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Marco Giorgio BEVILACQUA, Denise ULIVIERI (Eds.)

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A 3D integrated survey of fortified architectures: the medieval Canossa castle

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Abstract

Castles are complex fortified systems based on a solid relationship between the territory and the built architecture. The former defines the context of development, access, and defense conditions. The latter adapts to the context, proposing fortified structures in continuity with the orography of the territory. Both factors are crucial to understanding castles' historical evolution and social roles over time. In this knowledge path, the survey process assumes a primary role as a tool to analyze and interpret the built environment through bibliographic and iconographic analysis and the study of reality. Within the castle domain became essential to manage multiple scales of knowledge, acquisition, and representation, deepening the territory and the fortress systems. The case study analyzed is the Castle of Canossa, the epicenter of some critical events in medieval times. The authors describe an integrated survey process between active and passive techniques at architectural and territorial scales. Several geometrical validation steps have been introduced to verify the geometrical reliability. The pipeline highlights also the crucial relationship between territory and buildings, laying the groundwork for a more articulated analysis of the entire architectural complex. At the end, a superimposition between the geometrical model and a historical mock-up is suggested, collecting helpful information for the next reconstruction step.

Keywords: fortified castle, integrated 3D survey, spatial analysis, territorial representation.

1. Introduction

A fortified architecture may show multiple morphologies depending on the construction technique, the territorial context and role, the historical origin, and structure development. The dimension can range from the territorial scale, such as city walls or military outposts, to the individual building (tower, palace, gate) or portion of walls. Fortified castles are an admirable example of layered and complex structures with a substantial scale variability.

They are composed of multiple interconnected defensive systems and architectural superstructures. Besides, fortified castles build a relationship and dependence with the surrounding influence area, defining its development. The territory becomes a filter of access, especially in the case of fortified castles positioned in dominant positions. Therefore, the analysis of these buildings cannot be limited to the architecture study. It is essential to interpret the internal and external ecosystem development.

The case study reported in the paper is the Castle of Canossa (Fig. 1), a complex fortified building close to Reggio Emilia, Italy. The Castle's history

Fig. 1- Images of the Castle. From left: bottom view of the sandstone hill, RPAS view of the system, detail of the most preserved portion of the area (photos by the authors)

overlaps with Matilda of Canossa, an emblematic female figure in the medieval era. Today, the Castle has vestiges of its original shape, but most masonry portions have been lost during millennial history. The research project aims to study the entire building system in-depth from a historical, geometric, and material point of view, building a valuable information system to represent its original architecture. In the paper, the authors (1) suggest the first part of the project, the multiscale acquisition phase (Valenti & Paternò, 2021), and the first restitution of the Castle and its context, preparing the knowledge conditions for future interpretation.

2. Case study

Canossa Castle is located in the Reggio Emilia Apennines on a white sandstone hill (Fig. 1). The Castle is known for the famous "Walk to Canossa", an event involving Emperor Henry IV, Pope Gregory VII, and Countess Matilda di Canossa. The building is part of an articulated system of fortifications in the Reggio Emilia Apennine territory. To this day, little remains of the Matildic-era fortress, leaving a trace of a past imposing fortress. These ruins primarily date from the late Middle Ages to later centuries; only part of the foundations seem to refer to the original time of Matilda. The ruins include the remains of a monastery and some palace walls, built by Ruggeri in the late 16th century. Part of an apse and ruins have survived in the southern area, probably used to store provisions. The foundations of the tower-gate, located south of the building, which separated the worship area from the residential area, are still visible. At the same time, a raised section of the eastern tower is visible. The National Museum of Canossa is located in the centre of the archaeological area, containing many remains and a valuable historical reconstruction of the Castle. This latter was created by the *Reggiana Society of Archaeology* suggesting the original appearance of the fortress in Matilda's time. Starting from the plan of the excavations carried out by Gaetano Chierici in 1880, the model is the result of archival and on-site research. For this reason, this model has been analysed in the research, evaluating its reliability concerning the existing system.

