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From excavation to digital use, reconstructing and returning the past to small communities: the case of the medieval fortress of Cervara di Roma

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***Abstract* – The mediaeval fortress of Cervara di Roma, with its origins dating as far back as 1005, underwent numerous cycles of destruction and reconstruction until it came under the ownership of the Colonna family. Recent excavation campaigns conducted in the years 2006-2008 have unveiled four distinct evolutionary phases of the fortress. However, due to the scarcity of archaeological remnants, comprehending the layout and ancient structures of the site remains a challenge. This paper endeavours to provide the community with a means to comprehend the fortress's historical evolution through the medium of virtual reconstructions.To achieve this objective, a comprehensive digital reconstruction project for the mediaeval fortress was conceived, building upon existing studies and historical sources. The project unfolded through three integral phases: firstly, a photogrammetric survey conducted using drone technology; secondly, a digital processing endeavour to generate a 3D model; and lastly, the development of three-dimensional models to represent structures that have long since disappeared. Through these meticulous actions, this research seeks to bridge the gap in understanding the fortress's intricate history and architectural transformations.**

I. INTRODUCTION

In recent years, the widespread adoption of digital technologies and advancements in computer science has brought about a transformative shift in the approach to communication and dissemination of cultural heritage. Notably, the pivotal role in this evolution is played by three-dimensional (3D) technologies, which are instrumental in the reconstruction of archaeological contexts.

One of the greatest advantages concerns fragmented archaeological contexts, which are often difficult for the non-specialist public to understand: there, the archaeological evidence is missing or insufficient, allowing neither an understanding of the past nor its connection to the present context [1].

Moreover, the integration of technology with archaeological evidence facilitates the development of 3D virtual reconstructions, thereby offering valuable insights into the temporal evolution of archaeological sites. This innovation serves as a significant research and analytical resource, enabling the visualisation of conjectural scenarios pertaining to historical contexts that have undergone significant alterations.

Concurrently, virtual processing serves as a conduit to transform intricately detailed archaeological data, often beyond the grasp of the general public, into visually accessible imagery. The unique ability of multimedia content to elucidate complex concepts, such as deciphering an archaeological stratigraphic sequence, endows the virtual dimension with a potent tool for effective dissemination, particularly within museum contexts. It is paramount to emphasise that digital reconstructions, born from the meticulous process of “virtual anastylosis”, strike a harmonious equilibrium between scientific precision and the imperative of presenting information in a manner readily comprehensible and perceptible to the audience [2,3].

S.G.M.

II. CASE STUDY

This paper delves into the reconstructive hypotheses pertaining to the developmental phases of the Cervara di Roma fortress. Notably, between the years 2006 to 2008, three extensive excavation campaigns were meticulously executed under the remarkable scientific stewardship of Professors Letizia Ermini Pani and Professor Francesca Romana Stasolla. These on-field researches formed an integral component of the overarching research initiative overseen by the academic chairs specialising in Medieval

Archaeology and Mediaeval Topography at Sapienza University of Rome [4].

Cervara di Roma, situated within the picturesque Monti Simbruini Park, straddles the boundary between the Lazio and Abruzzo regions, occupying a lofty perch at an elevation exceeding one thousand metres. Remarkably, it reigns as the loftiest settlement within the Province of Rome, commanding panoramic views over the Aniene Valley.

Fig. 1 Cervara di Roma (RM)

The historical documentation preserved within the Regesto Sublacense (dated back 11th century) presents a compelling narrative, shedding light on the gradual evolution of Cervara's settlement. It meticulously traces the origins of this settlement to its earliest references, situated within the broader context of the Aniene Valley's intricate territorial landscape, with a particular emphasis on its relationship with the Subiaco monastery. Within the annals of history, the year 967 emerges as a pivotal milestone, encapsulating a defining moment when Emperor Otto I formally endorsed the monastery's rightful ownership of all assets associated with Cervara, a declaration that encompassed Cervariam. This enduring ownership was revalidated in the year 997, signifying a momentous juncture in the historical narrative. It is worth noting that the village acquired its designation as a "castellum" for the first time in the historical accounts dating back to the year 1005 [4].

In the 13th century, Cervara saw conflicts and a siege, as chronicled in the Chronicon Sublacense. The Colonna family took over Subiaco in 1492, and in 1508, Pompeo Colonna led the reconstruction of Cervara's fortress. [5]

Since the 1700s, artists like Corot, Herbért, and Kochosca have visited and depicted the village. In more recent times, artists like Alberti, Pasolini, and Morricone also found inspiration in Cervara.

