

## VILLA ADRIANA IN TIVOLI : A METHOD OF SURVEY FOR ARCHAEOLOGICAL HERITAGE

P.Clini, F.Fiori, N.Sciarra

DARDUS, Politecnico University of Marche, via Brecce Bianche, 60131 Ancona, Italy  
([p.clini@univpm.it](mailto:p.clini@univpm.it), [federica.fiori@univpm.it](mailto:federica.fiori@univpm.it))

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### ABSTRACT:

The complex of Villa Adriana at Tivoli is an outstanding archaeological site for its extension and articulation as well as for its state of conservation and originality. It is a sort of synthesis of the Roman genius for construction, providing an interesting review of all typological and construction techniques, from the villa to the theatre, the amphitheatre and the baths. Villa Adriana continues to intrigue and fascinate the scholars analysing its complex functional plan and to challenge the designers called upon to devise preservation works or to plan functional spaces and structures for tourist reception and management.

Either operation requires the study, survey and representation of structures and remains. The survey of complex structures like archaeological constructions is performed with techniques based on the integrated use of 3D Laser Scanning, photogrammetry and 3D modeling techniques and photorealistic rendering. These tools allow to obtain complex models that correctly represent the various elements that can then be used for the representation of objects, also with popularization purposes. The models will thus be virtual databases providing for easy consultation by any type of user. Since the diffusion of the information regarding this site for tourist purposes cannot but pass also through the Web, the most effective communication tool of our time, the material has been developed and organized for Web diffusion with a view to granting access to the virtual tourist to a reality of 3D scenarios and models that provide a highly realistic synthesis.

### INTRODUCTION

"I felt responsible for the beauty of the world" wrote Hadrian. This statement finds an exceptional confirmation in his Villa. With its 120 hectares, it is the largest Villa ever to belong to a Roman emperor but also the most complex and the least known, despite the fact that it has been excavated for more than 500 years. Researchers are still discovering its secrets and beauties while excavating and studying its complex plan and the wild variety of its architectural elements. Walking through Villa Adriana is like leafing through a manual of Roman architecture and at the same time examining the object collection of an emperor who travelled widely and accumulated cherished souvenirs in his favourite place. Villa Adriana is Hadrian, his culture, his passions, his travels and his empire, whose reflection materialises in its buildings. Therefore the site also contains several construction typologies inspired by other civilizations, like the Greek and the Egyptian. "I had given each of those buildings a name evoking Greece: the *Pecile*, the Academy, the *Pritaneo*. I well knew that that narrow valley interspersed with olive trees was not the *Tempe*, but I had reached an age where no beautiful site does not remind one of another ...." (The Memoirs of Hadrian, M. Yourcenar). Besides being Hadrian's manifesto, Villa Adriana has constituted over the centuries an inspirational model for Baroque architecture, for its highly scenographic landscape. Villa Adriana thus continues to intrigue and fascinate the scholars analysing its complex functional plan and to challenge the designers called upon to devise preservation works or to plan functional spaces and structures for tourist reception and management. The protection and valorisation of an ancient monument that has no equals in the history of architecture require its profound knowledge and communication



Figure 1. Plastic model of Villa Adriana in Tivoli

An architectural project in an archaeological area cannot but be based on the thorough exploration of the extant structures. The ruins, by their very loss of form and materials characteristics, are exceptionally difficult to represent, any representation being necessarily confined to their volumetric essence; the result of any project respecting the original structures is thus necessarily a highly incomplete one. 3D laser scanning surveys solve these problems, providing for rapid collection of detailed information and offering immediate and effective data that are well suited to the designer's requirements. In addition, these representations can be used to acquire precise and accurate measurements in a very short time compared with traditional architectural and archaeological surveys, and can be used without further processing. The aim of this study was to obtain 3D and 2D technical representations for use in scientific work and as aids

in protection and recovery projects that would also be suitable for web diffusion to a wide public. The shared goal of those who are involved in valorising our cultural heritage and making it known to the general public is to make this immense wealth available via virtual visits that, though certainly not replacing the emotional impact of an actual visit, nonetheless allow viewers to gain greater knowledge and awareness.

