APPLICATION OF MIXED TECHNIQUE FOR THE 3D MODELING OF THE NOBLE FLOOR OF THE VILLA REALE IN MONZA

Cristiana ACHILLE, Raffaella BRUMANA, Francesco FASSI, Hande TUNCER

DIIAR – Politecnico di Milano P.za Leonardo da Vinci, 32 – 20133 Milano, Italy
cristiana.achille@polimi.it, raffaella.brumana@polimi.it

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ABSTRACT:
The Villa Reale in Monza (ITALY) was founded as a symbol of the prestige and the greatness of the Asburgic family. The complex was built in an area not far from the Real Palace in Milan, the main imperial estate, in what once was a hunting haunt affording beautiful views near Monza, a small yet important trading centre. With its Gardens and the Park (later enlarged on Canonica's design), the great majestic Villa dominated the area, thanks also to the rational constructive rigour and the clear functionality with which it was built and the noble and sober elegance. Our work comes after the activities that we conducted in the last three years to prepare the material for the "International Design Competition for the Refurbishment and Enhancement of the Real Villa in Monza and its Gardens". In fact 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 of the Villa (the monumental complex covers a surface of about 36,000 square metres) trough rectified images, prospects, horizontal and vertical cross-section, plans of the interiors and the exteriors of every part of the Villa. The big work of survey had proceeded in the last year with the 3D modelling of the interiors and the whole noble floor of the Villa. This 3D model is oriented both to technical-scientific studies and to representative and publication aims: in particular to the three-dimensional representations, to the virtual navigation of the rooms, to the creation of an online virtual museum.

1. INTRODUCTION

The main aspect of this work is the integration of different kind of survey methodology: manual, topographic, photogrammetric and laser scanner. In fact we had two necessities: the multi-scale characterization of the Villa's representation and a very little bit time to finish the work for restoration time request. The multi-technique application supplies an optimal tool to speed up and to optimize both the survey and the modelling job and in the same time is a great method to product multi-scale and multi-functional data. In fact this type of approach let to have different kind of data that can be integrate to create both a texturized raw model for virtual navigation and also detailed high resolution digital objects. We think that this case of study can be a good example to explain different kind of survey methodologies, their integration and all the problems that we found both in the survey phases and also in the elaboration one. We used the laser scanner (Leica HDS3000) survey at low/middle resolution (circa 1cm) to extract basic information like corners and discontinuity lines. In fact the laser scanner let to make fast data collection (a whole room in circa 3 hours) so we were able to scan the whole noble floor of the Villa in few days and respect the imposed short deadline. The following elaboration process is focalized to extract from the points clouds all the basic elements useful for the traditional 3D modelling (Cad-Cam type) and to study and to handle with new software that are able to elaborate points clouds, meshes, and nurbs surfaces. (for example Rapidform2006 and Rapidform XO and PolyWorks). Our research interest was also focused to understand what kind of technique and elaboration process is able to better represent an element rather than another one and how it's possible to integrate all the different data into the whole "elements group". This instrument is also suitable to collect information of objects that are bad located or have a complicated shape like, for example, the vaults. The laser scanner points clouds was also used as DTM for the orthophoto production. Some high detailed laser survey (applied with Leica T-SCAN 706) is built to reconstruct the 3D geometry of some decoration and this is useful for the restoration work and for the reproduction of the object with rapid prototyping. The photogrammetric technique is used to have a complete database of orthophotos and rectified images of vaults and walls. The high resolutions images can be visualized up to a scale 1:10. In particular these types of products are also used for the colour mapping of the 3D models. We implemented one plug-in for 3D Studio max that let to apply an orthophotos on the 3D model using coordinates or georeference file. The manual survey, if available, is used to complete the information extracted with laser scanner where the low resolution doesn't let to represent the object with adequate precision. The final results of this experience are two kind of product: a collection of board with all 2D and 3D technical and architectonical information and a virtual online museum.

