Long Paper

# From Drone to Web Visualisation

## Accessing the 3D Model of the Roman Thermal Complex of Massaciuccoli

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**Abstract:** During the last ten years, photogrammetric surveys have become more intensive in archaeology, both in excavation and for obtaining accurate 3D representations of architectural monuments. The project aimed to create a free web interactive visualisation of the Roman thermal complex of Massaciuccoli (Lucca, Italy) 3D model. The workflow to achieve this goal is analysed step by step. In the first part, the methodology used to build the 3Dmodel is described, starting from a terrestrial and aerial photogrammetric acquisition to its merging, in a subsequent data processing phase, with a point cloud made in 2016 bythe inter-university centre e-GEA with a terrestrial laser scanner (TLS) within the project'Visual Versilia 3D'. The result of this work is the web visualisation of the ancient monument designed according to the open-source 3DHOP (3D Heritage Online Presenter) framework developed by the Italian CNR. The workflow delineated has enabled not only to obtain a high-quality 3D model, both from a metric and radiometric point of view, but also to support the interactive visualisation of that building, thus allowing a more significant number of people to enjoy the Roman bath complex of Massaciuccoli remotely.

***Keywords:*** *Roman Archaeology—Photogrammetry—UAV survey—Terrestrial Laserscanning—3DHOP*

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## Introduction

During the last ten years, photogrammetric surveys have become more intensive in archaeology, both in excavation and to obtain accurate 3D representations of architectural monuments. The project presented concerns the photogrammetric survey of a Roman thermal complex identified at Massaciuccoli (LU), carried out by an Unmanned Aerial Vehicle (UAV), implemented with a series of data acquired by a terrestrial laser scanner (TLS), the latter performed by Castagnetti, Giannini and Rivola (2017) of the inter-university centre e-GEA within the project 'Visual Versilia 3D'. The web visualisation of the whole model was achieved by using the open-source software 3DHOP, developed by Potenziani et al. (2015) within the Institute of Information Science and Technology ofthe National Research Council (ISTI-CNR).[1]

[1] As part of a joint work, the section "Survey" is by E. Taccola, while sections "3DHOP" and "Results and outlook" are by F. Sala. The authors are deeply grateful to Georgia Felton Smith for improving the English of this paper.

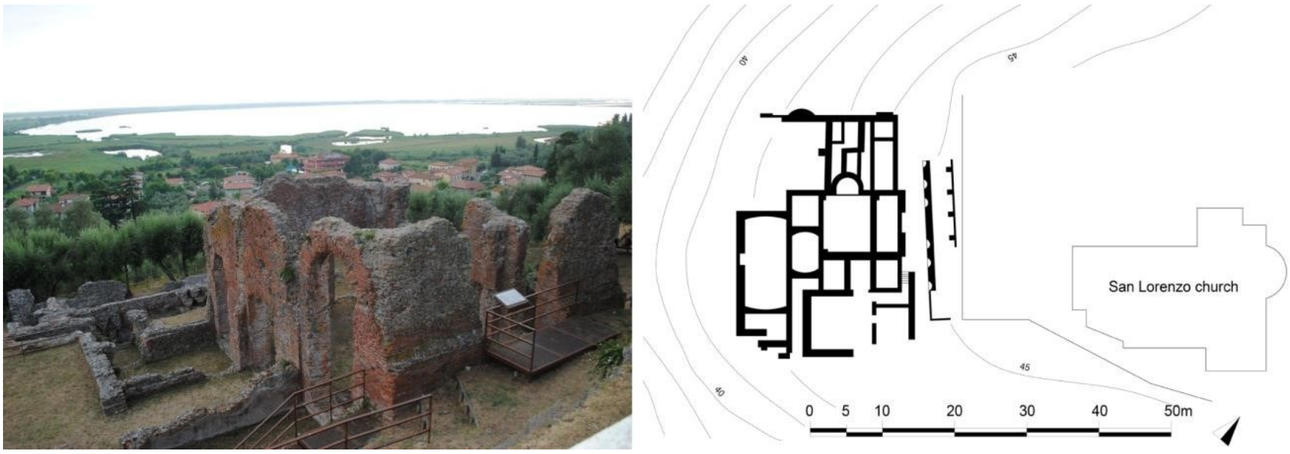


*Fig. 1. Panoramic view and (to the right) schematic plan of the Roman thermal complex of Massaciuccoli (© MAPPALAB-UniPI).*

