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The virtual reconstruction of Cervara di Roma fortress: methods and tools for the dissemination of the past

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ABSTRACT
Three-dimensional (3D) technologies play a crucial role in the philological reconstruction of archaeological contexts. The integration of technology and archaeological evidence has made it possible to develop 3D virtual reconstructions, providing valuable insights into the temporal evolution of archaeological sites. This innovation serves as a significant research and analytical resource, enabling the visualisation of possible scenarios related to archaeological contexts that have significantly changed over time. Moreover, understanding these changes, the past and its relevance to the current context could pose a challenge to the general public. This work aims to illustrate a scalable rendering system using open-source Web3D apps and platforms, allowing access to information, 3D models, and descriptions to enhance the experience of artworks.

Section: RESEARCH PAPER

Keywords: 3D reconstruction; cultural heritage; photogrammetry; survey; visualization

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1. INTRODUCTION

Following upon the paper presented at the 2023 IMEKO International Conference on Metrology for Archaeology and Cultural Heritage [1], this study represents its continuation.

The previous phase focused on the drone survey of the Rocca di Cervara di Roma, on the 3D digital reconstruction of its three phases of encastellation and on the creation of explanatory videos regarding the structural changes over the centuries. Specifically, these videos are currently on display in the Archaeological Room of the "Museo della Montagna Transumanti e Pitturi" in Cervara di Roma, constituting a component of a musealization project aimed at revitalizing digital communication related to the museum collection and the surrounding territory [2].

The current phase focuses more on the dissemination of the country's history beyond the boundaries of the Museum to reach a more diverse and expansive audience. To achieve this purpose, the three-dimensional (3D) models of the Rocca di Cervara di Roma were uploaded online using the open-source framework ATON, thereby enhancing accessibility to the content.

The models become accessible on any device and could also be easily implemented within the Museum website. In this way, both the history of the Rocca di Cervara di Roma and the evolution that has affected its territory become accessible even to members of the public who cannot physically visit the site, while also providing an opportunity for researchers interested in studying the territory.

The tools used for the creation of the 3D models (e.g. photogrammetric survey and 3D modelling) could play a crucial role in facilitating the communication of archaeological landscape with the public, as well as for the study and analysis of historical and cultural contexts.

In the archaeological framework, the main benefits of this innovation manifest themselves, above all, in fragmented and unclear contexts, in which evidence is scarce or insufficient to understand the past and establish connections with the current context.

Starting from the results of archaeological investigations and research, deriving from excavation campaigns, it is possible to create a 3D reconstruction representing a valid way of exploration and analysis. This approach allows the possibility to visualize hypotheses about contexts that have undergone alterations regarding their original configuration over time [3].

At the same time, digital processing encompasses tools capable of conveying highly specific archaeological data into images, making them accessible and understable to the public. In fact, the role of multimedia content in decoding concepts of intrinsic complexity, such as a stratigraphic archaeological sequence, allows the effective use of the digital dimension for informational purposes, as well as within museum exhibitions. It is essential that the digital reconstructions, outlined through a process of virtual anastylosis, demonstrate a precise balance between scientific accuracy and the need for an immediately perceptible and comprehensible restitution [4].

2. CASE STUDY

This contribution aims to examine the use of virtual reconstructions regarding the evolutionary phases of the Cervara di Roma fortress. Three excavation campaigns between 2006 and 2008 were carried out in this area, under the scientific direction of Prof. Letizia Ermini Pani and Prof. Francesca Romana Stasolla. The research activities were coordinated by the Medieval Archeology and Medieval Topography Departments at the Sapienza University of Rome) [5].

Cervara di Roma is a small mountain municipality located in the Simbruini Mountains Park.

Archaeological stratigraphy indicates the fortress underwent four phases from the 11th to 20th century, but due to natural collapses, historical sieges, and modern demolitions, previous structures were not conserved and are not visible today. The first defensive system (early 11th - late 13th century) consisting of a square-based tower with an attached enclosure and cistern, the base part of the tower in limestone blocks and blocks survived [6].

The upper part of the fortress was surrounded by a continuous wall that likely encompassed an external rectangular structure located near the walls. This building has been recognized as a church and it is located slightly higher than the current collegiate church of Maria SS. of the Visitation.

After a fire, the tower was destroyed. At the end of the 13th century, there was a renovation and a new construction of the defensive system on the hill [7].

This reconstructive hypothesis is possible thanks to the depiction of the castrum of Cervara di Roma in a fresco located in the Cosmatesque cloister of the Monastery of Santa Scolastica in Subiaco (first half of the 14th century).

