3D MODELING AND RESTORATION: FROM METRIC TO THEMATIC SURVEY. THE CASE STUDY OF SAN FRANCESCO AL PRATO IN PERUGIA

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ABSTRACT:

A multisensor approach seems to be the most suitable solution for complex environment modeling. In this paper such an approach was exploited to generate a model, capable of covering different interesting aspects of the church of San Francesco al Prato, in Perugia (Italy). It is one of the main churches of the city, reconstructed around the middle of XVIII century over a previous church, and enriched in the centuries with masterpieces by such artists as Perugino or Raffaello. Unfortunately, due to some earthquakes its structure suffered several major lesions, as for example the loss of the roof, and the recent decision to restore it led to the need for an accurate survey.
The procedures adopted for documenting this building and some preliminary results are described here. Due to its interesting aspects, the work was concentrated on the transept-apse complex, characterized by a complex spatiality, different building materials, a marked architectural decay, and a geological instability of the underlying ground that produced cracks and lesion all over the structure.
Topographic and digital photogrammetric tecniques have been employed in order to obtain complete and accurate data; 3D laser scanner has been employed only on the transept. The model has been obtained from the merge of the different acquisition.
The documentation of such a complex architectural space was planned according to progressive levels of critical synthesis; the surveying approach described here followed the same logic and allowed us to obtain a three-dimensional model of the structure under investigation, by adapting the space resolution to the complexity of the surface or to the historical and artistic interest. Such tradeoff involved also the optimization of fundamental resources such as acquisition time or computer memory space, that have to be carefully taken into account in order to make any high complexity surveying project feasible.

1. INTRODUCTION

The approach to restoration planning in order to give specifications needs more than an accurate *geometric survey,* although this is an unavoidable starting point. It needs to base itself also on a *critical survey* and often has to consider diagnostic studies in order to produce thematic mapping related to chronologic events, materials, pathologies, that will be considered in order to look for best solutions.
3D modelling of heritage monuments nowadays has increased significantly but the accurate and fully automatic capture of all details, for all types of application, remains, at present, elusive. So the requirements of the model depend, each time, on the application.
The effort to determine the 3D model requirements able to represent a thematic survey and able to be useful for a restoration planning is one of the aims of this work, still in progress.
To obtain data, geometrically correct, with suitable details and realistic representations, the main approaches today are interactive and automatic photogrammetry and terrestrial laser ranging. The other task of this work is to look for an integration between the two methods and to estimate the effectiveness and the potentialities of laser scanner survey.

1.1 The church of S. Francesco al Prato, in Perugia

San Francesco al Prato is one of the main churches of the city; the first plan (1251 -1253) at “crux commissa” was aisle-less, with three spans, wide transept and pentagonal apse. Unfortunately, due to some earthquakes (the first documented one is in 1340) its structure suffered several major lesions. Other damage was caused by landslides, which happened at the construction of external rampant arches (1421). Starting from the XIV century family chapels and other monuments were built. In 1527 heavy rains caused great cracks and the loss of important paintings. From 1599 to 1737 there were numerous collapses, after which Padre Giuseppe Modestini commissioned the architect Pietro Carattoli for the reconstruction of the church. He tore down the damaged vaults, reduced the height of the perimetral walls and built a lining with new thick walls with their own foundations; he also built a dome with a lantern on a high cylindrical tambour at the cross of the transept. In 1860 the church was used as a store and suffered ornament vandalism. A rapid decay of the structures transformed it in a ruin. The facade was reconstructed, in 1926, by Pietro Angelini and new hydrogeological study on the area was carried out, but the unsafe part of the church continued to decay. Only in 1932 consolidation works were planned. The eighteenth-century part was demolished to restore the mediaeval architecture. In 1968 the nave roof caved in, and in 1972 the construction of a new roof was begun. A recent decision of restoring the church to transform it in an auditorium, led to the need for an accurate survey. The transept-apse complex remains without roof, as a ruin, to be used only the summer season. Therefor our work seems, in all respects, an archaeological survey, with all the difficulties in the interpretation of the different constructive phases and with all the representation problems linked to the curve plan of the apse.