Throughout history, [6] a series of historical sieges, natural collapses, and contemporary demolitions have regrettably precluded the preservation of the fortress's original architectural fabric. Nevertheless, the outcomes of meticulous investigations have unveiled a stratigraphic record that facilitates the segmentation of the fortress's existence into four distinct phases, spanning from the 11th century to the 20th century. This stratigraphic insight provides invaluable context for understanding the evolution of this historic stronghold.

M. C.

The earliest defensive structure (early 11th - late 13th century) is a square-based tower with an attached enclosure and cistern; the basement part of the tower made of roughcast and limestone blocks has survived [6].

Drawing upon the visual representation of the castrum of Cervara, depicted in a fresco gracing the Cosmatesque cloister within the Monastery of St. Scholastica in Subiaco during the early decades of the 14th century, it is plausible to infer the existence of an encompassing upper perimeter, fortified by a continuous wall. This architectural ensemble likely encompassed an external rectangular edifice situated in close proximity to the walls, which has been identified as a church. Notably, this structure exhibited a slightly elevated positioning compared to the present-day collegiate church of Maria SS. della Visitazione [7,8]. However, a significant transformation was catalysed by a destructive fire, which precipitated the demise of the tower. Subsequently, at the close of the 13th century, an ambitious endeavour saw the comprehensive reconstruction of the defensive stronghold positioned upon the hill. This episode of architectural evolution underscores the dynamic history of the Cervara fortress and its ongoing adaptation to the exigencies of the time.

In the early 16th century [9,10], Pompeo Colonna's Renaissance donjon significantly altered the existing structures. It incorporated some remnants of the ancient tower and other elements, though only limited fragments remain visible today.

The introduction of a reinforced concrete lining in the 1950s, thoughtfully executed by the Genio Civile, regrettably inflicted irreparable damage upon the ancient spatial configuration of the site. This intervention has, regrettably, disrupted the site's historical legibility and spatial integrity.

In the absence of existing structures for contextual reference, virtual reconstructions in the Cervara Mountain Museum's archaeological room visually depict long-lost structures, aiding in their spatial connection with the current site configuration.

P. L.T.

III. VIRTUAL RECONSTRUCTION WORKFLOW

Digital reconstruction serves as a strong means to achieve two paramount objectives: the augmentation of the surrounding environment and the provision of enhanced insights, enabling users to delve deeper into the historical and archaeological narrative of the locale they either explore or call home.

Reviving knowledge and awareness unites the local community, fostering appreciation for their history and traditions, showcased in the village's sole museum.

The development of the virtual reconstruction undergoes a structured progression, encompassing the following distinct phases:

1. The first phase involves a meticulous evaluation of prior scholarly studies and excavation campaigns, coupled with the systematic collection of data concerning the extant archaeological remains in their original context.
2. Subsequently, the second pivotal phase encompasses the execution of a photogrammetric survey facilitated by drone technology, followed by the rigorous processing and elaboration of the resulting model.;
3. This phase centres on the tangled modelling of the photogrammetric survey, whereby the acquired data is meticulously transformed and represented in a digital format.
4. In the final stage, the focus turns to the creation of digital reconstructions of the structures, a process that involves the meticulous crafting of three-dimensional models for elements that no longer exist in their original form.

R. M.

A. UAV survey and photogrammetric processing

The area under scrutiny encompasses approximately 1.5 hectares, and the photogrammetric survey entailed the acquisition of a comprehensive dataset. This dataset comprised 507 high-resolution images, each boasting dimensions of 5472 x 3648 pixels and a file size of 12 MB, captured via a Mavic 2 Pro drone equipped with a 20-megapixel Hasselblad L1D-20c camera.

The employment of photogrammetry via drone technology offers an immense potential within the realm of digital archaeological site surveys and architectural documentation. This approach provides a cost-effective and expeditious means of amassing a substantial image dataset, ensuring comprehensive coverage across extensive areas [8,9,10].

Furthermore, the utilisation of Unmanned Aerial Vehicles (UAVs) extends the reach to otherwise challenging or inaccessible terrains, exemplified by the successful application in the case of the Rocca di Cervara di Roma (Figure 1). This innovative approach enhances the scope of archaeological survey methodologies, particularly in the context of challenging topographies.

