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Protocols for the Graphic and Constructive Diffusion of Digital Twins of the Architectural Heritage That Guarantee Universal Accessibility through AR and VR

Pablo Alejandro Cruz Franco [1,*], Adela Rueda Márquez de la Plata [2] and Elena Gómez Bernal [3]

1 Department of Construction, Polytechnic School, University of Extremadura, 10003 Cáceres, Spain
2 Department of Graphic Expression, University of Extremadura, 10003 Cáceres, Spain
3 Department of Construction, University of Extremadura, 10003 Cáceres, Spain
* Correspondence: pablocruzfranco@unex.es; Tel.: +34-927257195

Abstract: The objective of this article is to generate and validate a workflow that allows us to use virtual twins obtained from unique buildings of our architectural heritage. These twins will guarantee the preservation and dissemination of cultural assets and will promote universal accessibility through new technologies, such as databases, metaverses, virtual reality, augmented reality or gamification. This universal accessibility is based on new metaverses to offer experiences that allow us to overcome physical barriers and reach any user regardless of their economic or physical condition or their location. To obtain this workflow, we worked with digital twins obtained by photogrammetry. Different databases and metaverses were studied, understanding them as new systems for the representation and dissemination of architecture. These metaverses were critically assessed and screened, looking for the most suitable one to be integrated into an effective workflow that satisfies a series of imposed premises, such as being suitable for use in virtual reality and augmented reality environments. The ultimate goal is the aforementioned universal accessibility.

Keywords: digital heritage; metaverse; virtual reality; augmented reality; digital twins; virtual museum; digital survey; 3D database; photogrammetry

Citation: Cruz Franco, P.A.; Rueda Márquez de la Plata, A.; Gómez Bernal, E. Protocols for the Graphic and Constructive Diffusion of Digital Twins of the Architectural Heritage That Guarantee Universal Accessibility through AR and VR. *Appl. Sci.* **2022**, *12*, 8785. https://doi.org/10.3390/app12178785

Academic Editors: Zhihan Lv, Kai Xu and Zhigeng Pan

Received: 29 July 2022
Accepted: 27 August 2022
Published: 31 August 2022

1. Introduction

Over time, the way to understand the concept of accessibility in our society has changed. What used to be a purely physical concept has since become a cognitive and sensorial concept. We do not only have to provide physically accessible buildings to everyone, regardless of their physical condition [1]. We can and must also build digital worlds that guarantee access to culture (architecture, sculpture, painting, visiting museums, etc.) independent of which county we live in or our economic resources. The concepts of the metaverse and digital twin are particularly important in this 2.0 accessibility era [2].

These new digital worlds become especially important when they are applied to the field of architectural heritage and are made tangible by new technologies, such as methodologies for the generation of digital twins [3], integration in BIM models (building modeling information) and HBIM (Historic Building Modeling Information) [4,5], AI (Artificial Intelligence), and augmented reality (AR), virtual reality and mixed reality [6,7].

In countries such as Spain, where one of the most important economic activities is tourism, the pandemic highlighted the need to generate new tourist and cultural resources that are not dependent on one's physical presence. In 2019, tourism activity in Spain accounted for 12.4% of GDP (gross domestic product), and in 2020, it accounted for 5.5%, according to the INE (Spanish National Statistics Institute). Achieving universal accessibility that allows reaching each and every person, regardless of their limitations, and committing to the dissemination of cultural heritage through tools such as digital twins [8,9] are essential for the county's economic growth in the near future.

Thanks to the evolution of technology since the first 3D glasses were proposed by Ivan Sutherland in 1968 [10] (Figure 1) and the creation of new tools, we can establish workflows that adapt themselves to this new concept of universal accessibility. We currently have new techniques and technologies for capturing reality, such as photogrammetry using unmanned aerial vehicles (UAVs), terrestrial photogrammetry or a terrestrial laser scanner (TLS) [3,11–13]. We also have new ways of processing this documentation through software tools that enhance the value of the data and generate novel workflows that give rise to HBIM [14,15]. In this way, HBIM is a working concept made possible by new technologies that allow us to integrate all of the information available on a cultural property, and, as we shall see, it also facilitates new ways of disseminating it through digital twins and metaverses.

Figure 1. (**a**) On the left: Timothy Johnson working with Sketchpad III and (**b**) Ivan Sutherland's head-mounted 3D display (1968). Both devices were precursors of current technology influencing cinema and science fiction: (**c**) *The Matrix* (1999), directed by the Wachowski sisters; (**d**) 3D Glasses or SegaScope 3-D from the Master System, designed by Mark Cerny (1987); (**e**) Google Cardboard as a low-cost VR system (2014); (**f**) Ready Player One (2018), directed by Steven Spielberg; and finally; (**g**) Mark Zuckerberg at an Oculus demo; (**h**) Valérian et la Cité des mille planètes (2017), directed by Luc Besson, proposing an alternative to tourism through virtual reality.

The accurate documentation of our heritage will guarantee efficient conservation and management that will gradually achieve the aforementioned universal accessibility [16], accessibility that must use all of the tools at its disposal to reach the population without discriminating against anyone, from traditional documentation methods [17] to new, much more dynamic databases (Figure 2) [18,19]. In our case, we propose an improvement of the concept of accessibility through augmented reality (AR) and virtual reality (VR) applied to heritage [20–23].

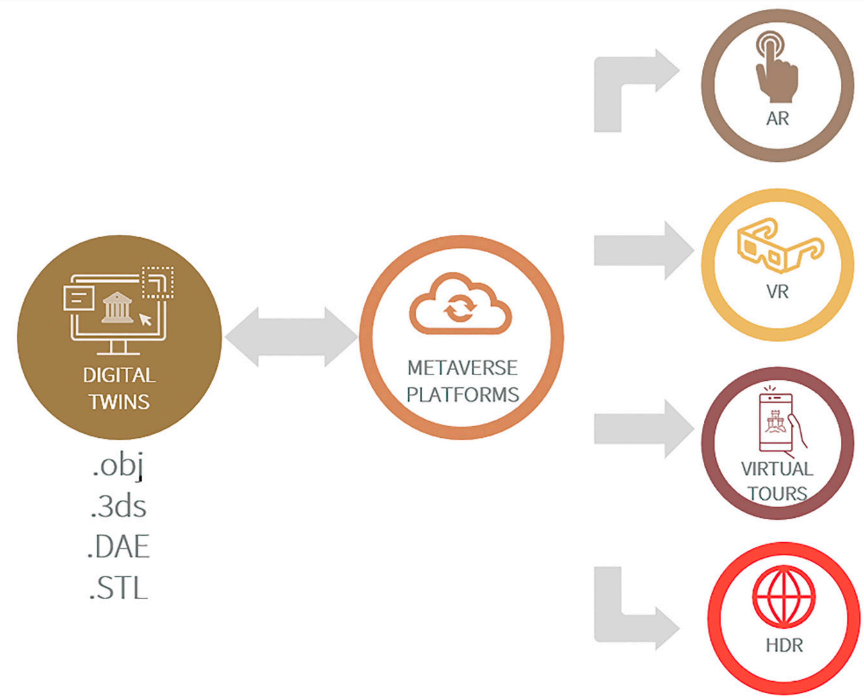


Figure 2. Workflow based on publishing digital twins on different digital platforms.

1.1. Related Works: Metaverse, Metatourism, AR and VR

Currently, the capture and parameterization of reality are issues of high scientific impact and are closely linked to the concept of the metaverse [24,25]. The metaverse or metaverses are environments allowing interaction between humans through avatars. As highlighted in the article UTAUT in Metaverse: an "ifland" case, the metaverse is becoming a meeting place between people, places and objects, a place of relationship in which we have no limitations when interacting. Barriers disappear and time and space disappear as limiting physical concepts. The aforementioned metaverse has the potential to change everything. Education is changing [26], and the use of augmented reality and virtual reality systems that allow us to improve student learning is becoming more and more common; it is influencing medicine [27] and has even changed the world of video games [28].

In short, today's society is maturing, and at a time when our judgment has changed as a result of a global crisis, our way of understanding the world is also changing, and with it, new ways of understanding tourism are appearing, which are compatible with the traditional ones in many cases but not in other [29,30]. In the article Tourism Using Virtual Reality [31]: Media Richness and Information System Successes [32], the need for these new ways of understanding reality after the COVID-19 pandemic outbreak is clear [33]. Once the borders were closed, human beings continued to need to travel and visit, and with that need, new doors were opened in the metaverse.

In summary, the metaverse is and will be the container of all of the heritage that we want to and must digitize for this universalization of accessibility.

On the other side of the scale are all of those contents that we must and need to process to introduce them into the metaverse. More specifically, these are the heritage that we want to make accessible and universalize. On this topic, the authors are diverse, and we find various methodologies that allow us to address the issue of heritage digitization from a very solid knowledge base. As we have said, the techniques are diverse and will be determined in each case by the needs of the "object itself", but it is necessary to highlight certain works and authors who, due to their trajectory and scientific solidity, are a reference in this subject [34,35]. In this section, it is important to highlight [19] digital musealizations, such as those developed in Granada: "The digital documentation of Alhambra a research project for the implementation of the museum complex".

Today, there are not only a few museums that are making their collections available to the world through the digitization of their contents [36]; among them, to name a few, are the British Museum, the Prado Museum, the Reina Sofía Museum and the National Gallery of Berlin, as we see in Figure 3.

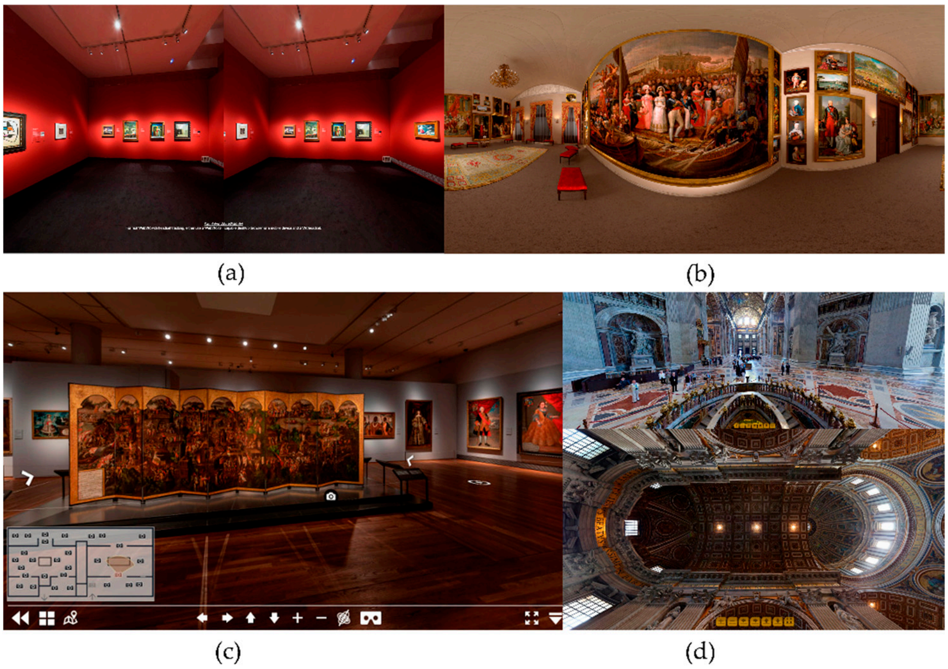


Figure 3. (**a**) On the left is WebVR with headset tracking of the collection "Dalí and surrealism" from the International Museum Thyssen-Bornemisza; (**b**,**c**) virtual visit: "Mythological Passions" of the Prado Museum; (**d**) virtual tour of Saint Peter's Basilica in the Vatican. Details of the Sistine Chapel.

As we can see, due to the incipient advance of the metaverse and the importance of tourism in our country, the concept of metatourism has already been consolidated as a new opportunity for the development of this sector. In addition to museums evolving based on these new technologies, their application in cultural and architectural heritage permits us to generate immersive experiences that favor its dissemination. Thanks to the development of metatourism, we remove the physical, cognitive and even economic barriers that limit the effect that heritage has in society.

1.2. Literature Review: Terminology and Concepts Applied to Architectural Heritage

In the field of architectural heritage, there is a recurring theme: this theme is documentation. Current technological development [37] is affecting this concept of documentation and is modifying both the technique of documenting and the concept of documenting. We are at a historical moment in which we must rethink this idea, and we must address all of the new concepts that technology offers us.

Among these new concepts are, as we have said, "digital communication" and "interaction with digital models". Both the academic world and the digital world are immersed in continuous change to adapt to this revolution, in which we obtain a response from reality:

digital twins [4], complex files capable of responding to multiple problems (tourism [38], conservation [31], documentation [39], gamification [40], education, etc.) and linking to different technologies.

One of the drawbacks that researchers are currently facing is processing the complex files that give rise to digital twins. Therefore, there is a strong need to organize this knowledge and structure it to define a framework linked to the new options that technology offers us [19]. In this way, an interactive database containing these digital twins and the metadata will be a necessary instrument to respond to the above problems and therefore, to form the historical memory of the cultural heritage, the architectural heritage of museum complexes, etc.

