# Integrated and advanced techniques of survey for the definition of lost facies of the monumental architecture

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## Abstract

*The analysis of an architecture characterized by geometrical, functional and historical complexity requires the fundamental and crucial acquisition of metrics data, iconographic and archival documents, followed by a correct comparison and interpretation of the collected information. The aim of this process is to give a precise critical interpretation of the building - or some of its specific areas - as close as possible to reality such as to allow a reliable reconstruction of those aspects that got possibly lost over time.*

*In the specific case, this approach wants to offer a vital support to the study of those aspects of the monumental architecture that have been heavily altered by inappropriate interventions.*

*In this paper, the methodological process is related to a quite large number of interventions on Villa Mondragone in Monte Porzio Catone (Rome), the largest among the princely houses of the Tuscolan Complex. The task, here, is to get an accurate reconstruction of the facades facing Piazzale Maggiore, a large inner courtyard of the vast complex, focusing in particular on the latest large process of transformation, started nearly a century ago.*

*We based our study on bibliographical sources, on recent years' historical data researches and on the analysis of the iconographic documentation, as well as on surveys of the state of fact by using different techniques. A considerable support to the research came from the use of the new survey technologies, which the main object of this article. These technologies have been managed in an integrated manner on the areas of interest. They have helped to obtain considerably accurate surveys such as to guarantee a high degree of reliability to the reconstructive hypotheses subsequently processed.*

*On one hand, the survey has relied on the capabilities of the laser-scanner, and of the other hand on the aerial photogrammetry with operations done with different types of UAV (unmanned aerial vehicle) and digital cameras. A series of different reasons required the use of various tools for indirect survey, as shown in the text. The most important one is due to the relevant dimensional characteristics of the building and the surrounding context.*

*This work is part of a broader line of research on the Ville Tuscolane and here it mainly refers to the applications of the most advanced systems for surveying and modeling of monumental architecture of historical interest. It has provided interesting food for thought and technological and methodological comparison on the theme of philological reconstruction of the lost internal fronts of Piazzale Maggiore of Villa Mondragone. This was possible thanks to some similar elements on the facade facing the outside of the Manica Lunga (the longest eastern side of of the building enclosing the court) emerged during the surveys of this front.*

## The complex of the *Ville Tuscolane* and the evolutionary phases of *Villa Mondragone*

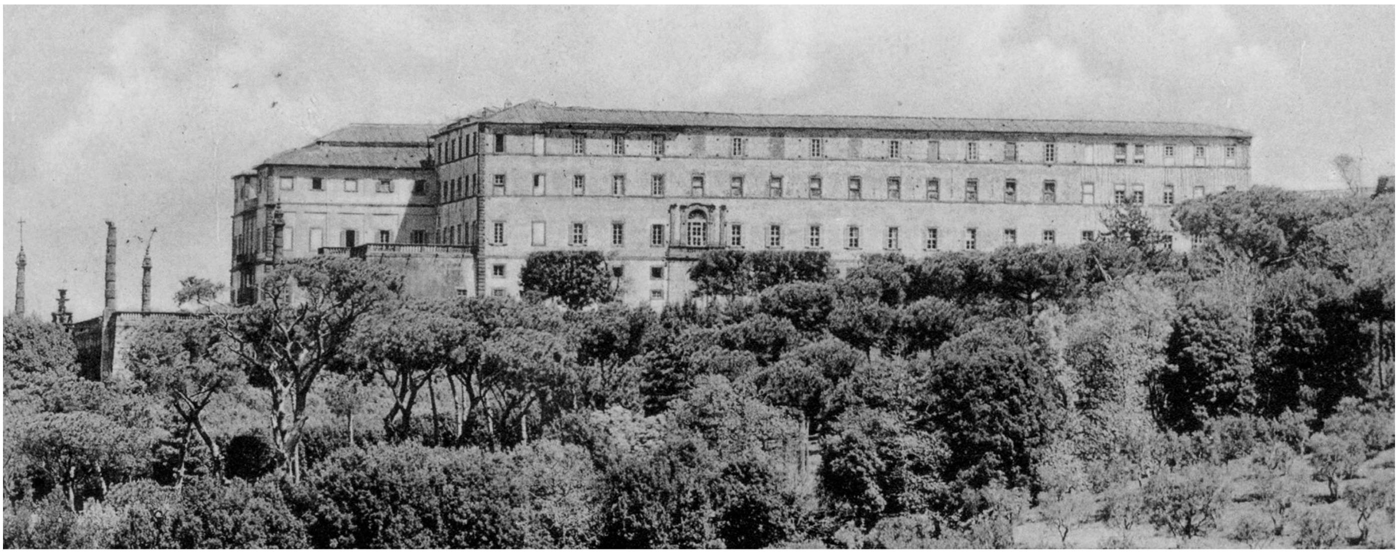
The Complex of the *Ville Tuscolane* consists of twelve monumental buildings erected around the town of Frascati from the middle of the sixteenth century and used as a summer residence of the papal court and the noble families linked to it. The trend of the construction of the Villas was probably due to the particular orographic and geological characteristics of the area, which led the ancient Romans to do the same: the dry and windy climate in summer and mild in winter, soil fertility, the presence of water, the availability of many high quality building materials (like the Sperone Stone of Tusculum, the Peperino, the Basalt, the pozzolanic ash). This territory was also suitable as a settlement since the old ages, because it was strategic location for Rome and the Roman countryside (suitable for both defensive purposes as well as for the panorama).