The process of elaborating the digital model unfolded within the Agisoft Metashape software, commencing with an initial phase dedicated to image matching. In this phase, the software executed the task of recognizing correspondences among the images within the dataset, striving to identify the maximum possible overlap between two or more shots.

Subsequently, during the reconstruction phase employing the structure-from-motion technique, the software's algorithms adeptly 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 scattered point cloud. The subsequent phase, known as multi-view stereo reconstruction, entailed the meticulous processing of a dense point cloud (as depicted in Figure 2), comprising an impressive tally exceeding 85 million data points. Additionally, an intricately detailed mesh, featuring a polygonal surface encompassing over 35 million faces, was extrapolated. The culminating step involved the reconstruction of the texture in full colour (as illustrated in Figure 3).

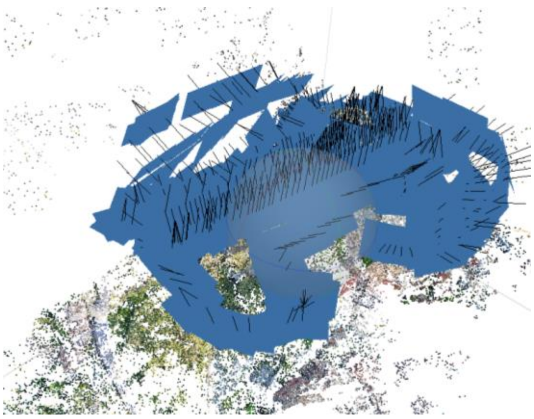

Fig. 2 Three-dimensional reconstruction process in Agisoft Metashape: sparse point cloud

Fig. 3 Three-dimensional reconstruction process in Agisoft Metashape: polygon model with texture

This comprehensive digital model faithfully captured the contemporary spatial configuration of the entire area, serving as a foundational framework for subsequent virtual reconstructions [11,12].

P. R.

B. Modelling the photogrammetric survey

The 3D model produced through the photogrammetric survey presents a unique challenge when it comes to seamless editing within standard 3D modelling software. Although its notably dense geometry ensures heightened precision in rendering intricate details, it is imperative to underscore that the task of manipulating or modifying this digital model demands the utilisation of high-performance hardware resources.

This perennial challenge is a recurrent concern when employing survey techniques renowned for their capacity to deliver exceptionally precise representations of the intended subject matter.

The burgeoning prevalence of 3D models within virtual environments, readily accessible through online platforms and smartphones, underscores the imperative of optimising these models. This optimization entails the creation of digital duplicates characterised by a diminished polygon count, often referred to as "low poly," to ensure compatibility with a wide spectrum of hardware configurations.

The optimization of the model is achieved through a meticulous retopology process, wherein the polygonal texture undergoes simplification, yielding a refined and more accurate geometry. Furthermore, this enhanced texture not only facilitates intervention within the digital model but also enables the incorporation of missing details with precision.

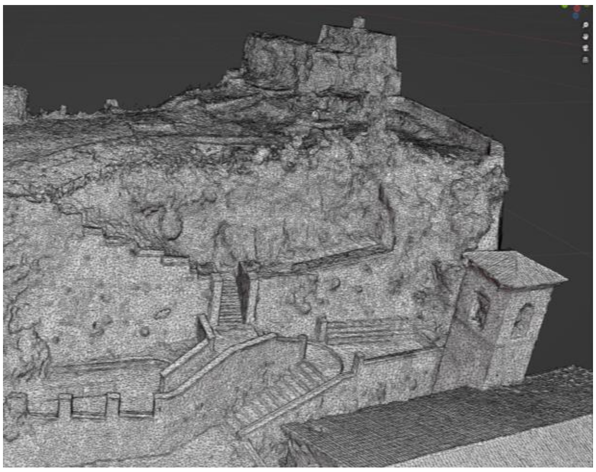

Fig. 4 Topology structure of the photogrammetric mesh model

Following the mesh decimation achieved via Metashape, the resulting mesh, in the form of a .obj file, was subsequently imported into Blender—a renowned open-source software esteemed for its capabilities in 3D processing and reconstruction. It's worth noting that Metashape's decimation algorithms excel in reducing polygon counts while preserving the essential "geometric texture" of the mesh, primarily composed of triangular faces (as illustrated in Figure 4).

In the pursuit of optimization and thorough refinement of the mesh, retopology emerges as a crucial step. This operation serves to eliminate elements that might potentially introduce errors in subsequent phases, simplifying geometries and thereby reducing the time required for the final rendering.

