proceedings

MDPI

Proceeding Paper

X-ray Analysis, Photogrammetry and Virtual Reality for the Study and Enhancement of Archaeological Contexts: A Case Study from the Necropolis of Crustumerium †

Roberta Manzollino [1,2,*], Saverio Giulio Malatesta [2], Paolo Rosati [2], Marco Raoul Marini [2], Marcello Colapietro [3] and Ombretta Tarquini [3]

1 Department of Classics, Sapienza University of Rome, 00185 Rome, Italy
2 Interdepartmental Center of Research DigiLab, Sapienza University of Rome, 00185 Rome, Italy; saveriogiulio.malatesta@uniroma1.it (S.G.M.); paolo.rosati@uniroma1.it (P.R.); marcoraoul.marini@uniroma1.it (M.R.M.)
3 C.N.R. Istituto di Cristallografia—Area della Ricerca Roma 1, Via Salaria Km 29300, 00015 Monterotondo, RM, Italy; marcello.colapietro@ic.cnr.it (M.C.); ombretta.tarquini@ic.cnr.it (O.T.)
* Correspondence: roberta.manzollino@uniroma1.it
† Presented at the Una Quantum 2022: Open Source Technologies for Cultural Heritage, Cultural Activities and Tourism, Rome, Italy, 15–16 December 2022.

Abstract: In this paper, we present the application of established methodologies to innovatively investigate a soil block containing a human skeleton and metal artefacts (VII century BC) from the necropolis of Crustumerium near Rome. The chemical composition was investigated using X-ray analysis, and digital acquisition was conducted for dissemination and enhancement purposes. This case study aims to show how the combination of virtual techniques (i.e., virtual anthropology and virtual reality) and X-ray imaging (XRI) can be useful tools for the study and communication of both ancient human remains and archaeological artefacts, especially when it is not possible to move and handle a fragile one.

Keywords: enhancement; virtual anthropology; archaeology; XRI; XR; VR; digital environment

check for updates

Citation: Manzollino, R.; Malatesta, S.G.; Rosati, P.; Marini, M.R.; Colapietro, M.; Tarquini, O. X-ray Analysis, Photogrammetry and Virtual Reality for the Study and Enhancement of Archaeological Contexts: A Case Study from the Necropolis of Crustumerium. *Proceedings* **2024**, *96*, 13. https://doi.org/10.3390/proceedings2024096013

Academic Editors: Gabriele Ciccone and Giuseppe Guarino

Published: 19 March 2024

1. Introduction

In this paper, we present the application of established methodologies, such as X-ray fluorescence (XRF), computed tomography (CT-scan), virtual anthropology (VA), virtual reality (VR), and photogrammetry, to innovatively study a soil block from the necropolis of Crustumerium, containing a skeleton and metal artefacts.

The Latin settlement of Crustumerium was founded in the IX century on the edge of the Sabine territory, 9 miles north of Rome. From the time of Romulus, the settlement fought against the expansion of Rome until they were conquered in 499 BC. The settlement flourished during VII and VI centuries BC, as suggested by the fortification walls, the shards of architectural decoration, and the wide necropolis surrounding the urban plateau [1–4].

If well preserved, findings discovered during archaeological excavations are recovered directly. However, if they are fragile and difficult to identify and preserve, it is preferred to circumscribe the area and extract the discovery with its surrounding soil, called soil block. This operation minimizes the risk of damaging the artefacts and allows them to be recovered later via microexcavation in a controlled environment and after appropriate analysis. This archaeological method helps preserve most of the information. These data could be acquired through X-ray analysis using completely non-invasive techniques, such as X-ray imaging (XRI) and CT scanning, which provides us with the opportunity to assess information about the distribution, shape, dimensions and state of the preservation of artefacts while also allowing the study of the inner part, invisible to macroscopic analysis [5].

The soil block technique is also employed when ancient human remains, such as skeletons, are in a state of poor conservation and challenging to recover [6].

2. Enhancement of the Archaeological Soil Block

Despite their recovery, these archaeological findings remain extremely fragile. Therefore, it is not advisable to exhibit them, considering both preservation and bioethical reasons [7]. To address these challenges, digital replicas can provide a solution. The use of photogrammetry and VR enable the creation of 3D replicas of the original findings, enhancing their accessibility for both research and broader enrichment and dissemination [8,9]. The application of virtual anthropology (VA) methods allows for advanced analyses of the skeleton without jeopardizing the preservation of the original discovery [10].

