Immersive Virtual Reality in Cultural Heritage Dissemination: A Comprehensive Application for Novice Users

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Abstract. This paper discusses the increasing relevance of immersive Virtual Reality (iVR) technology in society and its emerging applications, particularly in Cultural Heritage (CH) dissemination. However, the diversification of iVR experiences has led to a need for an application that summarizes the most common types of experiences to familiarize novice users with iVR. To address this need, an iVR application has been developed that presents the four most common types of iVR experiences: Passive, Explorative, Explorative Interaction, and Interactive. The experience includes different reconstructed CH environments and objects showcasing the possibilities for the dissemination of CH using this technology. The application is divided into four levels, and its key design factors are as follows: 1) one type of iVR experience for each level, 2) simple interactions that become more complex as the user progresses, 3) short duration and time-limited progression between levels, 4) development for standalone iVR devices, and 5) different types of reconstructed heritage showcased at each level. The experience was tested in exhibitions and achieved high performance on standalone iVR devices. Usability results are expected to be achieved in the future.

Keywords: Virtual Reality, Cultural Heritage, Head Mounted Display, Virtual Reconstruction, Tutorial

1 Introduction

In recent years, Virtual Reality (VR) has gained significant relevance. This technology has been in development since the 1950s, but it has not been widely adopted by the mainstream audiences until recent years [1]. With the development of technology, VR has evolved into immersive Virtual Reality (iVR), which surrounds the user in large 3D viewing areas such as the Head-Mounted Display (HMD) [2] and the Cave Automatic Virtual Environment (CAVE) [3]. Currently, the affordability and availability of software and hardware technology have contributed to the widespread adoption of iVR, which has opened a wide range of potential applications beyond its initial military and training purposes [4]. One promising application of iVR technology is the dissemination of Cultural Heritage (CH), where diverse experiences have been developed to take advantage of the benefits of iVR [5–7].

In recent years, iVR has emerged as a technology with significant potential in the fields of heritage dissemination [8], conservation [9], and education [10], due to its unique characteristics. Of these, Flow, Engagement, Immersion, and Presence are among the most important. Flow refers to the sensation of control, while Engagement refers to the connection between the user and the virtual activity. Immersion describes the sensation that the virtual environment replaces the real world, while Presence refers to the feeling of being present in the virtual environment [11].

Within the context of CH reconstruction, Presence is of particular importance, as it is the key factor that enables users to experience the virtual environment as though they were truly present within it [12]. The relevance of Presence in CH reconstruction is particularly significant, as this technology is often used to reconstruct vanished or transformed heritage. Given that virtual environments are used extensively in this context, understanding the impact of Presence on the virtual reconstruction of CH in iVR has been the subject of extensive scientific inquiry, as evidenced by some studies [12–14].

In addition to these features, iVR enables remote visits, which can aid in the preservation of CH by avoiding degradation of delicate elements [15]. Also, remote visits can improve the accessibility of CH, as many heritage sites are inaccessible to people with disabilities [16]. Moreover, iVR is a powerful tool for transmitting information, as its visual nature is much more direct, particularly for non-expert audiences [15], and enhance transmission of spatial information, including the ability to perceive scales and sizes of CH objects [17]. Furthermore, these capabilities have gained even greater significance since the COVID-19 pandemic, which has highlighted the importance of digital tools and demonstrated their effectiveness in the field of CH [18].

All these possibilities of iVR have led to the development of very different types of experiences. It can be mainly found four different types of experiences [19]. They are the following:

- Passive experiences, the user interactivity and movement are very limited, sometimes involving photography or 360° video experiences.
- Explorative experiences, which allows for free exploration of the virtual environment, but no direct interaction.
- Interactive explorative experiences, allow for free exploration and interaction in the virtual environment.
- Interactive experiences, which enable free interaction with the environment, but with restricted movement.

All these experiences differ significantly from one another, mainly due to the size of the environment and the freedom of interactions, resulting in highly diverse iVR experiences. The sum of all possible iVR experiences, coupled with the novelty effect, can create cognitive overload for many users, limiting their performance [20]. This situation highlights the need for the creation of tutorials and experiences that familiarize users and researchers with this technology so that they can understand its possibilities [21].

This paper presents an overview of the conceptualization, design, and implementation of an iVR experience intended to introduce users to the possibilities of iVR through four virtual reconstruction experiences of CH sites and objects. Each of these experiences corresponds to one of the four iVR experience which are presented sequentially to provide users with a comprehensive understanding of the potential of iVR.