## 1. “TEATRO MARITTIMO” IN VILLA ADRIANA

One of the most interesting architectural elements of Villa Adriana is without any doubt the so-called. “Teatro Marittimo” “...in the heart of that retreat I had an even more hidden refuge built, a small marble isle surrounded by columns, a secret room with a revolving bridge, so light that it can be moved with a single hand, it unites the shore, or rather, segregates one from it. I had two or three statues I loved moved to that pavilion, and that small bust of Augustus as a child that Suetonius gave me when we were friends; for the afternoon rest I would go there to sleep, think, read ...” The building was among the first to be constructed and stands right at the heart of the complex, in its barycentre, almost as a planimetric hinge. Its form suggests a miniature residence, a villa in the villa, with water all round, supported by Ionian columns and covered by a barrel vault.



Figure 2. Teatro Marittimo

Only traces of the elements that constituted it are extant, especially as regards the plan of the inner part, whereas its overall character and the originality of the plan can still be made out. The building was surveyed and appropriate forms of representation were studied. The work was performed in the afternoon of September 13<sup>th</sup> and the morning of the 14<sup>th</sup>, during the site’s opening hours, since the area is closed to the public, with the kind permission of the Monuments and Archaeological heritage Office of Latium. The team included Federica Fiori, Nicola Sciarra and Daniele Bartolucci, a technician with GEOTOP, the firm that has generously provided the Mensi GS200 instrument; Francesco Leoni performed a document and data search enabling survey planning.

## 2. THE SURVEY

### Method and Instrumentation

Data were acquired using a MENSİ GS-200 laser scanner, which surveys dense point meshes (3 mm x 3 mm at 100 m) at a

maximum rate of 5000 p/s and enables measurements at a range of 200 m, and up to 350 m in overscan mode. The motorised scanner allowed to acquire scans with 360°x60° view angle in a single session. The equipment also allows to render the real-time illuminance and RGB values of each point. Snapshots with a maximum resolution of 9 megapixels were acquired simultaneously with the survey. The manufacturer’s standard deviation values are shown in table 1.

Standard deviation						
Range (metre)	5	25	50	100	150	200
Typical values (millimetre)	1,4	1,4	1,4	2,5	3,6	6,5
Max. limit (millimetre)	3,0	3,0	3,0	4,0	6,0	10,0

Table 1. Standard deviation of GS200

Instrument setting and operation are managed via a notebook interface with a cable connection. We used the *Point Scope 3.1* Software (TRIMBLE) and a portable petrol-fuelled electric generator with 2-hour autonomy. Matching points rather than spherical targets were used for scan merging. The study object’s geometrical characteristics enabled acquisition of a limited number of scans. Each scan was supported by high-resolution photographs, required for subsequent management of the model, and of colour data. The complex of registered points, characterized by the signal return intensity of substrates, constitutes a digital 3D model that can be used for direct measurements, extraction of 2D deliverables, as well as for its highly descriptive value.

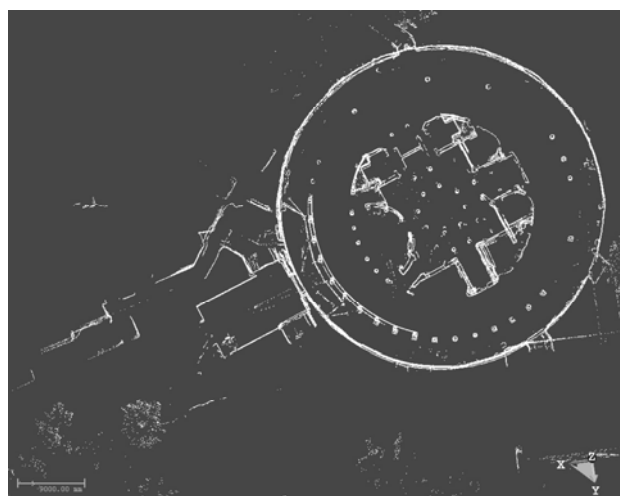


Figure 3. Horizontal section of points cloud

Given the circular plan of the structure, a 360° scan was acquired from a station at the centre of the building (station 11); further scans were subsequently obtained from stations outside the island. Given the structure’s complexity and the presence of innumerable curved shapes (ruins of walls, columns, the portico), including shadow cones, scans were acquired from 15 stations. We began from the first station outside the island (station 1) and then moved around it anticlockwise. Except in two cases (stations 8 and 11), where we acquired 360° scans, the field was narrowed to the area of interest. Two external scans were acquired from the main entrance (stations 7 and 8).

