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PRADO: an education tool for Moorish architectural heritage through virtual reality

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Abstract. This article presents a workflow for creating a 3D virtual environment, dedicated to the architectural heritage education. The objective is to make the process accessible to any museum, through a space by space construction. The obtained results are employed in a virtual tour of the Bardo of Algiers, a witness to Moorish palatial architecture.

Keywords: Built Heritage, Heritage education, Moorish Architecture, Virtual Reality, 3D modeling.

1 Introduction

Cultural institutions nowadays are increasingly using 3D reconstruction techniques and digital visualizations for heritage education, both to solve the matter of accessibility and to convey information in a simplified and fun way. Virtual Reality (VR) stands out for its ability to immerse the user in the virtual environment (Freina & Ott, 2015), and to simulate abstract concepts. It thus becomes possible to visit inaccessible or no longer existing spaces, and even to examine objects from various and unique points of view (M. Roussou et al., 2000). It also stands out for the engagement and the motivation it offers to the user. For museums, VR has become a real communication tool, making it possible to democratize access to their funds and to approach a younger audience (M, Hess et al., 2017). However, creating this type of content requires skills. It also requires coordinating several multidisciplinary teams and significant material resources (A.Cirulis et al., 2015). Despite the efforts developed by museums, this technology is often not accessible. In the end, given the cost and development time required, few 3D environments are made available to the public.

Several recent studies investigate the tools used to both simplify and reduce the time and cost of the production process of educational content for cultural heritage in virtual reality, while preserving a favorable level of interaction and immersion although the main content, being cultural heritage, requires a certain level of detail and realism in the modeling process, which can compromise the quality of real-time navigation (M. Skamantzari and A. Georgopoulos, 2016; K. Choromański et al. 2019 ; Luca Perfetti et al., 2020). For virtual representations of cultural heritage, photogrammetry methods are often used on small sized objects. However, to represent full architectural environments, the dimensions and complexity of the monuments require significant physical and material resources both in the data acquisition phase and in the processing and modeling phase. The geometric models resulting from the reconstruction often include several tens or hundreds of millions of geometric primitives, which are difficult to manipulate and visualize.

The aim of our study is to suggest a simplified approach, for Moorish architectural heritage education in virtual reality, which is accessible to museums. Our contribution addresses the methodology for creating a virtual reality environment using open access tools and standard computer hardware. The objective is to democratize the process to make heritage environments accessible to the greatest number, based on a geometric modeling by single spaces, along with a guided virtual tour system, and on-demand space loading. Each space is accompanied by a certain number of textual, sound and visual elements to complete the 3D geometric description.

The next section presents an overview of the state of art of the use of virtual reality in cultural heritage education. We then describe our methodology of an immersive virtual environment creation, which is intended for the Moorish heritage education in VR. We also present our results and discussions before our goal for future research.

2 The use of virtual reality in heritage education

Virtual reality's efficiency in cultural heritage communication and education has been proven for a long time and by many authors, starting with Maria Roussou's first experimentations back in 1999. Since that time, this technology has been widely used in the field. VR allows interactive real-time navigation; the user is in control of navigating through the spaces (Donald, H. Sanders, 2014). With virtual reality, the user's natural sensory information is entirely replaced by digital information (Eike Falk Anderson et al., 2009), which allows it to act on our senses resulting in an immersive experience filtered through the appropriate software and hardware (Carrozzino & Bergamasco, 2010). Thus, the use of VR in cultural heritage is not only about a virtual reproduction of objects and spaces: immersion also conveys knowledge and emotions.

2.1 Virtual reproduction of heritage objects

The first step in creating any cultural heritage dissemination application in virtual reality is the modeling of the virtual environment. Image-based rendering methods are often used to build 3D models of heritage. The most popular method is photogrammetry, which consists in estimating the positions of points on the surface of objects from photographs. This technique is prized for its accuracy and the model conformity compared to reality, as well as for the reduced costs compared to CAD (computer-aided design). This method has proven its efficiency when it comes to relatively small heritage objects, but its application in architecture with large archaeological sites remains a complicated process for several reasons: acquisition, image processing, number of required images and expensive equipment. The models generated are large (often tens of millions of faces) and difficult to use in VR.