3. Historical background

The Castle foundation traces back to the 10th century (Manenti Valli, 1987): Donizone reports that Adalberto Atto prepared, on the hill of the Reggio Emilia Apennines, a new fortified system (Donizone, 2008). The presence of a pre-existing settlement is not reported, even if recent research refers to a Roman settlement (Patrocini, 2001). The Castle faced the first two sieges in 953 and 957 by Berengar II of Ivrea and Adalbert, Berengar's son. It was still a little fortification composed of a tower with walls but already proved its impregnability.

In 1077, there was a meeting between Gregory VII and Henry IV. The Castle had been enlarged to host an important event and accommodate Gregory VII's court by that date (Fig. 2). In 1092, Henry IV attacked the Castle, losing the battle. A few years later, in 1106, the Castle underwent further expansion by Matilda di Canossa. Upon her death, the Canossian property in 1116 came into the possession of Emperor Henry IV, opening new claims from the Church. (Ferretti, 1884; Manenti Valli, 1987). In 1255, Reggiani people led by Albert of Canossa besieged the fortress reducing it to ruin. (Ferretti, 1884) A few years later, the Canossa family rebuilt it. Between the 13th and 14th centuries, a landslide reduced the hill on the southern side, probably due to anthropic reasons. Thus, the northern access would later be strengthened in defence (Manenti Valli, 1987).

In 1409 all the Canossian castles were part of the plan to strengthen the fortified structures by the Estensi (Manenti Valli, 1987). However, three years later (1412), there was a new siege by the Reggiani, with the help of the Parmensi, which probably caused a second landslide, this time on the western slope (Aceto, 1878). Very few damages have been caused by this last siege in the architectonic system. Only the walls have been seriously damaged. In 1512, the Castles passed to the Papal State, and in 1523 the Este reoccupied Canossa Castle, carrying on military interventions (Manenti Valli, 1987).

In 1557/58, the most destructive event was the cannonades by Ottavio Farnese, who caused a landslide in the northern area, destroying the entrance structure on the north-eastern corner (Aceto, 1878; Ferretti, 1884; Confortini, 2001). A year later, the Este family proceeded to fortify the walls and restore the palace with necessary interventions (Manenti Valli, 1987). From 1570, the Castle changed hands several times, starting with the Ruggeri, who turned the Castle into a stately home and ending in 1642 with the Valentini of Modena, who held it until 1796.

After this date, the fortress remains neglected and falls into ruin. The last significant destruction occurred in 1821 by the inhabitants of the surrounding area, while other natural events (1831-32 and 1846) caused further thinning of the cliff (Manenti Valli, 1987).

Finally, in 1878, the Italian state purchased the hill, declaring it a national monument. On the fortress site, the National Museum of Canossa, named Naborre Campanini, opened in 1893 and was reorganized in 2002. Since 2017, the Matilda of Canossa Cultural Association has managed the area. Since 2018, the Ministry of Infrastructure and Transport has started to monitor the hill transformations, ensuring the stability of the rock faces of the cliff (Fig. 3). Based on the collected sources, in agreement with the Matilda of Canossa Cultural Association, an extensive survey campaign was planned to investigate all morphological aspects of the castle-hill system in detail.

Fig. 3 - Ideal reconstruction of the castle of Canossa by an anonymous 18th-century artist (Municipal Library of Reggio Emilia)

4. 3D data acquisition

An integrated survey campaign based on active and passive 3D data acquisition methodologies has been planned to understand the Canossa system. The survey planning has foreseen three different one-day acquisition campaigns. A data system suitable for multi-scale analysis and representation has been acquired (Guidi et al. 2009), adapting the survey process to the different external conditions. Data redundancy made it possible to perform