The paper is structured as follows: Section 2 reviews the related work of iVR experiences involving the virtual reconstruction of heritage sites, with a focus on the four types of experiences. Section 3 explains the design and development of the experience, explaining the design of the experience as a whole and the design of each of its levels. Finally, the conclusions of this paper are presented in Section 4.

2 Related Work

This section will provide a summary of some CH reconstruction cases belonging to the four types of iVR experience, sorted by the following order: 1) Passive experience, 2) Explorative experience, 3) Explorative interaction experience and 4) Interactive experience.

Passive experiences are characterized by minimal interaction, often consisting of videos, photographs, or 360° renders. Despite this, many Passive experiences developed for CH reconstruction exhibit significant differences. These differences are mainly due to the use or absence of characters in the reconstruction and the possibility of a guided tour of the environment with various viewpoints. Examples include the virtual reconstruction of the "Villa with Ingresso a protiro" [22–24] which reconstructs a Roman villa located in Italy from the 2nd century. This experience includes many recorded actors and is composed of several 360° viewpoints. A slightly different experience is the reconstruction of the Viking camp in Torksey (UK) from the 9th century [25], which includes digital characters instead of recorded. Finally, another example is the reconstruction of the Presidential Palace in Finland from the 19th century [26]. This experience has also digital characters, but the user moves, but not in a free way, there is a camera that follows a predefined path to show all environment.

Explorative experiences are characterized by having a more or less large environment to freely explore, but there is no possibility of complex interaction with the environment. Considering these characteristics, one of the biggest differences is found in the size of the environments and the passive elements included in them, like panels, infographics, or characters. Some examples of large-scale environments are the reconstruction of the city of Wholverhampton (UK) in the 10th century [27], or the city of Stade (Germany) in the 17th century [28]. However, not all these environments are completely passive, there are also large-scale environments that include external elements such as videos or infographics to be observed by the user, such as the virtual reconstruction of the villa of Briviesca, located in Spain, in the 15th century [29]. This experience includes videos that explain its past and heritage at certain points in the city. There are even smaller environments but with greater vitality and animation, such as the reconstruction of a Neolithic village in Irak that includes a simulation of characters with different routines and behaviors [30].

In Explorative interaction experiences, the complexity of interaction increases, combining exploration with more advanced interactions, such as grabbing objects or some more complex ones that include elaborated games. Therefore, the differences are mainly due to the complexity of the interactions, besides the size. An example of low interaction experience is the reconstruction of Santa Maria d'Agano (Italy) in the 26th

century BC where the user can pick up a torch [31]. However, there are also other iVR experiences that are more similar to video games with missions or characters, in which a story is developed with different mechanics in a reconstructed CH environment. Some examples of this type of experience are the reconstruction of "Little Manila" (USA) in the 20th century [32], or the reconstruction of Paestum (Italy) in the 5th century BC [33].

Interactive experiences are characterized by having complex interactions, but limited exploration or absence of movement by the user. This poses two types of differentiated experiences in the field of CH. Those that include a sandbox with different activities to solve, such as the reconstruction of the Roman Theater of Cartagena (Spain) in the 1st century, where users must solve some educational mini-games [34]. Or those in which the developed interaction is an active part of the reconstruction itself, such as the reconstruction of the tennis court of Rennes (France) in the 17th century, where the user can play the sport with digital characters [35].

Table 1 provides an overview of the types of iVR experiences and variations found in cases of CH reconstruction. As can be seen in Table 1, the differences within the experiences are mainly due to the size of the environments, the inclusion of characters and some exclusive differences in the type of experience.

Table 1. Summary of the differences between types of experiences found in the related work.

Type of experience	Size	Characters	Exclusive Differences
Passive	There may be one or more viewpoints	Characters can be recorded, digital or not characters at all	The user can be static, or there may be a guided camera
Explorative	The size of the environment varies depending on the reconstruction	Characters can have complex routines, simple routines, or no characters at all	There may be non-interactive elements such as infographics, panels, or characters
Explorative interaction	The size of the environment varies depending on the reconstruction	Characters can have a high degree of interaction, low, or no characters at all	There can be simple or complex interactions
Interactive experience	The environment is always of small size	Characters can have a high degree of interaction, low, or no characters at all	Interaction may be part of the reconstruction or not

3 Experience design

In this section, will be summarize the design of the iVR experience. Firstly, the overall design of the experience will be explained. Then, it will be detailed the design of the 4 levels of the experience dedicated to each of the types of iVR experiences set in different virtual reconstruction CH environments.

