The so-called *insula dei Lottatori* and block V, III in Ostia: the combination of terrestrial laser scanner (TLS) and drones (UAS) in the field of cultural heritage

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Abstract

The paper illustrates the 3D survey of the so-called *Caseggiato dei Lottatori* and the Block V, III in Ostia, where the combination of terrestrial laser scanning survey with UAS photogrammetry was employed. The result is a high-quality 3D model and a set of high-resolution images, essential tools for further research, and for its proper conservation. This article describes in detail the general workflow followed, from survey planning to data archiving. This last stage, still too often disregarded, is placed in its theoretical context by highlighting the main standards available today.

Keywords

Terrestrial laser scanner, UAS, photogrammetry, urban archaeology, Ostia

Introduction

The work presented here should be considered as an appendix to the much wider research programme *Ostia ReLOADed. Reconstructing Life in Ostia along the Decumanus*, which are archaeological excavations carried out in ancient Ostia within the OsTIUM ARC Project 2021-2026. Through the study of the ancient city of Ostia, the *Ostia's Transformation – Investigating an Urban Model* project (https://www.ostium-arc.be/project), funded by *Fédération Wallonie-Bruxelles*, UCLouvain and UNamur, aims to understand how, with what means, and for what purpose people have transformed the urban space they inhabited over the centuries.

The *Ostia ReLOADed* research project coordinates various other initiatives such as doctoral dissertations in archaeology (Marano 2016-2017, Tomassini 2022; Glogowski 2023, Vyverman ongoinig), and books (Cavalieri, Marano, and Richard forthcoming). EQP funding by *Fonds de la Recherche Scientifique – FNRS*, the Belgian federal funds for research, has allowed the purchase of scanning, photography and remote sensing technology. With such equipment block V, III has been systematically analysed to provide Marano's dissertation with high-resolution 3D illustrations.

Topographical Framework

The Ostia block V, III is located within Ostia's *regio V*, which is in the south-eastern sector of the city, enclosed between the *Decumanus Maximus*, the Late-Republican walls and the *Semita dei Cippi*. The existence of five *regiones* in Ostia has been confirmed by epigraphy (CIL XIV, 352), but their current boundaries have been conventionally reconstructed in modern times

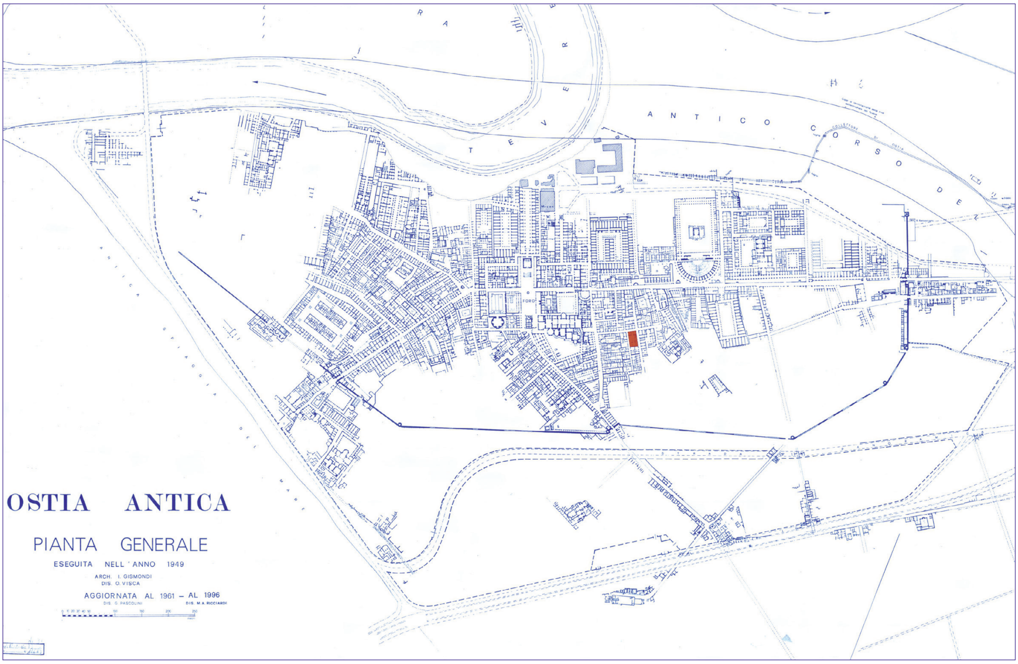

Figure 1 - Ostia, general plan showing the Caseggiato dei Lottatori (in Descoeudres 2001).