The Renaissance Roman aristocracy, for the early mentioned reasons, settled on the Tuscolani Hills with the idea of having a Casino (a home country of the nobles) where to stay according to the criteria of the Romans "otium et studium". The floor plan of these first units was initially inspired to the traditional Tuscan villa-castle characterized by corner towers and the airy loggias. Later, the complex of villas saw the growth of all the original plans through the addition of new wings that followed the strict rules of symmetry and volumes and that characterized, in principle, the architecture of the buildings as we see them today. In this way, the facades facing towards the north (towards the valley) was marked by austere openings, much smaller than those on the Southern facades which, along with the arcades of the ground floor, made more articulate and bright prospects. Moreover, given

the orographic conditions, containing walls were created both downstream and upstream to allow to have flat surfaces.
Between the late sixteenth and early seventeenth century the Villas were subject to other small construction projects and major changes in the external territory, with the placing of gardens and parks. In conjunction with the transfer of the pope's summer residence to Castel Gandolfo (which took place in 1626 for Pope Urban VIII's decision), the attention towards the *Ville Tuscolane* faded and many residents began a slow process of functional transformation that was the first of the causes of alteration of the original structures. Moreover, from the late nineteenth century and throughout the first half of the last century, irreversible changes to the twelve Renaissance buildings happened due to the switches in ownership and to the continuous interventions of functional recovery that may have directly or indirectly been due to the Second World War. In many cases these transformations were far from the canons of philological restoration, with the loss of historic stratification of these monuments.
*Villa Mondragone* also followed the same evolution of splendor and decadence of other *Ville Tuscolane*. As a matter of fact, after the relocation of the papal summer residence to Castel Gandolfo, the entire complex suffered an increasing decline, which peaked in the early decades of the nineteenth century. At this time some events (in particular, an earthquake of 1806 and the cantonment in 1821 of thousands of Austrian soldiers and knight sheading to the Two Sicily Kingdom) damaged the building so badly as to rouse the population and administrators of Frascati.
This ruinous decline was witnessed by few iconographic documents and some descriptions of the time complaining about, for example, the lack of roof, walls largely collapsed and windows without frames, especially on the west wing of the building (the so-called *Manica Lunga*), as well as disconnection of the floor of the vast courtyard called *Piazzale Maggiore*. A condition, this, that led the artifact next to the condition of ruin.
Only from the second half of 1800, *Villa Mondragone* was saved from its disastrous fate with the decision of the Prince Borghese, who had also tried to start a restoration (substantial one in many ways) in 1853, to conclude an agreement with Jesuits for which the noble family made the property available to a Jesuit College at no cost in exchange for the restoration of the *Villa*. The Jesuits performed many restoration projects in Mondragone since 1865. One of the most important was closing the windows of the arches facing Piazza Maggiore with decorative glasses. Other interventions concern the building installations, the construction of many toilets, re-flooring, the restoration of the stone covering the main staircase and the closure of hundreds of putlog holes.
Since the beginning of the teaching activities of the Noble College, continuous changes were made to the building to meet the growing demand for enrollment and the consequent need for optimization of space and functions. The success of Collegium Tusculanum greatly increased by the end of the nineteenth century when, in addition to the nobles, the doors were opened also to the rich bourgeoisie and upper classes of society. When, in 1895, the finances of Prince Borghese was running out, the College was saved by the Jesuits who acquired the property. They immediately changed their behavior in relation to the property. To cope with the many inscriptions which were again multiplied thanks to the equalization of the *Nobile Collegio Mondragone* to the Royal Institutes, in 1926 they closed the cloister porch on three sides allocating there the refectory.
They had to move from room to room like the noble's apartments. Therefore, when the building was transformed into a College, students had to go out in the yard to go in different classrooms. For this reason they were to construct large corridors on the ground, first and second floor. For this reason, since 1929, the Rector of the College, Aristide Delmirani, choose the engineer-architect Clemente Busiri Vici to design the transformation of the complex. In less than four years new volumes were built. They are mostly large corridors connecting the various floors of the west and south wings facing the *Piazzale Maggiore*, a gym-corridor on the east side and a few rooms for religious in roof-terrace, upsetting the original layout of facades of this courtyard of the building (figure 1).
To hide the differences between the new parts of the building with the ancient, Busiri Vici adopted the solution of dismantling and replacing the panels of Sperone Stone of Tusculum on new and advanced facades. This operation was performed badly and executed only in part for obvious geometric considerations (advancement fronts perpendicular within a concave corner leads to overlapping) and radically change the peculiarities that are present in the corners and in the original facades of the *Manica Lunga*.
In regards to the interventions designed and conducted by Clemente Busiri Vici, we find clear examples of how the process of acquisition of knowledge cannot be based only on the study of historical sources but must be necessarily supported by accurate surveys that are interpreted and read through the eye of a technical researcher.

## Laser scanning and photogrammetric survey of the *Manica Lunga* and the southern wing. Methodological, operational and technological aspects

As pointed out in the abstract, the survey based on integrated and evolved techniques (laser-scanning and aerial photo-