The case study (Figure 1) is located near the northwest coast of Tuscany, a few kilometres from Viareggio and Lucca, overlooking the coastal lake of Massaciuccoli. The structures lean well- preserved on a hill overlooking the small homonymous village. The complex still preserved, developed on two terraces, was probably built at the beginning of the 1st century A.D. According tosources, some structures were identified during the 18th century on an upper terrace at the top of the hill. Nowadays, these remains, unfortunately buried below the church of San Lorenzo, were interpreted by the discoverers as the ruins of a *villa d'otium*. The lower terrace is occupied by the actual thermal baths. The structures gravitate around a large pool (*frigidarium*) with a corridor and aseries of rooms to the west and a hypothetical vestibule to the east. To the south, there are two rooms with curvilinear walls and a large room with a heated floor (*sudatio*).

Ciampoltrini (1994) supposes the complex probably belonged to the mercantile and senatorial Pisan family of *Venuleii*. According to E. Paribeni (2012), other structures found on the slopes of the hill, a villa/*mansio* and a further small thermal complex with mosaic floor, are probably to be considered as manufacturing and service areas belonging to the powerful Pisan family that owned the large complex above. The entire site is a museum. Whilst the downstream sector is protected by a tensile structure, it can only be visited on specific occasions. However, the large thermal complex is freely accessible and unprotected. For these reasons, exposure to atmospheric agents makes the erosionof the complex particularly aggressive and compromises the conservation of the monument.

## Tools, methods, and procedures

The following section illustrates the workflow developed to build the textured polygonal model. In addition, the process followed to create the web visualization of the 3D model of the Roman thermal complex of Massaciuccoli, the main goal of the project, is described.

### Survey

The first work phase consisted of the creation of a network of 2 fixed points, measured with a dual-frequency differential satellite receiver (GNSS Trimble R10). The device can position a point on the ground with a sub-centimetre planar accuracy, under optimal conditions and settings. The survey procedure adopted on the site is defined as 'real-time kinematic' (RTK). With this setting, the device calculates the positioning on the point with stations of variable duration of 3 to 180 seconds. The antenna receives the differential correction – that is the refinement of the measurement – in real-time from a dedicated satellite put into orbit by the manufacturer of the device (RTX Trimble xFill Technology). This configuration resulted in a declared precision of about 1 cm horizontally, and 4 cm in elevation, with coordinates expressed according to the Gauss-Boaga projection system (zone1) and Roma40 datum, with the addition of the projection parameter Italy 90.

The measured benchmarks, placed to be visible from each other's location, set the basis for the topographic survey with an optical-electronic instrument (Trimble C5 total station). In detail, a technique called 'resection' or 'inverse intersection', was used. Through this calculation, it is possibleto obtain the position of an unknown point (the one where the total station is positioned) by snapping to the coordinates of two known points (the reference points measured with GNSS).

The photogrammetric survey was realised by integrating photos by UAV (Parrot Anafi) and terrestrial photos. In the first case, both automatic flights were performed, to document the site with vertical images, and manual ones, to detail the elevations of the walls with oblique images (4 mm, f/2.4, ISO 150 average). The automatic flight plan, designed with the App Pix4D Capture, consisted of a double photo capture grid with an 80% overlap at an elevation of 10 and 15 m, in order to acquire the whole complex and avoid capturing the surrounding olive grove. The operation required two flights for a total of approx. 12 minutes and 292 photos. The manual flight was accomplished by taking 191 photos in approx. 30 minutes of work. Nine ground control points (GCPs), consisting of coded targets, were positioned in the survey area to georeference the 3D dense point cloud. The GCPs were measured with the total station oriented with the aforementioned resection procedure, according to the reference system Gauss Boaga / Roma 40 / Italy 90.