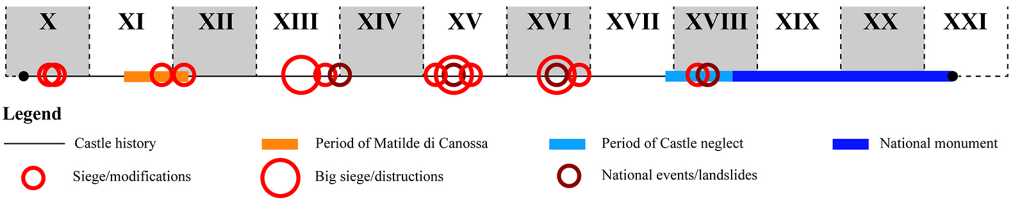

Fig. 2 - Schema with the main historical events that affected the castle-hill system (graphic elaboration by the authors).

metric validation on the quality of the acquired data, controlling the global and local accuracy (Magda Ramos & Remondino, 2015). Thus, the project pipeline included progressive validation steps to use the data at increasingly larger scales (Fig. 4).

4.1. Territorial survey

The Canossa hill presents a peculiar morphology, composed of rocky (south and north-east sides) and vegetation-covered areas: It has a high variation of ca. 60 m between the base and the summit. The entrance to the Castle is a narrow paved road that climbs among the trees of the south-west side. The survey was carried out by integrating a GNSS system with RPAS photogrammetry. Initially, 20 ground targets with A3 and A2 dimensions were distributed in the whole area with a higher density on the top of the hill. These targets defined the initial reference network of points acquired by GNSS and the photogrammetric system (PFA).

Most GNSS stations showed a sufficient satellite coverage but low or non-existent data signal. For that reason, the Network Real Time Kinematic (NRTK) configuration (Sokkya GCX3) was initially substituted with GNSS in static mode (Topcon GR3).

The master station was placed in the centre of the survey area, using a rover station with a minimum acquisition time of 10 minutes (1 epoch per second) for each target. Afterwards, NRTK acquisition problem was solved, turning the receiver on and off for each point, gaining priority access to the data band, and acquiring points with fewer epochs (5-10 epochs) and lower accuracy. Besides, three points for each hairpin bend of the paved way to the Castle have been acquired, bounding any change of staircase direction. This arrangement made it possible to contain the global alignment error within the 10 cm error highlighted at some points at the hill base. In addition, it defined a reference point's network to avoid range scan misalignment due to the small number of vertical surfaces.

The photogrammetric acquisition campaign was planned to use a DJI Mavic mini 2, equipped with a camera set up of 4 mm of focal length, f/2.8, ISO 100, and 1/1250 sec of exposition. The flying distance was 90 meters from the hill base. Two flights were scheduled with 13 to 15 waypoints with perpendicular flight directions, using the camera in the nadiral set-up. A third manual flight with the oblique axe to acquire the hillsides and the external walls of the Castle was integrated at the end. The final photogrammetric block was composed by 286 images with a mean GSD of about 3.2 cm at the bottom of the hill.

4.2. Architectonic survey

In the first stage, a photographic campaign related to the archaeological area and the Museum was carried out. It divided and coded the different areas, preparing a database structure to identify and optimize data management.

The integration of 3D terrestrial laser scanning and RPAS photogrammetry allowed facing the multi-resolution required. The ground survey was carried out with a Focus M70 (Faro). Its reduced dimension and lightness helped face different levels and slopes. The first scan was positioned in a barycentre position. A resolution of 3 mm-to-10m was set, acquiring a vast archaeological volume. The acquisition project foresaw 154 scans, ranging a resolution of 6 to 24 mm-to-10m, concerning the environmental conditions and the level of architectural details. The range-based approach allowed sampling of all the surfaces except the high part of the wall, the museum roof, and the external wall of the Castle. The photogrammetric survey by RPAS was carried out using some images from the previous flight, integrated with a manual flight devoted to acquiring a detailed part of the archaeological area.