We can define metaverses as virtual spaces in which we interact with all of their elements. Virtual worlds are nothing new, and there are a lot of them, especially in the video game industry. Metaverses do not seek to be a fantasy world but a kind of alternative reality in which we can do the same things we do today outside the home, but without moving from the room.

In our case, applied to heritage, we seek to generate knowledge bases that can serve to protect architecture and to be able to take it to any part of the world, regardless of physical or economic condition.

The term metaverse comes from the novel *Snow Crash*, published in 1992, and the term is used to describe visions of three-dimensional or virtual workspaces. These metaverses, therefore, refer to virtual worlds in which we can interact with objects, people, etc.

As for the precise concept of the metaverse that Facebook and other companies are betting on, the idea would be to create a parallel and completely virtual universe that we can access with virtual reality and augmented reality devices so that we can interact with each other within it and, from the outside, with the content we have inside. In the future, these metaverses will be fully immersive, or at least much more so than the current virtual reality. We will have virtual reality glasses, mixed reality, augmented reality or even sensors that record our physical movements.

Some of the main characteristics of a metaverse are as follows:

- Anyone can access the metaverse regardless of the device they use (mobile, computer, VR glasses, AR glasses, etc.)
- People relate to each other through avatars.
- Metaverses encompass both the real world and the physical world. In other words, we can relate to our environment through augmented reality.
- Virtual reality, augmented reality or even mixed reality devices may be used.
- Metaverses can generate an economy.

In this way, in this text, we can say that we expand the scope of the word metaverse because we are not only referring to those metaverses that have been born from video game brands such as Roblox or Fortnite, whose virtual worlds were built for entertainment, or outside of video games, such as Meta, previously Facebook. We are also referring to other minor platforms that meet some of the above characteristics, giving rise to more primitive metaverses, but which, due to their potential for communication or dissemination, we believe important to include in this study because their future depends on continuous advancement and evolution.

As mentioned, in our case, we expand the traditional concept of the metaverse in order to bring it closer to the case of architecture and, more specifically, heritage. In this study, we even included traditional infoarchitecture software platforms that, due to their new characteristics, evolve into a new mixed concept between the software and the metaverse. For example, the Enscape software studied here offers the possibility that different users can inspect a three-dimensional model, allows these users to communicate within the virtual model and allows the use of mixed reality and augmented reality; therefore, we made the decision to include it in this study and encompass it within the concept of the metaverse; although they are indeed more primitive metaverses, their new features and evolution surprise us every day.

2. Materials and Methods

2.1. Work Scheme

The ultimate goal of this research was to develop a low-cost workflow, according to Figure 4, that allows us to generate digital twins of reality and publish these resources on different platforms, similar to what was studied in Mergin' Mode: Mixed Reality and Geoinformatics for Monument Demonstration [41], in which the rapid and open distribution of information was also sought [42].

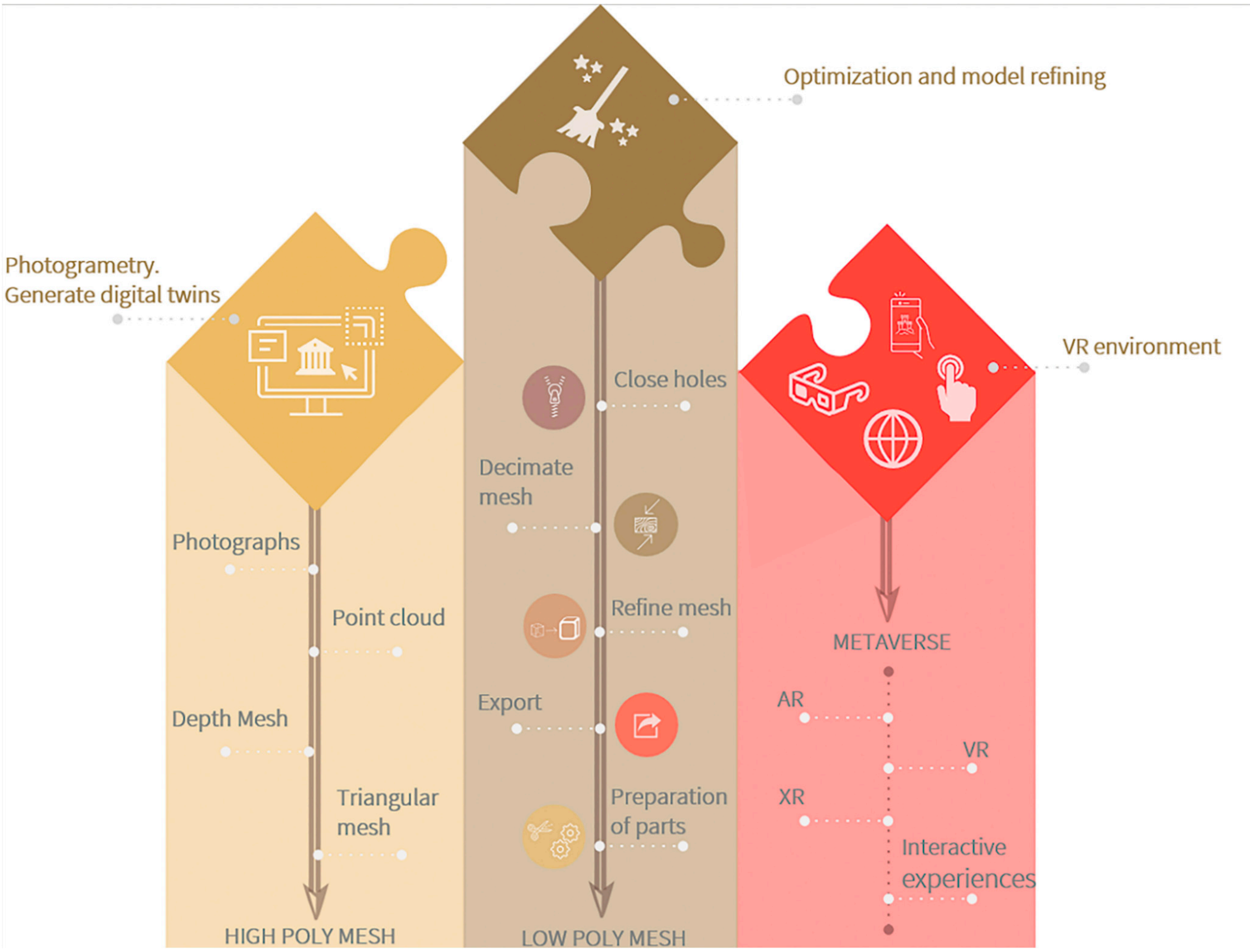


Figure 4. Schematization of work milestones.

The research work scheme is divided into the following 6 activities (Figure 5), which start from a digital twin generated by a photogrammetric [43] survey with a drone and work their way up to the different configurations of a particular metaverse:

- Activity I. The first activity of this workflow establishes a starting point prior to the deepening of the metaverse. In this activity, the heritage asset under study is filtered and selected, and the previously generated digital twin is optimized and prepared for its integration in the metaverse.
- Activity II. This activity is based on a general analysis of the metaverse according to the field in which it is active.
- Activity III. An overview is presented that allows us to distinguish between the different types and analyze the different digital resources currently available that can be used as metaverses to host our digital twins.

- Activity IV. In the development of this activity, the functionalities and capacities of 32 metaverses in which the generated digital twin could be included are listed and analyzed. Based on this detailed analysis, a first screening was carried out according to our requirements (digital infoarchitecture twins obtained through TLS or SFM [44]).
- Activity V. The 7 metaverses selected in the previous screening were analyzed, and a second filter was applied to select a single metaverse from which the results of the virtualization and integration in the metaverse are shown.
- Activity VI. The functionalities of the selected platform were tested with our working model in order to obtain results compatible with VR (virtual reality) and AR (augmented reality) environments [45].

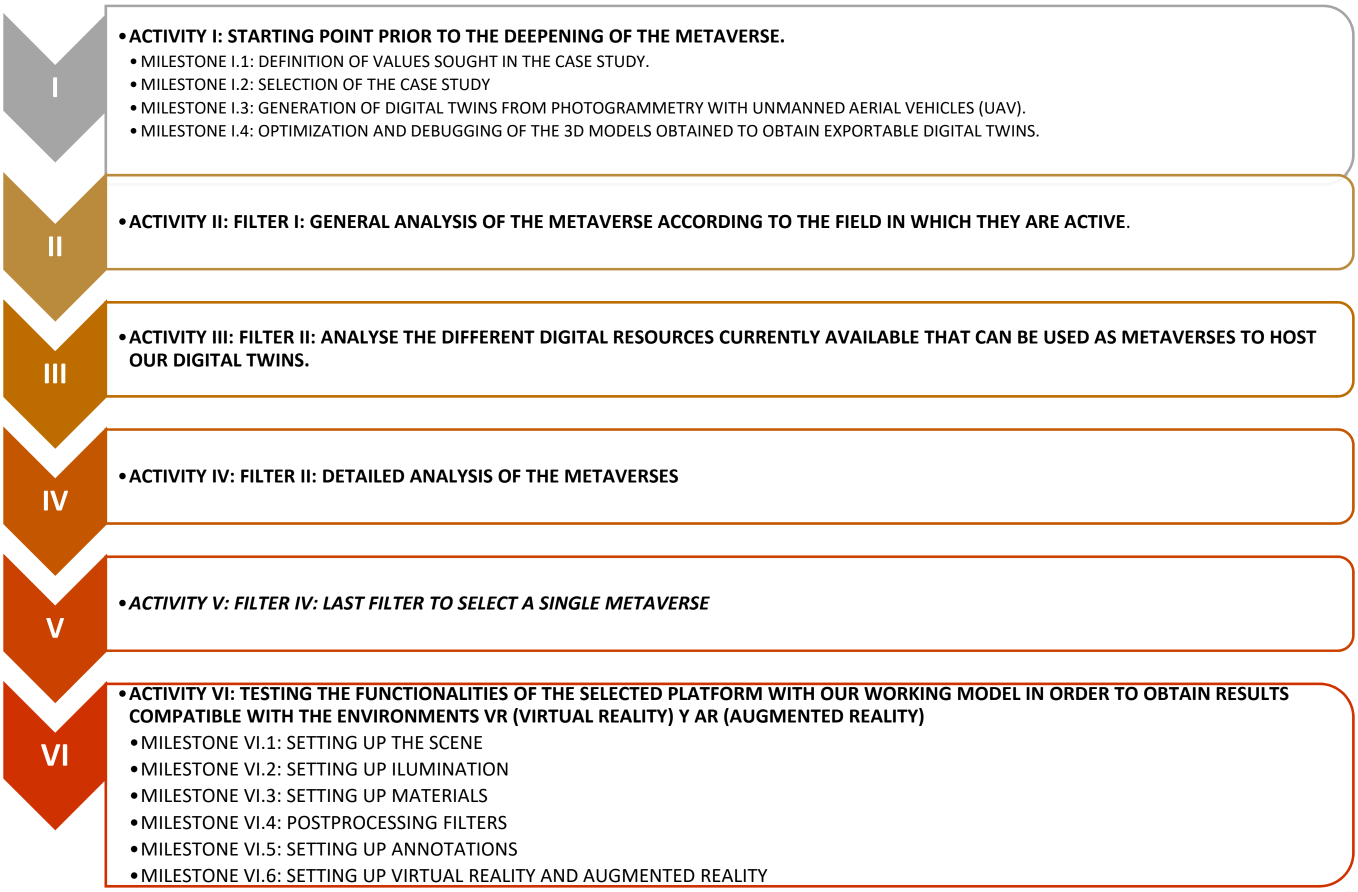


Figure 5. Schematization of work activities and milestones.

As we indicate above, a premise of this work is that the workflow is low cost. Figure 4 shows the main stages of this work. First, "stage 1: photogrammetry. Generate digital twins" is proposed using photogrammetry, because it is an affordable system in terms of both equipment and technology. In our specific case, the DJII Mini 2 UAV equipment and the Agisoft Metashape software were used. Comparatively, this technology is cheaper than traditional scans carried out with TLS (terrestrial laser scanner). The order of magnitude would be an initial investment that is 30 times less in both software and equipment if we compare it with current equipment, such as BLK 360 from the Leica company. This equipment has other drawbacks, such as the ghost zones it generates [35]. In "stage two: optimization and model re-fining", the use of three software programs that are common for processing the results obtained from data collection with UAVs such as TLS is proposed: Rhinoceros, Blender and 3D Builder. At this stage, there is no economic improvement from one method to another. Finally, in "stage 3: VR environment", as we show throughout the text, we have different alternatives, and a selection criterion is that our environment can be used by both the content generator and the content consumer at no cost for said universal accessibility, regardless of economic condition.

We can affirm that the total cost of the proposal carried out with photogrammetry would be 30 times less than one in which the capture was carried out with TLS equipment. It should be noted that the costs are attributed to the need to capture the reality of the built heritage because we would have free software alternatives such as BLENDER, and a premise for the choice of platform on which the content is hosted is that it is free.