2.1 Stratigraphic survey

Critical survey was founded on the USM (Unità Stratigrafiche Murarie) individuation, with the aim to interpret, on the palimpsest walls, the sequence of the works on the building. These are divided in *positive actions* (red in drawing) - e.g. extensions, elevations, closed openings - and *negative actions* (yellow in drawing) - e.g.

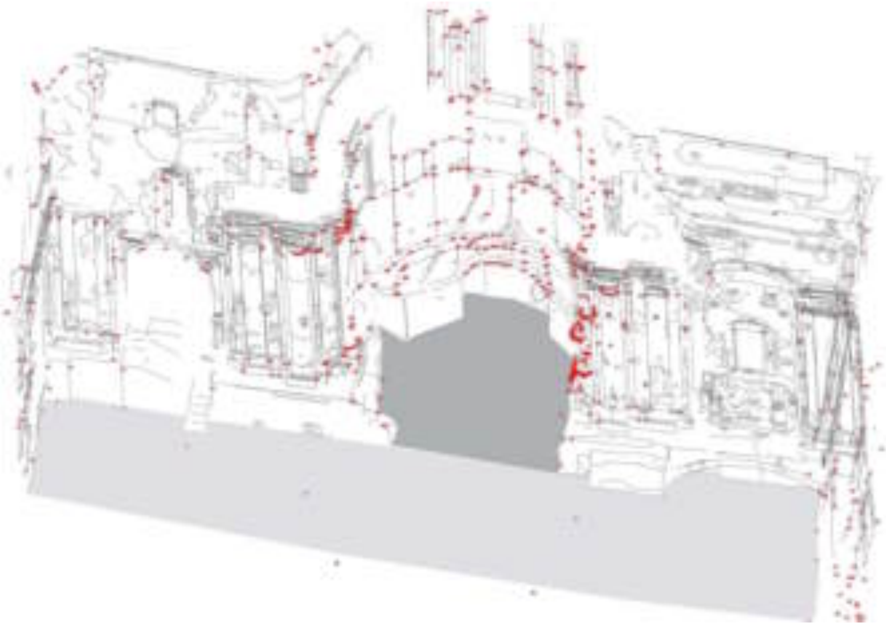

Figure 1. Matching of topographic data (red points) and photogrammetric restitutions

demolitions, opening of traces, etc. - which are recognizable because constituted of homogeneous materials or processing. For the most significant USM, material type, processing, mortar type and stratigraphic relation were defined. As every USM has a stratigraphic position that defines synchronic or diachronic relation with the other, it was possible to assign, at first, *relative dating* among the USM and then *absolute dating* (still to complete) comparing data of the building with historic documentation. It is possible to summarize five most important constructive phases and relative wall types; a complete report was draw up for everyone. Normally, the USM are drawn on 2D geometric survey or, if it is possible, on image rectification, or, even better, on orthoimage but the relations among them, in complex cases like this one, is difficult to represent. A 3D model can be a real evolution in this analysis to merge reconstruction of consecutive stratigraphic layers.

3.1 Geometric survey and 3D modeling

Survey operations were performed during consolidations works. Thanks to the present scaffolding, it was possible to plan acquiring data at different heights, focusing on transept-apse complex to obtain prospects, vertical and plane sections at 1:50 scale. The articulated geometry, derived from a mixture of architectonic elements, structural damage and superficial decay, has required the survey of many points, imposing the management of numerous detail drafts to choose the representative elements. This approach combines the data from different sources: topography, photogrammetry, laser scanner and image processing (either as image rectification or as surface mapping) this has been integrated to obtain, finally, a 3D model. Some considerations on the adopted procedures follow.