XRI support the XRF analysis of archaeological remains from excavation. XRI gives a complete document of the objects and suggests where to perform the XRF analysis, as well as structural and technical details and decoration information. The XRF analysis was carried out on the metal elements that already emerged from the soil. The analysis identifies a bronze alloy featuring all the artefacts (Cu, Pb, and Sn) [11]. CT scanning is useful for morphological studies of both the external surfaces and internal structures of an object. In this way, complementary information from all techniques can be obtained, superimposed and combined. The data are useful for characterising the material of which the object is made, determining its state of deterioration, helping us to choose the best restoration method and supporting the work of archaeologists [5]. These imaging and analytical techniques allow us to recognize the techniques of manufacture and thus contribute to our knowledge of the societies that produce the artefacts and to our broader understanding of the history of technologies [12].

3. Workflow

3.1. Bioanthropological and X-Ray Analyses

Tomb TV4 is dated from the VII century BC, the Orientalising Period, and was excavated during the 2010 archaeological campaign. The skeleton and grave goods were discovered in the burial ground, which was just brought to light along the track of the Trincea Viaria. The tomb constitutes a unicum. It is small in size compared to the standard, and it was intended for three individuals of infant age [4,5]. According to the archaeological evidence, the individual buried in the tomb is a child, and the sex should be female, as hypothesized by the presence of grave goods and a couple of ornaments adorning the arms [13]. From a bioarchaeological point of view, sex estimation in nonadult individuals is difficult because the individual has not yet reached sexual maturity, so diagnostic characters are not expressed. Hence, it is not possible to determine the biological sex using VA methods [14]. The estimated age at death is between 7.5 and 10.5 years of age, and this was determined by studying tooth development and eruption according to the AlQahtani method [15].

3.2. Photogrammetry and 3D Modelling

Photogrammetry was the chosen technology to acquire and create a 3D model, capturing the details of the shape, texture and material of the archaeological soil block. We used an APS-C camera equipped with a 20 mm lens, the Canon 60D. Small apertures (f8–f16) were selected to ensure optimal focus, particularly in critical scenarios where the camera was close to the object. The distance between the camera and the object varied (0.53m) based on the object's placement. To capture the images effectively, a minimum of 70% overlap was maintained between the adjacent images. Manual focus was employed for zoomed areas of the object in critical conditions to prevent undesired blurring due to unmanageable autofocus errors. The ISO level was adjusted appropriately for small apertures and normal illumination conditions.

The software Agisoft Metashape was utilized to process the digital images and generate a 3D model, resulting in a final mesh with a maximum of 4 M polygons (Figure 1).

The model was exported in the *.obj format along with its texture and then scaled using four targets, two placed horizontally and two placed vertically in front and on the side. Special attention was given to the texture, which is crucial for visualizing the simplified models in ATON [16]. Post-processing to obtain a closed 3D model was, in some cases, challenging due to gaps in the rear part of the object. As a result, the 3D models obtained were simplified to be uploaded inside the reconstructed environment. The final result is a highly detailed and accurate digital replica of the object suitable for various applications.

