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FROM PENCIL TO POINT CLOUD: A METHODOLOGICAL PROPOSAL FOR THE TOPOGRAPHIC STUDY OF THE SO-CALLED VILLA OF BRUTUS IN TIVOLI (ROME)

1. Introduction

The aim of this study is to present the methodology employed in the topographic work conducted during the first archaeological campaign of the Brutus Villa Project, led by the Pablo de Olavide University in Seville. The Brutus Villa Project was developed within the framework of a PhD study, focusing on the pre-existing nucleus beneath Hadrian's Villa and its contextualization within the phenomenon of Tiburtine *villae* of *otium*. The doctoral thesis project, entitled *Villa Adriana before Hadrian. Archaeological Analysis of the 'Republican Villa' in the Context of Italic Villae of Otium*, aims to contextualize the various cases documented within the Tiburtine territory through the integration of new research tools and methodologies, primarily focused on the constructive and architectural analysis of the monument (Algaba Torrealba 2024, 2025a). In this way, preliminary inspections carried out between 2023 and 2024, within the framework of the aforementioned doctoral thesis project, made it possible to ascertain the archaeological significance of the site known as the Villa of Brutus, as well as the research potential it offers. Consequently, the development of a comprehensive archaeological project focused on this imposing site became a scientific necessity, while also providing an opportunity to contribute a substantial body of new data on this sector of Latium during the Roman period.

Territorially, we are located in Tibur, the modern-day town of Tivoli, about 30 km from E of Rome. This area is significant due to a number of key elements, such as the construction of the sanctuary of Hercules, the Tiburtina-Valeria road, Hadrian's Villa, and the remarkable phenomenon of late Republican leisure villas. Moreover, the territory offered abundant natural resources and a highly reliable water supply, ensured by four of the most important Roman aqueducts, factors that undoubtedly influenced both architecture and the landscape (Tombrägel 2012; Notarian 2024).

From a lower geographical scale, the Villa of Brutus is situated at the well-known Curva del Regreso, between the ancient via Cassiana and the modern Strada Statale 5 via Tiburtina Valeria, approximately 1.5 km from Hadrian's Villa. The so-called Villa of Brutus is a significant Roman-era residential complex associated with the well-documented phenomenon of late Republican *otium* villas, which occupied a considerable portion of the Tiburtine region (Giuliani 1965; Tomei 1988, 1999; Tombrägel 2012).

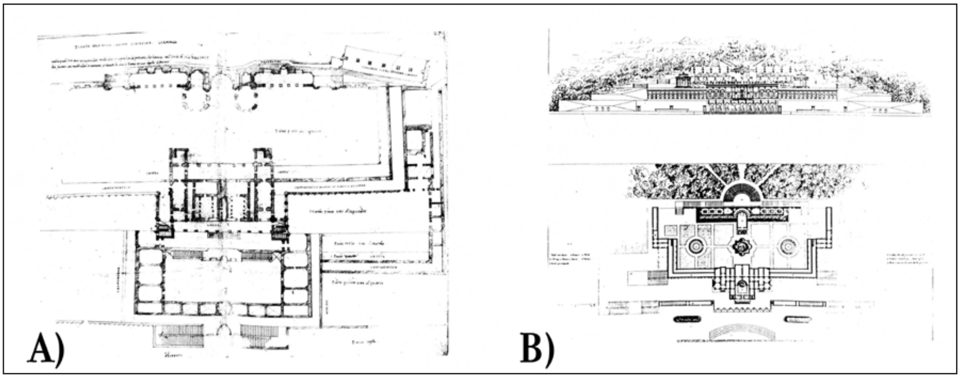

Fig. 1 – A) Plan of Pirro Ligorio; B) plan of Luigi Rossini (from Ranaldi 2001).

The interest in this monument dates back to the 16th century, when Pirro Ligorio produced the plan of the Villa Caiana Tiburtina Germanica. This work served as the basis for the ideal architectural interpretation made by Luigi Rossini in 1826 of the so-called Villa of Cassius. Similarly, Albert Christoph Dies produced engravings of the structures in 1794. In 1876, James Parker photographed parts of the villa, focusing particularly on the cistern located on the upper terrace (Fig. 1).