1.1 The Villa Reale in Monza

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 of the Villa trough rectified images, prospects, horizontal and vertical cross-section, plans of the interiors and the exteriors of every part of the Villa.

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[*] The Villa Reale in Monza was founded as a symbol of the prestige and the greatness of the Asburgic family. Maria Teresa decided to build it when she named his third-born child Ferdinand General Governor of the Austrian Reign of Lombardy. The Villa of Monza was designed and built, as of 1769 by architect Giuseppe Piermarini (1734-1808), a young apprentice and assistant of Vanvitelli.

The big work of survey had proceeded in the last year with the survey and the 3D modelling of the interiors of the whole noble floor of the Villa. The final results of this experience are two kinds of products: a collection of board and drawings with all 2D and 3D technical and architectonical information and a virtual online museum.

To summarize all the work in the Villa Reale's noble floor we made approximately seventeen 360°-scans with laser Leica HDS 3000 with a mean resolution of 1cm circa (2.000.000 point/scan). For every room were made some other more detailed (5 - 6 mm) scans of particular architectonical elements. We made circa 30 high resolution photos for every vaults and totally 40 photos for every rooms. For every room we collect a good amount of points topographically measured to connect and georeference all the data and to support the aerial triangulation.

2. CONSTRUCITON OF VAULT'S DIGITAL MODELS USING TOPOGRAPHIC, PHOTOGRAMMETRIC AND LASER SCANNER DATA

If a "photographic" measurable representation of a three-dimensional object is needed, as a vault for example, it is necessary to create a so called orthophoto which, unlike vector graphics, consists of a photography (photogrammetric shot, digital images) which is orthorectified with the altimetrical reference model.

The vaults of all rooms were surveyed using the classic scheme of photogrammetric survey which presumes a stereoscopic coverage of the object; also a topographic survey was performed in order to collect GCP for the photogrammetric triangulation elaboration.

In this case of study different sets of images[*] are taken in order to guaranty a correct coverage of the vaults; from 6 stereoscopic shots for smaller rooms to a maximum of 18 for ones of larger dimensions. The particular geometry of the vaults (relatively flat in the central part and almost vertical on the sides) has requested in general an increased overlap and sidelap to make stronger the image block. Moreover the presence of big ceiling lamp or scaffolds (due to restoration activities) and big wooden library, occlude the satisfactory view of the vaults, so it was necessary to increase the number of shots or to take convergent ones.

In this case we elaborated images with a software that allows us to compute the bundle adjustment of convergent image. The software Photomodel calculates the external orientation of every camera and to export it to other software. The matching elaboration was compute using Socet Set (BeaSystem).

To assure the necessary image resolution all shots have a pixel footprint of about 1,5mm that allows us to create a DSM with a grid space of 5mm and to obtain an optimal image resolution in ortophoto construction.

2.1 DSM model generated from a photogrammetric survey

DTM represents the surface of an object generated through out altimetric data of its points and is generally obtained by a process of autocorrelation of images. This operation is carried out by Socet set which applies principles of analytic

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[*]All the images are taken with camera Rollei db44 Metric (CCD PhaseOne H20 4080 x 4076 - 16 MegaPixel; pixel dimension 9μm; sensor dimension 36.9 x 36.9mm and CCD PhaseOne P45 7228 x 5428 – 39.2 MegaPixel; pixel dimension 6.8μm; sensor dimension 49.1 x 36.9mm; objectives used: 40mm; 80mm; 150mm; calibration for every objective).

photogrammetry using at least two shots in order to generate a digital model by image matching.