2.2. Activity I: Starting Point Prior to the Deepening of the Metaverse

Prior to the generation of immersive experiences in the metaverse, it is necessary to carry out a series of operations aimed at creating digital content. In this way, a simple workflow based on four important phases is established:

- Milestone 1: Definition of values sought in the case study.
- Milestone 2: Selection of the case study.
- Milestone 3: Generation of digital twins from photogrammetry with unmanned aerial vehicles (UAVs) [21,23,46,47].
- Milestone 4: Optimization and debugging of the 3D models obtained to obtain exportable digital twins [22].

2.2.1. Milestone I.1: Definition of Values Sought in the Case Study

When choosing the singular elements of the heritage to be included in the metaverses, it is necessary to establish a series of values that condition their choice (Table 1).

We start from the premise of the disclosure and dissemination of cultural heritage. Therefore, the starting condition for an element as the subject of this investigation is its consideration as part of our heritage. However, the condition of cultural heritage is not decisive due to the large number of elements of these characteristics that are preserved today.

Another of the most relevant conditioning factors when selecting the object of study for this research is the presence of singular elements and complex geometries. Although all of the properties considered to be heritage have a certain relevance, not all of them present detailed elements whose digitization contributes to their dissemination.

In addition, attending to the ultimate goal of this research, namely, the generation of virtual reality (VR) and augmented reality (AR), it is necessary to apply this workflow in spaces of dimensions that make it possible to start up immersive experiences in the metaverse, considering locations that have interiors with dimensions that allow entrance into them to be of added value. In this way, we achieve total immersion in the digitized heritage with its corresponding enhancement.

Table 1. Required values for the object of study.

Characteristics	
Protection	Cultural and architectonical heritage
Form	Complex geometries (vaults, arches, domes [13], etc.)
Details	Singular elements
Dimensions	Architectural elements that can be walked through in VR
Metaverse	Interiors to create immersive experiences

2.2.2. Milestone I.2: Selection of the Case Study

For the development of the work, the Vaquero’s Hermitage, located in the world heritage city of Cáceres, Spain, was selected. The property has the following characteristics (Table 2):

Table 2. Technical characteristics of "Vaquero's hermitage".

Characteristics	
Name	Vaquero's Hermitage
Coordinates	39°28′27″ N 6°22′06″ W
Altitude	426 m altitude above sea level
Construction	Siglo XVII
Extension	Siglo XVIII (baroque-style extension)
Area	281.73 m^2
Other features	It borders the Almohad wall of Cáceres [46].

The Vaquero's Hermitage is part of the oral and written tradition of the city of Cáceres (Figure 6). This hermitage is called the cowboy in reference to the profession of Gil Cordero, to whom, according to tradition, around 1326, the Virgin of Guadalupe appeared in the location that the hermitage now occupies. This apparition is the origin of the invocation of Our Lady of Guadalupe and, therefore, of the imposing monastery of Guadalupe, and it is one of the most important Marian traditions and surely the most significant for Hispanic people [47,48].

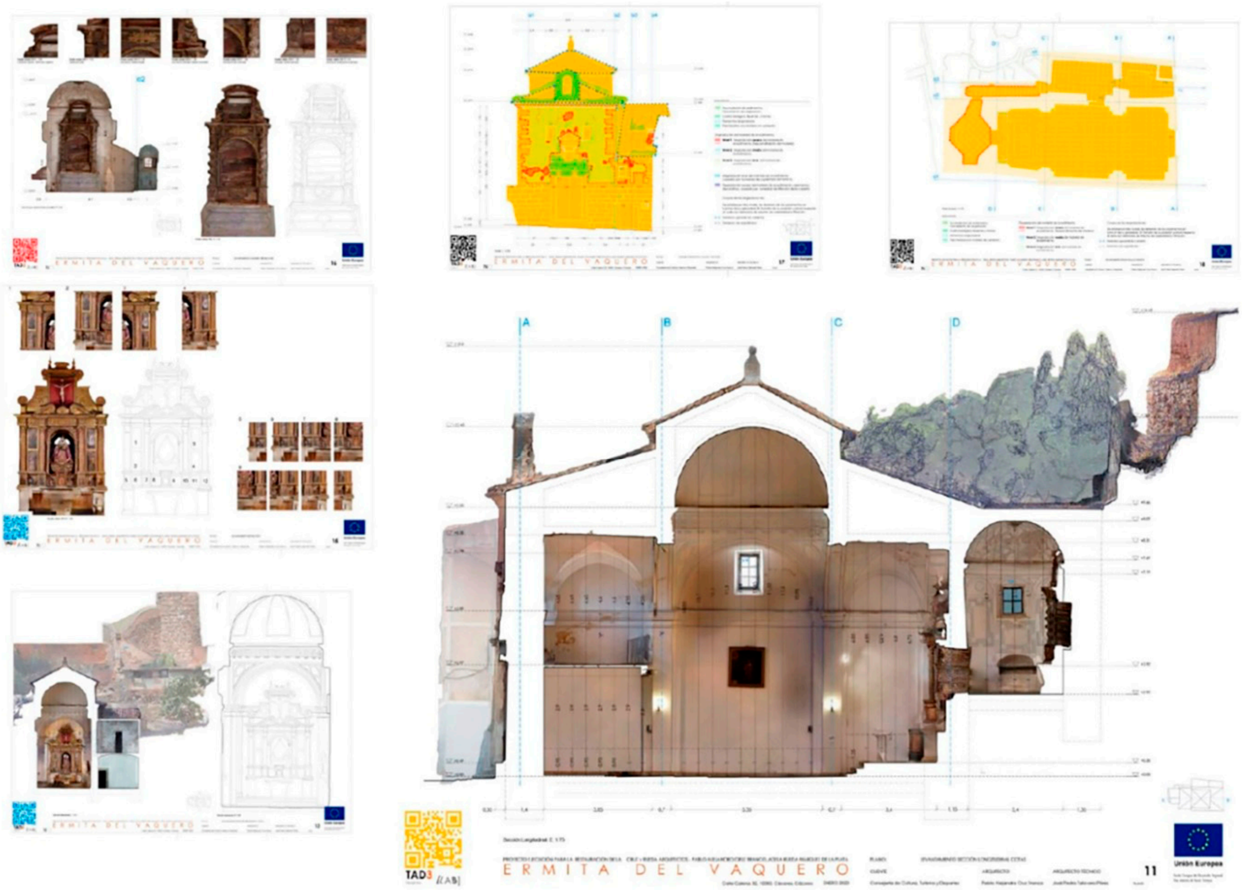


Figure 6. Planimetry of the execution project for the restoration of the Vaquero's Hermitage of Cáceres. Author Pablo Alejandro Cruz Franco.

The origin of the construction of the hermitage dates back to the beginning of the 17th century. Later, to this first work, probably as early as the 18th century (see Figure 7), a baroque-style dressing room was added, which has a polygonal floor plan and is adorned with plasterwork. This is an assumption since we did not find any documentary references to this dressing room or its financing, date of construction or master builder, but in any case, it is evident from the style and conformation that it is an element subsequent to the hermitage chapel.

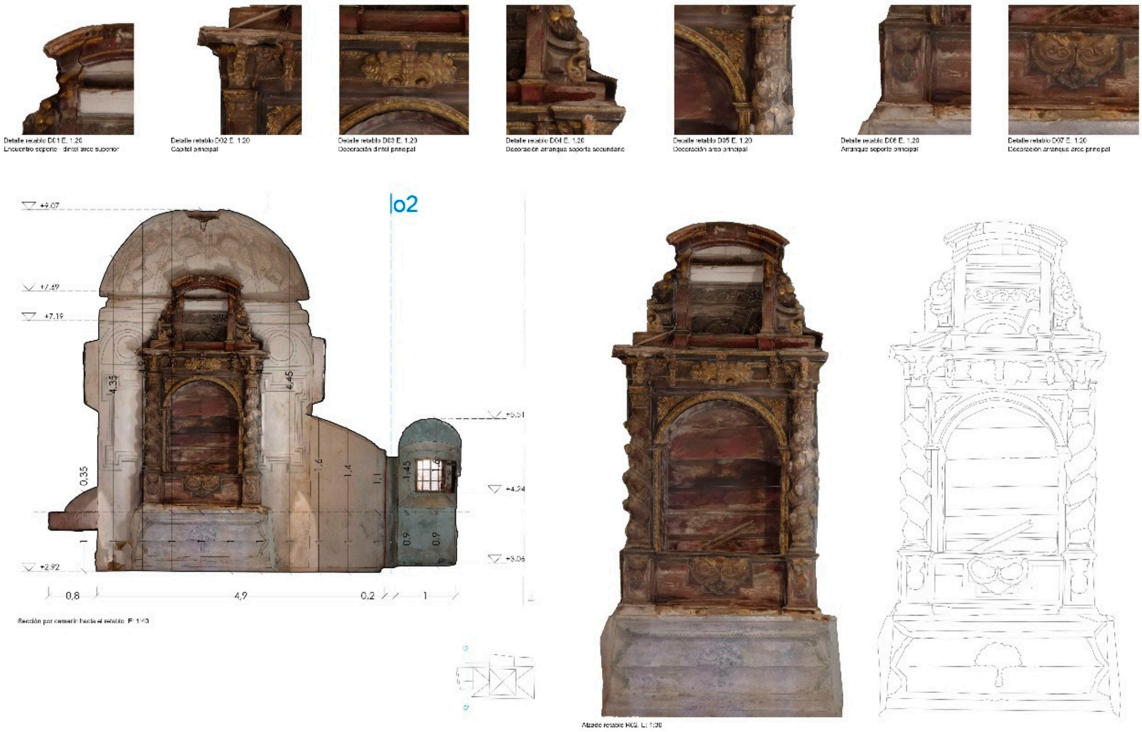


Figure 7. Architectural and pathological analysis of the chapel and the altarpiece located at the back of the hermitage. The study highlights the need to document this unique piece from the 18th century to guarantee its conservation. It has suffered substantial degradation. The boards are very deteriorated due to humidity, the pictorial decoration has been lost, and there are detached boards and serious structural problems.

The hermitage complex was completed with a sacristy, located on the side of the main nave, from where one can access the hermit's house, which is a simple and modest house, typical of a complex of this type, where an old kitchen and a typical cupboard stand out. From this house, there is access to a patio located on the extrados of the wall, from where the old canvas and the outside of the dressing room can be seen.

This space is a unique and ancient element that deserves to be studied in detail since it houses several remains of constructions that could have archaeological and historical value. Thus, it contains a drain made with large pieces of slate that could have been used before the hermitage and could have been used to evacuate the water from the wall; on part of it, there are some pieces of slate of uncertain function (covers, walkways, etc.), and with these, we can see the remains of several constructions that could well have been part of the wall.

2.2.3. Milestone I.3: Generation of Digital Twins from Photogrammetry with Unmanned Aerial Vehicles (UAVs)

First, photogrammetry is carried out using a Structure from Motion (SfM) methodology [49], in which the reality capture process is carried out through the use of drones, and the subsequent processing of the data captured is performed in Agisoft Metashape. In this case, the photogrammetric survey is carried out using drones because it is a low-cost and non-invasive methodology for the photogrammetric survey of cultural and architectural heritage.

On the other hand, the processing of the photographs obtained is a topic that has already been studied in numerous research works, so its development is not the subject of this article. However, in order to improve the understanding of the workflow proposed as the basis of this research, it is essential to at least briefly mention the steps to follow to obtain a quality digital twin from the photographs. These steps are shown in Figure 8:

- Orientation of photographs. This orientation allows the scattered point cloud to be obtained.
- Generation of dense point cloud and depth maps.
- Dense point cloud optimization by point filtering.
- Generation of the triangulated mesh.
- Generation of the texture from the images taken by the drone.

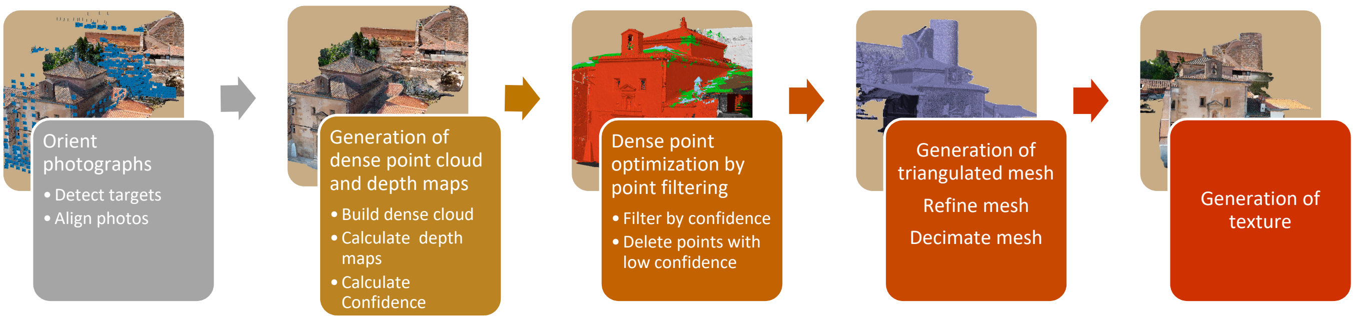


Figure 8. Photogrammetric processing of the data obtained by UAV.