The debate over the ownership of the complex, between Cassius and Brutus, has been a prominent issue in 19th-century archaeological scholarship, with the original toponym of the villa being determined, without any scientific criteria, as belonging to Brutus (Pietrangeli 1951). Arguably, Norman Neuerburg (1965, 1968) is responsible for the most significant scholarly contribution to date on this complex. According to this author, the Villa of Brutus represents the most important example of a villa of *otium* in the *ager Tiburtinus*, second only to Hadrian's Villa.

Zaccaria Mari (1991) devoted several lines to this residential complex in his study of this sector of the ager Tiburtinus within the Forma Italiae series. Some years later, he produced a plan based primarily on earlier topographical works (Ligorio and Rossini), which nonetheless remains far removed from the archaeological reality (Mari 2015). Finally, Martin Tombrägel (2012), whose work represents the most recent study on the issue of Tiburtine villas, notes that he was unfortunately unable to carry out an in-depth analysis, despite the fact that this is one of the most significant complexes in the Tiburtine territory.

Thus, less than 30 km from Rome and as late as 2025, a complex of primary archaeological and architectural importance still lacked a study commensurate with the significance of the site, one capable of updating the

Fig. 2 – Post-processed point cloud without olive grove (elab. Authors).

limited body of available information, largely philological in nature, and of producing a topographic documentation that would not only allow for a proper understanding of the monument, but also contribute to its preservation, in coordination with the relevant institutions, by generating an accurate record of its state of conservation at the time the topographic survey was carried out.

2. Initial fieldwork season of the Brutus Villa Project

During the first archaeological campaign, carried out in February 2025, the research focused on the analysis of the southern sector of the archaeological site. Particular attention was devoted to the topographical and architectural documentation of the monument, using a Hi-Target ZTS-320R total station, a Leica RTC 360 laser scanner, a Leica Zeno FLX100 Plus GNSS antenna, a DJI Mini 3 Pro drone, and a Canon EOS 77D camera. In parallel, geophysical surveys were conducted. Their results, together with their integration with the data presented here (Dabas *et al.* 2018; Ronchi *et al.* 2023), are currently being prepared for publication.

Accordingly, this initial phase of the study was characterised by the application of non-invasive methodologies aimed at generating a comprehensive topographical database, conceived as a framework for future research, conservation, and valorization activities.

2.1 *Methodology*

From the outset, the specific characteristics of the site have conditioned both the selection of the available instrumentation and the methodological

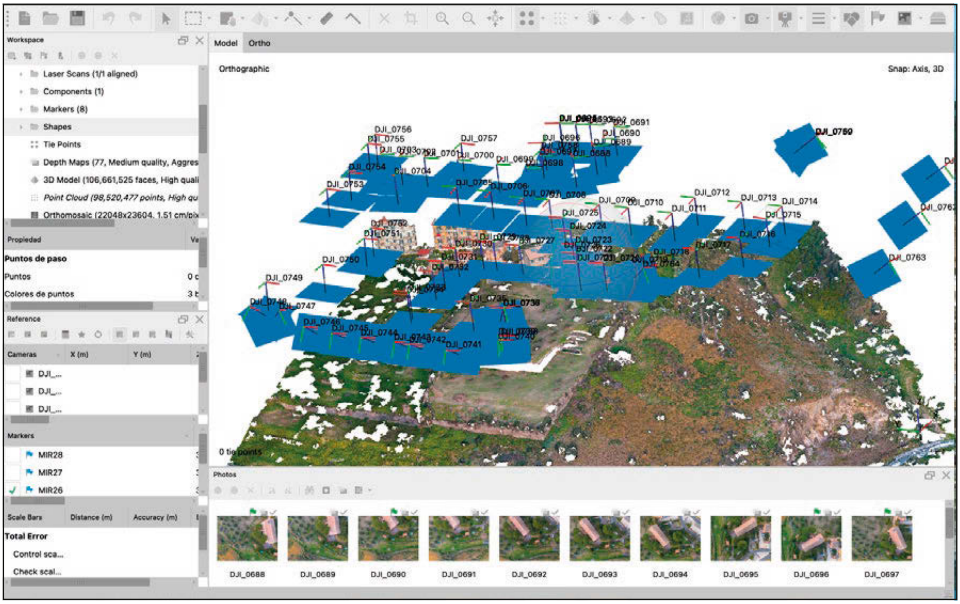

Fig. 3 – Creation of the point cloud from drone flight and processing in Agisoft Metashape (elab. Authors).