(Bakker 1999). Block V, III is located at the western sector of Ostia's *regio V* and is delimited by a minor *decumanus* to the north (the *via della Fortuna Annonaria*), by the *via delle Ermette* to the east, by the *via della Casa del Pozzo* to the west, and by an unnamed side-road of *Semita dei Cippi* to the south. The portion of our interest has an elongated rectangular shape (ca. 76x15.5m), is oriented northwest-southeast and hosts five housing blocks, built in different times (V, III, 1-5).

To the north, the so-called *Caseggiato dei Lottatori*, has a rectangular plan (ca. 29x15.5m) and it dates to the earliest decades of the 2nd century CE and continued to be used – through restorations and transformations — until at least the 4th century CE (Fig. 1). It opens towards *via della Fortuna Annonaria* through three entrances: the middle one leads to the vestibule, while the side ones provide access to two separate *tabernae.* The plan is organised around a central courtyard (*atrium*), leading to a vast hall sided by two *alae* and four little rooms. The shape of the central courtyard changed several times. Initially, there was located an *impluvium* surrounded by pillars, whose massive travertine bases still survive. Three other entrances gave access to *via della Casa del Pozzo* and *via delle Ermette*. The *insula* is named after a fighting scene depicted at the centre of a black-and-white mosaic from the vestibule of the *Casa dei Lottatori* (V, III, 1): it is similar to an *emblema*, showing two fighters wrestling, and dating back to the end of the 2nd and the beginning of the 3rd century CE. Two Latin inscriptions tell us the names of the athletes: *Artemi(dorus)* and *Seca[m?].* Possibly, during the mid-Imperial period the northern section of the *insula*, originally a *domus*, was transformed into a *schola*, or a college hosting the fighters' association (Marano 2016-2017, 87, note 336) (Fig. 2).

Figure 2 - Ostia, plan of block V, III (in eds. Calza et al. 1953).

The house V, III, 2 is located at the central portion of the block. It has a square plan with a central corridor and four rooms at the sides (ca. 15x15,5m). It was built at the beginning of the 2nd century CE on pre-existing structures and seems to have undergone a limited number of transformations. Four entrances open on *via della Casa del Pozzo* and three on *via Ermete*.

The southern sector of the plot is occupied by three constructions built in the earliest decades of the 2nd century CE alongside the *Caseggiato dei Lottatori*. These buildings share perimetral walls and face respectively *via della Casa del Pozzo* (V, III, 3), the unnamed southern road (V, III, 4) and *via delle Ermette* (V, III, 5). The current shape of building V, III, 3 dates to the 3rd-4th century CE, when a pre-existing building with a *medianum* (i.e. a rectangular living space from which all the other rooms can be accessed) was turned into a *domus* (the so-called *Domus del Pozzo*). The main rectangular plan of the original building (ca. 23x8m) was not significantly altered, while the interior underwent renovation to tailor the needs of the time. All parts of the house are connected by a corridor which also links to the reception hall through a wide anteroom. The reception hall occupies the northern section of the building and can be accessed via a hallway lined with columns. A long and narrow second corridor connects the kitchen/lavatory with the other rooms of the house. Behind the *Domus del Pozzo*, is located a rectangular building (V, III, 5) with five *tabernae* and a staircase (ca. 23 x 7,7 m); in the southern part another building was found (V, III, 4) with rectangular plan and set aside from buildings V, III, 3 and V, III, 5 through an east-west wall (ca. 15,5 x 8,8 m). A corridor (*medianum*) links the reception rooms while a second, T-shaped, corridor, leads to the utility rooms.

The preservation status of the elevation of the five buildings is not homogeneous. Walls were extensively restored in the last century and today reach a considerable height, especially in the northern and central sector of the plot, where these measure over 2 metres high; they are progressively lower in the southern part of the block. Floor slabs in the *Caseggiato dei Lottatori* and in the *domus del Pozzo* are embellished with geometrical mosaics and were repositioned back in 1981, after restoration. Currently, they are gradually subsiding, and some sections of the tiles are detaching.

General Workflow

In July 2023 a 3D survey was carried out on the whole block V, III (Fig. 3). The aim was to complete the data produced by Martina Marano's research on the reconstruction of the phases of the architectural complex from the Late Republican period to Late Antiquity.