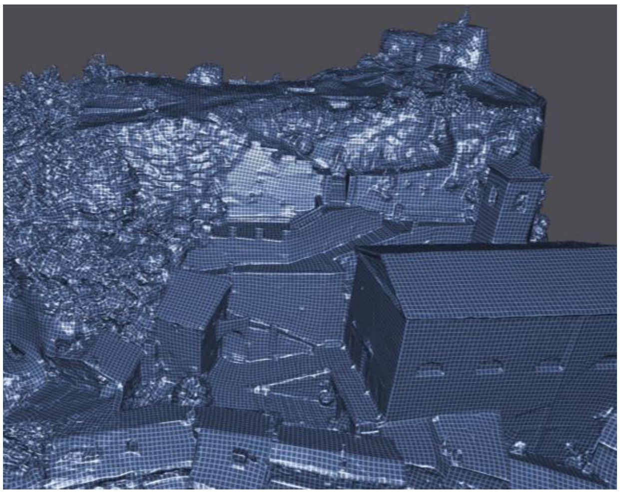

Fig. 5 Preview of the retopology process in Instant Mesh

Among the diverse tools available for this etymologization process, the decision was made to employ Instant Mesh—a freely available external tool celebrated for its proficiency in managing a substantial volume of polygons. As a result of this meticulous process, a lighter mesh featuring quadrangular polygons was generated (depicted in Figure 5).

This refined mesh, in turn, facilitated the unwrapping of the low-poly model. 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.

C. Digital reconstructions of structures

The photogrammetric model served as a fundamental reference for the terrain modelling process. This involved the adaptation of the terrain to a planar configuration with a heightened geometric density. Within this framework, sculpting techniques were deployed, leveraging alpha-textured brush strokes to artfully simulate the rugged topography, particularly the rocky asperities.

Furthermore, this terrain element underwent optimization, a strategic measure aimed at reducing its polygonal density, thereby rendering it amenable for seamless operation within the Blender environment [13,14]. This optimization step contributed to the overall efficiency of the modelling process.

Utilising photogrammetry, we determined the heights of ancient fortress remains and crafted models to resurrect long-lost structures. We reconstructed the initial defensive features and the primitive church. The second phase involved the demolition of the tower, the construction of domestic quarters, and a hypothetical larger church structure.

The third phase, featuring the Renaissance donjon (Figure 6), ingeniously integrated with the rocky terrain, marking the transformation of the fortress into the Colonna family's seat of power.

Fig. 6 Digital reconstruction of the fortress of Cervara di Roma (third phase)

Fig. 7 Digital reconstruction of the fortress of Cervara du Roma (fourth phase)

In the final phase (Figure 7) we superimposed the photogrammetric model onto the rock volume. Textures for each phase drew upon archaeological data and historical sources. PBR textures (colour, normal, roughness, ambient occlusion, height) were meticulously crafted in Adobe Substance Painter 3D and then integrated into Blender with a reconstructed node configuration.

G. C.

IV. CONCLUSIONS

The Cervara fortress, bereft of tangible archaeological artefacts to elucidate its historical narrative, stands as an enigmatic vestige, seemingly detached from its once-prominent role in the surrounding territory. This underscores the pressing imperative of rendering the comprehension of the fortress's evolutionary stages accessible to all, with particular emphasis on engaging the local community.

The reopening of the Cervara di Roma Mountain Museum, serving as the canvas for the creation of virtual reconstructions, has bestowed upon the village's residents a cultural haven strategically designed to elevate their appreciation of local history and traditions.

Initiating from the foundation of the 3D reconstruction, a series of 2D renders has been meticulously crafted and subsequently employed as illustrative elements within the museum panels adorning the newly arranged archaeological room.

Furthermore, an informative video has been painstakingly produced. This video artfully showcases the metamorphosis and structural evolution of the Rocca across the centuries, serving as a concise synthesis of the content featured in the panels.

The imperative to reconstruct the past for the purpose of communication and communal enrichment aligns harmoniously with the guiding principles articulated in the Faro Convention of 2005. This convention underscores the importance of cultivating a progressively deeper comprehension of cultural heritage and its intricate interplay with the concept of citizenship. It does so by fervently endorsing all endeavours directed towards heightening awareness of the cultural worth inherent in objects and locales, as well as nurturing a profound sense of affinity and belonging to them.

S.G.M.

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