INTEGRATED DIGITAL TECHNOLOGIES TO SUPPORT RESTORATION SITES: A NEW APPROACH TOWARDS A STANDARD PROCEDURE

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ABSTRACT:

LIDAR data integrated with digital photogrammetry today represents one of the most attractive ways of facing the metric surveying of an architectural object. Many papers have illustrated the possibility of building a complete 3D model using just these two techniques. In practice, not many restorers are used to managing 3D models and traditional graphic results, such as plans and sections, are usually required.
The paper defines a correct balance between the use of traditional (manual and total station) and innovative (LIDAR and digital photogrammetry) techniques in order to satisfy the usual requirements for the metric survey of an architectural object.
A project was carried out to obtain knowledge of the “Chiesa di San Giovanni Decollato” which is locally known as the Church of the “Misericordia” in Turin; it was necessary to prepare the survey graphic drawings that would be used for the restoration both of the decorative motives and of the structure of the church.
The most important aspect of this work is the integration of traditional topographic techniques with the LIDAR technique. This integration was necessary because of the complexity of the object that was to be surveyed (many decorative details, poorly illuminated objects and no available scaffoldings) and of the requested short times necessary to realize the survey. The tools implemented in the new Sir-IO software (realized by a DITAG research group of the Politecnico di Torino) were of great help in this work. In fact, thanks to this software, it was possible to directly plot the details that were to be surveyed on the realized solid images and orthophotos, thus making the preparation of the survey graphic drawings considerably easier.

1. INTRODUCTION

In the last few years, a great deal of experiences have been gained on the use of LIDAR techniques, usually integrated by digital photogrammetry, in order to obtain 3D models of cultural heritage objects (Guerra et al., 2002; El-Hakim et al., 2008).
Ranging from small object to buildings, building complexes, historical centres and natural landscape, the papers presented in many congresses and symposia have demonstrated the possibility of obtaining a complete answer to 3D knowledge and understanding using just these two innovative techniques (Agnello et al., 2008).
It should however mentioned that no costs/benefits analysis have been performed to show the real applicability of the obtained results in practical works and no one has considered that, in most cases, the final users usually require 2D graphical results such as plans and sections.
The setting up of plans and sections by using LIDAR data can be interpreted as a low level usage of them and the obtained results do not have the same quality as the ones obtained using traditional techniques. Furthermore, digital photogrammetry is not the best technique to provide 2D representations by means of plans and sections.
On the other hand, traditional techniques (e.g. direct approaches using distance measurements or indirect approaches using reflector-less total stations) involve remarkable limitations due to poor lighting conditions and inaccessibility of the details, especially when ad-hoc scaffoldings can’t be used.
In these situations, a productive integration between traditional and more innovative techniques is advantageous.

In the following sections, a real application of an integrated metric survey of a historical church in Italy is described in detail. A possible solution to obtain the best economic impact and the best final solutions will be shown.

2. THE SURVEY OF THE CHURCH OF THE “MISERCORDIA” IN TURIN

Located in the historical centre of Turin, the Church of the “Misercordia” has a rich interior decorated in baroque style and a neo classical façade (see fig.s 1 and 2).

Figure 1: The main façade of the Church of the “Misericordia”

The Church has structural movements which affect the decoration of the interior, therefore a restoration project was financed in order to repair structural weaknesses and to restore the decorative parts.

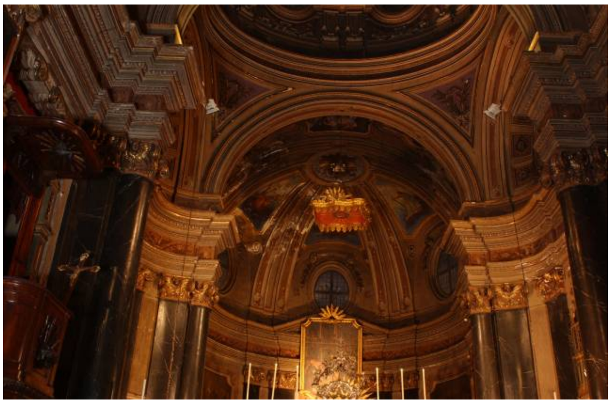


Figure 2: Inside view of the Church of the "Misericordia"

