Integrated Digital Documentation for Conservation, the Case Study of the Torre deli Upezzinghi Called Caprona, in Vicopisano (PI) Italy

Giovanni PANCANI

Department of Architecture, University of Florence, Italy

giovanni.pancani@unifi.it

Keywords: Tower of Caprona, Heritage Management, Digital Survey, Aerial Photogrammetry, Documentation, SFM

Abstract. Located on the Rocky Promontory overlooking the town of Caprona, the Upezzinghi Tower is a 19th-century reconstruction of a watchtower that once served the ancient castle, which existed in the mid-11th century and was destroyed by the Florentines in 1433. The hill on which it stands has been gradually eroded due to stone quarrying, significantly altering the landscape around Caprona. Until the mid of the last century, the rocky promontory was still substantially intact, and the remains of the medieval fortress could be identified beneath the tower. However, at its base, the remains of the medieval tower's foundation are still visible. The structure is currently in an advanced state of architectural decay, and the extraction of stone material has been so aggressive that the quarry's limit has come within about 50 cm of the tower's profile. The small square-shaped building appears to be smaller than the one demolished in 1433 since measurements at the base of the current tower have confirmed one side to be approximately 4.50 meters, while the remains of the medieval tower had a side of about 5.00 meters. Digital surveying has been carried out for the preservation and conservation of the tower, which is in urgent need of restoration. TLS (Terrestrial Laser Scanning) and UAS (Unmanned Aerial Systems) tools were used with multiple acquisitions that were subsequently compared and calibrated, using the laser scanner point cloud as a reference. The maximum misalignment error of the TLS point cloud was within a maximum range of 0.015 meters. The delivery of the survey results, considering the modest size of the structure, was performed at a 1:20 scale.

Introduction

On the rocky spur overlooking the town of Caprona, you can see the "Upezzinghi Tower," which is a 19th-century scaled-down replica of the tower from the ancient castle that existed in the mid-11th century and was dismantled by Florence in 1433 [1]. The extraction of stone from the quarries in Caprona has gradually transformed the landscape of the town. In fact, at the beginning of the 20th century [2], the rocky promontory was still largely intact, and it was possible to see the remains of the medieval fortress around the small tower (fig. 1). Unfortunately, at the present state, there are not many significant traces of the entire fortified complex, except for a foundational base at the foot of the 19th-century tower, which likely could belong to the medieval tower. The medieval tower was constructed to control the narrow strip of land situated between the Arno River and the southern extension of Monte Pisano and to facilitate communication with the surrounding fortified structures, such as Rocca della Verruca and the towers of Uliveto. The Upezzinghi Tower has been the subject of a multidisciplinary study involving the Department of Architecture (DIDA) at the University of Florence, the Department of Earth Sciences, and the Department of Energy, Systems, Territory, and Construction at the University of Pisa. This collaborative effort has already conducted a territorial-scale survey [3].

In this article, focusing on the study conducted by the Department of Architecture at the University of Florence, we will discuss the data acquisition methods, the technologies employed, and the results obtained concerning the digital 3D architectural survey work.

Fig. 1, A picture of the Caprona tower at the beginning of the 20th century where the remains of the medieval fortress can be clearly seen.

Methodology

For the TLS (Terrestrial Laser Scanning) survey, a Zoller+Frogich Image 5016 laser scanner was utilized. This instrument is a Phase Difference-based tool with a range of 360 meters, a vertical field of view of 300 degrees, and a horizontal field of view of 360 degrees. It includes an integrated camera with HDR technology in a dual configuration and integrated LED flash. The measurement noise does not exceed 0.2mm at 25m with 80% reflectance, without the use of optimizations. The specific shape of the rocky promontory on which the tower stands, with one side bordered by a 90-meter cliff and the others presenting steep slopes, required careful handling and precise leveling of the instrument (fig. 2). The ten scans were performed along a polygonal path on three sides around the tower, while the fourth side was reached by extending the polygonal network for capturing the interior of the tower [4].

Fig. 2, On the right, the cliff where the Caprona tower stands, and the scanner used is the Z+Inager 5016.

Fig. 3, On the left, the interior of the tower with the Dji Mini 3 Pro drone at work.