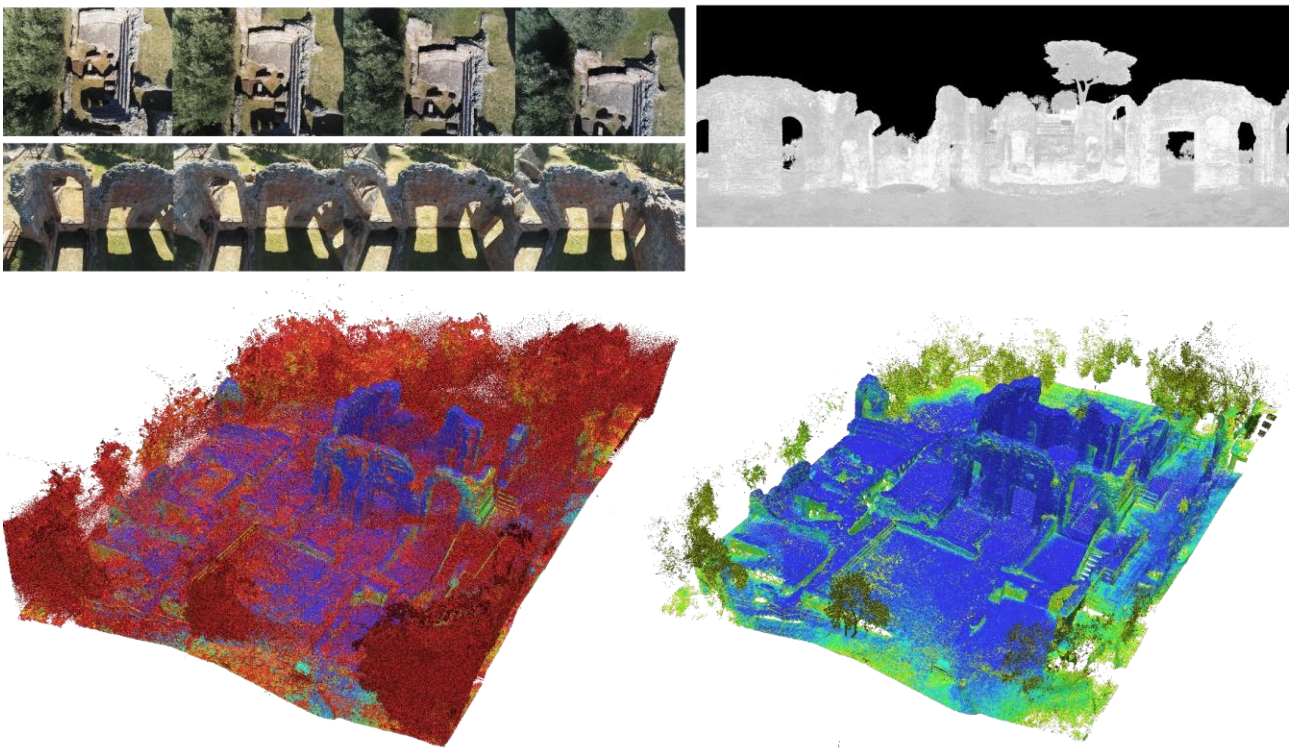

*Fig. 2. Above: examples of vertical and oblique images acquired by the UAV and (right) the TLS scan in .ptx format as displayed in Agisoft Metashape. Below: the dense point cloud before (left) and after automatic cleaning through the tool 'filter by confidence' (© Ladire-UniPI).*

In a subsequent phase of the survey, 175 terrestrial photos with an SLR camera (Nikon D3500, 18 mm, f/9, ISO 100) were acquired to document the sides of the structures not visible from the drone,such as the lower sides of architraves and vaults and the internal sides of the jambs.

As mentioned in the introduction, a laser scanner survey (TLS) was also supplied for the baths of Massaciuccoli by the inter-university centre e-GEA. The 30 scans were acquired in September 2016 with ScanStation C10 by Leica Geosystems and exported in the exchanging format .ptx.

The survey's primary purpose was not a representation of the thermal complex at a given drawing scale but the interactive visualization of the 3D model within the 3DHOP software. In this sense, the issues in terms of point cloud quality that eventually emerge with the integrated use of terrestrial and UAV images, and, more generally, images coming from different platforms with different parameters (for which targeted solutions are implemented depending on the project and its aims, see Farella, Torresani and Remondino, 2019; Banfi and Mandelli, 2021) did not affect the result.

The source data – drone and terrestrial images and TLS data – were processed into a single chunk with the software Agisoft Metashape Professional 1.7.2. The time between the acquisition of the TLS (2016) and the photogrammetric data (2021) was not a significant problem. The TLS survey was performed after a specific cleaning of the monument from the vegetation, which instead covered limited portions of the wall surfaces at the time of the photogrammetric survey. To avoid inconsistencies in the resulting point cloud, the parts in which a shrub or bush appeared on the walls were masked in every single photo to be excluded from the processing and, therefore, not appear as a 3D point.

Overall, the workflow, from the alignment step to the creation of the textured polygonal model, took 5 hours. Optimisation of cameras based on GCPs measured with total station refined the dense point cloud error to an average value of 0.0055 m. The final 3D dense point cloud, made of 35,668,907 points, cropped and edited to eliminate the surrounding vegetation as much as possible, was cleaned and further optimised through specific Metashape tools by filtering and removing the least accurate points and those that caused the most noise in the cloud (*filter by confidence*), for example, the black background of the .ptx image (Figure 2).