approach adopted. The Villa of Brutus is characterised by a pronounced altimetric gradient, with a vertical difference exceeding 30 m, a considerable spatial extent (approximately 30,000 m² in its final overall development, a substantial portion of which corresponds to hypogean spaces), the coexistence of significant subterranean structures with extensive open-air areas, monumental façades with marked vertical development, limited GPS connectivity, and a dense cover of vegetation and woodland, among other factors (Fig. 2). In this context, the topographical survey was conceived as an integrated process, aimed at combining heterogeneous datasets within a shared reference framework, with the objective of establishing a topographical database. This was intended as an essential tool for a long-term research project, designed to ensure methodological coherence and continuity of work over time.

The common reference framework adopted for the integration of the different types of data is the X, Y, Z coordinate system. To this end, a closed polygonal network consisting of eight points was materialised using a total station, forming the geometric and metric basis for all subsequent operations. With regard to the use of a GPS antenna, these fixed points were initially recorded within an absolute coordinate system. Subsequently, each point was observed from different stations, with a minimum of three control observations per point, in order to minimise potential instrumental and human errors. The values obtained by the total station were compared with those recorded by the GPS instrumentation, and numerical discrepancies were corrected through the calculation of a weighted average of the complete dataset. Consequently, the georeferencing system was based on the total station as the primary reference, with the corresponding translation and adjustment of the values obtained via GPS (KC *et al.* 2024).

The use of the drone has been essential for the territorial contextualization of the site, as well as for the generation of the overall volumes of the terraces and structures (Mongelli *et al.* 2017). In this regard, a photographic survey comprising 77 images was conducted in a single flight, with camera angles between 90° and 70°, allowing for the documentation of the site's diverse terrain features. In total, an area of approximately 110,000 m² was covered. Based on the photographs and the use of Agisoft Metashape software, a georeferenced point cloud was subsequently generated (Fig. 3).

This initial approach has been crucial in the large-scale topographical study of the villa. To facilitate subsequent calculations and actions, as well as to avoid errors arising from misinterpretation of the software, a digital cleaning of the point cloud of the villa's terraces was carried out, removing trees that significantly distort the processing of values related to the Z axis (Fig. 2). This process has enabled the creation of a digital elevation model, essential for the understanding and study of an architectural complex built using a terraced system (Fig. 4).

In the case of the wall faces forming the exterior fronts of the terraces and given the importance of these structures for the architectural and constructional study of the monument, particular attention has been devoted to them. In these instances, a detailed photogrammetric model was produced using a photographic camera, whose final resolution allows for a result suitable for working at a much finer scale. The orthophoto generated from the drone flight achieves a resolution of 1 cm/pixel, while the model produced using the photographic camera allows for a resolution of 0.6 cm/pixel. This second process is, to say the least, fundamental for the study of a series of structures that, in most cases, exceed 6 m in height, and whose stratigraphy reveals the life and constructive peculiarities of the monument (Fig. 5).

As mentioned at the outset, the underground environments posed an additional challenge within the topographic and documentation process. In the case of photogrammetric recording, the absence of natural light in several spaces, where architectural elements of particular interest required high-resolution documentation, made the use of artificial illumination unavoidable. In this regard, previous studies have demonstrated that variations in lighting conditions can significantly affect the accuracy and stability of image-based 3D reconstructions, highlighting the need for homogeneous and constant