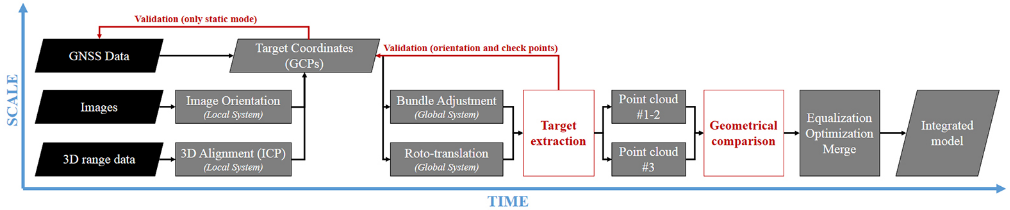

Fig. 4- Pipeline process of 3D acquisition and modelling (graphic elaboration by the authors)

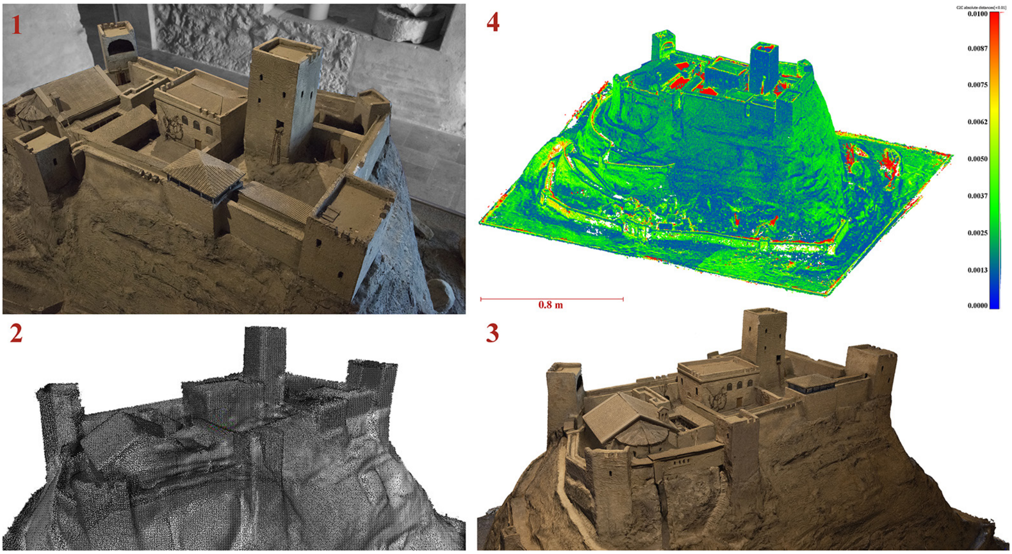

Fig. 5 - Image sequence with the original maquette, the gripping pattern, the two range-based and image-based models (bottom), and the comparison between the two models (graphic elaboration by the authors)

The final photogrammetric block has been composed of 356 images obtaining a ground GSD of 7-10 mm.

4.3. Interpretative maquette

The maquette preserved in the Museum was acquired with both range-based and image-based techniques. Regarding the former technique, 12 scans were planned with a 2.4 cm-to-10 m sampling step, working at an average distance of 2 meters and at different heights to reduce the shadows. As for the photogrammetric survey, the lighting conditions required a testing phase to reduce the effect of natural light coming from the museum exit.

A Nikon D810 camera with a 35 mm focal lens, f/9 and 1/160 sec. set-up was used for the acquisitions. The image campaign involved a sequence of 40 photographs with converging axes on four highs, imposing a working baseline of about 50 cm, a working distance of 2 meters and a mean GSD of 0.3 mm.

5. Data process

The absolute coordinates of the master GNSS were firstly determined by downloading data from two permanent stations of the TopNet Network. Then, the coordinates acquired by the rover system were processed with short baselines and integrated with NRTK ones. All elevations were transformed from ellipsoid to geoid heights within IGM grids, ITALGEO2005 undulation model, obtaining the final list of coordinates framed in ETRF2000(2008.0)-UTM32. The standard deviation of the GNSS static points considered in the project has been lower than 3 cm, while an error within 10 cm has been accepted for NRTK coordinates.