The scans were recorded and processed using Recap-pro software (fig. 4). The 3D point cloud model was then exported in e57 format, followed by verification and certification using Cyclone software. Certification and testing of the point cloud were necessary because each survey requires validation of its reliability and accuracy before it can be made available to scholars who will use it for their research needs [5]. Verification of compliance with minimum error and reliability requirements involved extracting a series of horizontal and vertical cross-sections from the point cloud, both during partial scans and from the overall point cloud of all scans. In the identified sections, it was verified that the section lines (fig. 5), representing the profiles obtained by cutting through the point cloud, from different scans had a matching alignment. Even when not perfectly aligned, the section line thickness did not exceed 15 millimeters. Point cloud certification ensures that the results are based on reliable and credible data for subsequent analysis and considerations [6].

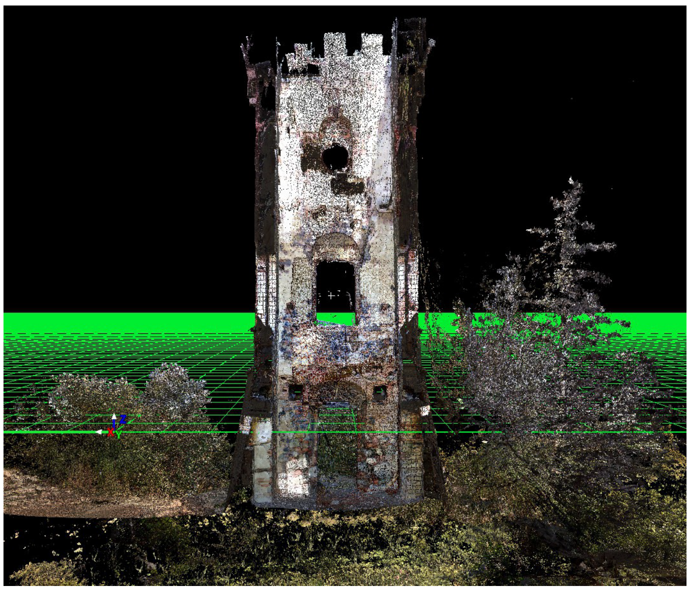
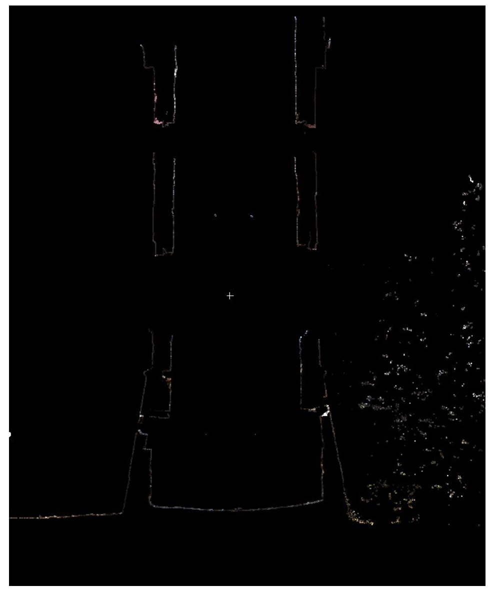



Fig. 4, On the left, the point cloud of the survey of Caprona Tower, sectioned but with a view of the space (Section Elevation), is visible along with the horizontal cutting plane.

Fig. 5, On the right, the sliced point cloud with a thickness of 1 cm, the section lines are clearly visible, which are evaluated for survey certification.

In addition to the laser scanner survey, a highly accurate Structure from Motion (SFM) photogrammetric survey was conducted with a very high shooting density, approximately 10 pixels per square centimeter. For ground-based surveying, a Sony alpha 900 camera with a 24-megapixel CMOS sensor and a Sony 24-70mm f/2.8 ZA SSM Carl Zeiss Vario-Sonnar T* lens was used. Aerial acquisitions (fig. 3)were carried out using a DJI Mavic Mini 3 Pro Unmanned Aerial System (UAS) equipped with a camera featuring a 1/1.3-inch CMOS sensor with 12 effective megapixels and a flexible ISO range. The acquired photographs were processed using Reality Capture software. The results from the two point clouds, one from the 3D laser scanner survey and one from the photogrammetric survey, were optimized and compared using Cloud Compare software [7].

The meshes obtained from the laser scanner and photogrammetry were exported from Reality Capture and compared using Geomatic Wrap. The results revealed a maximum positive distance of 0.100 meters and a maximum negative distance of -0.100 meters. The areas at the top of the tower showed the most significant differences, partly due to the scanner's difficulty in reaching all points. The average distance between the meshes was 0.001 meters, with a maximum positive value of 0.056 meters and a maximum negative value of -0.056 meters. The standard deviation was 0.062 meters, and the RMS estimate was 0.062 meters (fig. 6).