In 1492, the Colonna family took control of the Commandery of Subiaco. Later, in 1508, Pompeo Colonna [8] became the abbot of Subiaco and oversaw the reconstruction of the Rocca di Cervara. The Renaissance fortress, commissioned by Pompeo Colonna at the beginning of the 16th century, was partly built on the remains of the ancient tower. Unfortunately, this invasive construction affected the previous structures, and only some fragments of the old structures are visible today.

From 1700 onwards, many artists of the Grand Tour visited and stayed in Subiaco. These artists, including Camille Corot, Oscar Kochosca and Ernest Herbért, represented the beauty of the village in their works.

Figure 1. Three-dimensional reconstruction process in Agisoft Metashape: sparse point cloud.

In the 1950s, a Civil Engineers project created a reinforced concrete lining to support the rocky ridge which irremediably compromised the ancient spatial configuration, altering its legibility.

The virtual reconstructions developed during the set-up of the archaeological room of the Museo della Montagna Transumanti e Pitturi could help in understanding the historical and archaeological context of the fortress. These virtual reconstructions graphically represent both the structures that no longer exist and the different phases of use of the fortress. This allows for a simpler spatial reconnection with the current archaeological site, as existing structures that help in reading the archaeological context are not available.

3. VIRTUAL RECONSTRUCTION WORKFLOW

The combination of computer science and archaeological evidence enables the creation of 3D virtual models to analyze the temporal evolution of archaeological sites [9], [10]. This innovation serves as a significant research and analytical resource, enabling the visualization of possible scenarios related to archaeological contexts that have significantly changed over time. Moreover, understanding these changes, the past and its relevance to the current context could pose a challenge to the general public. In this sense, 3D virtual reconstruction could help overcome this challenge by providing visually accessible images and consequently aiding the comprehension of the archaeological context [11], [12].

3.1. UAV Survey and photogrammetric processing

The area of Cervara di Roma involved in the project covers about 1.5 hectares. The photogrammetric survey was conducted using a Mavic 2 Pro drone equipped with a 20-megapixel Hasselblad L1D-20c camera, which captured a detailed dataset of the site. The process of creating the digital model was carried out with Agisoft Metashape.

During the reconstruction phase employing the structure-from-motion technique, the software's algorithms attributed distance, width, and focal length parameters to the camera. Through a triangulation procedure, the software ascertained the precise positions in three-dimensional space from which the photographs were captured, thereby generating a spatial representation in the form of a sparse point cloud (Figure 1). The subsequent phase, known as multi-view stereo reconstruction, entailed the meticulous processing of a dense point cloud (85 million points).

In addition, a highly detailed mesh was generated. The final step involved reconstructing the colour texture. This completes

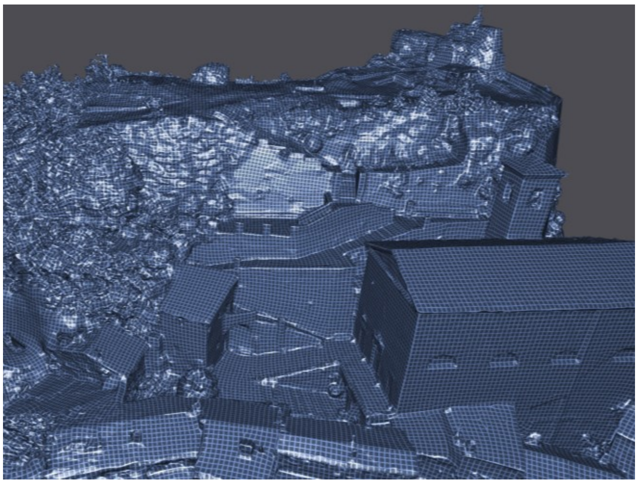

Figure 2. Preview of the retopology process in Instant Mesh.

the digital model, which represents accurately the contemporary spatial layout of the entire area and serves as the basis for virtual reconstructions.

3.2. The optimization of the photogrammetric model

The growing prevalence of 3D models in virtual environments accessible via online platforms and smartphones underscores the need to optimize these models.

The process of optimization involves creating digital duplicates with fewer polygons (low poly) to ensure compatibility with a wide range of hardware configurations. This is achieved through a process called "retopology".

Among the diverse tools available for this retopology process, Instant Mesh, a freely available tool celebrated for its proficiency in managing a substantial volume of polygons, was used.

As a result of this process, a lighter mesh (85 thousand polygons) featuring quadrangular polygons was generated. This refined mesh, in turn, facilitated the unwrapping of the low-poly model (Figure 2). The UV mapping reference system played a pivotal role in encoding colour and normal information through the baking process, effectively translating these details from the high- resolution model to the low-poly counterpart in 2D images. The output images, when configured within Blender's shader editor, allowed for the transference of identical characteristics. Consequently, the high- resolution texture acquired through the photogrammetric survey, originally associated with the high-poly model, found its counterpart in the low-poly digital replica, thereby preserving both colour and relief information.