A. Dhanda et al. (2019) have suggested an implementation process to optimize virtual models resulting from photogrammetry applied to architecture. This method intervenes onto the resulting mesh and therefore, after the data acquisition steps and the generation of point clouds and mesh, this allows smooth navigation in VR, but does not reduce the cost and difficulty of the process of creating the 3D model.

Several other authors combine laser scanner and geometric modeling using CAD software for modeling heritage spaces. This method also requires significant material resources and a multidisciplinary team. In the example of the modeling of the Selimiye Mosque, Turkey (T. P. Kersten et al., 2017), a laser scanner and a camera were used for data acquisition. The acquisition involved the mobilization of three people for a month while the geometric modeling phase required 24 people for several weeks.

2.2 Visualization in virtual reality

In virtual reality it is imperative to engage the user's senses in order to uncover the aspects of free navigation, interactivity and immersion in the virtual environment. The gaming industry offers intuitive visualization tools to meet these needs. D. John et al. (2017) explore the use of game engines in creating virtual, interactive, historical sites. They conclude that these engines can provide a good overall picture of reality.

In order to ensure smooth navigation through these platforms, the complexity of the geometric models must remain moderate; this would require taking this constraint into consideration during the modeling phase, especially since maintaining an optimal level of fluidity is essential in an immersive experience in virtual reality, not only for it to be appreciated, but also to avoid the motion sickness that the use of a VR headset could cause.

For this technology to be truly a heritage dissemination and education tool, it must also convey multisensory information with which the user can interact. Several authors have addressed this matter (Nazrita Ibrahim et al., 2011; Pujol L et al., 2012; Yildirim et al., 2018), and all conclude that the important elements for ensuring an educational tool with maximum interaction are the following:

1. multisensory, and immersive experience as realistic as possible;
2. interactions with the environment for increasing the user's interest;
3. user-oriented tool for increasing learning capacities.

3 Method and case study

In the context of a real historical site (namely the Bardo Palace in Algiers), our methodology provides a complete virtual environment, including 3D objects reconstructed using photogrammetry. Immersion is performed using Unity. The Bardo is an 18th century summer palace, built in a typical Moorish style. It is classified as a historic monument since 1885 and was reconverted into a museum of prehistory and ethnography in 1930. Today, the monument is still known by its original name Bardo, which is a distortion of the Spanish word *prado*, meaning a meadow.

The objective is to build a realistic virtual environment which takes into consideration both the educational aspect and the specificities of the built heritage field, in particular considering the details: textures, shapes, proportions, etc. Virtual (re)construction time and costs also have to be as reduced as possible, and the immersion/navigation experience has to be perfectly fluid. Therefore, our methodology relies on an open source, easy to use software and standard computer hardware:

- geometric modeling: SketchUp Free;
- photogrammetry software: Regard 3D, Meshlab;
- free image processing software: Photopea: advanced image editor;
- game engine: Unity in its free version.

The hardware used is a MacBook pro Core i7 laptop, a Canon 700D reflex camera, and a laser rangefinder.

3.1 3D data acquisition

The 3D data acquisition relies on multiple sources, mainly the architectural drawings produced by HAMEG Cabinet (in charge of the restoration of the palace back in 2006) published in the book "Monument du Bardo : chronique d'une restauration", which we completed with on-site measurements, according to our needs, using a laser rangefinder allowed us to save time on the modeling process.

3.2 The modeling process

Each space is created independently from the others, and linked in the visualization phase in Unity. This choice not only simplifies the modeling process, but it also avoids generating a complex 3D scene with a very large number of geometric primitives. The photographs are collected on site and then used as textures to give a realistic image of the environment. The spaces we have modeled to set up a first version of the application are (Fig. 1): (1) the marble courtyard which allows access to the selected spaces; (2) the room of the favourite; (3) a row of salons, accessible from one to the other; (4) the Skifa: used in Algerian culture for receiving foreigners (Fig. 2). To ensure both privacy and security, foreigners were not allowed to enter the house. This space is decorated with Zelij (earthenware tiles) from different regions of world.



