THE CREATION OF THE DIGITAL MODELS FOR THE PROTECTION OF CULTURAL HERITAGE: THE BAPTISTERY OF CREMONA

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ABSTRACT:

In the Spring of 2003, it was realised a survey of the baptistery of Cremona (Italy) combining photogrammetric and laser scanner techniques. All the survey is composed by 22 photogrammetric images taken with a Nikon D100 18/2.8 digital camera and 14 scans collected by Optech's ILRIS-3D Laser Scanner. The geo-referencing was carried out with some natural and artificial targets displaced in the structure of the baptistery. The artificial targets used for this survey, were purposely projected, in order to get the best radiometric response and univocal geometrical definition; instead the natural target were surveyed in a traditional topographic way with a Total Station. The solid modelling of all the monument was made using a commercial software called PolyWorks; this software allows to align different scans with different reference systems and mapping some topographic information recording that on the 3D model.
This method permits to get a good architectural representation (accuracy about a centimetre, calculated with some control points) and map the images onto the numerical model; thus the metrical quality of the survey remains unchanged without loosing the semantic settlement.

1. INTRODUCTION

The Spatial Information technologies offer interesting opportunities for the architectural survey both for the positioning survey, form, geometry and colour and for the surveyed representation. For the survey of the monumental structures, for which it is difficult to have the contact with the object either for the operating context or for its valuable features, two are the leading techniques: the photogrammetric survey and the laser scanner techniques.

The first can be identifying with a classic technique even if in the last years it is visible a rapid methodological evolution of the photogrammetric close-range due to the coming of the digital camera. The classic scheme of acquisition of one or more stereo-couples, with normal shots at the object and consequent graphic restitution by stereo plotter, has nearly totally left space to much more flexible geometric schemes where are normal the shots even much convergent or at a different scale making practicable the images analysis only by monoscopic systems, having the advantage of using the wide reliability of the multi-images systems.

The laser scanner for land use is certainly, the most innovative and promising methodology in the architectural survey panorama. The capacity of acquiring hundreds or thousands points per second with high accuracy allows the knowledge of the surveyed up to the minimum particulars, supplying important results. For this reason, it is very important the use of a software of data processing equipped with a high number of base functionalities and big operating flexibility able to explore all the points and re-construct by modelling the surveyed surface and at the same time able to filter the data and create geometric primitives by fitting.

Of great interest is the union of these two methodologies, the photogrammetric and the laser scanner ones.

If unbalanced from the photogrammetric side it can supply orthophotos of accuracy thanks to the precise detail of the digital model produced by the laser or, if laser is the main instrument, it can supply texture mapping on architectural surfaces which introduce the creation of virtual realities.

In order to investigate the potentialities of the two methodologies, with special attention to the metric accuracy and to the georeferentiation issues, in Spring 2003, on the occasion of a lab training of a Photogrammetric Course organised by Politecnico of Milan, it has been carried out the survey of Cremona Baptistery.

The building (figure 1) is in the main square of Cremona, a place around which the civic, religious and economic core of the Medieval City was established. The Cathedral, The Torrazzo, The Baptistery, The Town Hall and the Loggia of Militi are one of the most striking monumental architectural complex of Italy: particularly the Baptistery on the southern side of the square was built in 1167 on octagonal map and is very similar to The Baptisteries of Florence and Parma.

The building, once wholly in terracotta tiles, is articulated with buttresses and decorations and on the top there is a series of single and double lancet windows. The structure suffered, since 1533, different interventions of renaissance which produced the exclusion of two of the three entrance doors. The one towards the square was left and later it was leant by a *protirus* on *stilofori* lions.

The ancient loggia with bartisan was substituted by the existing coping gallery surmounted by a band of open circle windows. Finally the northern and western sides were covered in pink bricks. On the top a lantern dominates a wide roof at triangular gores which lines a big covering with eight sides.

The interior, enlightened by the skylight, keeps its typical Romanesque spatiality.

The survey has been carried out only outside concentrating the attention to the finalities of the metric survey. The photogrammetric taken have been planned and realised by the students of the Course, who have also taken care of the supporting point by a topographic survey.

To complete the acquiring of the metric information it has been carried out a survey with laser scanner, as to achieve, together

with the photographic survey, a texture mapping of Baptistery to compare with the tri-dimensional model carried out photogrammetrically.