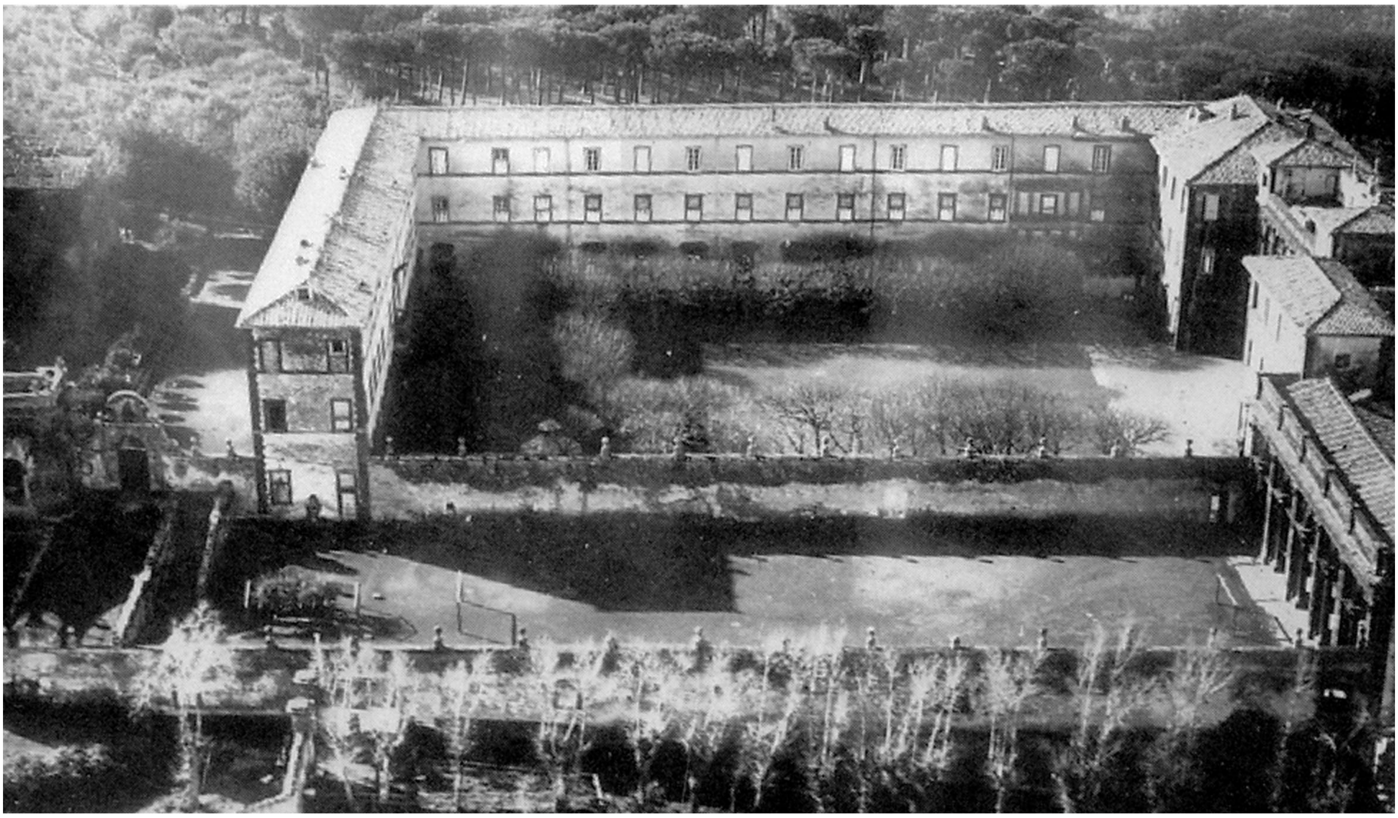


Figure 1 – Detail of antique postcard representing the external western facade of the *Manica Lunga* (top); aerial photo before 1929 representing the internal eastern façade of the *Manica Lunga* (down).

grammetry) of the environment of the *Manica Lunga* and the *braccio meridionale*, built at the beginning of the 900's, and in particular of the facades facing both the *Piazzale Maggiore* and the outside of the *Villa* have provided, as you will see, an interesting point of discussion regarding the accurate reconstruction of *Villa Mondragone*.
Since it is the survey of a building characterized by a large sized structures, it was necessary to draw up detailed preliminary project of data acquisition steps, verify the geometry and dimensions of the artifact, and the accessibility to places. For this reason, laser scanning was chosen to survey the interior of the *Manica Lunga*, and the corresponding facade that faces *Piazzale Maggiore*. The aerial photogrammetry (using UAV) was used to survey the other facade of the *Manica Lunga*, the outer-western wall and the roof of the building, to complete the three-dimensional model.
The decision to use the laser scanner to survey ancient buildings seems, in many cases, obvious due to the numerous and well-known advantages it offers in terms of precision, accuracy, and speed in which information is acquired and data is processed. In our case, however, the orographic conditions and natural objects surrounding the *Villa* (including the pres-

ence of other artifacts, as well as tall trees, which are very close to the facade) does not allow an easy and profitable use of laser scanning for the survey of the external facades (figure 2). This issue has been resolved by using UAV for aerial shots. The possibility to raise cameras has allowed to perform photographic survey of the architectural surfaces were being studied. The numerous images taken were then used for subsequent photogrammetric operations to reconstruct the three-dimensional model of the building.

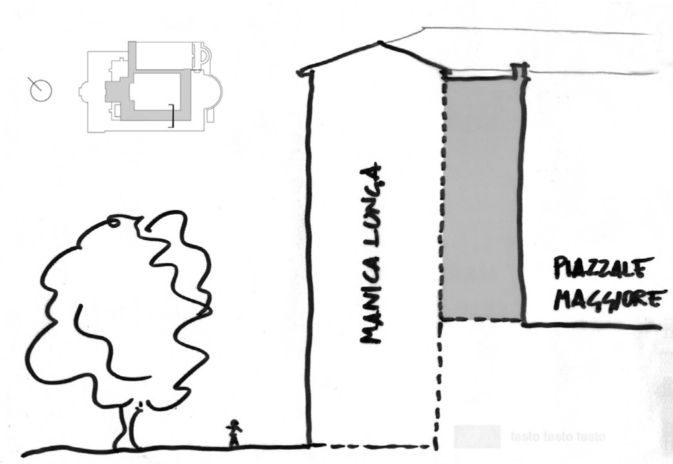



Figure 2 – Sketch of cross section on the *Manica Lunga*. In grey extension of 1929.

Laser scanner technology allows to acquire digitally three-dimensional objects of various sizes in the form of point clouds. The automatic data acquisition erases the previous discretization of the point to be mesured, indispensable step when directly surveying or when using total station. The 3D acquisition systems are differentiated according to the way in which they operate. In particular, within the class of laser scanners used for the survey of the architecture and territory, there is a clear distinction between phase shift scanners (Range Image Scanner) and time of flight scanner. The two types of scanning technology mentioned differ in the way they acquire information. These differences include, the speed of data acquisition, the accuracy, and the range. The TOF method guarantees an accuracy of up to 5mm and a maximum range that varies between 800 and 1000 meters. The RIL, however, has a greater range of accuracy (up to 2mm) but has a more limited scope that only reaches a maximum length of 300 meters.

Comparing the scanner to a light source, there should be enough points of acquisition in order to cover all of the shadow areas caused by the object, undercuts, recesses, and other various inevitable impediments. When estimating the calculation of the final density of the points acquired, one must consider that the overlap of multiple scans increases the density of the point clouds, and this overlap must be equal to about one third of the area acquired in order to ensure a sufficient margin for the final recording. This phase, also called the post-processing phase, is conducted with reverse engineering software, which allows to align the various point clouds captured from different scanning stations. This process may be conducted manually, by identifying at least three pairs of homologous points on two successive scans, or in a semi-automatic manner, exploiting the presence of the target recognized directly by the software. To obtain even more accurate three-dimensional models it is possible to integrate the three-dimensional survey with digital photogrammetry. Most of the laser devices are equipped with an inner camera, which acquires images.The same reverse engineering software allows to align coordinates of the image pixels with those of the points surveyed, applying the photograph on the 3D model and responding to the demand of realism of the 3D model.

