related to whatever is presented in between the interaction points: "When I didn't see any augmented content, I was bored", "It was easy to walk between one point of interaction to another one", "I think I found all of the artifacts in the historical site", "It was easy to find the artifacts". So, even if there is no significant difference between the groups, the results expose "exploration" as the main interaction within the cultural heritage experience and also present an overall good performance in usability matters.

Moreover, from the 15 non-normal distributed answers 26, we identify four relevant ones; also related with how engaged the user felt during the visit and how easy was to interact with the augmented content. These answers put in favor the Window-on-the-World paradigm by exposing a significant difference according to the Mann-Whitney Test, however, it's possible that the virtualization of the experience made it difficult to perceive the full experience and the meaning of the "lantern"-like interaction proposed by the World-As-Support tool.

Finally, the comparison between the paradigms within the recalling multimodal surveys didn't expose a significant difference, nevertheless, both presented an impressive performance. At first glance, it seems like the participants managed to remember with relatively high accuracy the location of each interaction point 31 32; despite that, we may speculate about a possible tendency that favors World-As-Support paradigm. This trend seems to be more evident in the "recalling actions" exercise since WoW data is a bit more spread out than WaS 33 34; which may expose one of the initial thoughts that the WoW-based device hinders the observation of the environment due to its innate requirement of looking at the reality through a display.

4.2 Conclusions, Limitations and Future Work

Despite the fact that the presented data belongs to a simulated version of the environment, which may suggest a high influence over the user's understanding and overall experience, the executed trials offer a trustworthy methodology either for future in situ or remote trials; also from conceptual, design, development and experimental perspectives, involving AR state of the art technology.

Additionally, the virtualization of the test decreased the impact of physical motion and exploration over the experiment, disabling any Full-Body Interaction comparison. Therefore, the innate explorative experience proposed by the physical lantern-based interaction from the World-As-Support tool was totally mitigated, which may indicate a bias towards the Window-on-the-World paradigm since the simulator already suggests looking at the environment through the computer screen.

However, the results indicate that interaction points within a cultural heritage experience considerably increase the users' capabilities to recall representative elements of the visit; not only locations but also specific details such as the number of clothes in a scenario or ingredients required to create the ancient Garum. Furthermore, the augmented content suggests an explorative experience that motivates the users' movement within the museum paths in order to find out if there are more augmented elements.

In addition to group trials in situ to allow the analysis between the holder and non-holder users, future work could integrate a comparison between interaction points, aimed to identify guidelines, allowing designers and developers to create augmented reality experiences depending on the desired paradigm, either World-As-Support or Window-on-the-World. Also, specifications about how to guide the users between interaction points and a design methodology to define what information fits the learning, usability, and user engagement requirements for a cultural heritage AR experience.

List of Figures

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Appendix A

Objectives Tree

Augmented Reality through a Heritage Experience: From Individual to group Interaction			
General Objective			
Compare the emergent paradigms World-as-Support and Window-on-the-World in order to detect potential improvements within the cultural heritage experience presented in the Museu d'Història de Barcelona (MUHBA).			
Main Objectives		**Secondary Objectives**	**Actions**
Conceptual	Determine the main elements related to the ancient Barcino within the MUHBA in order to propose points of interest with the respective way to interact with them.	1. 1. Inquire about the ancient Barcino culture to understand its characteristic aspects.	1. Find the ancient Barcino Map. 2. Visit the MUHBA with guided tour. 3. Compare the Barcino Map with the current state of the zone.
		1. 2. Potentiate the visible spaces inside the museum that are still making reference to their location in the past.	1. Find the visible places that fit the requirements of the technology and have the potential to provide a valuable experience.
Design	Create an embodied and interactive experiential system supported by both WaS and WoW paradigms.	2. 1. Define the main ways to interact with the system and its respective outcomes.	1. Identify possible points of interest related to the concept previusly defined. 2. Execute a brainstroming workshop to propose multiple micro-experiences. 3. Filter the micro-experiences proposed in order to fit place and technology limitations. 4. Create a list of assets required to elaborate each micro-experience.
Development	Develope an embodied and interactive experiential prototype that satisfies both WaS and WoW paradigms.	3. 1. Determine the technology to be used	1. Look for the most convenient software and hardware 2. Adquire the sofware and hardware 3. Understand the required elements from the choosed AR library
		3. 1. Elaborate a prototype to sequentially proceed with experimental steps.	1. Code the required scripts for each micro-experience. 2. Integrate the required assets.
Experimental	Analyse the system to generate valid conclusions about the WaS and WoW paradigms.	4. 1. Elaborate a plan to execute experimental design.	1. Define the specific elements to be tested. 2. Closed testing in-lab for each micro-experience. 3. Closed testing in-MUHBA for each micro-experience. 4. Define main parameters for testing with real users. 6. Elaborate the script for testing with users. 7. Elaborate questionnaries.
		4. 2. Apply experimental design.	1. Execute testing with users. 2. Analyse data. 3. Propose a tentative adjustment for the system acording to the results

