

LASER SCANNING METHODOLOGY FOR THE STRUCTURAL MODELLING

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ABSTRACT:

Laser scanning methodology which has been used in different sectors, allow surveying an object by means of very dense and accurate point clouds acquisitions. The alignment and co-registration in a defined reference system allow generating a 3D model of the object, with the possibility to associate the radiometric information useful in many applications.

In this paper, the operations in order to develop the three-dimensional models of the medieval town-walls of Padua and Cittadella (Padua) are described and analyzed. The accurate geometric information extracted was used in the structural analysis with the aim of the restoration: has been considered the just weight of the walls and the wind action to evaluate the planimetric distribution of structural tensions and to characterize the more critical areas.

1. INTRODUCTION

Terrestrial laser scanners have found applications in many measurement tasks, especially for engineering projects and cultural heritage documentation (Bitelli, 2002). The high resolution and the accurate and rapid point clouds acquisition allow low cost and impressive productions of the as-built engineering models and features extraction of cultural heritages (Boehler et al., 2001; Gaudini et al., 2006; Spalla 2003). Terrestrial laser scanners are currently tested for their accuracy and precision (Lichti, Gordon, 2004; Boehler et al., 2003; Schulz, Ingensand, 2004; Staiger, 2005) in comparison also to more traditional techniques.

The surface material affects the signal that the scanner receives back and can cause problems with the strength of the signal. Results can therefore be affected, so research into the effect of the materials is currently occurring. Several different materials can be tested, although those associated with structures are of most interest, i.e. concrete, wood, rock. Reference to this is the work done by Lichti and Harvey (2002) who have used various materials and scanned them at close (3m) and medium range (53m) (Roberts, Hirst, 2005).

Furthermore, a more specific application of the laser scanning data can be found in the sector of structural modelling: the accurate geometric information becomes the input for the structural computations software (finite elements or boundary elements) (Achilli et al., 2005). The laser scanner's applications include the ability to record and document the structural architecture. This can be invaluable for historic buildings and for planned or future renovation works (Roberts, Hirst, 2005).

In this paper two cases are presented and analyzed; both are relative to the medieval town-walls with structural problems: the first one is related to a section of Cittadella encircle-walls, the second one is referred to some parts of the remained walls in Padua.

2. THE MEDIEVAL TOWN-WALLS OF CITTADELLA AND PADUA

Cittadella, medieval village located in the north of Padua (about 30 km), was founded in 1220 for military purposes planned by the Padua town: its town-walls have irregular elliptic shape and

encircle the village-centre for 1461 m length and 13 m height. The thickness is about 2 m and the section is constituted by 2 external walls, where the interstice is filled up by stones, gravel and lime. Over the top there is a walk-way, which is protected and reinforced by 32 towers: the town-walls are ideally subdivided in 4 parts, among the four main roads. The survey has been performed over the 25 % of the whole town-walls (figure 1, 2).



MEDIEVAL TOWN-WALLS OF CITTADELLA (PADUA) SURVEYED

Figure 1. Orthophoto of the Cittadella village-centre enclosed by the medieval town-walls

The medieval town-walls of Padua (1500) have very similar characteristics of the Cittadella encircle-walls, but only some portions are still present. The survey has been performed in the sections among "Torriione Venier" and "Torriione Buovo" (figure 3).

At the beginning of the 1500 the Padua town-walls, already constructed, were reinforced improving the form and the constructive technique using more resistant materials (stones and bricks).

In the same period were constructed the Bastions and, in the analyzed area, following the course of the rivers, were raised an uninterrupted defensive curtain, protected at levant by two of these Bastions ("Portello Vecchio" or "Buovo" and "Portello Nuovo" or "Venier"). The "Torrione Buovo" was developed by means of cylindrical shape with 42 m diameter and 6 m medium thickness of the wall. The downstairs, underground, is accessible by means of a gallery that finishes in correspondence to a great room of 18x9 m. From "Torrione Buovo" to "Torrione Venier" the town-walls are rectilinear with, about in the center, the "Castelnuovo" Bastion where the walls are 8 m thickness; the Castelnuovo has length of 113 m, shelf of the arc of 37 m and curving beam nearly to 62 m (Fabris et al., 2007).