The laser scanner used for this case study was the 'Faro Focus 3D x 130' that, under optimal environmental conditions, guarantees a scanning range of between 60 centimeters and 130 meters, a measuring speed of up to 976,000 points per second, and a margin of error between -2 and +2 mm. There were two settings used for the 75 scans (table 1): one for the external (1/2 resolution: one point acquired every 3 mm to a distance of 10 meters; quality 3x: scanning speed of 244,000 points per second; 84 images per scan; length of scan – 10 minutes and 31 seconds): one for the internal (1/5 resolution: one point acquired every 7mm to a distance of 10 meters; quality 4x: scanning speed of 122,000 points per second; 84 images per second; length of scan – 35 minutes and 42 seconds).The settings of the scanner were chosen due to the level of resolution we expected of the final output (figure 3).

Table 1 – Laser scanner settings.

| | Spaces | |
| --- | --- | --- |
| | External | Indoor |
| Resolution | 1/2<br>1 pt. each 3.1 mm at 10 m | 1/5<br>1 pt. each 7.6 mm at 10 m |
| Quality | 3X | 4X |
| Speed (pt./sec.) | 244.000 | 122.000 |
| Duration single scan (sec.) | 631 | 222 |
| Number of scans | 29 | 46 |

The post-processing phase is, in general, the most challenging. The software used was the Faro Scene in its version 5.2.The first operation was to create a new project: the software automatically organized the data in a general file and in a series of smaller sized files, in which they were archived in a 'ranking order', not only the raw scans , but also the chronological

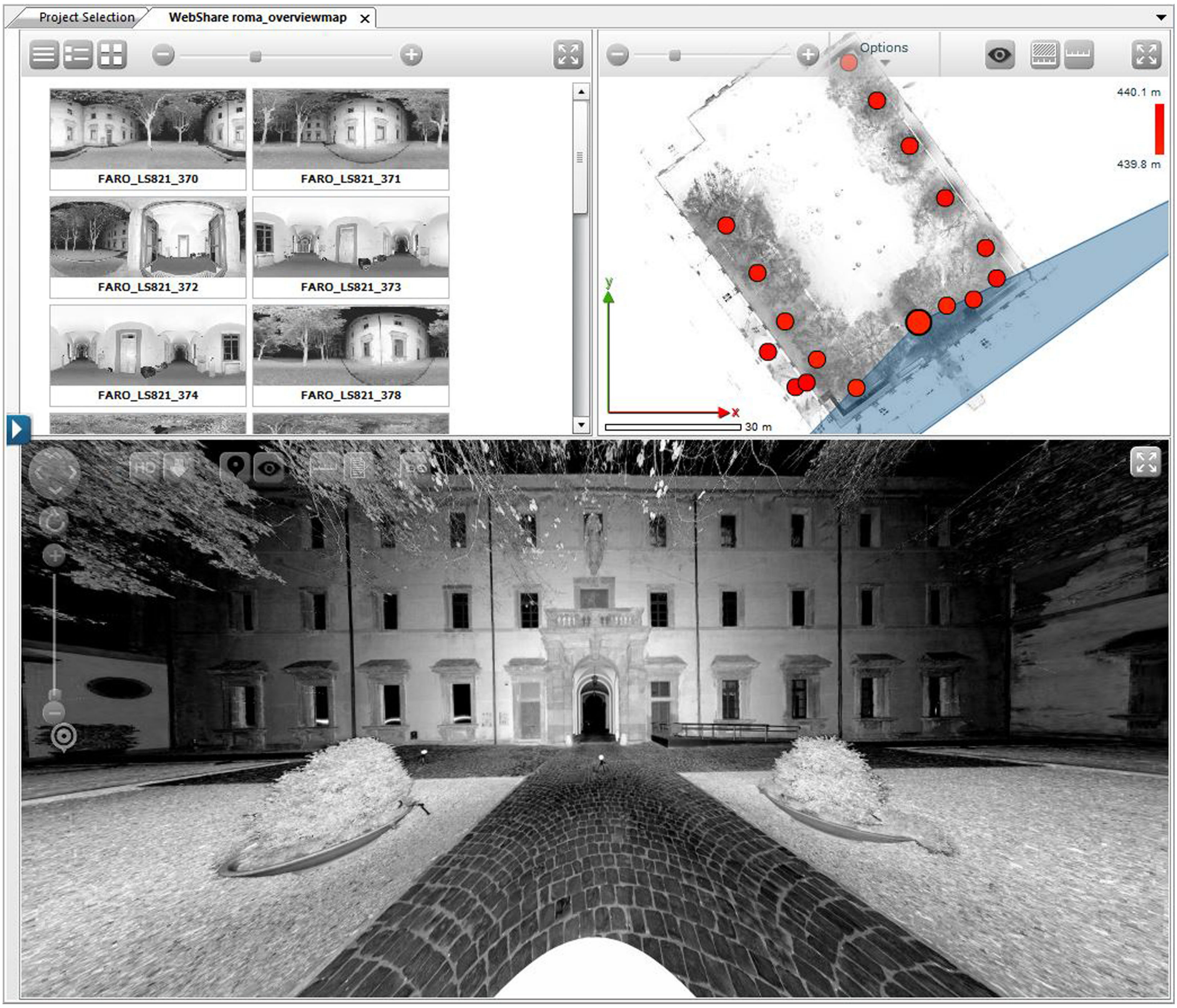



Figure 3 – Overview map with scan positions in *Piazzale Maggiore*.

steps performed within the operation. Within the software, these steps are labeled 'revision'. Once all the scans had been imported into the created project, it was necessary to proceed to their alignment, meaning their positioning in respect to one system of reference. This operation was done semi-automatically because, in the phase of survey, spherical targets were placed on site and chessboard targets were placed on the vertical surfaces (figure 4). The three-dimensional model obtained has more than 400 million points and represents, in true form, a very extensive portion of the *Villa Mondragone,* in this case the first two parts added in 1929, and all the internal facades of the *Piazzale Maggiore* (figure 5).

