

3D MODELING OF COMPLEX ARCHITECTURE INTEGRATING DIFFERENT TECHNIQUES – A CRITICAL OVERVIEW

Francesco Fassi

D.I.I.A.R - Politecnico di Milano, P.za Leonardo Da Vinci 32, 20133 Milano, ITALY
Laboratory of survey, photogrammetry, cartography, GIS
francesco.fassi@polimi.it

Commission V, WG VI/4

KEY WORDS: Terrestrial Laser Scanner, Close Range Photogrammetry, Architectonical Survey,

ABSTRACT:

The laboratory of survey, photogrammetry, cartography and GIS of the Politecnico of Milano has reached in these years a good experience in the field of architectural survey, representation and 3D modelling. We applied different types of methodologies for the surveying and modelling of complex architectures: manual measurements, classical topography, photogrammetry and laser scanner. In the last years we had the opportunity to test all these kind of methodologies in a very complete and complex contest: the Real Villa of Monza, Italy. In this paper we will explain this big survey experience where we test and integrate different kind of survey methodologies. The aim is to synthesize our opinion on the actual state of art in this field, reporting the main results and some critical comments.

1. INTRODUCTION

In 2003 we began with the Lombardy Region a set of survey in the Real Villa of Monza to know in detail the condition and the state of fact of the whole body (the monumental complex covers a surface of about 36 000 square metres) of the Villa through rectified images, prospects, horizontal and vertical cross-sections as well as plans of the interiors and the exteriors of every part of the Villa. The big work of survey had proceeded later with the survey and the 3D modelling of the interiors of the whole noble floor. The principal body of the first noble floor of the Villa and was realized between 1777 and 1778 on a drawing of Giuseppe Piermarini. Every room and the big halls have square or rectangular plans and are covered by hip-roof vaults. The principal body is composed of 17 environments between halls, service rooms, ballroom, entrance hall and the big staircase. The total surface of the noble floor is circa 2039 m² [De Giacomi, F., 1994].

In this paper we shortly expose the different aim and the workflow of the case studies. In the first part I will describe what kind of instrumentation we used for the work and what kind of methodologies we adopted to elaborate the data. In the second part of the paper is presented a critical dissertation about the obtained results and a description of the difference, the difficulties and the problematic we found to conduct both the survey and the elaboration. In particular the aim is to answer to these question “It’s better Photogrammetry or Laser Scanner approach?”, “Is the manual, topographic to forget?”.

Processing and results are explained. Some particular case studies a different scale are explained in detail: The entrance hall, the walls survey and modelling methodology, high resolution decoration 3D reconstruction.

2. THE REAL VILLA IN MONZA: GOALS, WORKFLOW, METODOLOGIES, RESULTS .

2.1 Aim

The main aspect of this work is the integration of different kinds of survey: manual, topographic, photogrammetric and laser scanner. The reported case study is a good example to test different kinds of survey methodologies and their integration. In fact the work in Villa Reale is oriented to technical-architectural studies as well as to representative and publication aims. In particular for the three-dimensional representations, the virtual navigation of the rooms and the creation of an online virtual museum is one of the primary goals. Moreover our research interest is focused on the understanding of which kind of digital surveying technique (photogrammetry and laser scanner) and elaboration is able to better represent an element rather than another one and how it is possible to integrate all the different data into the whole “elements group” [Monti C. et al., 2005].

During our work, we had to face to face two main problems: (i) the multi-scale characterization of the Villa’s representation and (ii) a very short time to finish the work for restoration time request.

The final results of the project consist of different kinds of products: a collection of board and drawings with all 2D and 3D technical and architectural information and a virtual online museum.

2.2 Instruments and methodologies.

We use different kind of laser scanner instruments: a time delay one, for low/middle resolution and massive data collection and triangulation-based sensor for scanning details at high resolution. In particular:

Leica T-scan: the T-Scan is a high-speed hand scanner normally used for high precision industrial measurements. The working distance (depth) ranges between 40 and 120 mm while the scanning width (within working distance) ranges respectively between 90 and 25 mm. Set-up times are minimal, and there is no need for photogrammetric targets. The accuracy of the instruments is about 50µm.

Leica HDS 3000: this active sensor is a TOF (Time of Flight) laser with a system performance between 0 and 100 m range. The accuracy in the distance measurement is about 4mm; in the position measurement is 6mm and in the angle (both vertical and horizontal) is about 60microradians. This type of scanner let also a target recognition that can be very useful for scans registration. The accuracy in the target acquisition is about 1,5mm; and the nominal precision for the surface modelling is about 2mm (Information taken from official Leica website.).

As far as the photogrammetric survey concerns, we employed a **Rollei db44** digital metric camera with a CCD-Chip of 36,720 x 36,684 mm which provide for images with 4080 x 4076 pixel. We use one 40 mm Zeiss Lens. The camera have an official calibration certificate.

2.3 Workflow and results.

The whole work in the Villa Reale consisted in the survey of seventeen room of the noble floor. 3D models, orthophoto of the vaults and rectified images of walls were required.

For every room, we collected a large amount of points topographically measured to connect and georeference all the data and to support the image triangulation.

The acquired high resolutions images can be visualized up to a scale 1:10. In particular this type of data is used not only for the

recovery of the 3D geometry of some architectural areas but especially for the texture mapping of the 3D models at the end of the whole process. For the 3D modelling of the vaults a typical aerial photogrammetry image acquisition was applied [Guidi G. et al., 2004]: generally we use three strips with 8/9 photos per strip. For the photogrammetric elaboration we use SOCET SET and/or PCI Orthoengine. We needed powerful software instruments to make robust triangulation and get a sufficient accuracy for the final representation. But the use of aerial photogrammetric software produces a series of problems. Every photo-block and ground points set should be roto-traslate in a standard reference mode (z-axis pointing towards the camera) and this causes some loss of time and precision and difficulties in choosing a new local temporary reference system. Moreover the creation of the vaults orthophotos is a quite difficult job both in the acquisition phase and in the elaboration one for the presence in every room of big chandeliers. These objects cause shadows and different illumination in every photographic shot, leading to the necessity of acquiring more photos to get hidden particulars and also a time-consuming post-processing in the mosaicking phase for every single orthophotos.