2. DATA COLLECTION

Increasing automation of the acquiring and elaboration of data processing are essential to widen the use of the 3D model, but despite this, at present, to represent and to elaborate data, is still, unavoidably, a selective operation: what changes is the moment in which synthetic interpolation, to obtain structured data, is required. With every survey technique we obtain a synthetic model of reality, but different cognitive approaches are available derived from different measurement techniques: topography and photogrammetry data collection phase requires a preliminary interpretation process, while, laser scanner acquisition collects redundant data, and synthesis is postponed to a post-elaboration phase.

2.1 Topographic survey

Topographic techniques need graphic restitution, in which the object has to be defined with line interpolating measured points. The operator has to be able to interpret, at the moment of survey, the object of study. We can also say that with few measured points we can obtain exhaustive form and geometric representation, because additional geometric information derives from the operator.
About one thousand detail points has been collected with a reflector less total station Leica TCR703, after having traced a small net of arrangement; the adjustment has been performed by using the least squares method. At the same time, about 100 control points have been measured - natural points on the transept, 40 targets on the apse and 17 specific Cyrax targets on the entire scene - to orient photogrammetric stereoimages and to define a reference system for range images.

3.1 Photogrammetric survey

In this case, measured data and represented data are approximately the same, except editing processing. Human critical selection about what to represent - autocorrelation algorithms, automatic restitution, furnish interesting results in small scale survey but are less applicable at the specific requirements of cultural heritage - takes place simultaneously at the restitution phase, with additional, well known, advantages derived from the separation between orientation and restitution phases.
The images have been acquired by means of both semimetric Rollei 6006 camera (f=40 mm), and digital Nikon D1 camera (f=24 mm).
With semimetric camera, three stereocouples have been acquired