The photogrammetry area, as said, was used to survey, not only the roof of the *Villa Mondragone*, but above all, the external facades of the *Manica Lunga.* The photogrammetry represents a technique that has been used for a century in the cartographical sense configured with the most trusted method of acquisition of metrical and thematic data that has also been successfully used in the field of architecture. It, infact, allows us to define the object's position, shape, and dimension using the information (the homologous point) contained in the photographic image taken from different perspectives of each individual object. In short, the main principle is based on the stereoscopic vision. In general, three are the steps involved in the photogrammetric survey: the acquisition in which is defined the characteristics of the photographic image, the orientation, meaning the registration of the image and the consequent realization of a three-dimensional models; the restitution, regarding all of the operational outputs and measurements.

For the case-study discussed in this paper, we have used two UAV, equipped with different types of digital cameras. For the

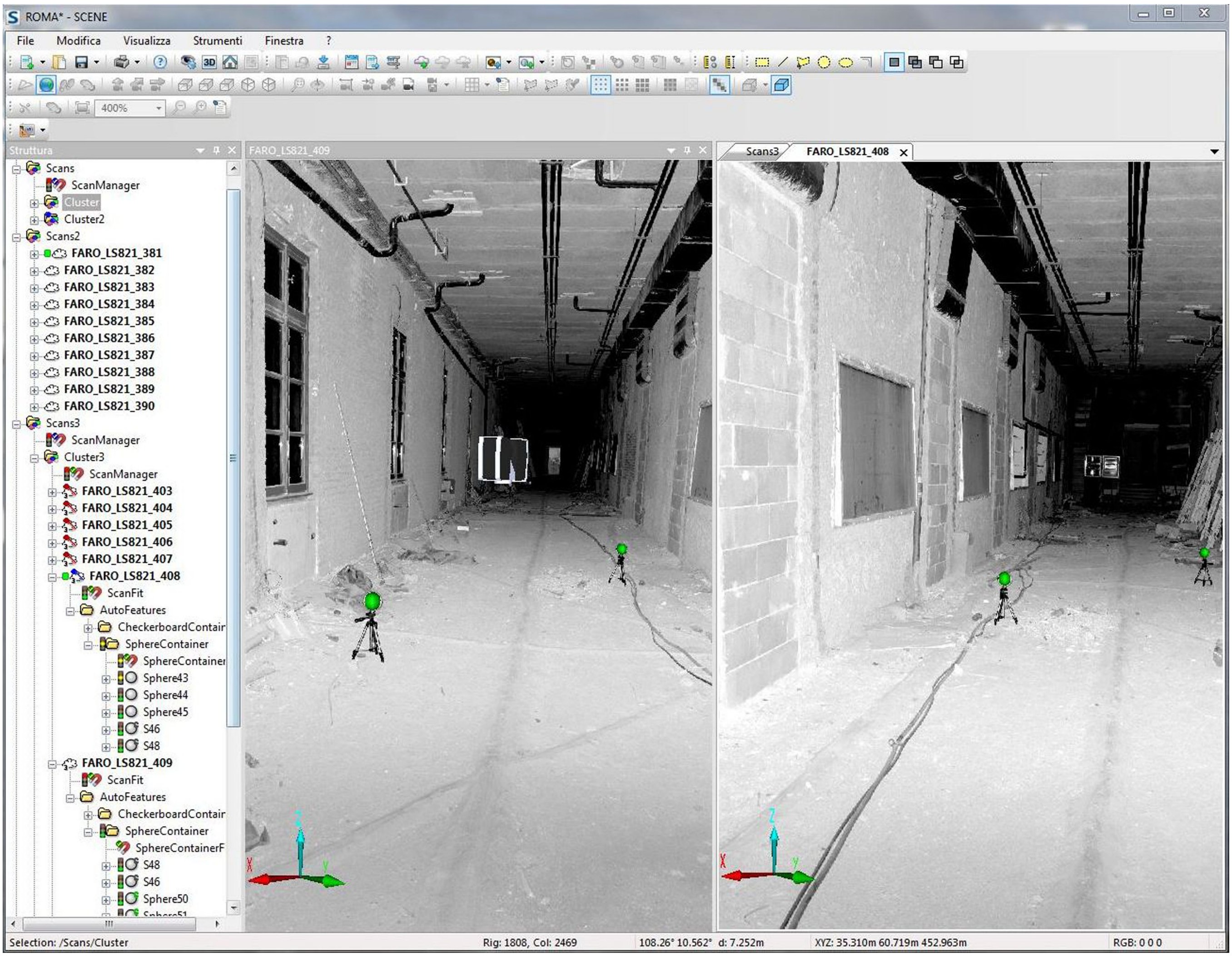



Figure 4 – Scans alignment with spherical target on the extension first floor of the *Manica Lunga*.


Figure 5 – Point cloud model of the *Piazzale Maggiore* obtained by laser scanning.

survey of the roof we used the Aibotix X6V2, an UAV equipped with a GPS receiver, accelerometer and ultrasonic sensors. It has a weight of 3.4 kilograms, a reaching distance of 50 km/h, and a reaching altitude, in optimal conditions, of 3,000 meters. The digital camera mounted on the command post is a 17.2 mega-pixel, mirror-less Olympus E-PL5 with an approximate weight of 450 grams. Once we projected the plane of flight within the AiPro Flight software (figure 6), we took 278 photo shoots using the highest resolution, with an area of overlap between shoots of more than 80% at a maximum altitude of about 60 meters above the ground, encompassing an area, aside from the roof, which included the *Terrazzone*, the *Giardino della Girandola*, the *Piazzale Maggiore* and the upstream embankment with a total surveying extension of about 1.6 hectares.