Fig. 1. 2D Plan of the Bardo palace, marble courtyard level

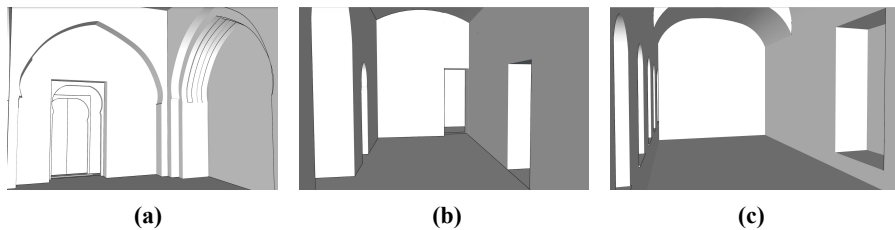


Fig. 2 . Simplified 3D spaces, modeled using Sketchup : (a) the room of the favourite, (b) the salons, (c) the Skifa.

Photogrammetry can be used to represent complex objects, integrated into the entire 3D scene. We applied this method to the marble fountain of the courtyard, 107 photos were used to generate the mesh and the texture of the latter.

3.3 Processing and applying textures

Textures are extracted from the photographs taken in-situ after processing (cropping and correcting perspective distortion), using any image processing tool (we have employed Photopea). The processing steps are the following:

- Step 1: correcting perspective distortions, using several tools: perspective crop, ruler;
- Step 2: color processing: since we did not use artificial lighting when taking the photographs, post-processing was necessary to obtain a uniform result (brightness, contrast, color balance, etc.);
- Step 3: resizing and scaling: this phase can be performed in the image processing software, or after importing it into the modeling software (in our case SketchUp);
- Step 4: applying textures to the model: by importing the images onto the modeling software platform as textures.

The number and size of textures may compromise the fluidity of navigation. For the patterns that are repeated on large surfaces, we have grouped, when possible, several patterns in the same texture, to cover a maximum of surface instead of using individual textures for each model (Fig. 3).

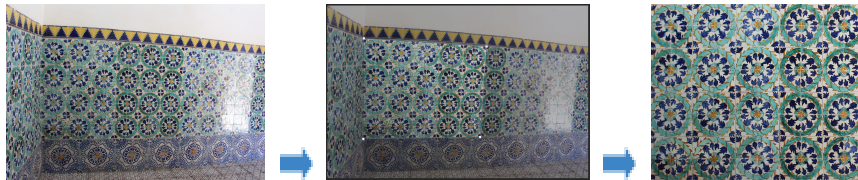


Fig. 3. Wall tiles of the salon, before and after the use of the perspective crop tool.

When required, panoramic images can be made from several photos, such as when the patterns did not repeat uniformly over the entire surface, for instance when the distance is too short to take the entire surface in a single photo (walls and ceilings). The panoramic can be created automatically depending on the software. We opted for a manual panoramic by first correcting the perspective on each of the photos then making a collage (Fig. 4).



Fig. 4. Panoramic images created for a ceiling based on a combination of perspective crop tool and manual panoramic (Room of the favorite).

3.4 Virtual tour setup

The virtual tour is implemented using the free version of Unity game engine. The transfer of the 3D model from SketchUp to Unity, does not require any conversion, the two are compatible. This platform provides access to most of the necessary functions without having to go through scripts, which require qualifications in programming languages. Throughout the process, only a few simple lines of code were needed (in C# language) for custom actions. Simplified documentation and tutorials are available on the internet, with only basic programming knowledge.