Figure 2. a), b) Different view of the analyzed area; c) Structural degradation of the town-walls

3. THE SURVEYS

The both surveys have been performed with the laser scanning methodology: Leica HDS 2500 laser scanner was used for the points cloud collection with a mean grid size of 2 cm for the Padua and 3 cm for the Cittadella town-walls. The instrument allows to measure single points using the time of flight technique, providing an accuracy of 4 mm for the distance measurement and of 6 mm for the positioning definition (measurement ranges from 1.5 m to 50 m); the accuracy for angles definition is 60 micro-rad. The laser scanner captures data in 40° x 40° field of view (FOV). This FOV limits the amount of space that can be acquired in a single scan, but the scan head can be turned to coverage a broader spatial area; furthermore the entire laser scanner can be placed in different positions to acquire similar or different scans from different points of view. This approach at various locations allows scanning from multiple angles to produce a 2.5D view of the target object (Waskiewicz et al., 2004). During the scanning phase, several reflective targets, located by means of semi-automatic identification, are used as control points and acquired with high resolution scans; the coordinates are measured in a local reference frame using the total station Leica TC2003.

Some scans were acquired without targets, due to the impossibility of signals positioning: in these cases, the scans has been performed with a high overlapping percentage between adjacent points clouds (about 60%). For the total coverage of the town-walls portion of Padua were acquired 130 scans (with overlap of about 10% between subsequent scans with targets, in order to guarantee the continuity of surveying and

representation) with 280 targets; the same procedure was used for the coverage of the Cittadella town-walls portion, acquiring 125 scans mosaicked through 275 targets.

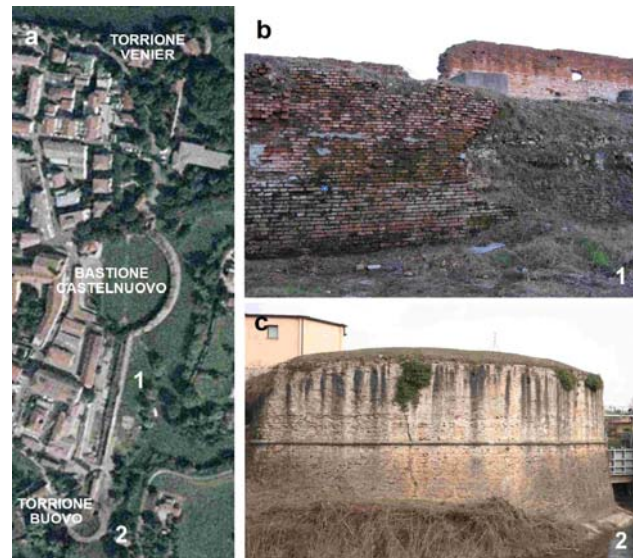


Figure 3. a) Detail of the orthophoto of the Padua city in correspondence to the town-walls surveyed; b), c) Superficial and structural degradation

Due to the absence of intervisibility between the internal and external areas, some station-points have been measured with the GPS methodology (static positioning) and have been referred to the same local reference frame (Leica System 1200 receivers). For the Padua surveying, 8 different stations were performed with sessions of 60 minutes and 15 seconds of sampling rate; for the Cittadella 8 stationing were needed, 45 minutes sessions and 15 seconds sampling rate.

For the town-walls of Padua and some portions of Cittadella ones, also the radiometric information has been acquired thanks to an high resolution photographic surveys performed with the digital metric cameras Canon EOS 1 - Ds Mark II (16.7 mega pixels resolution) and EOS 300 D (with calibration certificate). The acquisitions were performed from the laser scanner positions and from other stations to minimize the shadow zones.

4. DATA PROCESSING

GPS data has been processed by means of the GeoGenius 2000 software obtaining the coordinates of the station-points in the WGS84 reference frame and, subsequently, transforming them in a local system; for the Padua town-walls ellipsoidal GPS heights have been converted in orthometric heights knowing the vertical differences between geoid and ellipsoid.

The topographic networks have been processed by means of the "constrained network" scheme on the GPS points, obtaining the coordinates in the reference system assumed with rms from 0.1 to 1.2 mm.

The Cyclone v. 5.4 software has been used to align the points clouds acquired by the laser scanner and to generate the global 3D models using the Survey Registration and Cloud Registration procedures. In the first approach, each scan has been roto-traslated in a local reference system, imposing the coordinates of the targets (control points); in the second one, the scans without targets have been co-registered with the roto-traslated scans (figure 4).