For the 3D global modelling, a part from images, we used range sensors. We performed different kind of scans: the HDS 3000 was employed at low/middle resolution (circa 1cm) to make the general survey (360°-scans) of the whole noble floor of the Villa (survey of the whole room in circa 3 hours with circa 2 million point/acquisition). In this way we were able to complete all the scans in few days and respect the imposed short deadline. With the big amount of measured data, we could extract all the basic information like corners and discontinuity lines useful to build the structure of the 3D model. The

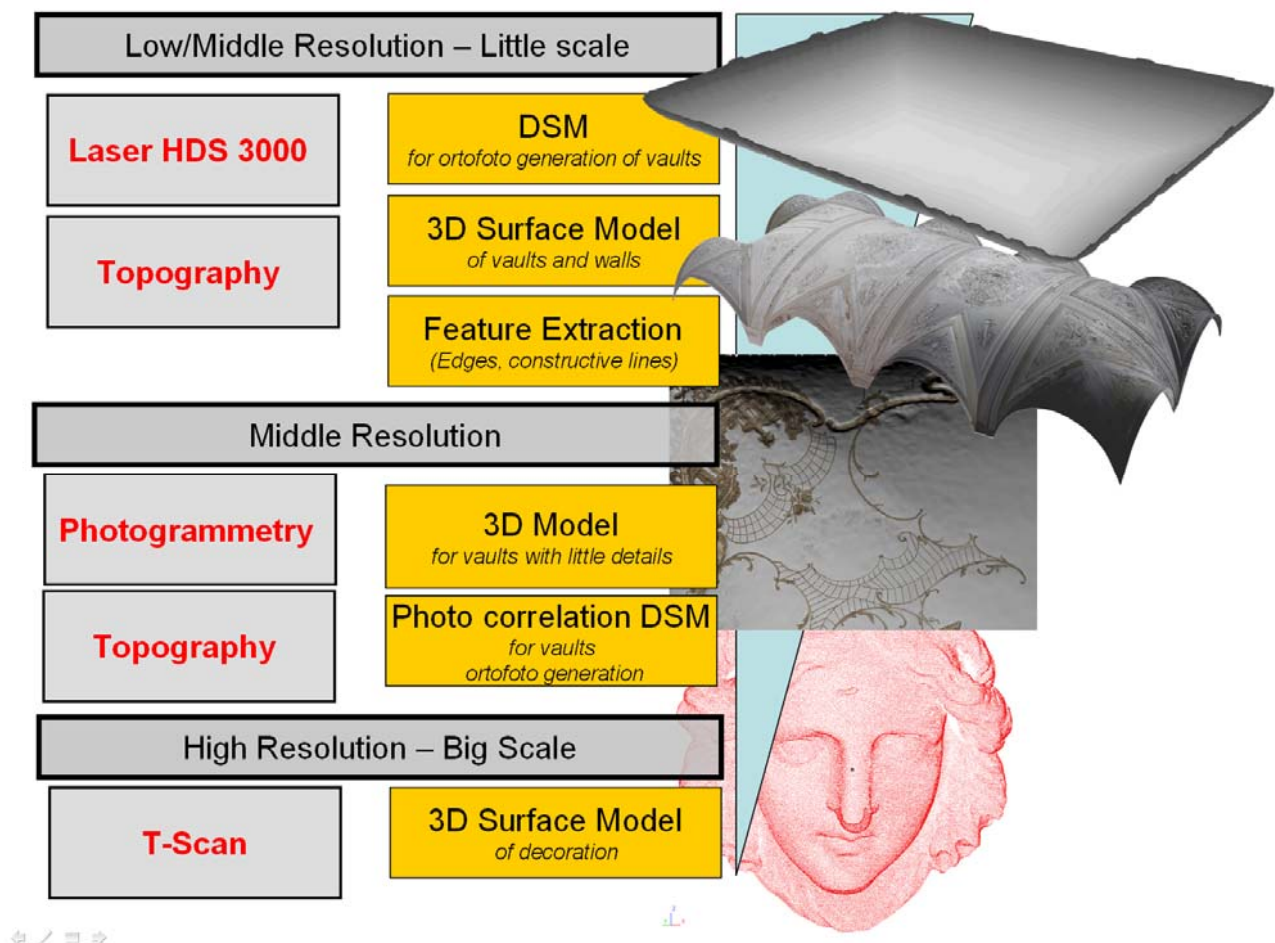


Figure 1: Scheme of our work in the noble floor of Real Villa.

extraction of this information is not an easy task normally and we used the photogrammetric and data and topographic survey to integrate and control the quality of the entities extracted from the range data. The HDS 3000 was also applied to make a middle-high resolution scan (circa 0,5 cm) of some details that are interesting and important elements in the 3D reconstruction of the single rooms. Objects like marble fireplace, decorated niche and doors or complicated windows were scanned singly, modelled and later integrated in the simplified 3D structure of the rooms.

The multi-techniques (Figure 1) approach supplies an optimal tool to speed up and to optimize both survey and 3D modelling tasks and, at the same time, is a great method to produce multi-scale and multi-functional results. This type of approach allows to have different kind of data that can be integrate in order to create:

- classical technical architectural drawings
- detailed high resolution digital 3D objects
- textured raw models for virtual navigation or web application

Technical architectural drawings are useful for the practical and technical management of the project and must be structured for a proper use, with respect to a given precision and tolerance. Normally these kinds of products are in CAD-CAM format as a standard in the architectural word.

Detailed 3D models help in the comprehension of the architectural object, the photorealistic representation (rendering) and also let the creation of two-dimensional elaboration with the extraction of sections, slices, edges etc.

In the next sections we report some results of the different modeled areas of the Villa: the entrance hall, the walls, the ornaments.



Figure 2. View of the entrance hall before the restoration work. It's possible to see the complex geometry of the vaults: almost vertical elements, many undercuts, the diffuse light color and the lack of texture on the vault doesn't let a good matching in the 3D model generation in particular when taken are very close to the vaults.

2.3.1 The entrance hall. It was digitized with the Leica HDS 3000 with 7 scans. Every scans was at a resolution of about 1cm at a distance of ca 15 m. We needed 3 days to complete the survey. The main problem in this case is the huge number of points to elaborate, as each point cloud has in fact circa 8 million points. All the clouds could be handled and registered together with Rapidform XO, but only after a drastic filtering and point sampling with a resulting heavy loss of resolution.

At the end of the elaboration the obtained surfaces are useful to create a complete model of the vault for a 3D virtual navigation

but they are too simplified and have a very low-resolution for a detailed 3D representation or for the usage for orthophoto creation. In fact all the edges are too smooth and the decoration create only noise on the surface without bringing important and real information to the shape (Figure 4).

