FROM THE ACQUISITION TO THE REPRESENTATION: QUALITY EVALUATION OF A CLOSE RANGE MODEL

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ABSTRACT:

In this paper a multisensor approach (topography, photogrammetry, laser scanning) was exploited to generate a close range model of a cultural heritage object in order to evaluate the accuracy of data in all steps of the model production, from the acquisition to the representation.
A programmed data redundancy allowed to verify the accuracy of each technique as well as the presence of possible surveying errors. At the end, a comparison from data acquired by different tecniques was done in order to verify the accuracy of the laser model. We have explored the entire workflow to obtain a complete 3d model: range image registration, points decimation, triangulation, mesh editing, model texturing. The results are here presented.

1. INTRODUCTION

New three-dimensional models can be useful for programs of analysis and conservation of cultural heritage. Models make easier the understanding and the communication of particularly shaped architectonic structures, through a synthetic vision. A multisensor approach seems to be the most suitable solution for articulated geometry. Our study case is the transept-apse complex of S. Francesco al Prato in Perugia, one of the most important Franciscan Friars churches, the second after that of Assisi.
To acquire metric data, different procedures have been employed: topography was used to establish a reference system and to acquire natural and target control points; photogrammetry was employed to obtain breaklines and sections from an accurate restitution, in order to compare them with laser scanning data; and laser scanning. The model has been obtained from the merge of these different acquisitions in order to evaluate the accuracy of data in all steps of the model production, from the acquisition to the representation. A programmed data redundancy allowed to verify the accuracy of each technique as well as the presence of possible surveying errors. At the end, a comparison from data acquired by different tecniques was done in order to verify the accuracy of the laser scanner model.

2. DATA ACQUISITION: METHODS AND INSTRUMENTATION

The articulated geometry, derived from a mixture of architectonic elements, structural damage and superficial decay, required the survey of many points, imposing the management of numerous detail drafts to choose the representative elements.

Topographic data: about one thousand detail points were collected with a reflector-less total station Leica TCR703, after having traced a small net of arrangement; the adjustment were performed by using the least squares method. At the same time, about 100 control points were 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.

Photogrammetric data: the images were 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 were acquired on the apse, with mobile scaffolding, obtaining about 1:350 scale of images. On the transept, twelve stereocouples were acquired at about 1:250 scale (longitudinal overlap =80%, transversal overlap = 40%). The images were oriented and restituted with both analytic stereoplotter Digicart 40 (by Siscam) and digital Stereoview (by Menci Software).

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

3. DATA PROCESSING

Increasing automation of data acquisition and processing is 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.

3.1 Photogrammetric data processing

The following outputs were produced from the orientated photogrammetric models:
- wireframe 3d model: all the geometries, and breaklines due to the materials and pathologies, were plotted. This is the most widespread output for the architectonic use because it allows to take out the conventional 2d drawings as prospects, vertical and plane sections. A solid model can also be obtained as a subproduct of the wireframe plotting. It requires a large interpolation of data and the result is, in any case, a semplified model of the main geometries in which the details related to the irregularity of the materials can be later added as photorealistic texture;
- vertical sections, with a step of 10 cm, aimed at making elements of comparison for laser scanning data: the sections, indeed, have plotted points dense enough and, in addition, derive from an accurate selection of more significative discontinuities;
- digital model: starting from a stereoscopic couple of images with the fitting in of the plotted sections as constraint for the altimetry, an automatic DEM by image correlation was produced. In order to compare the results with laser scanning data, a step of 1 cm has been set as a resolution. Output data was interpolated and overlapped to the photogrammetric plotting so as to calculate surfaces with triangular and square meshes.

3.2 Laser scanning data processing

Laser scanner acquired points are generally more than necessary to obtain a meaningful shape representation. At any rate, 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.
Presently, 3D modeling of real free-form shapes consists of the following steps: registration, pre-processing, mesh generation, post-processing, texturing. The range map registration was carried out with Cyclone software (by Cyra).

3.2.1 Registration: Range maps registration were carried out with Cyclone software (by Cyra): 20 in all, 13 for the right zone and 7 for the left zone. In order to align the range maps, different kinds of constraints were used:
- automatic pre-alignment by specific targets in the lower part of the transept;
- manual pre-alignment by selected homologous couples of points;
- optimization by the analysis of the overlapping portions of the clouds.