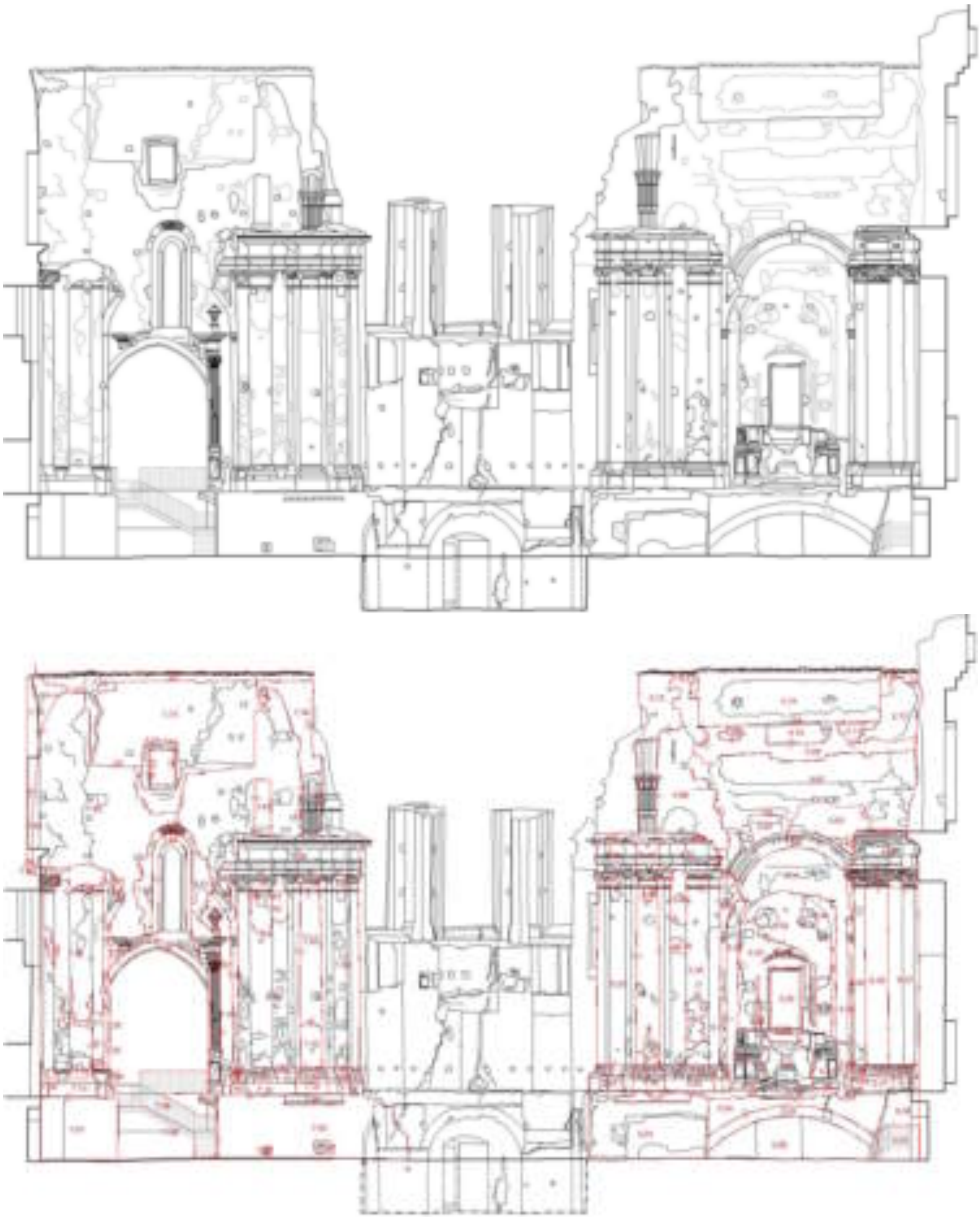

Figure 2. Cross section of the church: it has been obtained from the editing of photogrammetric restitutions.
It has also been used to have a support for stratigraphic data: USM are represented in red, while the number inside refers to a specific report. The overlapping symbols in the area indicate *positive* or *negative* actions.

on the apse, with mobile scaffolding, obtaining about 1:350 scale of images. On the transept, twelve stereocouples have been acquired at about 1:250 scale (longitudinal overlap =80%, transversal overlap = 40%). Thanks to the scaffolding set for consolidation works, it has been possible to take photos in the best condition for stereoscopic restitution. In parallel, a photographic campaign with digital camera has been performed to have, on one hand, model of details at greater scale, usable for deeper and particular elaborations, on the other hand, a collection of oriented images to use as model texture. The images have been oriented and restituted with both analytic stereoplotter Digicart 40 (by Siscam) and digital Stereoview (by Menci Software).

For the surfaces that could be considered approximately flat image rectification with Archis software (by Siscam) has been used. A radiometric adjustment has been performed in order to reduce the different light exposures of the used images. This type of raster data is very useful to report USM analysis and, in general, for thematic representation, but geometric constraints of the surface planarity limit the application fields. Texture data, besides 3D vector data, enhance the users cognition and is the direct transposition in the 3D world of what is already consolidated in 2D world.

2.3 Laser scanner survey

Different from the above-mentioned techniques, acquired points are generally more than necessary to obtain a meaningful shape representation. Anyway, a kind of interpolation from measured data was performed when we pass from a discrete (cloud of points) description to a continuous one (surfaces). Data processing is mainly based on reducing cloud point data, by filtering, and on mesh optimisation. This is like saying that, in front of a great number of acquired points, only a percentage of them will belong to the final model. The level of details of the models obtained from low resolution scanning is not comparable to that obtained from