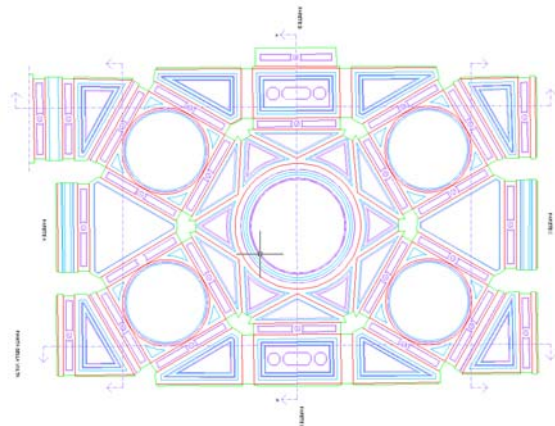


Figure 3 The plan of the entrance hall. The four external vaults have a diameter of circa 3.3 m. The central one has a diameter of 4.70 m. The elevation of the vault is circa 8 m.

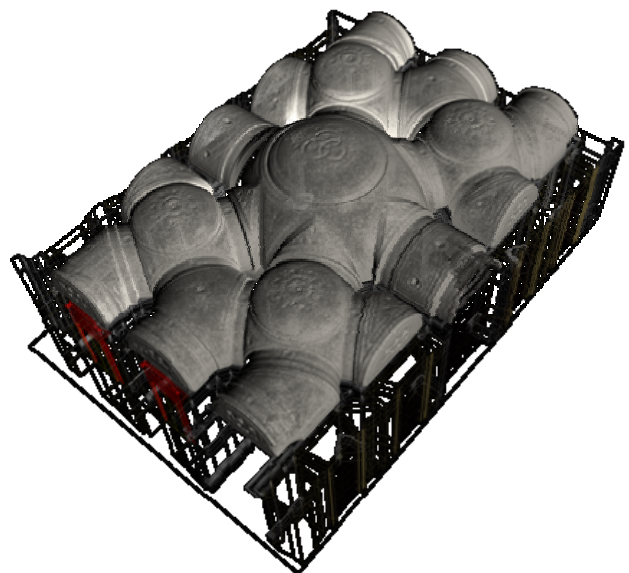


Figure 4: Global 3D model of the entrance hall.

To work with more detailed models we did a back step to the original scans to consider and to handle every single part. In this way we can use more detailed scans (the resolution of the original vaults point clouds is surely less than 0.6 cm) but we have to georeference every single part separately with a subsequent lost of precision. In order to study and to test the differences between different methodologies we try to build the 3D model also from images. For research purposes, the complex geometry of the vaults was also modelled using images and photogrammetric software. The image acquisition was a relative laborious job. We took about 27 photos of every vault: from nine position and with three different perspective from every perspective to create a good image-block for the bundle adjustment and also to reach all the part of the vault. The external orientation parameters of the block are calculated in PhotoModeler (Figure 6) using different set of images and than exported for the surface measurement and generation.



Figure 5: Laser scanner surface of a part of the vault of the Villa Reale entrance. The represented surface is the meshed original surface. The resolution is about 0.5 cm and this let to model with good accuracy detail whose dimension is bigger than 2- 2.5 cm.

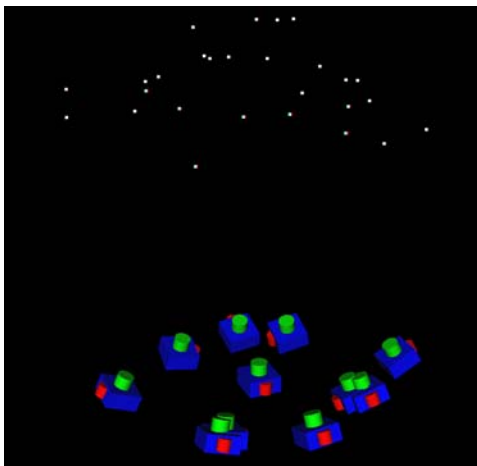


Figure 6: A scheme of some taken with the control point used in the bundle adjustment with PhotoModeler.

Firstly SocetSet 5.2 was tested. The initial results of the SocetSet DTM extraction tool were not satisfactory due to different reasons: (i) the texture of the vault is not sufficient for a good and automated image matching; (ii) the geometry of the vault is very complicated and being fully 3D the object is not really optimal for normal SocetSet aerial application. Therefore the only solution to recover a good surface model of the vaults was to use the laser scanner point cloud as “seed DTM”. The result are reported in Figure 5. This type of product can be used for the orthophoto creation but not as precise geometric 3D model.

In Figure 8 the 3D comparison between the two results (laser scanner and SocetSet) is reported. The main big differences are in those areas with a big undercut region. The laser scanner was able to scan more surface, while, the photogrammetric images could not cover this zone accurately. The second big difference is the noise. This is probably due to the lack of texture in the image data that did not allow a very good matching process.

As second software employed to recover a dense surface model of the vaults we test the Topcon PI-3000 which gave a relative good result (Figure 9). The generated surface contains most of the details even if, as expected, the same problems are present in the undercut areas and some noise due to the low texture.

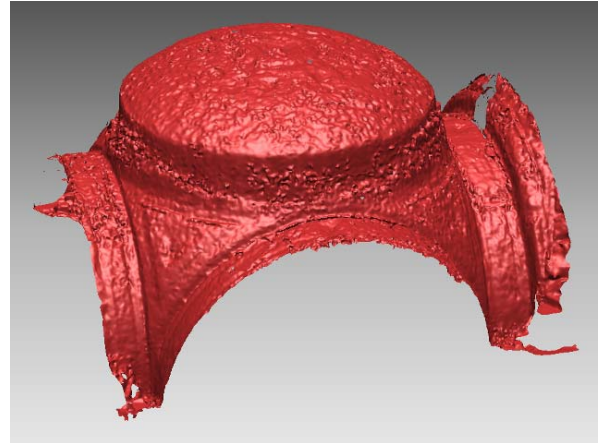


Figure 7. DSM extracted using SocetSet ‘DTM Automatic extraction’ tool, using the laser 3D model as Seed DTM

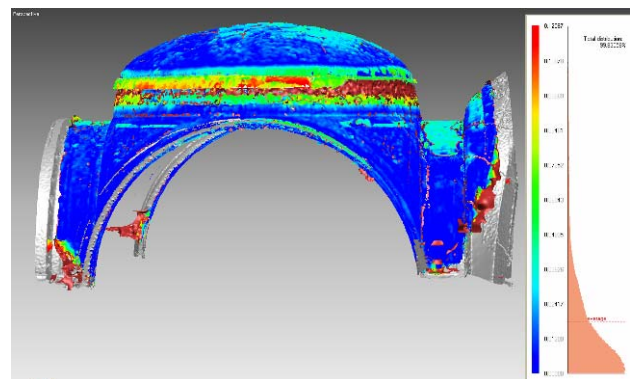


Figure 8: Comparison between the Leica laser scanner surface model and the photogrammetric one, recovered using SocetSet. The zone with biggest error are in the undercut region where there is also a 12 cm of difference. In the other zones the noise of about 1cm is caused from the noise.