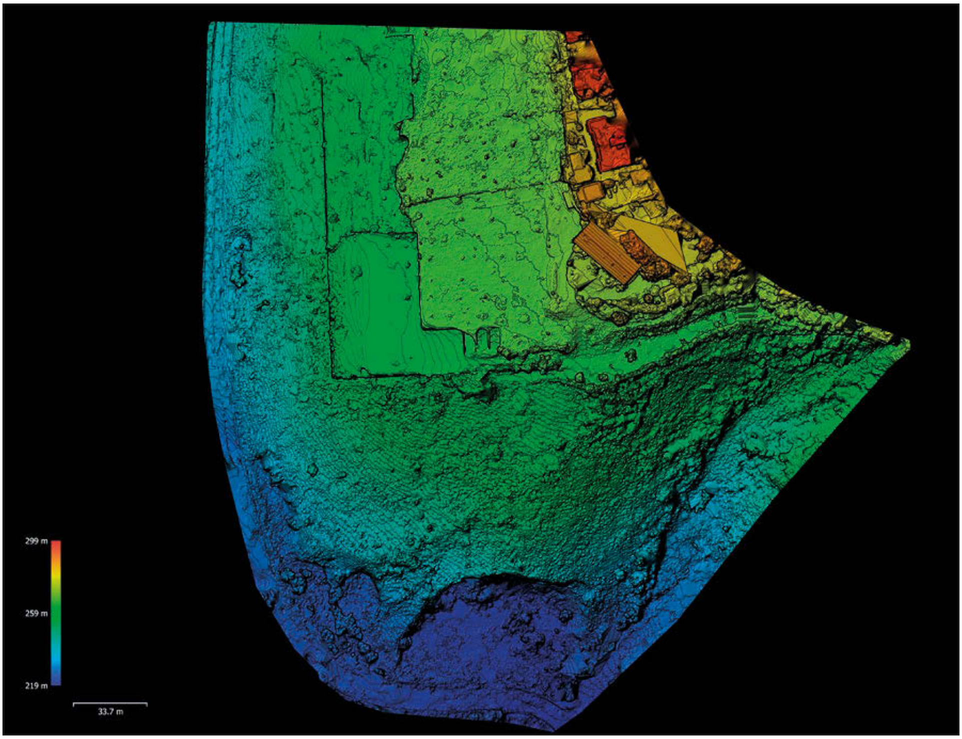

Fig. 4 – Digital Elevation Model (DEM) from the point cloud. Post-processed result after vegetation removal (elab. Authors).

Fig. 5 – Detailed orthophoto of the western terraced front (elab. Authors).

illumination during image acquisition (Bruno *et al.* 2021). Consequently, four fixed light sources of 10 W and 800 lumens each were employed throughout the entire photographic survey. The use of stable, non-variable artificial lighting was specifically intended to minimise inconsistencies in illumination and shadowing, which are known to negatively influence image alignment and dense point cloud generation within Structure-from-Motion workflows, such as those implemented in Agisoft Metashape.

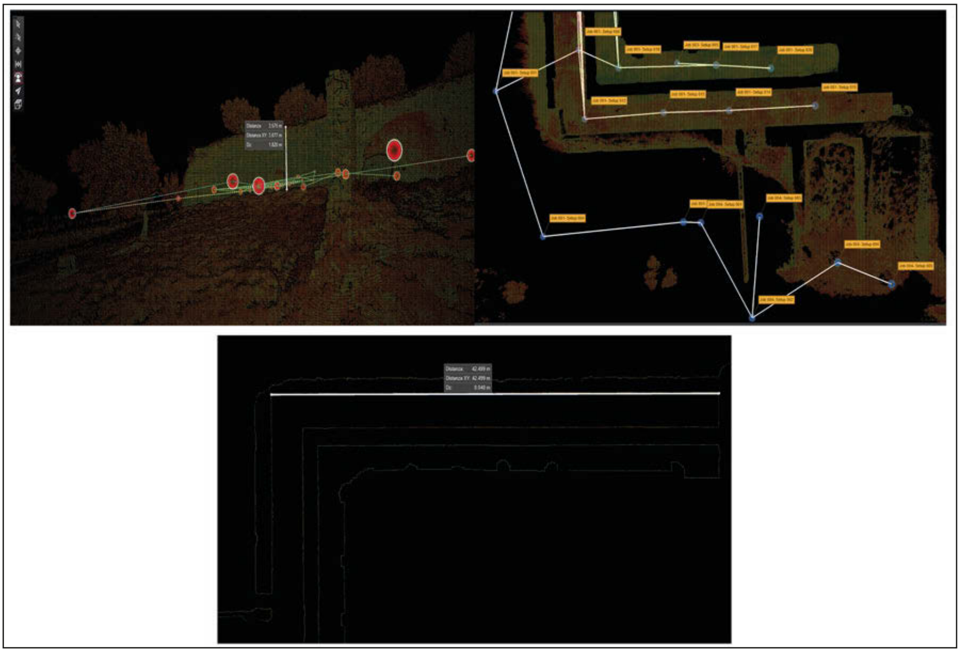

Fig. 6 – Processing in Cyclone Register 360 Plus of the point cloud generated from laser scans (elab. Authors).