This experience has been raised to transmit the possibilities of virtual reconstruction of CH in conjunction with iVR to novice users. For this reason, it has been designed to be easy to understand and with the least number of unnecessary stimuli for the user. For this reason, each of the levels seeks to be the simplest type of experience in its category. Therefore, elements such as digital characters to interact with, free navigation between levels or scenarios, vast environments, or complex mechanics more typical of serious games have not been included. In addition, to show the possibilities of virtual reconstruction of CH through this technology, a different type of heritage belonging to different historical periods has been included in each level.

Figure 1 show the design of the application and the elements that have been given consideration in its development. Horizontally, the progress between levels can be seen, and vertically, the characteristics of each level are presented. These characteristics include the type of iVR experience, the type of interaction, the size of the environment, the type of heritage, and the time limit for each level.

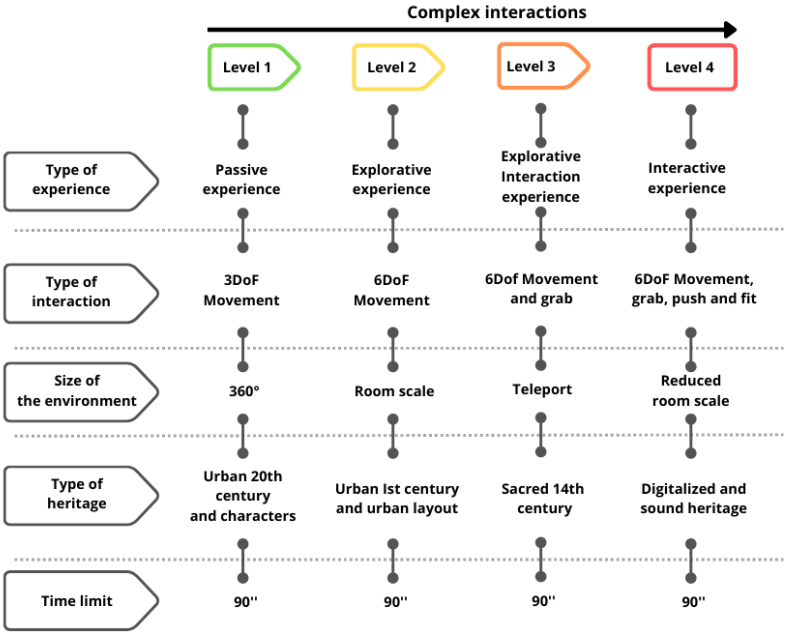

Fig. 1. Summary of the design of the experience.

Firstly, each level has been ordered from least to most interactive (Passive - Explorative - Explorative interaction - Interactive experience). This results in the following types of interactions. The Level 1 is a completely passive 360° scenario, allowing 3DoF move, where the user only to move their head, but not move around de scenario. In the Level 2, the user has 6DoF move, where the user can rotate the point of view and move in all directions [36]. In this level the user and can freely walk in a bounded area of $4m^2$. In the Level 3, the user can move forward using a teleportation locomotion system (in addition to walking), the locomotion system most used in iVR [37]. The grabbing mechanic is introduced, allowing the user to pick up a glowing torch and light candles

with it. In the Level 4, the teleportation locomotion system is removed, and the movement is reduced to $2m^2$ room scale so that the user can focus on the new mechanics. These include pressing buttons and placing pieces. Additionally, to highlight all these new interactive elements, the entire scenario is in white except for the interactive objects. Figure 2 shows how the interactive elements are highlighted in Level 3, with a halo, and Level 4, with color. This level layout has been designed to promote progressive learning by the user [38]. As the levels progress, the user gains more freedom of movement and possibilities for interaction. In the Level 4, the user's freedom of movement is reduced so they are forced to interact with the environment in new proposed ways. It has been searched to make the interaction with the controls as simple as possible. Therefore, the triggers can only be used to grab objects, and pressing any of the buttons or the joystick will activate the teleportation locomotion system.

Fig. 2. Image from the user's perspective of the highlighted interactive elements in Level 3 (left), with the glow and Level 4 (right), with the color.

Each level ends after one and a half minutes. Each new level has only a few new mechanics, so one this time is sufficient to explore them. After various usage tests, it has been determined that a minute and a half was enough time to explore the possibilities of each scenario. It has been chosen this predetermined time system for the following reasons. One the one hand, a task-based level advancement system could cause the user to feel frustrated if they do not know how to advance to the next level. On the other hand, a free advancement system could cause users to accidentally skip parts of the experience.