Figure 1. Photogrammetric plotting: wireframe model

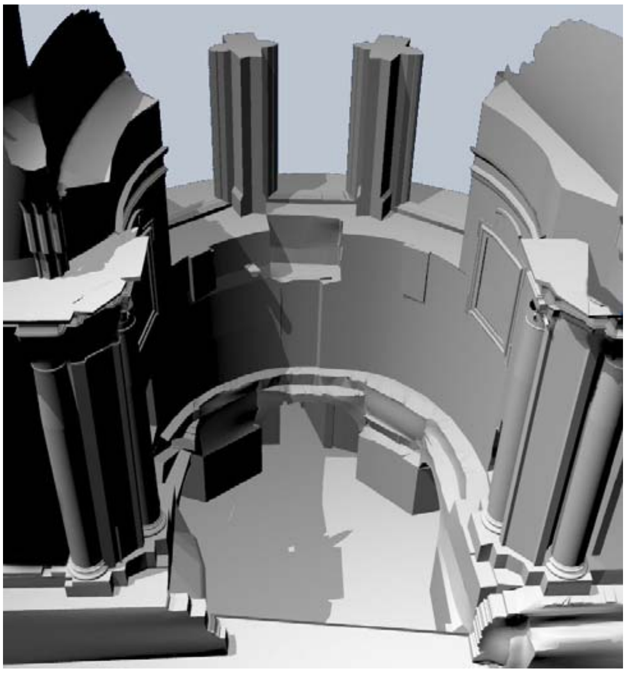


Figure 2. 3D model elaboration using topographic and photogrammetric data

The results are affected by the percentage of overlapping between the range maps, by the morphology of the acquired portion of the object (better alignment with "strongly 3d" form), by the percentage of points used in the computation (3 or 5 % in almost all range maps except for the high part of the transept where the planarity of the surfaces and the difficulty to collect data overlapped enough required from 30 to 50 % of the points). In order to set a unique reference system for all types of data, also to compare the results with topographic and photogrammetric survey, specific targets, topographically measured, were used as constraints in the global range data alignment. The registrations were performed in scan block; all of the following data processing was done on portions of the entire model, to be able to manage acceptable file dimensions and to reduce the elaboration time. Also the visualisation became modifiable in real time. At the end, all of the blocks were reassembled according to the established reference system in order to create a unique model.

BLOCK	SCANS #	TARGET #	PTS original cloud x1000	PTS cleaned cloud x1000	PTS sampled cloud x1000	N. cluster /cloud #	TRIANGLES x1000
lato dx	17	6	9.407	9.021	5.981	4	11.805
fondo dx	3	5	2.826	2.253	1.042	1	1.993
parte sx	7	6	7.614	5.847	3.535	4	6.779
complet model	27	17	19.847	17.121	10.558	9	20.577

Table 1. Data about laser scanning project

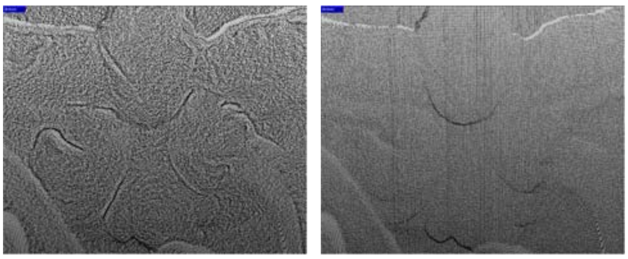
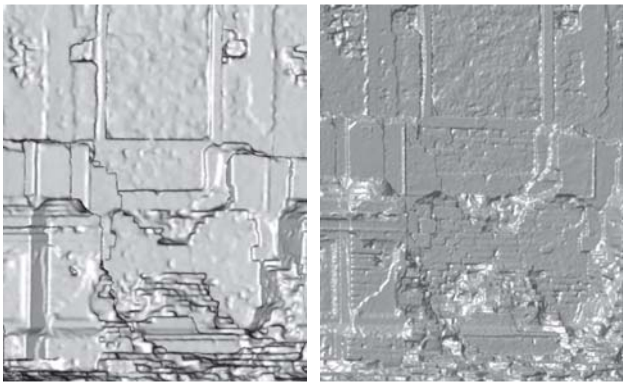


