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Virtual museums. Captured reality and 3D modeling

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ABSTRACT

Virtual spaces for the dissemination of cultural heritage and virtual experimentation were developed combining 3D image acquisition techniques like digital photogrammetry (captured reality) and computer 3D modeling. This is a novelty in peripheral countries, particularly in Latin-America, since there is almost no development of this kind of virtual museums in the region. Two virtual scenes are presented in the frame of a digitization project of the collections of Argentine museums. On one hand, a virtual museum named *Virtual Collections* was created. It exhibits, in a computer generated environment, the collections of the participating museums in the aforementioned project, digitized by 3D photogrammetry. On the other hand, a virtual tour that recreates a retrospective exhibition was also built as an interactive recording for documentation of the event. In both cases 3D modeling and texturing techniques were used, achieving realistic results. Two instances of immersion are available for the visualization and interaction with both virtual environments: screen, keyboard and mouse (Desktop VR) and HTC Vive (VR visualization headset).

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1. Introduction

For almost three decades there has been a continuous development of virtual reality (VR), making it possible to create environments that simulates the real world and create interactions and visualizations that are impossible otherwise.

One of the uses of this technology is linked to the exhibition of art and cultural heritage. Since the 90s, there are virtual spaces on the Internet called “virtual museums”, which aims to disseminate art online. Much of this art is created especially to be shown online, but there is also photographic records and information about real world museums collections. It is important to highlight that the first virtual museums are not virtual environments where the user can move around; they are collections of digital archives with the sole purpose of disseminating art.

There are many definitions of VR and each one is related, in one way or another, to the following concepts: simulation, interaction and immersion. A virtual environment is a simulation we can interact with, and generate a sense of immersion so realistic, that we feel ourselves inside that world [1]. VR applications have two

levels of immersion. The first one uses the traditional computer screen as a window to the virtual world and a keyboard and mouse as a means of interaction (Desktop VR). Some examples are: *The Virtual Museum*, an apple computer CD-ROM released in 1992 [2]; the Museum of Computer Art (MOCA) [3] and Encarta Virtual Tours [4]. In these virtual tours, the most frequently type of art shown is pictorial art. This is the case of the *Zeitreise* project [5] that recreates a XIX century building where an exhibit of paintings from the same epoch can be found, with the particularity that the curatorial design corresponds to that of the same century. In this way, this exhibition works both for the dissemination of the XIX century art and as a teaching mechanism for the XIX century curatorial method. There are also many interesting examples of this type of virtual tours in the virtual world *Second Life*, where people can find really large collections of artworks in a virtual setting. For example, the virtual environment *The Museum of Fine Arts* has temporal exhibits with paintings and multimedia content like audio and video that guide and explain the exposition, just like a real world museum [6].

The second level of immersion in a virtual environment is achieved by using a VR system that allows a user to feel a total sense of immersion. This means having six degrees of freedom (6DOF) tracking for the output(perception) and input(interaction) devices. The most basic setup which makes this possible is a head mounted Display (HMD) and a VR controller. With this interface the user is able to observe the virtual environment just like being inside and the controllers are designed to permit interactions with buttons,

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joystick and/or touchpads [7]. In this level we can mention *Archeologie Den Haag's* virtual tour or the virtual experience made by the Museu d'Arqueologia de Catalunya-Ulasteret in 2017, where all the late city of Ulasteret is built from planes using 3D modeling techniques [8,9]. The virtual tour offers an audio-narrative experience that guides the user through the space and time of the city, teaching about its traditions, culture and fall against the Roman Empire. It is important to point out that in more advanced setups there are also controllers and navigation systems that enable interaction with gestures, perform tracking of individual fingers and capture a user motion to use this as an input and create the sense of locomotion in the virtual environment [10].

There is also a middle point between both levels of immersion; for example, *The museum of the future* uses an HMD as method of visualization but keeps mouse and keyboard as an interface for controlling movement inside the environment, where the user can find images made by digitizing real life paintings [11].