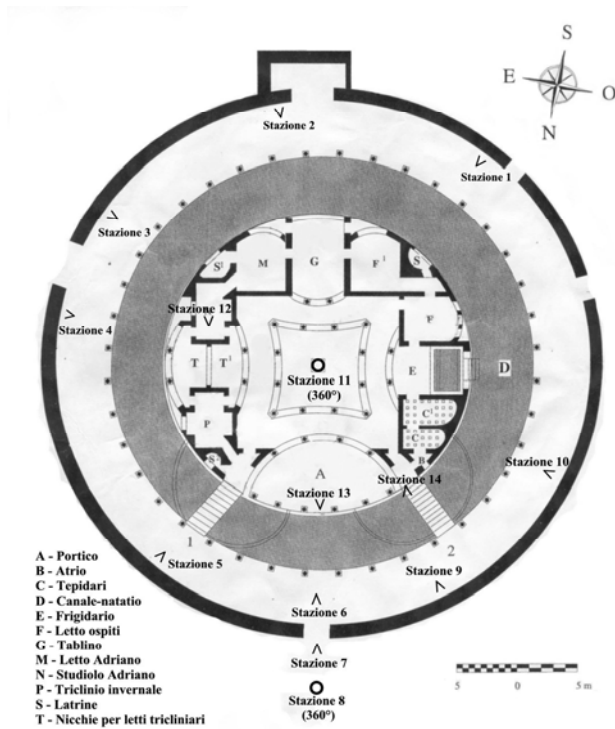


Figure 4. Positions of the 15 stations

**Parameter setting and scan acquisition.**

Fifteen scans were acquired from different stations in 6 hours, 56 minutes (considering only scanning time), at an average velocity of 573 p/s, surveying 15,299,099 points and generating 439 images. Parameters for the snapshots were automatically selected; the software created photographs in jpeg format that were automatically associated with the scans. This allowed to view directly the photograph of each region of the relevant point cloud during cloud merging and subsequent phases. The *number of shots* parameter, i.e. how many times the laser beam was trained on each point, was set at 6 (range 4-25), for greater accuracy and to improve the standard deviation. A higher value would have enhanced accuracy to the expense of scanning time, which would have risen inordinately due to the size of the scanned object. The overscan mode was never used; rather, we selected the maximum scanning depth by measuring the farthest point of the object and entering it as the upper limit.

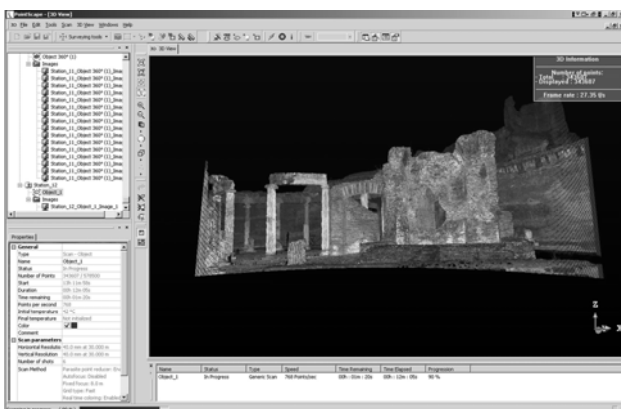


Figure 5. Scan acquisition

**Scan Merging.**

For this operation and the first steps of cloud processing we used TRIMBLE's *Real Works* software to create an output by merging all the clouds obtained from different scans. For this process we did not use flat or spherical targets, but matching points on overlapping scans. In particular, after identifying three matching points in two adjacent scans the *overlap* function was selected; then the *refine* function was applied several times to optimize accuracy, until a 2 mm precision was obtained. The process was carried out for each station and each scan was related to the reference scan. This approach allowed to generate a complete cloud with origin in the reference system of station 11, which nearly coincided with the centre of the round plan model. During overlapping operations the model was also preliminarily refined by directly discarding useless points and decimating the dataset.