With regard to the general planimetry of the structures, the initial phase was carried out using a total station. For this purpose, an ideal sectional plane was established at approximately 1.5 m above the current ground level. While its use in the exterior areas posed no issues and allowed for the production of a planimetric layout with millimetric precision, the use of this instrument in the internal galleries presented a series of challenges, as visibility between the selected station point and one of the polygonal points (backsight) was limited.

To correct the potential cumulative error in stations with limited orientation, laser scans of the internal spaces (*substructiones*) were carried out. Due to the size of the files generated by the laser scanner, post-processing was facilitated by dividing the scans into sectors and georeferencing each of them independently through the placement of markers. As in the case of photogrammetry, these markers were positioned directly on the structures and surveyed using a total station.

With regard to the number of scans, 6 laser scans were carried out in Gallery A, 3 in Gallery B, 7 in Gallery C, 3 in Gallery D, 5 in Gallery E, and 4 in Gallery F. These, together with those performed in the exterior areas, amount to a total of 42 laser scans conducted during this first archaeological

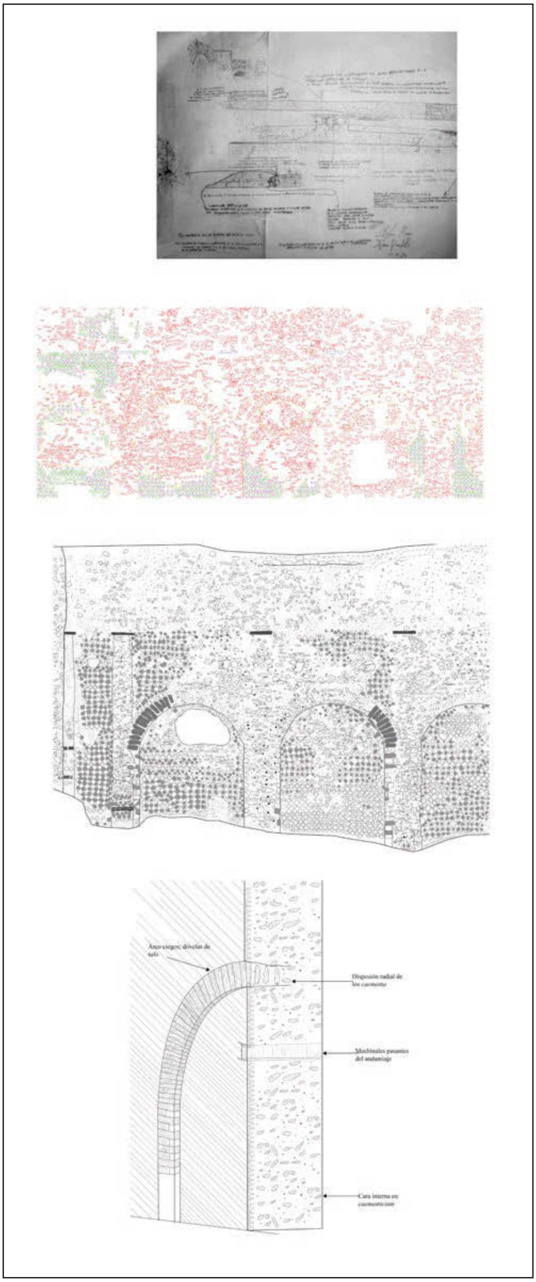

Fig. 7 – Drawing process: hand drawing in the field, sectorisation process, and architectural and constructive reconstruction (elab. Authors).

survey campaign (Fig. 6). Throughout the entire scanning process, the instrument was configured to operate with a low point density. With regard to the innermost spaces, which were in complete darkness, the instrument was unable to provide orientative texture to the points, as the images captured during the scanning process were not suitable for the colorization of the point cloud. However, this does not affect the topographic accuracy of the generated point cloud, which appears monochromatic. The alignment error of the point clouds, prior to their georeferencing within our overall topographic work, is below an average of 2 mm. Likewise, the use of the laser scanner has made it possible to incorporate 3D recording into the study of the vaulted galleries, whose analysis through 2D representation alone would have resulted in a significant gap in our understanding of the complex.