The topographical survey presented several challenges and required careful consideration of the techniques to be used. Due to the limited time available for the survey, the extensive surface of almost 1,200m² and the planimetric complexity of the site, as well as the height of some of the walls, it was not possible to rely solely on a terrestrial laser scanner (TLS). To cover the entire area and produce high-quality orthophotos of the buildings and some elevations, we combined photogrammetric UAS surveys with TLS. This approach is at present very widespread since it offers several advantages, including the ability to survey areas inaccessible to TLS and to obtain a superior quality of the textures used in the final 3D model and

Figure 3 - Ostia, general view of block V, III (Google Earth base map, orthophoto from A. Peeters).

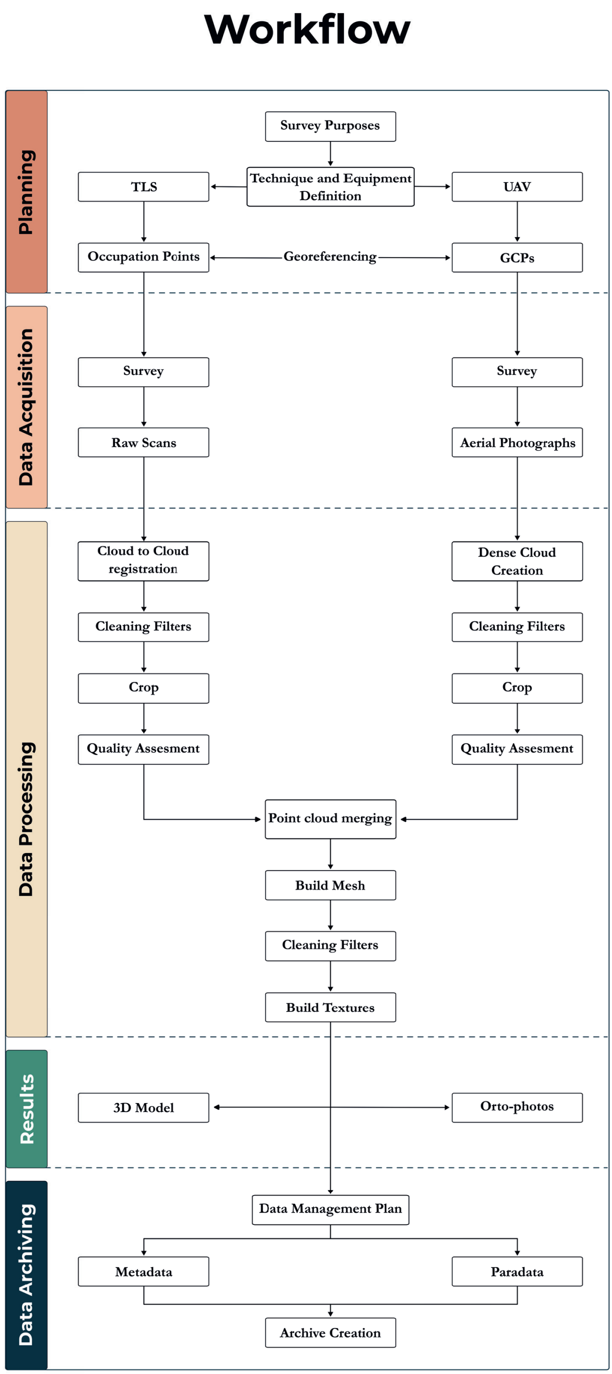

Figure 4 - General workflow (adapted from Chatzistamatis et al. 2018, 145).

orthophotos, particularly for the elevations. However, using both technologies also results in a longer survey phase; to better plan the field operations, we drew on many studies published in recent years on methods to merge the data produced by these two technologies (Chatzistamatis et al. 2018; Kompoti et al. 2023; Chandler and Buckley 2016; Jo and Hong 2019; Dawn and Biswas 2019; Angelini 2013).

The survey operations were limited due to constraints imposed by the Ostia Archaeological Park, such as the presence of visitors, and the proximity of the Roma Fiumicino airport. Surveys were only conducted on Mondays when the park was closed and at a maximal altitude of 25m a.g.l. The south-eastern part of the complex was exclusively surveyed using UAS, providing an overall view of block V, III with two levels of accuracy while respecting time constraints. The use of drones for photogrammetric surveying provides a faster alternative to ground-based TLS, albeit with reduced accuracy (Chandler and Buckley 2016).

The general workflow of the field operations (Fig. 4) includes survey planning for TLS (location and number of stations) and UAS (flight plan and location of GCPs), data acquisition, and data processing, final model production and data archiving.

Figure 5 - Ground Control Points (GCP) located in block V, III (Google Earth base map, orthophoto from A. Peeters).

