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Architectural survey and analysis of the costal tower of S. Maria dell'Alto in Nardò (Lecce, Italy).

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***Abstract* – The Santa Maria dell'Alto tower in Nardò (Lecce, Italy) represents one of the many types of coastal towers of the ancient Terra d'Otranto province. It was built between 1568 and 1569 becoming part of the defensive system of the Ionian coast of Salento against the Turkish threat. The architectural survey ad analysis of the tower allowed us to investigate constructive elements, wall discontinuities, additions, subtractions and functional modification in order to understand the phases and the change of the structure over the centuries. Digital photogrammetry and infrared photography have been useful to elaborate a mapping of all the surface degradation and of the different construction materials. The information collected will be used for a restoration and environmental qualification project in order to offer new features to a building abandoned for years. The final phase of the work involved the creation of contributions in 3D Computer Graphics to offer a graphic and documented visualization of the achieved results.**

I. INTRODUCTION

This paper presents the results achieved as part of the investigation carried out by the Information Technology Laboratory (ITLab) of the Institute of Sciences of the Cultural Heritage of the National Research Council (ISPC-CNR) of Lecce and commissioned by a group of freelancers in order to plan a restoration and a requalification project of the Santa Maria dell'Alto coastal tower and the surrounding area, located in the natural park of Porto Selvaggio and Palude del Capitano in Nardò (Apulia, South of Italy).

The tower represents one of the many types of coastal defensive structure of the ancient province of Terra d'Otranto along the Ionian coast from Nardò to Porto Cesareo against the Turkish threat. It is one of the eight towers of the Nardò series and was built between 1568 and 1569 by the *magister* Angelo Spalletta. Thanks to its position, placed on a promontory at about 51 m above sea level, and to the large dimensions, it is one of the most spectacular and eminent well preserved defensive fortification. This towers of the Nardò series have a truncated cone base and a parallelepiped upper volume with four congruent sides, or perfect quadrangular implants. The volume of these towers inside is divided into two floors: the ground floor, in most cases, is filled by an embankment, while the first floor has a single vaulted vault. In many towers the tank for collecting rainwater was detected. A string-course bull divides the base from the upper volume. They differ in size and characteristics from the towers with quadrangular bases typical of the Kingdom of Naples.

Fig. 1. The tower of Santa Maria dell'Alto: aerial view.

II. ARCHITECTURAL SURVEY

The survey and the graphical representation of the coastal tower of Santa Maria dell'Alto contributed to verify and to correct the old survey realized using direct method. Different indirect survey methods have been used since the use of a single technology does not allow to achieve a good result in terms of geometric accuracy, portability, automatism, photorealism and low costs. The sensors used for the survey use light radiation; a further distinction can be made depending on the nature of the light used to make the measurement. If natural light is used, measuring instruments are defined as *passive* (photogrammetric technique, Image-Based, etc.); if the light is generated in the measurement process, we are talking about *active sensors* (laser scanners, radars, total