The negative aspect is that the software handle only with photos that have the “k angle”. For this reason to complete a good 3D model of this kind of vault many set of photo must be treated and oriented in distinct projects. The post-processing operation to clean every DSM coming from each project and to merge them together would be a laborious modeling process.

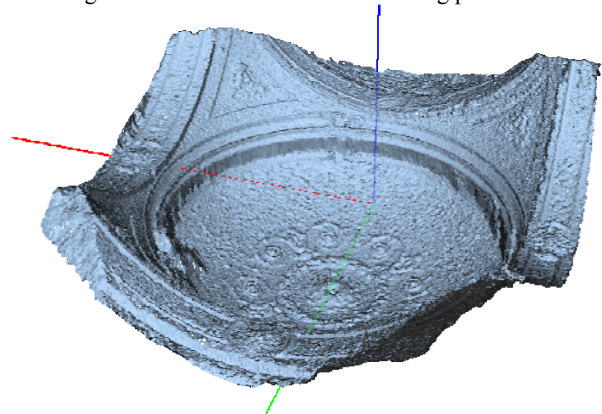


Figure 9: The DSM extracted using the matching of Topcon PI-3000 software. The visible part of the photo show a relative good results also near the undercut region because the used photos was oriented to this zone. From the other side the result is not so good. For this reason is advisable to take different shots from different position and build different DSM that can later be elaborated and merged together.

Finally we conducted a test using the in-house matcher SAT-PP. The program was developed at the Institute of Geodesy and Photogrammetry of ETH Zurich, Switzerland [Zhang, 2005; Remondino and Zhang, 2006]. This software is a matching algorithm that automatically extracts a DSM from two or more oriented photos. The particularity of the software is that it combines different kinds of matching strategies and works with different image features: grid points (regularly distributed), feature points and edges. Furthermore, if more than 2 images are employed, it combines simultaneously all the data performing the so called Multi-Photo Geometrically Constrained Matching [Gruen and Baltsavias, 1986].

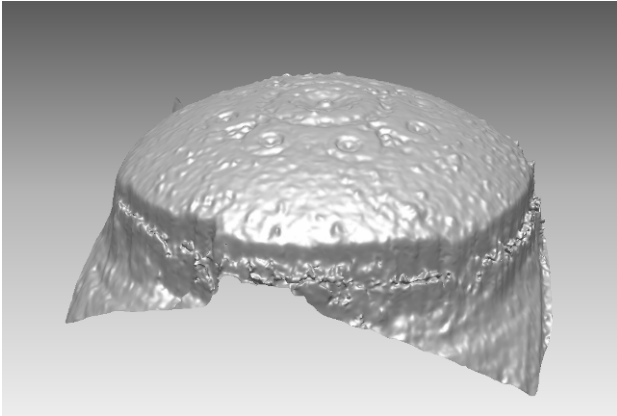


Figure 10: 3D meshed model generated using SAT-PP.

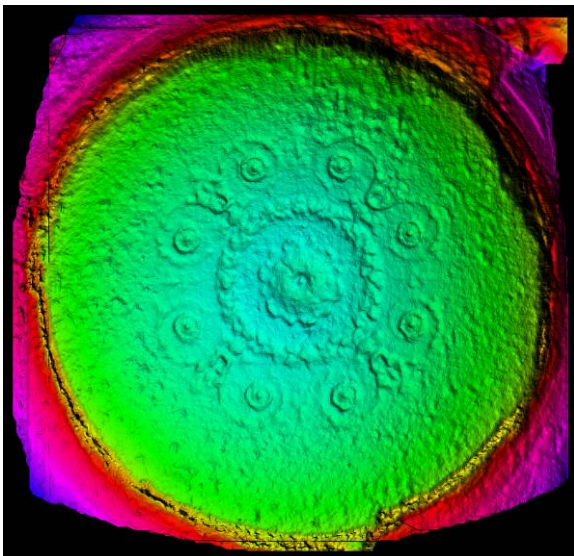


Figure 11: 3D model of the vault (coloured with elevation information) created with SAT-PP matcher.

The results of SAT-PP (Figure 8 and 9) are very close to the SocetSet one: the undercut region gave a bad response and create a lot of topology error. Also in this case we use only one set of photos that have the same perspective. Using different set of shots and merging the relative created DSM can give a better results but with a huge post-elaboration time.

In Table 1 the presented test cases are summarized. The Topcon software seems to have the better result. This software can apply the bundle adjustment and create a good DSM in term of geometry and also noise. SocetSet gave a relative good result usable only for photogrammetric purpose as orthophoto creation but not sufficient for 3D model reconstruction of a hard complex shape like this. Moreover in this case the use of a

support DTM was necessary. For Sat-PP gives more or less the same results as SocetSet but without the use of one Seed DTM. In particular in Photogrammetric approach the topographic measurement are always required to georeference all the data together and to scale all to the right measure. In the laser scanner approach they are not necessary but can be useful for the scans registration and for a final quality-test of the complete model.

For complicated architectural geometry, like the entrance hall, the laser scanner acquisition is for sure the most useful and faster method. The photogrammetric process doesn't give a very excellent result. With the advent of new software that are explicitly for close range application (for example PI-3000 of Topcon) the photogrammetric approach could become a useful methodology also in a very complex case like this.

2.3.2 Walls models. For every walls the model were built very simply from direct geometric survey or extracting feature manually from laser scanner survey. For rich decorated areas laser scanner and photogrammetry were both applied.

In this case photogrammetry allowed to recover better results, faster and in particular with less laborious work compared to a range-based approach. From few images the operator can build simple DSM using triangulation and automatic DSM extraction; in post-processing the extraction of lines and edges in stereoscopic mode help to improve the results. The laser scanner creates a relative fast model but it can be sometime a very hard work in the post-processing phase. There are many cases that need huge 3D modelling elaboration to fill holes and parts that where hidden by decoration or jutting edges.

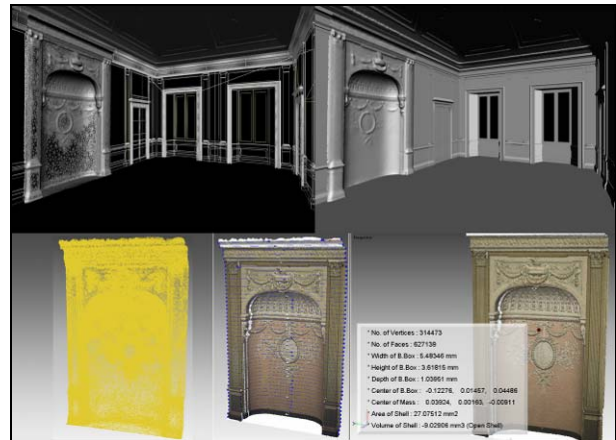


Figure 12: "Sala da Pranzo di Famiglia": The solid models generated by Boolean operation and a detail (due to the complex geometry of the object; is generated as mesh) inserted in the model.

