Optimization Strategies for Standalone Virtual Reality Experiences: the virtual reconstruction of the city of Aquinum

Bruno Rodriguez-Garcia*
University of Burgos, Department of Computer Engineering

Giuseppe Ceraudo†
Department of Cultural Heritage, University of Salento

Laura Corchia‡
Department of Cultural Heritage, University of Salento

Lucio Tommaso De Paolis§
Department of Engineering for Innovation, University of Salento

Abstract

This study presents an optimized 3D modelling procedure for the development of immersive Virtual Reality (iVR) experiences. It has been tested by conducting the virtual reconstruction of the Roman city of Aquinum (Italy), a key archaeological site. The resulting 3D model demonstrates a high Level of Detail (LoD) across a total area of 17,570 m² (2,470 m² of which are explorable) with a file size of only 46.2 MB, incorporating just six unique textures. This research not only delivers an accurate reconstruction of the city of Aquinum but also introduces an effective optimization method based on open-source tools.

Index terms: Level of Detail, Virtual Reality, Cultural Heritage, 3D modelling

1 Introduction

Aquinum is an ancient Roman colony located in Castrocielo, Lazio, Italy. Over 15 years of excavations, along with earlier studies, have established it as a key site in Italian archaeology, uncovering significant findings related to its urban layout, domus, theater, and thermal complex [1]. Despite the wealth of knowledge available about the site, its study remains challenging for non-specialists since much of this information has not been graphically represented. This research uses immersive Virtual Reality (iVR) to visualize decades of historical and archaeological findings through a virtual reconstruction.

Aquinum is a large urban environment, which inevitably poses challenges for the optimization of 3D models due to the scale of the project. This issue becomes more pronounced when developing for standalone Head-Mounted Displays (HMDs), i.e., iVR devices that operate independently of a computer. This technology is particularly important for education and the dissemination of cultural heritage, as it makes iVR experiences more accessible by reducing costs and user inconveniences such as computers or cables, making them especially suitable for environments like classrooms or museums [2]. Although optimization is an important factor, especially with limited devices like standalone HMDs, it is an area that still needs significant improvement in cultural heritage, as the Level of Detail (LoD) achieved by many reconstructions is often scarce, especially when the reconstruction is large, or it has greater interaction [2].

This project virtually reconstructs the city of Aquinum using a highly optimized 3D modelling methodology tailored for standalone iVR and implemented with open-source software tools. It details the site's characteristics, the modelling and optimization process, the 3D model's features, and concludes with an outcome analysis.

2 Study case: Aquinum

Aquinum, a key Roman colony along the Via Latina, holds historical significance due to its strategic location. Extensive archaeological research, including excavations, aerial photography, and Ground-Penetrating Radar, has revealed a rich array of remains, offering valuable insights into its layout and history[3]. To maximize the representation of heritage elements, the reconstruction focused on a central area of the city near the intersection of the Cardus Maximus and Decumanus Maximus, where the Via Latina passes through. The selected section includes the following features: (1) the theater, (2) parts of the urban layout, (3) the thermal baths, (4) a *taberna*, (5) the forum, (6) several domus, and (7) representations of the city's inhabitants.

The generated 3D model encompasses a total of 17,570 m², of which 2,470 m² are explorable, with the remaining area designed to provide an immersive environment. A high LoD was employed, as this is critical for accurately representing cultural heritage. Additionally, virtual agents were incorporated to enhance immersion and convey elements of intangible heritage [4].

3 Procedure

To achieve a high LoD in a large-scale model such as this, an optimized modelling procedure tailored for standalone HMDs was implemented. This process exclusively employed open-source tools, including Blender for 3D modelling, and GIMP and Materialize (Bounding Box Software) for texturing. The optimization techniques, both for modelling and texturing (the latter being the most critical), are summarized below. Figure 1 summarizes the complete modelling workflow.

Each 3D model was created in both low-poly and high-poly versions based on the site's study, with the appropriate version displayed based on the user's proximity to the object. Most models were instantiated to maximize efficiency and promote the historical review. Even high-poly models were not overly detailed, as most detail was incorporated through texturing. Once the modelling phase was completed, the final 3D model was divided into blocks based on users' visual areas, allowing the development engine to leverage occlusion culling effectively [5]. Textures were created using processed photographs or baked photogrammetry maps to