The metric survey had to fit the needs of a detailed design therefore a final tolerance of 2 cm was adopted (e.g. 1:50 nominal scale).
The production of the main plans (fixed at 1.2 m and 8 m above the floor) and of 7 vertical sections were decided on according to restorer requirements.
Some practical problems arose during the design of the metric survey.
First, the church was continuously open during the survey and permission to place of scaffoldings was denied.
The complete acquisition phases had to be completed in no more than two weeks and no special illumination was allowed.
Finally, all the interior decorations on the walls are made of yellow, brown and black marble.
Considering all these constraints and the necessity of obtaining the required tolerance of 2 cm, even in the upper part of the church (more than 25 m above the floor), the combined use of digital photogrammetry and LIDAR acquisition for all the details not on direct contact with a human operator represents the only possible solution.
Only the traces of the plans and of the sections were surveyed using total station. Manual measurements were made of the hidden details, as this approach was considered the most efficient in this particular case.
All the steps of the survey are presented in the following sections in order to point out the correct integration and the obtained final results.

2.1 The first order network

In each metric survey, a first order network had to be fixed in order to define a local 3D coordinate system and to control the error propagations under the fixed 2 cm of tolerance (at 95% of probability).
In order to reach the last goal, estimated accuracies of less than 1 cm had to be reached on the points of the network.
Considering that the control network had to circumscribe the survey space, the most of the points were placed inside the building.
Classical angle and distance measurements were therefore performed for the planimetric survey and geometric levelling was used to define the network in the third dimension.
The planimetric first order network was made up of 22 control points (see fig. 3 and 4) permanently materialized on the floor with metallic nails and a suitable sketch was realized for each of them.

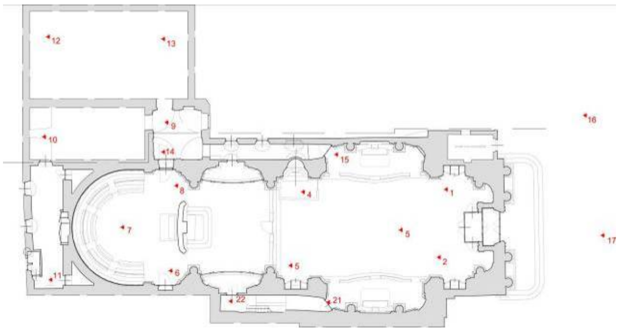


Figure 3: Low ground map with indication of the control points

The survey scheme that was adopted is the free topographic network realized with a number of measured angles and distances that is exuberant with respect to the minimum geometric constraint in order to estimate the obtained precisions.

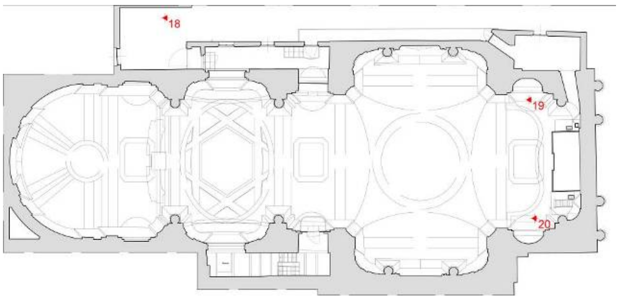


Figure 4: First-floor map with indication of the control points

The Topcon GPT 8201A total station and an electronic level LEICA NA2002 were used for the measurements. All biases were eliminated using hardware and ad hoc solutions.
The coordinates of the control points were estimated with a least square adjustment (Starnet by Starplus Technologies), obtaining precisions that were suitable for the following field survey phase.
The local coordinate system has its origin in the point 2 (X = 100 m, Y = 100 m and Z = 100 m) and the line passing through point 1 defines the y-axis.
The scheme of the measurements and the standard error ellipses on each control point are represented in figure 5.

