GEOMATIC TECHNIQUES FOR THE COLONNADE STRUCTURAL ANALYSIS OF THE HISTORICAL " CHIARAMONTE STERI" BUILDING

P. Orlano

Geomatic Area, Dept. of Engineering, University of Palermo, Viale delle Scienze – pietro.orlando@unipa.it

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ABSTRACT:

The monitoring of building structures has an increasingly important role in the engineering field, above all because they are concerned with the impact that such structures have in the area where they were built. Often, when walking through the old town centres, we realize just how obsolete and dangerous some buildings (even historic-cultural ones) are. The interest of some local governments in this problem has led, in the last few years, to the study and the trying out of measuring and monitoring methods which, quickly and at low cost, allow to define the extent of the deformation and the degrade in an accurate and reliable way.
The Courtyard of "Palazzo Steri - Chiaramonte" is composed of a colonnade on two orders. On the ground floor there are eight columns made up of cylindrical overlapped tuff bricks, with the same radius, while at the first floor there are 12 marble columns with a reduced section compared to those on the ground floor. All the columns have been characterized by a displacement compared by the vertical direction. This paper aim is describing the used methodology in order to evaluate the structural displacements of the colonnade and to monitor them in the future.

1. INTRODUCTION

The building was begun in the early 14th century, according to Giuseppe Spatrisano, and was the residence of the powerful Sicilian lord Manfredi III Chiaramonte. From the late 15th century to 1517 it housed the Aragonese-Spanish viceroys of Sicily; later it was home to the Royal Customs and, from 1600 to 1782, the tribunal of the Holy Inquisition. Restored in the fifties by the architect Carlo Scarpa it is now the administrative headquarters of the University of Palermo. During the restoration of the facade came to light grooves made by heavy cages hanging where they were exhibited the severed heads of the barons who rebelled against Charles V. The Sala Magna (also known as the Barons), it is characterized by a wooden ceiling (1377-1380) painted by Cecco di Naro, Simone da Corleone and Pellegrino Darena from Palermo. Inside the Palace it is also guarded the famous painting by Renato Guttuso, the "Vucciria".
Numerous changes and restorations, more or less invasive, occurred over the centuries, from 1726 to 1973 up to the last extensive restoration ended in 1998. In particular, the restoration carried out in 1973 by Roberto Calandra and Carlo Scarpa, when the building becomes the Rectorate of the University of Palermo, leaded to extensive modifications that converted part of the historic building, the "Osterio", into offices, exhibition areas and museums. The square plan of the palace, with a side of about 40 meters, consists of four wings surrounding the magnificent courtyard, with its portico on the ground floor and the upper loggia, that anticipates the mansion Renaissance model, accessible from a vestibule on the east side of the building.
The double-arched courtyard has essential shapes with ogival arches resting on columns. It covers an area of about 420 m2, with a square floor of 20.25x20.40m and a total height of 19.50 m, on two levels. The courtyard is the dominant architectural element of the building and is the subject of this study. The masonry of the loggia, on the other hand, is made of irregular stones and, during the last restoration, has been improved with mortar injections reinforced with fiberglass. On the second floor, on the terrace (fig. 7a), is the famous "hall of capriate", whose adaptation to an art gallery has long been debated in the early twentieth century. The courtyard of "Palazzo Steri" is composed of a colonnade on two orders Figure 1, 2. The courtyard is the subject of this study. In particular, on the ground floor there are eight columns made up of cylindrical bricks of superimposed tuff, with the same radius, while on the first floor there are 12 marble columns with a reduced section compared to those of the ground floor. The objective of this article is to describe the methodology used to evaluate the movements of the colonnade and monitor them in the future.

