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Virtual Reality and how to learn to see how it was

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Abstract

This paper presents a solution based on immersive virtual reality for the interactive visit of a historical heritage site located in the province of Jaén. This work therefore aims to facilitate the tour to this historically significant yet difficult-to-reach site, while also providing contextual information regarding its location, surroundings, and architectural features. To this end, the original 3D model of the site has been textured and provided with interactive, informational content, which is dynamically retrieved from a remote database, allowing for continuous updates and scalability. Finally, an approximate historical reconstruction of the site has been developed. Both the current and reconstructed versions have been deployed across multiple platforms (including desktop and mobile applications, a website, and virtual reality headsets) ensuring flexible interaction tailored to different usage contexts and user preferences.

1. Introduction

This paper presents a Virtual Reality (VR) application designed to enhance the accessibility and understanding of the Castle of Arenas, a medieval fortress located in the mountainous region south of Jaén, Spain. The Castle of Arenas, set in steep mountainous terrain at approximately 1370 m above sea level, preserves only a few standing towers and walls. Its rugged topography made it an ideal Moorish stronghold, but today poses challenges for public access. Although limited historical records exist for the castle and no archaeological excavations have been conducted, its cultural and historical significance makes it an ideal candidate for digital preservation and virtual accessibility through VR technology. Through a comprehensive process of acquisition, processing, and management of archaeological data, we offer a virtual experience that enables users to explore the castle interactively, learn about its construction, surroundings, and history, and engage with a site that is otherwise difficult to reach. The results demonstrate how technical barriers were resolved to create an accessible experience across desktop, mobile, WebGL, and VR headsets. This study contributes to a replicable framework for heritage digitization.

2. Related Work

VR, while being widely associated with the entertainment industry, has long been applied in scientific domains, including cultural heritage. The digital reconstruction of historical sites has greatly improved due to recent developments in high-resolution imagery and 3D modeling, offering new ways to preserve and share cultural assets. Recent research emphasizes the use of photogrammetry and UAS-based surveys in order to create accurate 3D modeling of heritage sites. For example, [MCRVG*23] combined photogrammetry and LiDAR data to obtain a three-dimensional model of the archaeological sites of the Cerro del Castillo de Belmez and its surroundings in the south of Spain. However, this virtual reality experience provided a simplified interaction format, preventing the user from being able to freely explore the virtual environment, sacrificing interactivity and immersion. Another key limitation in existing VR heritage projects is the static nature of informational content. While some frameworks, like that of [DPFG*22], integrate basic UI panels, few systems use remote databases for dynamic updates. Moreover, most heritage VR applications target single platforms, prioritizing standalone mobile apps and high-end VR. As previously stated, while some studies have aimed to create virtual guided tours, challenges such as model optimization, cross-platform deployment, and dynamic content integration remain understudied. Our work addresses these gaps by developing a pipeline for photogrammetry-based 3D reconstruction optimized for real-time VR, implementing a scalable database-driven content system, and evaluating multi-platform usability.

3. Material and Methods

An Unmanned Aircraft System (UAS) is, according to the definition given by the International Civil Aviation Organization (ICAO), an aircraft and its associated elements which is operated with no pilot on board [ICA11]. In the test, the aerial survey was undertaken with a Matrice 210, equipped with a Zenmuse XT2 camera. The RGB camera has an 8 mm nominal focal length, a 1.1.7" CMOS 12 megapixel sensor, a resolution of 72 ppp, and the dimensions of the image are 4000 x 3000 px. The maximum flight time of the Matrice 210, with full payload, is 24 minutes which is a strong restraining when designing a flight test. In Table 1, there is a brief summary of the camera specifications.

In Table 2, there are the main characteristics of the computer that we have used for the data processing. It must be pointed out the generation of the dense point cloud process is very time consuming.