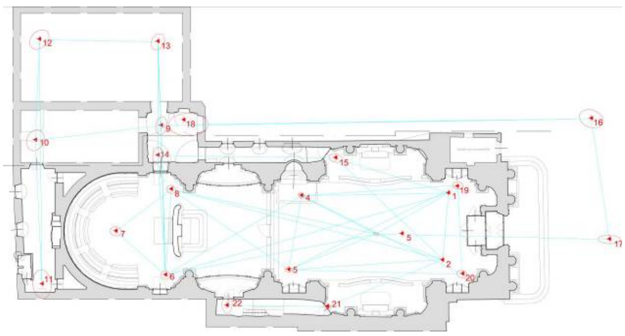


Figure 5: Scheme of the measurements and of the standard error ellipses of the control points (110X zoom)

Control points	σ_x [cm]	σ_y [cm]	σ_z [cm]
1	0.081	0.000	0.023
2 [origin]	0.000	0.000	0.036
3	0.079	0.013	0.014
4	0.083	0.012	0.019
5	0.050	0.094	0.065
6	0.146	0.155	0.089
7	0.157	0.191	0.033
8	0.137	0.153	0.045
9	0.301	0.184	0.068
10	0.362	0.292	0.098
11	0.487	0.319	0.085
12	0.335	0.317	0.033
13	0.279	0.220	0.044
14	0.276	0.168	0.059
15	0.142	0.228	0.063
16	0.304	0.405	0.055
17	0.141	0.385	0.083
18	0.389	0.666	0.074
19	0.125	0.173	0.022
20	0.126	0.173	0.023
21	0.879	0.657	0.057
22	0.651	0.897	0.031

Table 1: 1σ estimated values of the control point coordinates

These results show the correspondence between the measurements and the statistical precision model. The achieved precisions are a lower order of magnitude than the tolerance required for the field survey.

2.2 Traditional surveys

In order to acquire the needed points for the realization of the drawings, a traditional survey was conducted using a total station. All the station points were located on the vertexes of the control network. A LEICA TPS 805 total station was used for all the detail surveys.
The surveyed points were integrated with direct measurements and interpreted in order to draw the required plans and sections.
Figures 6 shows the intermediate results of the instrumental survey and the final drawing of a plan detail, produced after integration and interpretation following the traditional guidelines for architectural representations.

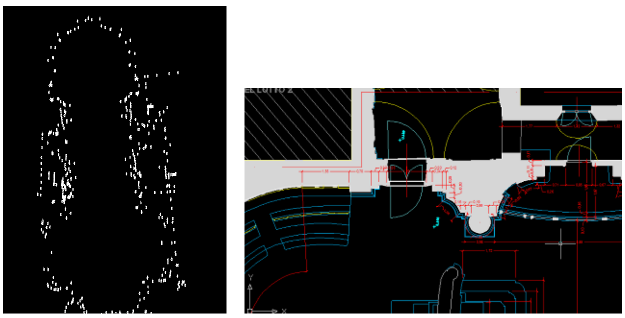


Figure 6: Surveyed points and final drawing after integration and interpretation

The complete surveys of the plans and sections required three days and the results were used for the drawing phase at the end of each day in order to speed up the interpretation and representation phases.

The completion of the sections and plans always requires knowledge of the details which are visible in the direction of the section planes, therefore particular attention was paid to record all the visible details.

2.3 Photographic rectifications

The photographic rectification technique was employed to describe some decorative parts of the church,.
The use of this technique was limited to some particulars of the church (the ones that could be approximated to plains), such as the side chapels and the confessionals.
The digital images that had to be rectified were acquired using the calibrated Canon EOS 5D camera (12.8 Mpixel); the points necessary to define the mean plains for the rectification process were measured using the total station. The analytic photographic rectifications were realized using the Archis 2D software (Galileo Siscam). The use of a calibrated camera and experimental software realized by the DITAG research group allowed the elimination of the residual radial distortions from the acquired digital images. The portions of the church that were subjected to photographic rectification are indicated in figure 7.

Figure 7: Positions of the images (red lines) subjected to the analytic photographic rectification process

An example of a rectified image and the subsequent digitization process is reported in figure 8.

Figure 8: Original photo and rectified photo employed for the representation of the decorative elements for the section representation

Thanks to these methodologies it was possible to provide the designers with a useful product for the representation and documentation of some internal parts of the Church.
The methodology was acceptable because the visible parts were not subject to the strict tolerance of the survey, therefore walls that are not perfectly plane can also be recorded in this way.