Figure 1. Ground floor of the courtyard, tuff bricks columns

Figure 2. First floor of the courtyard, marble columns

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2. DATA ACQUISITION AND ANALISYS

In order to get these purposes, knowing how much and towards which direction the main axis of the all columns deviates is necessary. The Geomatic offers different techniques to get these goals but the laser scanner one has been chosen. Terrestrial laser scanning (TLS) technology is nowadays more and more used for the documentation of cultural heritage monuments. The thorough exploitation of the main advantage of terrestrial laser scanners that is the acquisition of extremely dense discrete points in a relatively small time period leads to detailed 3D representation of the monument, overcoming possible difficulties such as limited accessibility. Most often, this 3D representation is used for the monument's documentation as well as for virtual tours in, out or around it. This detailed documentation can be used for one more purpose: the estimation of the deformation that its elements have experienced through the centuries, to create a Data-Base very useful for the future restoration planning and because of comparing different laser scanner surveys, carried out in different times, is very easy, cheap and quick.
In this case, the Faro 3D laser scanner Focus was used. It is a compact scanner characterized by an operative range that varies between 0.6 m and 120 m with a linear distance error of ±2 mm for scanner object distances comprised between 10 m and 25 m, and a noise (that is to say, the standard deviation of the values with respect to the best-fit plan) which varies from between 0.6 mm and 10 mm with a reflectivity of 90% and 2.2 mm to 25 mm with a reflectivity of 10%. It has a vertical visual field of 305° and a horizontal one of 360° Figure 3. The vertical and horizontal resolution is 0.009°. It has a scanning speed of 976.000 points/sec, and a reduced weight. Incorporated into the laser is a digital camera with a resolution of 70 megapixels.

Figure 3. Faro Focus 3D

The laser scanning provides a point cloud with a high density points, each one of them having the coordinates x, y, z, relative to an intrinsic reference system to the instrument and the reflectivity, which is indicative of the physical characteristics of the surface scanned. By way of the digital images obtained, the scansion is completed with RGB information of the object scanned; allowing for the integration of the analyses of the structure, e.g., those referring to the degrade of the building materials. In order to cover all the courtyard, 42 laser scanner stations, from different points, at ground and firs floor, have been carried out. In particular, for all the columns, a very high accuracy survey has been done.

With the aim to monitor the possible displacements in the future, a topographic network with 4 vertices, has been determined, so a fixed reference system, external to the building, has been done Figure 4.

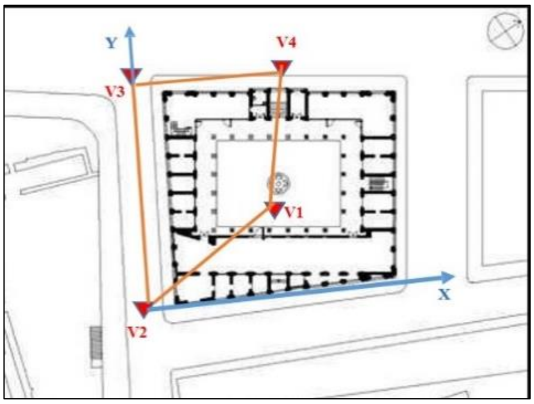

Figure 4. Topographic network

2.1 Data processing

Basically there can be distinguished four steps while converting measured data into common and constant polygonal surface for every scan.
1. Pre-processing, which includes all manual cleaning, noise reduction and sampling points in order to reduce the computation time.
2. Registration and determination of the global topology, at this stage all adjacent scans have been registered into one common coordinate system.
3. Triangulation, creating a polygonal surface, with certain parameters and available tools meshes are generated.
4. Post-processing, all operations that lead to improving and repairing models: smoothing, closing holes and, if images available, texturing is performed.
In order to minimize the noise on surfaces the value of the point, that was measured, has been substitutes with the mean value from its surrounding area then a thinning filter has been applied.
In order to allow the alignment of all the points clouds in the set reference system, several targets, around all the Courtyard both the ground floor and first one, so that at least 5 targets are visible from each laser scanner station have been collocated Figure 5. From the V1 topographic vertex, the coordinates of all the targets, in the set reference system, have been surveyed. The Bundle adjustment process, carried out by Scene software, prevents an error propagation and successively one after another has produced a unique 3D points cloud model, with a high accuracy, about 3 mm.