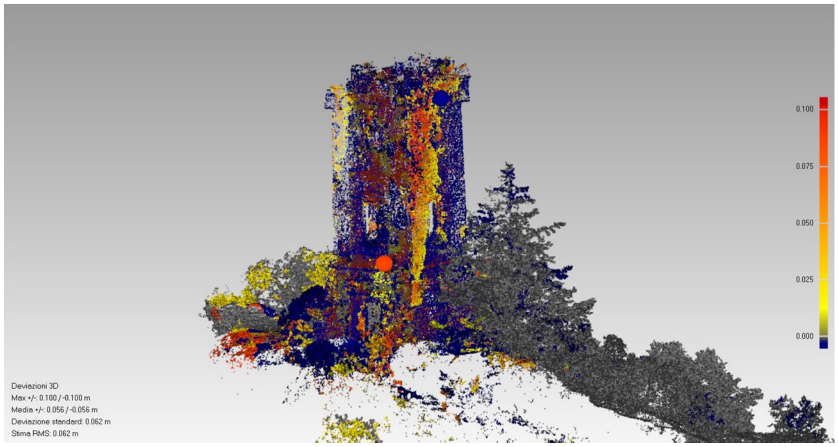
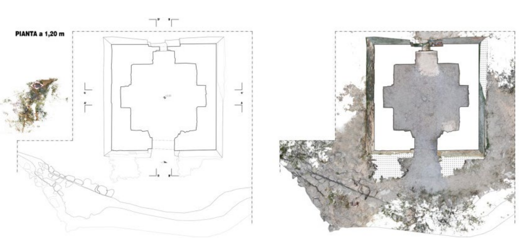


*Fig. **6**, The comparison between the point clouds where critical points are evident and those where the laser scanner survey point cloud closely corresponds to the photogrammetric survey point cloud.*

To achieve a high-quality 3D photomodel, essential for producing quality photoplanes, certain principles were considered during both the photographic acquisition and subsequent data processing phases. To create a photoplane at a 1:20 scale and print it at 300 DPI, the following conditions needed to be met. In order to achieve a 300 pixels per inch print definition without quality loss, the images had to have a resolution that adhered to the following parameters. In the chosen scale for this survey, which is 1:20, one real meter is represented by 5 cm of print. Therefore, for simplicity, we will assess pixel density in centimeters rather than inches. Namely, 1 inch equals 2.54 centimeters, which means 300 pixels divided by 2.54 cm equals 118.11 pixels per centimeter. Thus, the print needed to meet the 118 pixels per centimeter parameter, rounded to 120 pixels. Consequently, in a 1:20 scale print, one square meter of real surface had to be represented by at least 120 pixels in 5 centimeters, or 600 pixels. Therefore, the images for creating the photomodel had to be captured with a resolution of at least 6 pixels per centimeter. Considering that during acquisition, dimensions of the surfaces to be photographed are estimated empirically and that native resolution may be lost during photomodel processing, it's highly advisable to acquire images with a resolution greater than the necessary minimum. This implies that the images should have a resolution of approximately 10 pixels per centimeter [8].



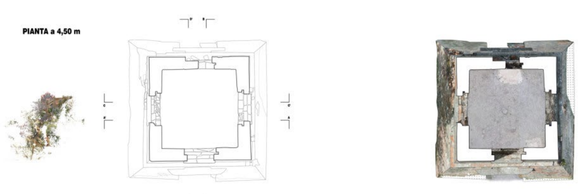


Fig. 7, On the left, shows the floor plan with the wireframe and the photomap of the ground level, at a height of 1.20 meters.

Fig. 8, On the right, displays the floor plan with the wireframe and the photomap of the level at 4.50 meters

In the deliverable, the certified point cloud, exported from the Recap software in e57 format, was imported into AutoCAD, where section planes were identified. The representation of the structure was organized following the classical scheme, with a plan view relative to the rocky outcrop on which the small tower stands, a ground level plan, one at a height of 4.50 meters, another at a height of 7.50 meters, and finally, a top-down view above the battlements (fig. 7, 8, 9, 10). Additionally, four internal section-elevation views and the four elevations were created. The elevation of the remains of the base, likely belonging to the previous medieval tower, was also depicted. These graphic representations provided a detailed description of the deteriorated state of the tower's masonry surfaces and were overlaid with high-resolution photomaps, with a resolution of at least 300 DPI [9]. All deliverables were presented at a scale of 1:20.

Fig. 9, The East elevation, on the right, and the elevation section D-D', were first rendered with the wireframe, and then with the photomap on the right.