Appendix B

Behavioral Data

B.A Data Structure


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        "position": [45.5, 54.2, -23.3],
        "rotation": [0.5, 0.2, -3.3],
        "time": 323423423456},
    {
        "type": 'INTERACTION',
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        "action": 'drop',
        "time": 323423423456},
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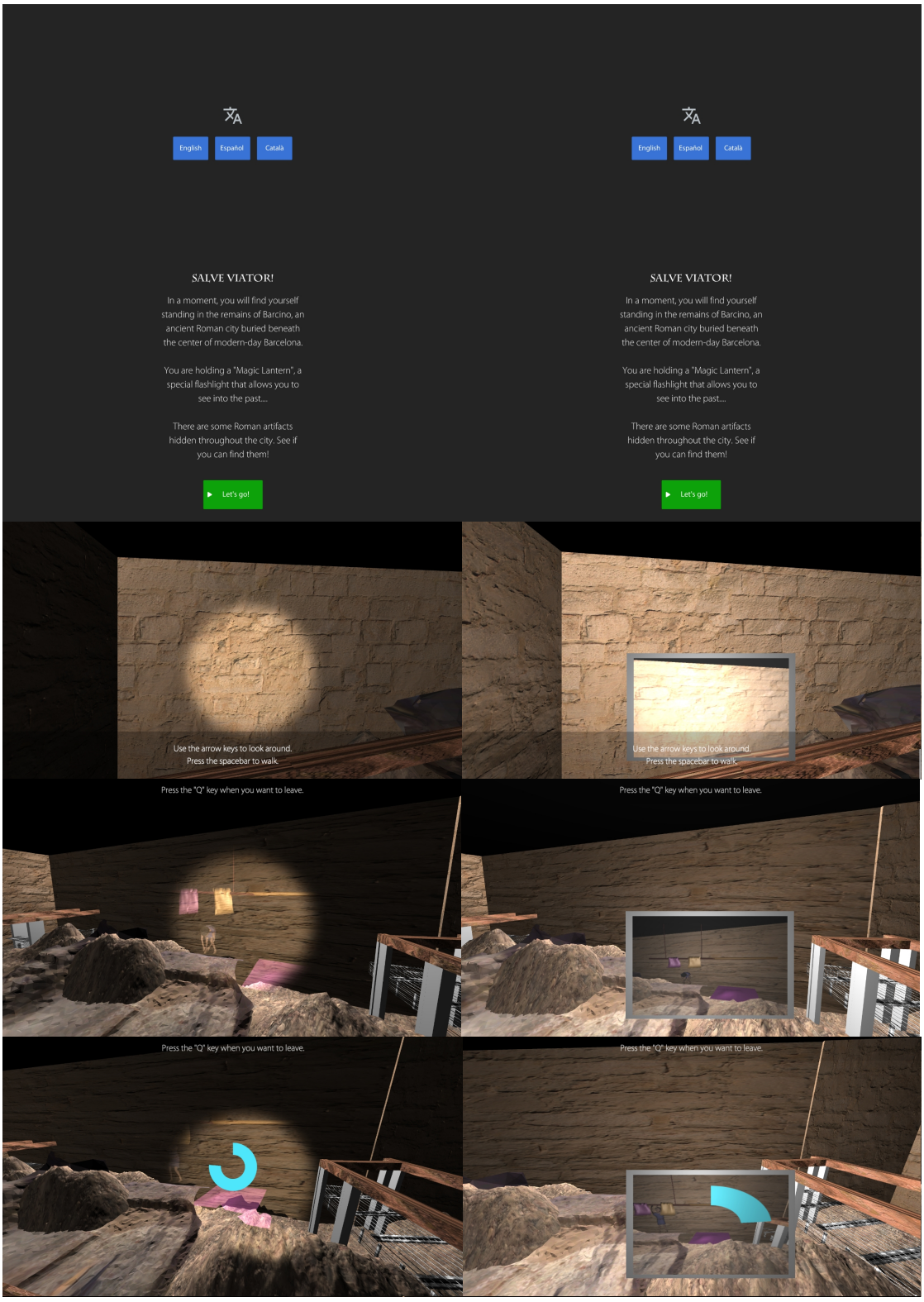
        "time": 323423423456}
}
```

B.B Simulator Flow



Appendix C

Declarative Survey Data

C.A Complete Questionnaire

ucf-was-2020 → QEX 08.07.2020, 14:30

Galley-proof

The galley-proof and print view show all pages of the questionnaire in one view using the chosen layout. Like in debug mode, the question IDs will be displayed.

Please note some differences compared to the actual questionnaire:

- Filters do not work on principle,
- questions within PHP code will only be displayed if their ID is static,
- the way the question will be displayed may differ, due to the question IDs, and
- wildcards and dynamic elements can not be seen on principle.

Tip: Enable the "print background images" option in the print settings of your browser. Otherwise the browser may incompletely print sliders and custom inputs (or export them incompletely to a pdf.

Print View · Variable View · Table (download) · Filters · PHP Code

Page 01

CQ05 Welcome

Welcome back!

We will now begin the post-trial interview. Here are a few things to keep in mind:

- The interview should last between 5 and 15 minutes, depending on your speed.
- There is no time limit to the interview.
- All questions are required. If you don't want to answer anything, you may choose "no response" if it is an option
- Due to the structure of the research, we have disabled the "Back" button during the questionnaire. Please do not try going back to a previous page.
- Please try to complete the interview in one sitting, as there is no way to return to an interrupted interview.

Thank you!

Page 02

DG01 Gender

1. To which gender do you most identify?

○ Female
○ Male
○ ______
○ Prefer not to say

DG02 Age

2. How old are you?

○ I am __ years old

○ I prefer not to say

DG08 Country Of Residence

3. In which country are you currently living?

Start typing a country name or abbreviation ______ ☐ I prefer not to say

Page 03

CQ07 Have you played?

4. Have you played Barcino XR before?