For the particular geometry of pavilion vaults we always found problems in the correspondence of the conjunction point between vault and walls during the automatic processing of DSM creation. We integrated the laser data as seed DTM to correct with defect.
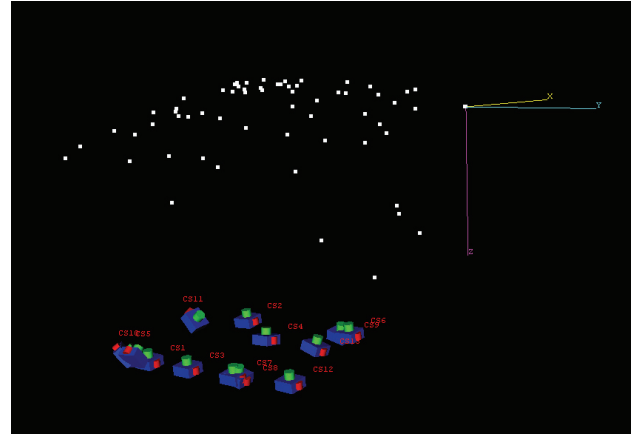

Figure 1: The 3D scheme of the photogrammetric survey. In this case the camera position and orientation is computed with convergent images.
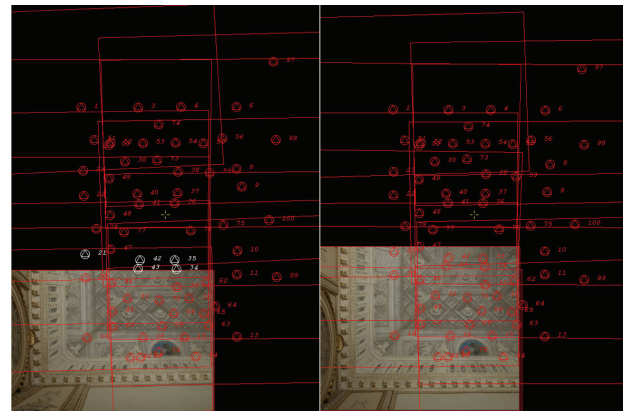

Figure 2. An example of two shots of the same strip after a correct exterior orientation and a GCP collimation (in the case of "Sala degli Arrazzi" 120 points were registered)

2.2 DSM model generated form laser scanner data

The laser scanner records numerous points on the surface The scanning result is a cloud of points that include the coordinates x, y, z of the all points considering the origin point the position of scanner.

To use this data as supply in DSM elaboration, the laser scanner data must be brutally filtered and decimate and georeferenced in the same coordinate system of the photogrammetric process. In this operation there is naturally a lost of precision of about 1 cm due to the picking of the point that are used in the rototranslation process; but using this georeferenced data as seed DTM (as support) will not invalidate the general accuracy of the whole process.

2.3 DSM model generated from classic survey data

A classic combination "topography – photogrammetry", widely tested by now, consents to obtain excellent results. A complex geometry of vaults can be represented by a generation of a three

- dimensional model drawn up from a topographic survey (total station) and by determination of points that describe generatrix and diretrix necessary for a construction of breaklines and edges lines. Obviously, this is necessary for particularly complex vaults that are very rich of rough edges. This kind of features are imported in post processing in the DTM elaboration in CAD format to build a better geometry of the object. (Monti, C., Achille, C. and others, 2005)

3. CONSTRUCTION OF 3D MODEL

The laser scanner data was also used to build 3D complex models. In this case we use this data to generate accurate models, an operation that requires to collect a huge amount of data and information; by the other hand creates some problems during the elaboration. The management of the data becomes more difficult during the passages between different software. To avoid these problems; the use of model has to be taken into consideration in the planning phase. In the case of "Villa Reale di Monza" were processed two different methodologies for the generation of tree-dimensional model;

- Crude model: generation of solids by Boolean operations in CAD systems.
- Detailed model: generation of mesh. When the geometry of the object is complex. More higher the accuracy is acquired; more densely will be the points cloud and then the representation of the details.
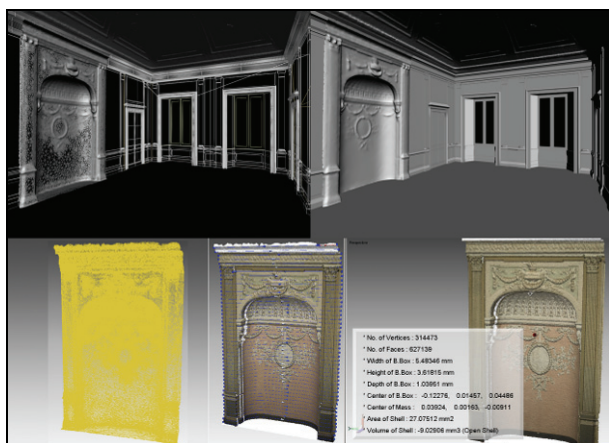

Figure 3. Sala da Pranzo di Famiglia: The solid models generated by Boolean operation and a detail (due to the complex geometry of the object; is generated as mesh) inserted in the model.