The photogrammetric data have been processed in Metashape (Agisoft). An image pre-processing activity has been developed to reduce light variation between rocky and vegetation areas, working on the brightness value of the photogrammetric block. In the general photogrammetric project, the average residual obtained using 25 PFAs at the end of frame orientation was around 4 cm, while around 10 cm on control points. Besides, in the architectonic survey project, the residual orientation error on the same PFAs was reduced to 2.7 cm, while on control points to 7 cm. The range-based clouds were aligned in JRC Reconstructor (Gexcel) by alternating ICP and bundle adjustment to stiffen some blocks, with an alignment error of a few millimetres consistent with the standard deviation (1 sigma) of the instrument. The entire system was roto-translated into the absolute reference system, with an average error of 3.7 cm between the 11 targets used for orientation. A separate discussion

Fig. 6- Integrated point cloud of the entire Castle-Hill system (graphic elaboration by the authors)

deserves the entrance to the Castle. The paved entrance was oriented separately to control better the position of the key scans for each bend of the road concerning the visible targets. The other scans were then aligned using a bundle adjustment.

In the end, the reconstructive model scans were aligned and globally oriented. Besides, the images were processed again in the Metashape environment. The two models were compared to validate the image-based models (Fig. 5), showing a mean distance lower than 2 mm.

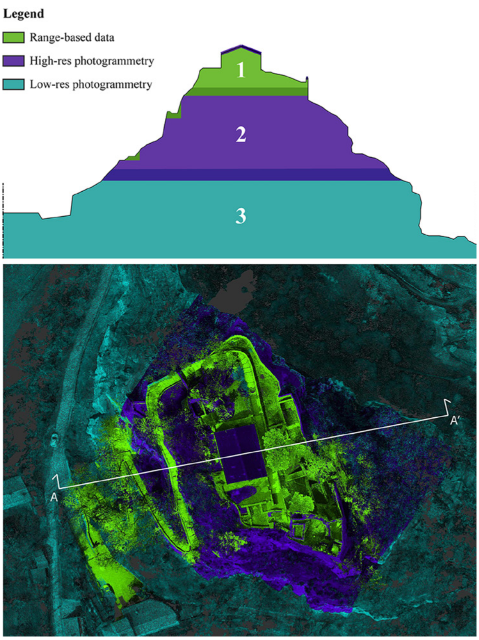

Fig. 7- Schema on data integration between the three models (graphic elaboration by the authors)

6. Data integration and analysis

All point clouds were imported and managed in JRC Reconstructor platform (Fig. 6).

The image-based and range-based clouds have been equalized to 1 cm, a suitable sampling step for 1:50 representations. The whole data system was cleaned and optimized (Fig. 7), reducing overlaps according to the following boundary conditions:

- range-based data should define most of the archaeological areas and the access to the Castle;
- the detailed photogrammetric data should define the wall ridges, the Museum roof, and all the surfaces not covered by the range-based data;
- the general photogrammetric data cover the rest.

Several products have been extracted to deepen the Castle-territory relationship. They include general orthoimages, sections, DTM with related contour lines, and urban representation (Fig. 8).

Besides, the image-based maquette was scaled to the real dimension and aligned to the global system once it was validated metrically. This comparison had supplied some helpful information on the historical reliability of the maquette to deal with the data interpretation process better (Fig. 9).

7. Conclusions

Castles and their territory represent examples of complex but closely interconnected systems.