Figure 9: Extract of a section with decorative elements recovered from rectified images

2.4 LIDAR and digital photogrammetry integration

Both LIDAR and Digital photogrammetry are techniques that can allow the acquisition of the primary data in a very short time and they therefore seem to be a correct approach for a survey.
As far as LIDAR is concerned, the subsequent registration, segmentation and modelling phases are more expensive in terms of time and require professional skills. Digital photogrammetry requires great deal of time and experience to orient the images and to extract the needed geometric information from stereo-models due to the complexity of the object which makes the necessary to carry out manual extraction of the geometry.
LIDAR primary data can however offer some useful analysis instruments in a complete automatic procedure and digital photogrammetry can use great deal of information from LIDAR that is useful to obtain oriented images in an automatic way and to map the images on the point clouds.
In addition, a new instrument, based on a multi image correlation was used to describe the main altar of the church.

2.4.1 Data acquisition

A Riegl LMS Z-420 laser scanner (figure 10), a TOF instrument, was employed. Table 2 summarizes the main technical details of the used instrument.

Measuring range	up to 350 m
Minimum range	2 m
Distance measurement accuracy	± 5 mm
Measurement rate	3000-9000 pts/sec
Vertical Scanning range	80°
Horizontal Scanning range	360°
Weight	14.5 Kg

Table 2. Key specifications of the *RIEGL LMS-Z420*

In order to obtain a good quality in the detail description, a scanning interval of 50 mgon was employed in all the scan positions. Only the pipe organ was scanned at a 35 mgon scanning resolution; seven different scan positions were taken in the church.

Figure 10: Vertical and horizontal acquisitions

The wall decorations of the church were acquired using the laser scanner in the vertical position while the vaults were surveyed putting the instrument in the horizontal position (see fig. 10). Figures 11 and 12 show the areas that were acquired in each scan position.

Figure 11: Surveyed surfaces in scan positions 1-2-3-4

Figure 12: Surveyed surfaces in scan positions 5-6-7

Metric images were acquired using an high resolution digital calibrated camera (Nikon D1X, 18 MPixel, equipped with 14 - 24 mm lens) which was mounted onto the top of the LIDAR instrument. In the survey, both 14 mm and 24 mm lens were employed in the image acquisition, in order to achieve approximately the same field of view in the laser scanner and the camera acquisitions, considering the different fields of view of each scan.

During the laser scanner acquisition, several reflector markers (see fig. 13) were placed in the church. Their positions were chosen in order to guarantee a minimum number of common points (at least 5) for each adjacent scan-pair with a suitable localization and a good geometrical strength (locating them at different heights).
All the markers were measured by the total station and referred to the coordinate system defined at the beginning of the survey.

Figure 13: Reflector markers employed during the laser scanner survey

2.4.2 Data processing

The first step of data processing was carried out using the RiscanPro Software. Thanks to this software, each scan position was relatively oriented to the photographs (mounting).
All the other processing steps were performed using the Sir-IO software, which was recently realized thanks to the cooperation between the Politecnico di Torino spin-off SIR s.r.l and the Geomatics research group of the same university.
Using this Software, the point clouds were filtered through a median filter (Bornaz et al., 2001) in order to reduce the data noise. The radiometric information was then linked to each scan, in order to obtain coloured point clouds.
The scanner yields a point cloud in the sensor coordinate system (x,y,z) for each position.
The data sets of all the scan positions were oriented relative to each other (traditional registration); moreover, using the reflector marker coordinates, an absolute orientation of all the scans was performed using the "laser triangulation algorithm" (Bornaz et al., 2002) implemented in the Sir-IO software (figure 14). The final result was a complete point cloud of the internal surfaces of the church in the local topographic system (figure 15), achieving a σ_0= 1.19 cm with respect the final tolerance of the survey.

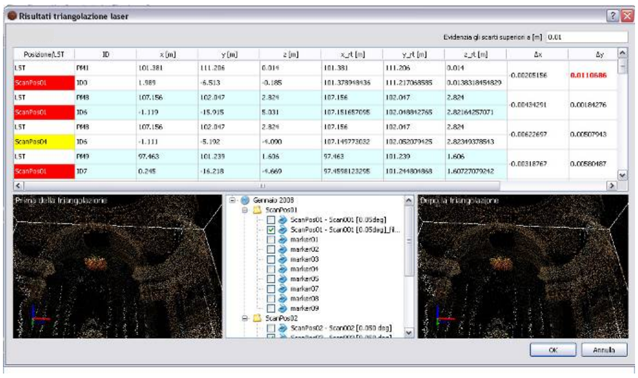


Figure 14: Laser triangulation in the Sir-IO Software

Figure 15: Complete coloured 3D model of the Church

It is well known that a point cloud of a church is useless in restitution work; it is very difficult to extract coherent information from millions of points without a segmentation and a modeling phase.