The obtained models are very useful to generate cross sections and to extract profiles with the aim of the restoration of the

town-walls; this task has been performed using the Reconstructor software that allows to manage the 3D models in order to filling lacunas, to extract edges, to generate meshes and to provide the texturization of the object (figure 5).

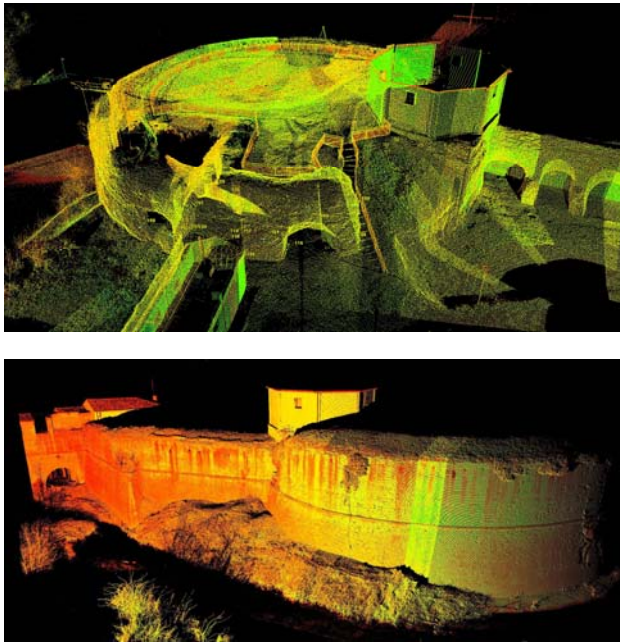


Figure 4. Example of 3D final model of the Padua town-walls (Torrione Buovo section)

For the Padua town-walls, the texture application on the 3D model has been performed using the Z-Map software. For the same area, more different images acquired from different points of view have been used in order to coverage the occluded areas: photorealistic information has been added to the 3D model to obtain an integrated product useful to map the degraded areas (figure 6).

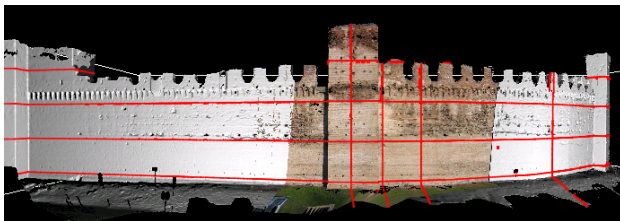


Figure 5. Example of the 3D model with texture and some cross-section (red lines) for the Cittadella town-walls

5. STRUCTURAL ANALYSIS

The Finite Element Method (FEM) allows to modelling structures geometrically complex in three dimensional space, analyzing the characteristic parameters of the materials implemented in the model and performing different analysis on the same geometry (linear, not linear, dynamic, etc...). Generally, the FEM analysis is integrated with traditional statistical approaches: in fact, an accurate modelling of complex structures is possible, providing the stress of the structure, but the response of the elements not traction-resistant is not determined. The structural analysis of the historical buildings is very difficult because the material properties are often not so well defined (due to the limited approaches to destructive tests) and the obtained results could be very different for the same

analyzed section. The problem is independent to the calculation method and depends by the chosen hypotheses for the elaboration of the model: assuming the material as homogenous, isotropic and continuous is so no realistic in many cases. The geometric information of the object is also very important: in fact, small geometric variations can induce different stress properties. In this context, the laser scanning application is very useful in order to generate high resolution and precise 3D models.

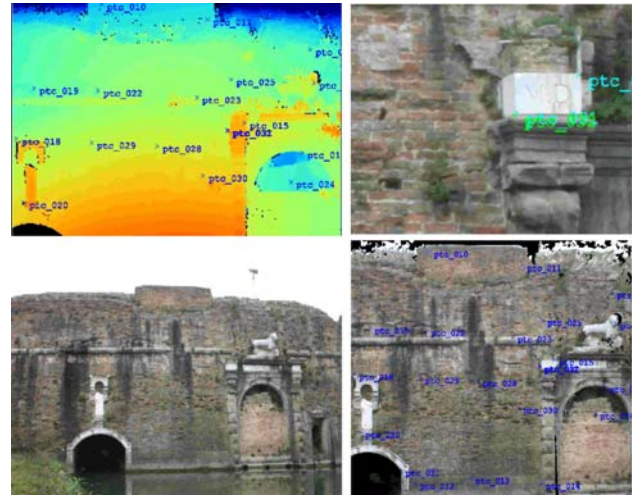


Figure 6. Texture mapping of the Padua town-walls (Bastione Castelnuovo)