For the survey of the *Manica Lunga's* external facade, however, we had experimented the handmade prototype of an "esacottero"(weighing 2.4 kilograms) equipped with an electronic DJI A2 and with GoPro Hero 3+ digital video camera, weighing only 80 grams, which, is used for sports activities. From this video, in full HD quality, we extracted about 2,200 frames at a resolution of 2 megapixels, divided into 6 flights that framed the entire external prospect, which covers almost 3,200 square meters (table 2). With this instrumentation most of the flight operations, like the speed and course, are manual and cannot be set in advance (figure 7).

Table 2 – Digital camera settings.

| | Ambienti | |
|---|---|---|
| | Roofs + gardens | External facade |
| Resolution (Mpx) | 16,1 | 2,0 |
| Involved surface (mq) | 16.000 | 3.200 |
| Flight speed (m/sec.) | 1 | 0,5 |
| Flight duration (min.) | 12 | 42 |
| Number of pictures | 278 | 2.200 |

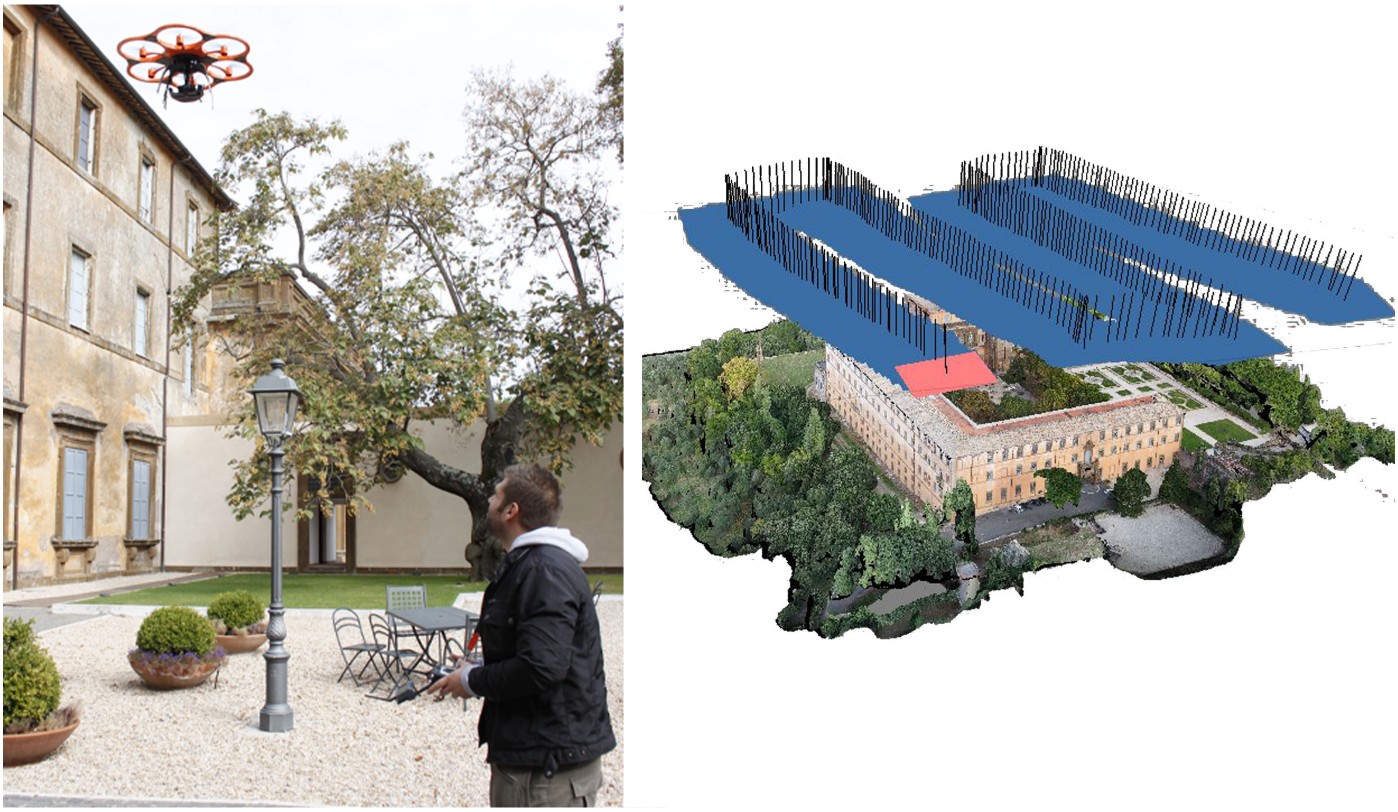


Figure 6 – Drone Aibotix X6 V2 in flight equipped with digital camera Olympus E-PL5 (left) and layout frame on the roof (right).

The three-dimensional model of the point clouds was obtained from the developing of hundreds of photo shots with the Agisoft PhotoScan software. The most significant operations were those involving the importation of data, automatic pre-alignment, and the frame by frame manual corrections, of at least two pairs of homologous points, and the insertion of the 'support point' coordinates, which were surveyed with the total station and GPS (figure 8). This last operation permits us to correct the measuring errors and to generate a true to form 3D model (figure 9), considerably reducing the distortions directly linked to the photogrammetry operations.

## The philological reconstruction of the lost facies of the *Manica Lunga*.

Analysing the historical documentation (surveys, drawings,


Figure 7 – Drone DJI A2 in flight equipped with digital video camera GoPro Hero 3+ (top-left) and flight project on the eastern external facade of the *Manica Lunga* (top-right and down).