Considerations

This research has significant implications for the documentation and preservation of the historical and cultural heritage of Caprona. The detailed 3D representation of the Upezzinghi Tower will allow for an in-depth study of the structure and its changes over time. Initial assessments from the survey data suggest that the current tower is smaller than its medieval counterpart, appearing to have been constructed more as a memory marker of the past. The external dimensions of the current square-plan tower have a base side measuring approximately 4.50 meters, while the dimensions at the narrowing of the buttress are 3.40 meters, with a height of 10.00 meters at the level of the merlons, which are about 0.50 meters. When compared to the length of the found foundational base, which is over 5.00 meters, it can be presumed that the medieval tower was considerably larger and, most importantly, taller.

The comparison of data acquired from different technologies provides a unique opportunity to assess the accuracy of data acquisition methodologies. This knowledge can be applied to other historical sites with similar purposes. However, to enhance the representation quality of this survey, it is believed that, in compliance with European regulations regarding public works management, it would be appropriate to enrich the documentation with a Historical Building

Information Modeling (HBIM) process. For this purpose, a project could be developed to model and parameterize the data obtained from this work [10].

Finally, despite being aware of the destructive effects of the adjacent stone quarrying, small archaeological tests could be conducted in the areas surrounding the remaining foundational base near the tower. This would provide insight into what the unwise quarrying activity has spared. Additionally, further data can be extracted from the study of the mortar present in the current tower and the mortar in the foundational base [11].

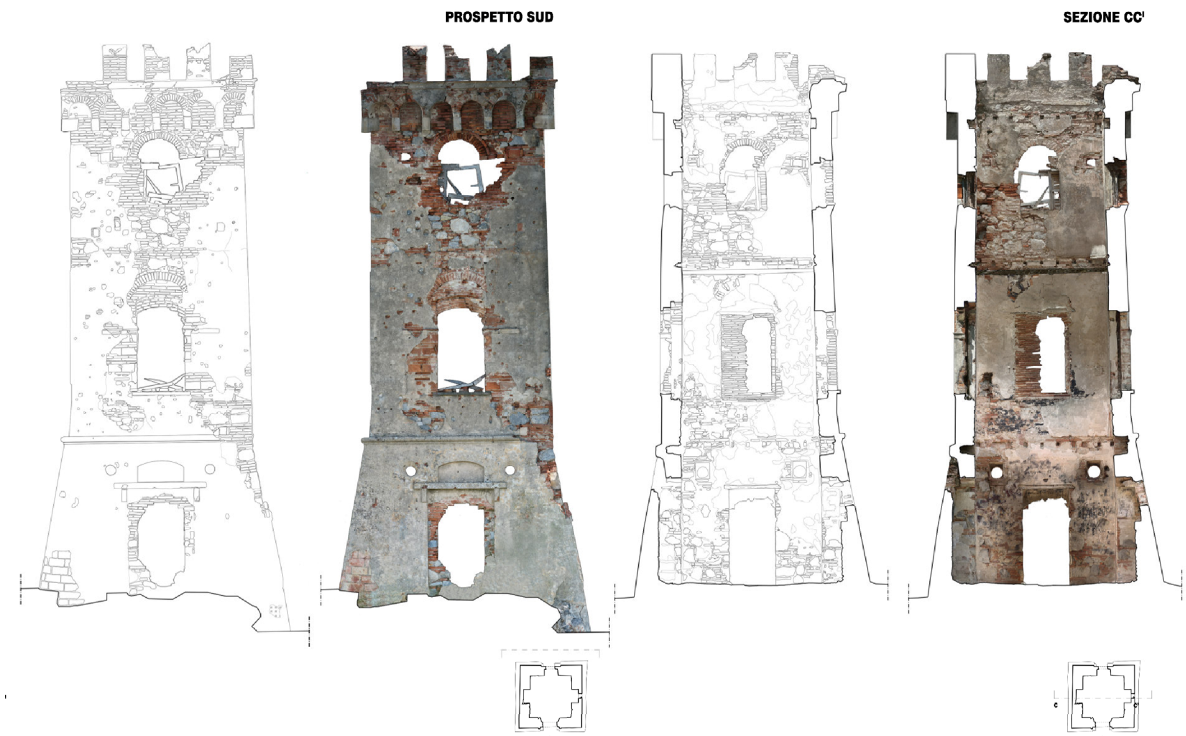


Fig. 10, The Sud elevation, on the right, and the elevation section C-C', were first rendered with the wireframe, and then with the photomap on the right.