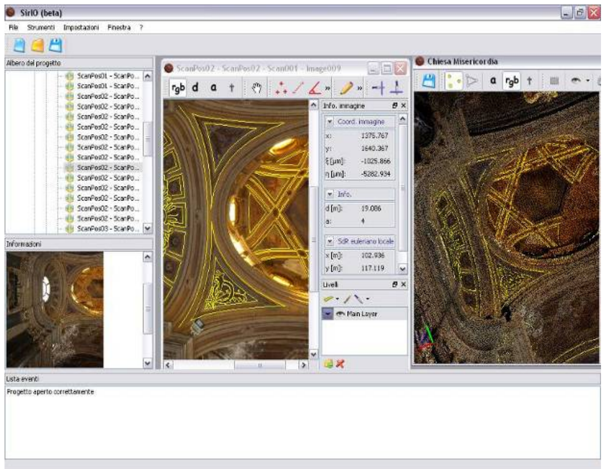


Figure16: Plotted details in a solid image

For this reason, in the last few years, the Geomatics research group at the Politecnico di Torino has developed new instruments in order to make the use and the extraction of suitable information from laser scanner data easier when no complete 3D model is required.

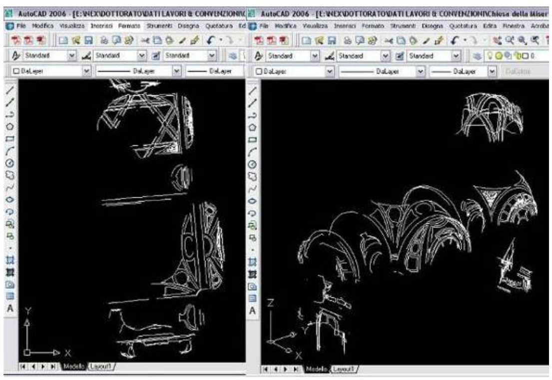
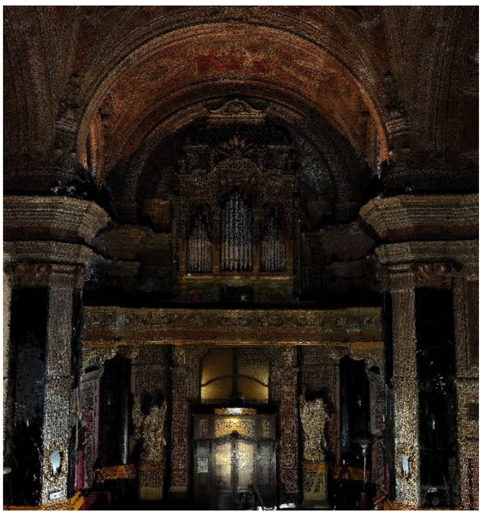


Figure 17 : 3D details exported in Autocad

In some ways the Sir-IO software represents the last step of this work because it allows solid images (Dequal et al., 2003) and solid orthophotos to be generate.

Furthermore, it is possible to survey the required details just by redrawing the contour of the objects on these products, as shown in figure 16.
With reference to the Misericordia church, about 70 solid images were created in order to document all the internal surfaces of the church. Moreover, several solid orthophotos were realized to document and accurately describe the vaults and the church ceilings.
From these products, it was finally possible to draw the parts to be projected in the representation of the longitudinal and transversal sections and to describe the fine decorations of the upper parts of the church with the required tolerance.
The information obtained from the Sir-IO software, such as distances, angles, point coordinates, and in particular the vector plotting, were finally exported in a CAD software (figure 17) in order to merge this information with the information achieved in the topographic survey in order to make the final correct drawings (see fig.s 18, 19 and 20).
The solid images were also suitable for the evaluation of the deterioration of the walls due to water damage.