3.1 The construction of 3D model using data laser

The laser scanner of Leica HDS 3000[*] has been used for the laser survey of "Villa Reale di Monza". Considering the data collection and elaboration; the halls of the "Villa Reale di Monza" have been scanned with an resolution of 10 – 12 mm and some particulars with a resolution of 5 – 6 mm. Employed time for the scanning is approximately 3 – 4 hours for a hall which has the dimensions about 8m x 10m.
The scanner provides the information of RGB values, by converting the ambient light to an RGB triple, and intensity

data, analysing the reflection of the material type, of each acquired point, using a camera[**] already integrated in the system. The image resolution can be defined as; low, medium, high by the user. The scanner Leica HDS 300 can make 111 images with a field of view 360° x 270°. They are automatically spatially rectified and overlapped with the corresponding georeferenced point. However, these images are not sufficient for high quality texturing. It is useful to identify the points during the manual alignment process.

Laser Scanner Leica HDS 3000 (resolution about 10- 12 mm)		
Halls	**Number of points**	**File *.IMP**
Sala degli Arazzi	3.611.236	140 MB
Salone Ballo	7.470.085	300 MB
Sala Pendola	2.533.409	105 MB
SalaPranzo Famiglia	2.333.168	150 MB
Salotto	1.789.452	96 MB
Gabinetto	2.002.745	85 MB
Biblioteca	6.254.747	205 MB

Table 1. The number of points acquired

3.2 Alignment of points clouds

The original data is a *.IMP file which is the original object database format of the laser scanner and can be operated by software Leica HDS Cyclone. Every single scan has its own local reference system; with the origin at the laser station, and an arbitrary rotation, depending on the direction that the laser is pointing to. Therefore it is necessary to orient the all scans respect to one common reference system to get a one complete three-dimensional model. To align different scans, is necessary at least 3 common points between two scans. In the presence of the targets, the software Cyclone recognizes them automatically and geo-reference scan data. In case of the manual registration, Cyclone has the ability to align overlapping areas to optimize the alignment of point clouds, but it is necessary to control the error vector between the aligned scans. In some cases, in Villa Reale di Monza especially for the halls that have been renovated, it was not possible to place a sufficient number of artificial targets; have been utilized recognizable elements; the edge of the panels, doors, windows etc.
After the registration process, the points clouds can be exported in ASCII formats (XYZ, SVY, PTS, PTX, TXT) in order to be elaborated in CAD/CAD ambient.

3.3 Extracting of profiles from points of clouds and integration with direct survey

To generate the three-dimensional model of the interested object, it is necessary to represent it in the form of plans, elevations and sections. The point cloud was processed in AutoCAD by a plug-in CloudWorkx. The point clouds can be operated by commands "clip points to section, clip points to slice" to extract horizontal and vertical profiles. The command "Fit point clouds, section" interpolates the designed poly-line with the section of point clouds and avoid the human error.
When it is designed the profiles, by the help of Boolean operations; extrude, revolve etc, the solid model can be

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[*] Maximum 360°x270° field of view, <6mm spot size @ 50m, <6mm positional accuracy @50m, Spot size; 0-50m:4mm (FWHH - based); 6mm (Gaussian - based), Scan row (horizontal) 20,000 points/row, Scan column (vertical) 5,000 points/column.