Figure 3. The same range map detail before and after noise reduction



	NOISE + SMOOTH FILTER POINT SHIFTING		
	max distance [m]	avg distance [m]	st deviation [m]
	0.003	0.001	0.0006
	0.004	0.001	0.001
	0.006	0.002	0.001

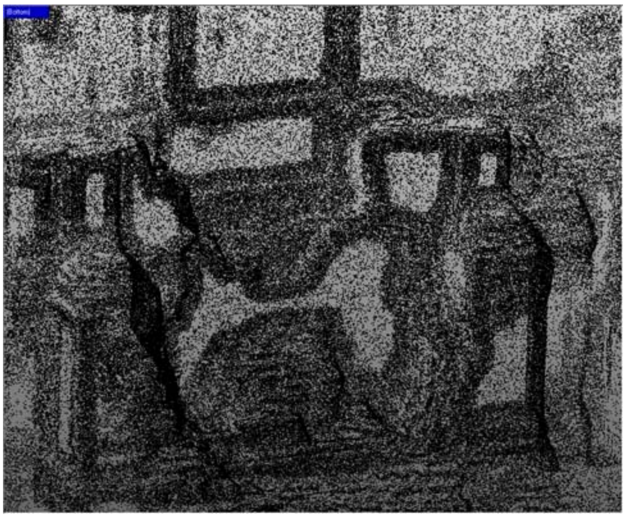
Figure 4. Surface model with different levels of noise and smooth filter: it is possible to appreciate different details in the material texture.

Table 2. The shifting applied to the points after different levels of noise and smooth filter

After the global registration, the final residuals are, on average, lower than one centimeter; this can be considered a good result related to the accuracy of the employed instruments (± 6 mm).

3.2.2 Preprocessing: Often during the scanning it is not possible to remove the obstacles on the scene: in Perugia we could not avoid scanning elements as scaffoldings and other materials of the yard in progress in addition to the weeds. Sometimes these obstacles give great shadow which have to be considered in the survey project. Automatic selection with a distance based filter, is only useful in preliminary, approximate cleaning of data. In a lot of parts, manual selection was used to obtain more accurate results. The reduction of the points was considerable (14%).
The final cloud of points (17 million points) was partitioned marking the boundary of relevant architectonic portions of about one million points in order to optimize the following operation and to allow data management in real time. These clusters of data were elaborated and joined one by one in a unique surface model, drastically decimated. Saving the data in every step of the elaboration would allow to assemble the model in every phase of processing.
Noise reduction: The noise reducing operation was carried out by a filter available in Raindrop Geomagic: using statistical methods, the operation determines where the points should lie, then moves them to these locations. Depending on the magnitude of the errors, it is possible to choose a minimum, medium, or maximum noise reduction setting.
Two options help optimize the operation for the type of model with which it is working. If the point set represents a freeform or organic shape, the operation reduces the noise with respect to surface curvature. If it is a mechanical or prismatic shape, the operation helps keep features sharp such as edges. After the noise reduction is complete, statistics are displayed in the Dialog Manager that indicate the Maximum Distance, Average Distance, and Standard Deviation of the points from their original positions.
Tests with range maps at a different resolution were performed: the first one with a single range map, acquired at maximum resolution (6 mm) on the capitals area and the second one with a lot of range maps acquired at 1.5 cm of resolution on a more extended portion of the transept.

First we tested the smoothness level parameter on the range map carried out with maximum resolution. In function of the obtained results, summed up in the table, we chose to apply to all the data a noise reduction with medium smoothness level. In more realistic operating conditions, however, there are a lot of range maps acquired with less resolution. In these cases, the effects of the overlapping add to the noise effects and join themselves. We have also noticed that the combined application of noise and smooth filters involve a significant reduction of the descriptive capability of the model in order to represent both the surface texture and the edges of the architectonic elements. At the end, we preferred to apply a noise reduction with a minimun smoothness level to the final model.
Decimation: Data derived from laser scanning are characterized on one hand by redundancy of measured points and on the other hand by no critical selection to describe the morphology of the object. The decimation procedure is aimed at reducing the huge number of points in order to give a better approximation to the shape of the object. It is possible to use different criteria:
- random sampling, a percentage decimation, applied to the whole cloud of points in a random way;
- uniform sampling, that subdivides the model space into equally sized cubical cells (the dimension of the cells is a function of the fixed level of decimation) and deletes all but one point from each cell;
- curvature sampling, in which points that lie in a high curvature region remain in order to mantain the accuracy of the surface curves; because flat regions require less detail, points in those regions are more likely to be deleted. On the same range map above mentioned, we applied different decimation algorithms: to apply random sampling is similar as to acquire data with a wider sampling step, useful only for coarse decimation; the uniform sampling allows to have more regular triangles in the surface but the descriptive capability of the complex shape is