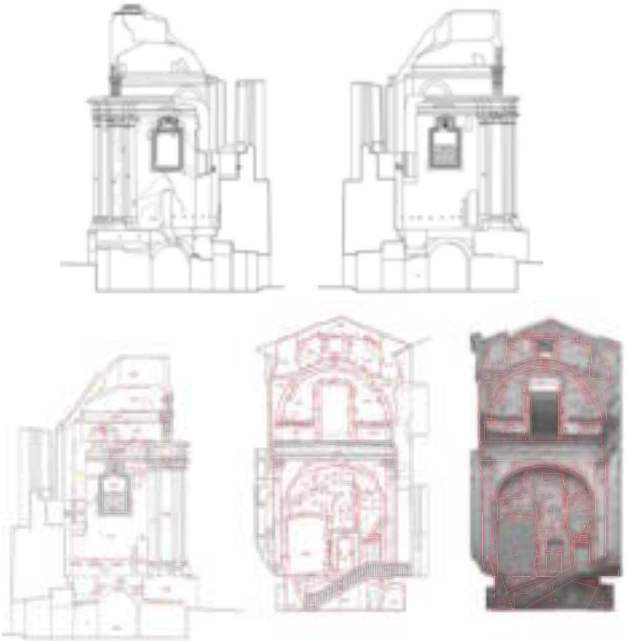

Figure 3. Longitudinal apse section and one facade of the transept. There USM on vector map and on raster image rectification are shown

high resolution scanning subjected to reduction procedure.
Only for the transept, Cyrax 2500 laser (by Leica) has been used, with sampling step of about 1.5 cm; in this way all the transept has been covered. For more complex details, as for example, capital blocks, a sampling step of 6 mm has been set.
In all, 20 range maps, with an overlapping of about 40% have been generated. This overlap has been performed not only to align 3D images but also to cover undercuts and hidden zones. Laser scanner has been mounted on its tripod or simply placed on the scaffoldings, at various levels, to avoid great inclinations.

3. FROM POINT CLOUD TO SURFACE

Actually, 3D modeling of real free-form surfaces consists of the following steps: registration, pre-processing, mesh generation, post-processing, texturing. Range map registration has been carried out with Cyclone software (by Cyra). To obtain the transept complete model, 20 range maps have been registered, 13 for right zone and 7 for left zone. In order to establish connection with the two parts, (interrupted by the apse) and in order to set a unique reference system for all type of data, specific targets, topographically measured, have been used as additional constrains in the range data alignment. These target are automatically recognized by the software which calculates the

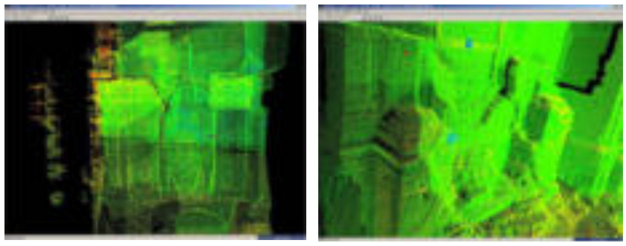

Figure 5. Example of range map registration: we can see target position, automatically determinated, used to rototranslate the model in the topographic reference system

centre. The registrations have been performed in scan block; for each one, 5 or 6 targets were available, 3 for the rototranslation in the reference system and the other as control points.
All following data processing has been done on portions of the entire model, to be able to manage acceptable file dimension and to reduce elaboration time. Also visualisation became modifiable in real time. At the end, all blocks have been reassembled in order to create a unique model.

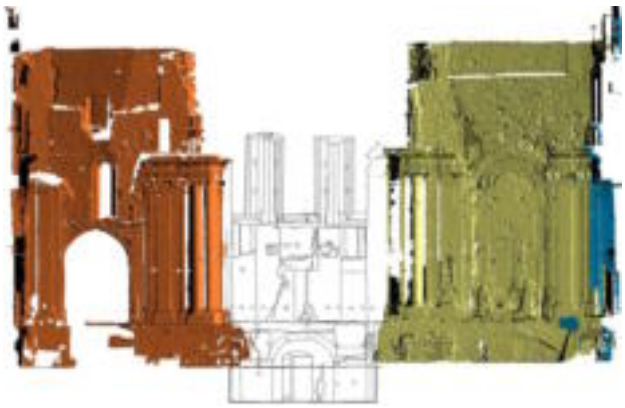

Figure 6. A view of the model, integrated, in apse area, with the photogrammetric restitution

