"Low cost" techniques for building surveying and their 3D representation

A. Chiorboli , M. Gatti

Abstract—**The fast improvement and the latest years cost decrease of digital cameras allow the use of photogrammetric solutions for 3D modelling, even in not specialized companies. Beside that, some cheap software solutions are available on the market. This article deals of two different solutions. The first one requires only some photographs, which elaboration is based on a cadastral map. The second one needs a stereopair and some distance measurements. The 3d modelling is done using a low-cost and user-friendly software.**

***Index Terms*—3D, Close range, Low cost, Representation , Surveying.**

I. INTRODUCTION

The italian reality of civil engineering and architecture companies is often characterized by small and middle-sized entities, that attend several aspects of their professional activities at the same time.

All that entails a low specialization and a limited investment power into each of their fields, to which is added a more and more specific intervention request on the existing building heritage (buildings, monuments, roads, urban parks, …).

Starting from this preamble, it has appeared to us so interesting to realize and to test some surveying and building 3D representation methods, sufficiently accurate, of low-cost and with easy applicability even for little skilled users.

The methods, based on the terrestrial photogrammetry, use consumer digital cameras, on a telescopic tripod, and tools for the direct distance measure (handheld laser EDM, tapes, etc.).

The first test has been developed on a building estate area in Ferrara with one road and a monumental square. On the main road, there are buildings of urbanistic and historic importance. The survey was limited to the photogrammetric portion only, without a first order network.

Thanks to a support of a digital map, it was possible to scale the rectified photos and to make a 3D model, in a multimedia environment. The surveyed object representation was done with "consumer" software.

A second test has been made on a monument of historic and artistic worth, with a particular shape and geometry. In this last case, besides of photos, even photogrammetric support measures have been scheduled. The photogrammetric elaboration and the 3D object representation have been made with a low-cost photogrammetric software, on the *AutoCAD* environment. The model, obtained from the test has been compared , to measure the accuracy, with the real one. Finally, work times and realization costs have been valued for both tests. and they are compared with these originated from the application of more professional photogrammetric methods.

II. THE AREA OF THE TESTS

The first test was carried out in a urban area of Ferrara, build during first years of the 20th century: the *Rione Giardino* neighbourhood. Building and demolition activities succeeded several times, so many past simbols and testimonies were destroyed. The present plan, called *Fascist Addition*, has the XXIV Maggio piazza as the core of the area. In the middle of the piazza there is the *Acquedotto* (water reservoir), which completes the perspective axis through Vittorio Veneto avenue (Fig. 1).

Fig. 1. A present sight of XXIV Maggio piazza , with the axis of Vittorio Veneto avenue.

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III. THE FIRST METHOD

A first test has been carried out on the whole Vittorio Veneto avenue, as far as the XXIV Maggio piazza and the result is a 3D photo-realistic model, in a multimedia environment [1].

For the photogrammetric surveying of buildings it was used a Canon IXUS430 amateur digital camera, with a CCD sensor of 1/8", resolution of 4.1 Mpixels, lens 7.4-22.2 mm (equivalent to a 36-108 mm on the 35mm format), making JPEG format files over a Compact Flash card. The bi-dimensional representation was executed on a cadastral map in a raster format, at the 1:1000 scale, subsequently transformed in a vectorial file in a *AutoCAD* environment. Then, the map was scaled, using as a datum line a side of a building measured directly from the cadastral map.

The vectorial map , obtained in that way, served for:

- to determine the dimensions, on the plan, of buildings (those dimensions will allow to "scale" the rectified images of the elevations);
- to rebuild the perspective sight of the avenue, with all buildings on the sides.

The rectification of the digital images was done through a fast method which consists into drawing in the photo a grid, then to use that such as reference for the rectification [2]. This method allowed to keep the images with a roughly proportion, without the need of control points. A generic imaging software allowed to correct the perspective deformations, getting the elevation dimensions with a minimum error. Starting from the cadastral map file, the solid building shapes has been created, getting the three dimensions of each building, up to the tile level.

Two are the 3D models obtained: the first one, in a *AutoCAD* environment, allowed to determine the tile level and some characteristic dimensions of some buildings, choosed such as sample. Tile levels was used to make the second 3D model, whereas the vectorialization (on the sides of building 3D models) of some architectural details allowed to carry out a reliability test of the used rectification methods. The second one, made with the *SketchUp* software, is built with the idea that it can be used for the visualization, in real time and through different points of view, of the urbanistic composition of the avenue. On the last one, the rectified images has been inserted.