The virtual version of Barcino (Barcino XR) is used in other research studies. Have you been a participant in a study that used the same virtual environment?

○ Yes
○ No

CQ08 Have you been to the museum?

5. Have you been to this museum exhibit?

This experience is based on an exhibition in the Museum of the History of Barcelona (MUHBA). Have you ever visited it?

○ Yes
○ No

Page 04

CQ02 Interest in History

Statement	1 strongly disagree	2	3	4	5 strongly agree	No response
I am interested in history	○	○	○	○	○	○
I am interested in archeology	○	○	○	○	○	○
When I go to museums or other cultural heritage sites, I like going on a tour led by a guide	○	○	○	○	○	○
When I go to museums or other cultural heritage sites, I like using an audioguide	○	○	○	○	○	○

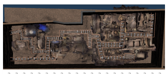
Page 05

EX01 Locations Visited

6. During the visit, you walked through multiple locations related to the ancient culture. Which places do you remember?

Place them onto the map based on where you remember they belong to.

1. Click an image to select it
2. Click on the map in the approximate place you remember seeing it.
3. If you don't remember where you saw it, place it below the map in the area labeled with "???"



? ?

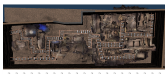
Page 06

EX02 Actions Made

7. While walking through the ruins, you found some interactive activities. What actions did you execute and where?

Place them onto the map based on where you remember have done each one.

1. Click an action to select it.
2. Click on the map in the approximate place you remember you did it.
3. If you don't remember where you did it, place it below the map in the area labeled with "???"
4. You can place each action up to three times.



? ?

1 View · 2 Hang · 3 Collect · 4 Throw · 5 Mix · 6 Wash · 7 Jump · 8 Build · 9 Contemplate

Page 07

EX03 Memory Task

8. During your visit to the museum, you were presented some representative elements from the Barcino culture, can you remember them?

How many clothes did you discover? 1 ●——— 7

How many ingredients were required to prepare the Garum sauce? 1 ●——— 7

Page 08

EX04 Garum Ingredients

9. You were asked to prepare the ancient Garum sauce; do you remember the ingredients?

Could you organize the ingredients in the order you added them?

Urine · Salt · Fish · Herbs · Apples

1
2
3

Page 09

CQ03 Qualities of Visit

In answering the following questions, please consider your overall experience of (virtually) visiting the Barcino heritage site.