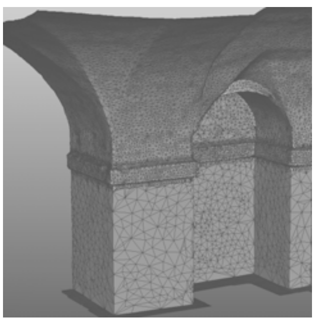


Figure 5.
Curvature sampling. We can note the effects of the decimation: stronger in the regular surfaces

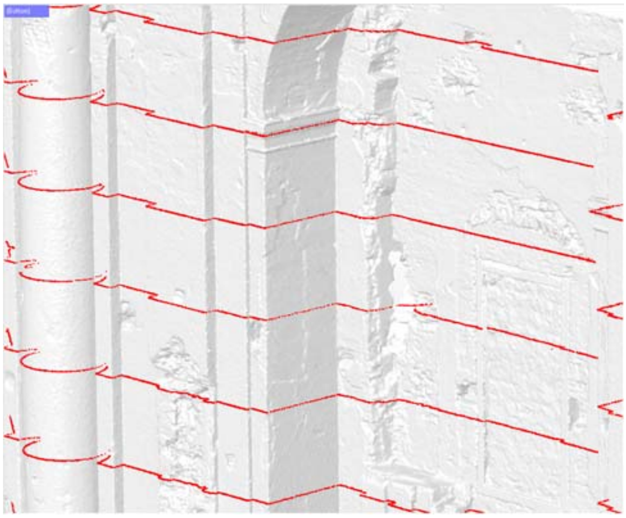


Figure 6.
Strips of points useful to support conventional drawings

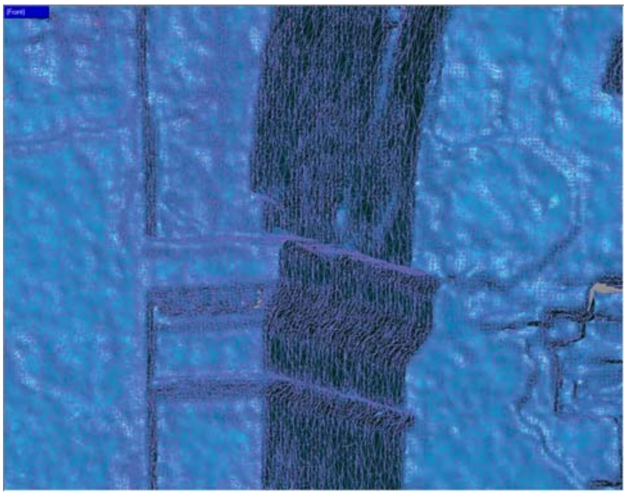


Figure 7. Detail of the triangulated model

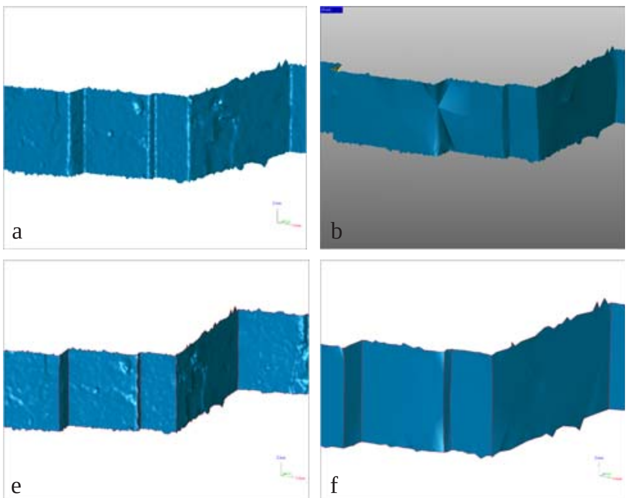
reduced enough; a decimation with curvature sampling originates instead, in the triangulation phase, a surface with mesh of variable dimensions according to the complexity of the object.
On the other hand, operating only with automatic procedures, it can be hard to regulate the decimation level without losing too much data in the uniform areas with the result also to produce