Most of these examples offers either 2D images or 3D models made with modeling techniques instead of using Captured Reality techniques. We define Captured Reality (CR) as the exact virtual 3D reconstruction of a real object. To obtain a 3D model of a real object there are techniques like laser or structured light scanning and, most recently, digital photogrammetry [12–15]. Using these tools it has been possible for museums to create virtual repositories with 3D reconstructions of real objects. This is the case of the Argentinian project *Digitalización de bienes culturales mediante imágenes 3D* [16], or the project *Sketchfab for cultural heritage* which has more than 450 institutions participating [17]. Naturally, one of the main objectives of both projects is the dissemination of cultural heritage.

By combining VR technologies and CR, it is possible to create virtual tours with elements from the real world. This way, the public has access to environments that are otherwise inaccessible to them. This is the case of the virtual reconstruction and tours of the tombs of *Bertocchini*, *Bettini* and *Inscriptions*, where an HMD and a kinect sensor were used, allowing the users to interact with the environment and creating a layer of information to navigate and interact with [18]. Another good examples of the usage of these technologies are the virtual museums of “The Eutroscanning project” which use 3D modeling and photogrammetry for re-create two tombs: *Regolini Galassi*, the grave of a princess in the Sorbonocropolis of Cerveteri, and *Tomb n.5 in Monte Michele*, the grave of a warrior, in Veii. This virtual museums also use kinect sensor to interact and navigate through the space [19].

Even though all these technologies are relatively accessible to everybody, as far as we know, there are no virtual museums that avoid modeling the exhibited objects and use only fully reconstructed models with 3D photogrammetry. On the other hand, there are at the moment very few projects that aim to visualize art and cultural heritage by combining 3D modeling and CR, to generate virtual spaces that offer tours showing reconstructed objects in a realistic way [20].

Virtual museums, also, add new possibilities to the exhibits, allowing for a new relationship between the object and the visitor in ways that physical museums do not provide [21]. One of the key aspects of virtual museums is the possibility of going beyond the exhibition of a particular museum, combining the collections and resources of multiple institutions in a single exhibition. Therefore, the virtual reality format has great potential at curatorial level. It allows to create an exhibition that is based entirely on the idea of what the curator wants to show without physical limitations of spaces and type of objects to be exhibited [22–24]. In addition, it enables the creation of interactive simulations with museum pieces, without the risk of damaging them. It is precisely this phenomenon that we refer to when we talk about virtual experimentation.

In this work, we present the creation of virtual environments for the dissemination of cultural heritage and virtual experimentation, combining CR 3D recordings obtained by digital photogrammetry and computer 3D modeling. Two virtual scenes were developed and analyzed in the framework of the project *Digitalización de bienes culturales mediante imágenes 3D*, developed by the Laboratory of Laser Ablation, Photophysics and 3D Images (LALFI) of the Centro de Investigaciones Ópticas (CIOp). On one hand, a virtual museum named *Virtual Collections* was created. It exhibits, in a computer generated environment, the collections of the participating museums in the aforementioned project, digitized by 3D photogrammetry. On the other hand, *Krause. Vestigios disponibles*, an exhibition that took place at the Museo Provincial de Bellas Artes Emilio Pettoruti in 2017, was performed by using both Captured Reality and computer generated 3D modeling.

2. Research aims

The objective of this work is the creation of virtual museums combining Captured Reality techniques and computer 3D modeling for the dissemination of cultural heritage and virtual experimentation. This is a novelty in peripheral countries, particularly in Latin-America, since there is almost no development of immersive virtual museums in the region. In this sense, one of the aims of the work is to combine the collections and resources of multiple regional institutions in just one virtual museum exhibition. Another aim of this work was that the 3D reconstructions of the exhibited objects were made by the staff of each participating regional museum.