The model has been rendered realistic thanks to the use of detail components, such as trees, flower-beds and the insertion of lights, which position is determined with the geographic latitude and the day of the year when the user wants to see the 3D model. The main feature in that representation (Fig.2) is

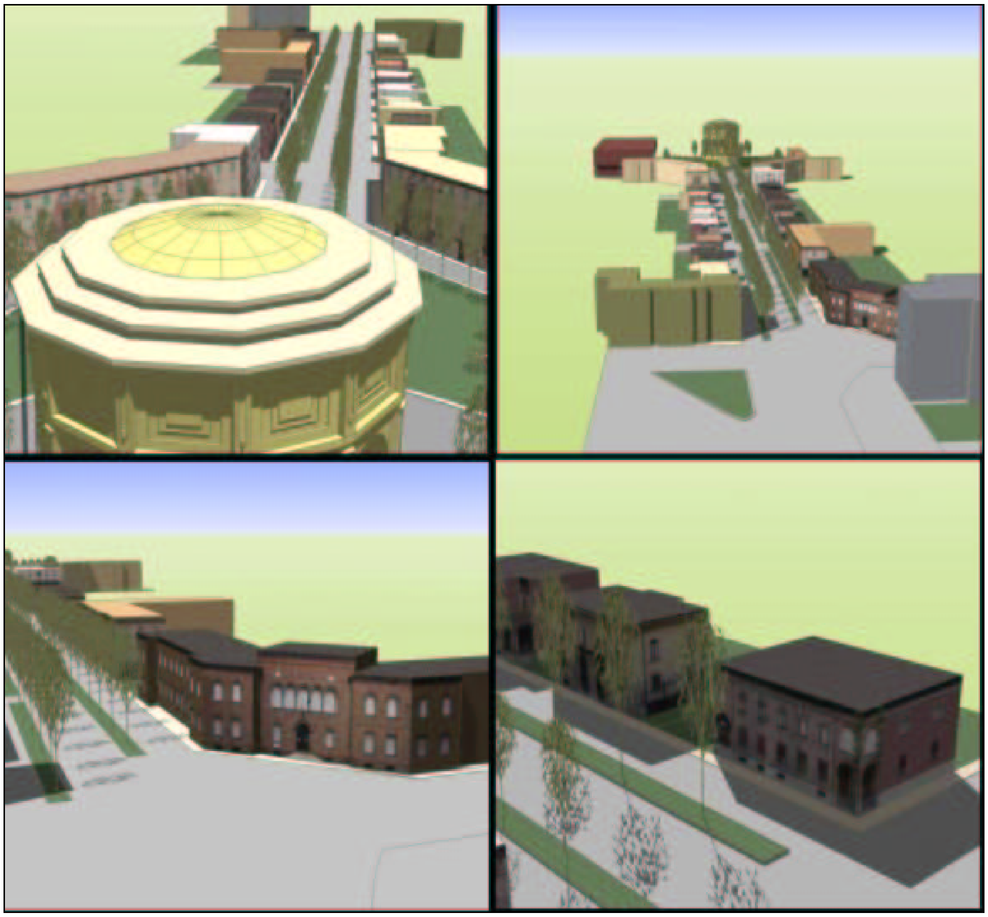

Fig. 2. Some images of the 3D realistic model [1].

the possibility of to have, in real time, metrical data from the 3D represented model.

IV. THE SECOND METHOD

In the second test, we took into consideration the surveying of a Southern elevation portion of the monumental building called *Acquedotto*, through a low-cost photogrammetric method, called *Fotogram*. *Fotogram* is a *AutoCAD* plug-in, which allows to use all the management tools of images and 3D representation of the main software. It is suitable for either not professional users or for users not expert in the photogrammetric techniques [3].

The experimented photogrammetric system requires a stereopair, that means two photos with parallel viewing directions, made with the same camera settings. Pictures can be done with any amateur camera, preferably digital camera.

To proceed with the surveying, the measures are the follow:

- The measure between the two points where the camera is installed to do the stereopair. This segment is called *base*.
- From 1 to 4 lengths of the calibration segments, defined between the control points. Those segments have to be parallel to the base.
- The measure of the distance between each calibration segment to the base.
- The relative position of the right extreme of the first calibration segment, taken from the left point of the base. This value, not always necessary, is called X_A.

In the Fig. 3 there is a schematic plan of the survey operations, needed for the *Fotogram* elaboration.

Once the segment measurement values have been inserted and the segment calibration extremes have been selected in both images, the software suggests four elaboration options. For each one, there will be a final report, where each cartesian direction has a estimated error value. The operator will choose the best elaboration option to minimize the errors presented in the final report. When the X_A measure is available, *Fotogram* can compute even the image rotation around the viewing camera direction.