To convey the dissemination possibilities of virtual reconstruction of CH, it was decided to include reconstructed heritage of different types and periods. All environments have been reused from previous work of the research group. In the Level 1, an urban environment from the 20^{th} century, the city of Burgos in 192 was reconstructed. Additionally, recorded actors were included in this level to convey some aspects of intangible heritage from that time. In the Level 2, a 1^{st} century urban environment, the Roman

city of Legio (now León) Spain, was reconstructed. In this case, to show the urban layout, the user is positioned as a giant who views the city from above. The Level 3 reconstructed a sacred building of the 14th century, the Chapel of San Juan de Acre in Spain. No environment is reconstructed in the Level 4, as the idea of the level is a white stage where the interactive elements stand out. However, sound heritage, such as a 1930s radio with Spanish radio spots or digitized elements like the skull of "Miguelon", a Homo Heidelbergensis fossil found in the Atapuerca site, are included.

Blender was chosen as the 3D modeling software and Unreal Engine 4 as the development engine for this iVR experience. The choice of Blender was based on the development team's previous experience in some reconstructions [10, 39] and its free and open-source model. In addition, the choice of Unreal Engine 4 as the development engine was also based on the team's previous experiences [40, 41], as well as its ease of programming thanks to its visual programming system [42] and the realistic result that can be achieved with this engine [1]. The process of modelling in Blender and programming in Unreal Engine 4 is similar to that described in a previous article by the research group [8]. These two software choices aimed to achieve the highest Level of Detail (LoD) possible to create the best impact on the user [43].

The Oculus Meta Quest 2 has been chosen as the device to run the experience. This device stands out for its affordable price and for being a standalone 6DoF HMD. Standalone HMDs are characterized by not requiring an external computer to run iVR [2], which greatly improve their use by end-users. On the one hand, the absence of wires and computers makes it easier to transport the HMD and eliminates the wire as a potential nuisance for the user. In addition, its low cost facilitates its acquisition. On the other hand, the limited hardware of the device has made the development of the application hard, requiring the optimization of all resources to obtain a visually attractive experience.

Due to the project's requirements, these 4 levels have been carefully designed to be user-friendly and to showcase the possibilities of virtual reconstruction of CH through iVR.

3.1 Level 1: Burgos 1921

Level 1 is developed in the virtual reconstruction of the Main Square of Burgos (Spain) in the year 1921. Figure 3 shows an image of this level from the user's point of view. This scenario serves as an introductory level to the experience. This level is a Passive iVR experience. In this case, a 360° video-based iVR has been chosen. In this experience, the user can only rotate the viewpoint to interact with the environment. Only one 360° point of the virtual reconstruction has been introduced, as a change of environment, even if it is within the reconstruction of Burgos in 1921, could give the user the feeling of advancing to another level. It has been intended to show the simplest possible type of Passive iVR experience, without guided movement, with only one 360° environment to be observed. On the other hand, characters have been introduced in this level. The reason for this design decision is to present to the user the dissemination potential of characters in a virtual reconstruction in the most controlled environment possible, a Passive experience. If they had been introduced in the following levels, users

might have approached them to try to interact with them. By including them only in the Passive experience, characters can only be observed, and in this case, they serve the purpose of conveying other heritage information such as clothing or mores of the people of Burgos. The development of this reconstruction is explained in a previous paper of the research group [44]. The reconstruction has been documented through graphic documents such as photographs or building plans and the square has been digitized through 360° photography and photogrammetry to preserve the elements of the city that have not changed in this century. There have been no development issues caused by the limitations of the standalone HMD because the iVR run with a 360° video.