## 3DHOP

Thanks to the constant progress of new digital technologies applied to cultural heritage, in 2015 the Institute of Information Science and Technology of the National Research Council (ISTI-CNR) developed an open-source software for the online visualisation of large 3D models, called 3DHOP (3D Heritage Online Presenter). This program allows anyone to examine and interact with the 3D objects produced by any researcher, directly online and without installing any software. This projectaimed at using 3DHOP to present the 3D model of the Roman baths of Massaciuccoli to a broader public.

From the site https://3dhop.net/download.php, 3DHOP software files were downloaded. In further detail:

- The Nexus 4.3 software, for the compression of the .ply file and its conversion into a format readable by the program.
- The 3DHOP 4.3 software, including files and templates for web visualisation.

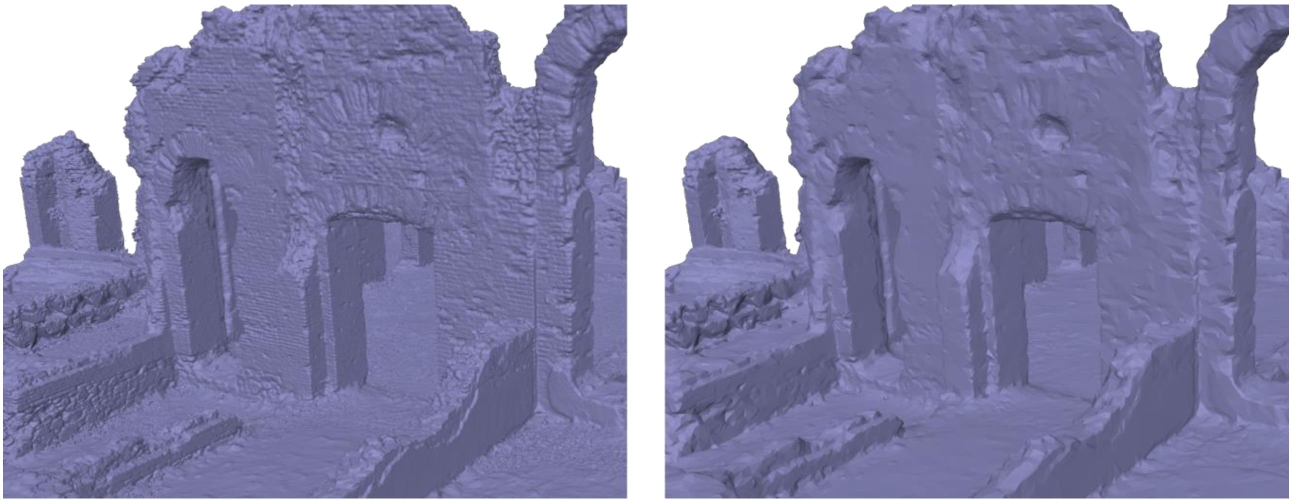

*Fig. 3. The 3D model before and after mesh decimation (left) (© Ladire-UniPI).*

For the specific purposes of the case study, the point cloud was initially transformed into a 3D polygonal model, made up of 35,403,277 triangles, on which 8 textures in .jpg format (4096x4096 MP each) were projected.

Before exporting the photogrammetric model from Agisoft Metashape, it was necessary to reduce the triangles of the mesh from 35,403,277 to 497,492 to allow faster loading within the server. To do this, it was necessary to re-execute the mesh creation operations by entering as parameters a lower level of detail so that the 500,000 triangles were not exceeded. At the end of these procedures, it was possible to export the mesh in .ply format with its relative texture. In fact, 3DHOP is not yet implemented to handle more than 1 texture (Figure 3).

The second step consisted of the conversion of the .ply file into a format usable within the 3DHOP software. The exported 3D model was copied (together with the .jpg of the texture) inside the folder named Nexus 4.3 in which the software 'nxsbuild' is contained. Such a program allows the conversion of the .ply file into .nxs format. In completion of this procedure, the file was compressedthrough the use of further software contained in the folder and denominated 'nxscompress', which returns a file in .nxz format to be placed in the sub-folder 'models' enclosed inside the folder 3DHOP 4.3 previously downloaded.