Statement	1 strongly disagree	2	3	4	5 strongly agree	No response
I liked exploring the remains of Barcino	○	○	○	○	○	○
I liked the layout and presentation of the virtual visit to Barcino	○	○	○	○	○	○
I liked the paths available to explore Barcino	○	○	○	○	○	○
I had fun during my virtual visit to Barcino	○	○	○	○	○	○
I want to tell others about my virtual visit to Barcino	○	○	○	○	○	○
I would recommend that others visit ancient Barcino, physically or virtually	○	○	○	○	○	○
I want to visit the real Barcino heritage site the next time I am in Barcelona	○	○	○	○	○	○

Page 10

CQ04 Augmented Content

During your visit to Barcino, you may have encountered some artifacts from the past in your flashlight beam. Please consider them as you answer the following questions.

Statement	1 strongly disagree	2	3	4	5 strongly agree	No response
I liked finding and examining or interacting with the artifacts of the past	○	○	○	○	○	○
I think I found all of the artifacts in the historical site	○	○	○	○	○	○
I liked the paths available to explore Barcino	○	○	○	○	○	○
It was easy to find the artifacts	○	○	○	○	○	○
It took too long to find the artifacts	○	○	○	○	○	○
I understood what the artifacts were supposed to be	○	○	○	○	○	○
The artifacts were appropriate in their environment	○	○	○	○	○	○
The artifacts added value to my visit	○	○	○	○	○	○

Page 11

EX05 Reaction Technology

10. During your virtual visit to Barcino, you held a special device that let you see into the past.

Please consider it when answering the following questions.

Statement	1 strongly disagree	2	3	4	5 strongly agree	No response
I liked exploring the Barcino ruins with a device that let me see augmented content from the past.	○	○	○	○	○	○
When I didn't see any augmented content, I was bored.	○	○	○	○	○	○
When I didn't see any augmented element, I thought I was doing something wrong.	○	○	○	○	○	○
I like the idea of using some kind of device like this that adds augmented imagery to a historical site during a visit.	○	○	○	○	○	○
I like the idea of using the device for visits to the Barcino heritage site.	○	○	○	○	○	○
I would like to try using the technology in visits to other heritage sites or museums (physical or virtual).	○	○	○	○	○	○
The device was a useful mechanism to help me look for augmented objects.	○	○	○	○	○	○
I found the idea of holding a device to be adequate in the exploration activities.	○	○	○	○	○	○
I found natural the interaction between the augmented content and the environment	○	○	○	○	○	○