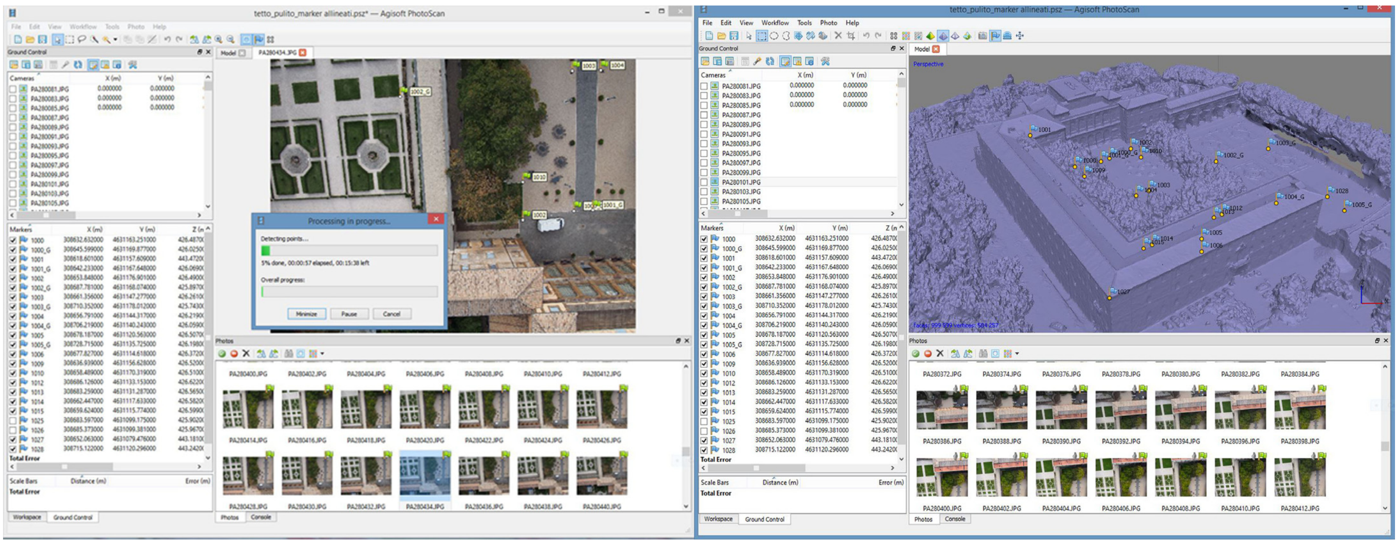


Figure 8 – Import and pre-alignment of the frames, with support points from the total station (left); 3D mesh model of the *Villa Mongradone* (right).

projects, photographs, files, etc.), studying the literature of reference, and especially by the processing and interpretation of the surveyed models obtained using modern technology of acquisition (laser scanning and photogrammetry), we have been able to graphically reconstruct models of the original *facies* of the front of the *Villa* overlooking the *Piazzale Maggiore* as they were before 1929 – more precisely dating back to 1865.

In-fact, once the infographic three-dimensional point cloud model of the enlargement of the *Manica Lunga* and the *braccio meridionale* was obtained, it was possible to realize also the longitudinal sections of the buildings. These sections, located in the added corridors and facing towards the original fronts on the *Corte* (and they were the subject, in 1929, of substantial functional modifications) have been, as will be seen shortly, a great support for the hypothetical recon-

Figure 9 – Point cloud model of the *Villa Mondragone* obtained by photogrammetry.

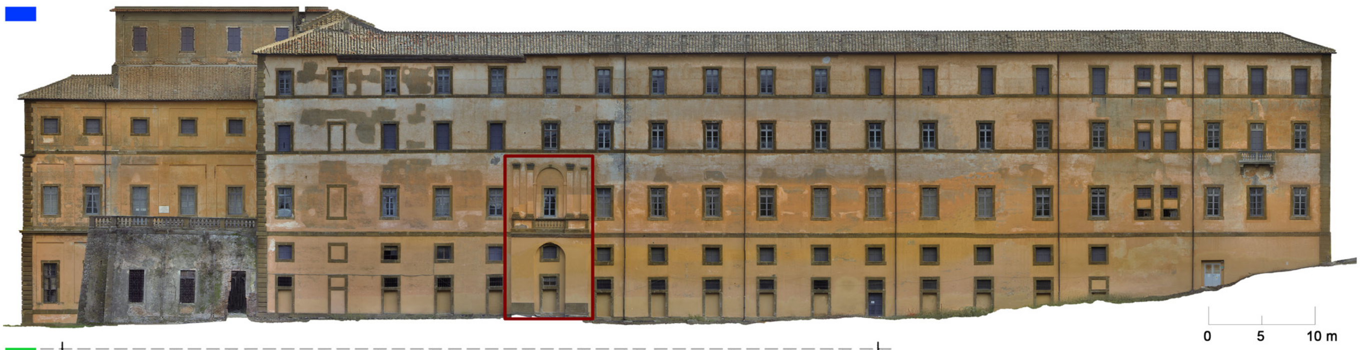
structions. Also of great importance for these studies, was the photogrammetric survey of the *Manica Lunga's* external façade. It was not restorated by Busiri Vici and for this reason it still shows signs of the 1853 attempted restoration, not visible in the span corresponding to *Piazzale Maggiore*. The orthophoto in true form was used to obtain information about the original compositional proportions of the corresponding 'lost' internal prospect of 1929 (figure 10). Another important contribution to this study was also the three-dimensional modeling (using 3D Studio Max software) of the philological reconstruction of all the internal prospects of the *Piazzale Maggiore* realized with the support of the point clouds obtained by the laser-scanner surveys.

During the first analysis, the construction of the new volumes of the *Piazzale Maggiore* generated the disappearing of the only curvilinear shaped window of the Villa; the vertical lines of the opening of the *Manica Lunga* were reduced from 14 to 13 and from 16 to 12 on the *braccio meridionale,* with the loss of the ancient visible compositional blueprint, in part and with due care, as seen in the section shown in figure 10. The majority of the windows dating back to the situation 'before 1929' were transformed, of course, into linking doors leading to the new volume, the others, instead, were sealed (above-all on the first floor). Busiri Vici also created an axis of symmetry in the facade absent in the year 1865, this axis was emphasized by the displacement, in the central position, of one of the twin doors originally present in the south western angle of the *Corte,* and by the placement of the two new doors through to the extremities of the façade (figure 11).

The small interventions, realized by Busiri Vici in 1929, have misled even some authors who have generally alluded to modernization (Franck), or have attributed the volumes of 1929 to other eras (Belli Barsali-Branchetti) or have not understood the slightest distortion of the layout of the openings defined by the roman architect-engineer (Marucci-Torresi). This allows us to say, that the latest transformations of *Villa Mondragone,* showed little respect for the original historical architecture. In this document, we focused on only one of the many upheavals suffered by the Villa less than a century ago: analyzing even one of these, we can say that one of the most valid philological and critical method to study the transformations of a factory was represented by the reconstruction using the scientific methods of disciplines of architectural survey.