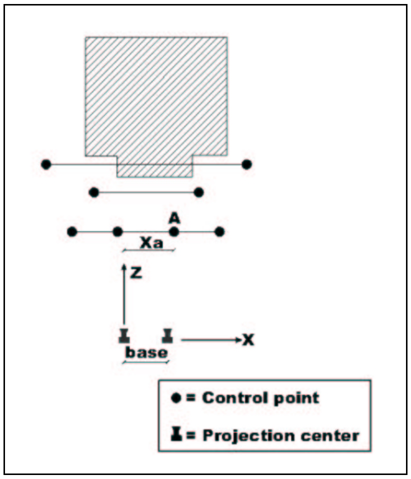

Fig.3 Schematic representation of a *Fotogram* survey.

Fig. 4 The Nikon D70 digital camera posed on a surveying tripod through a teflon connector.

A. *The instruments*

Last generation digital cameras are suitable for medium accuracy photogrammetric purposes, with satisfactory results [4], [5], [6]. Even for that reason, for the second test, we used a Nikon D70 reflex digital camera with a sensor resolution of 6 Mpixels. We did not calibrate it, since *Fotogram* does not require the calibration constants.

The Nikon D70 CCD size is 23.7 x 15.6 mm, lower rather than a traditional camera (36 x 24 mm) [7]. According to that, the focal length of the Nikon D70 is about 1.5 times of the 36 x 24 camera (Table I).

For the realization of the stereopair, the digital camera was installed on tripods of surveying instruments. On each tripod, there were a tribrach with a spheric spirit level. A teflon connector allowed to screw the digital camera on the 5/8" tribrach support (Fig.4). The use of a toric spirit level, inserted on the flash support on the top of the digital camera, allowed to keep horizontal the camera body.

In conclusion, to avoid the possibility of slight movements, the photo commands were given through an infrared Nikon remote control.

We printed some targets (Fig.5), on a thick paper of the A4 format. The same targets were used both for to put on the surveyed object the control points and to locate some other points that were necessary to verify the accuracy of the photogrammetric system.

For the photogrammetric elaboration of images, the system needs the use of very simple measurement tools, such as a tape measure.

TABLE I

35 MM AND NIKON D70 FOCAL LENGTH

	Focal length					
35 mm camera	17	20	24	28	35	50
Nikon D70	25.5	30	36	42	52.5	75

Fig. 5 The shape of the target makes easy the centre location singling out. In particular, the central cross, in the center of the smallest circle, allows a easy and fast center location recognizement with the use of a theodolite. The aim of the big cross is to make easier the recognizement of the target center during the photogrammetric elaboration, as it is showed in the central and left images.

However, in this case we used a Topcon GPT 2005 reflectorless total station, with the purpose of to evaluate the accuracy of the whole method.

B. The measurement activities

To obtain the best results, it is necessary that:

- The calibration segments must be parallel to the base.
- The calibration segments and the base must be horizontal.
- The viewing directions of both images must be parallel.

However, the software can correct slight image rotations about the main axis. The perfect-rate base dimension depends from the focal length; a indicative ratio is 1/10 of the maximum distance between the objects and the camera.

Taking advantage of the presence of the total station, we prepared a simple Excel sheet, inserted in a laptop carried in the field during the surveying operations. The sheet was done on the base of geometric requirements, said just before, for the properly use of *Fotogram*.

The surveying operations were the follows:

- Location, on the real object elevation, of the first calibration segment through the application of two targets.
- Setting up of the total station and execution of linear and angle measurements on the two extrems of the first calibration segment; the perpendicular to this segment, passing through the middle point, is the symmetric axis of the surveying.
- Location of other targets, with a arbitrary position; these targets are the first origins of the following calibration segments. Execution of linear and angle measurements on these points.
- Introduction of angle and linear distances in the Excel sheet and coordinates computation of second extremes of calibration segments.
- Location, on the object, of the second extremes of calibration segments, using the tracking function of the Topcon total station;
- Materialization on the object of the second extremes of calibration segments through the targets and materialization of the base.

About the photogrammetric exposures, following settings were used:

- The lowest light sensitivity value (ISO 200).
- Aperture priority setting.
- High sharpening of the image.
- JPEG Image file with a resolution of 3008 x 2000.

Eight control points and the two base points have been surveyed, to define the four calibration segments and the base. We even measured the position of 12 more targets, with the aim of verify the accuracy of the 3D model made with

Fig.6 An image of the photogrammeteric and surveying operations.