- Step 1: creating a *scene* for each space.
- Step 2: setting physical parameters of the models (gravity, appearance, etc.)
- Step 3: setting the user avatar that moves in the environment
- Step 4: integrating text and audio annotations, as explanations on the history of the places, and their initial use (Fig. 5).
- Step 5: scene switch: we included a function to navigate between the different scenes on demand. This load on-the-fly system ensures a simple and fluid virtual environment. For this step, the creation of the following script was necessary (Algorithm 1).



Fig. 5. Example of messages for the activation of annotations/audios: (left) in the marble courtyard and (right) Skifa.


```

public class SwitchScene : MonoBehaviour {
    public string destination_name;
    public KeyCode key;
    [...]
    void Update () // called once per frame
    {
        if (Input.GetKeyDown(key)) {
            Scene currentScene = SceneManager.GetActiveScene();
            if (null != currentScene) {
                SceneManager.UnloadSceneAsync(currentScene);
            }
            SceneManager.LoadScene(destination_name);
        }
    }
}

```

Algorithm 1. Function defined for switching between architectural spaces.

4 Results

Fig. 6 illustrates the 3D lightweight scenes obtained with textures, guaranteeing smooth navigation. The time spent modeling the different spaces does not exceed one day for one person only.



Fig. 6. Results of the 3D modeling of the room of the favorite, salons and, Skifa.

Photogrammetry should not be employed for modeling architectural spaces since the creation of a dense point cloud and the mesh took more than 48 hours in our experiment (Fig. 7), using 124 photographs. Table 1 shows a comparison between the results obtained in photogrammetry and in geometric modeling using SketchUp.

The means used do not allow us to use photogrammetry for all spaces; that said, its use for individual objects such as columns and fountains is possible and it allows to have a higher level of realism. These objects can either be integrated into the models created in SketchUp or directly into the scene in the game engine. We used photogrammetry for the fountain; the result was integrated into the 3D model built previously (Fig. 7). We set the quality of the construction of the point cloud and the mesh to “medium” (computation time for building the point cloud is 4h02 and the mesh more than 18h).

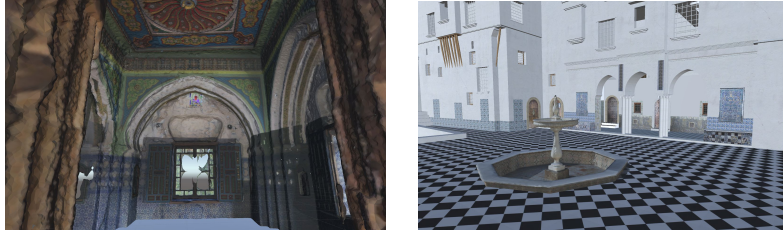


Fig. 7. Results of photogrammetry : (left) the room of the favorite (right) the fountain.

Table 1. Comparison between the results of the two modeling methods of the room of the favorite.

	Photogrammetry	Sketchup
Number of points	33,404,768	/
Number of faces	812,517	4512
File size	255,1 Mo	79,1 Mo

Integrating the resulting model to the rest of the virtual environment did not cause any problems. Nevertheless, there is an additional 19 MB tacked on to the size of the original model. Adding multiple 3D objects created through photogrammetry to the same scene can compromise the fluidity of navigation. Additional annotations and interaction with the environment on Unity does not require an important programming qualification; a basic knowledge in C # languages is sufficient. The final application can be used on a computer or a VR headset with a compatible smartphone. The user can move from one room to another by getting closer to a door, which then displays explanatory texts or audio explaining the history of each place.

5 Conclusions and future work

The aim of our work is to set up an educational tool for the Moorish architectural heritage in virtual reality, accessible to museums, which often lack the resources to invest in this type of content. This workflow is ideal for dissemination and communication purposes. The use of free, easy-to-use geometric reconstruction tools like SketchUp allowed us to have satisfying results close to reality, while being optimized enough to allow a fluid real-time navigation. Future work involves studying the integration of pedagogical programs and the learning component to the virtual environment in order to make an efficient heritage education tool with pedagogical objectives.

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