

3D models of cultural heritage

V. Barrile, G. Bilotta, D. Lamari

Abstract—Recent advances in the techniques of laser scanning and the increase in computing power in last years have enabled astonishing experiments of virtual reality. The three-dimensional digitizing of cultural heritage and its modeling are so becoming increasingly widespread. This work shows a comparison between the consolidated operating mode of the laser scanner with the techniques of image capture and generation of 3D models based on photographs made with ordinary digital cameras. Thanks to a special software exploiting appropriate photogrammetric techniques and algorithms defined as "Structure from Motion" (SfM), we can reconstruct high-resolution DEMs (Digital Elevation Model) of high quality. We studied a masonry tower in the south of Italy (Marina di Gioiosa Jonica, Reggio Calabria), dating back to the fifteenth and sixteenth century.

Keywords—Geometrical survey, Masonry structures, Photogrammetric techniques, Structure from motion, Terrestrial laser scanner.

I. INTRODUCTION

THE world of cultural heritage is experiencing a phase of promotion and development of its assets thanks to the progress of survey techniques and multimedia communication.

The introduction of new measuring devices such as 3D laser scanners, spherical photogrammetry, structure-from-motion photogrammetry and the latest methods of image-based modeling produced a strong change in the mode of acquisition, treatment and restitution of metric information. These new techniques allow the construction of digital photo-realistic 3D models that can be used as an information system and as an aid to structural modeling.

The digital model becomes an operational tool that can be implemented in new information systems able to handle complex and typologically heterogeneous data for both single buildings and large geographical areas.

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In this paper, we applied a promising photogrammetric technique to a XV-XVI century masonry castle in southern Italy (Marina di Gioiosa Jonica, Reggio Calabria) called Torre Galea (Fig. 1) for for comparison with a TLS survey.



Fig. 1 Views of Torre Galea- Marina di Gioiosa Jonica (RC)

The flow chart of Fig. 2 shows the workflow, starting from the digital images, yields to the 3D model.

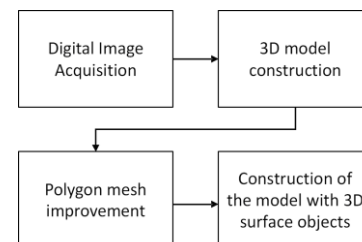


Fig. 2 Workflow for the realization of the model 3D photogrammetric

II. ACQUISITION AND OPTIMIZATION PHOTOGRAPHS

Of crucial importance is obviously the acquisition of good digital photographs. In this phase it is certainly useful to use a camera, even if a compact camera, and even smartphones give good results.

In some situations it can be very helpful to use a tripod, especially indoors in low light where the risk of blurred images is very high; it is in fact to avoid the use of flash. While the use of drones is appropriate in cases where the object to be photographed is particularly high and it becomes impossible to take photographs even the most elevated part of the object.

Operationally, we take a first photograph, then we move sideways taking another, making sure to create an overlap between the images, and so on until we come full circle around the object and we returned to the starting point; it is recommended to take a picture at least every 15 degrees of movement. After the first round, if the shape or position of the object require it, we can take again photographs from below, above, and a series of close-ups to capture specific portions of the surface, as decorations or areas particularly hollowed and hidden [1]. We recommend of taking a lot of pictures, at least a hundred, and then eventually select the best and discard those that have problems. In this application we used 219 photographs.

We also were careful to the following aspects:

- The lighting is critical because the algorithms behind the Image-based Modeling rely on "texture" of photographs: too many gray areas, or too many areas of excessive light, flatten the three-dimensional object, making it difficult to reconstruct;
- Photos taken outdoors at different times of the day or even after a few days can cause problems as it will have different lighting;
- The use of photographs at high resolutions requires appropriate computing resources.
- The best images for this type of processing are those taken from a distance such as each of them hugs a good portion of the object to be detected and with a high degree of overlap, not only between adjacent images, but also between many images.