In parallel, the process of documentation and topographic analysis based on high-precision technologies was accompanied by hand drawing, conceived not as a subsidiary practice but as a fundamental tool for observation, critical comparison, and interpretation. Through simple field sketches, it was possible to illustrate and critically verify the vast amount of metric information generated – millions of points whose restitution requires complex and meticulous post-processing procedures – thereby reintroducing into the survey process an analytical dimension that is difficult to replace through automated workflows alone. It should not be forgotten that, although one of the main objectives of this initial phase of the project is the production of high-precision mapping, this goal is inseparable from the need to construct an analytical narrative of the monument. In this sense, technology provides a high degree of metric accuracy, but not understanding; the latter remains the outcome of an intellectual process that necessarily resides with the archaeologist as an interpretative agent (Fig. 7) (Vitti 2015, 2016; Giuliani 2017).

3. Postproduction and laboratory work

One of the most significant outcomes following the generation of a point cloud is the creation of a detailed digital elevation model (DEM) of the area surrounding the villa (Fig. 4). This is particularly crucial when considering the issues and limitations associated with the use of publicly available LiDAR data in Italy (García Sánchez 2018). The contour lines, represented at intervals of 0.5 m of elevation, provide a clearer graphical understanding of a terrain and a complex characterised by significant changes in elevation. In this regard, the prior processing of the point cloud has been essential to prevent the presence of the 17th-century olive grove from distorting the topographic reading of the ancient terraces. To achieve this, we selected and digitally removed the points corresponding to the olive trees from the point cloud. In this way, we are able to correct the distortions caused by these vertical elements in the DEM. The

Fig. 8 – Integration of drone and laser scanner point clouds within the Brutus Villa Project: top, isolated *substructiones*; bottom, *substructiones* integrated within the entire complex through drone survey plan of the ongoing work carried out during the first archaeological campaign of the Brutus Villa Project (elab. Authors).

RGB representation of these data clearly highlights the existence of different artificial terraces, even in areas where the current vegetation hinders their individualization.

Another key aspect in the processing of topographical data has been the integration of laser scans into the point cloud generated photogrammetrically. The alignment of the 43 scans, conducted in sectors, was carried out using Cyclone Register 360 Plus software, with a total error of less than 2 mm. Given the limitations of this software, the point cloud was processed in CloudCompare using a PTS file, and through georeferencing, it was incorporated into the general point cloud in Agisoft Metashape (Fig. 8) (Adembri *et al.* 2015).

This has been crucial in integrating internal and external spaces, whose volumes are difficult to represent in a 2D format. This process has enabled us to generate a 3D graphic representation of the complex, essential for understanding the system of substructures and creating an image that was previously non-existent in the many terraced complexes that make up the Tiburtine landscape (Fig. 8). Alongside the topographical survey conducted with the total station, an integration has been carried out using the 3D drone-laser scanner model. This has enabled the creation of a series of georeferenced sections at specific points of interest, such as the lower terracing lines, where work with the total station was hindered. The sections have been incorporated into the general plan thanks to their georeferencing and representation through vectors (Fig. 8).

A similar system was employed in areas where the presence of surface structures made the need for detailed archaeological representation evident. As previously mentioned in the methodology, the production of detailed georeferenced orthophotos enabled their integration into the general plan, likewise through their vector-based characterisation. In the case of the aqueduct located in Gallery C, the average coordinate precision is approximately 6.8 mm of error, indicating that the use of different surveying systems does not result in a higher error rate (Douglass *et al.* 2015).

A particularly important aspect of the post-processing phase was the production of orthophotogrammetric models of the interior spaces, conceived as the base upon which the analysis and interpretation of the monument could be developed. In an initial stage, the generation of these models from the coloured point cloud produced by the laser scanner resulted in heavily distorted and poorly readable outputs. This was primarily due to the limited quality of the colour information provided by the scanner's integrated camera, a limitation further exacerbated by the conditions under which the scans were acquired, namely in the absence of controlled artificial lighting and under strong contrasts of light and shadow or, in some cases, near-total darkness.