In the aim of the work to complete the work as soon as possible and with the best results, the combination between topography, direct survey and photogrammetry was optimal; the integration of laser scanner detail makes the model more complete.

2.3.3 Modelling some ornaments and decorations. For some decorations we employed the T-Scan System (gently supported by Leica Metrology Italy), a laser-scanner normally used for mechanical precision measurements. This kind of instrument allows to work in difficult conditions, with high precision, deep resolution and very good handiness and flexibility.

Table 1: Comparison table between the different approaches and software results.

	Laser Approach	Photogrammetry Approach			
Acquisition Phase					
Time of Acquisition (Single Vault)	10 minutes	1Hour			
Time of Acquisition (Complete Vault)	14 hour	Circa 24 ore			
Acquired data (single vaults)	1 local scan	27 photos			
Acquired data (Complete vaults)	6 (180°scans) 1 (360° scans)	Circa 80 shots			
Resolution/ footprint	Circa 6 mm	Circa 2 mm			
Topographic acquisition	Not necessary but useful	Requested			
Post-processing phase: Model Creation (Single Vault – 3 Photo set)					
	RapidForm	Socet Set 5.2	Photo Modeler	PI-3000	Satpp
Time to orient photos	/	/	3 hours	3 hours	/
Time to create DSM (5mm)	/	Circa 1.5 hours	/	Circa 1 Hours	Circa 1.5 hours

The Villa is rich of wooden decorations and friezes that are in bad condition or lacunose. In particular this kind of ornaments consists of repetitive geometric figures around doors and windows. This kind of operation is useful for the restoration work and for the reproduction of the object with rapid prototyping. These models were afterwards integrated in the global 3D model. For these kinds of objects the use of photogrammetry can be also useful and for sure more practical and cheaper. For this reason, we tested a photogrammetric approach but it failed as the resolution that we could reach with our metric camera was too low for detailed 3D modelling purpose. To obtain a very high resolution model, the images should be acquired in macro-mode or far-away but with one tele-lens. Our metric camera does not have this kind of modality and the macro-focal step is also not calibrated. We are still working on this to test the photogrammetric 3D modelling in macro modality. Moreover the lack of texture of the decoration would create different problems during the matching elaboration .



Figure 13: The whole wooden decoration that we scan with Leica T-Scan. In the red box is possible to see the particular described in the paper.



Figure 14: A particular of the surface mesh of the ornament generated using the Leica T-Scan. The size of the shown part is circa 7 cm.



Figure 15: A particular of the prototyped ornament. It is evident the high level of detail of the object. This kind of prototype can be used to build silicone moulds or stamps for wax or sand melting.

3. CRITICAL DISSERTATION

3.1 Data acquisition and processing: laser scanner, photogrammetry and topographic measurement.

This paper will be a little dissertation about the use of photogrammetry and laser scanner or the integration between the two kind of survey methodologies.

In the case of the entrance hall of Villa Reale we have a good example to describe the three different approach for the survey and for the modelling of the hall.

In particular it's very important to think what is the difference between a topographical survey (total station), a laser scanner measurement or the photogrammetric modelling.

3.1.1 **In a classical survey** the operator measure a low number of points that he can simply naked-eye recognize and that must suffice to reconstruct the geometric form of the object in a simplified way. *Basically he surveys only what is useful to build the model.* This kind of survey is relative slow and must be accurately prepared: you must have a priori knowledge of the object and the elaboration workflow of the surveyed data.

The elaboration procedure is in this case relative simple and quick because everything is already planned at the beginning: the acquisition phase must be done already thinking at the final elaboration step. The final 3D object is naturally simplified but the accuracy and the simplification rate of the final product is known because every procedure is conducted manually. Sometime, as in our case, this simplification is not enough for the requested representation scale, the topographic and the geometric relief was to simple for the final purpose and also very difficult to plan and to execute with major resolution.

The topographic survey is anyway the essential way to georeference all the part together and to control the final precision.

3.1.2 **With a laser scanner** survey we can get the total complex form of the object but we can't select the single points to be surveyed. Generally the whole scene is scanned *with a predefined (low) resolution, then only the area of interest is acquired at higher resolution.*

In this case the operator can extract useful information from the acquired data or elaborate all the data together building the total form of the object. The level of simplification depend from the predetermined scan resolution. The acquisition is very fast, simple, doesn't require particular skin but is today still very expensive and required an instrumentation that is portable but not extremely manageable. The elaboration phase is on the contrary still very hard and less automatically and requires a more detailed explanation .

3.1.3 **Photogrammetry.** One time photogrammetry was mainly used in cartographic application. With the event of digital photogrammetry, it started to be more and more often used also to digitally document cultural heritage contests.

In the last decade, with the production of several commercial software, photogrammetry became really an important methodology also in architectural contest and it can also be used from not expert people. The photogrammetric procedure is very close to the laser scanner one: only instrumentation is different. *We survey everything in toto with a predefined pixel resolution that depends on the camera focal length, object distance and sensor pixel size. The elaboration product is (as for laser scanner) a DSM that can be used to extract what I really need for the modelling or elaborate all the complete model.* The photos must be done in stereoscopic way and the operator must control to see every point of the object at least in two photos. The difference with laser scanner is that photogrammetry requires an intermediate step (the photo orientation procedure) before obtaining the 3D model. The difficulties of this kind of survey is that the photos must be done very accurately, every shots must have and the same illumination same equalization; different shadows, illumination and reflection can create very big problem in the matching elaboration for the 3D model extraction. For this reason some reflective and bright object (as coins for example) are quite

impossible to be photographic surveyed. The possibility to see the scene in 3D mode with stereographic monitor help the operator to apply DSM manual correction and to introduce in the model some corner, edges, lines that help to a correct final results.

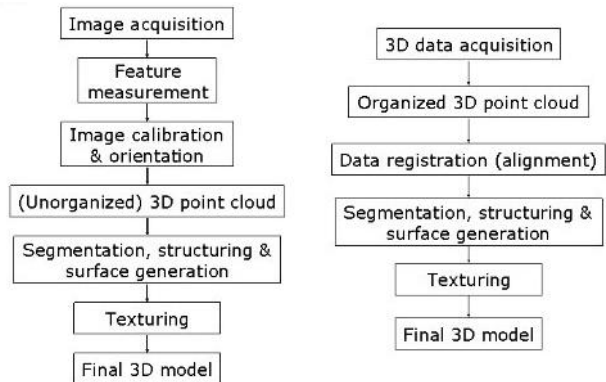


Figure 16: The different workflow of Photogrammetric (on the left side) and Laser scanner (on the right side) methods.