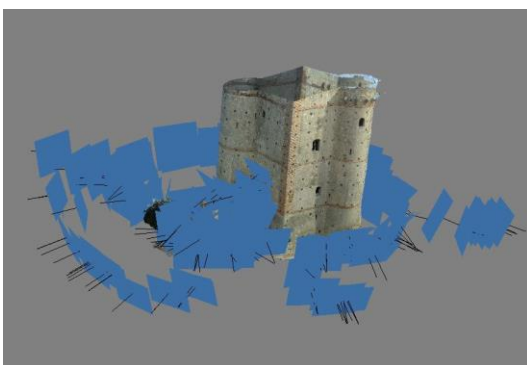


Fig. 3 Texture with the position of the camera (blue square)

III. CONSTRUCTION OF 3D MODEL

The procedure of photographs processing and 3D model construction comprises four main steps:

1. The first phase is the alignment of the camera. At this step, PhotoScan [8] seeks common points on the photographs to merge with each other through the identification of a matching camera for every image and parameters of aging and calibration. As a result, they form a cloud of scattered points and a series of shots. The points of the cloud representing the alignment results between photos and will not be used directly in a further procedure of construction of the 3D model (except for the method of reconstruction cloud based Fig. 4). However, it can be exported for further use in external programs. For example, the cloud obtained can be used in a 3D editor as a reference to any evaluations.[15] On the contrary, the set of positions taken by the camera are essential for the construction of the 3D model via PhotoScan.[16]

2. The next phase is the construction of dense point cloud. (Fig. 5) Based on the positions of recovery estimated and extracted from the photos, PhotoScan generates a point cloud more dense and detailed. This point cloud can be modified and classified before proceeding with the export or the generation of three-dimensional mesh model.

3. Then we proceed with the construction of the mesh [2] (Fig. 6). PhotoScan reconstructs the surface of a 3D polygon mesh representing the object based on the dense point cloud obtained from the previous stage. In this case, Point Cloud based method can be used for the rapid generation of geometries based on point clouds scattered. Generally, there are two algorithmic methods available in PhotoScan that can be applied for the generation of 3D meshes: Field Height - for the type planar surfaces, or Arbitrary - for each object type.

4. After building the polygonal network, it may be necessary to adjust them. PhotoScan is able to make some corrections, such as decimation of the mesh, the removal of isolated components, the closing of holes, etc. When a more complex and detailed editing is pursued, a professional editing software has to be used. In this regard, PhotoScan allows exporting the mesh and to edit it with another software and then reopen it in PhotoScan through the most common interchange formats.

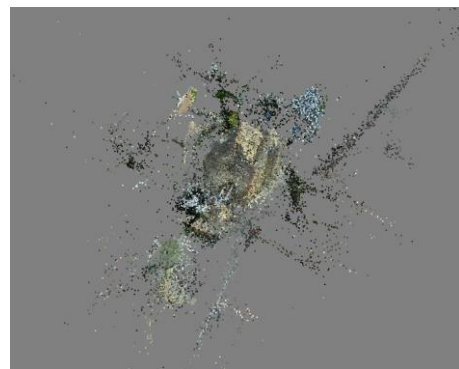


Fig. 4 Point Cloud Base



Fig. 5 Dense Point Cloud

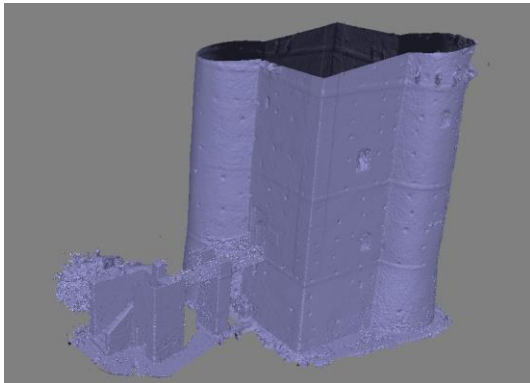


Fig. 6 Mesh



Fig. 7 3D model with texture

5. After the geometry (and hence the mesh) has been reconstructed, it can be structured and/or used for the production of orthophotos. There are several ways in texturing PhotoScan, described in detail in the manual supplied with the software.