Figure 1 – North side of the Baptistery with the portal. The Cathedral is in the left side.

2. DESIGN AND SURVEY

The project of the photogrammetric survey has been carried out trying to achieve an accuracy of centimetre on the control points. For this reason it is important to remember that the accuracy achieved by monoscopic multi-images restitution can be describe by the following formula (Mason. 1994):

$$\sigma_c = \frac{m_f \sigma_i q}{\sqrt{k}} \qquad [1]$$

where:

σ_c is the restitution accuracy

mf is the photogrammetric scale (relation d/c)

σ_i is the accuracy of measure on the image

q is a geometry coefficient which can vary between 0.4 (very convergent shots) and 0.7

k is the number of shots which are used to plot the single point.

In relation with the classic bond valid for normal stereo-couples at the object (where the accuracy in the perpendicular direction to the shot is directly proportional to the distance square and to the measure accuracy of the plates, and in inverse relation to the base product of shot and principal distance), in the formula (1) is possible to consider both the number of images which cut on the object and the best geometry that is guaranteed by the convergent shots.
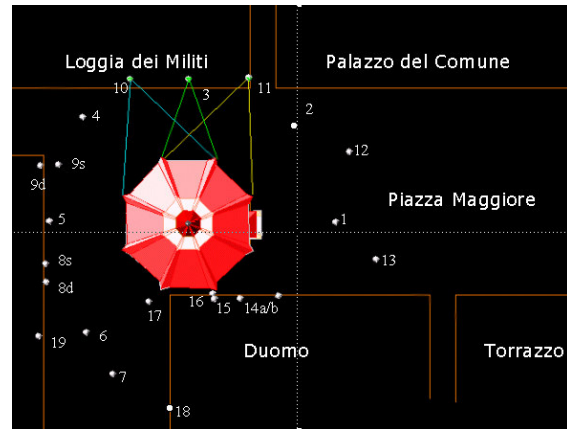
The camera used is a Nikon D100 with lens with principal distance c of 18mm and f/2.8.

The digital back of 6 Mpixel has dimensions 23.4*15.6 mm², which needs a dimension of pixel of 7.8 µm and a sight corner computed on the diagonal, of about 76°.
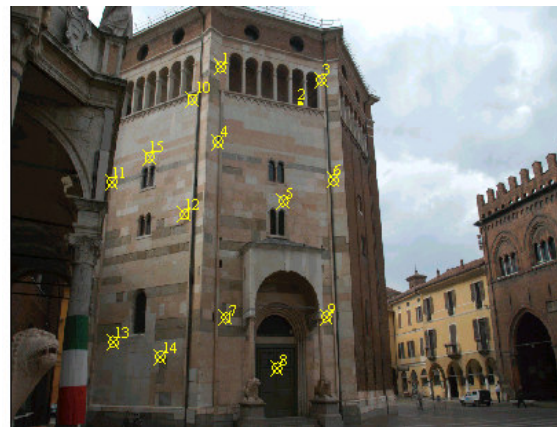
The camera, of a no metric type, has been previously reamed by self calibration on a tri-dimensional test field.

In figure 2 is visible the scheme of the 22 taken. It is remarkable that the followed logic scheme is that of surveying each of the eight sides of the Baptistery with a series of 3 images: a frontal and two lateral ones. The frontal one (position 3 in the figure 2), practically perpendicularly, is placed at the distance of about

16m, the two sides (10 and 11) are perpendicularly to the edge but convergent to the sides: the wider distance of survey allows a wider field of vision which allows to observe contemporary 2 sides.

a)

b)

Figure 2 – a) Geometric design of the photogrammetric taken; b) position of the Ground Control Points.

This scheme has been proposed for six out of the eight sides of Baptistery. The remaining two, leant to the structure of the Cathedral, have been surveyed by a series of convergent images which lie outside the scheme shown above. In practice, only the side on the right of the *protirus* has been put in the solid model, of the last side, distant to the base no more than 1.5 m from the Cathedral, and it has been possible to insert only the top side.

Finally, due to the lack of dominant points of sight (Torrazzo was closed the day devoted to the survey) it was not possible to make a photogrammetric survey of the roof.