Carrying out these steps gives us large digital twins formed by meshes of thousands of faces in such a way that their integration into the metaverse is impossible. Therefore, it is necessary to carry out an optimization and debugging process on the 3D model.

2.2.4. Milestone I.4: Optimization and Debugging of the 3D Models Obtained to Obtain Exportable Digital Twins

The optimization of the model is necessary to obtain exportable files in different exchange formats. To carry out the debugging of the model, we used Rhinoceros, which allowed us to repair and reduce the mesh as well as generate cuts and sections of the digital twin to give rise to independent pieces of the complete model and content that favors the understanding of the heritage [1,12] (Figure 9).

The first step is to repair the mesh by closing holes in areas where the point cloud is not dense enough to form a closed mesh from it. Once the holes are closed, we can reduce the mesh, that is, reduce the number of triangles, until we reach a simplified mesh that considerably reduces the size of the source file. The next step is to smooth the mesh. Mesh smoothing consists of approximating straight edges to radii with a given curvature while maintaining mesh density. In this way, we obtain a model that is more in line with reality by eliminating perfectly straight edges that do not really exist in the heritage elements.

From this model, we can generate detailed pieces using vertical and horizontal planes that intersect and cut the model into meshes of smaller dimensions. As mentioned, the Hermitage of the Vaquero has several unique elements whose digitization is of particular interest, such as the altarpiece, the domes and the pendentive.

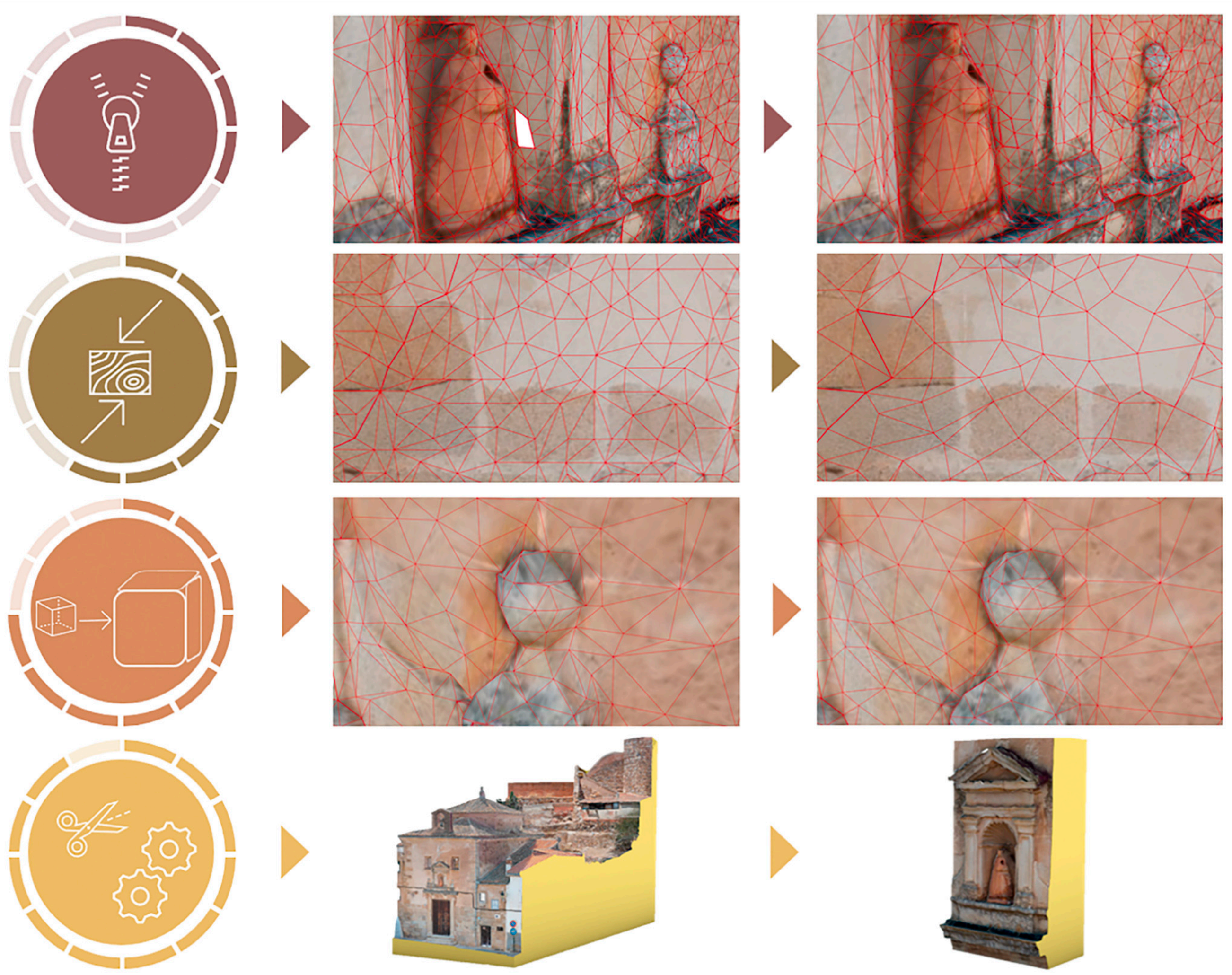


Figure 9. Optimization, debugging and preparation of the digital twin for inclusion in the metaverse.

The step prior to testing the different metaverses is to export the debugged model in an exchange format compatible with the metaverse in which we want to integrate it. To do this, it is necessary to know in advance which destination metaverse will be used and the admissible formats for it.

Once the 3D model is optimized [25], we have digital twins capable of being integrated into the different metaverses by importing the generated files. Depending on some requirements established in advance, we import the file into different metaverses in order to achieve the objectives proposed in this investigation.

For this, the next step is to collect the necessary information and analyze different metaverses in terms of the way they work and the results they offer. The comparison of the functionalities of the metaverse with requirements corresponding to the dissemination of the heritage leads us to the choice of the appropriate metaverse.

2.3. Activity II: Filter I. General Analysis of the Metaverse According to the Field in Which They Are Active

In this step, a general analysis of different metaverses is carried out, from general metaverses that allow the development of any type of activity, metaverses similar to the world we know today, to very specific metaverses focused on digital commerce, the holding of meetings or the development of video games where the development of other activities is not allowed. Some of the best-known general metaverses are Unreal Engine or Breakroom (Figure 10a,b), while The Sandbox is focused on the creation of videogames and digital assets for monetization; Decentraland (Figure 10c) carries out this monetization through the construction of its plots, and AltspaceVR is aimed at the socialization of people, taking the concept of social networks a step further [40].

(a) (b) (c)

Figure 10. (**a**) On the left are screenshots of Unreal Engine: infoarchitecture and character modeling. (**b**) Breakroom metaverse meeting environments, designed for virtual collaboration: from immersive experiences to virtual events, virtual classrooms or digital workspaces. (**c**) On the other hand, we have other experiences, such as Decentraland, in which concepts such as cryptocurrencies, represented here as mana, already appear.

2.4. Activity III: Filter II. Analyze the Different Digital Resources Currently Available That Can Be Used as Metaverses to Host Our Digital Twins

We carried out a detailed analysis of various digital platforms based on virtualization and the production of digital content focused on the generation of virtual reality and augmented reality (Table 3). That first analysis was based on previously selected characteristics such as the capacity to generate VR and AR, the possibility of interacting with the space as if it were a videogame and the generation and reproduction of 360° panoramic images and videos. In addition, two fundamental aspects should be kept in mind when selecting one metaverse instead of another one: the access to the metaverse, which can be local or through the cloud, and the system support on which it is based. The importance of the method of access lies in the need to have an internet connection when we are working online or, on the contrary, the storage capacity and the power of the equipment hardware that we are going to use when we are working locally. On the other hand, we have metaverses that are supported by other infoarchitecture and modeling software, such as *Revit*, *SketchUp* or *3ds Max*, while others are autonomous and only need a 3D model or 360° images and videos to generate this virtualization.

Table 3. Analysis of digital resources based on the metaverse concept.

	Place	VR	AR	Gaming	HDR	System Support
A-frame	Local/cloud	✓	✓	✓	✓	Self-governing
Blender	Local	✓	✗	✓	✓	Self-governing
CloudPlano	Cloud	✓	✗	✓	✓	Self-governing

Table 3. *Cont.*

	Place	VR	AR	Gaming	HDR	System Support
Concept3D	Local	✓	✗	✓	✓	Self-governing
CenarioVR	Local	✓	✗	✓	✓	Self-governing
Enscape	Local	✓	✗	✓	✓	Subordinate to other software
Fusion18	Local	✓	✗	✓	✗	Self-governing
Google AR/VR	Cloud	✓	✓	✗	✗	Self-governing
Google Earth VR	Cloud	✓	✗	✗	✓	Self-governing
IrisVR	Local	✓	✓	✓	✗	Subordinate to other software
Lumion	Local	✓	✗	✓	✓	Subordinate to other software
LiveTour	Local	✓	✓	✓	✓	Self-governing
Marmoset Toobag	Local	✓	✗	✗	✗	Subordinate to other software
MODO VR	Local	✓	✓	✓	✓	Self-governing
Pannellum	Local	✓	✗	✓	✓	Self-governing
Pano2VR	Local	✓	✗	✓	✓	Self-governing
Panorama Image Viewer	Cloud	✓	✗	✗	✓	Self-governing
Photo Sphere Viewer	Local	✓	✗	✗	✓	Self-governing
Powertrak CPQ Software Suite	Local	✓	✓	✓	✗	Self-governing
Revit	Local	✓	✗	✓	✓	Self-governing
Shapespark	Local	✓	✗	✓	✗	Subordinate to other software
Sketchfab	Cloud	✓	✓	✗	✗	Self-governing
Verge3D	Local	✓	✓	✓	✗	Subordinate to other software
Vray	Local	✓	✗	✓	✗	Subordinate to other software
VRdirect	Local/cloud	✓	✗	✓	✓	Self-governing
TechViz	Cloud	✓	✓	✓	✗	Subordinate to other software
Trezi	Local	✓	✗	✓	✓	Subordinate to other software
Twinmotion	Local	✗	✗	✓	✓	Subordinate to other software

2.5. Activity IV: Filter III. Detailed Analysis of the Metaverses

As for the data obtained from the previous analysis, we can apply the first filter in order to select a metaverse according to the results we obtain from each one and according to the conditions in which we will develop the virtualization process. However, it is interesting to perform a second analysis that differentiates between content generated by digital twins and content generated from reality captured in 360° images and videos. In this way, we are able to select the working metaverse not only according to the development conditions but also according to the content we want to generate (Table 4). Thus, we have applications such as Google Earth VR that provide VR and AR from reality, and we also have other software programs such as IrisVR that start from 3D models to obtain VR.

Table 4. Analysis of digital platforms according to the possibilities of results they offer.

	"Digital Twins" Creators	AR/VR from "Digital Twins" (*)	AR/VR from 360° Images and Videos from Reality (*)	Virtual Tour from "Digital Twins"	Virtual Tour from Reality	HDR from "Digital Twins"	HDR from Reality
3DCloud	✗	✓	✗	✗	✗	✓	✗
3DViewer	✗	✓	✗	✗	✗	✗	✗
A-frame	✓	✓	✓	✗	✗	✓	✓
Blender	✓	✓	✗	✗	✗	✗	✗
CloudPlano	✗	✗	✓	✓	✓	✗	✗
Concept3D	✗	✗	✓	✓	✓	✓	✓
Cenario VR	✗	✓	✓	✗	✗	✓	✓
Enscape	✓	✓	✗	✗	✗	✓	✗
Fusion18	✗	✓	✗	✗	✗	✗	✗
Google AR/VR	✗	✓	✓	✗	✗	✗	✗
Google Earth VR	✗	✗	✓	✗	✗	✗	✓
IrisVR	✓	✓	✗	✗	✗	✗	✗
Lumion	✓	✓	✗	✗	✗	✓	✗
LiveTour	✓	✓	✓	✓	✓	✗	✗
Marmoset Toolbag	✗	✓	✗	✗	✗	✗	✗
Marzipano	✗	✓	✓	✓	✓	✓	✓
MODO VR	✗	✓	✗	✗	✗	✗	✗
Pannellum	✗	✓	✗	✓	✓	✓	✓
Pano2VR	✗	✓	✓	✓	✓	✓	✓
Panorama Image Viewer	✗	✓	✓	✗	✗	✓	✓

Table 4. *Cont.*

	"Digital Twins" Creators	AR/VR from "Digital Twins" (*)	AR/VR from 360° Images and Videos from Reality (*)	Virtual Tour from "Digital Twins"	Virtual Tour from Reality	HDR from "Digital Twins"	HDR from Reality
Photo Sphere Viewer	✗	✓	✓	✗	✗	✓	✓
Powertrak CPQ Software Suite	✓	✓	✓	✓	✓	✓	✓
Revit	✓	✓	✗	✗	✗	✓	✗
Shapespark	✗	✓	✗	✓	✗	✗	✗
Sketchfab	✗	✓	✗	✗	✗	✗	✗
Verge3D	✗	✓	✗	✗	✗	✓	✗
Visor 360°	✗	✗	✗	✗	✗	✓	✓
Vray	✓	✓	✗	✗	✗	✗	✗
VRdirect	✗	✗	✓	✗	✓	✗	✓
TechViz	✗	✓	✗	✗	✗	✗	✗
Trezi	✓	✓	✗	✗	✗	✗	✗
Twinmotion	✓	✓	✗	✗	✗	✗	✗

(*) It involves metaverses that only generate AR, those that only generate VR or those that include both of them.