A knowledge process based on historical, geometric, material, and technological analysis

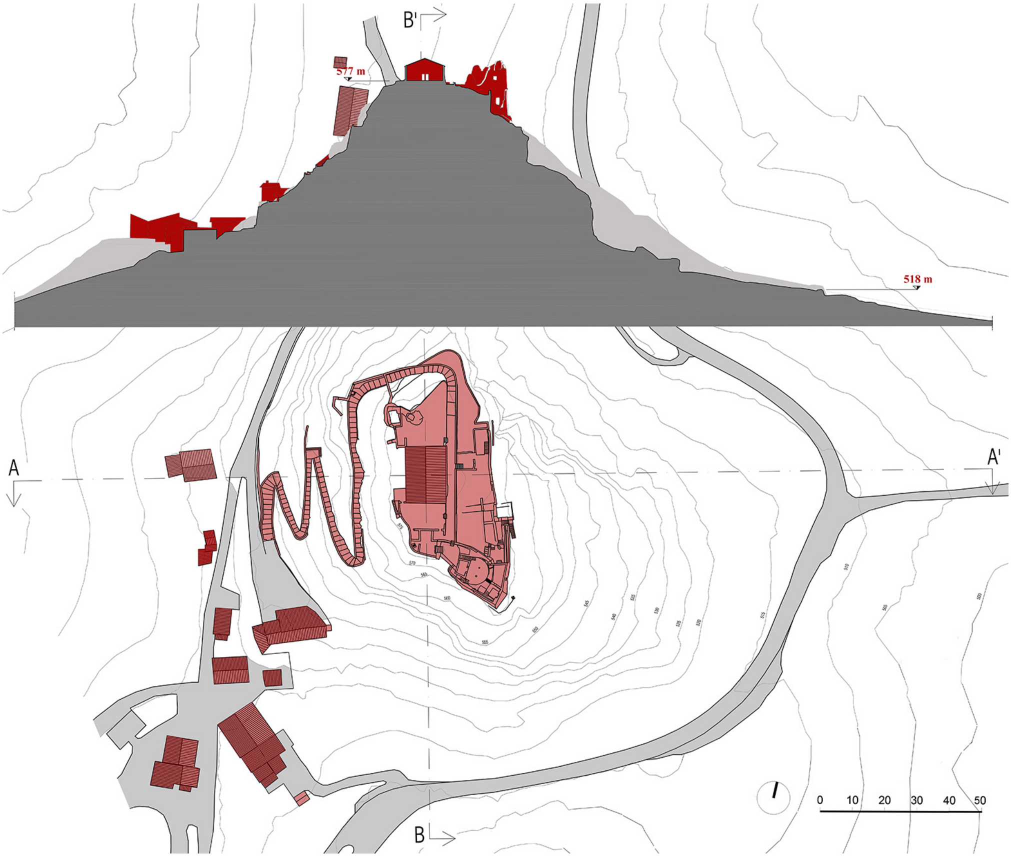

Fig. 8 - Drawing (scale 1:500) of the area with section superimposed (graphic elaboration by the authors)

Fig. 9 - On the left a superimposition between the sectioned point cloud of the area (red) and the scaled model (blue), on the right the comparison between the actual remains and the reconstructed ones (graphic elaboration by the authors)

represents the basis for fully understanding the origin and development of these architectures. Besides, this pipeline must be adapted to the different scale levels contained in the fortified systems. The research regards Canossa Castle, a complex system located in the Reggio Emilia territory. The article suggests a consolidated survey methodology based on active and passive multi-resolution techniques integrated with source analysis. Some bottlenecks in data acquisition and management are discussed in the process, highlighting how to preserve accuracy related to the multi-scale specificity. These validation steps have been planned in the pipeline to obtain a reliable integrated model. The data extracted at the end of the process represent a substantial base to define some 2D representations of the area and prepare its 3D reconstruction. Some reconstructive analyses are collected at the end, comparing the actual castle and a historical reconstructive model.

Notes

(1) The research is the result of joint and integrated work among the authors. In writing the article, M.R. was responsible for paragraphs 1 and 7, F.P. edited paragraphs 5 and 6, G.F. paragraphs 2 and 3, and A.P. paragraph 4. Finally, E.R. had the role of verifying the general content.

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