The first step was to establish and georeference the ground control points (GCPs), to be used for both surveys to ensure a seamless integration of the point clouds produced by the TLS and the UAS. A total of forty-eight markers within and around the block, along four main northeast-southeast lines were placed (Fig. 5). As far as possible, at least one marker in each room of the architectural complex was placed. Markers were also placed on certain walls' ridges to correct vertical errors. The markers were georeferenced in the reference system of the archaeological park, Monte Mario/Italy Zone 2 (EPSG:3004), using a Topcon HiPer HR GNSS rover, paired with a Topcon HiPer HR base that was located on the park's topographic benchmark of the *Fullonica* at the intersection of *Via degli Augustali* and *Via della Fortuna Annonaria*.

TLS

The TLS Topcon GLS-2200 laser scanner was used for the *Caseggiato dei Lottatori* due to its topographical approach. For each scan, a station is set up at a specific point (Occupation Point) and its coordinates are checked by measuring the distance from another station (Backsight Point). In this way, scans are natively georeferenced, which improves survey accuracy and simplifies operations when there are visual obstacles between each scan, as in the present case. Moreover, it is not essential to achieve the same degree of overlap as with a conventional TLS, which relies on markers and matching with surrounding scans for alignment (Ebolese, Lo Brutto, and Dardanelli 2019). To improve measurement accuracy, a stationary tripod with a 360° prism was positioned on a backsight point outside the building to avoid any unwanted elements within the scan. The tripod was only relocated when the prism was no longer visible

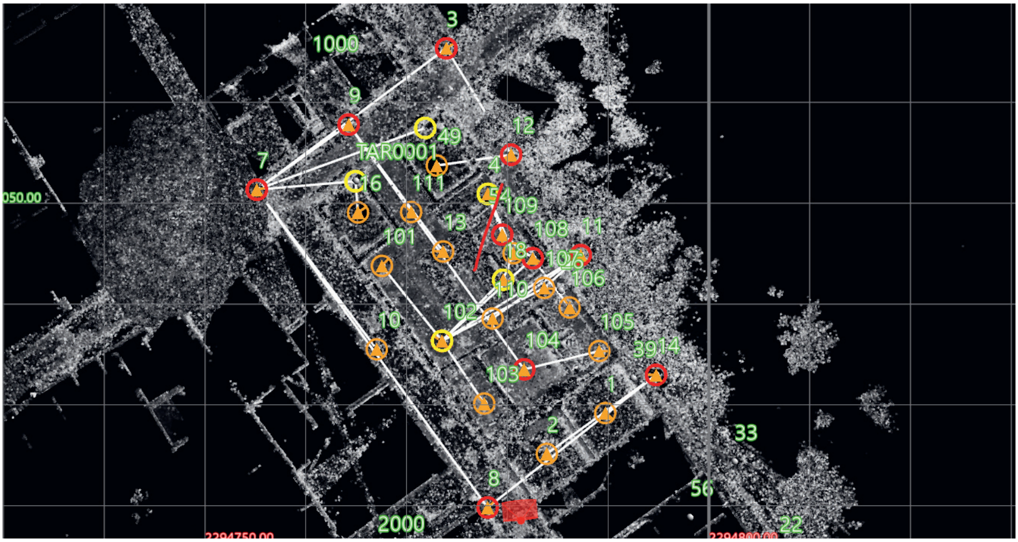

Figure 6 - Scanning stations inside and outside the Caseggiato dei Lottatori.

to the laser scanner. Although this method may result in slightly higher error than using a traverse, it allows faster surveying in the field.

Due to the complexity of the site, including its size, numerous obstacles, and small dimensions of certain spaces, we had to improve survey coverage of difficult areas by adding several minor scans. This required two days of TLS scanning. The first day was dedicated to the main scans, while the second day focused on more complex areas. In total, twenty-seven stations were established in and around the *Caseggiato* (Fig. 6). The scans were taken at a resolution of 3.1mm, at a distance of 10m, with a full-dome field of view (360° horizontal and 270° vertical). The resolution level was chosen based on the smallest element to be scanned, which in this case were the mosaic *tesserae* and the joints between them (Historic England 2018, 29-30).

Thanks to its active approach, TLS still has an advantage over photogrammetry in terms of accuracy. As Jim Chandler and Simon Buckley point out in a comparative study of the two techniques, "TLS offers advantages in terms of accuracy, repeatability and reliability, and can still be viewed as the 'gold standard' for 3D measurement" (Chandler, and Buckley 2016, 3). Many recent devices, including the model used in our study, incorporate HDR cameras to colourise the point cloud. However, the quality of these images is often average. To overcome this limitation, it is possible to merge the point cloud generated by a TLS with the texture produced by photogrammetry. This results in a significantly higher quality of the 3D model.