2.6. Activity V: Filter IV. Last Filter to Select a Single Metaverse

(*) From all of the information gathered from the two previous analyses, we obtained the characteristics of 32 digital content generation metaverses described in detail. These characteristics allowed us to reduce the study sample to a significant fraction of 7 metaverses, on which we tested the documentation generated through the digital twin generation procedures. We established the limit of 7 test metaverses in order to show all of the possibilities of generated documentation (VR, AR, virtual tours, visualization and generation of HDR images and videos, etc.) without obtaining redundant results that do not provide us with more interesting information for this research. The selected platforms are those described in Table 5, together with the file formats supported by them.

Table 5. Selection of digital platforms according to the previously mentioned filters.

	Formats
CloudPlano	.jpg, .jpeg, .png, .tiff
Concept3D	CAD files, .jpg, .jpeg, .png and .tiff
Enscape	Plugins of Revit, Rhinoceros, SketchUp, Archicad and Vectorworks
IrisVR	Plugins for Revit, Naviswork, Rhinoceros and SketchUp and .obj, .fbx files
Lumion	Plugins for Revit, SketchUp, Rhinoceros, Vectorworks, AutoCAD, ARCHICAD and BricsCAD, and it is compatible with ALLPLAN and 3ds Max.
Shapespark	Extension for SketchUp, 3ds Max, Revit Maya and Cinema 4D. Other .fbx, .obj and .DAE files.
Sketchfab	.fbx, .obj, .DAE, .blend, .STL, gltf, .bin, .glb, .3dc, .3ds, .las, .ply, .igs and .usd

The selection of the platforms mentioned in Table 5 was made for the following reasons:

CloudPlano is similar to Pano2VR. Both of them generate virtual tours from 360° images and videos, allow annotations to be entered, generate VR and allow its visualization through all types of devices, both of them being paid metaverses. However, we selected CloudPlano instead of Pano2VR due to the ease of working in the cloud, without the need to install any additional platforms on our devices.

Concept3D is a viewer of virtual tours generated from 360° images and videos with the added feature of generating a map with references to where each 3D image is located with informative notes. In addition, this metaverse allows VR in the different virtual tours generated.

Enscape is a 3D rendering platform that works locally in real time and is subordinate to 3D modeling programs. In addition, it also generates VR by connecting to VR glasses such as Oculus Rift S or HTC Live.

IrisVR, as with CloudPlano and Pano2VR, is a metaverse that shares many features with other studied metaverses, such as TechViz. However, IrisVR was selected because this metaverse is more focused on the building and architecture fields than the others.

Lumion is also a 3D rendering platform, but, unlike Enscape, it does not generate VR but rather generates photorealistic videos and images in real time from models generated by programs such as SketchUp, Rhino or Revit. This platform allows textures and finishes to be defined and complementary elements to be added to these 3D models in order to obtain more realistic results.

Shapespark is a platform capable of locally and autonomously generating virtual tours with or without VR, even allowing video calls inside the virtual tours generated to carry out online work on the digital twin.

Sketchfab is the only autonomous work platform that generates VR and AR from 3D models in the different formats shown in the table above.

Despite the above selection, it is worth highlighting the versatility of the A-frame platform in terms of generating digital content. It is the most complete platform, which can also be developed in the cloud, making it easy to access and work with. However, the disadvantage of this platform is that the generation of digital content is based on HTML or JavaScript files, which requires advanced computer skills that make it difficult to use.

Finally, the last analysis was performed according to Table 6.

Table 6. Last selection of digital platforms.

	Digital Twins from Photogrammetry	**Free Access for Users**	**AR from Digital Twins**	**VR from Digital Twins**
CloudPlano	✗	✗	✗	✓
Concept3D	✗	✗	✗	✓
Enscape	✓	✗	✗	✓
IrisVR	✓	✗	✗	✓
Lumion	✓	✗	✗	✓
Shapespark	✗	✗	✗	✓
Sketchfab	✓	✓	✓	✓

In this last analysis of the platforms, we introduced a series of differential requirements that made us opt for the Sketchfab platform. These requirements were the following.

They can work with digital twins of complete buildings (both exterior and interior) obtained through photogrammetry. In other words, not just any digital twin will do (we can have twins made in SketchUp, Revit, etc.). In this last analysis, we only worked with digital twins obtained by photogrammetry with complex geometries according to activity I.

The second requirement is fundamental: free access. Since we seek universal accessibility, it is essential that we do so through a platform that allows us free access. The free distribution of knowledge is prioritized.

In this latest screening, VR and AR were separated, with Sketchfab being the only platform that offers both immersive experiences.

Given all of the above, the Sketchfab platform was selected.

2.7. Activity VI: Testing the Functionalities of the Selected Platform with Our Working Model in Order to Obtain Results Compatible with VR (Virtual Reality) and AR (Augmented Reality) Environments

Once the platform is selected, the different functionalities it offers are checked with the model selected in activity I. The final objective is to obtain a high-quality digital resource for tourism [50], education, informative purposes, etc. [51–53] (Figure 11). The postprocessing of the virtual twin [54] is based on a workflow with 6 functionalities that allows us to optimize it for different uses.

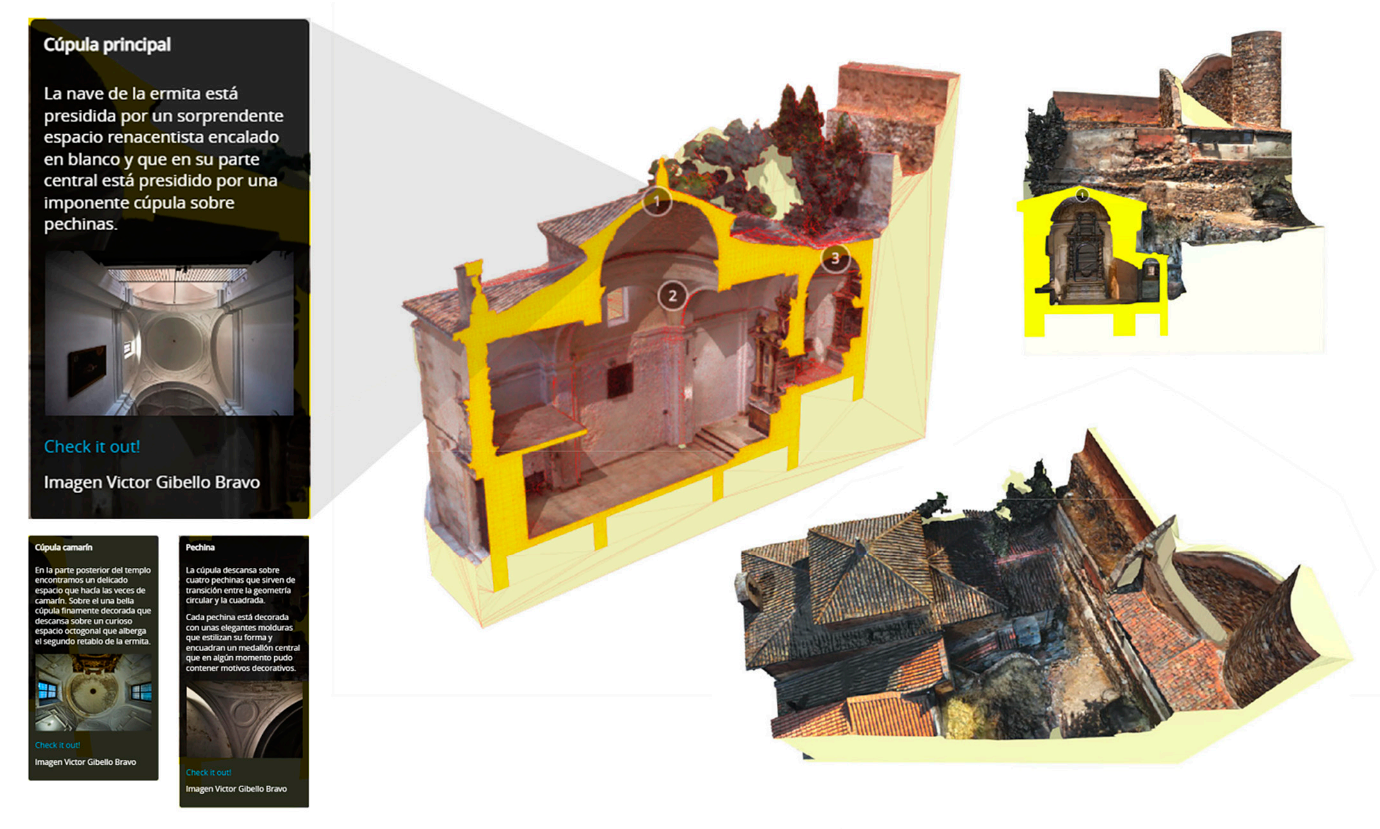


Figure 11. Assembly of the proposed model.

The 6 milestones or activities that constitute the workflow start from the scene configuration to the definition of the immersive experience of cultural heritage (Figure 12). Postprocessing is based on the editing of the 3D settings that Sketchfab provides, and its functioning is based on the following steps:

- Milestone VI.1: Setting up the scene. The first step is defining the position of our digital twin in the space, as well as other basic visualization options. In addition, at this milestone, we can even determine the behavior of the materials in the model. In the case study, the textures were obtained through photogrammetry.
- Milestone VI.2: Setting up illumination. Thanks to this option, we can determine the lighting parameters of a maximum of 3 lights as well as include HDR images that supply ambient light to the digital twin.
- Milestone VI.3: Setting up materials. From the decision adopted in milestone 1 about the type of materials the digital twin will have, we can modify the characteristics of each one independently.
- Milestone VI.4: Postprocessing filters. The use of filters for digital content is already normalized in today's society in order to obtain different ways to visualize anything. In this case, thanks to Sketchfab, we were able to apply up to 10 filters to Vaquero's Hermitage.
- Milestone VI.5: Setting up annotations. The selected platform allows us to include additional information that contributes to a cognitive improvement of the cultural heritage. This information can appear as text, images and even links to web pages that provide more information.
- Milestone VI.6: Setting up virtual reality and augmented reality. In order to generate immersive experiences in the architectural heritage, it is necessary to define a series of issues, such as the initial position and the size of the avatar with respect to the heritage element that we are interacting with.

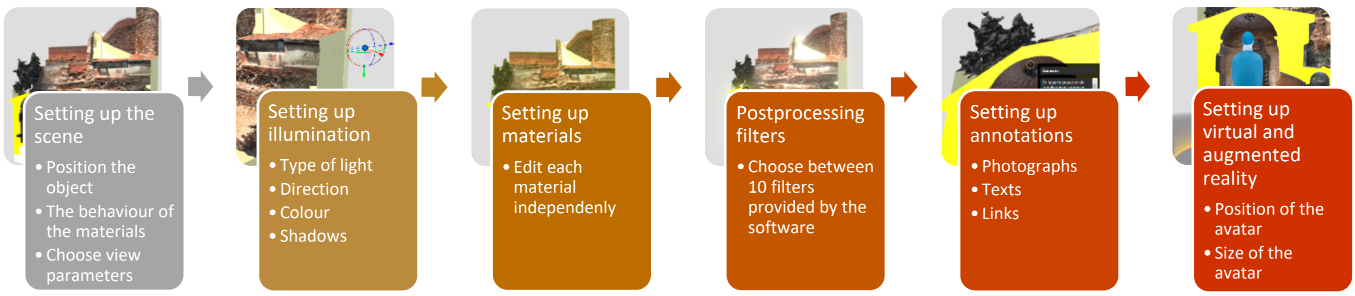


Figure 12. Postprocessing workflow.

All of these options are easily handled through drop-down menus that permit us to carry out the fast editing and selection of parameters, as we discuss later.

2.7.1. Milestone VI.1: Setting Up the Scene

We are able to position our object with respect to the coordinate axis. The application works as a traditional rendering engine in which we work with different parameters [55]. With a rendering engine, we are able to decide the behavior of our materials (in the case study, the materials were uploaded from photogrammetry results). These textures can be treated as materials by PBR (physically based rendering). This is a technique that approximates real illumination models together with the definition of the physical characteristics of the materials to generate higher-quality scenes. In this case, we could activate (Figure 13a) or deactivate the shading of the object (Figure 13b). Finally, MatCap Shaders (Figure 13c) are complete materials that include illumination and reflection.