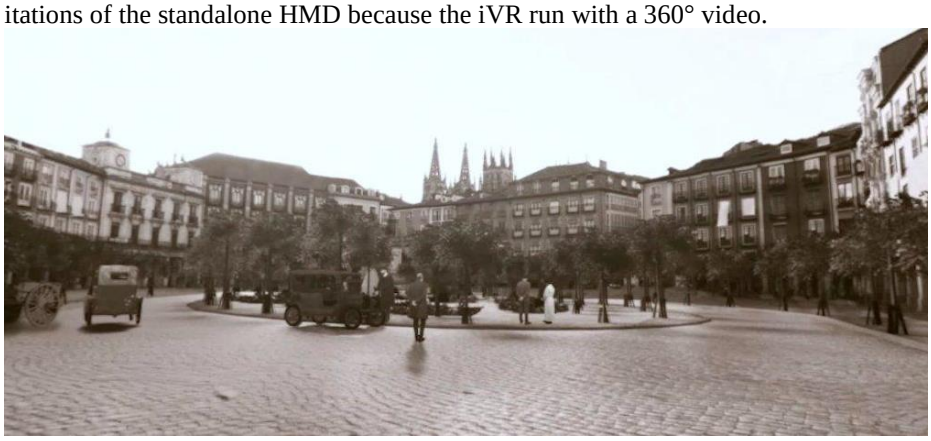

Fig. 3. Image from the user's perspective of the virtual reconstruction of the Main Square of Burgos (Spain) in 1921.

3.2 Level 2: Legio 1st century

Level 2 takes place in the virtual reconstruction of the city of Legio (Spain) in the 1st century, known as León at currently. Figure 4 shows a user's view of the level. In this level, user interaction is expanded to become an Explorative experience. The environment is of a large size, encompassing the entire city, but the user's movement is limited to 4m^2. The size of the environment has been reduced to make the experience more usable. With this limited movement area, the experience can be walked through without the need for a complementary locomotion system such as teleportation system. No extradiegetic elements, such as panels that expand heritage information, have been introduced. This limitation of interactive elements makes this explorative experience as simple as possible. There are characters in the reconstruction populating the city, but they are static being more similar to figures in a model. The archaeological remains of the city were used as historical sources in the reconstruction. Due to the lack of documentation, the user was placed in an elevated position to appreciate the city as a whole and the distribution of the streets, instead of focusing on the details. Due to the technical limitations of the standalone HMD, the model had to be highly optimized. To make it affordable, the original model's geometry was reduced by 64.34%, and ten texture

atlases of 4096x4096px were used to make the final .fbx file as lightweight as possible, at 29.2mb.

Fig. 4. Image from the user's perspective of the virtual reconstruction of the city of Legio in Ist century. The user is located at an elevated viewpoint to better understand the urban layout.

3.3 Level 3: Chapel of San Juan de Acre in 14th century

Level 3 takes place in the virtual reconstruction of the 14th century Chapel of San Juan de Acre, in Spain. Figure 5 shows a view of the level from the user's perspective. In this level, the iVR experience becomes Explorative interaction, introducing new forms of interaction with the user's controls. The scenario is of medium size, consisting only of the interior of a chapel. However, it is impossible to walk from one end to the other in a normal-sized room. Therefore, the teleportation locomotion system is introduced in this level, which can be activated by pressing the buttons or joysticks of the controller. Additionally, in this level, the user can pick up a torch by squeezing the controller. The torch has a halo of light to make it visually prominent. Both the torch and the candles that can be lit with it are placed in separate points of the environment to force the user to use the teleportation locomotion system. Like in the other levels, it was decided to keep the experience as simple as possible within its category. Therefore, no missions, characters, or complex mechanics were introduced. The only new mechanic is the ability to grab objects and the teleportation locomotion system. The historical sources used in this reconstruction are the archaeological remains of the site and graphical and written documentation. Due to the limitations of the standalone HMD, adaptations had to be made to the original model to make it work correctly. The model was modified to improve the performance of the light, and the number of textures was reduced to six texture atlases to make the final .fbx file as lightweight as possible, 4.05 MB.

Fig. 5. Image from the user's perspective of the virtual reconstruction of the Chapel of San Juan de Acre (Spain) in 14th century.

3.4 Level 4: Workshop

Level 4 takes place in a completely white workshop that houses CH elements in colour. Figure 6 shows a view of the scenario from the user's point of view. In this level, the iVR experience becomes an Interactive experience. The size of the scenario is reduced by $2m^2$ so that the user can interact with the heritage elements on the tables without moving. The system of grabbing objects by squeezing the controller is maintained, but the mechanics of pressing buttons and fitting objects are implemented and the teleport locomotion system is removed. The button of a 1930s radio can be pressed to play a Spanish period advertisement. The mechanics of fitting objects are implemented in a puzzle made up of parts of a mosaic from the Roman villa of La Olmeda that can be observed in Figure 6. To visually guide the user, images have been placed showing how objects should be arranged, such as in the mosaic puzzle. These interactable elements, along with others that work with the grabbing mechanics, such as the "Miguelon" skull, are in colour to visually stand out for the user [38]. In order to achieve the simplest Interactive experience no characters or elements with complex interactions have been included, being all small simple mini-games. The heritage elements included in this level are partially digitized, such as the mosaic or the skull. To make the environment work correctly, the number of elements in the scenario was reduced, creating a very simple, white environment to run properly on a standalone HMD.