3. Materials and methods

The Mu3D digitization system, based on digital photogrammetry with Structure from Motion (SFM), was used for the 3D recording of the heritage objects [14]. Mu3D uses a friendly graphical user interface (GUI) created by LALFI for museums staff in order to facilitate the interaction with complex software systems involved in the 3D reconstruction process. The software used for this work were: VisualSFM, CMP-MVS, COLMAP and openMVS. Digital Single Lens Reflex cameras were used for photographic acquisition.

A DJI Phantom 4 drone was used for the photogrammetric recording of large scale objects that required being photographed from heights of more than 2 m. This type of digitization was performed by the LALFI researchers, unlike the rest of the pieces, which were made by the staff of the museums trained in the framework of the project.

The cultural heritage objects exhibited in *Virtual Collections* were a selection of the CR 3D recordings obtained with the Mu3D system in the project *Digitalización de bienes culturales mediante imágenes 3D*. These models have a resolution of $\sim 200 \mu\text{m}$ and an accuracy of $\sim 99\%$ with respect to the real object [10]. Each 3D model has $\sim 1,000,000$ – $3,000,000$ faces and a size of ~ 100 Mb, depending in each case on the scale and complexity of the geometry of the piece.

For *Krause. Vestigios disponibles* we used modeling and texturing techniques for building most of the exhibited objects. We chose this method due to the fact that, for the original artworks like paintings or drawings, planes textured with photographs could be used, and also because the volumetric objects were not original artworks. Only one original model of the author was reconstructed with Mu3D.

For the creation of the *Virtual Collections* museum, we designed the architectural space, the signage and the supporting furniture of the heritage objects. These elements were digitally modeled and textured using the Blender free software, by using standard meshes.

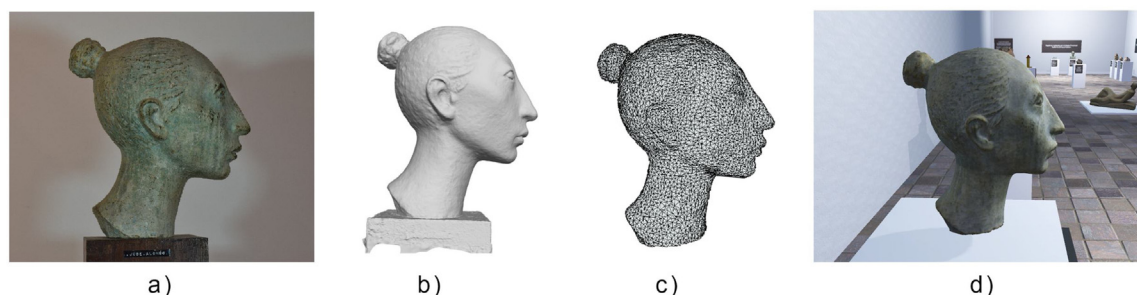


Fig. 1. (a) Photograph of the object. (b) Original high resolution mesh. (c) Simplified mesh. (d) Simplified textured mesh placed in the virtual environment. Object: *Cabeza* by José Alonso, cement, 1947, Museo Provincial de Bellas Artes Emilio Pettoruti Collection.

Also, solidification algorithms, Boolean operations and face extrusion were used.

In every 3D model, UV unwrapping texturing techniques were used. These techniques consist of unfolding the polygons of the mesh to match them with a two-dimensional image (i.e. photographs of the objects). To achieve a more realistic result, a texturing method called Physically Based Rendering (PBR) was used. In PBR textures are employed to carry information about the physical properties of the material (e.g. roughness, metalness, etc.) as an approach to model the flow of light. For example, this process uses textures that modify the normals of the object, creating the illusion of bumps and cavities that are not in the mesh. This is useful when we want to reduce the number of polygons of a mesh keeping the details that are visible in the texture but not in the simplified mesh.

Fig. 1 shows the reconstruction of a stone sculpture obtained with Mu3D and its location in the *Virtual Collections* environment. In order to use these models in a virtual environment, a simplification process was necessary, reducing the number of polygons of these models to ~15,000 faces. The reason for this simplification is that large mesh sizes impact on the performance of the virtual museum software, decreasing the frame rate and generating an unusable experience.