Figure 8.
Sample of the triangulated model without simplification

holes in the meshes. In other case study, with more regular geometries, we obtained a positive outcome with a manual selection of portions of the cloud and with the application of different levels of curvature sampling.

3.2.3 Triangulation: The cloud of points, after registration and pre-processing operations as we have described above, is an important "storage" of metric documentation. It is possible to extract punctual dimensional information or to select "strips" of points to support the drawing of conventional plans and sections or to proceed in a sort of restitution identifying lines of discontinuity with manual or semiautomated procedure that analyze the curvature. More often the cloud of points needs to be transformed into surfaces: a triangulation converts the given set of points into a consistent polygonal model (mesh).

3.2.4 Polygons editing: Finally, different kinds of elaborations can be performed on the model of surfaces, according to the requirements that the graphical output should have, in order to satisfy our aims: static views, shaded or texturized, interactive exploration from local workstation or the Internet.
As we know, the editing of the model must balance two opposite needs: on the one hand it is necessary to take into account the "weight" of the model and, on the other hand, the geometric and topological description must be preserved. The decimation of



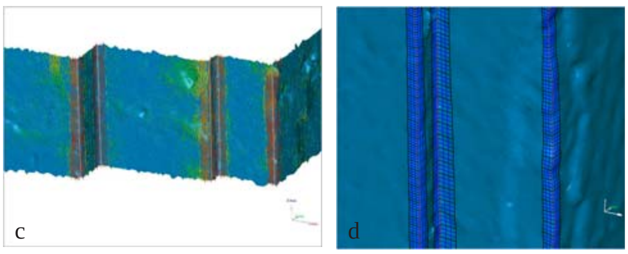


Figure 9. Polygon editing:
a - detail of the starting model; b - decimation (1% triangle) without edge reconstruction and fixed breaklines;
c - automatic breakline detection, supported by curvature surface analysis;
d - edge reconstrution; e - the same detail after edge reconstruction; f - decimated model (1% triangle) with fixed boundaries

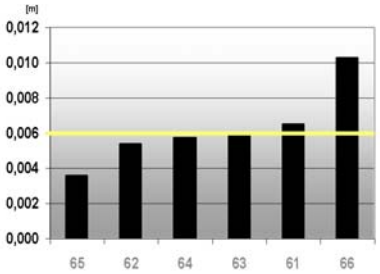


Table 3. Comparison between targets, topographically measured, and the same ones on the cloud of points after global registration

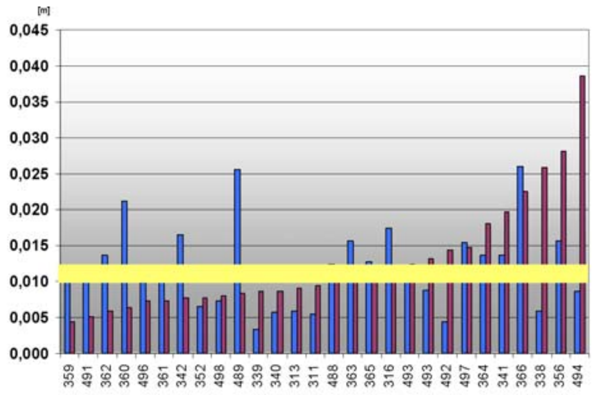


Table 4. Comparison between natural points, topographically measured, and the same ones on the surface model