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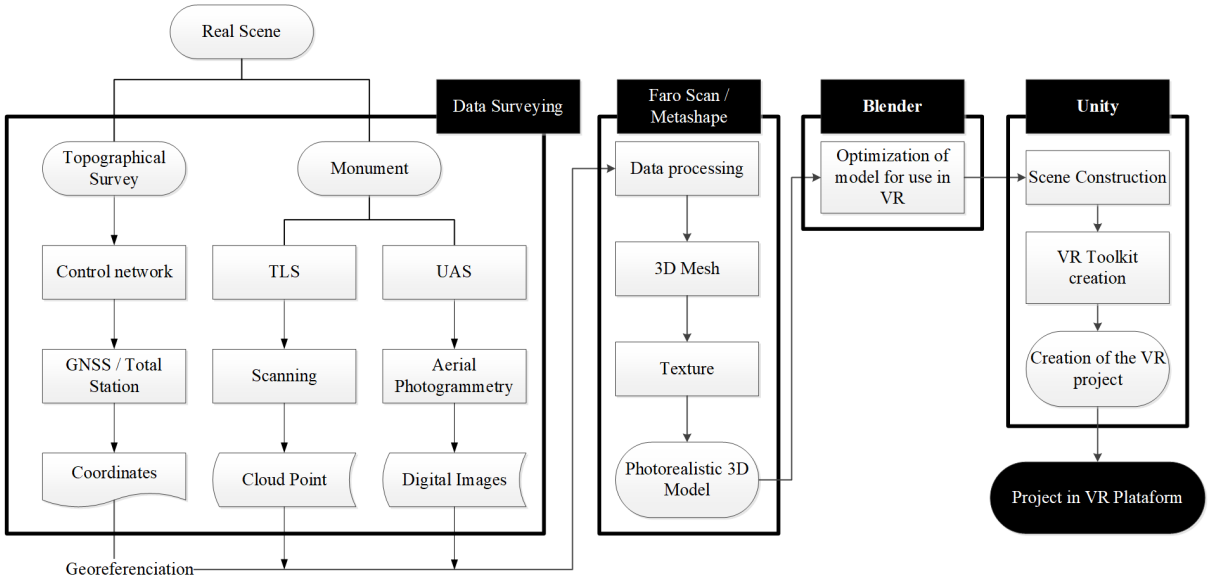


Figure 1: *General workflow necessary to generate a VR model*

Table 1: *Technical specifications of the cameras and image captures from the UAS*

Camera	Focal length (mm)	Field of View	Image Size (px)	Sensor (Mpx)
RGB	19	57.12°× 42.44°	4000 x 3000	12

Table 2: *A summary of computer specifications*

Hardware	Specification
RAM	31.64 GB
CPU	Intel(R) Core(TM) i7-8700 CPU @ 3.20GHz
GPU(s)	GeForce GTX 1060 6GB

In Figure 1 can be seen the four well-defined stages which defines the workflow of the whole process. In brief, the stages are:

- The fieldwork, where we collect the data we need to build the model.
- The processing of the digital images. Once the data has been collected, we process it with the appropriate software to obtain a photorealistic 3D model
- The optimization of the model to be used in VR. Unfortunately, the generated model is usually too heavy to be used as a source for the VR project. So, we have to optimize it using Blender, Mesh Lab or similar software.
- Creation of the VR project. Finally, the VR project is created using Unity.

3.1. Field work

This section outlines how data is collected and processed using a UAS. Two main processes are involved: GNSS and UAS. First, Ground Control Point (GCP) coordinates are acquired to georeference the images. This step is essential in order to obtain accurate geolocation and geometry quality in later steps. However, if the UAS is equipped with RTK or georeferencing is unnecessary, this step can be skipped. GCP data can be obtained through methods such as Terrestrial Laser Scanning (TLS), airborne LiDAR, or photogrammetry. For simplicity, only TLS and UAS are shown in Figure 1. The second step is the design of the flight plan. In this stage, key parameters of the flight will be defined, such as altitude, overlap and survey area. A total of four automated flights were conducted, one nadir flight, which involved capturing imagery perpendicular to the ground, and three oblique flights to acquire data from the wall sides. The first flight was conducted at an altitude of 60 m above ground level, while the oblique flights were carried out at an altitude of 50 m. During image acquisition, frontal and side overlaps were set at 85% and 80%, respectively, ensuring sufficient coverage for photogrammetry. The resulting Ground Sampling Distance (GSD) was calculated to be 2.1 cm/pixel for visible imagery. The flight operations were scheduled close to midday to minimize the occurrence of shadows on the archaeological remains.

3.2. Processing the data

After image acquisition, processing was conducted using Agisoft Metashape (version 1.7.5), which reconstructs 3D models from photos using the SfM algorithm. The image alignment and 3D reconstruction were automated using images acquired from the UAS, generating a georeferenced dense point cloud and an orthomosaic of the castle as outputs. The last one is needed to identify the elements and the structure of the castle and it can be seen in Figure 2. For further details, refer to [AEJ*22].