Fig. 8 Markers with flags

It is possible to scale the 3D model starting from a known measurement, for example, we measured in a site the size of the door, which was found to be 0.90 meters.

In order to scale the model we define two markers (Fig. 8) that allow defining the distance between two known points, then we proceed to create a "scale bar" and to change the known distance.

IV. POLYGON MESH IMPROVEMENT

For eliminating defects of mesh, we proceed exporting the 3D model from PhotoScan in STL format, and then we imported the model into Geomagic Studio software [9]. This software provides editing point cloud, mesh and editing functions of advanced surfacing, in addition to its accurate functions of processing 3D data.

The Mesh Doctor is an automatic improvement of polygon mesh. It is generally preferable to use the Mesh Doctor after importing a polygonal model. [3]

The steps to follow in order to improve the mesh are:

1. Import the model (STL) within Geomagic Studio to set the unit of measurement.

2. The software automatically recognizes the presence of mesh and then provide information to that effect and asks if you want to launch an analysis mesh doctor, once made the analysis shows us graphically (Fig. 9) identifying with red areas the parts of the mesh that need to be repaired.

3. If necessary, we can rescale the model using the specific tool available in Geomagic (Fig. 10, 11).

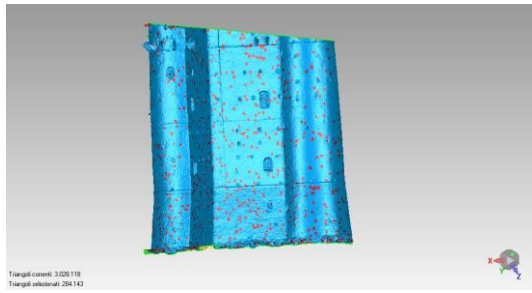


Fig. 9 Mesh with damaged areas identified in red

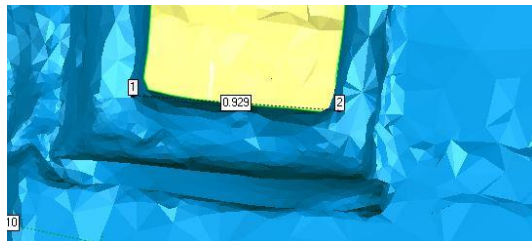


Fig. 10 Measurement of the door by two points



Fig. 11 The tool "Resize"

V. INSTRUMENTS AND SOFTWARE USED

For the survey we used the laser scanner Leica HDS 3000 (Fig. 12 and Table I) distributed with the software supplied by Leica (Cyclone™) that allows us to manage both scanning operations and those of computing and data processing.

The scans required the use of 16 targets arranged on the frame in such positions that, the various scans, had in common at least 4 targets, fundamental for the subsequent phase of recording and sewing of consecutive scans. [6, 7]

After the survey phase, in the laboratory, we generated the

3D model of the structure through the recording operations of the various scans (whose characteristics are shown in table III) and the subsequent thinning of the raw data by eliminating the highest number of points not belonging to the structure and surrounding vegetation. [5] We thus obtained a single cloud of points representative of the investigated object. Since, also, the tool equipped with an inner camera to the CCD for the simultaneous acquisition of images of the raised portion, it was obtained a model highly realistic (Fig. 13) resulting from the association, with each point laser detected, of information of the color of its digital image. [13, 14]



Fig. 12 Laser Scanner Leica HDS 3000

Table I Technical features HDS 3000

Technology	Time Of Flight
Range	up to 300 m at 90%; 134 m at 18% albedo
Field of view	up to 360 ° horizontal x 270 ° vertical
Scan rate	above 4,000 points / sec
Scanning	Double scanning window
Positioning accuracy	6 mm to 50 m
Accuracy in distance	4 mm to 50 m