In the pre-processing phase we have removed unrelated elements to the object of survey. This is an operation only partly automatic, for instance, using on-distance based filter. To refine the selection of these elements, manual operation is required (Figure 7).
Also, noise reduction enhances the scan quality by removing excessive speckling with statistic methods, as we show in figure 8.
In figure 9, there is an example of clusterization of registered block of range map. The partition has been performed marking the boundary of significative architectonic portions of about one million of points.
The conversion of the measured data into a consistent polygonal surface implies the generation of triangular surfaces (Figure10), satisfying some quality requirements, and mesh optimization

Figure 4. Laser scanner setup

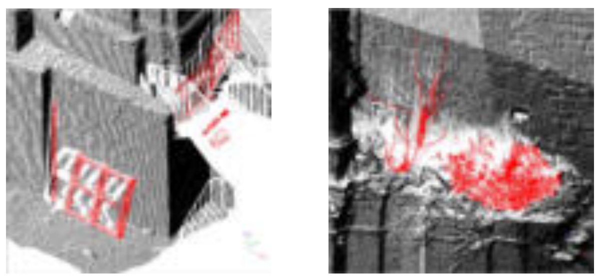

Figure 7. Examples of unrelated elements

BLOCK	SCANS	TARGET	PTS original cloud	PTS cleaned cloud	PTS sampled cloud	N. cluster /cloud	TRIANGLES	TRIANGLES decimated mesh	SIZE .OBJ format
	#	#	x1000	x1000	x1000	#	x1000	x1000	kB
lato dx	10	6	7.354	6.645	4.494	4	8.920	2.141	81.255
fondo dx	3	5	2.826	2.253	1.042	1	1.983	478	17.959
parte sx	7	6	7.614	5.847	3.535	4	6.779	1.627	61.171
complet model	20	17	17.794	14.745	9.071	9	17.682	4.246	160.383

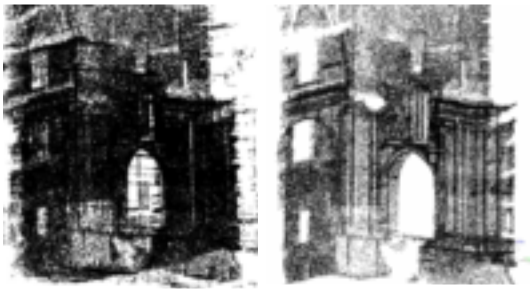

Figure 8. Cloud point sample.
A "curvature sample" operation was performed
(with Raindrop Geomagic Studio software).
Points that lie in a high-curvature region remain in order to maintain the accuracy of the surface curves. In this way it has been possible to halve the acquired points

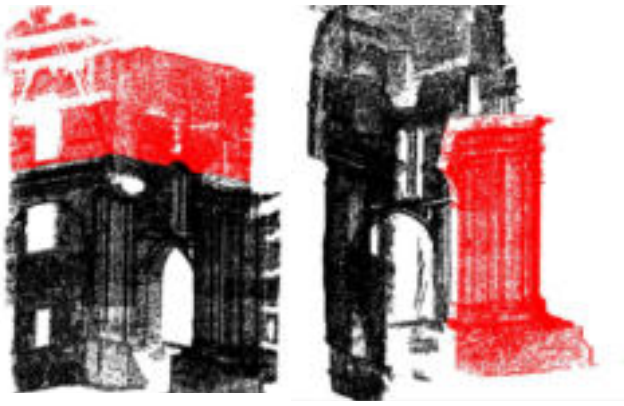

Figure 9. Clusterization of range map

(Figure 11), to refine and correct imperfections or errors in the surface. The clusters, previously defined has been converted in a mesh and then an optimization has been performed. In order to preserve surface integrity and details, a method of polygon decimation (based on shape preservation), allowing the number of triangles to be reduces while maintaining the overall shape of the object has been employed. A comparison between the final resulting mesh and the original acquired cloud of points has been carried out. The deviation is displayed as a colour map (Figure 12). Although the original measured data has been reduced by about 15-20%, shape description is both satisfying and accurate from a metric