Conclusions

The ongoing multidisciplinary analysis and 3D reconstruction of the Upezzinghi Tower in Caprona have provided a detailed understanding of the structure and its surrounding environment. The integration of data from laser scanning, photogrammetry, and drones has yielded results that are sufficiently accurate and detailed. This information has allowed the research team to gain knowledge of the real state of decay in which the tower is situated, and the dimensional information has enabled the formulation of historical typological considerations. Finally, the high-resolution photoplans deliver an updated and accurate depiction of the site. This research represents a well-established methodological approach developed for the documentation and preservation of historical architectural and cultural heritage, which can serve as a valuable tool for the conservation of such an emblematic and significant site for the entire Pisan territory. In this regard, we would like to highlight the studies conducted by Pascal Cotte, who advances the intriguing idea that the Caprona tower, along with the Verruca Fortress, is part of the background in Leonardo's Mona Lisa [12].

Materials Research Proceedings 40 (2024) 134-140 https://doi.org/10.21741/9781644903117-14

References

[1] E Repetti. (1833) Dizionario geografico, fisico, storico della Toscana contenente la descrizione di tutti i luoghi del Granducato. Firenze, Repetti, Vol. I, pp. 366-367.

[2] A Alberti. (2014) Monasteri e castelli sul monte pisano. Insediamenti medievali in un'area di confine (X-XII secolo), in: Salvatori E. (a cura di) Studi di Storia degli Insediamenti, Pisa, Pacini Editore, pp. 149-163.

[3] D Billia, V Croceb., G Montalbanoc., P Rechichid. (2023), La Torre degli Upezzinghi a Caprona:Caprona: analisi storico-archivistica e rilievo digitale per la documentazione dell'evoluzione temporale, in Bevilacqua M. G. , Ulivieri (a cura di), Defensive Architecture of the Mediterranean, Vol. XIII / (Eds.), Pisa University Press (CIDIC) / edUPV.

[4] F Condorelli. & F Rinaudo. (2018), *Cultural heritage reconstruction from historical photographs and Videos*, ISPRS Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII–2, 259-265.

[5] A Arrighetti., F Fratini., G Minutoli., G Pancani., (2022), *Historical Seismic Events and Their Traces on Medieval Religious Buildings,* in D'Amico S., Venuti V. (a cura di), *Handbook of Cultural Heritage Analysis*, pp. 2182-2209, Srpinger Nature Switzerland (ISBN: 978-3-030-60015-0).

[6] G. Pancani (2017), *Il centro storico di Poppi, analisi a livello urbano per la valutazione del rischio sismico*, "DisegnareCon", Vol 10, No 18 (2017), PDF 9.1-9.10. (ISSN 1828-5961).

[7] R De Marco.;, S Parrinello. (2021). Digital surveying and 3D modelling structural shape pipelines for instability monitoring, in, historical buildings: a strategy of versatile mesh models for ruined and endangered heritage, ACTA IMEKO, vol. 10, pp. 84-97, ISSN:2221-870X.

[8] G. Pancani, M Bigongiari. (22 June 2019), *The integrated survey of the Pergmum by Nicola Pisano in the cathedral of Pisa*, in a cura di Kremers H., *Digital Cultural Heritage*, Springer, Cham, Basel, (January 2020), pp. 373-388, DOI: 10.PA1007/978-3-030-15200-0, eBook ISBN: 978-3-030-15200-0.

[9] S Parrinello.; R De Marco.; A Miceli (2020). *Documentation strategies for a non- invasive structural and decay analysis of medieval civil towers: an application on the Clock Tower in Pavia*. RESTAURO ARCHEOLOGICO, vol. 28, pp. 18-43, ISSN:2465-2377.

[10] A Dell'Amico., S Parrinello. (2021). *From Survey to Parametric Models: HBIM Systems for Enrichment of Cultural Heritage Management*. In: Cecilia Bolognesi, Daniele Villa. 978-3- 030-49278-6, pp. 89-107, Cham: Springer.

[11] F. Fratini (2023), The Rocca Vecchia fortress in the Gorgona island (Tuscany, Italy): building materials and conservation issues, in Bevilacqua M. G. , Ulivieri (a cura di), Defensive Architecture of the Mediterranean, Vol. XIII / (Eds.), Pisa University Press (CIDIC) / edUPV.

[12] P. Cotte (2019) *Monna Lisa dévoilée: les vrais visages de la Joconde*. Parigi, éditions Télémauqe.