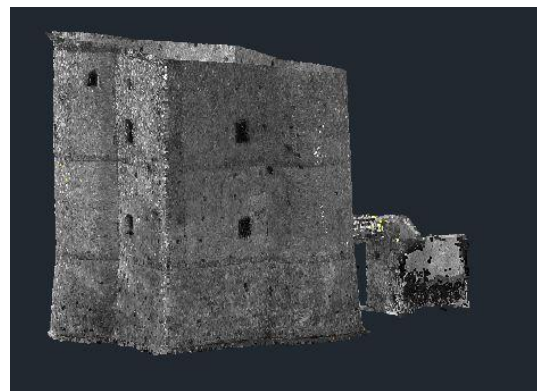


Fig. 13 Grayscale point cloud obtained by laser scanner survey

3D laser scanning of the tower was carried out by two operators. There have been 4 scans around the outer perimeter of the object in a time of ca. 1.4 hours. To merge the scans have been used 16 target. For the next RGB color scans have been used 52 photographs. The entire point cloud thus obtained ca. 26 million, was sampled up to a distance of 1 cm with Geomagic Studio software.

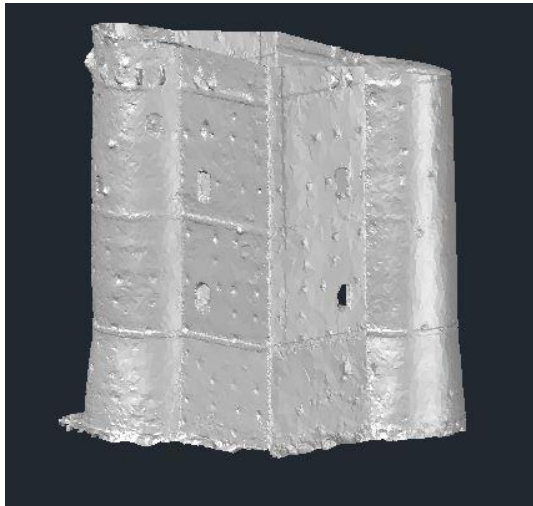


Fig. 14 Texture obtained by laser scanner survey

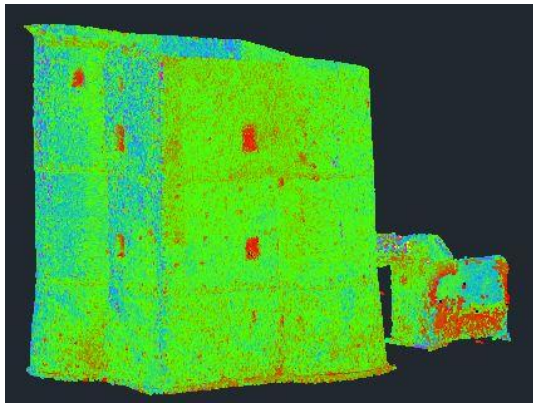


Fig. 15 Point cloud (spectrum) obtained by laser scanner survey

It was subsequently generated a 3D mesh with 1.3 million vertices ca. and 2.5 million faces ca. The work activities related to TLS can be so summarized: 1,4 hours for the acquisition of the 4 scans, 1,5 hours for the RGB coloring of all scans, 2,5 hours to the meshing in Geomagic Studio for a total 5.4 hours for the entire workflow

The generation of 3D point clouds from photogrammetric data with related models was carried out with the open-source software bundler / PMVS2 and VisualSFM and with low-cost software PhotoScan produced by Agisoft. A feature common to both VisualSFM that PhotoScan is the use of algorithms that make wide use of the CPU in order to significantly accelerate

the processing of data. The images were captured with a Samsung model PL20 (Fig. 6) whose technical characteristics are summarized in Fig. 17. The images obtained have dimensions of 4320 x 33240 pixels.