To measure the positioning of the supporting points and of a certain number of control points (GCP) (figure 2b), it has been made a closed polygonal of three sides, from the top of which the 3D coordinates of 37 points were determined.

For this aim it was used a total station Leica TC307 that for measures up to 80 m doesn't need a back-reflecting prism; this has allowed to accelerate the survey of the supporting points, chosen nearly entirely in correspondence with edges of the wall. Only three points used for the georeferentiation of laser shots are artificial targets. Plywood panels have been used to reach this aim and on these, on dark setting (at low reflectivity) is drawn a circular white surface (with elevated reflectivity). The different radiometric answer between the light and the dark side,

makes the geometric reconstruction of the target centre easy from the software which interpolates the light surface among the points falling back on it (some hundreds) with accuracy of some millimetres. At last the cross appearing at the target centre allows to survey the centre by total station (figure 3).
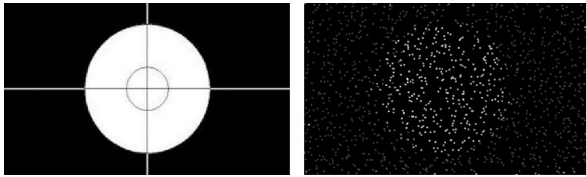

Figure 3 - Target used for the laser taken and radiometric answer of the points.

The coordinates of the Ground Control Points (GCP) have been determined with uncertainty of 1.2 cm in the x coordinates, 1.6 cm in y, 1.1 cm in z, according to the presumed accuracy of the photogrammetric restitution and of the laser survey.
The surveys with laser scanner have been carried out with a terrestrial laser Optech ILRIS -3D of the Codevintec srl of Milan. This scanner can work up to 800-1000m in the best conditions of the surface reflectivity. The field edge is 40° x 40° while the frequency of the points measure is maximum 2000 points/s. At a distance of 100 m the laser trace on the object is about 30 mm (perpendicular shot) and the accuracy on the flat surface is about 3-5 mm on the points.
For the Baptistery survey 14 scanning have been carried out: 13 of which at the square level have been done contemporary to the photogrammetric survey. The last one, taken from the top of the loggia of Torrazzo at about 100m on the square level, has been taken after some months.

3. CREATION OF THE SOLID MODEL

In photogrammetry the creation of the solid model is made after the external orientation of the images and from the consequent fixing of some characteristic control points. Connecting these points, we created the primitive meshes of the model. By now, the photogrammetric algorithms allow, knowing the external orientation of the images, to find out automatically both of the characteristic points on the object surveyed (thought the operators that pick the characteristic points basing on the chromatic variation of the image) and the homological points on the other images. For this purpose, in the close range photogrammetry it's not allow to use the automatically airborne triangulation programs because the geometry of the image is much less standard than the airborne case. Anyway it's already exists some algorithms based on the epipolar geometry or on the field of the parallaxes variation that, after calculating with good approximation the orientation of the images (Sansò, 1973 or Zeng at al., 1992) helps to calculate the coordinates of the homologue points and, consequently to determinate the object points and to improve the external orientation of each image.
In our case it has been used the software Photomodeler (www.photomodeler.com), a program with huge spread that allow to calibrate the cameras, to calculate the external orientation of the images, to define the coordinates the object points, to reconstruct the surfaces and the images overlapped (even if, in this case with some limitations).
It has been defined 507 points observed at least on 2 frames, 17 of that chosen between the GCP with known coordinates; these allowed to define together the external orientation of the images and the remaining points in a local Cartesian reference system tied at the total station points. Moreover it has been

added other 1274 points close to the particular feature of the structure: corners, edges, lines, windows and all the points necessary for the construction of the solid model.
In the end, with AutoCad, it has been reconstructed the surfaces and assigned at each one an arbitrary texture (figure 4). It has to point out that the roof of the baptistery has been "invented" because, as already mentioned, there are no photogrammetric images about that.
Regarding the processing and the modelling of the laser scanner data, every scan has got an own reference system relative of the survey point, therefore the creation of the solid model is dependent by the merging of all the scans made by different positions using any one reference system. The software used for this application and for processing the data is the module IMAlign by PolyWorks (http://www.innovmetric.com); this software allow to chose some natural point for linking up different scans (such as some recognizable feature on the object surveyed, house corners, identifiable geometry, different reflectivity of the walls, etc).
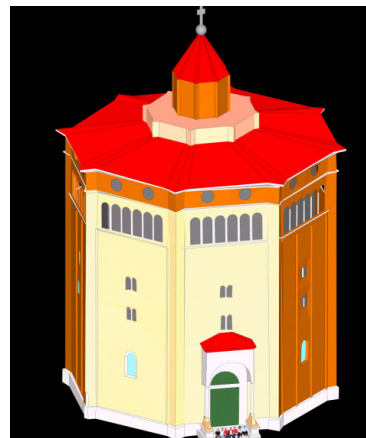