Figure 5. targets distribution

2.2 Data analysis

All the processing operations, except for the alignment, have been performed by Geomegic 3D Wrap software and from the point clouds a polygonal surface 3D model of all the Courtyard has been produced and in particular, for every column, a high accuracy 3D model has been done, Figure 6.

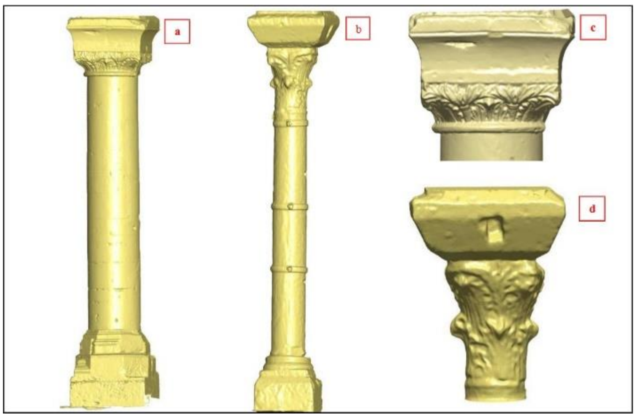

Figure 6. 3D column - a) ground floor, b) first floor, c) "capitellum" - ground floor, d) "capitellum" - first floor

For every column, from the 3D model, different sections at set altitude have been extracted long all the columns altitude. If the main axis is vertical the centre of every section (a circle) is almost overlapped to the next one otherwise, the displacement between every centre of the circles, increasing from the bottom to the top of the column, shows how much and towards which direction the axis of the column is displaced compared to the vertical, Figure 7, 8. This methodology has been applied to every column for the ground and first floor and every displacement and direction have been acquired. The tables 1, 2 show the displacement and the components of the displacement vectors in the set reference system Figure 10, 12.

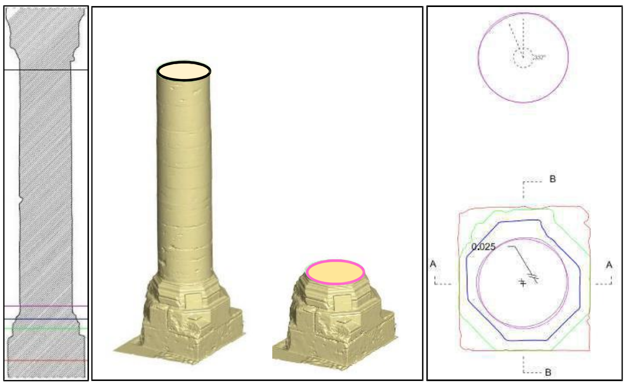

Figure 7. Displacements of a ground floor columns

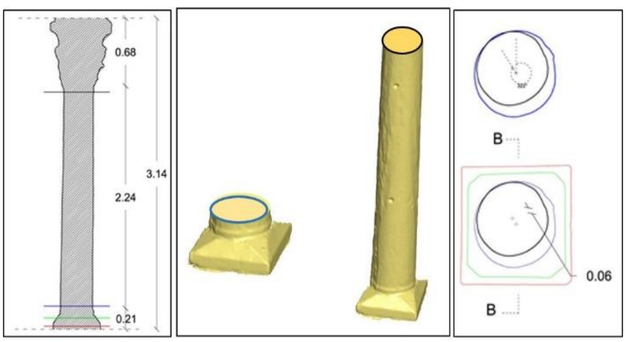

Figure 8. Displacements of A first floor columns

	id column	ΔX (cm)	ΔY (cm)	displacement (cm)
Ground floor	column A	2,0	-1,30	2,5
	column B	1,0	-0,18	1,0
	column C	2,3	-2,18	2,5
	column D	0,8	0,62	1,0
	column E	-1,7	-1,04	2,0
	column F	-0,9	0,65	1,0
	column G	-3,2	-1,64	3,8
	column H	0,7	-0,92	1,0