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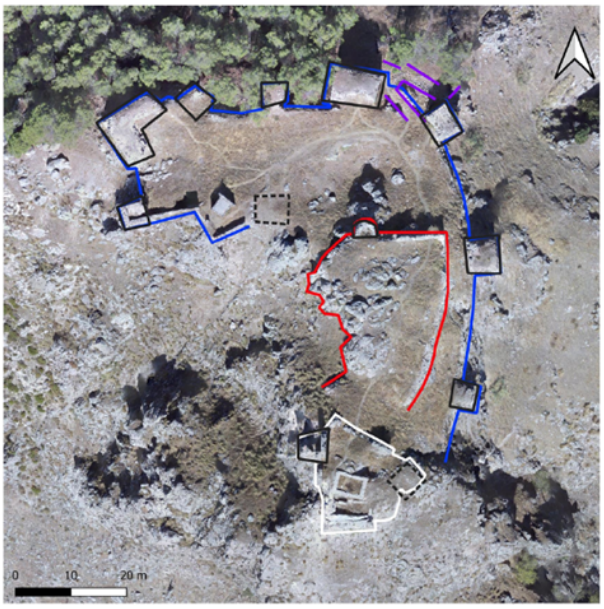


Figure 2: *Orthomosaic of the castle [CEML*23]. In blue, the outer enclosure; in red, the middle; in white, the interior; in purple, the gate; in black the towers are highlighted and, in dashed, the remains of other towers that have been identified by thermal imaging.*

3.3. Optimizing the cloud point

The original point cloud was nearly 9 GB, containing over 33 million points, making it difficult to work with using 3D editing software. To optimize it, priority was given to finding free software that was sufficiently robust. As Blender proved to be unfruitful when trying to load such a large amount of data, MeshLab was finally chosen to perform simplification. The mesh was reduced incrementally (50% at a time) using the Quadric Edge Collapse Decimation with Texture filter until reaching 250 MB. Since the original file was in OBJ, texture was stored together with the coordinate information of the vertices that make up the geometry [Eka22]. The Transfer Vertex Attributes to Texture filter allowed exporting the texture as a JPG, ready for import into 3D modeling software.

3.4. Creating textures in Blender

Although the original idea was to import the simplified 3D model and its texture directly into Unity, its texture lacked detail (polygons were clearly visible). It was then decided to use Blender, a leading free and open-source 3D modeling program, to create textures manually, using photographs of the archaeological site. These were retouched in GIMP to create texture images, and CrazyBump was used to generate texture maps for added realism. Once the necessary materials had been created, UV mapping was performed, and textures were painted directly onto the model using Blender's stencil tool and a graphics tablet. The resulting UV maps were saved as PNG files. This process was repeated for each structure, while environment materials (soil, rock, grass) were sourced freely from Poly Haven. Finally, grass was added via Blender's particle system.

3.5. Development in Unity

Two types of models were developed in Unity: the realistic 3D scan textured in Blender, and a historical reconstruction of the castle in the period in which it was built. Both models were designed for deployment on PC, WebGL, Android, and Meta Quest VR, using Unity's Universal Render Pipeline (URP) for cross-platform support [sfa]. The Blender model was exported in FBX format with textures, scaled to real-world dimensions, and imported into Unity.

For interaction, a first-person player was included, with navigation tailored to each platform (mouse/keyboard, joystick, or touch). The environment was enhanced by adding trees, ambient sound, animated texts, and a skybox created from real photographs of the castle surroundings. Seven interactive information panels were also included, pulling content from a MySQL database hosted remotely. The content is easily configurable and reusable for future heritage projects, without requiring a deep knowledge of the Unity development environment. Consequently, it is possible to update the information shown as new discoveries are made at an archaeological site. Depending on the type of deployment, two different methodologies have been followed to obtain the information from the database:

- For PC, Android, and VR, the application downloads data from the server on first run (via UnityWebRequest [sfb]), saves it in a local data.json located in the application's persistent data path, which is platform-specific and stores data that must survive between sessions of an application [sfc], and loads it asynchronously. This ensures functionality without constant internet access. The server has been developed with php technology, which allows the added functionality of database requests to be provided by an Apache web server. In particular, the tests have been done with a local web server deployed with Xampp on Windows, and the final version has been deployed with a server running the Ubuntu 18.0 Linux distribution.
- For WebGL, the app fetches data from the server in real-time with every panel activation, requiring constant internet access.

To reconstruct the medieval version of the castle, the modern elements were removed in Blender. Once the model was imported into Unity, the reconstruction was carried out according to the historical data available, following the design in Figure 2. Given the extent of the project and the scarce information available about the castle, it was then decided to design only the area between the outer and the middle walls. The nine towers have been reconstructed by blocks that according to the experts formed the outer enclosure, the semicircular tower of the middle enclosure and the two towers of the inner enclosure, as well as the walls belonging to each of them. The access gate to the castle was also reproduced according to the design available. Additional details—like houses, stairs, and furniture—were added from Unity assets. The reconstructed model includes vegetation, ambient audio, and platform-specific navigation. Figure 3 illustrates the final result.