Figure 4 – Solid model of the Baptistery generated by the photogrammetry images, upon that there has been impose some arbitrary texture

All of this procedure permit to be easier the survey on the field and at the same time to be faster for the absence of the artificial targets, used only for the georeference of all the model. The align of different scans in made individualizing three or more connection points present on both of the two adjacent scans. These points, who the position is known in their respective reference systems, at the beginning, consent to move closer the two scans; the software, that used ICP algorithm, realises subsequently an automatic research of the "homologue" points, performing a spatial rotation and translation without scale variation respect to the reference system of the adjacent scan and it estimates the 6 independent parameters: the 3 rotation around the axis XYZ and the 3 spatial translation.
In this way with the alignment it has been given the parameters estimation of the orientation and generated a roto-translation matrix for each scan. This process has been applied on each scan and permits the creation of the complete solid model of the object surveyed.
At the end of this process we has been realised a triangulation (TIN) to the single mesh and it has been made a georeference of all the model to set it in the reference local system tied to the points surveyed by the total station. This process has been done using some artificial targets, above described, positioned on the surface surveyed.
Once known the spatial position of at least one of this three

targets it is possible to roto-translate all the model and geo-reference each point of the scan.

Analysing from a metrical point of view the result obtained with this two methodologies, with 11 points topologically estimated it has been calculated the gap of the three coordinates. Table 5 reproduces the statistic of the coordinates difference defined with the two methods.

	Mean [cm]			St.Dev.[cm]		
	x	y	Z	x	y	z
Photogrammetry	0.0	-0.2	-0.3	1.6	1.6	1.7
Laser Scanner	-0.4	0.1	0.1	1.8	1.2	1.5

Table 5 – Gaps statistics of the GPC coordinates surveyed with the total station

The comments of this schedule are: firstly the number of the points is less than the GCP used (20) because both in the laser model than in the photogrammetric one the measure of some points is hard (for bad resolution) instead for some one is affected by a blunder.

The average is more restricted and shows the goodness of the geo-reference in both of this two methods with the topographic one. In particular about the laser scans, this shows how the estimation of the coordinates of the artificial targets, used to roto-translate the instrumental reference system, has been done with excellent accuracy.

In the end the standard deviation of the difference is, for the coordinates and in both of this cases, of the same order of the precision of the GCP, at the confirmation of the uniformity of the accuracy of these three survey methods.

4. TEXTURE MAPPING

The Texture mapping is the possibility to drape the picture upon the solid model. This representation was made with the commercial software TexCapture by NRC (National Research Centre) of Toronto (Canada). For this application we used the Nikon Coolpix 4300 (2300 x 1700 pixels) camera with 8 mm of focal objective and 1/1.8 shutter.

TexCapture, like many digital photogrammetric software, allows to calculate the internal and external orientation parameters of the images and the following "ortho-projection" upon the triangulated solid model.

During the survey we used some cunnings; the images were acquired with the similar angle of the laser scans, using a high resolution camera (it is important to have a CCD greater than 3.2 MPixel) and we left the same zoom in order to keep the same camera calibrations for every texture. Actually we did not use this mean because the calibration parameters were estimated for each of the six shots (five on the side and one on the top).

During the calibration and orientation the parameters to define are 15 and in particular:

- 6 parameters of external orientation of the camera: 3 coordinates (Xc, Yc, and Zc) of the camera projection centre and 3 rotations of the camera (pitch, roll, and yaw);
- 3 parameters of internal orientation: principal distance and the coordinates x and y of the principal point of the images;
- 6 parameters of camera calibration including: 2 affined image parameters to correct for scale difference and non-perpendicular of the x and y image coordinates, 2 radial lens distortion parameters (third and fifth order), and 2 decentring lens distortion parameters.