[**] Integrated colour digital imaging: User-defined pixel resolution, Single 24° x 24° image: 1024 x 1024pixels, Full 360° x 270° dome: 111 images, approx. 64 megapixels, automatically spatially rectified.

generated. But it is necessary to design the profiles of the elements as a closed polygon for the Boolean process. When the profile of the element is very complicated, AutoCAD can not operate it, and then it is necessary to simplify or divide it in parts to create the solid. A solid can be extracted through slicing, sectioning subtraction, joined to another solid and other constituent operation of solid modelling.

In the case of "Villa Reale the Monza" for the left part of the Nobile Part, have been utilized the direct survey by nominal scale 1:50, which was provided a good basis for modelling process. Instead, the left part of the Nobile Part; all the plans and sections are generated by extracting from the points clouds.
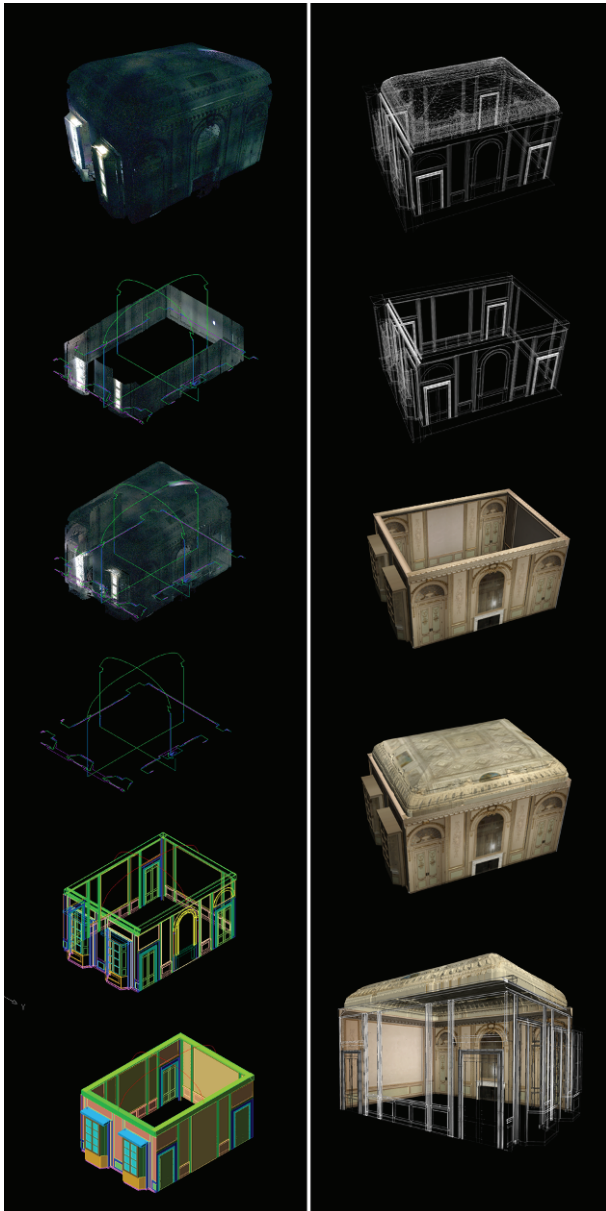

Figure 4. The representation of the halls as point clouds. Extracting profiles from the points of clouds and the production of plans, elevations and sections. The generation of solid models by Boolean operations; extrude, revolve etc, the point cloud was processed in AutoCAD by a plug-in CloudWorks.

3.4 Generation of mesh

When the elements have a complex geometric shape, it is almost impossible to generate a tree-dimensional model by Boolean operations. Another methodology was performed: the generation of triangulated surface directly from point clouds.

In "Villa Reale di Monza" the vaults, fire-place and some other complex details are modelled utilizing the software RapidForm. The original points file is exported in .pts or in .ptx format and imported in RapidForm for the elaboration and the generation of the Mesh. The ptx format consents to get a better result because this type of format also contains the position of the scan and supplies a complete structured data. In this case some problems like false normal computation and all topological errors in surface generation are limited or eliminated. The subsequent elaboration becomes faster, more automatic and verifiable.