TABLE II

RESULTS OF THE FOTOGRAM ELABORATIONS

	Theodolite	Fotogram			
		No deformation	Low deformation	Medium deformation	High deformation
Calib. segment 1 (m)	3.541	3.528	3.54	3.543	3.545
Calib. segment 2 (m)	9.073	9.092	9.093	9.095	9.099
Calib. segment 3 (m)	3.527	3.509	3.521	3.524	3.526
Calib. segment 4 (m)	12.689	12.773	12.705	12.671	12.64
Base (m)	3.496	3.4833	3.4947	3.4979	3.5002
Rotations					
RZ1	//	-0.34°	-0.34°	-0.34°	-0.34°
RZ2	//	-0.04°	-0.04°	-0.04°	-0.04°
RX2	//	-0.06°	-0.06°	-0.06°	-0.06°
RY2	//	0.09°	0.09°	0.09°	0.09°
RZ2 (bY)	//	1.33°	1.32°	1.32°	1.32°
Estimated errors					
E_X %	//	0.44	0.15	0.13	0.20
E_Y %	//	0.75	0.36	0.35	0.42

Fotogram.

C. *The 3D modelling*

The 3D modelling was done with *AutoCAD* using the Fotogram plug-in. The operator must choose on manual the positions of the control points and insert some parameters: the calibration segment lengths, the distance between the base and the calibration segments, the measure of the base, the X_A coordinate (Fig.3). Finally, we proceeded with the elaboration using all four options: high deformation, medium, low, and no deformation (Table II). We choosed the medium deformation solution, because it has the lowest estimated errors.

D. *Accuracies*

The Cartesian reference system used by *Fotogram* has the origin in the center of the left photo, the XY plane coincides with the plane of the left exposure; in particular the X axis joins the left exposure center with the right one. The Z axis is perpendicular to the picture plane. In this reference system we compared the two different coordinate sets obtained from the whole procedure: the first one made with the 3D coordinates given by *Fotogram* and the second obtained with the total station surveying. So, the result is a matrix of 36 3D coordinates for each method. With this sample, we obtained the differences, ΔX, ΔY, and ΔZ , the difference averages ΔX_{med} , ΔY_{med} ,and ΔZ_{med}, their variances $\sigma_{\Delta X,\ med}$,$\sigma_{\Delta Y,\ med}$, $\sigma_{\Delta Z,\ med}$, and the maximum and the minimum of each of them (Table III).

TABLE III

THEODOLITE AND 3D FOTOGRAM COORDINATES DIFFERENCES

	ΔX_{med} $\pm\sigma_{\Delta X,med}$	ΔX_{min}	ΔX_{max}	ΔY_{med} $\pm\sigma_{\Delta Y,med}$	ΔY_{min}	ΔY_{max}	ΔZ_{med} $\pm\sigma_{\Delta Z,\ med}$	ΔZ_{min}	ΔZ_{max}
Theodolite and 3D Fotogram differences (cm)	1.5 ± 0.3	0.3	2.9	9.9 ± 1.9	0.7	20.7	7.2 ±1.2	2.4	13.1

V. CONCLUSION

The terrestrial photogrammetric systems described in this article are not "professionals" methods. However, the gained results confirmed the possibility of use them as either complementary or alternative methods to the more professional surveying techniques. The field photogrammetric part of the whole work needs less time as usual, whereas the 3D modeling and representation time are remarkably reduced. The realization costs are quite low because they are represented by the purchase of a high quality off-the self digital camera, with a sensor of at least 6 Mpixel, and the purchase of a *Fotogram* software licence, with a total cost of about 1000 Euro.

Finally, the *AutoCAD* environment reduces remarkably the training times and increases the number of operators that can complete autonomously a 3D surveying in a short time.

REFERENCES

[1] M. Gatti , C. Pacchiega, "Il rilevamento e la rappresentazione di un ambiente costruito. L'esempio di via Vittorio Veneto in Ferrara," Rivista dell'Agenzia del Territorio, Roma. To be published.

[2] P. Midulla, "Un metodo speditivo per il raddrizzamento e il posizionamento tridimensionale di immagini digitali," presented at 4th Conferenza Nazionale Asita 2002, Genova, Italy.

[3] G. D'Annibale , Fotogram. Restituzione 2D e 3D dalle fotografie.

Palermo, Italy: Dario Flaccovio, 2003.

[4] Y. Ejima , H. Chikatsu, “Performance evaluation of card size digital camera for photogrammetric applications,” presented at the 2004 ISPRS meeting, Istanbul.

[5] J. Cardenal , E. Mata, P. Castro, J. Delgrado, M.A. Hernandez, J.L. Perez, M.Ramos, M. Torres, “Evaluation of a digital non metric camera (Canon D30) for the photogrammetric recording of historical buildings,” presented at the 2004 ISPRS meeting, Istanbul.

[6] A.F. Habib , A. M. Pullivelli, “Stability analysis and potential applications of amateur digital cameras,” presented at Italy-Canada Workshop on 3D Digital Imaging and Modeling Applications of: heritage, industry, medicine &land, 17-18 May 2005, University of Padova, Padova, Italy.

[7] Nikon Corporation , “Guida Nikon alla Fotografia Digitale con la D70 Digital Camera”.