3.3. 3D Virtual reconstructions

By conducting a photogrammetric survey, it was possible to determine the heights of the remains of the ancient structures on the fortress, above which the volumes were modelled to reconstruct what no longer exists today. Referring to the first defensive system, the city walls and the tower with the adjoining wooden structure were rebuilt; a little further down, the volume of the original church was reproduced (Figure 3).

The 3D reconstruction of the second phase concerns the demolition of the tower and the creation of a domestic environment linked to a different destination of the fortress. Furthermore, in the area now occupied by the current Church of Maria SS. of the Visitation, a larger structure referable to the church has been hypothesized.

The protagonist of the third phase is the Renaissance fortress (Figure 4) which, in its grandeur, was rebuilt on top of the

Figure 3. Virtual reconstruction of the fortress of Cervara di Roma (first phase).

Figure 4. Virtual reconstruction of the fortress of Cervara di Roma (third phase).

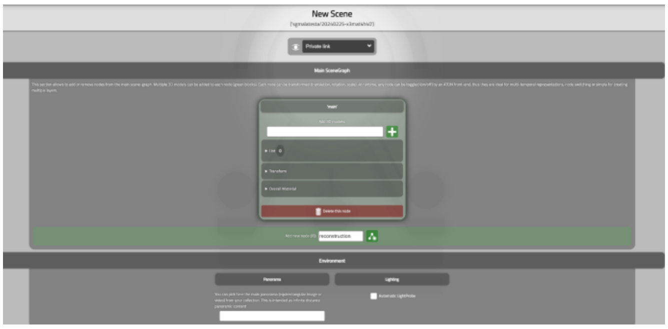

Figure 5. Shu back-end: add a new scene.

previous structures and directly incorporated the rocky bank. During this phase, the fortress lost its defensive features to become the seat of power of the Colonna family.

4. VIRTUAL RECONSTRUCTION WORKFLOW

In order to be able to visualize the virtual reconstructions of the evolutionary phases of the Cervara fortress, ATON has been used, an open-source framework developed by B. Fanini for CNR-ISPC [13].

ATON is a scalable, flexible and modular open-source framework that allows the creation of Web3D/WebX apps accessible from multiple devices (mobile, desktop, VR), without any installation and using common web browsers.

Thanks to an integrated back-end ("Shu"), the author, through authentication, can upload three-dimensional contents exported in the .glTF format directly from the open source Blender software. The 3D scenes (Figure 5), if necessary, can be organized into real virtual collections/galleries. Each publication

Figure 6. Visualization of the photogrammetric model in ATON front-end on a web browser.

Figure 7. Visualization of the photogrammetric model and the virtual reconstruction layer in ATON front-end on a web browser.

is assigned a unique ID through which the scene uploaded online via link is easily accessible.

The 3D model of the Cervara di Roma fortress, produced by the photogrammetric survey by drone, was uploaded into "Shu"; the scene was then customized via "Hathor", the official front-end integrated into the framework which intuitively allows you to create web applications to view and present three-dimensional models or environments (Figure 6).

Among the available functions, the most useful are:

a) the exploration of the 3D scene, with the possibility of zoom-in and rotation;
b) the possibility of changing direct and ambient light settings; c) the possibility of carrying out measurements;
d) the activation or deactivation of individual layers is particularly advantageous in the presence of reconstructive hypotheses, as through this tool it is possible to isolate the archaeological data obtained from the 3D survey and the individual hypothesized virtual reconstructions.

Furthermore, the possibility of creating semantic annotations associated with a specific area traced on the 3D model permits to activate further in-depth content in relation to the displayed scene.

These areas can be linked to IDs or descriptive texts, which implement the multimedia contents.

Unlike other web viewers, ATON supports PBR (Physically-Based Rendering), offering an advanced and realistic way of viewing materials, a requirement of fundamental importance when working in the cultural heritage field.

Accessible at the link [14], or with QRcode, the 3D scene containing the reconstructive hypotheses of the phases of the fortress of Cervara di Roma includes a window with an introductory text to which a localization mask has been

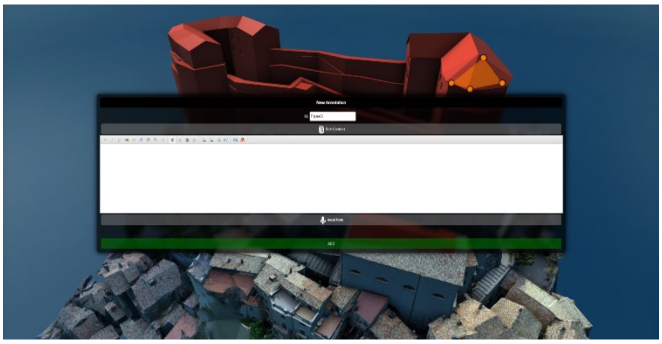

Figure 8. Polygon tool for adding semantic annotation.

associated. This can be recalled at any time by clicking on the "i" icon at the bottom right.