Fig. 16 Digital Photo Camera - Samsung PL20

OBIETTIVO	
Tipo di sensore	CCD 1/2.33"
Risoluzione Max	14 Megapixel
Risoluzioni supportate	4320 x 3240 (14M), 4320 x 2880 (12M), 3648 x 2736 (10M), 4320 x 2432 (10MW), 2592 x 1944 (5M), 1984 x 1488 (3M), 1920 x 1080 (2MW), 1024 x 768 (1M)
Dist. minima a fuoco	5 cm
Otturatore Apertura	F= 3,5 (W) - 5,9 (T)
Zoom ottico	3x (equivalente ad un 27 - 135 mm nel formato tradizionale a 35 mm) mm
Zoom digitale	12,5x
Mirino ottico	Non presente
Posizioni	ISO 80, 100, 200, 400, 800, 1600, Auto

Fig. 17 Camera Samsung PL20 features

The images were taken at eye. A total of 219 photographs were taken for the entire outdoor area. The generation of point clouds was conducted with a Workstation DELL T7610 processor XEON 2680 v2 10 core with 32 GB of RAM equipped with an NVIDIA Quadro FX 4800 with 1.5 GB of RAM and running Windows 7 Professional 64-bit. Table II summarizes the results obtained from the use of the three software.

Table II Statistics on the production of clouds of points with the use of the three software

	Visual SFM	Bundler/PMVS2	PhotoScan
No. images	219	219	219
No. points	8741118	13527920	28431222
Time	2,10 h	3,25 h	4,75 h
Standard deviation σ	8 cm	4,5 cm	2 cm

You may notice the important differences in the results obtained. All the clouds generated by the three software have been scaled using different reference distances measured in the field. The accuracy [21] of the distances of the reference appears significantly influenced by the density of the points constituting the cloud. It is to highlight how the software PhotoScan offers the possibility to locate and fix the control points in the shots made at high resolution, to use a sophisticated model of camera calibration including the determination of the focal length and the distortion of the radial lens.

VI. 3D MODELS IN COMPARISON

3D photogrammetry is affected, in addition to errors resulting from inherent processing algorithms, to those typical of photography. First of all the picture quality both in terms of resolution in terms of both optical distortion generated by the lens for aberration and perspective deformation. Another problem is linked to the straightening: the photography is in fact a central perspective, in which the objects change shape and size as a function of their distance from the center of the outlet.

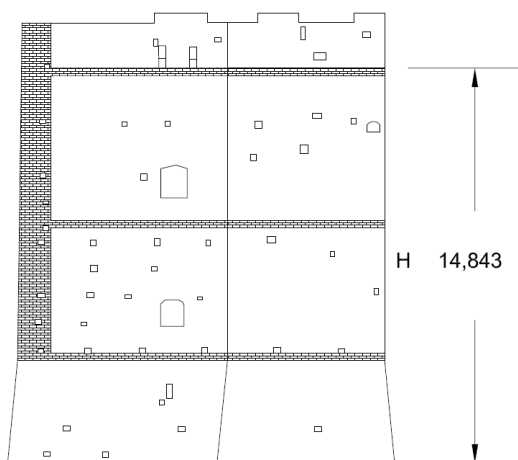


Fig.18 Elevation and height measure from the precision survey

Therefore they must be transformed into photoplan with consequent errors caused by the deviation from the reference plane on which lie the points or lines of support, because the elements, which are on the chosen plan, will be identified and reconstructed with the greatest possible precision. Those who are not on the plan, however, will be much less accurate the more they move away from the plan: they will be affected by an error sum of two terms, one dimensional and one of position (parallax error).