To obtain high fidelity textures in the simplified model, the pipeline consists of: using the high resolution virtual textured mesh that was obtained by photogrammetry, superimposing on it a simplified version of the same mesh, creating a UV map of the simplified mesh and bake the texture of the original mesh over the simplified one. The result is a texture where features that are on the surface of the original mesh and not in the simplified one are observed. Only one color image is used to texturize each model.

With the model simplification this problem was solved, and the baking process allows to preserve the appearance and the real object in the simplified mesh. This is one of the advantages of using baked textures instead of high resolution 3D mesh.

The development of the virtual reality experience was carried out in the Unity game engine. The textured 3D models were organized and placed to attain a comfortable tour. At first, these environments were focused on creating tours to be seen in the computer screen, and interact with mouse and keyboard. Subsequently, an HTC Vive HMD (also called Live Headset) was used as a display device for experimenting VR, with a Unity plugin called *SteamVR*. The HTC Vive HMD that was used is outside-in” positional tracking system [25,26].

4. Results

Two virtual scenes were developed. *Virtual Collections* exhibits the collections of the Argentine museums, digitized by 3D photogrammetry. On the other hand, *Krause. Vestigios disponibles*, was performed by using both Captured Reality and computer generated

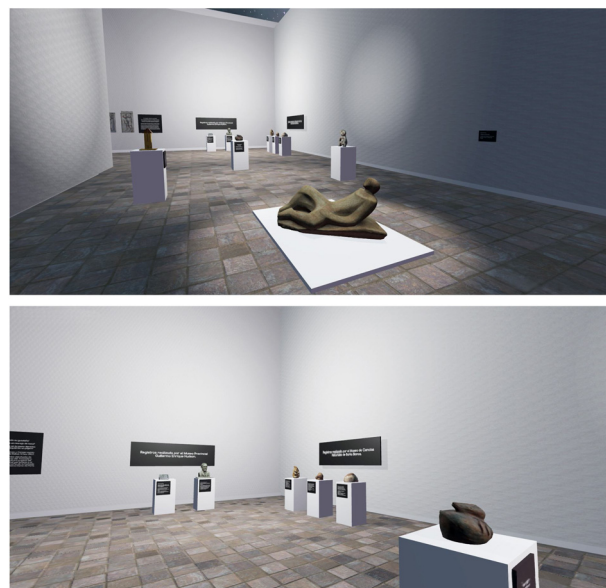


Fig. 2. Different point of views of the *Virtual Collections* tour.

3D modeling. Four exhibitions of the 3D immersive virtual experiences were released to the public. About 100 people between the ages of 10 and 70 have participated.

4.1. Virtual Collections tour

The list below shows the entire set of cultural heritage objects exhibited in *Virtual Collections*. All of them were simplified by the described procedure.

- *Zoomorphic Ceramic Vase*. Found in: Arroyo de Leyes, Provincia de Santa Fe [27].
- *Piedra Blanca cave*. Rock art. Prehispanic period. Found in: Vertiente Occidental de la Sierra Central de San Luis, Ayacucho, Provincia de San Luis [28].
- *Egg fragment, probably from a saltasaurus (Saurischia, Sauropoda, Titanosauria)*. Cretaceous. Patagonia, Argentina [29].
- *Molar fragment of Stegomastodon platensis (Proboscidea, Gomphotheriidae, Anancinae)*, Pleistocene, Quaternary [30].
- *Proximal epiphysis of the femur of Megatherium americanum (Tardigrada, Xenarthra)*. Camet Norte (north from Mar del Plata), General Pueyrredón, Provincia de Buenos Aires. Late Pleistocene. c.a. 24.5 – 9.5 Ka B.P. [31].
- *Enrique Hudson*, bust by Oberdan Brunetti [32].
- *El pájaro y el árbol conocieron la pureza de tu espíritu* by César Bustillo [33].
- *Tower with lightning rod to inflame alcohol* by Max Kohl [34].