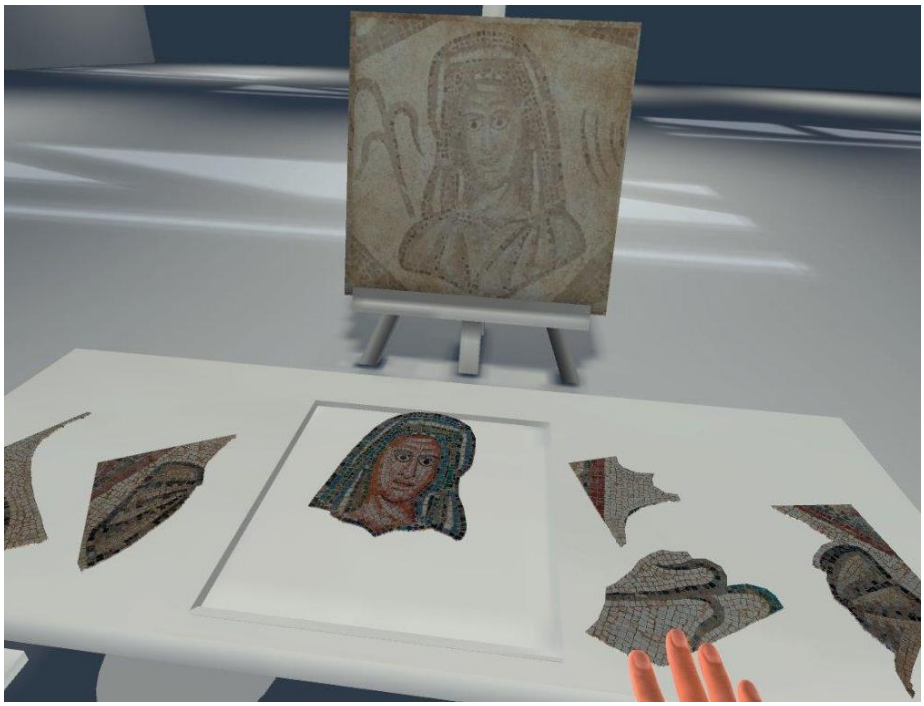

Fig. 6. I Image from the user's perspective of the Level 4. All the elements are in color with except the interactive ones. The background image shows how the puzzle should be solved.

4 Conclusions

iVR technology is becoming increasingly relevant in society. Since its first military and training uses, the technology has expanded into new areas. Among these emerging applications is the dissemination of CH through iVR. However, technological advancements have led to the diversification of iVR experiences, resulting in an increasing number of experience types that are hard to understand for users who do not regularly use iVR. This situation highlights the need for an application that summarizes the most common types of experiences to familiarize novice users with iVR, particularly in the context of dissemination of CH.

For this reason, the development of an iVR experience has been carried out, which presents the 4 most common types of iVR experiences (Passive experience, Explorative experience, Explorative interaction experience, and Interactive experience), showcasing various reconstructed CH environments and elements. The key design factors of this experience are as follows: 1) 4 levels focused on each type of iVR experience, 2) Simple interaction systems that become more complex at each level, 3) Short duration of the experience and time-limited progression between levels, 4) Development of the application for standalone iVR devices to increase usability for users, and 5) Inclusion of different reconstructed CH environments and objects showcasing different possibilities for the dissemination of CH using this technology.

Level 1 presents a Passive experience showcasing the virtual reconstruction of the city of Burgos (Spain) in 1921, including recorded characters. Level 2 provides an Explorative experience of the city of Legio (known as León currently), Spain in the 1st century with limited range of movements. Level 3 showcases an Explorative interaction experience in the medieval Chapel of San Juan de Acre (Spain) in 15th century with a teleportation locomotion system and object gripping. Level 4 offers an Interactive experience with a series of heritage elements, such as digitized objects and sound heritage, introducing new mechanics such as button pressing and fitting pieces.

The development of the application has been successful, achieving high performance on standalone iVR devices. The application has already been tested in museums and exhibitions, and usability results are expected to be achieved in the future.

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