Table 1. Displacements of ground floor columns

	id column	ΔX (cm)	ΔY (cm)	displacement (cm)
First floor	column 1	0,1	0,22	1,0
	column 2	6,6	1,73	7,0
	column 3	2,0	1,89	2,0
	column 4	2,1	2,70	3,0
	column 5	-0,2	-5,25	6,0
	column 6	0,1	1,88	2,0
	column 7	2,5	-3,00	3,0
	column 8	1,3	3,66	4,0
	column 9	-4,1	4,72	6,0
	column 10	2,4	2,99	3,0
	column 11	2,6	2,08	3,0
	column 12	-0,1	-0,65	1,0

Table 2. Displacements of ground floor columns

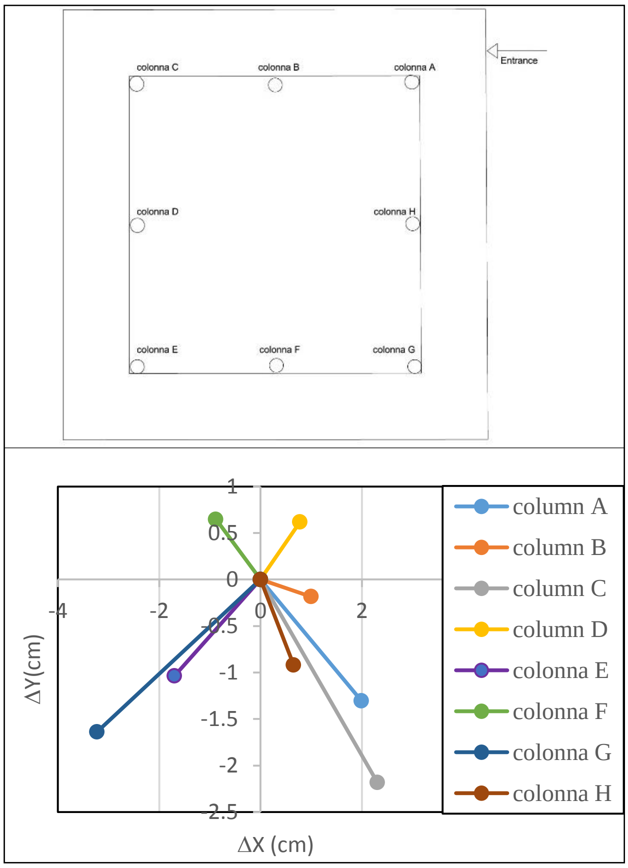

Figure 10. Representation of the ground floor plan and vectors

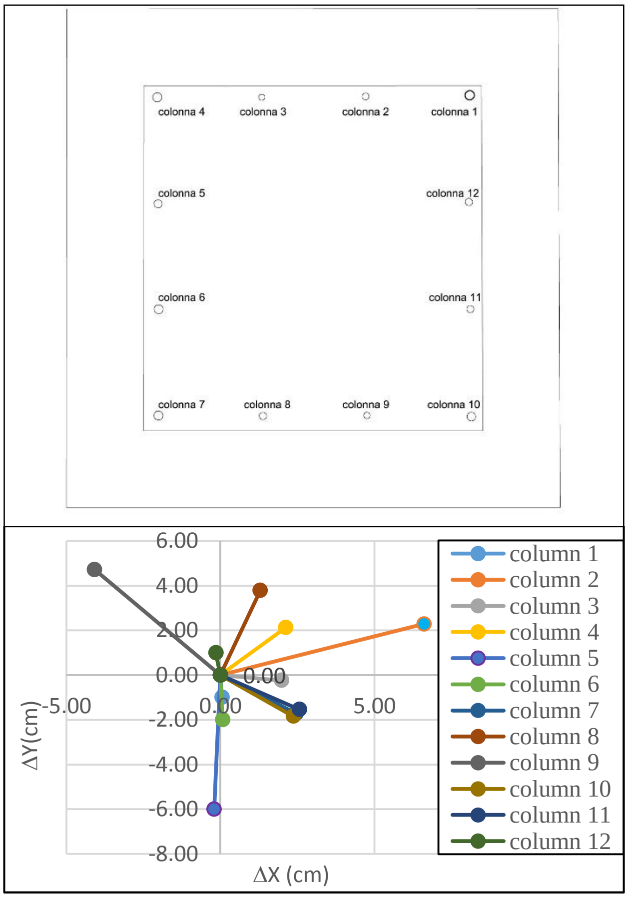

Figure 12. Representation of the first floor plan and vectors

An extruded model from the gotten section from the bottom of every column has been produced and for every column a displacements map has been produced comparing the surveyed model and the extruded one. This kind of representation is useful to evaluate probable not linear displacement along all the altitude of the columns Figure 13.

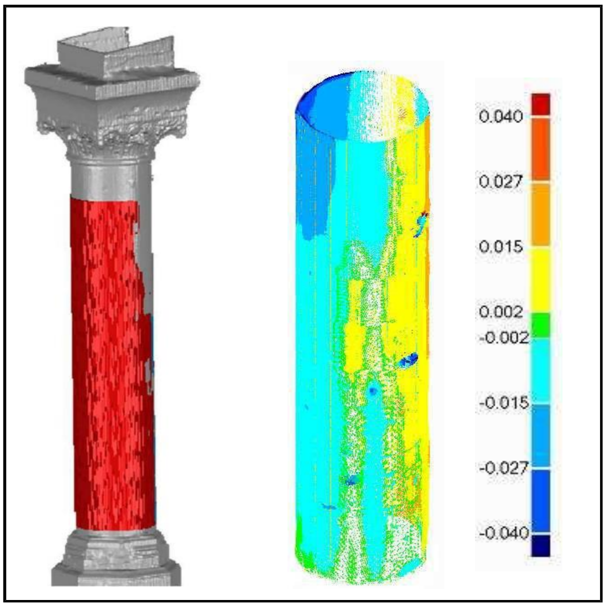

Figure 13. Displacements map, surveyed model (grey) extruded model (red).

The methodology accuracy is strongly correlated to the accuracy of the topographic and laser scanner survey. In this case, the gotten accuracy both for the alignment of the points clouds points and for the topographic network, is about 3-4 mm, very inferior to the searched displacements, more than 2 centimetres.
The 3D model has also useful for a numerical model that can be used for theoretical and experimental dynamic characterization of the colonnade. Lastly a photorealistic 3D model for every column and for all the Courtyard has been done Figure 14,15.

Figure 14. 3D photorealistic model –ground floor

Figure 15. 3D photorealistic model – first floor

3. CONCLUSION

“Palazzo Steri – Chiaramonte” is a wonderful example of the historical heritage in Palermo. The inner courtyard, characterized by its magnificent dual arcade, is the dominant architectural element of the building. This described methodology has been very useful to evaluate the displacement and in the future, from the same topographic network (some vertexes, V2 and V3 have been permanently materialized), a new laser scanner survey can be easily carried out. The representation of displacement vectors shows that there is no prevailing direction of column displacement
Moreover, TSL provides the geometry of a building or structure (form and dimensions), even if the latter are inaccessible. The possibility of having highly accurate 3D models allows for the study of structural deformations in a very reliable and thorough manner. This gives the opportunity to attentively evaluate the

interventions needed in order to restore a structure to its original state, bearing in mind the costs and work times involved.
TLS survey allows to acquire a high number of points that enable more accurate controls and monitoring with respect to the limited number of points that a more traditional type of scanning might have.
Among the disadvantages, we can enumerate: the complex nature of data processing; the difficulty in extracting plans and sections from the 3D model in an automatic manner and without the intervention of an operator. Without doubt the utilization of TLS, for these purposes, offers far more margins for improvement that enable the speeding up of data processing operations and data extraction.

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