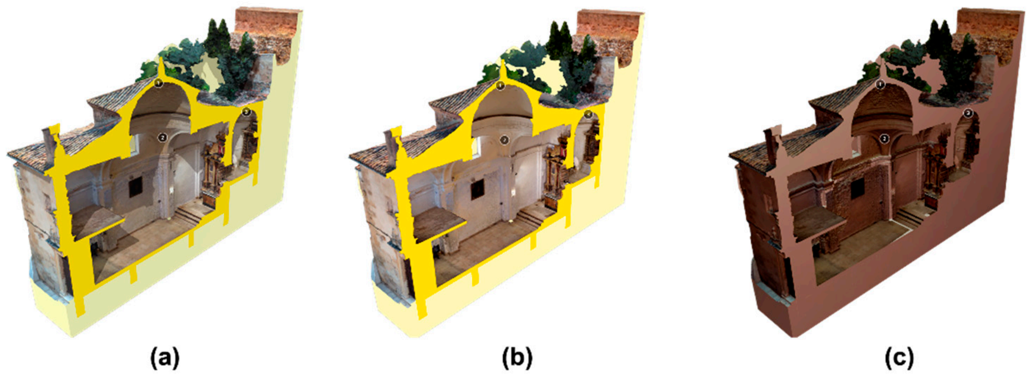


Figure 13. (**a**) PBR with lit shading, (**b**) shadeless PBR and (**c**) MatCap renderer.

At the same time, we can modify other parameters: the camera and its field of view; we can visualize the wireframe of our three-dimensional model, making it easier to understand the geometry and the background of our image.

In our particular case study, we opted for a PBR (physically based rendering) configuration with shading lit, as it is the most appropriate since we moved our textures within the photogrammetric application when activated. For the camera, we selected a 45° field of view, and we switched off the limit orbit camera option due to its incompatibility with annotations (milestone VI.5). We also switched off the wireframe and selected a neutral color for the background to favor the clarity of the model display (Figure 14).

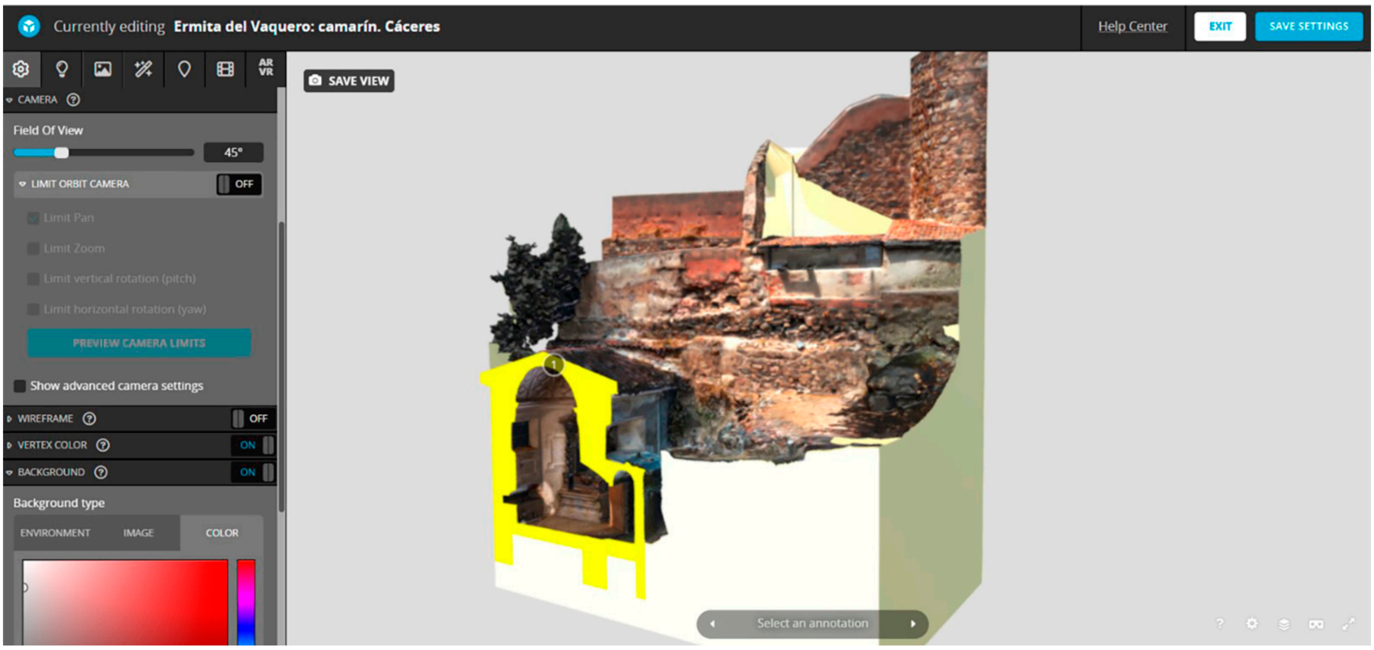


Figure 14. Sketchfab interface. Setting up the scene.

2.7.2. Milestone VI.2: Setting Up Illumination

Again, as in a traditional rendering engine, we can modify the lighting parameters of our scene. The application allows us to modify the type, direction, color and shadows of our scene with a maximum of three lights (Table 7).

Table 7. Lighting modifier analysis.

	Light Properties	Ground Shadows	Environment	Shadows	Light Intensity	Shadow Bias	HDR from Reality
PBR (lit shading)	✓	✓	✓	✓	✓	✓	✓
PBR (shadowless)	✗	✗	✓	✓	✓	✓	✓
MatCap	✗	✗	✓	✗	✗	✗	✓

We can even include ground shadows to show the effect that our digital twin would produce on the floor.

For the environment, we have a number of options: on the one hand, it is important to highlight the possibility of incorporating HDR images as an environment of the set or lighting resources; however, the platform includes several default HDR images that we can use directly instead of uploading one of these images from our devices.

In view of the comparison and our aim to generate a resource with the highest possible quality, we propose to use PBR with lit shading, as indicated in Section 2.7.1.

In the case study, we incorporated 3 lights, switched off the ground shadows and used the previously selected neutral background. We introduced some small changes through orientation, brightness and shadow options for better control over the illumination that the hermitage receives (Figure 15).

Figure 15. Sketchfab interface. Setting up illumination.

2.7.3. Milestone VI.3: Setting Up Materials

The customization options of the material are determined by the first decision taken in setting up the scene to use PBR (physically based rendering) or MatCap (material capture). Each of these materials that compose the imported model can be configured independently. In these cases, we are able to modify the textures that we imported from our modeling platform (Figure 16); in our case study, we were especially interested in the textures obtained by photogrammetry, as these are textures with high resolution adapted to a simplified model [25].

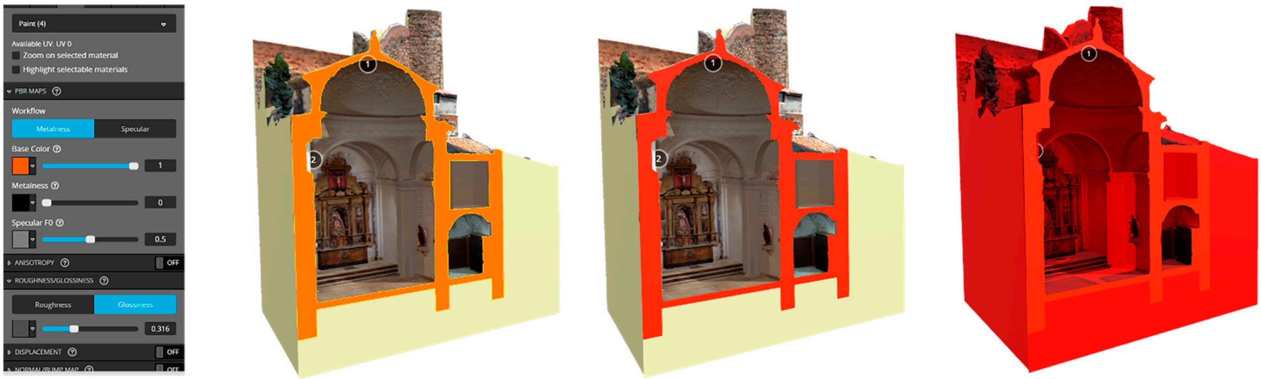


Figure 16. Different customizations in PBR of the preconfigured materials in activity I. Customization of the clipping region in orange and red and, finally, replacement of all texture maps by a solid red color.

In this way, if the exported model is ordered in pieces in activity I, we have the freedom to edit the materials of each piece independently. Each piece can be textured as if we were using a typical 3D program (3D Studio, Rhinoceros, AutoCAD, Maya, etc.) with complex materials and textures or solid colors.

Among the modifiers that we can use depending on our needs, we can highlight the following: anisotropy—add reflections over a patterned surface; roughness or glossiness—select how surface irregularities affect the reflection of light; displacement—add a grayscale depth map to displace the model vertices; normal and bump map—use texture to add bumps to the surface of the model; and other traditional modifiers, such as clear coat, ambient occlusion, cavity, opacity, emission, etc. In short, we can handle the material library as if we were using a traditional rendering engine (Figure 17).

All of these configurations are based on the selection and definition of various effects, so the materials set up for a heritage element may not be suitable for another architectural element. Therefore, we should test and combine settings until we find the option that best shows our digital twin in the metaverse.

Figure 17. Sketchfab interface. Setting up materials.

2.7.4. Milestone VI.4: Postprocessing Filters

Similarly to the Enscape rendering engine, we can apply postprocessing filters to our scene to obtain different results in our model [56]. These filters are the following: Screen Space Reflections (SSR; Figure 18a), Screen Space Ambient Occlusion (SSAO; Figure 18b), Grain (Figure 18c), Depth of Field (DoF; Figure 18d), Sharpness (Figure 18e), Chromatic Aberration (Figure 18f), Bloom (Figure 18g), Vignette, Tone Mapping (Figure 18h) and Color Balance (Figure 18i).

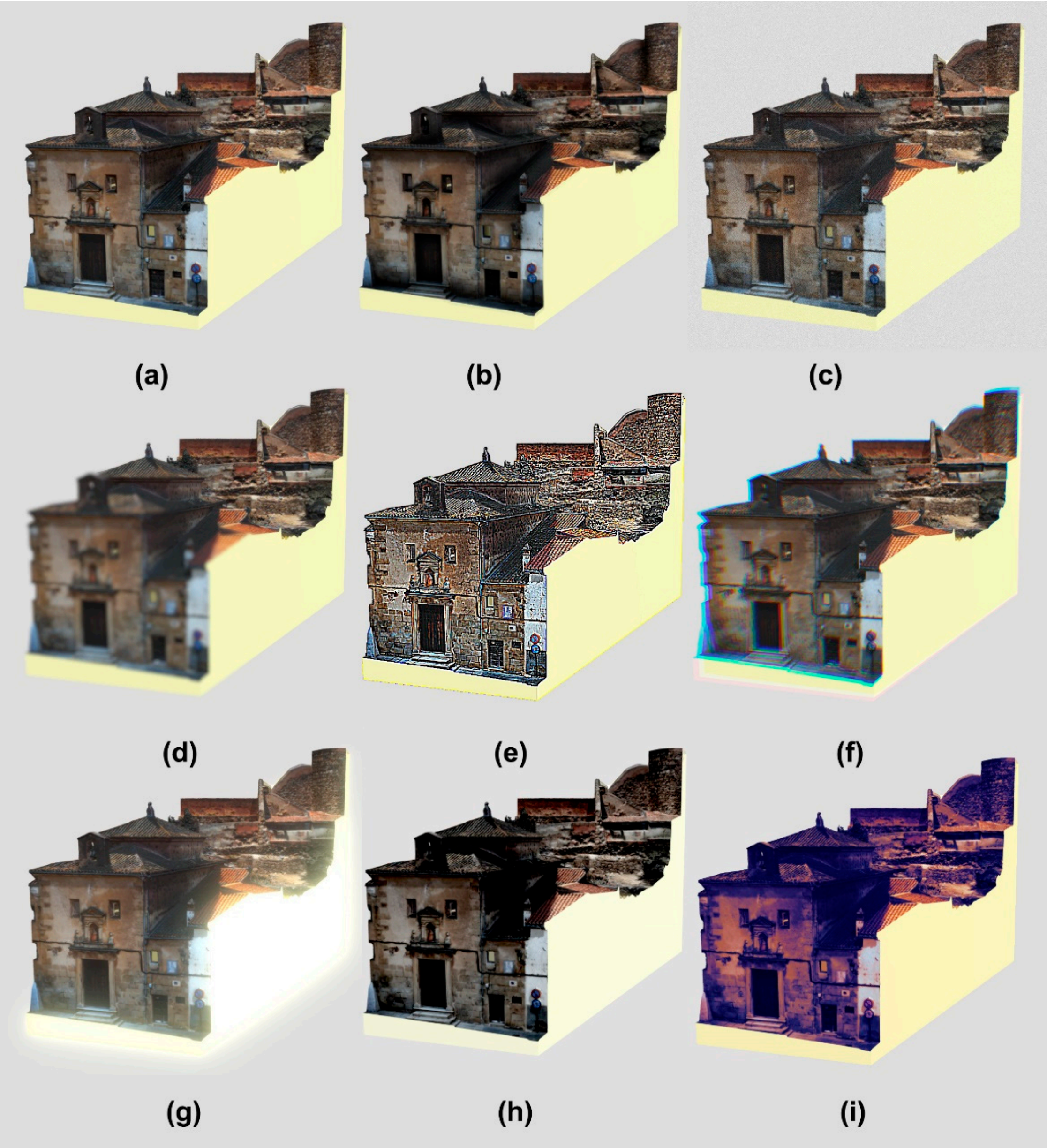


Figure 18. Different customizations in PBR of the preconfigured materials in milestone VI.1. Customization of the clipping region in orange and red and, finally, replacement of all texture maps by a solid red color: (**a**) Screen Space Reflections (SSR), (**b**) Screen Space Ambient Occlusion (SSAO); (**c**) Grain, (**d**) Depth of Field (DoF), (**e**) Sharpness, (**f**) Chromatic Aberration, (**g**) Bloom, (**h**) Vignette, Tone Mapping and (**i**) Color Balance.