These are the steps to perform the mesh from the point of clouds;

- Register –Merge: Aligns two or more shells on the basis of the coordinate of a fixed shell. It calculates the exact position of each shell by comparing and fitting the overlap region of two or more surfaces.
- Filtering
- Triangulation – Surface - 3D: Converts a full 3D point cloud set to a polygonal model.
- Clean faces; non-monifold, redundant, crossing and unstables faces: Fix topological or geometrical defects of the generated mesh.
- Filling the holes
- Decimation and re-mesh: Re-triangulates the faces of a mesh and improves the quality of each face in it by calculating the topology of the surface.

The created mesh can be exported in *.OBJ format to be able to inserted in CAD systems; AutoCAD and 3ds MAX for the process of mapping and rendering.

3.5 Texturing of 3D Model by Orthophotos and Rectified images

The generated orthophotos can be utilized as textures to map the 3D model and can be used for metric calculation of the surfaces, not flat, from the models. This opportunity supports the further operations in restoration for the specialists; mapping and classification of the materials, analysis the state of fact, individuation of deterioration and disruption (diagnose of paintings etc.).
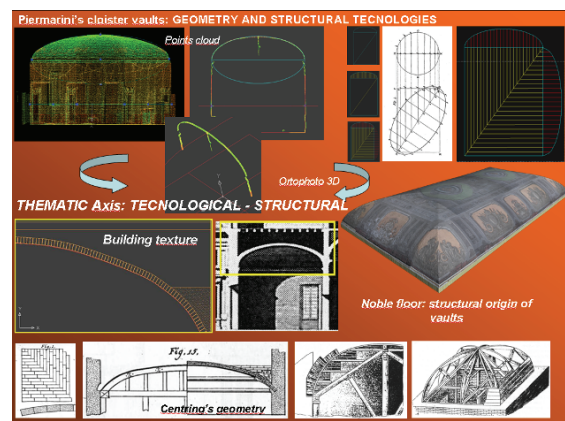