Figure 11. Example of mesh optimization

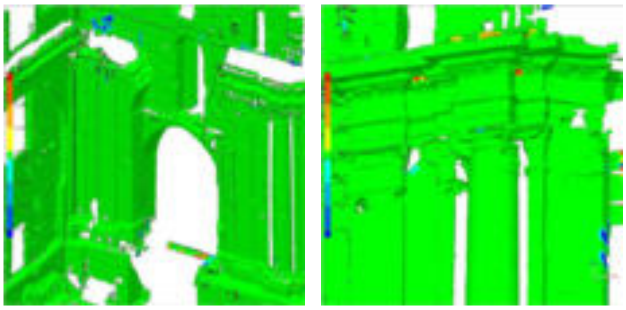

Figure 12. Comparison between the final resulting mesh and the original acquired cloud of points. As side color scale shows, green indicate deviation < ± 0.005 m

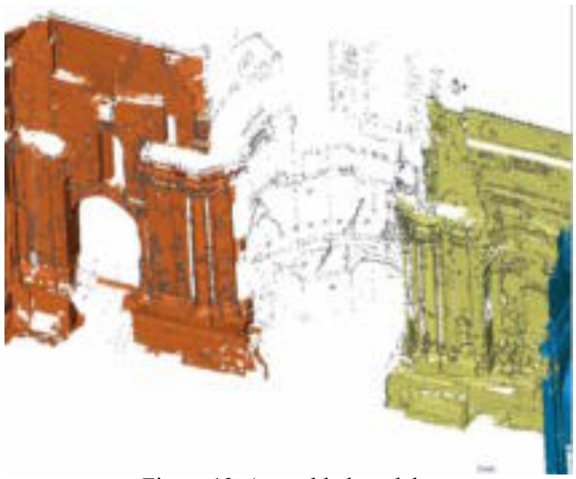

Figure 13. Assembled model

point of view. At the end the entire model has been assembled in a reference system and overlapped with photogrammetric restitutions, also available for the apse (Figure 13) .
The application of new survey techniques has to be able also to produce standard graphic elaborations with these requirements consolidated in time; so, simple renderings can be considered a base to extract vector data (Figure 14). In this way it is possible

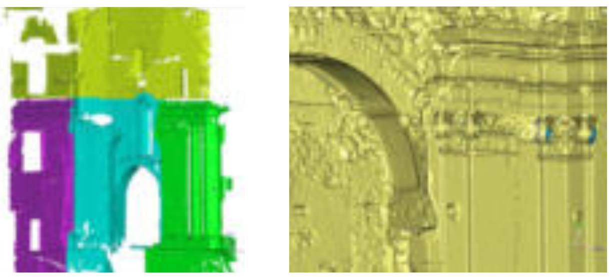

Figure 10. From point to surface: example of triangulation

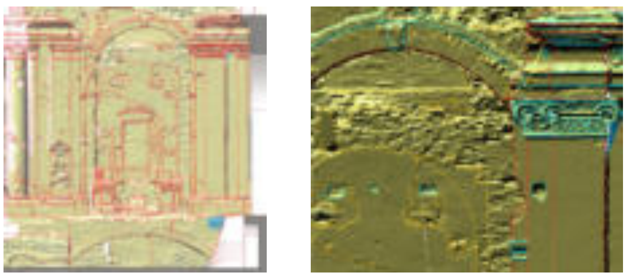

Figure 14. Examples of manual edge extraction

Figure 15. Examples of model texturing

to free the operator (who does not have to be a photogrammetric specialist) from the limitation of reading information only on one plane, as happens using rectification images. The thematic representation, useful in conservation analysys and projects, can also be acquired directly by the conservator observing texturized model (Figure 15).