Figure 18: Longitudinal section 1:50 (not in scale)



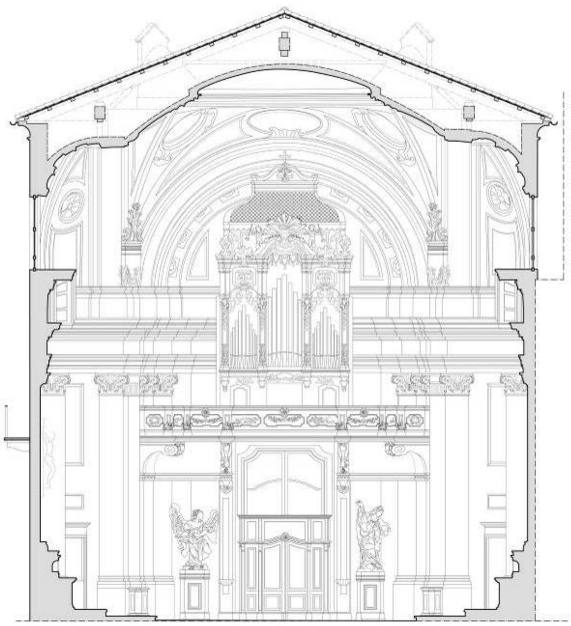


Figure 19: Screen shot of a part of the 3D model of the Church [left] and corresponding drawing (transversal section 1:50, not in scale) [right]

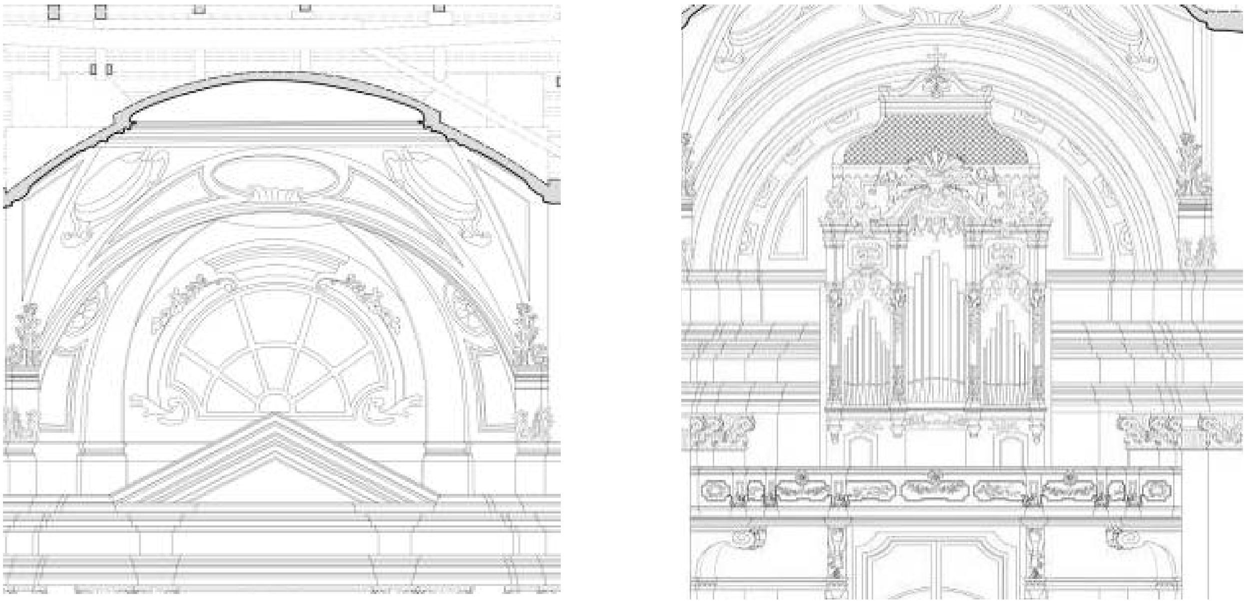


Figure 20: Decoration details 1:50 (not in scale)

3. MAIN ALTAR SURVEY

One of the most important objects in the church is the main altar. It would have been difficult to survey the main altar using the traditional techniques because of the irregular shapes of all its components.
A detailed survey was performed using a new digital photogrammetric instrument based on the multi-image correlation: the Z-Scan (by Menci Software - Italy).
A calibrated bar allows many images to be taken with a regular and known base length.