Figure 5: Reconstruction of structural technologies from laser scanner data: Comparison between vertical sections taken from historical manuals and actual state.
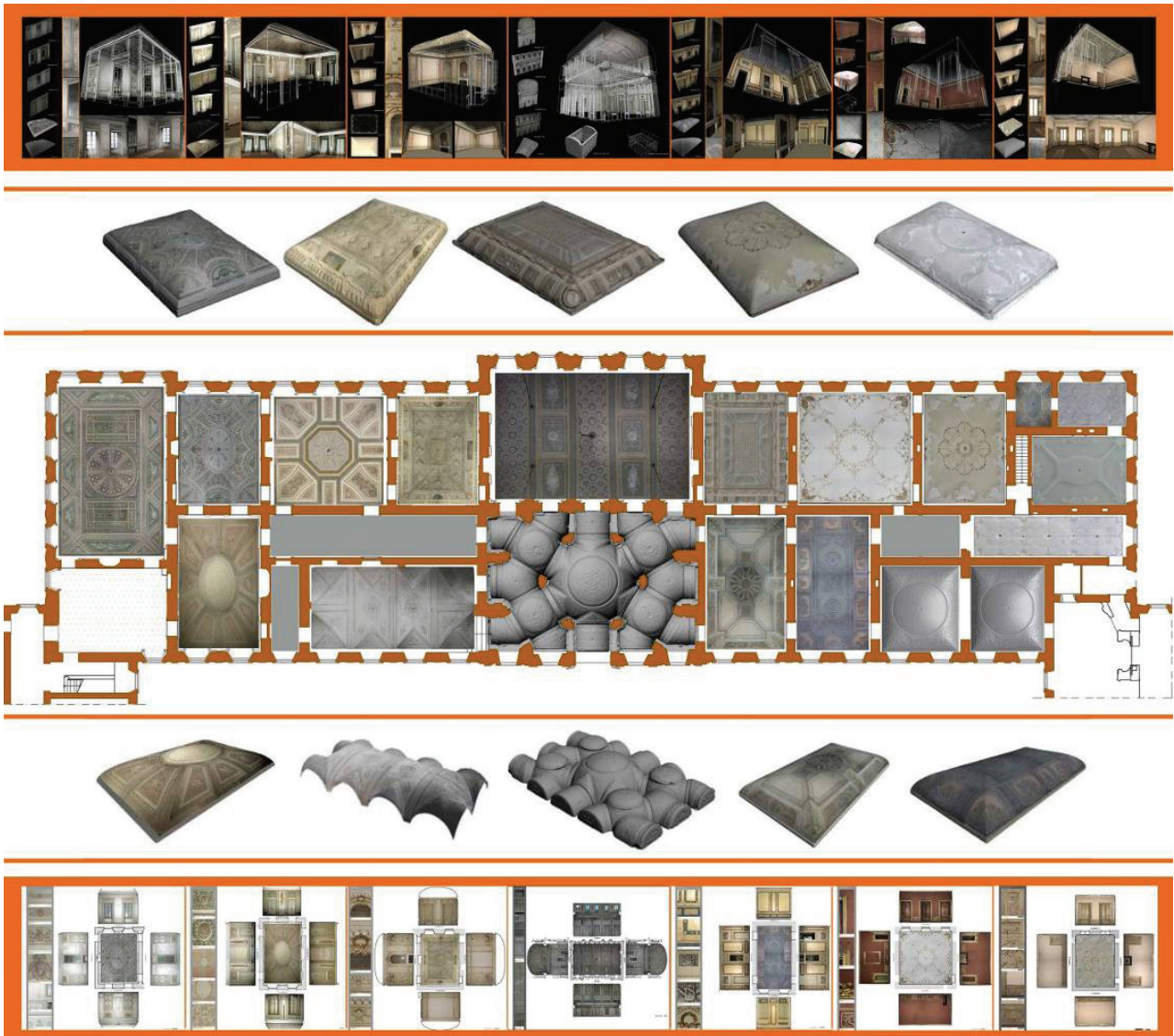
Figure 6. The plan of the noble floor of the Villa Reale: all the realized orthophotos (Sala da Pranzo Ufficiale, Sala degli Uccelli, Sala del Trono, Sala degli Arazzi, Salone Centrale, Sala della Pendola, Sala, Camera da Letto, Ritirata, Bagno, Bodoir, Guardaroba, Biblioteca, Studio, Camera da Letto di S.M., Atrio, Scalone, Sala da Pranzo, sala Bianca d'Angolo) Inside the "Villa Reale di Monza" seventeen 360°-scans have been done 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 were made to model of complex architectonical elements. In some rooms, where interesting , were made some very high accuracy (0,1 mm) scanning with Leica Tscan in order to model some ornament and details. So we performed a multi-scale model of a room: from a raw model that can be navigated as virtual model, to a high detailed one that can be used for restoration purpose and also for prototyping.
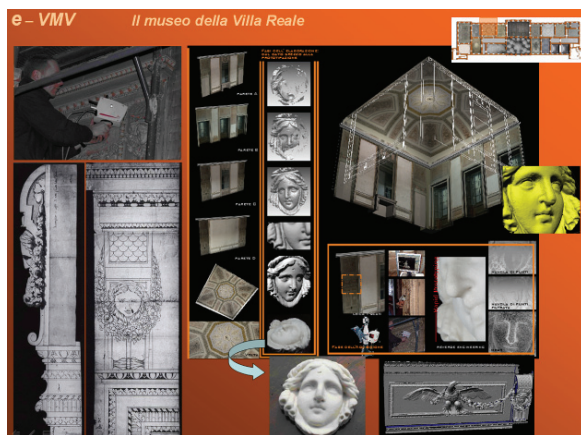

Figure 7. Multi-scale representation and survey.