3.2 The modelling

For both laser scanner and photogrammetry, the modelling results is generally a DSM, represented by a point cloud or a triangulated mesh that can be elaborated in two ways.

Having a point cloud, the most automatic way is to create a meshed surface of the object applying automatic mesh generation and eventually some kind of filtering and post processing procedure to refine the results and to clean up the object from topological errors. This kind of elaboration let to have at the end the total 3D geometry of the object. This let to elaborate complex shapes with no mathematical surfaces.

The second kind of elaboration is the extraction from the whole model constructive lines, edges, break-lines that can help to build a simplified model with Boolean procedure typical of CAD/CAM 3D modelling.

In both case and after huge elaboration procedure is very difficult to understand what kind of precision has the final model. Most of the commercial software apply automatic procedures and don't give a significant measure of the accuracy of the final product. This is particularly remarkable in the case of cultural heritage modelling where the surfaces are definitely more complex and geometrically irregular. Many algorithms that can be used in commercial software give very good results with mechanical objects where the edges are very clear, the curvatures follow analytical laws, and the surfaces and lines can be brought to simple geometric primitive as planes, straight lines, circles, spheres and cylinder. Moreover in mechanical or industrial applications, a relative little object is generally considered. In the reported case, it is clear that kind of automatism can't be so easily used. In the cultural heritage field the artistic estrus and the time wear make every surface rich of imprecision, singularity and patchiness. From time to time the operator must decide what should be modelled and which kind of simplification can be applied. In fact the operator must consider the purpose of work.

In general the modelling of an artistic object has another mean of the industrial Reverse Engineering. The aim is to have a digital copy of the object as it is at the moment of the survey step and not to get the object as it was originally: the 3D model is "a 3D image of the state of art at a particular time". Also for restoration and conservation purpose the aim is to represent all

the particular and the details of the object surface. Moreover there is not a reference object with which I can compare the obtained digital model.

In this sense the photogrammetry and the laser scanner methodologies can give surely a good results but the elaboration procedure of the 3D model is still a very hard-work in particular when the model is very complex (As in the entrance hall case). The operator must have a professional skill in 3D modelling and design to get a good results. Normally this kind of knowledge is not own of restorers, architects, surveyor, or also for expert of photogrammetry and in this time seem to become very important to get a good knowledge of this kind of application.

The last important thing to evaluate before beginning the work is what kind of accuracy I need at the end of the job and how accurate would be my model comparing to the original object. With the classical (topographic and geometric) survey, as already told, the measurement error is known a priori and the simplification is imposed by the operator.

In the case of laser scanner the things is more complicated. In industrial application a previous CAD/CAM digital model of the object exists and can be consider as reference. In this case the precision and the accuracy of the model can be compared. But normally in architectural and cultural heritage contest there is not a reference object and you can't examine resemblances and differences between the real object and the elaborated digital model.

The instruments acquire data with its own accuracy and with a resolution chosen from the operator, the unknown is due by all the subsequent elaboration. This, as described in the paper, are relative automatic and oft can not be controlled by manual parameter that can be changed or chose by operator; so the final results can't also be completed tested by some quality standard. In some software there are some parameters to adjust but often these have an obscure meaning and no explanation is added on help or online tutorial. The setting of these values are often dictated by experience. A lot of elaborations cause the movement of vertices; the smoothing of surfaces or the addition of parts (for example in the case of holes filling) modify the original data and the evaluation of the deviation between the model and the real object is very hard.

The photogrammetric elaboration as the bundle adjustment or the matching gives back statistical parameter that assures a mathematical evaluation of the accuracy of the process. The argument about the post processing of the 3D model is the same already done for laser scanner 3D model.

4. CONCLUSION

The subsequent table can be a good conclusion of the reported work. Photogrammetry and laser scanner have different approaches to survey a cultural heritage object. The difference between the two methodologies depends today in particular by costs and software development. The photogrammetric one is today surely the most cheaper opportunities but the software for close range application are still very few and are still not extremely good to complete all the process and automatically generate dense surface models. The laser scanner solution is very expensive (excluding some particular cases) both for hardware and for software but it's indispensable in very complicated case if an accurate model is requested.

In both laser scanner and photogrammetric approach, a topographic survey is necessary or at least suggested for quality testing and precise georeferencing procedures.

For both methodologies "the modelling aspect" becomes more and more important. A new skill to add in our preparation!

Table 2: Summary table Photogrammetry versus Laser

	Photogrammetry	Laser scanner
Tested hardware	<ul style="list-style-type: none"> • Rollei DB44 Metric 	<ul style="list-style-type: none"> • Leica HDS3000 • Leica T-Scan
Tested software ¹	<ul style="list-style-type: none"> • Socet Set 5.2 • Photomodeler • Topocon PI-3000 	<ul style="list-style-type: none"> • Rapidform • RapidformXO • Geomagic • Polyworks
Conclusion	<p>Ideal for:</p> <ul style="list-style-type: none"> • Object with distinct and abundant texture. • Object that can be described mainly by point- or line-based structures. (geometric shapes) • Object with not reflecting surface. • Object also in very difficult position. 	<p>Ideal for:</p> <ul style="list-style-type: none"> • Object that can be described mainly by surface-based structures. • Very complex objects. • Object that can be reached relative simply. • Object with poor or no texture.
First Results	<ul style="list-style-type: none"> • A set of Photo that need to be oriented 	A raw discrete 3D Model of points
Final Results	<ul style="list-style-type: none"> • 3D DSM model • Photogrammetric products: Orthophotos and Rectified Images 	3D DSM Model
Costs of hardware	Cheap (Amateur camera) or not so expensive (metric camera).	Very expensive or hugely expensive (In case of T-Scan)
Costs of software	Cheap (Photomodeler, Iwitness, Australis) Can be also expensive when we speak about SocetSet or LPS	Expensive to very expensive.
Difficulty skill in software usage	<ul style="list-style-type: none"> • Good preparation in photogrammetric theory; but some commercial software are "for everybody". • Good experience and preparation in 3D modelling for post elaboration of the 3D model. 	Good experience and preparation in 3D modelling
Difficulty skill in hardware usage	Good experience in photography.	Very simple procedures that require only some experience in software usage..

¹ The software was tested on different computers. Every computer was furnished with 2 Giga Ram and professional Graphic card.

REFERENCES

De Giacomi, F., 1994. *La Villa Reale di Monza*. Editrice Associazione Pro Monza.