The user can deepen his knowledge of the 3D models through different levels of visualization. The photogrammetric drone model, which represents the current configuration of the Cervara di Roma fortress (fourth phase), constitutes the main layer, on which the three-dimensional models, relating to the three evolutionary phases, have been superimposed.

ATON allows both a simultaneous display of all reconstructive levels and the possibility of viewing them individually.

In this case, for each reconstructive hypothesis it was chosen not to visualize the 3D model with texture, but with a solid colour material: in this way a simultaneous reading of the evolution of the volumes of the individual phases is offered (Figure 7).

The possibility of simultaneously viewing multiple reconstructive layers allows you to distinguish chromatically between the elements reconstructed starting from the archaeological data and the elements developed based on hypotheses and comparisons.

For each phase, a semantic annotation was drawn on the model using the polygonal tool (Figure 8). In this way, the area is activated by changing its colour on mouseover: by clicking the user obtains further information which is displayed in a window to the right of the scene.

2D renderings of virtual reconstructions have also been added within it to allow the user to view 3D models with textures.

5. DISCUSSIONS AND CONCLUSIONS

An overall discussion regarding the advantages of 3D technologies applied to the case study is presented here.

The combined use of computer science and 3D technologies on a global scale has not only introduced significant changes in cultural heritage research [15] but has also encouraged the creation of innovative solutions for musealization [16].

Furthermore, the infusion of innovative elements, such as the exploitation of VR and AR based technology, has led to notable improvements in communication, along with the emergence of new avenues for accessibility, cultural management, and marketing [17]. In this sense, both photogrammetry and 3D modelling could be powerful tools for research activities and for museum dissemination.

As previously discussed, ATON boasts advanced functionalities, which include real-time collaborative features, visual and immersive analytics, and integration with complex multimedia content, all of which make it an invaluable asset in cultural contexts [18]. Its unique capabilities make it an ideal solution for research and communication also in the archaeological area.

This is especially notable as it provides the opportunity to upload 3D models online in an open-source way, enabling the content to be accessed and appreciated globally.

The results provided by archaeological research offer different glimpses into the past lifestyle, and often the data allows for a reconstruction of past scenarios [19]. However, imagining the way an archaeological site, such as the Cervara Fortress, might have looked in the past can be challenging for a non-specialist audience. VR applications such as 3D visualization and modelling technologies can help overcome these limitations and more. On the one hand, 3D digital reconstructions support communication, education, and dissemination of scientific data in both museum and school settings by engaging different audiences, local or foreign, such as museum visitors or scholars, in an innovative and inspiring way; on the other hand, they unlock a deeper level of knowledge for the local community [20]: the rediscovery of a significant part of their intangible heritage and origin, the historical awareness and cultural education of Cervara di Roma.

By implementing VR technologies, users will be able to travel back in time and relive the different phases of the settlement of the fortress to appreciate the changes over the centuries. This typology of content could be disseminated either on the web, through upload in the ATON framework, or with a VR station or printed replica in the Museo della Montagna: in either case, even the people who are unable to physically visit the archaeological site still have the opportunity to learn about its treasures and history. Nevertheless, this digital exploration has the potential to inspire users to visit Cervara di Roma and its related archaeological site. Visitors can now better understand the archaeological remains with newly gained knowledge and tools.

The use of 3D technologies in the Cervara di Roma case study provided a graphical representation of the four phases of the castellation. The initial phase showcased the defensive features and the early church. Later, the tower was demolished to make way for residential quarters and a larger church structure. The Renaissance donjon phase was cleverly linked with the rocky terrain, marking the transformation of the fortress into a position of power. Ultimately, the photogrammetric model was overlaid on the natural rock formation, providing a clear depiction of the current state of Cervara di Roma.

Photogrammetry and 3D modelling are powerful tools that offer numerous benefits to both research activities and museum dissemination. Despite their potential, the process of producing a 3D reconstruction of an eradicated and scarcely known archaeological site can be quite challenging. However, in central Italy, 3D digital reconstructions often serve as a robust tool for disseminating knowledge to a wider audience, as demonstrated in several studies targeting students [21] and employing rigorous methodological frameworks . By leveraging these methodologies, people without specialized knowledge in archaeology can develop a deeper understanding of the significance of the archaeological museums they visit [22]. Building upon prior experiences, photogrammetry, 3D modelling, and related technologies have emerged as significant tools for archaeological research and community management within museum settings, thereby facilitating improved public access to these sites.

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