4. THE VIRTUALIZATION OF THE VILLA

The three-dimensional models of the internal spaces of the Villa Reale in Monza are a perfect example of how a "static" 3D model can be transformed into a "dynamic and interactive" one. The solid model is imported in 3ds MAX so as assemble all the pieces together, to simplify it further more if too heavy for a virtual interactive reconstruction, to proceed with "clothing" of the model and to create ambient lights, atmosphere, views, camera paths, movement and interactive elements .

The texture of all walls and simple objects is extracted from rectified images which were divided into single architectural elements and then later compressed. For complicated smaller objects we coloured the 3D model using home-made photogrammetric software that use DLT algorithm to project a

single image on the 3D model. For the vault we re-project the orthophotos on the 3D models using the georeferenced file.

In this way the textures coming from rectified images and/or orthophotos are used as materials in the material editor of 3ds MAX. This material will define all the different three-dimension elements through "plan texturing" which means projecting the image on the appropriate solid model detail.

The last phase of virtualization and of creation of the three dimensional environmental is exportation of the model in VRML (Virtual Reality Modelling Language) format. This language consents to create interactive three dimensional worlds that can be passed through, flied over or simply explored.

Furthermore, these kind of products are very useful for architectural planning as they allow us to insert our project into the existing model and interact with it in order to test the suitability of the project for the environment we are studying (see figure 9).
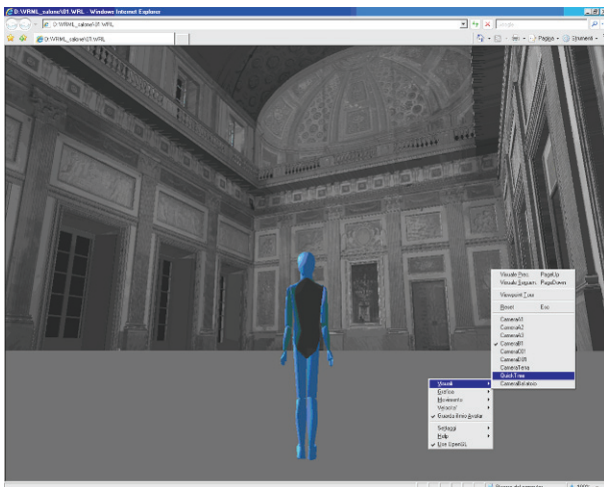

Figure 8. Virtual Naviagation Interface in VRML at right side is possibile to see the virtual interaction panels.
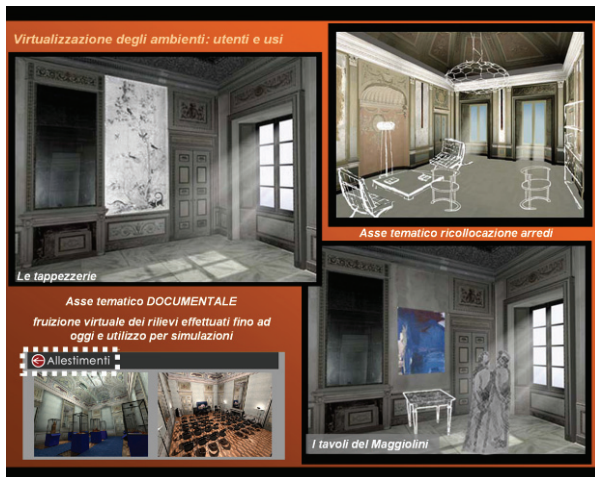

Figure 9. Few examples of architectural projects as a proposal for the future use of some rooms of Villa Reale in Monza.

5. CONCLUSION

This paper has a demanding task to synthesize the huge work of a group of circa 10 people that was carried out in a period of three years and was handled with a lot of technologies and methodologies of architectural survey and 3D modelling. We try to choose the best strategy to get the most accurate results and to adapt traditional methodologies with new instrumentation in order to obtain faster and most complete output. It is a very wide-ranging example of multi-technologies, multi-technique and multi-target job that describes a whole process from the traditional topographic measurement, to 2D and 3D representation up to the web and virtual representation.

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