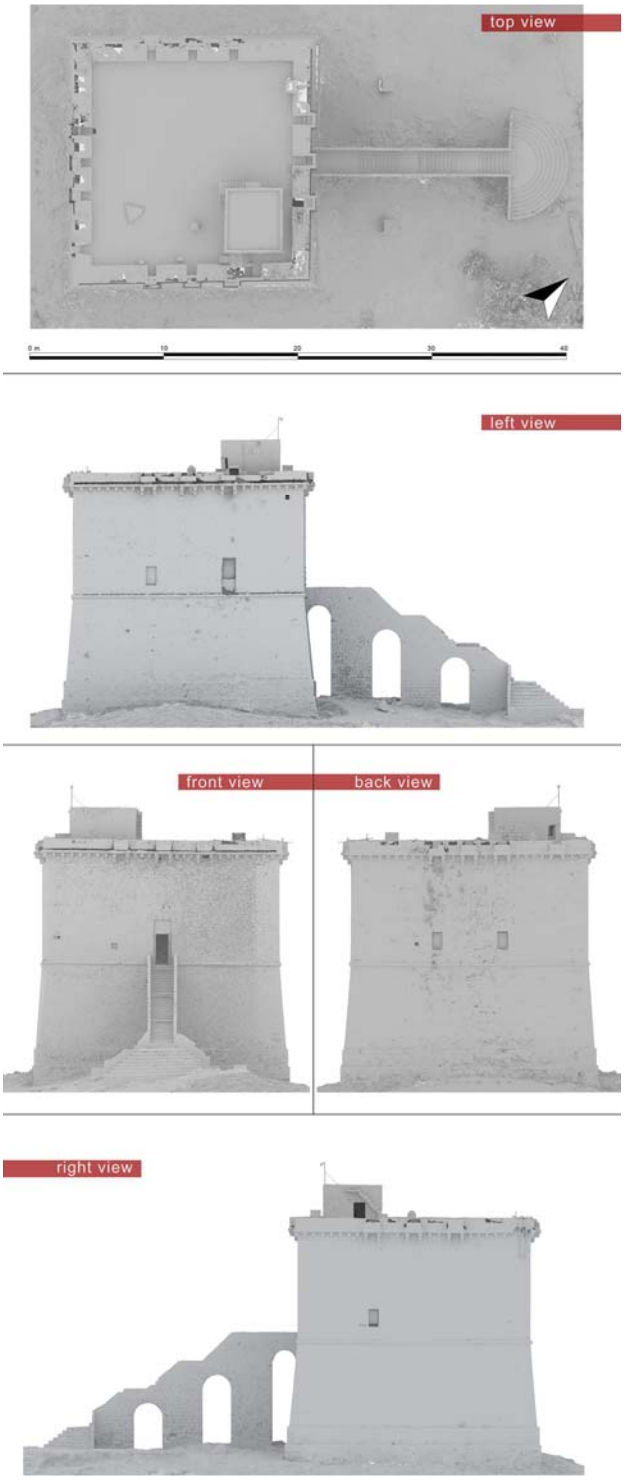

Fig. 2. 3D model of the coastal tower of Santa Maria dell'Alto from laser scanner point clouds.

stations, etc.). The integration between different systems of three-dimensional relief represents a central topic of research in different disciplinary fields, within which new methods are being studied to integrate various technologies in an automatic or semi-automatic manner, enhancing their potential. Both active and passive sensors show a high level of complementarity.

A. Laser Scanner

The survey was performed with a Leica P20 laser scanner using an accuracy of 6 mm on a dome of 10 m radius for the interior while an accuracy of 3 mm on a dome of 10 m for the exterior. A total of seventy laser scans were realized to cover all surfaces.

The matching of point clouds was done manually. From them a three-dimensional model was obtained with a mesh of about 7 million polygons with a resolution of 10 mm. Starting from the scaled model the 2D plan and the sections of the area have been elaborated.

B. Digital photogrammetry

Digital photogrammetry is very useful when there is a limited permanence in the place of the surveyors or if the artefact can be described exhaustively by the points and lines. On the contrary, the laser scanner requires more time in the acquisition of data and in the post-processing phase from merging of the cloud point is up to the processing of the polygonal mesh.

This, clearly, offers very precise data not achievable with traditional photogrammetry. An approach based on the use of different surveying instruments able to offer metric data characterized by a variable resolution, called *multiresolution*, allows to achieve an exhaustive result with the different representation of all geometries presents in the environment. The UAV airframe used was a quadcopter Scrabble 4HSE that was designed and manufactured by Italdron, and equipped with a high resolution digital camera (Panasonic DMC-GH4, 16Mpx, focal length: 28.0 mm; sensor resolution. 4608x2592 pixels) fixed on 3-Axis gimbal. The maximum weight was 9 kg, with the upper limit of flight endurance of 10 minute. To cover the whole area, flights were performed with nadir orientation of the camera. Additional flights in manual piloting with a 45° camera (i.e. oblique images) was carried out to collect aerial images of the sub-vertical walls area. The redundant set of images acquired at the selected timing facilitates the SfM approach. Totally, have been taken 380 aerial photos using a distance of shoot of about 5 m, at a midrange distance from the ground of 20 m. The tower was covered with a sufficient image overlap (about 70-80%), essential in order to get the tracking points in space and their resulting 3D position. The processing of the images by the software Agisoft Photoscan software (v. 1.4.0.5076) led to the alignment of all the photos with a minimum margin of error (0.6/2.0 pixel) and to the creation of a dense cloud of about 8 million points. The model obtained was georeferenced through 6 ground control points (GCP) located on the corners of the boundary wall and on the roof. All GCP have been acquired with a total station, to guarantee its correct scaling and orientation.