The extracted cross-sections of the Padua town-walls have been used in the static analysis: in this work a specific cross-section obtained from the intersection of a plan crossing the centre of curving of the Bastion Castelnuovo and the Bastion itself was considered. Furthermore, a foundation typology (as large stair-step, figure 7a) has been taken in account with its material characteristics. The analysis was conducted considering the just weight of the walls, the force of the terrain in the inner part, the hydrostatic force of the water on the external part and the wind action (has been assumed the analyzed portion as a gravity wall). The accurate geometric information extracted was used in Straus v. 7 software (which permits structural calculations) together with the characteristics of materials to evaluate the planimetric distribution of structural stress and to characterize the more critical areas: several thematic maps have been also produced, providing the stress distribution for the zones which are subjected to deformations.

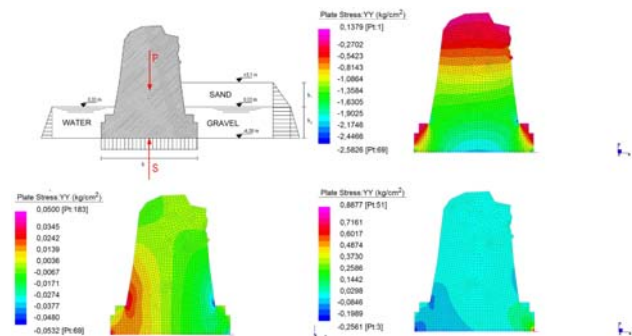


Figure 7. a) Static scheme of calculation; b) output of the vertical tensions due to the just weight; c) output of the vertical tensions due to the wind action; d) output of the vertical tensions due to the force of the terrain

Considering a depth of 1 m, the three-dimensional model has been subdivided on "plate" elements and has been imposed tie block to the points at the base of the section (static linear analysis). As shown in figure 7b (tensions induced by the just weight), the greater part of the section are compressed; the wind pressure induces an increasing compression in the inner part and a traction zone in the external part of the wall (figure 7c); the tensions generated by the terrain provide a section almost completely compressed (figure 7d).

For the Cittadella town-walls the same procedure has been adopted. In this case, the horizontal movement in the direction outside the lead has been evaluated. In the less favourable condition, at the top of the wall is observed a movement of 1.34 cm (inclination of 1/1157): these movements can be acceptable even if in the prohibitive geometric conditions (until a maximum of 6° of inclination respect to vertical one) many problems can be take place. In the figure 6 are shown, in amplified scale, the effect of the forces increasing progressively (figure 8).

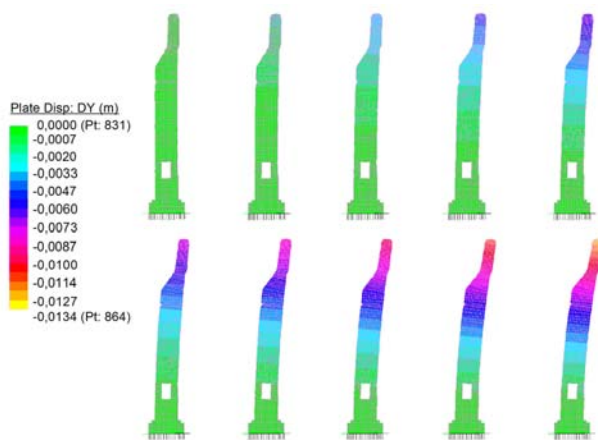


Figure 8. Evaluation of the movement increasing the applied forces (amplified scale)

6. CONCLUSIONS

In the paper the procedures for the generation of three-dimensional models of the Padua and Cittadella town-walls using the laser scanning methodology integrated with the classic topographic surveys and the GPS technique are described and analyzed.

The surveys, performed with the aim of the restoration of the town-walls, have been carried out also acquiring the photographic information by means of two metric cameras.

The alignment of different scans allowed generating the three-dimensional models: this information, together with the radiometric data used for the models texturization, has allowed producing different maps of the discontinuities and superficial degradation.

The accurate geometrical information obtained has been used in the FEM analysis. The Straus v. 7 software has allowed evaluating the planimetric distribution of structural stress providing several thematic maps where the stress distribution have been represented for the zones which are subjected to deformations.

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