As we can see, each one provides us with a different image of the digital twin, highlighting different elements of our 3D model. The selected filter for Vaquero's Hermitage visualization was SSR (Screen Space Reflections; Figure 18a) because this effect gives us a better resemblance to reality than the rest (Figure 19).

Figure 19. Sketchfab interface. Postprocessing filters.

2.7.5. Milestone VI.5: Setting Up Annotations

This option permits us to add different types of information to the model, improving the experience for the user by including photographs, texts, links to web pages and preconfigured views (Figure 20).

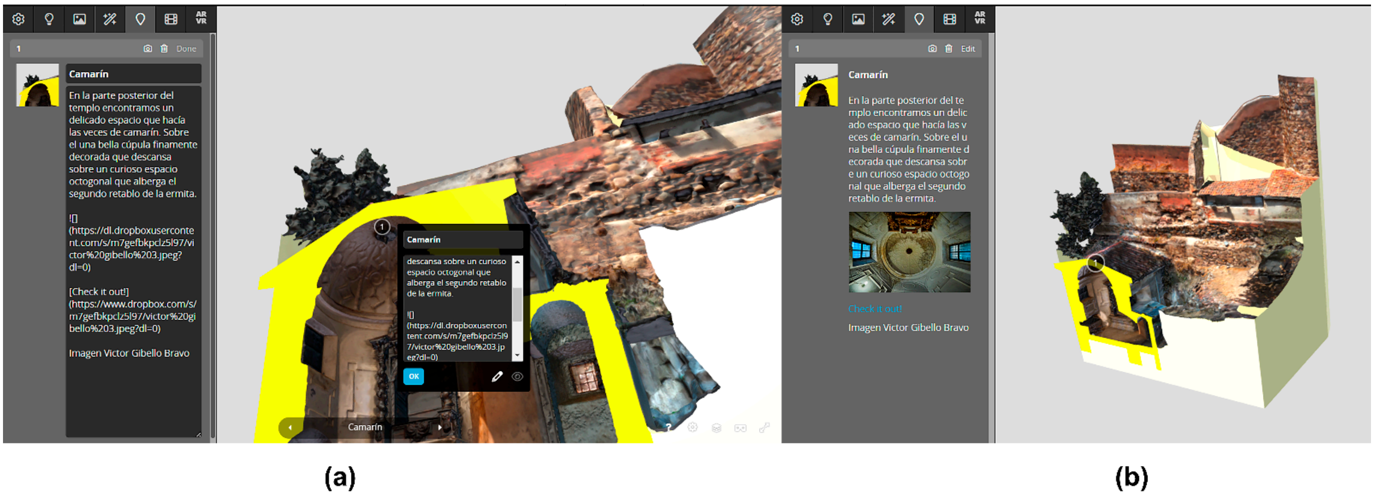


Figure 20. (**a**) Editing of contents within the model. (**b**) View of contents: detailed photograph and link to other web pages.

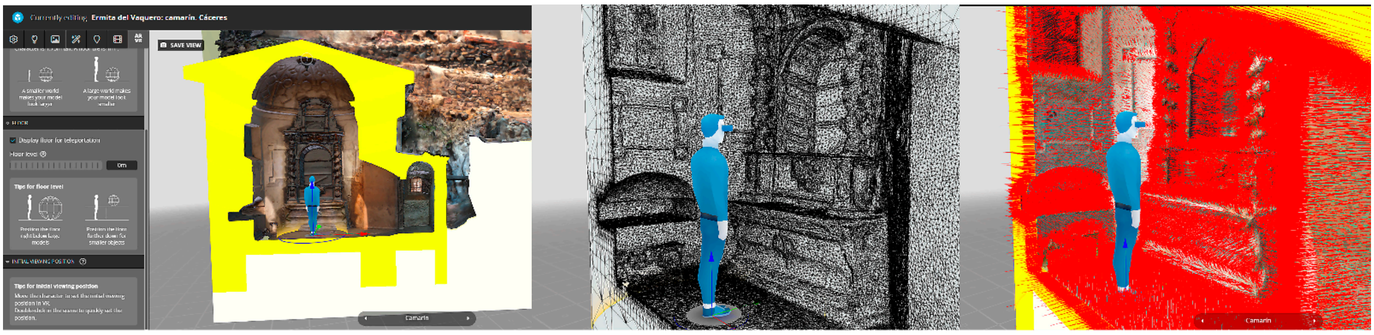
To add annotations, we only have to stay in the Annotations tab and double-click the exact point of the digital twin where we want to insert this annotation. After that, a dialogue box appears, in which we can include the title and the content of the annotation. If we want to include a photograph, we have to specify a web direction because Sketchfab does not support *.jpg fields.

In the following image (Figure 21), we show how we make an annotation, which appears with the number 1. It includes text, an image and a web link that allows us to see a larger-sized version with a better resolution of the mentioned image. This one, in this case, was uploaded through the platform Dropbox, and we only had to insert the link to this page in the annotation.

Figure 21. Sketchfab interface. Setting up annotations.

2.7.6. Milestone VI.6: Setting Up Virtual Reality and Augmented Reality

From an informational point of view, it is probably one of the biggest strengths of this virtual environment/metaverse: the ability to interact with our models in both virtual reality and augmented reality (AR) [57] (Figure 22).



(a) (b) (c)

Figure 22. (**a**) Determinacion de la posición inicial del avatar para VR; (**b**,**c**) Escalado del modelo respecto de la malla.

We can configure the starting position of our avatar, that is, the point of the model it shows (outside, inside, aerial view, etc.), and we can also configure the size of the model relative to our avatar, that is, the relative size-aspect; this determines if, when we relate to the model, it has its real size or the size of a scale model or a configuration we decide.

The selected scale for our avatar is 1.19. This avatar should rest on the floor inside Vaquero's Hermitage to obtain a line of vision similar to the human eye (Figure 23).

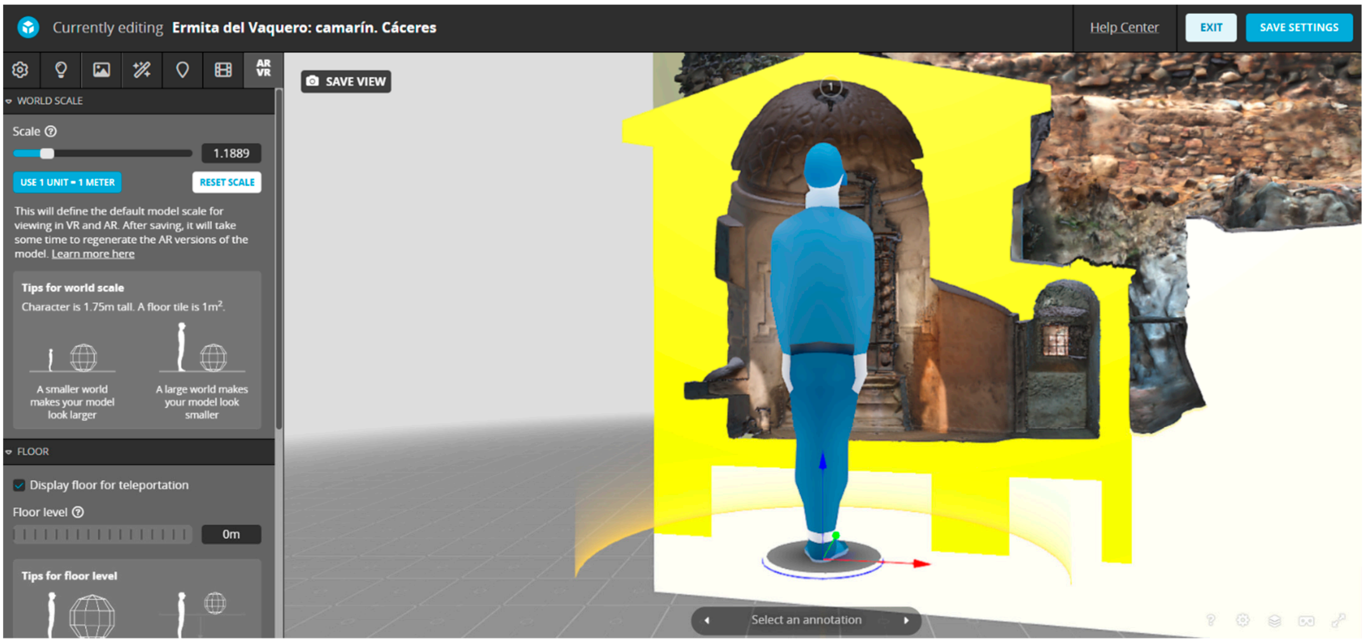


Figure 23. Sketchfab interface.

Regarding the hardware, Sketchfab allows us to interact both with mobile devices with Cardboard or similar and with desktop devices or laptops compatible with devices such as Oculus (Rift/Rift S/Quest via Oculus Link) (Figure 24), SteamVR (HTC Vive, Valve Index, etc.), Windows Mixed Reality, OpenXR-compatible HMDs (with OS Windows) with Cardboard, Daydream View and Lenovo Mirage Solo (with OS ANDROID) [58].

Figure 24. Virtual reality and augmented reality visualizing the altarpiece of the Vaquero Hermitage.

With the app Sketchfab for mobile devices [48], we can access augmented reality content (AR). With a simple mobile device, such as a tablet or a smartphone, we can see our models positioned in space and in relation to other physical elements in the environment. We can scale them, rotate them, surround them, etc.

Therefore, all of these functionalities offer a multitude of options in terms of the final result that can be obtained once the digital twin has been introduced into the metaverse. The combination of the selection of materials, lighting, scenes, etc., makes it possible that a single digital twin reaches the end user in an infinite number of different ways. In summary, the following diagram organizes the post-production operations that can be carried out with Sketchfab (Figure 25).

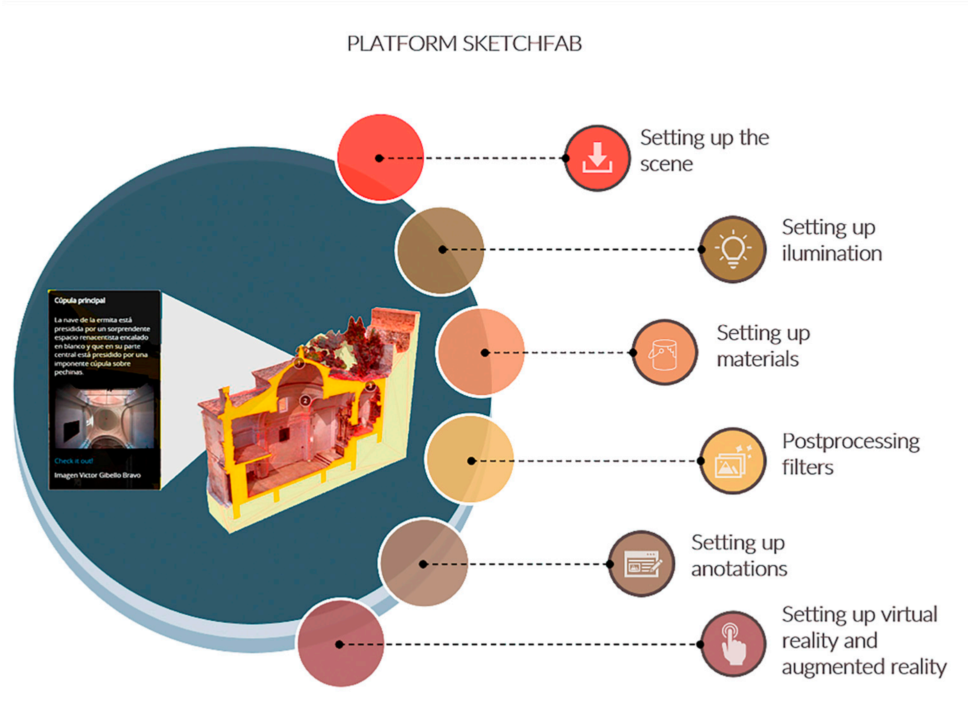


Figure 25. Development of the functionalities of Sketchfab.