4. CONCLUSION

New tridimensional models can be useful for programs of conservation of the architectonic heritage. We have good hopes in to the future in which it will be possible to walk in a 3D space phases, following the reconstruction projects or to schedule the routine maintenance and simulating technical installation. Since many years the member of this local research pool are involved in problems concerning the analysis and metric survey of ancient architecture and archaeological fields. Recently we were involved in laser scanner evaluation, both for image communication and for metric precision. It is too early to make statements about this work: we are still completing the model. Our purposes are: to complete the apse modeling from photogrammetric and topographic data and to merge it with the transept model; to combine stratigraphy data with 3D model; to navigate our site in 3D and to be able to replay the constructive phases as they proceeded through different time.

5. REFERENCES

Astori, B., Bonora, V., Garnero, G., I*l rilievo laser scanner del teatro romano di Ventimiglia: esperienze e prospettive*, Atti della 6a Conferenza Nazionale ASITA, Perugia, 5-8 novembre 2002.

Bitelli, G., 2002. *Moderne tecniche e strumentazioni per il rilievo dei beni culturali*, Atti della 6a Conferenza Nazionale ASITA, Perugia, 5-8 novembre 2002.

Boccardo, P., Dequal, S., Lingua, A., Rinaudo, F., 2001. *True orthophoto for architecturale and archaeological applications*, proc. of International Workshop on Recreating the Recreating the Past - Visualization and Animation of Cultural Heritage, Ayutthaya, Thailand, 2001.

Bonora, V., Chieli A., Spanò, A., Testa, P., Tucci, G., *3D metric modelling for knowledge and documnetation of architectural structures (Royal Palace in Turin)*. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 5/W12

El-Hakim, S.F., Beraldin, J.-A., *Detailed 3D Reconstruction of Monuments Using Multiple Techniques, International Workshop on Scanning for Cultural Heritage Recordin*g - Complementing or Replacing Photogrammetry, Corfu, Greece, Sept. 01 and 02, 2002: NRC 44915
http://www.vit.iit.nrc.ca/References/NRC-44915.pdf

Guarnieri, A., Vettore, A., 2002. *La modellazione 3D di ambienti complessi*, Atti della 6a Conferenza Nazionale ASITA, Perugia, 5-8 novembre 2002.

Guarnieri, A., Guidi, G., Tucci, G., Vettore, A., *Towards automatic modelling for cultural heritage applications, The International Archives of the Photogrammetry*, Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 5/W12

Guidi, G., Tucci, G., Beraldin, J.-A., S. Ciofi, S., Ostuni, D., Costantini, F., El-Hakim, S.F., *Multiscale Archaeological Survey Based on the Integration of 3D Scanning and Photogrammetry, International Workshop on Scanning for Cultural Heritage* Recording - Complementing or Replacing Photogrammetry, Corfu, Greece, Sept. 01 and 02, 2002: NRC 44914
http://www.vit.iit.nrc.ca/References/NRC-44914.pdf

Guidi, G., Ostuni, D., Costantino, F., Pieraccini, M., Tucci, G., Beraldin, J.-A., 2001. *Photogrammetry and 3D scanning: assessment of metric accuracy for the digital model of Donatello's Maddalena*. Italy-Canada Workshop on 3D Digital Imaging and Modeling Applications of: Heritage, Industry, Medicine & Land, Padua. (on CD ROM)

Malinverni, E.S., Fangi, G., Gagliardini, G., 2003. *Multi-resolution 3D model by laser data*, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 5/W12

Yokoyama, H., Chikatsu, H., 2003. *3D representation of historical structure for digital archives by laser scanner, The International Archives of the Photogrammetry,* Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 5/W12

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