UAS

A DJI Mavic 3 device was used to acquire aerial photogrammetric data (Historic England 2017; Remondino et al. 2014; Bianco, Ciocca, and Marelli 2018) due to its affordability and ability to produce high-quality photos. The drone's weight of 895g, the 46-minute battery lifetime, the three-axis stabilised gimbal, and the high-quality 4/3 sensor camera with 20mpx and ND filter

Figure 7 - Flights plan of the UAV survey.

compatibility make it an ideal choice for photogrammetry. Additionally, a recent software update allows for semi-automated flight planning[1]. However, unlike other drones such as the DJI Matrice 300 or DJI Mavic 3 Enterprise RTK, this model does not have Real Time Kinematic (RTK) support for more accurate geolocation, which makes it essential to use GCPs distributed throughout the survey area to significantly reduce errors (Štroner et al. 2020; Forlani et al. 2018; Gerke and Przybilla 2016).

To reach the desired level of detail and quality, three flights were necessary to cover the entire area. The presence of obstacles such as vegetation and other buildings, as well as the size of certain rooms, made it impossible to obtain sufficient coverage using a conventional flight plan. Therefore, the following three flights were carried out (Fig. 7):

1. north-south and east-west grids at an altitude of 8m with a camera angle of approximately 45° to cover all the structures and their elevations;
2. north-south parallel lines, with a zenith viewing angle, to survey floors and wall bases;
3. a detailed survey of the external elevations and the smallest rooms, which required additional photos.

As a result, a total of 1116 images were taken to cover the entire area uniformly, for a total flight time of 75 minutes. For all three series, the camera had a fixed aperture of f/8 and an

[1] In comparison with other drones, this functionality is limited. The manufacturer only allows automated waypoint-based flight through their application. Tools such as WaypointMap (https://www.waypointmap.com/, last access on 12.07.2024) have been developed to overcome this limitation.

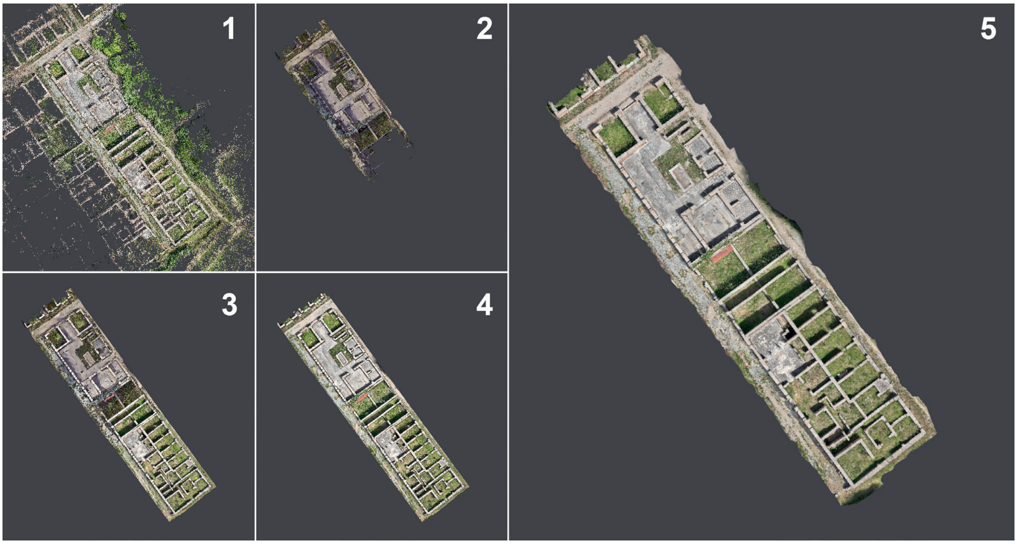

Figure 8 - The different steps in data processing and merging: (1) Photogrammetry image alignment; (2) TLS dense cloud; (3) Merging of TLS and photogrammetric dense clouds; (4) 3D Model; (5) Orthophoto.

ISO value of 100, while the shutter speed was variable, to ensure the best possible sharpness for all images. Thanks to these parameters and the flight altitude, a ground sample distance (GSD) of 2.8 mm per pixel was achieved.