III. ANALYSIS OF THE STRUCTURES

We present the results emerged from a survey performed with the joint use of 3D laser scanner technologies and Structure from Motion (SfM) photogrammetry techniques. The survey allowed us to investigate constructive elements, wall discontinuities, additions, subtractions and functional modification in order to understand the phases and the change of the structure over the centuries.

The tower is about 21 m high and have a truncated pyramidal base measuring ca. 19 x 19 m, separated from the upper portion by a stringcourse cornice. The upper floor, equipped with an access door, ends with a corbelled cornice and is equipped with battlements and ten machicolation distributed on all four sides. A big staircase supported by three arches allows the access to the first floor (about 13 m high), that consists of three rooms. The first room have a rectangular plain (12 x 6 m), with barrel vault, a fireplace and two windows aligned on the N-W and S-E sides. Two gates allow access to two same size rooms (4,50 x 5,80 m), both with barrel vaults and windows on the S-W sides. Two posthumous rooms have been carved in the wall thickness on N-W side and on N-S side under the staircase leading to the terrace. An additional window was obtained on the side S-W emptying the wall thickness. These addition leads to a weakening of the tower's stability. In the eighties all the wall surfaces were deprived of the original plaster.

The 3D laser scanner survey also involved part of the structures located under the floor of the N-W room. Here are some vaulted rooms used for the storage of rainwater coming from the roof. These rooms have been modified over time for other uses, as evidenced by the traces of attendance observed. From the analysis of historical documents, we recognize that, between the end of the seventeenth century and the beginning of the eighteenth century, these rooms were used as lazaret for the Turks and pirates landed on the coasts. From constructional analogy it was therefore possible to hypothesize graphically the presence of similar structures in the north side not yet investigated. The accuracy of the survey shows a rhombic deformation of the plant generated during the construction works. A detailed analysis of the monument surfaces, allows us to identify some construction defects particularly evident in rows of calcarenite blocks. Digital photogrammetry and infrared photography (Camera IR Flir SC 660 with FPA sensor) have been useful to elaborate a mapping of all the surface degradation and of the different construction materials. In addition to the rooms, the wall thicknesses and the structures in them placed (like the access staircase to the upper terrace and the flue pipes of the three large internal fireplaces) were accurately documented. The architectural analysis was carried out in order to identify some structural criticalities, which have been taken into account for consolidation, restoration and recovery works that hopefully will be scheduled in the near future.

Fig. 3. 3D model of the coastal tower of Santa Maria dell'Alto from digital photogrammetry.