Gruen, A., Baltasvias, E., 1986: Adaptive least squares correlations with geometrical constraints. *Proc. of SPIE*, Vol. 595, pp. 72-82

Guidi G, Beraldin A.J., Atzeni C (2004) High-accuracy 3-D Modeling of Cultural Heritage: The Digitizing of Donatello's "Maddalena. *IEEE Transactions on image processing*, Vol. 13, NO. 3

Monti, C., Achille, C., C.C., Monti, Savi, C., Survey and representation of the Villa Reale di Monza to support of the international design competition, *CIPA 2005: XX International Symposium*, Torino, Italy, 27 September-1October

http://www.leicageosystems.com/corporate/en/ndef/lgs_35152.htm (accessed 4 June 2007)

http://www.leicaeosystems.com/corporate/en/ndef/lgs_62189.htm (accessed 4 June 2007)

Lombardy Regional Government and the Monza Municipality, 2005. www.villarealemonza.regione.lombardia.it (accessed 4 June 2007)

A cura di Marina Rosa, *Villa Reale di Monza*, I quaderni, Ministero per i Beni e le Attività Culturali Soprintendenza per i Beni Architettonici e per il paesaggio di Milano, Beta Gamma editrice, 2003G.A.)

Ministero per i beni e le attività culturali, Soprintendenza per i Beni Architettonici e per il Paesaggio di Milano (2006) *I quaderni della Villa Reale di Monza*. – A cura di Marina Rosa, ed BetaGamma, Viterbo

Remondino, F., Zhang, L., 2006: Surface reconstruction algorithms for detailed close-range object modeling. *IAPRS&SIS*, Vol. 36(3), pp. 117-123

Zhang, L., 2005: Automatic Digital Surface Model (DSM) generation from linear array images. PhD Thesis Nr. 16078, IGP, ETH Zurich, Switzerland, 199 pages



Figure 17: Another example of meshed model of vaults

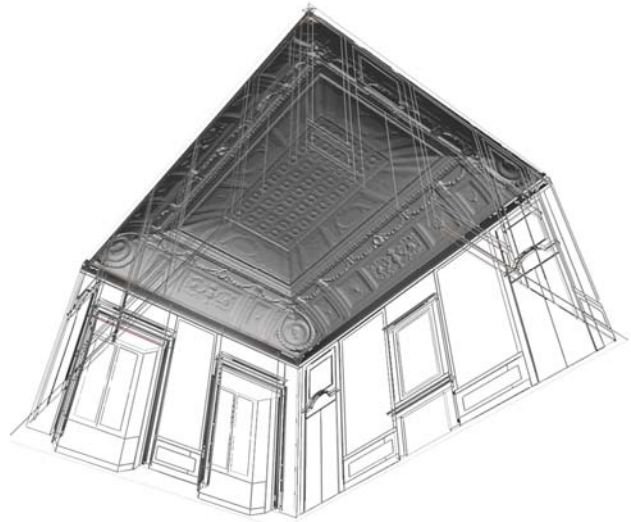


Figure 18: A wireframe visualization of the Pendola room. The meshed vault surface is assembled in the CAD 3D model of the rooms.

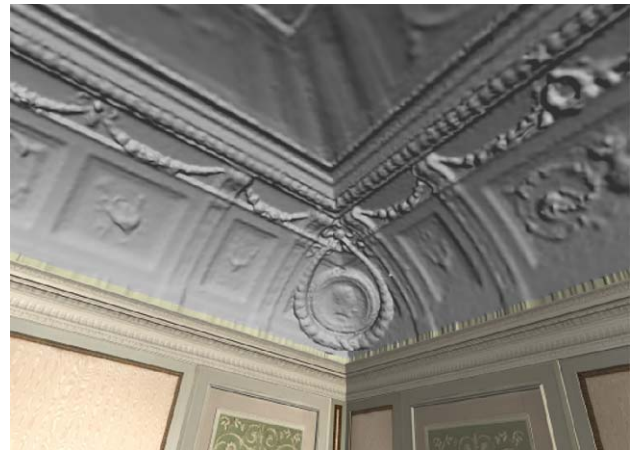


Figure 19 An example of the 3D model of the "Pendola room" in the Villa. In the upper image the meshed surface of the vault is assembled on the 3D textured model of the walls. Below the same model but with the colour orthophoto projected onto the vault.