By contrast, a significantly higher graphic quality – allowing for more effective and reliable analytical work – was achieved through the generation

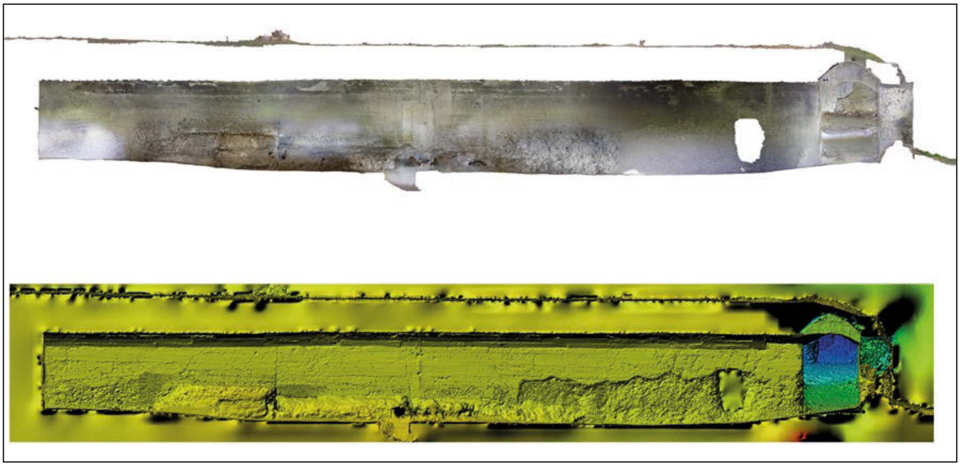

Fig. 9 – Generation of orthophotogrammetric models: top, model derived from the coloured point cloud; bottom, model generated from the Digital Elevation Model (DEM) (elab. Authors).

of orthophotogrammetric models derived from dedicated photogrammetric workflows and restituted in the form of Digital Elevation Models (DEM). These products provided a homogeneous and legible representation of the surfaces, thereby constituting an appropriate support for the detailed analysis and interpretation of the monument (Fig. 9).

Another important aspect of the post-processing phase involved the digitization of the traditional archaeological drawings produced in the field (Figs. 7-8). For this purpose, we relied on a base of high-resolution orthophotos onto which all features identified through archaeological analysis were drawn. This process is fundamental, as it provides the basis for the archaeological and architectural analysis of the monument (Vitti 2016).

4. From survey to knowledge

As stated from the outset, the primary objective of this project has been to advance the understanding of a monument that had, until now, largely remained outside the scope of scholarly research. The limited graphic documentation available prior to this study – consisting mainly of a sixteenth-century plan, a later nineteenth-century plan, and a small number of photographs dating to the mid-twentieth century – was insufficient to provide a clear or comprehensive understanding of the complex, as it illustrated only a few isolated portions of the monument.

In this way, the set of reflections and analyses developed during this first fieldwork campaign has made it possible to achieve a detailed understanding of the southern sector of the complex from a topographical perspective, with a millimetric level of precision, while seeking to maintain a comparable scale of detail in terms of comprehension and interpretation. In spatial terms, the area investigated covers approximately 10,000 m², out of a minimum total extent estimated at around 30,000 m².

From a strictly archaeological perspective, the existence of at least two major architectural projects has been corroborated. The first corresponds to the original *basis villae*, of which it has been possible to document, during the present phase of research, an area of 997 m², associated with the substantial retaining wall and its system of buttresses. The use of *opus incertum* masonry built with limestone rubble, together with the construction logic and technologies associated with these structures, plausibly places the origin of the Villa of Brutus within a chronological horizon spanning the late 2nd century BCE to the early 1st century BCE (Algaba Torrealba 2025a).

In a phase subsequent to the one only preliminarily analysed here, the entire complex underwent a profound and radical transformation, marked by a second architectural project of an ambitious and innovative character. The new construction reflects a fundamental shift on the part of the builders in the way the project was conceived and materialised. The principal objective of this second-phase architectural programme was the expansion of the earlier *basis villae* through the creation of new terraced substructures. To this end, the new *platea* enveloped the preceding terrace along its southern, western, and northern sides, through the systematic application of a substructural system of *concamerationes*. The western façade of this system presented an imposing architectural front which monumentalised the intermediate terrace of the complex by means of blind arches, semi-columns, and a centrally aligned nymphaeum.

The use of bichrome *opus reticulatum*, the construction techniques employed in the vaulting, and the advanced level reached by the technological building solutions all support the hypothesis that the expansion of the original villa took place between the final decades of the Late Republican period and the early Augustan age (Algaba Torrealba 2025a).

5. Conclusions

The topographical surveys carried out during the first fieldwork campaign of the Brutus Villa Project have enabled the production of a planimetric representation of the complex with a level of technical precision and reliability previously unattained at the site. In this way, the present study contributes for the first time to the development of a fully archaeological investigation, overcoming the long-standing tradition of predominantly philological approaches that had characterised research on the complex from the sixteenth century to the present day.