Data Processing

The cloud points were firstly edited separately before being merged to create the final 3D model (Fig. 8). After transferring all the georeferenced scans from the TLS to the Magnet Collage software, the registration accuracy of each scan was checked using the Root Mean Square (RMS) value produced. To reduce the RMS value resulting from a significant vertical error, a cloud-to-cloud registration based on the Iterative Closest Point (ICP) algorithm was applied (Besl and McKay 1992; Rajendra et al. 2014). The lowest vertical error station was selected as the reference, resulting in an RMS resolution of 0.0162m. The 27 scans were exported in PLY format for cleaning operations using Cloud Compare software. The scans were manually cleaned to remove unwanted elements such as tripods and prisms placed on reference points, and they were merged into a point cloud containing over 427 million points. The number of points was reduced to 295 million points after cropping to the study area, refining the cleaning process by removing the last unnecessary elements such as surrounding vegetation, and applying the "duplicate point removal" and SOR (Statistical Outlier Removal) filters.

For the photogrammetric processing of the UAS photographs, Agisoft Metashape Pro software was used. This software can process various types of data, including aerial, satellite, multispectral, and thermal photographs, as well as TLS scans (since version 2.0) (Papoutsaki et al. 2023, 150). The images were aligned according to their GPS position recorded in their EXIF data, and a sparse point cloud of over 2 million tie points was generated, which were accurately positioned in the EPSG:3004 coordinate system using markers. A dense point cloud

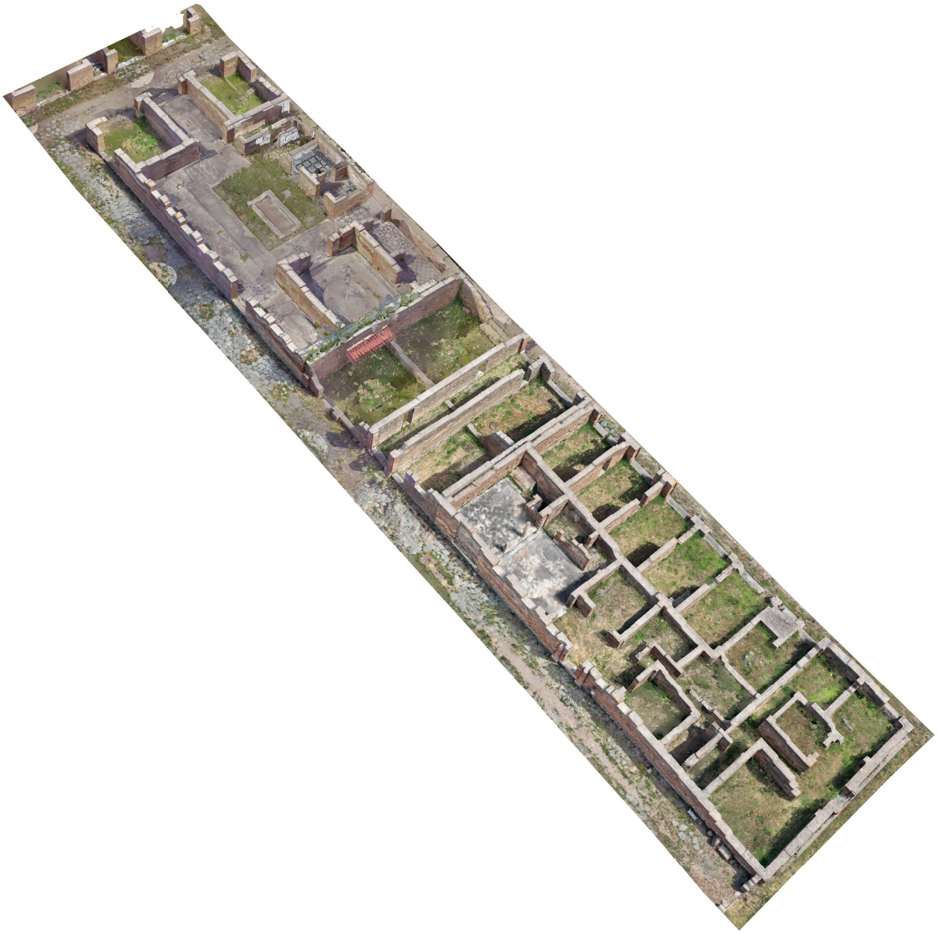

Figure 9 - The final 3D model of block V, III in Ostia.

of almost 76 million points was generated, which was then filtered and cleaned using Cloud Compare, resulting in 49 million points remaining.