To make the photogrammetric model visible and interoperable within the server, it is necessary to place the .nxz file within an HTML template provided by the software developers. To accomplish this procedure, the template was opened with an HTML source code editor Bluegriffon. First of all, in the initial part of the code, the project name is changed within the string:

<title>Terme_Massaciuccoli_Pieve_San_Lorenzo</title>

In the template there is a series of strings for the visualisation and operation of various options, in which those related to the creation of the hotspots button are added:

```
style="position:absolute; visibility:hidden;"/>
presenter.setScene({
meshes: { "Obj_1": {

url: "models/Terme_Massaciuccoli_def.nxs"

}
```

Afterwards, there is the section dedicated to the visualisation of the photogrammetric model. At this step, the path of the compressed file .nxz, previously created is inserted, through the following HTML code:

Inside this section, and with the same modalities, the file path relative to the small model in .ply format is also inserted, representing a simple sphere to be used as an interactive base for the visualisation of the hotspots. This 3D model is provided free of charge by the software developers in the subfolder where the previously compressed file was saved.

The next step involves placing the hotspot within the scene and setting the colour of that option. To accomplish this step, it is necessary to insert into the HTML code a new section entitled 'spots' which can be written through the following strings:

```
Sphere": {

mesh:    "Sphere",   trans-
form: {

matrix: SglMat4.mul(SglMat4.translation([3.340, 6.981, 42.045]), SglMat4.scaling([1.0, 1.0,

1.0]))

},
```

The coordinates of the positioning are retrieved from the 3D model developed with 3DHOP and inserted in the section of the code 'SglMat4.translation'. The colour instead is defined within the RGB spectrum with a gradation ranging from 0 to 1.0 (in this case it was decided to use a light blue colour defined by the number 0.25).

Subsequently, it was necessary to create a function that allows the option of turning on and off the hotspots. For this purpose, a string was added in the javascript section of the code related to this operation:

```
else if(action=='hotspot'|| action=='hotspot_on') { presenter.toggleSpotVisibility(HOP_ALL, pre-
senter.enableOnHover(!presenter.isOnHoverEnabled());                                    true);

hotspotSwitch(); }
```

```
function   onPickedSpot(id)   {
switch(id) {

case 'Sphere' : alert("Ambiente H Frigidarium"); break;

  }
```

After all these operations, a string in javascript language was inserted at the end of the HTML page, which allows the user to visualise a small description once the hotspot option is turned on and clicked. Below is the code used:

Lastly, the HTML file was uploaded to the server of the MAPPALAB (Digital Methodology Applied To Archaeology) website of the University of Pisa[2] (Figure 4).

[2] https://www.mappalab.eu/3DHOP/3DHOP_4.3/minimal/Terme_Massaciuccoli_Pieve.html

*Fig. 4. The 3D model as displayed in 3DHOP. On the right, some of the features provided by the program: coordinate (purple) and distance (red) calculation, and cross-sections (cyan) (© MAPPALAB-UniPI).*

## Results and outlook

This project presented has allowed the testing of a specific procedure for the web visualisation of large 3D models. In addition to the basic web visualisation provided by 3DHOP, namely, zoom in and out and orbit exclusively on the z-axis, the model has been implemented with interactive tools. More specifically, a trackball allows the view of the thermal complex to rotate in any direction, while through another tool it is possible to change the direction of the default light source to simulate sunlight illumination. A further level of interaction consists in measuring features, acquiring point coordinates, and creating cross-sections. Moreover, at a deeper level of complexity, the model could be annotated by inserting selected hotspots, linked to short textual descriptions. The project thus made it possible to extend the usability of this model to a broader and diversified public. For this reason, the Municipality of Massarosa solicited this project to promote its territory and safeguard itscultural heritage, considering that the site is, unfortunately, exposed to constant erosion by atmospheric agents.

The 3D model could also help to perform further studies related to the reading and analysis of the stratigraphic units of the walls' elevation, thanks to its high level of accuracy, both metric and radiometric. According to this approach, the project could set the basis for the creation of hypotheses on how the thermal complex must have looked in ancient times, helping a virtual reconstruction of the building following the Extended Matrix method created by Demetrescu (2015; Demetrescu and Ferdani, 2021).

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## Author Contributions

**Conceptualization:** Filippo Sala and Emanuele Taccola
**Data curation:** Filippo Sala and Emanuele Taccola
**Formal Analysis:** Filippo Sala and Emanuele Taccola
**Investigation:** Filippo Sala and Emanuele Taccola
**Methodology:** Filippo Sala and Emanuele Taccola
**Software:** Filippo Sala
**Visualization**: Filippo Sala
**Writing – original draft:** Filippo Sala and Emanuele Taccola

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