Fig. 10 – Workflow for the creation of immersive 3D reconstructions derived from prior topographical surveys (elab. Authors and EDUCA360).

In this regard, it was considered appropriate to develop a study aimed at systematically detailing both the documentation process and the methodology applied in the topographical survey. However, this work is structured around two fundamental questions – the how and the why – with the explicit intention of distancing itself from a merely documentary approach, which has become increasingly common in certain currents of contemporary archaeology.

For this reason, an effort has been made to deliberately move away from an understanding of method as an end in itself, without overlooking the fundamental importance of precision and accuracy inherent to the topographical discipline. In this sense, the work carried out does not seek to disregard traditional forms of reflection and interpretation – such as drawing – in favour of the exclusive use of point clouds, which, while essential for ensuring the metric accuracy of a structural intervention, may in certain cases contribute little to the archaeological and architectural understanding of a monument.

Likewise, the methodology adopted, which places the point cloud as the central database, makes it possible to analyse the building from a three-dimensional perspective, an approach that is essential for understanding the technical and constructive complexities embodied in this monument. Accordingly, this study does not privilege one method over another, but instead promotes the effective integration of all available approaches, attributing equal importance to digital tools and traditional drawing, provided that both are driven by a genuine process of comprehension.

It should be borne in mind that, despite the high level of technical precision achieved through the instrumentation employed, the dating of this complex – like that of a substantial part of Roman architecture – relies on positivist frameworks formulated in the mid-twentieth century (Lugli 1957), which cannot be conclusively corroborated or refuted until stratigraphic excavations are carried out in the near future. Likewise, the case study analysed – beyond Villa Adriana, which represents a landmark in every respect – constitutes the first example of an archaeological analysis carried out using modern methodology and instrumentation within the important system of villae of *otium* in the Tiburtine hinterland (Mari 2003). This approach will make it possible to investigate more closely the dynamics and defining characteristics of this phenomenon.

As a result of this process of inquiry, prompted by the complexity of the monument, a collaborative framework was established with other actors, including the graphic design and virtual reconstruction company EDUCA360 (Fig. 10). Throughout the process described above, this collaboration made it possible to work within virtual environments, in this case focusing on one of the constructive processes associated with the second phase of the complex. In this way, a genuine experimental laboratory was created in which these issues could be explored and tested, working with volumes, spatial relationships, and light-fundamental architectural concepts that are sometimes overlooked in strictly technical documentation and analytical workflows (Algaba Torrealba 2025b).

It should be noted that, although the data presented here are particularly valuable – as this represents the first modern analysis, beyond Hadrian's Villa, of a monumental villa in the Tiburtine countryside – this contribution was conceived primarily as a methodological article, focusing on the analytical approach and on the results of the first survey campaign conducted in a single southern sector of the site. This work has not only made it possible to establish a methodological framework for approaching the study of this complex, but has also enabled a direct engagement with the monument itself, allowing the identification of different construction techniques and the modus operandi of its builders, as well as the recognition of at least two major architectural projects. For the study of other parts of the complex, as well as for more strictly constructive aspects or issues related to the history of architecture, the reader is referred to future publications currently in preparation.

From the perspective of conservation and heritage protection, our study is fundamental for the future of the site, as the technical precision of the instruments employed, together with the adopted methodology, enables a comprehensive understanding of the building's condition at the time of analysis. In this way, our work contributes to the monitoring of the building, preserving and documenting it, thereby collaborating with public administration and raising awareness of a monument of significant importance in the territory, thus contributing to society. Although our analysis has focused on the southern sector of the villa, we hope that future campaigns will encompass the entire complex.

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ABSTRACT

Despite its proximity to Rome and its historical and cultural significance, Tivoli remains largely unknown in many respects. In this regard, the close association with Hadrian's Villa and the prominent role this site has played in the development of archaeology have contributed to obscuring one of the most characteristic phenomena of the Tiburtine countryside in antiquity: the *villae* of *otium*. With this in mind, the Universidad Pablo de Olavide has launched a new archaeological project aimed at highlighting one of the most significant residential architectural complexes in the *suburbium* of Rome during the Late Republican period. Given the absence of a modern plan of the site, the first phase of the project has focused on producing a topographic survey and an architectural analysis that combine cutting-edge methods with the clarity and effectiveness of traditional analogue systems.