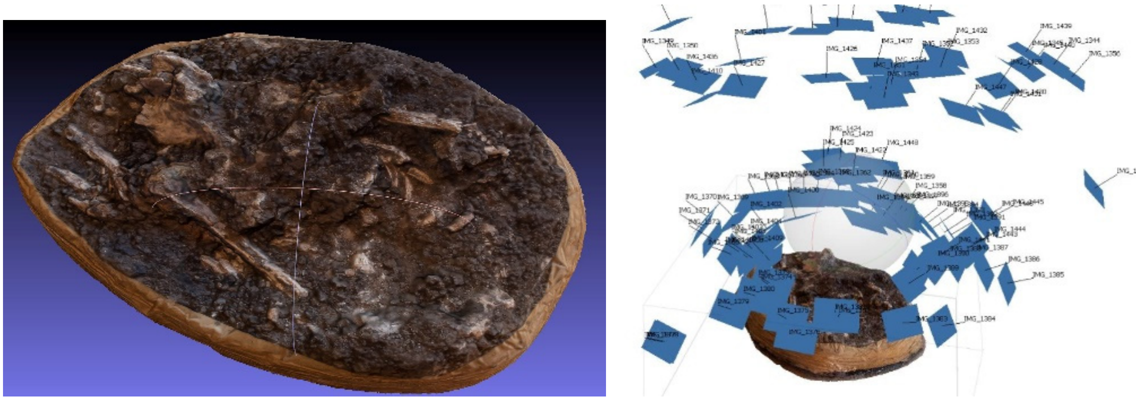

Figure 1. Photogrammetric shooting process (**left**) and processing (**right**). The final 3D result, which can be interacted with within the ATON digital environment, is available at http://archeo3d.uniroma1.it/crustumerium (accessed on 28 February 2024).

3.3. ATON Framework

ATON is a framework developed by CNR ISPC to create Web3D/WebXR apps interacting with cultural objects and 3D scenes on the Web [16]. It offers a powerful application programming interface (API) to manipulate scene graphs, customize event handling for rich interactions and much more, alongside a scalable rendering system with responsive interfaces. It encompasses cutting-edge features such as the advanced rendering of 3D objects using physically based rendering (PBR) and virtual environments, the management of viewpoints (POV), spatial user interfaces for extended reality (XR) sessions, real-time collaborative capabilities, visual and immersive analytics, and integration with complex multimedia content. These digital assets also serve as potent instruments for interactively conveying their significance to non-specialist people, simplifying the comprehension of complex or unclear ideas. VR and AR are effective tools for interacting with 3D models, making it easier for people to understand and appreciate cultural artefacts. These technologies can play an important role in education, providing visitors with the ability to explore different spaces and periods. They enable the presentation of information and concepts that might otherwise be intricate in an accessible and appealing manner [9]. By employing this framework, it became feasible to transform the 3D model generated through photogrammetry into a navigable structure, making it entirely explorable and supplementing it with annotations about the different elements integrated into the landscape. It also accentuated objects that might not be readily apparent (Figure 2) [16].

Figure 2. A series of screenshots of the 3D model of Crustumerium in ATON showing an example of tagging and mapping.

4. Conclusions

The purpose of this paper is to demonstrate how the integration of VA, VR, photogrammetry, and X-ray techniques can serve as effective tools for studying and communicating anthropological remains, particularly when handling a delicate specimen is not possible. In addition to the research aspect, it is essential to consider how to approach the process of disseminating the archaeological context, especially in situations where there are no visible remnants left of the ancient settlement of Crustumerium.

The process illustrated here naturally progresses into the digitization, exploration, and storytelling of the discovered find, accentuating its critical importance within the realm of anthropological research. Modern technology allows us to enjoy intense experiences in two ways: storytelling and natural interaction. In this context, the developed system exploits all the available functionalities according to the most recent standards in the state of the art for promoting knowledge exchange in this cultural heritage field.

The possibility of interacting with the artefact digital replica, discovering their history and context, and understanding how they have come down to us and the nature of the finding itself was explored, which allows us to immediately transmit the historical value and archaeological area and to sensitize the local community towards the testimonies of the past that are too often ignored. This underscores the potential for future research utilizing advanced hardware, enhanced sensors and refined techniques for 3D model reconstruction and natural interactions within virtual environments. Overall, it can be stated that the suggested project appears to be a promising concept that could serve as a foundational framework for future experiments in this field. This direction increasingly emphasizes the merging of research and outreach, creating a virtuous path that unites researchers and the public, experts and non-experts, all working collaboratively towards the preservation and enhancement of cultural heritage.