* e-mail: brunorg@ubu.es

† e-mail: giuseppe.ceraudo@unisalento.it

‡ e-mail: laura.corchia1@unisalento.it

§ e-mail: lucio.depaolis@unisalento.it

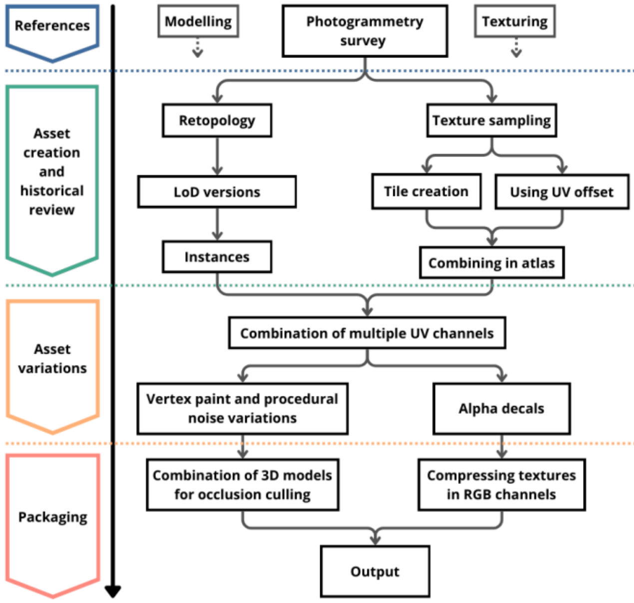

Figure 1: Modelling workflow

generate various texture layers. To minimize the number of images, textures were designed, for instance models used to construct the final scene, taking advantage of UV space overlapping and tiling. These images were subsequently compressed and grouped into three texture atlases, utilizing UV space offsets [6]. Additionally, a fourth texture atlas with decals was added to introduce variability to the 3D models. To further reduce the total number of textures, black-and-white texture atlases were compressed using red-green-blue channels and coordinated with multiple UV maps. Procedural noise, such as Perlin noise and Voronoi fractals, was integrated through vertex painting to add even more variability to the models. To test the 3D model, a preliminary iVR experience has been developed using Unreal Engine. In this experience, users can freely navigate the environment through a teleportation system. Animals and virtual agents perform looped animations, such as walking or talking, and use a basic artificial intelligence system to follow routes and move around the environment.

The resulting 3D model has a total file size of 46.2 MB, composed of: 6 4K textures, weighing 16.6 MB across six materials. And 405.248 polygons (138,172 uninstanced), with a total size of 29.6 MB. This method is scalable, as additional texture atlases and instances can be created for unreconstructed elements, such as the interior of the thermal baths. Figure 2 shows an image of the interior of the therma as an example of the LoD achieved. In its standalone HMD version with forward rendering, the iVR experience runs at a stable 90 FPS with approximately 120 draw calls and a quad overdraw of 1 close to the user, increasing up to 3 for more distant elements due to perspective. This iVR experience has been tested on the Oculus Meta Quest 2 HMD with satisfactory results and can run on later versions, as well on previous, as the Meta Quest 1, with some performance trade-offs.

4 Discussion

This study presents an optimized 3D modelling procedure for the development of standalone iVR experiences. The procedure was tested through the virtual reconstruction of the city of Aquinum, achieving promising results with a large-scale 3D model featuring low file size and high LoD. Although none of the optimization techniques used are completely original, as they are based on other successful cases [6] and the prior experience of the research group


Figure 2: Interior of the reconstructed Aquinum therma

in application development [5], their combination in an open-source workflow creates an agile and efficient method for developing iVR experiences that meet the needs of cultural heritage works. This is because the method is based on the use of the available historical resources, especially archaeological ones (like the columns in this case), to sample them, which increases both efficiency and historical accuracy. Additionally, the use of instances allows for constant historical review and a high LoD, something crucial when recreating a lost environment, and which is typically not achieved in iVR cultural heritage reconstructions [2].

However, this is a work-in-progress project, and further improvements are needed to enhance optimization. Future development lines include integrating this 3D model into an educational iVR experience to evaluate its impact with real users.

References

[1] G. Ceraudo, “Luck is in the research method: Aquinum, the rediscovery of an ‘invisible’ town,” in Roman Urbanism in Italy: recent discoveries and new directions, OXBOW., A. Launaro, Ed., 2023, pp. 44–60.

[2] B. Rodriguez-Garcia, H. Guillen-Sanz, D. Checa, and A. Bustillo, “A systematic review of virtual 3D reconstructions of Cultural Heritage in immersive Virtual Reality,” Multimed Tools Appl, Apr. 2024, doi: 10.1007/s11042-024-18700-3.

[3] M. Lazzari, L. De Giorgi, G. Ceraudo, and R. Persico, “Geoprospecting Survey in the Archaeological Site of Aquinum (Lazio, Central Italy),” Surv Geophys, vol. 39, no. 6, pp. 1167–1180, Nov. 2018, doi: 10.1007/s10712-018-9497-8.

[4] S. Sylaiou and C. Fidas, “Virtual Humans in Museums and Cultural Heritage Sites,” Applied Sciences, vol. 12, no. 19, p. 9913, Oct. 2022, doi: 10.3390/app12199913.

[5] D. Checa and M. Alaguero, “Optimization of a Standalone VR Experience Through User Perception: A Journey to the Hidden Spaces of the Burgos Cathedral,” in 2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), IEEE, Mar. 2024, pp. 893–894. doi: 10.1109/VRW62533.2024.00243.

[6] D. Ferdani, B. Fanini, M. C. Piccioli, F. Carboni, and P. Vigliarolo, “3D reconstruction and validation of historical background for immersive VR applications and games: The case study of the Forum of Augustus in Rome,” J Cult Herit, vol. 43, pp. 129–143, May 2020, doi: 10.1016/j.culher.2019.12.004.