## Conclusions

The interpretation of the reconstructive models and drawings proposed in this paper, were obtained, as seen, by accurate surveys taken by using integrated and advanced technologies, this should allow us, thanks to the fundamental support of the study and interpretation of iconographic testimonies and archival documents, to have a better understanding of





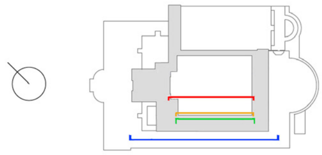


Figure 10 – Analysis of the *Manica Lunga*. From top to bottom: orthophoto of the external front obtained by photogrammetry (blue); longitudinal section, obtained from the 3D point cloud model, in correspondence to the hallway with a view to the old front (green); philological reconstruction of lost facies overlooking the *Piazzale Maggiore* modeled in 3D (red); current interior facade obtained from laser scanning (orange). Highlighted by red frame spans of the attempted restoration of 1853.

some of the transformations of *Villa Mondragone.*

This methodology can easily been used for other monumental facilities or in other contexts, becoming a valuable (and perhaps necessary) tool for the correct understanding of the historical layers. There are, in fact, many advantages of digital reproduction, including the acquisition of full 3D geometric objects; its digital reproduction, preserving the information over time; the display of the model on different software platform, etc.

The utilization of the new devices for the indirect survey and the new possibilities offered by the software, which manages the data from the mentioned hardware, in fact, has profoundly altered the method of surveying historical artifacts, and more. That is why, the incessant progress of scientific and industrial research in this field generates continuous technological improvements, and for this reason it is essential to be updated for a responsible and conscious understanding of this type of experimentation.

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Although the paper is the result of a joint research, the authors report in agreement that the paragraph 'The complex of the *Ville Tuscolane*...' is attribute to R. M.Strollo, the paragraph 'Laser scanning and photogrammetric survey...' is attribute to S. D'Auria and the paragraphs 'The philological reconstruction...' and 'Conclusions' are attribute to G. Sini.

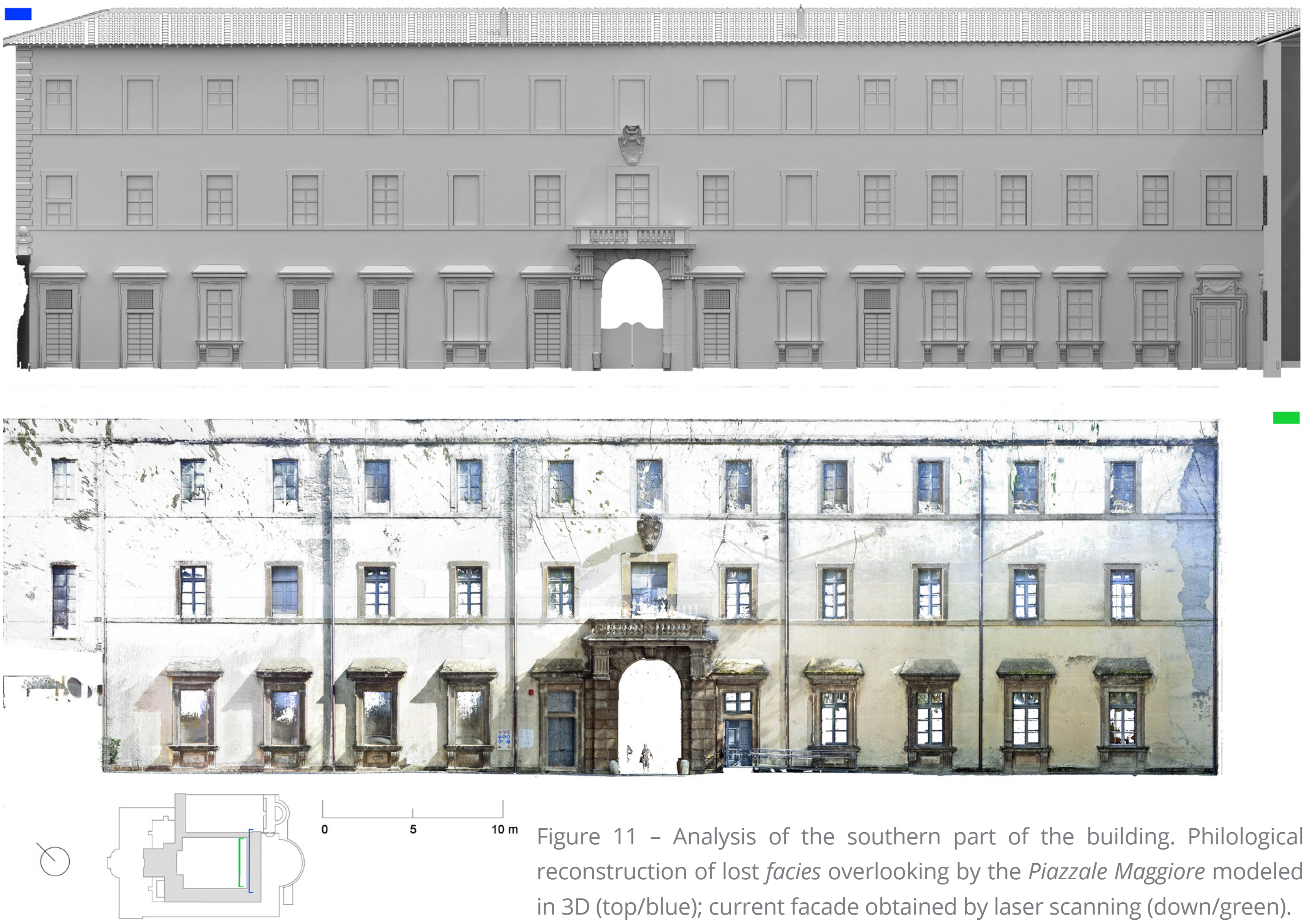

Figure 11 – Analysis of the southern part of the building. Philological reconstruction of lost *facies* overlooking by the *Piazzale Maggiore* modeled in 3D (top/blue); current facade obtained by laser scanning (down/green).

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