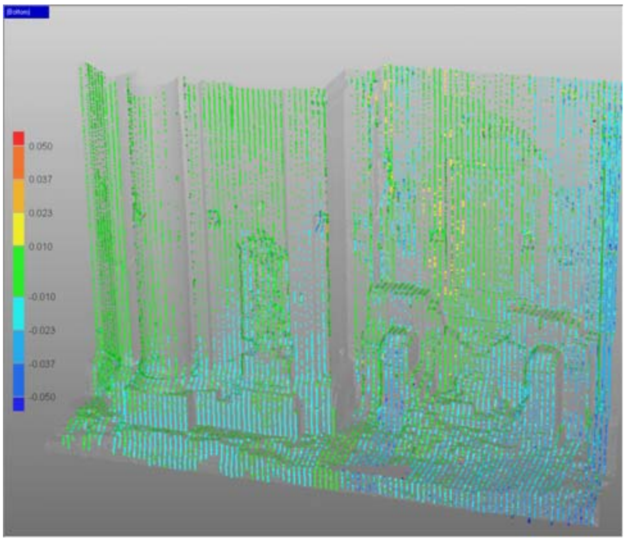


Figure 10. Graphic comparison between photogrammetric sections and laser scanning model. Residuals < ± 2 cm

the polygonal model can be carried out with criteria similar to those adopted to decimate the cloud of points. In order to fulfil the aforesaid need to maintain, as well as possible, the geometric shape, it is possible to choose to leave the details related to the material texture. Before applying the polygonal decimation, breaklines may be detected. These breaklines are useful for the edge reconstruction and can be computed as fixed boundaries in a stronger polygonal decimation. Surface smoothing can also be applied with the aim to increase the quality of the mesh, optimizing its geometry, without modifying fixed boundaries.

4. METRIC EVALUATION

The accuracy of the different kinds of models obtained from la-

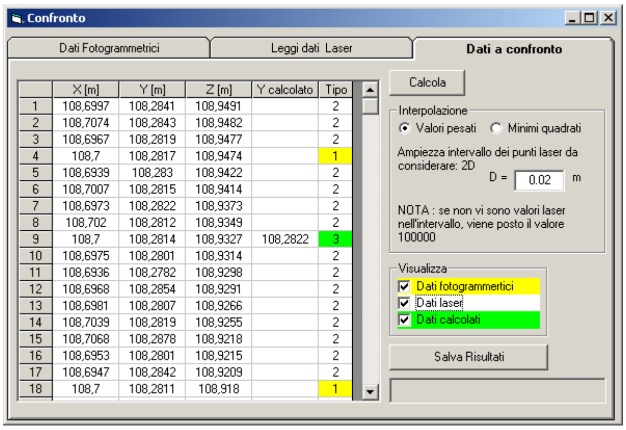


Figure 11. Screenshot of the program for comparison between photogrammetric section and the “strips” of points extracted from the cloud: Residuals < ± 1 cm

ser scanning does not depend only on the acquisition accuracy (type of instrument or scan resolution) but also on the different data processing, applied both on the cloud of points and on the triangulated surface. At the end of the main elaborations of the acquired data, a comparison between the final resulting mesh and the original acquired cloud of points was carried out. For that purpose sample tests have been done both on punctual elements and on tridimensional surface with the statistic evaluation of the standard deviation.

4.1 Measured targets vs. automatic recognized targets on the cloud of points

As mentioned above, the registrations were performed in scan block. Every block is referred to the unique reference system thanks to the special targets, topographically determined, and automatically recognized in the cloud of points. There is no interpretation or collimation error to determine them. The residuals are of the same order of magnitute as measurement accuracy of the employed instruments (± 6 mm)

4.2 Measured natural points vs. manual extracted points on model of surfaces by laser scanning

Another comparison, point vs. point, was performed between the complete model of surfaces and the topographic measure of the detail points. In this case the points on the model were manually chosen so they are affected by an unavoidable interpretative component. Indeed it is not possible to separate the metric evaluation from the descriptive one. Thirty natural points, well distributed on the selected area, were measured with reiterated collimations: the mean residuals are not much higher than one centimeter.

4.3 Model laser scanning vs. photogrammetric plotting sections

Vertical sections, every 10 centimeters, were plotted with a Digicart analytic plotter and overlapped on a triangulated model: the average distance between the plotted vertices and the surface is of 1.3 cm, with standard deviation of 0.9 cm.
The visualization of these distances by means of a colour map allow to highlight the distribution, the systematic error or the deformation of the model.