I could easily move the device to explore the full size of the augmented objects found	○	○	○	○	○	○
I thought the manipulation device had a natural feel to it	○	○	○	○	○	○

Page 12

EX06 Reaction Augmented Content

11. During your virtual visit to Barcino, you held a special device that let you see into the past by revealing certain elements and interact with some of them.

Please consider it when answering the following questions.

Statement	1 strongly disagree	2	3	4	5 strongly agree	No response
I found that the augmented content helped me to imagine how the place used to be	○	○	○	○	○	○
It was easy to identify how to interact with the augmented elements	○	○	○	○	○	○
I liked the timing of the progress bar to execute the actions related to the augmented content	○	○	○	○	○	○
The speed of the animations was clear enough to understand what was happening	○	○	○	○	○	○
It was easy to walk between one point of interaction to another one	○	○	○	○	○	○
The augmented elements made the experience more valuable	○	○	○	○	○	○
Augmented content made the visit more interesting	○	○	○	○	○	○
The device distracted me from paying attention to the ancient ruins	○	○	○	○	○	○
I think that the device helped me to explore the past	○	○	○	○	○	○
The device allowed me to easily compare the current state of the remains against the past state of the city	○	○	○	○	○	○
I like the idea of interacting with augmented content during a visit to the Barcino heritage site	○	○	○	○	○	○
I think these augmented content would improve visits to museums and other cultural heritage sites	○	○	○	○	○	○

Page 13

CD10 Debrief Experiences

Post-experiment Debrief

You were invited as a participant in the research study entitled "BarcinoXR". This study is being done by the Full-Body Interaction Lab as part of a masters' thesis in Cognitive Systems and Interactive Media at the Universitat Pompeu Fabra.

Thank you!

Your participation in this research study is valuable, and we are grateful for your time.

Now that the experiment is over...

For this study, it was important that we withhold some information from you about some aspects of the study and your participation. Now that your participation is completed, we will describe what was withheld from you, why it was important to do so, and provide you with the opportunity to make a decision about whether you would like your data to be included in the study.

What was withheld?