Fig. 3. Krause. *Vestigios disponibles*. (a) Photograph of the actual exhibition. (b) Virtual interactive recording.

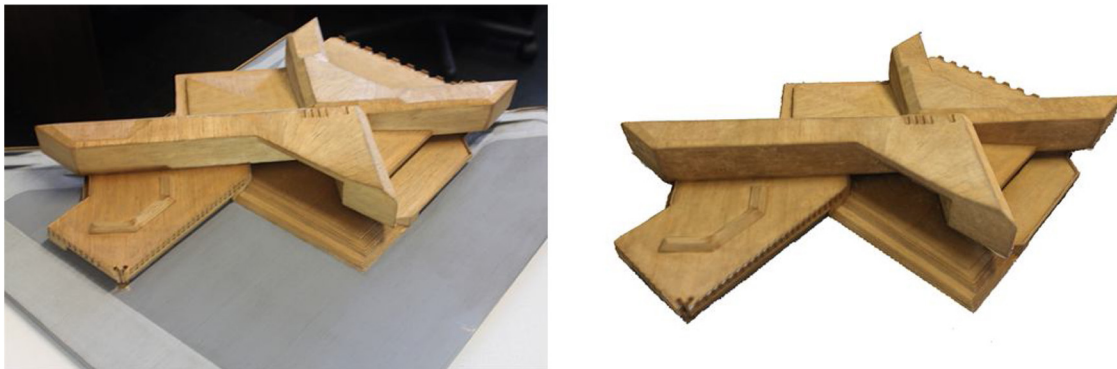


Fig. 4. Left: Photograph of the mockup *Amsterdam*. Right: 3D CR reconstruction with photogrammetry.

- *Cabeza* by José Alonso. Cement [35].
- *Viejo Cuyano* by Juan Bautista Leon. Cement [36].
- *Cecilia* by Marta by Bellocq. Stone [37].
- *El vagabundo* by Liberato Spisso. Fibro cement [38].
- *Doña María Eva Perón* by Juan D Aniello. Plaster [39].
- *Figura reclinada* by Naum Knop. Marble [40].
- *Figura* by Aurelio Macchi. Bronze [41].
- *Un campesino llevando un manojo de heno*. Plaster cast. The original belongs to the Portal of the Virgin, north portal of the western facade of the Notre-Dame cathedral in Paris [42].
- *Joven hombre sostiene en la mano derecha una flor y en la mano izquierda un pájaro*. Plaster cast. The original belongs to the Portal of the Virgin, north portal of the western facade of the Notre-Dame cathedral in Paris [43].
- *Un segador afilando su guadaña*. Plaster cast. The original belongs to the Portal of the Virgin, north portal of the western facade of the Notre-Dame cathedral in Paris [44].
- *Cabeza de Rey*. Plaster cast. The original is in the Musée de Sculpture Comparée/C. Pouzadoux Palais de Trocadero [45].
- *Meteorologic shelter*. Facultad de Ciencias Astronómicas y Geofísicas. La Plata, Argentina [46].

Fig. 2 shows different point of views of the *Virtual Collections* tour. The virtual environment was designed so that the general public recognizes its interior as a traditional museum, emphasizing the CR objects. On the contrary, the exterior simulates a completely artificial reality, since the museum is located on an asteroid in the middle of the space. The exhibit does not have a fixed orientation nor circulation. It has a circular path that allows the user to see the entire selection of sculptures and archaeological objects, no matter the starting point. This helps when a user takes off or puts on the HMD in any point of the tour.

A dark background color and white typography was chosen for the signage, since this combination produces less eye fatigue when working with screens [47], this was designed taking into account that the HMD is a screen over the user's eyes. On the contrary, in the signage of real museums, a white background with black text is usually used.