Figure 21: Z-Scan image acquisition

An automatic software carries out the relative orientation of the images (with a bundle adjustment approach) and the point matching by considering all the possible images.
During the XXI ISPRS congress (Beijing, July 2008), the authors demonstrated that multi-image correlation can give point clouds with the same density and accuracy as the ones usually acquired with the LIDAR approach.
The main advantage is the low cost of the acquisition instrument (a metric camera) and the scalable reachable precisions (by varying the base/distance ratio).
Figure 22 shows the results of the multi-image matching of the main altar.

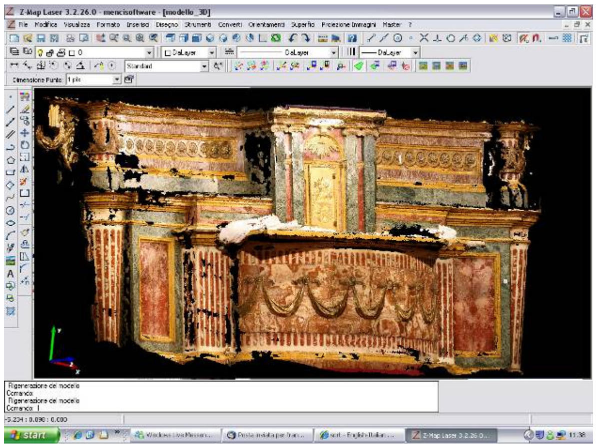


Figure 22: 3D point cloud obtained by the Z-Scan

4. SURVEY DOCUMENTATION

A complete documentation of a survey is currently a mandatory task that has to be completed at the end of each survey.
First, it should be clearly stated that the final drawings, 3D models etc. are not the results of the survey, but just a way of representation.
In fact the final drawings (see fig.s 18, 19 and 20) do not allow complete accessibility to the original survey data that are useful to integrate, substitute and extend the acquired data.
The final drawings and the 3D models do not allow a new elaboration of the acquired results and therefore do not allow the possibility of using the advantages obtained from the new data elaboration method which can be defined many years after the acquisition of the primary data.
It is possible to state that a correct documentation of the survey involves the recording of the used coordinate system and of the primary data.
The coordinate system is defined by the control network points, therefore the measurements used to compute their coordinates and the final sketches have to be saved.

The primary data change according to the techniques that are used. In the case of direct measurements, the filled sketches and the original measured distances have to be saved.
In the case of total station measurements, all the angles and the distances have to be recorded according to the technical specifications of the used instruments.
As far as a photogrammetric survey is concerned the original images, the calibration data of the used cameras and the control points used to orient the images have to be saved.
Finally, in the case of LIDAR surveys all the original files have to be recorded with the control points used to recover the final coordinate system and the sketches demonstrating the taking points for each scan.
In order to complete the documentation a simple metadata structure is also needed in order to give the authors, their addresses, the time when the survey was made and the extension of the survey.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

An integration between traditional and innovative techniques in an architectural survey has been presented in this paper.
The correct balance between the four different used approaches (manual measurements, total station, digital photogrammetry and LIDAR) is influenced by the size of the object, the lighting conditions, the materials, the field restrictions and the tolerances.
The kind of required final representations (e.g. plans and sections, 3D models, etc.) also influences the number of surveyed points and of the usable techniques.
The LIDAR technique and digital photogrammetry, thanks to new management instruments (e.g. solid images), can also be used when 3D models are not the final products required by the end user.
The example described in the previous sections shows that a correct use of the LIDAR technique and of digital photogrammetry can speed up the acquisition phase and give all the information needed for a complete graphic representation of a surveyed object.
The LIDAR technique and digital photogrammetry in particular can be used not only when 3D models are required but also to help traditional techniques to speed up the survey of the inaccessible points without performing the heavy segmentation and modeling phases, that at the present state of art, require a huge human intervention.
The Research Group at the Politecnico di Torino activated a new research activity concerning the possibility of merging digital photogrammetry and LIDAR segmentation in order to reach a higher degree of automation.
The basic idea is to extract, from the oriented images, radiometric edges which usually match geometric break-lines (the results of the segmentation) in order to drive the segmentation algorithms towards affordable solutions without human validation and correction intervention.
The success of this research goal will allow a change in the strategy of the metric survey and a different integration between traditional and innovative metric survey techniques.

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