4. Results

The final project in Unity consists of a main menu and two scenes: the realistic model and the reconstruction. On launch, the user is presented with the main menu, from which they can choose either

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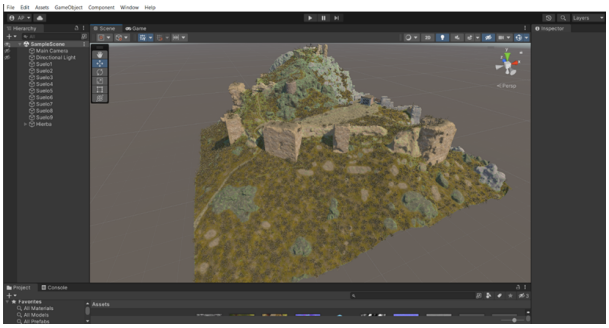


Figure 3: *Final realistic model imported into Unity.*



Figure 4: *Main menu in the display for Android.*

scene and switch between them at any time. Scene loading is asynchronous, and implementations vary by platform. As a sample, only the Android screen is shown.

4.1. Computer and WebGL

On PC and WebGL, the main menu is a 2D interface created using Unity UI, with two buttons navigated via mouse click. Both scenes use the First Person Controller asset from the Unity Asset Store for movement. Navigation is handled via WASD keys and the mouse for camera rotation; spacebar enables jumping. Ambient audio is included in both scenes, and resolution is set to 1920×1080 (Full HD). In the realistic model, information panels are triggered by approaching them and pressing the "B" key. Data is loaded from a local data.json file. Panels close with the "X" key, restoring the initial message prompt.

In the WebGL version, data is fetched live from the remote server. A custom script handles mouse locking/unlocking for full 360° view control by toggling the right-click. This deployment balances performance and accessibility, delivering detailed visuals ideal for educational applications.

4.2. Android

The main menu on Android is identical to that of the PC and WebGL versions, with the only difference being that touch input is used to select a scene. As for the motion controls, Unity's First Person Controller includes a mobile-friendly UI featuring on-screen joysticks (Figure 4), allowing character movement, camera control, running, and jumping. The resolution is maintained at 1920×1080, ensuring compatibility with modern smartphones. In the realistic model, the interaction system uses touch-based panel activation. This ensures a smooth, intuitive user experience on mobile devices. Due to the widespread use of smartphones and their user-friendly touch controls, Android offers the widest reach, making it ideal for tourism and educational purposes.

4.3. Virtual Reality (Meta Quest glasses)

The Meta Quest deployment differs significantly from the computer and Android versions due to the constraints and capabilities of immersive VR environments. A 2D menu is not feasible, so a 3D menu panel was created using UI elements provided by the XR Interaction Toolkit and the official VR plugin for Unity. User interaction relies on raycasting from the VR controllers. By pointing at a button on the panel and pressing the rear trigger, the user can enter the desired scene. Movement within scenes is achieved either through teleportation or by physically walking, thanks to the six degrees of freedom offered by the headset, which allow natural head and body movement for exploring the environment. The information panels also use raycasting for activation. Scene transitions follow the same in-scene panel-based interaction due to VR limitations. The game runs at 1600×1440 pixels per eye, the maximum resolution supported by the Meta Quest 1 hardware (Figure 8). Meta Quest VR offers the highest immersion, making it ideal for research and museum installations, though its hardware requirements limit accessibility.

5. Conclusions and Future Work

This work has developed a comprehensive and advanced solution for the interactive visit of a historical heritage site, the Castle of Arenas in the province of Jaén. By leveraging immersive virtual reality, the physical barriers that prevent access to this historic site have been overcome, offering users a detailed, engaging, and adaptive experience. Additionally, this work has laid the foundations for future research and similar applications in the field of virtual reality and the use of ICT, and cultural tourism. The following are some suggestions for the improvement of this project in the future:

1. Optimize application performance, especially in scene transitions and the loading/unloading of data from the database.
2. Enrich the content by incorporating images, audio, and other multimedia elements into the database.
3. Improve server configuration flexibility by replacing the current .txt configuration file with a JSON format or by developing an in-game configuration panel.
4. Simplify the configuration of information panels to enable easier updates without modifying Unity scripts.
5. Add a guided path option in the realistic scene using waypoints or landmarks. This would allow for structured, guided tours of the castle and offer visual aids for users unfamiliar with the site.
6. Expand the reconstruction scene to include the remaining two areas of the castle and introduce interactive animated characters. This would improve user understanding of the historical context

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and allow comparisons between past and present states of the site.

7. Enhance the visual realism of the model by integrating a skybox or fog effects to obscure unwanted real-world elements.

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