4.2. *Krause. Vestigios disponibles* exhibition

For the virtual interactive recording of *Krause. Vestigios disponibles* all the elements of the real exhibition were digitized. This virtual exhibition contains drawings, paintings, a collage of photographs, models, a cane, a “mate” straw (*bombilla*) and a knife. The original proportions were kept and the lighting criterion used in the original exhibition was taken into account, as well as the layout of the objects and shape of the room. Fig. 3 shows a comparison between a photograph of the actual exhibition and the virtual interactive recording.

Fig. 4 shows the mockup *Amsterdam*, made in wood, reconstructed with Mu3D and simplified by the procedure described in the first part of this section.

For this virtual exhibition, the rest of the objects were modeled, using the texturing methods mentioned in Section 2. The images used for texturing were taken from the photographic records of the actual exhibition and original files.

Web releases of *Virtual Collections* and *Krause. Vestigios disponibles* are available online [48].

4.3. *Virtual reality interface*

In both immersive museums the navigation can be carried out interacting with a virtual controller that is identical to the real one that the user is holding. A virtual hand that is holding the virtual

controller does the same action that the user does with his/her real hand. The navigation is performed by just pressing and releasing a button. While the button is pressed a line is drawn from the virtual controller position to the floor of the environment, and the user can move the controller to select the place where he/she wants to teleport when the button is released. The color of the line is cyan when the place that the user is pointing is available for teletransportation and red if it is not. The objects are inspected as one may do it in a traditional museum, then it is not possible for their manipulation. However the user can get as near as possible to the object, which is not often allowed in real museums.

5. Conclusions

This work shows the possibility of creating virtual exhibitions focused on the user and not on the collection that is displayed. The same virtual environment can be arranged either for different collections or the same collection in a different layout that fits different groupings of objects that respond to different contexts, uses and users. This is a place that can be created dynamically and several forms of organization of objects, for different types of users, can be developed automatically and very quickly. For example, in *Virtual Collections* the entire museum could be reorganized chronologically, thematically or by the institution where they were digitized. It would be interesting to explore the possibilities of this dynamism, creating exhibitions that automatically reorganize themselves taking into account considerations such as averaging the level of attention that the objects receive or maximizing the user's stay time in the environment. A hypothetical example of this adaptive behavior could be the following: By measuring and monitoring how much users are observing the objects (attention) and where the users are passing by (activity in location), an automated system appended to the virtual museum could try to average the attention that the objects are receiving by shifting the position of the least observed objects to the more active places, or the system could try to maximize the attention that a specific object receives by placing it in the more active location.

On the other hand, in this work two types of procedures have been presented to obtain digitized models of objects: CR objects, reconstructed by digital photogrammetry and computationally modeled objects. Each of these procedures has advantages and disadvantages that must be considered according to the objective sought. First, the CR allows an exact reconstruction of the object, with micrometric resolution and a high quality texture. This is generally valid for objects of size on a metric scale and whose material conforms to this technique. If the user needs the most exact reproduction of the objects, it will be necessary and more appropriate to use CR techniques, for example in the case of institutions that require the digitization of objects of heritage value. Otherwise, if the user does not have this need, it is possible to use computationally created models to recreate the objects to be displayed. In the same way, the user's needs will determine if the context that surrounds the exhibition is fictitious or a reconstruction of a real space.

The digitization of environments and objects integrated to virtual experimentation allowed us to test texturing techniques and optimize them in order to achieve the closest appearance to the materiality of the real object. An aspect not yet explored in cultural heritage is the use of shaders [49] or stochastic methods that are widely used in video games, and can be used to achieve more realistic results.

As shown in this work, virtual experimentation allows museums to design an exhibition in a fast and versatile way. In the same way, these virtual structures can be used to create an interactive tour as a record for a past exhibition and to assist in prototyping a real life

exhibition; for example, trying out lighting and testing several ways to organize the objects. So it is possible to optimize the exhibition. In the real world this would be very expensive and demands a very large time investment.

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