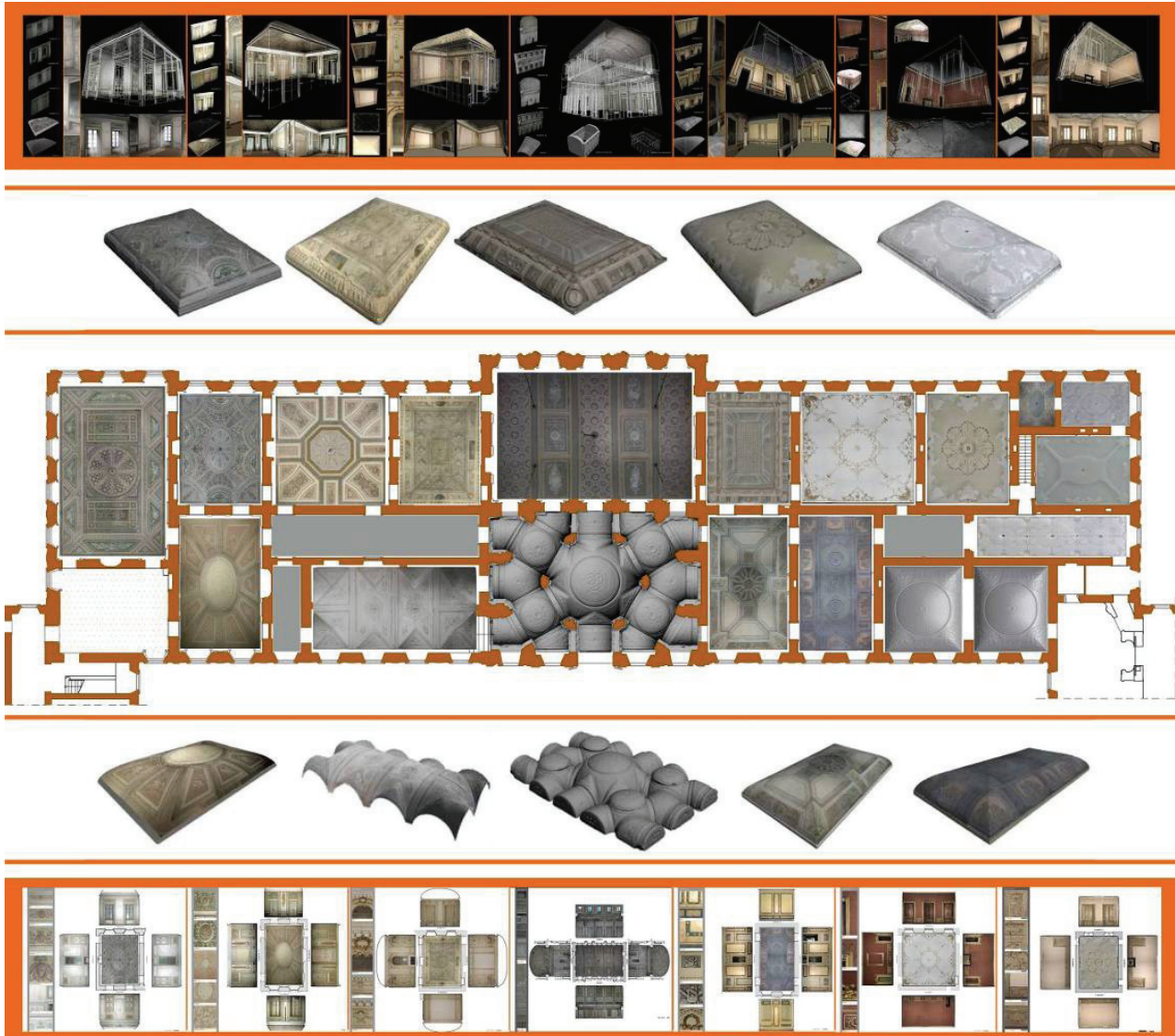


Figure 20: The plant of the noble floor of the Villa Reale: all the realized orthophotos (Sala da Pranzo Ufficiale, Sala degli Uccelli, Sala del Trono, Sala degli Arazzi, Salone Centrale, Sala della Pendola, Sala, Camera da Letto, Ritirata, Bagno, Bodoir, Guardaroba, Biblioteca, Studio, Camera da Letto di S.M., Atrio, Scalone, Sala da Pranzo, sala Bianca d'Angolo) Inside the "Villa Reale di Monza" have been realized seventeen 360°-scans using laser Leica HDS 3000 with a mean resolution of 1cm circa (2.000.000 point/scan). Some other more detailed (5 - 6 mm) scans was made to model of complex architectural elements. In some room, where interesting, were made some very high accuracy (0,1 mm) scanning with Leica T-scan to model some ornament and details. So we perform a multi-scale model of a room: from a raw model that can be navigate in virtual model, to a high detail one that can be used for restoration purpose and also for prototyping.

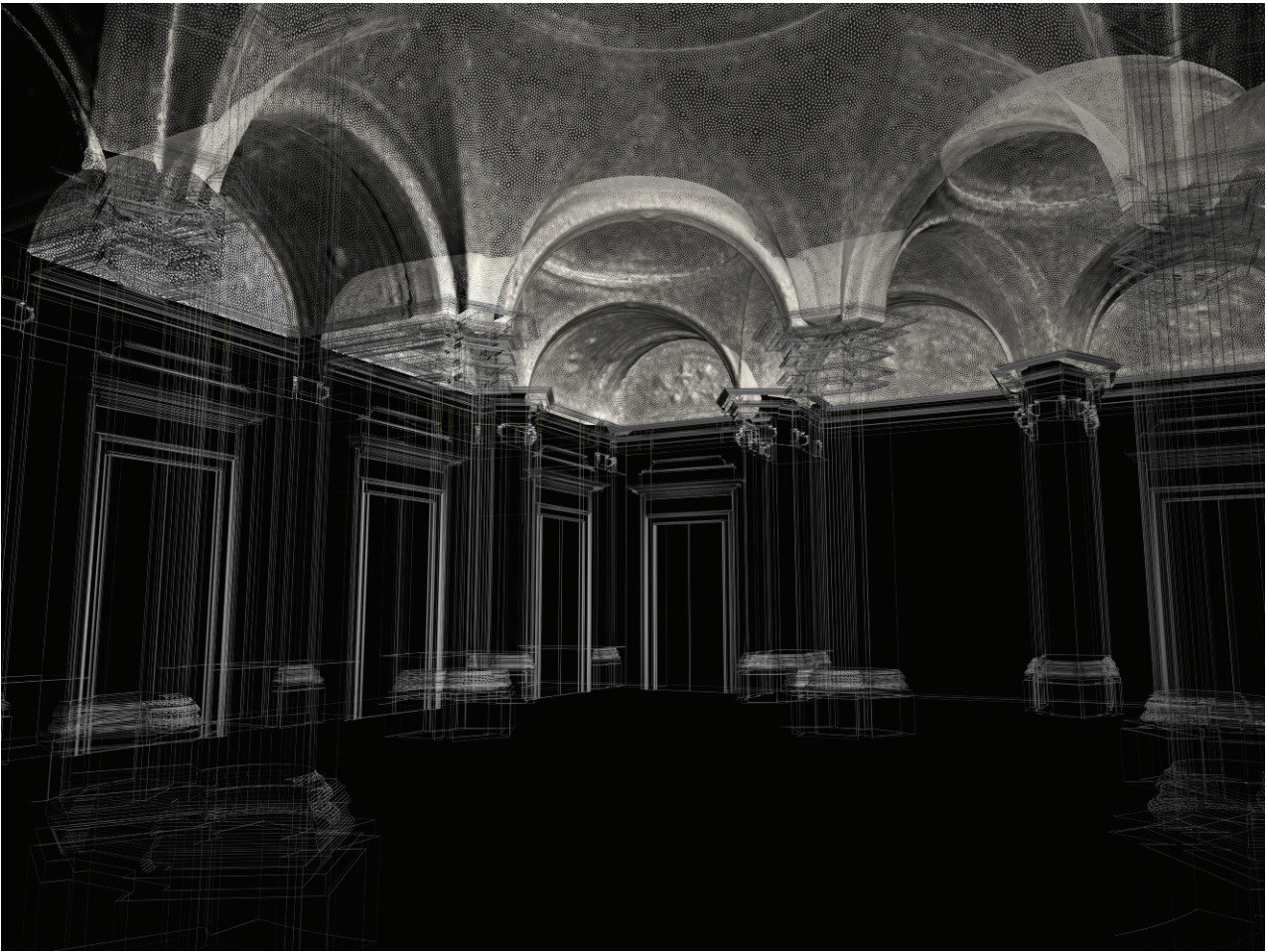


Figure 11: A wireframe visualization of the Entrance hall. The vault surface comes from laser scanner acquisition with a resolution of circa 1.5 cm. This kind of product is used for a virtual 3D model of the Villa that can be used for virtual navigation and representation in an online museum.



Figure 22: A virtual representation of the entrance hall.