Author Contributions: Conceptualization, R.M. and S.G.M.; methodology, R.M., O.T. and M.C.; software, S.G.M., P.R. and M.R.M.; validation, R.M., O.T. and M.C.; formal analysis, R.M., O.T. and M.C.; data curation, S.G.M., P.R. and M.R.M.; writing—original draft preparation, R.M. and S.G.M.; writing—review and editing, R.M., O.T. and M.C.; visualization, S.G.M. and M.R.M.; supervision, R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

Acknowledgments: The authors thank B. Fanini and M. Camicioli for the support provided in the visualization and graphics process.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Amoroso, A. Crustumerium, da città arcaica a Suburbium di Roma. *Bull. Della Comm. Archeol. Comunale Roma* **2000**, *101*, 263–282.
2. Di Gennaro, F. Crustumerium e la sua necropolis. In *Roma. Memorie dal Sottosuolo—Ritrovamenti Archeologici 1980/2006*; Mondadori Electa: Verona, Italy, 2004; pp. 222–223.
3. Di Gennaro, F.; Amoroso, A.; Schiappelli, A. Un confronto tra gli organismi protostatali delle due sponde del Tevere. Le prime fasi di Veio e di Crustumerio. In *Further Approaches to Regional Archaeology in the Middle Tiber Valley*; Archaeological Monographs from the British School: Rome, Italy, 2004; Volume 13, pp. 147–177.
4. Quilici, L.; Quilici Gigli, S. *Crustumerium*; Vetus, L., III, Ed.; CNR: Roma, Italy, 1980.
5. Re, A.; Corsi, J.; Demmelbauer, M.; Martini, M.; Mila, G.; Ricci, C. X-ray tomography of a soil block: A useful tool for the restoration of archaeological finds. *Herit. Sci.* **2015**, *3*, 4. [CrossRef]
6. Pacciani, E. Note tecniche per il recupero ed il restauro dei resti ossei umani. *Museol. Sci.* **1985**, *2*, 2–5.
7. Licata, M.; Bonsignore, A.; Boano, R.; Monza, F.; Fulcheri, E.; Ciliberti, R. Study, conservation and exhibition of human remains: The need of a bioethical perspective. *Acta Biomed. Atenei Parm.* **2020**, *91*, e2020110.
8. Profico, A.; Bellucci, L.; Buzi, C.; Di Vincenzo, F.; Micarelli, I.; Strani, F.; Tafuri, M.A.; Manzi, G. Virtual Anthropology and its Application in Cultural Heritage Studies. *Stud. Conserv.* **2018**, *64*, 323–336. [CrossRef]
9. Barsanti, S.G.; Malatesta, S.G.; Lella, F.; Fanini, B.; Sala, F.; Dodero, E.; Petacco, L. The WINCKELMANN 300 project: Dissemination of culture with virtual reality at the Capitoline Museum in Rome. In Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences—ISPRS Archives, Riva del Garda, Italy, 4–7 June 2018; Volume XLII-2, pp. 371–378.
10. Weber, G.W. Another link between archaeology and anthropology: Virtual anthropology. *Digit. Appl. Archaeol. Cult. Herit.* **2014**, *1*, 3–11. [CrossRef]
11. Tarquini, O.; Colapietro, M.; Belelli Marchesini, B. *X-Ray Imaging, X-Ray Fluorescence and Diffraction to Study Metal Archaeological Remains from Excavations, In Atti del Congresso*; Vezzalini, G., Zannini, P., Eds.; Patron Editore: Bologna, Italy, 2012.
12. Tarquini, O.; Colapietro, M. X-ray imaging and successive imaging processing. In *Crustumerium Death and Afterlife at the Gates of Rome*; Ny Carlsberg Glyptotek: Copenhagen, Denmark, 2016; pp. 65–66.
13. Fraioli, F. *Relazione di Scavo*; Soprintendenza Speciale Beni archeologici di Roma: Roma, Italy, 2010.
14. Steyn, M.; Işcan, M.Y. Sexual dimorphism in the crania and mandibles of South African whites. *Forensic Sci. Int.* **1998**, *98*, 9–16. [CrossRef] [PubMed]
15. AlQahtani, S.; Hector, M.P.; Liversidge, H. Brief communication: The London atlas of human tooth development and eruption. *Am. J. Phys. Anthropol.* **2010**, *142*, 481–490. [CrossRef] [PubMed]
16. Fanini, B.; Ferdani, D.; Demetrescu, E.; Berto, S.; D' Annibale, E. Aton: An open-source framework for creating immersive, collaborative and liquid web apps for cultural heritage. *App. Sci.* **2021**, *11*, 11062. [CrossRef]