4.4 Laser scanning sections vs. photogrammetric plotting sections

Figure 12. Graphic representation of the comparison, carried out with the above mentioned program, between the photogrammetric sections and the corresponding sections on the registered cloud of points

We have chosen to use the array of sections, obtained by photogrammetric models, as a reference for testing laser data.
In fact, they correspond to the following requirements: they are representative in a homogeneous way of a tested area, the accuracy is known and they are indicative of the shape of the object with a sufficient density, able to be compared with laser scanning data. On the other hand, the measurments taken with topographic and photogrammetric techniques are normally referred exactly to those elements (edges, cornices, ...) not well-defined with laser scanning. Therefore, these deviations are not related to the nodes of the photogrammetric plot, but to those points which are able to better describe the surface. The aforesaid points were chosen as medium points between two subsequent nodes of the plotted polylines. At the end, we evaluated the deviations between the photogrammetric sections and the corrisponding sections of the registered cloud obtained as described in the sequel.
The residuals are < ±1 cm.

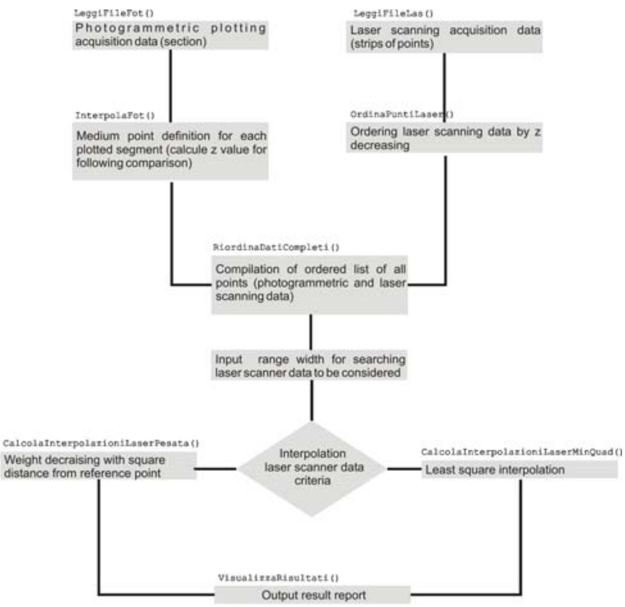


Figure 13. Flow chart of the program aimed at the comparison between the sections

4.4.1 Laser scanning sections: To make a point by point comparison between the photogrammetric plots and the laser scanning, with an automatic procedure, a Visual Basic program was developed. The flowchart in figure 13 shows its working.
1. To have an important sample of laser data, strips of points, 1.5 - 2 cm wide, were cut out. The corresponding photogrammetric section was plotted at x value equal to the center of the strip.
2. After having verified that there are not considerable variations in x direction, in the examined thickness of the strip, x value has been ignored: this is like projecting the points of every strip on zy planes.
3. Photogrammetric data are ordered according to the sequence of the plotted polyline vertices. For each segment a medium point is calculated and its z value is stored for consequent comparisons.
4. A subroutine orders laser scanning data by decreasing z. This criterion is true in the portions with a vertical tendency but it is not appropriate in the horizontal one, where z value does not indicate the correct subsequence of the laser data. In our case, the sections describe prevalently vertical surfaces; other criteria should be defined to generalize the approach.
5. Different search ranges can be defined around the previously calculated medium point (step 3); in order to better define it, both the quantity of plotted points and the object shape have to be considered.
6. A laser data interpolation is made with the purpose of defining those points with an y value corresponding to the previous stored z value. Interpolation can be performed according to two different criteria:
a - the points included in the search ranges are weighted with inverse square distance from the point used as reference;
b - a linear regression based on least-squares method is applied.
7. At the end, for each calculated z value, both photogrammetric and laser scanning y value, are compared and visualized.

5. CONCLUSION

In this paper an accuracy evaluation of an architectonic 3d model by laser scanning has been carried out. The main phases of elaboration have been tested and a comparison with reported accuracy values by the producer has been done. In general, we can say that the results are confirmed, also after registration, on the cloud of points but that the value proposed as “Modeled surface precision” (± 2 mm) is valid only in case of simple surfaces (level surfaces, spheres...) while with complex surfaces (as the most common cases in the architectural survey) it is not quite favorable, even though it remains in the accuracy range required in the cultural heritage survey.

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