- This research has been grounded on previous studies from the Full-Body Interaction Lab that suggest new paradigms related to Augmented Reality, called: Window-on-the-World and World-as-Support. Those propose different interaction approaches and so we aim to identify their overall impact.
- As a participant, you were placed into one of two groups:
  - *Group A*: You perceived the augmented content with the help of a tablet, a Window-on-the-World based device
  - *Group B*: You perceived the augmented content with the help of a "Magic Lantern", a World-as-Support based device
- While you played, we logged your position and orientation in the game, as well as when you saw an augmented element or interacted with it.

Comments, questions or concerns?

If you have questions, please reach out to Luis Palacio at luis.palacio01@estudiant.upf.edu. If you would like to receive a copy of the final report of this study when it is completed, please feel free to contact the researcher.

Consent to inclusion of data

Clicking "yes" below indicates that you have been debriefed, have had all of your questions answered, and that you agree to have your data used in this study. Also that you will not disclose content, research procedures, and/or purpose to anyone from outside of the study.

○ No, I do not agree (do not participate in this study)
○ Yes, I agree

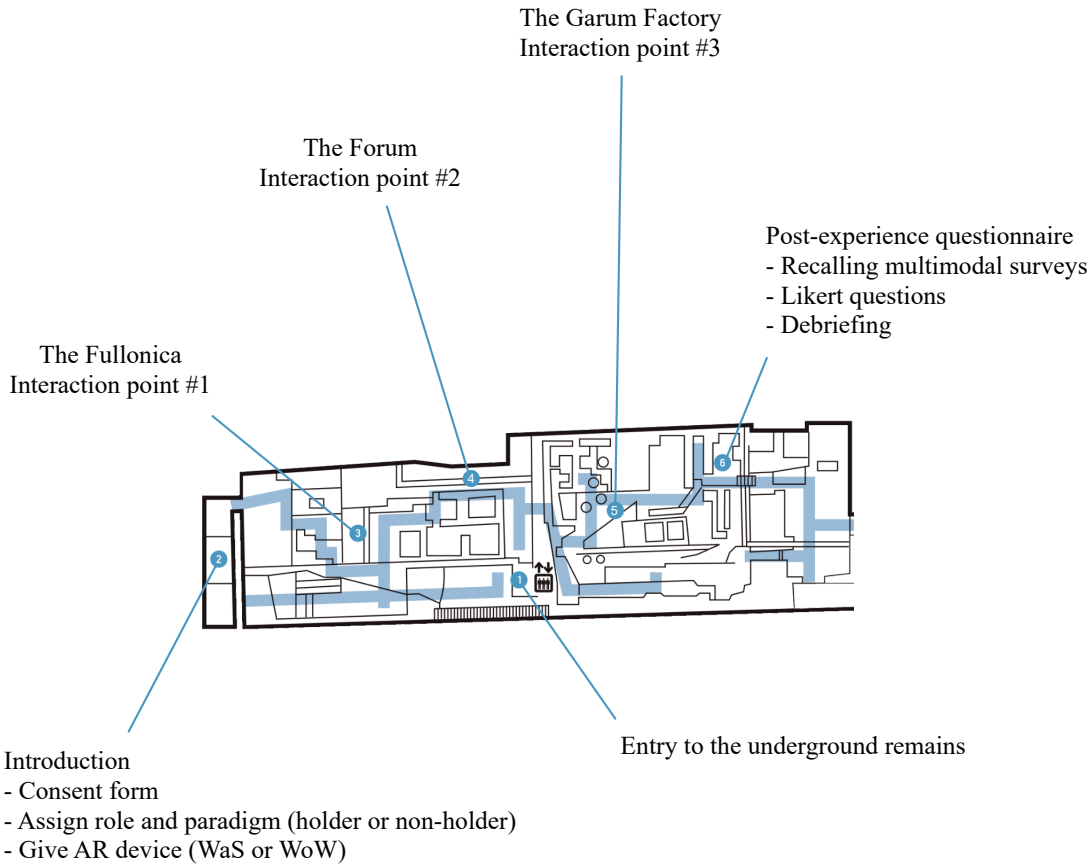
Last Page

Thank you for completing this questionnaire!

We would like to thank you very much for helping us.

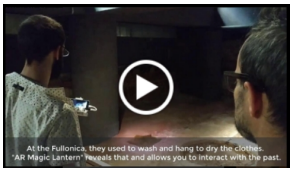
Your answers were transmitted, you may close the browser window or tab now.

C.A.1 Experimental Set-Up



C.A.2 Virtualization of the experimental Set-Up

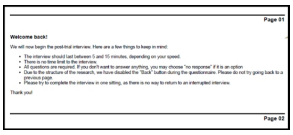
Invitation to join the research experiment



- Ask for user's Operative System
- Assign paradigm (WaS or WoW)

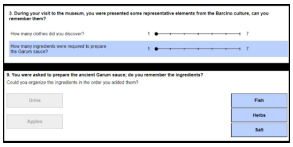
User watches a video of the experience in situ to help him/her imagine how the real experience could be

User downloads the simulator and play for a while, up to 15 minutes
- Position, rotation and interactions were stored in Firebase cloud service

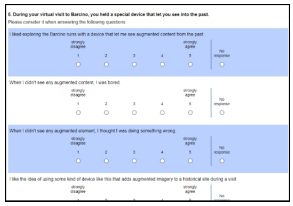


User is redirected to the post-experience questionnaire

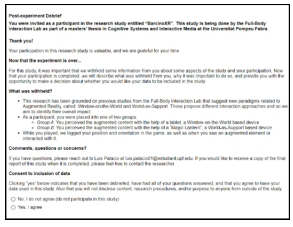
Recalling multimodal surveys (location and actions)



Recalling details multimodal surveys



Likert questions



Debriefing and data usage agreement

C.B Multi-Modal Questions

1 View | 2 Hang | 3 Collect | 4 Throw | 5 Mix | 6 Wash | 7 Jump | 8 Build

9 Contemplate