3. Results

By applying the methodology proposed in the case study of Vaquero's Hermitage, we can highlight several results based on the objectives initially proposed.

First, some basic characteristics of a study model were defined, and a study model was selected from these basic characteristics. Let us help define the workflow. In this first step in the workflow, it is important to define both the platform and the steps to debug the virtual twin. It is important to highlight the origin of the initial digital twin, since we are starting from meshes or complex geometries with high-resolution textures obtained by photogrammetry.

In this refinement of the virtual twin, a refinement protocol is established according to Figure 26, which allows us to have a virtual twin of the highest quality.

The second objective, developed in parallel, was an in-depth analysis of the existing metaverses at the time of writing this article. Secondly, we determined which were the most appropriate for our established requirements: architectural analysis, dissemination, education, generation of databases for the protection of the heritage, universal accessibility, etc.

For this second objective, the Sketchfab metaverse was finally selected because it is the most suitable for the specified requirements: dissemination, virtual reality, augmented reality, generating databases for the protection of the heritage, free access, universal accessibility, etc.

A virtual twin refining protocol was generated again within the app to obtain the best features and meet accessibility specifications.

Figure 26. Tourist information proposal.

The case study was a success because, from the virtual twin obtained by photogrammetry, fantastic results were obtained that allowed us to access the documentation in a new and dynamic way. Not only did it generate a new concept of planimetric documentation that combines augmented reality by incorporating QRs into the document, but it also generated valuable resources that guarantee: dissemination, conservation and education.

4. Discussion

New digital representation technologies are a discipline that is continuously evolving. Since their inception, they have had the ability to expand our sensory experiences, especially sight. They can show us spaces that would otherwise not be accessible. With recent advances, we can not only experience other places but also expand the experiences of the places we visit (augmented reality and mixed reality). We can mention digital experiences in digital environments.

The protection of heritage and its disclosure is an obligation of today's society. New representation technologies offer us a multitude of possibilities to protect and disseminate our heritage, and now, it is multidisciplinary teams of researchers who are in charge of developing protocols to achieve the maximum dissemination of information.

Today's society has an obligation to digitize heritage [37,59–61], but it also has the challenge and obligation to disclose it and take advantage of all of the possibilities of the information society.

The proposed methodology is divided into two phases. The first phase of data collection and digital twin generation is divided into four steps (developed in activity I), and the second phase, in which the digital twin is incorporated into the metaverse, is divided into six steps (developed in activity VI).

Regarding the first phase, we can state that:

- First of all, as a society, we have an obligation to digitize the world in which we live in order to preserve it as a digital twin for future generations: the present database.
- Secondly, from these digital twins, we have the opportunity to recreate lost architectural environments and future digital environments: foundations of the past and the future.
- There are many digitization methods, each with advantages and disadvantages [11,58,59,62–64]. In the present study, a low-cost methodology based on the use of UAVs [23,65] was chosen, which was outlined and incorporated into the workflow. This scheme is supported by other works and the professional experience of the authors [66,67].
- For some time now, new representation technologies have allowed us to create resources and content that reflect how our heritage is and could be. These digital twins, both the digital copies of the present and the digital proposals of the past and future [68], give rise to huge databases that have traditionally been used for the development of restoration projects, as in the case study of the Hermitage of the Vaquero, but once the work was completed, it was complex and difficult to use them as a knowledge tool.

At this point, our methodology continues. We started from the definition of metaverses as environments in which humans interact and exchange virtual experiences and which are therefore tools for disseminating knowledge.

An extensive analysis of the possibilities that researchers have at their disposal today was carried out. In our proposal, an easy alternative is given that guarantees the free diffusion of digital twins. The advantages of this second part of the methodology are the following:

- These databases are a tool of unquestionable value to change our ways of learning, traveling, disseminating, etc.
- We give continuity to previous works by both the authors and other authors [16,68–73]. In these works, digital twins were obtained, but the problem of transferring said digital twins to society was not resolved.
- In phase 2 of the methodology, in four simple steps, we can upload our virtual twins to a proposed metaverse.
- The choice of the metaverse is based on looking for the one that best suits our needs.
- The resources obtained in the metaverse are effective tools to use in education. They offer us the opportunity to give our students new digital resources through QR codes or other tools that complement and improve learning by offering resources in augmented reality and virtual reality that can be handled by students.
- In the same way, the resources obtained are a way for new tourism capable of reaching all places, regardless of money, location or physical conditions.
- This new tourism can travel through resources (VR or AR) not only to an existing site but also to new virtual environments from the past or proposals for the future.

We do not believe that virtual reality can replace the physical experience of interacting with a building, but we do believe that it is a very important complement in order to preserve and spread heritage (Figure 27), a complement to which we cannot turn our backs. It ostensibly improves the concept of accessibility because it allows access to the monument to any person, regardless of their physical condition, place of residence or economic condition.

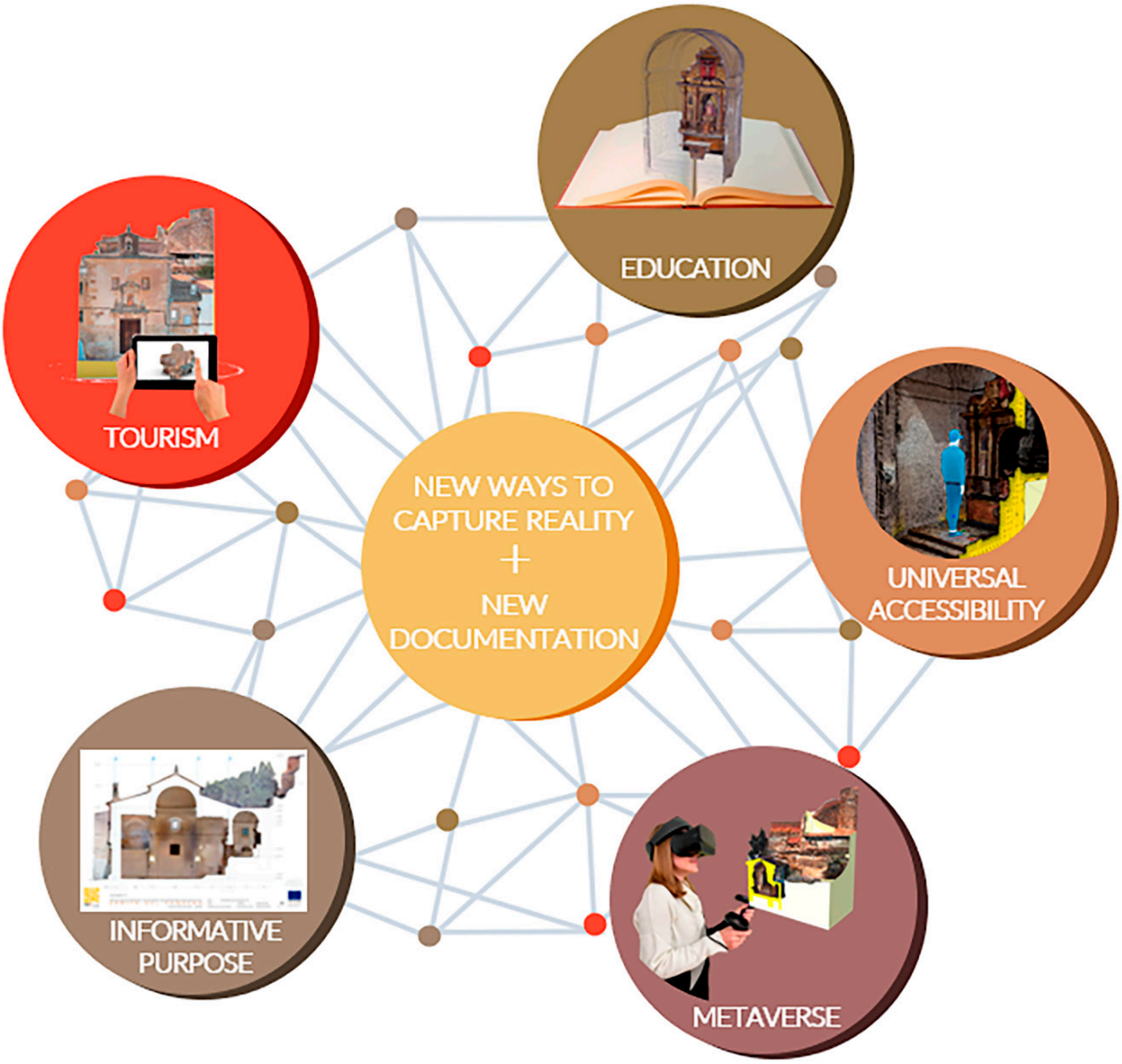


Figure 27. New functionalities based on the new digital documentation.

This virtual reality, augmented reality and all of the new content become a tourist attraction by improving the way we approach our buildings and even help us reach places that were not accessible before.

They are also transformed into unprecedented educational resources. Our children can see a dome, a portico or how a building is built without leaving the classroom.

These digital twins are a way to preserve our present. It is a necessity and a duty to generate them because they become the imprint of the moment in which we live. We emphasize that it is a duty because catastrophes, wars or crises are unfortunately common today, and the only way to preserve our legacy for new generations is through these tools.

5. Conclusions and Future Works

Through the application of VR and AR technologies to the heritage, we are not only able to reach a wider audience for its dissemination. The use of metaverses, AR and VR allows us to achieve universal accessibility that removes space and time barriers in all areas. We are not only referring to physical barriers that limit access to the heritage for a large part of the population. We are also referring to sensorial and cognitive barriers that are becoming more and more important in today's society. Moreover, this study also breaks down economic barriers by using low-cost technology and free access and distribution software that permits us to bring heritage to the whole of society. In this way, the metaverse serves a dual function: it ensures universal accessibility that, at the same time, promotes the dissemination of the heritage.

All of this means that the integration of digital twins of our cultural heritage in different metaverses appears to be the future of museum resources. Visitors have changed, and they have forced the main touristic and cultural attractions, the architectural heritage, to reinvent themselves. It is based on creating more dynamic content able to attract a larger number of visitors through detailed descriptions, the generation of digital guides to and playful exploration of the environment and immersive experiences from any part of the world [74], even when in front of the heritage, using technologies such as mixed reality (MR).

Now that we have studied and developed the configuration and generation of augmented reality (AR) and virtual reality (VR), we are beginning to develop mixed reality (MR) as a combination of both. Through MR, the user could physically visit Vaquero's Hermitage with a digital device compatible with this type of technology that allows us to interact with the real world through videos, explanations and other digital content.

These informative actions and the application of this new technology are also consolidated as the future of sectors such as education. At lower levels, students can relate learning to real problems, facing real situations and complex cases that allow them to increase their interest and study in more detail in a more independent way. Long processes of change and development that have traditionally been explained in a theoretical way could be solved in the classroom by simulations because there are no space and time limitations. This rupture of space and time constraints also favors the student's understanding of historic facts and figures [75]. Lastly, the application of VR and AR in education is used to develop specific training courses, such as those related to medicine, driving, machine repair, etc., where practical skills are developed with zero danger while students use low-cost technologies [76].

Author Contributions: The editorial responsibility of the paragraphs is credited to: P.A.C.F., A.R.M.d.l.P. and E.G.B.; conceptualization, P.A.C.F. and A.R.M.d.l.P.; methodology, P.A.C.F. and E.G.B.; validation P.A.C.F. and E.G.B.; formal analysis A.R.M.d.l.P. and P.A.C.F.; investigation P.A.C.F., A.R.M.d.l.P. and E.G.B.; resources, P.A.C.F. and A.R.M.d.l.P.; writing—original draft preparation, P.A.C.F. and E.G.B.; writing—review and editing, P.A.C.F., A.R.M.d.l.P. and E.G.B.; visualization, P.A.C.F., A.R.M.d.l.P. and E.G.B.; supervision, P.A.C.F. and E.G.B.; project administration, P.A.C.F. and A.R.M.d.l.P. All authors have read and agreed to the published version of the manuscript.

Funding: This publication has been made possible thanks to funding granted by Consejería de Economía, Ciencia y Agenda Digital de la Junta de Extremadura, and by the European Regional Development Fund of the European Union through the research project "Aplicación de tecnologías VR y levantamientos 6D para la implementación de una accesibilidad universal en el patrimonio arqueológico de edificación pública romana" through reference grant IB20096. The authors are also thankful for funding granted by the Consejería de Economía, Ciencia y Agenda Digital de la Junta de Extremadura, and by the European Regional Development Fund of the European Union through reference grant GR21159 (COMPHAS researcher group).

Acknowledgments: This work has been developed by the members of the TAD3 lab of the University of Extremadura, specialized in the application of new techniques and technologies in architecture. This publication has been partially developed thanks to the SEXPE Innovation and Talent Program 2021 of the Junta of Extremadura: Protocolos para la implementación de modelos de información en ciudades patrimonio de la humanidad para la búsqueda de una accesibilidad universal. For the development of this research, we have had the support of the Comphas research group of the University of Extremadura, which has provided us with the material means and tools.

Conflicts of Interest: The authors declare no conflict of interest.

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