Table III Comparison between survey and Photoscan measurements

Measurement position	Survey [m]	Photoscan [m]	Δ [m]	$ \Delta\% $
side AB	5,463	5,435	0,0282	0,52%
side BC	5,531	5,563	-0,0313	0,57%
side DE	5,563	5,533	0,0299	0,54%
side EF	5,829	5,801	0,0279	0,48%
side BE	13,768	13,834	-0,0653	0,47%
side IJ	16,285	16,192	0,0926	0,57%
height H	14,843	14,931	-0,0882	0,59%
door width	0,892	0,897	-0,0048	0,53%

Table IV Comparison between survey and TLS measurements

Measurement position	Survey [m]	TLS [m]	Δ [m]	$ \Delta\% $
side AB	5,463	5,466	0,0030	0,05%
side BC	5,531	5,535	-0,0036	0,07%
side DE	5,563	5,567	0,0038	0,07%
side EF	5,829	5,833	0,0044	0,08%
side BE	13,768	13,760	-0,0084	0,06%
side IJ	16,285	16,294	0,0090	0,06%
height H	14,843	14,851	-0,0080	0,05%
door width	0,892	0,891	-0,0010	0,11%

Table V Comparison between TLS and Photoscan measurements

Measurement position	TLS [m]	Photoscan [m]	Δ [m]
side AB	5,466	5,435	0,0312
side BC	5,535	5,563	-0,0277
side DE	5,567	5,533	0,0337
side EF	5,833	5,801	0,0323
side BE	13,760	13,834	-0,0737
side IJ	16,294	16,192	0,1016
height H	14,851	14,931	-0,0802
door width	0,891	0,897	-0,0058

Table VI Summary results from PhotoScan

Photo No.	Acquisition time	Processing time	Dense cloud	Vertices No.	Sides No.	Standard deviation σ
219	0,4 h	4,75 h	28431222	1516899	3028118	4 cm

Table VII Summary results from TLS method

Setting up No.	Acquisition time	Processing time	Dense cloud	Vertices No.	Sides No.	Standard deviation σ
4	1,4 h	4 h	25822457	1314597	2518047	0,5 cm

A further source of error is mosaicking (the union of the various frames to generate a single image sum of the other) which is subject to problems both of radiometric type due to the different lighting phase both due to the roto-translation of the images in a single absolute reference system.

Accordingly, for the assessment of the accuracy, we made measurements on the same element in the 3D model obtained with 3D photogrammetry and TLS, and compared with the actual measurement carried out with precision instruments (total station Topcon GTS 312) on site and shown in table, for each element, the errors in terms of standard deviation and percentage difference $\Delta\%$. We made a direct comparison between the measures resulting from the 3D model obtained with 3D photogrammetry with TLS showing in the table, for each element, errors in terms of standard deviation Δ .

The tables summarize the results obtained from the survey and Photoscan TLS.

VII. CONCLUSIONS

This work shows that, next to the surveys carried out with laser scanner systems, even low cost systems based on photographic shots are able to produce 3D of large objects such as the Tower under study. Data acquisition with cameras is fast, flexible and economical than laser scanning. The results obtained with the software PhotoScan resulting geometrically very close to the data obtained by laser scanning.

The software VisualSFM and Bundler/PMVS2 well suited to the acquisition and generation of 3D models of small objects, for the return of large objects show all their limits. As regards the quality and the reliability, the limiting factors of SFM are, in general, and especially for large objects, the light conditions, the number of images, and the resolution of the photographs taken. They are also to be particularly important measurement procedures and the identification of control points for resizing the 3D model obtained. To this purpose, the

use of a camera with high resolution and with the objectives of superior quality could improve the results obtained. In the present case, we could obtain results significantly more optimized and precise if the acquisition of the images was made using UAV systems.

It is evident as the performance capabilities of the computers are critical to the minimization of the processing time of the data, especially for larger objects, characterized by a large number of photographs necessary for a complete reconstruction of the object acquired. At present, experimentations continue in order to optimize the generation of 3D models with particular reference to the findings of archaeological. To do this, we make extensive use of UAV systems with substantial results.

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