The two cleaned point clouds from TLS and UAS were re-imported into Agisoft Metashape Pro and then merged to produce the 3D model (mesh) with a root mean square (RMS) error of 0.01m. The model was then textured using UAS photographs.

Results

The survey of block V, III in Ostia has resulted in a high-resolution, textured 3D model by combining TLS, UAS, and GNSS data (Fig. 9). It allows the export of detailed images and facilitates the acquisition of new data, particularly in terms of measurements. To analyse the various phases of the architectural complex and its modern restorations, which can

Figure 10 - Orthophoto block V, III in Ostia.

be distinguished using different materials, horizontal projections were also required. Agisoft Metashape was used to produce zenith orthophotographs (Fig. 10) and views of each external wall, correcting for any distortion caused by the photographic sensors. The high-quality and numerous photographs taken by the UAS from various angles enabled us to create high-definition orthophotographs. These images can be used in the future to produce plans of the different phases of the structures and their prospections.

Data Archiving

A fundamental step of the project was data archiving. Like any other form of data, the transfer and archiving of 3D models produced in archaeology must be considered. Currently, there are no European standards for the storage of this type of data, despite its widespread use in recent decades. This observation was already made in 2019 by the *consortium 3D SHS*, which includes TGIR Huma-Num, CINES and the Archéovision laboratory in Bordeaux: "dans le meilleur des cas, [les modèles 3D] sont sauvegardés sur les machines des chercheurs avec éventuellement un stockage supplémentaire, considéré comme plus sécurisé, sur un autre poste ou un autre support. À long terme, ces conditions ne sont pas satisfaisantes pour conserver ces données" (Dutailly et al. 2019, 29). Since the early 2000s, various international charters and recommendations have been promulgated to highlight the importance of protecting cultural and digital heritage, such as the UNESCO Charter on the Preservation of Digital Heritage[2] in 2003 (Denard 2012), the London Charter for the Computer-based Visualisation of Cultural Heritage[3] in 2009, and the Seville Principles[4] ratified by ICOMOS in 2017. The

[2] https://www.unesco.org/fr/legal-affairs/charter-preservation-digital-heritage, last access on 12.07.2024
[3] https://londoncharter.org/, last access on 12.07.2024
[4] https://icomos.es/wp-content/uploads/2020/06/Seville-Principles-IN-ES-FR.pdf, last access on 12.07.2024

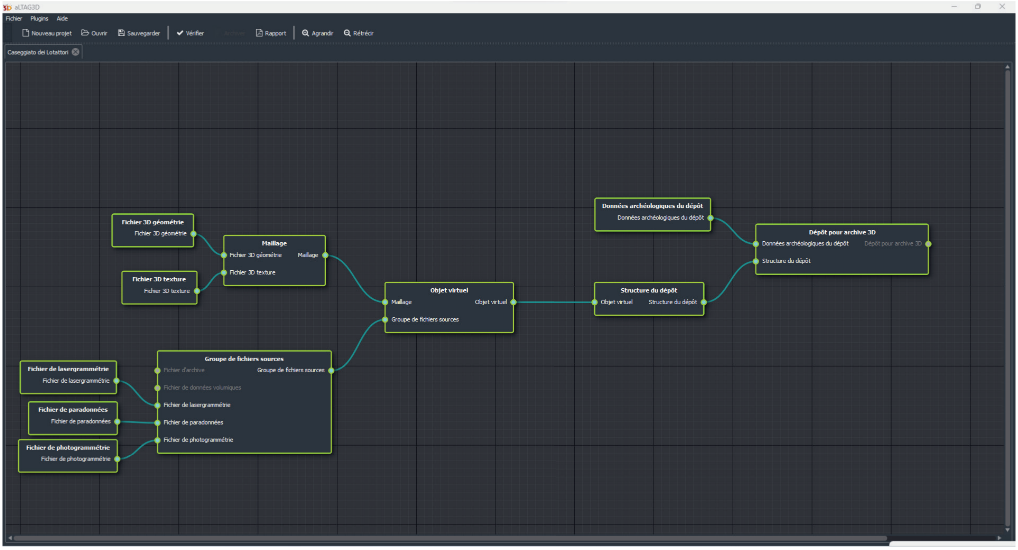

Figure 11 - Screenshot of the project archive created with aLTAG3D software.

latter, taking the London Charter as a reference, underlines eight fundamental principles for virtual archaeology, which include scientific transparency.