The software achieved this purpose writing a co-linearity equations system for at least 8 homologues points, recognised on the solid model and on the images.

For the Texture mapping of the Baptistery of Cremona, we individualised at least 20 points of each scan, chosen in a uniform way, not lying on the same plane. At the beginning we estimated the 15 parameters in a combined way; subsequently, after analysing the meaning of calibration parameters estimation, we locked the orientation parameters and set on zero the insignificance one. Anyway the principal distance and the positioning of the principal point was kept at the value estimated step by step.

After calibrating the camera the TexCapture software allowed us to "drape" the images on the triangulated model, deleting both the distortions due to the intrinsic characteristics of the camera we used (objective distortion, etc.) and the prospective distortions.
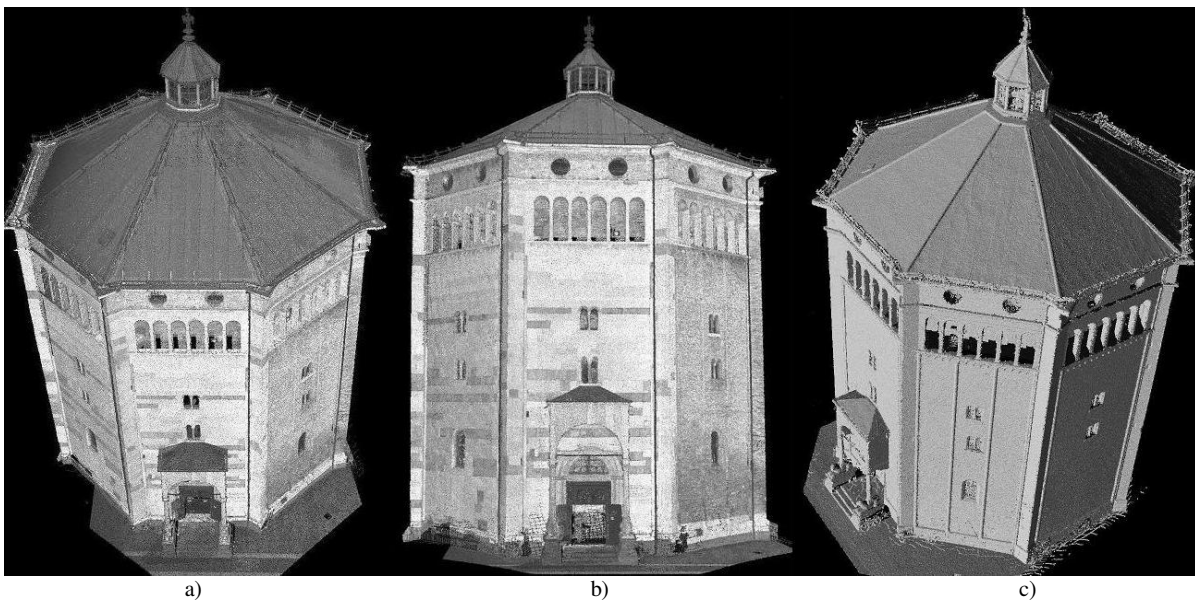

| a) | b) | c) |

Figure 6 – Laser scans aligned a) and b) image with intensity of the laser scanner data c) solid model

Fig 7 – Texture mapping of the North side of the Baptistery

As you may notice in figure 7 the final result is a triangulated solid model with a single mesh coloured by the photo images. In blue it is possible to see the zone where the model has no data (these are data holes in the structure due to the shadow zones).

5. CONCLUSION

The representation of the Baptistery of Cremona gave to the authors the possibility to check the capacity of these different survey techniques. In particular we realized two different solid modulations with the laser scanner and photogrammetric technique. In both cases, realizing the analytical model of the Baptistery, we reached high accuracy, about 1.5 cm on the three coordinates, estimated on some control points surveyed by the total station.

Certainly the laser scanner survey shows more completeness, thanks to the point cloud with a spot spacing of some centimetres, and also to the quickness of acquisition and processing of the data. The texture mapping, realized by colouring the surfaces triangulated of the solid model with the correspondent shades of the oriented digital images, gives a result matching the extremely accurate analytical solid model and the truthfulness of the topographical survey.

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