Figure 6. Merging of point clouds

**File export**

Besides actual metric values, the *Real Works* files also contain illuminance and RGB data. Each file was exported to an ASCII format by creating three different files with different meshes and applying a *spatial sampling* filter to decimate the points. The characteristics of the ASCII files are shown below.

Pitch	Size of files in Mbyte	N° of points
100 mm	41 Mb	745.363
50 mm	118 Mb	2.885.511
20 mm	387 Mb	6.994.067

Table 2. Size of exported files

The decision to export differently sized files addressed the problem of finding the best possible compromise between accuracy and ease of dataset processing.

**Point cloud processing:**

For final point cloud processing and the realisation of the 3D model we used the *Rapidform 2006* software by INUS Technology, which provides a large number of data management and processing tools and applications but involves the severe limitation of not allowing import and management of RGB and illuminance information, which is therefore lost in

this phase. The sheer amount of data, the large datasets and the high number of points require exceptionally powerful hardware for management, processing and finally display and exchange. For this reason, three point clouds (100 mm, 50 mm and 20 mm meshes) were processed with the *Real Works* software. Although decimated datasets provide for easier management and processing, they also involve the loss of a considerable amount of data and consequently reduced accuracy and impaired graphic rendering of the final product. A number of similar operations were performed in all three cases, as follows:

1. *refining* by manual selection of cloud points and deletion of data representing unnecessary objects;
2. application of the *redundancy* filter to delete presumably matching points;
3. application of the *noise* filter to suppress points generated by registration errors in unwanted regions (albeit excesses may remove correct data);
4. cloud simplification using the *sample points* command, to suppress data in regions of lesser importance;
5. dataset subdivision into separate *shells* to enhance manageability and the ease and accuracy of subsequent triangulation steps.

In contrast, we did not implement the *smooth points* and *thin points* commands, which are based on matrices that would have caused the point positions to move, leading to an, albeit slight, loss of consistency between model and object.

The operations described above enabled simplification by targeted deletions of negligible data. The table below reports cloud data before and after processing.

Point cloud	N° of points in the original cloud	N° of points after decimating
100 mm	745.363	323.385
50 mm	2.885.511	2.139.617
20 mm	6.994.067	3.747.881

Table 3. Size of decimated point clouds

We thus moved from processing an initial 15,299,099 point cloud generated by overlapping scans to three much smaller ones, while preserving survey quality and reliability.

**Procedure adopted for the 20 mm point cloud:** The starting point was the *Real Works* file containing data for 6,994,067 points (387 Mb). Import into the format used by the 3D modelling software involved the loss of RGB values. The point number and the size of the file required its simplification in view of greater ease of use and application. This required deletion of the points belonging to irrelevant regions and undesired objects. Manual selection and deletion of these data produced a 5,301,251 point cloud. *Redundancy* filters were not applied, to avoid losing relevant data and consequently accuracy. Therefore, rather than decimating the whole cloud we decided to perform targeted point reduction in less important regions. In the terrain percent reduction (*sample points*) was applied so as to preserve a number of points that would enable its morphological reconstruction while at the same time lightening the file. This required dividing the cloud into several *shells* for separate processing. The first such operation led to generation of 90 *shells*. This allowed application of the *redundancy* filter for the deletion of putatively overlapping points in regions of lesser relevance, by a 20 mm or greater pitch, which achieved the goal of substantially reducing the

dataset. A *noise* filter was then applied to each shell to suppress points generated by registration errors in irrelevant regions, by working on clusters of at least 100 points, thus obtaining clouds of 4,137,838 points. The object was further divided into shells, in some cases applying percent point reduction. The final result was an 85.6 Mb file containing data for 3,775,624 points subdivided into 178 shells.