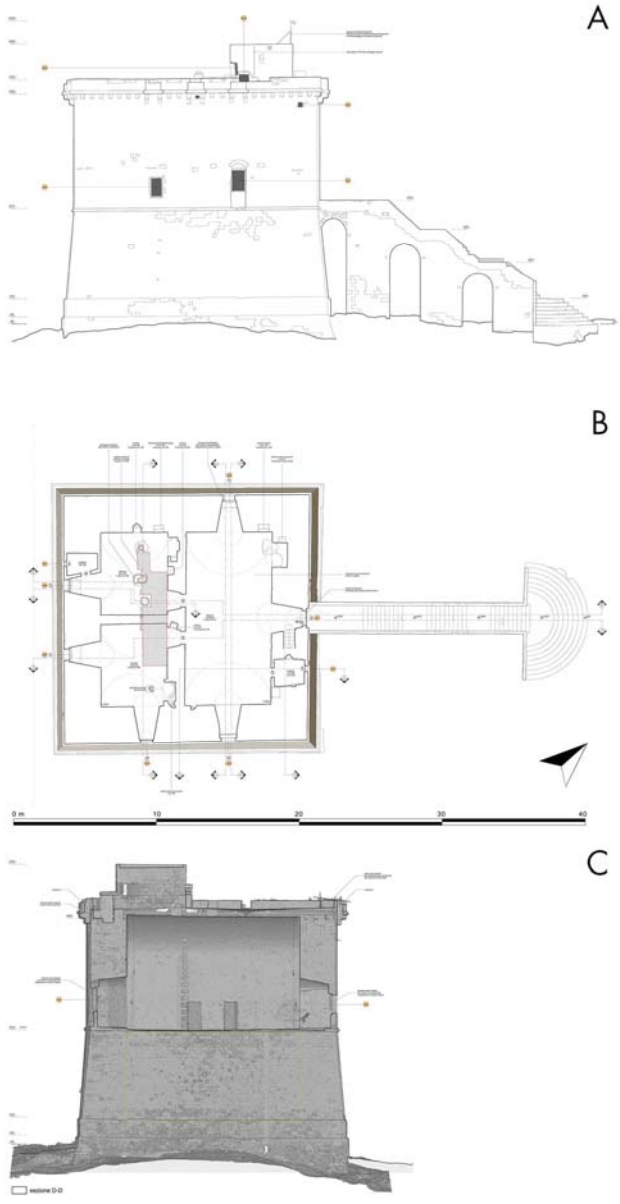

Fig. 4. The coastal tower of Santa Maria dell'Alto: a) south elevation; b) planimetry; c) longitudinal section.

IV. VIRTUAL 3D RECONSTRUCTION

The final phase of the work involved the creation of contributions in 3D Computer Graphics to offer a graphic and documented visualization of the achieved results.

The collected data also allowed us to elaborate an hypotheses of 3D virtual reconstruction of the tower with the drawbridge.

V. CONCLUSION

Finally, the work flow planned and the data obtained allowed us the management of the all information within a single 3D work space, two digital models predisposed

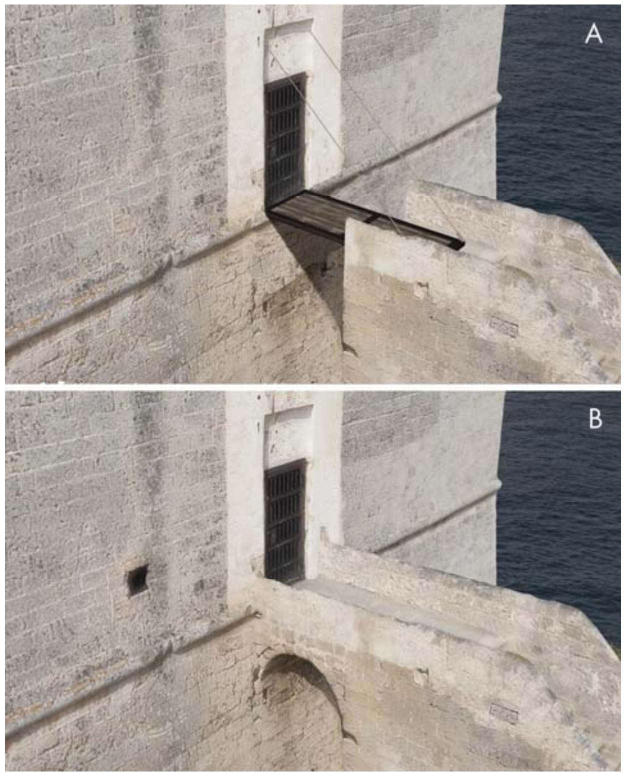

Fig. 5. The coastal tower of Santa Maria dell'Alto: a) detail of the 3D reconstruction with the drawbridge; b) detail of the 3D survey.

to quickly provide all the information about the geometry and the color of the analyzed scenario. This is particularly useful for restoration, maintenance or monitoring.

The integration between these technologies demonstrates how the single instruments are characterized by a level of complementarity that makes an integrated system more performing and flexible, able to provide a much better result in absolute terms and able itself to adapt to the single morphological features of the different objects contained in the detected scene. The complementarity of the techniques allows to optimize the acquisition and modeling process, exploiting the maximum potential of the single instrument. The result achieved is a digital cognitive model, that is a repository of information that can be interrogated at various levels.

VI. CITATIONS AND REFERENCES

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