In recent years, two major research consortia have produced recommendations for archiving and documenting 3D models. The first consortium is the Archaeology Data Service (ADS), which has been providing advice on creating and managing digital data since 1996. In 2011, in collaboration with tDAR (the Digital Archaeological Record - Arizona State University), they published the third version of their *Guides to Good Practice*[5], which includes 3D data (McManamon et al. 2013). The text describes the metadata that should be included in the archive following the MIDAS standards (*A Manual and Data Standard for Monument Inventories*, The Forum on Information Standards in Heritage 2012). The metadata is divided into four main levels: Project-level, Resource-level, File-level, and administrative metadata. For 3D scans, additional data is provided for acquisition, registration, and mesh processing.

The *Consortium 3D SHS*, which has been renamed *Consortium 3DHN* since 2023, is the second main research institution to address the issue. Since the launch in 2014, its objectives have included drafting recommendations and guides for the use of 3D data in the human and social sciences, particularly in archaeology. In 2019, it published recommendations about "l'archivage pérenne des modèles numériques 3D pour les SHS" (Dutailly et al. 2019). Based on previous research, including that of ADS, the authors outline optimal techniques for archiving 3D models, from creating a management plan to writing metadata and using open file formats. The authors propose a more concise schema for metadata than the one by ADS, which allows a greater flexibility in project management. Additionally, they have developed a software, called *aLTAG3D*[6], which provides a visual interface for encoding metadata, automatically extracting

[5] https://archaeologydataservice.ac.uk/help-guidance/guides-to-good-practice/ (online version, last access on 12.07.2024).
[6] Open-source software available from: https://altag3d.huma-num.fr/ (last access on 12.07.2024).

certain information from files, and for creating the archive. These recommendations and this software were used to create a comprehensive archive of our project, ensuring that the files will be preserved for an extended period.

After creating the project in the aLTAG3D software, site and project information were encoded (Fig. 11). The source files, which include TLS scans in PLY format and photos taken by UAS in JPG format, were imported along with the relevant technical data. The paradata, which outlines the overall process, was also included in a pdf file. The latter contains the reports from Agisoft Metashape and Magnet Collage, along with a detailed explanation of the cleaning filters that were applied. The final 3D model and its associated texture file were then inserted into the software, which exported the final archive in ZIP format. The archive includes all the source and result files produced, as well as metadata (.xml) and paradata (.pdf). Multiple copies of this archive have been saved to ensure its preservation.

Conclusion

The 3D model created for this project is an essential research tool for the future. It not only preserves a digital record of this architectural complex at a specific moment, which is essential for its proper conservation over time, but also provides a 3D scientific illustration for Martina Marano's publication and offers a collection of unpublished data for a better understanding of the phases of Ostia's Block V, III, from the Late-Republican period to Late Antiquity.

This case study illustrates the rapid implementation of a survey using TLS and UAS photogrammetry, which is nowadays possible thanks to a greater availability and easier utilisation of those high-performance tools and techniques. However, specific training is required, along with the ability to adapt to any situation, to find solutions to problems that arise during the survey. This was also true for this project, where the need for a high-resolution survey had to be balanced with time, logistical, and administrative constraints, as well as obstacles in the surrounding area and the limited size of certain rooms.

This case study allows us to identify the advantages and disadvantages of the two employed techniques. In terms of measurement accuracy, TLS still has a significant advantage (Chandler and Buckley 2016, 3). It is increasingly used in archaeology, despite its unattractive price. Using a topographic TLS is also advantageous in terms of processing, as the point clouds are directly georeferenced and require only minor cleaning and optimisation filters. On the other hand, UAS and photogrammetry are now widely used in archaeology thanks to their affordability and ease of use. The technique is also becoming more professional, with the introduction of protocols that make the survey more accurate and reproducible. As this case study shows, UAS photogrammetry also has an undeniable advantage when it comes to the speed of acquisition and the image quality. However, it requires longer processing times after the survey. Therefore, if the study's aim is to achieve a high accuracy and high-quality texture result, and if the resources (i.e. financial and time) allow it, the combination of the two techniques seems to offer a real added value.

Finally, this 3D survey could be at the centre of a future broader project to promote and communicate this important site at the heart of the Ostia Archaeological Park. In recent years, 3D models and reconstructions have proven useful for communicating new information to visitors (Gonizzi Barsanti et al. 2015; Loaiza Carvajal, Morita, and Bilmes 2020; Keumoe and Blot 2023; Wachowiak and Karas 2009). Furthermore, the increasing number of applications using virtual or augmented reality demonstrates the interest of these immersive solutions for a wide audience. While digital documentation cannot replace the archaeological object, it can provide complementary solutions for its preservation, promotion and study.

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