### 3. CREATION OF THE 3D MODELS

Starting from 100 mm and 20 mm clouds, three continuous 3D models were created which differed considerably in image quality but preserved excellent consistency with the geometrical characteristics of the object. In fact, in the model generated from 100 mm point clouds, the geometrical rendering of objects was blurred, in some cases preventing their identification. We then attempted to process a portion of the theatre by selecting the slice with the highest architectural value, the one including the portico, starting from the 20 mm point cloud. The satisfactory results obtained demonstrated that the study goals would be best served by a model generated from the 20 mm point cloud, which yielded the required quality level, even though this involved long processing times and a large size of the final output, due to the large number of meshes. Indeed, the attempt to reduce the dataset via export into various different formats failed to give the desired result. A substantial difference in the processing applied to the 20 mm compared with the 100 mm file was that in the latter the whole model was triangulated with a single command, by operating simultaneously on the whole cloud, whereas in the former the file had previously been subdivided into 178 shells, creating a mesh by working on each with separate operations. This not only improved the quality of the 3D model, but especially enabled easier management in the subsequent processing phases. The operations performed were essentially as follows:

1. triangulation of the whole model or of individual shells;
2. search for meshes containing registration errors, and deletion of redundant and mistakenly generated meshes;
3. normal inversion whenever the automatic process had selected the wrong one, and application of the manual method to individual mesh groups;
4. application of the *fill holes* procedure, carefully checking consistency with the original model.

Model	Size of files Mbyte	n° of points	n° of meshes
100 mm	13	620.213	320.053
"Spicchio" da 20 mm	33,5	845.078	1.665.499
Completo da 20 mm	141,0	3.747.881	7.310.877

Table 4. Size of various models

The problems to be faced more and more often when using this method and technologies is the very easy and fast data acquisition compared with the subsequent processing, which is required to move from the discrete clouds of points model to the

more highly representative model of continuous textured surfaces.

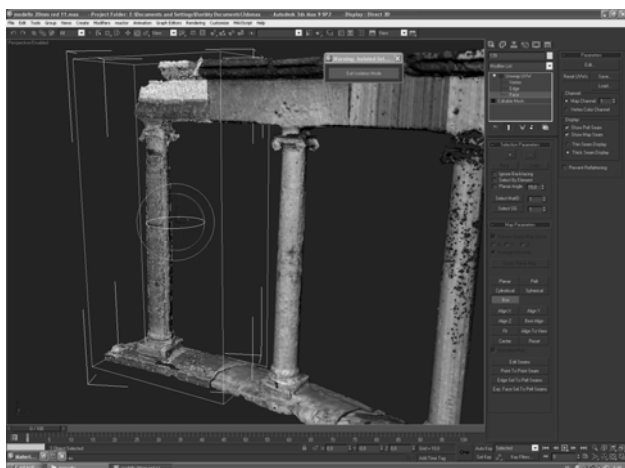


Figure 7. Section of textured model

Managing the accuracy achieved with point clouds and the highly photorealistic definition of the continuous model is still difficult, and becomes even more so when the work envisages the diffusion of data through that most universal of channels, the web.

## CONCLUSIONS

The output of the work may be synthesised into two types of deliverables as a function of their utilisation, one based on the point cloud itself and characterised by the usability of metric and geometrical values and the intrinsic accuracy of the model, and the other constituted by the continuous surface model for use in representation, characterised by high realism that can be achieved with photorealistic rendering and simulation of natural light conditions. The latter model is easier to use, but such easier diffusion comes to the expense of perfect metric correspondence with the original due to highly optimised bases for the simulation of perceived reality. The models generated will constitute the access portal to all the information collected with regard to each element, so that exploration of the 3D model will allow to move from the geometric to the historical information and to that on materials, enabling the proposal of historical reconstruction hypotheses. The models will therefore provide immediately accessible databases by any type of users. To this end, the material has been entered into the database of the DARDUS department of Università Politecnica delle Marche, which for several years has been archiving, organising and managing a large amount of graphic and visual material and information. The LADA (Laboratorio Archivi Digitali di Architettura) has created a system connecting the digital archives and the georeferencing system, one of the most interesting and innovative features of the work. This type of archiving enables systematic data cataloguing according to multiple parameters, including their organisation in a SIT. Integration of satellite GoogleMaps with regional survey as well as thematic maps ensures a higher level of representation and consequently of data utilisation. The information system devised for the present project is capable of being connected to the Region's document collections and archives through application of a local network powered by a search engine. This may contribute to the creation of an 'information pole' ensuring

integrated access and consultation, also on-line, of a highly significant scientific and cultural heritage, and especially of services for the knowledge and use of that heritage. An ideal space for a popularization operation that turns the virtual space into a dynamic museum prototype accessible via the Web by theme, time, geographic route or user profile.



Figure 8. Home page of LADA