ISSN 1828-5961

Michele Russo
Ph.D., Architect, Associate Professor of Representation at the Department of History, Representation and Restoration of Architecture, Sapienza University in Rome. His research focuses on 3D survey and modeling, AR, and AI mainly applied to Cultural Heritage. Author of several works on 3D Imaging and Digital Representation, he is co-founder of the REAACH Symposium and REAACH Association.

Federico Panarotto
He is Research Fellow at the Department of Engineering at the University of Ferrara. He also participates in research and learning activities at the Laboratory of Drawing and Representation (LDR), with a particular interest in three-dimensional and computer modelling BIM processes, carried on at the Department of Civil, Construction and Environmental Engineering at the University of Padua.

Giulia Flenghi
Ph.D. student in the Department of History, Representation and Restoration of Architecture, Sapienza University in Rome. Graduated in History of Art, her research focuses on hybridization of AR and AI systems for the study and knowledge in Cultural Heritage. She is member of the Editorial Committee for the volume REPRESENTATION CHALLENGES, and the Organizing Committee of the REAACH Symposium.

Valentina Russo
Expert in Geomatics and APR pilot, graduated with honors in Civil Engineering at the Faculty of Engineering in Bologna. She's currently a freelance. The professional activity mainly deals with topography and geomatics, specifically photogrammetry, monitoring, laser scanning applications, terrestrial and UAV surveying. In 2012 she founded the Errealcubo studio, located in Bologna.

Alberto Pellegrinelli
Associate professor of Topography and Cartography at Engineering Department, University of Ferrara. He has scientific and applied experience in digital photogrammetry, laser scanner, GNSS, remote sensing and UAVs for cultural heritage surveying. He was coordinator of local and national research groups and responsible for research contracts with public administrations and private companies.

Ultralight UAV for steep-hill archaeological 3D survey

The role of drones is becoming increasingly important within current 3D survey methodologies. Their flexibility of use and the ability to acquire images from inaccessible viewpoints make them a critical instrument in multiple fields of application at both urban and architectural scales. This success is mainly due to the progressive development of technology, including data acquisition sensors, flight systems, and data processing programs.
The Cultural Heritage domain is one with the most widespread and massive applications. Besides, due to the RPAS regulations in Italy, drones less than or equal to 250 g have seen a considerable expansion in use in recent years. The improved quality of the cameras and the recent introduction of flight planning has made them proper for photogrammetric applications. Recent research reports experiments in the architectural and archaeological domains aimed at verifying the metric reliability of the acquired data compared with active instruments.
In archaeological surveying, drones can cover large complex areas quickly, minimizing shadow areas concentrated in the crests of walls. The case study presented is the Canossa Castle, a medieval archaeological complex close to Reggio Emilia and extended on a steep hill with rocky spurs. The work describes integrating GNSS, 3D scanners, and ultralight RPAS photogrammetry, gathering multi-scale geometric information.
The integration between the different surveying techniques allowed to plan different verification moments on the metrological reliability of the multi-resolution model.
Al last, the data acquired made it possible to produce complete architectural and urban representations, improving the knowledge needed to prepare the virtual reconstruction of the entire complex area.

Keywords:
Ultralight-RPAS; Archaeological analysis; Image orientations; Accuracy validation

DOI: https://doi.org/10.20365/disegnarecon.29.2022.3

INTRODUCTION

The role of drones is becoming increasingly important in current 3D survey methodologies. Their flexibility of use and the ability to acquire images from inaccessible viewpoints make them a critical instrument in multiple fields of application at both urban and architectural scales (Nex and Remondino, 2014: 1-15). This success is mainly due to the progressive development of technology, including data acquisition sensors, flight systems, and data processing programs. The Cultural Heritage domain is undoubtedly one with the most widespread and massive applications (Murtiyoso and Grussemmeyer, 2017: 206-29).
RPAS can be equipped with high-definition RGB, multispectral, hyperspectral, thermal imaging cameras, or lidar. GNSS RTK and NRTK can support flight systems in defining external camera orientation parameters without using GCP. The software allows for data management: geo-referenced point clouds, orthoimages, textured polygonal models, and hyperspectral or multispectral thematic maps. Besides, the RPAS regulations, with national and European prescriptions, have changed over time. In Italy, the pilot's qualification concerns the payload and the context of application (critical and non-critical areas). Because of this last limitation,
drones less than or equal to 250 g have seen a considerable expansion in recent years. Moreover, they are easy to fly, low cost, and do not require a specific qualification. The improved quality of the cameras and the recent introduction of flight planning has made them proper for photogrammetric applications. Recent research reports experiments in the architectural (Russo et al., 2018: 549-568; Carnevali et al., 2018: 217-224) and archaeological (Adami et al., 2019: 15-21) domains aimed at verifying the metric reliability of the acquired data compared with active instruments (Barba et al., 2019).
In archaeological surveying, drones can cover large complex areas quickly. The integration between TLS and RPAS can also be particularly advantageous in minimizing shadow areas, mainly concentrated in the crests of walls. It allows integrating accessible and inaccessible areas in the same reference system (Galasso et al., 2021). Range-based and image-based data can be oriented using GCPs surveyed on the ground (by total station or GNSS). Sometimes it is possible to use the 3D point cloud to frame the photogrammetric cloud.
The case study presented in the paper [1] is the Canossa Castle. It is a medieval archaeological complex close to Reggio Emilia, lying on a steep hill with rocky spurs (Fig. 1). The article suggests an integrated survey approach with GNSS, 3D scanners, and ultralight RPAS photogrammetry (not equipped with RTK or PPK). The acquisition aims to gather multi-scale geometric information, showing data comparison, validation, and flexibility in using different reference data (with or without GCPs). This latter may optimize the process, reducing the global orientation error of the integrated data system.
The inherent resolution limit of the camera mounted on the ultralight drone is also discussed, deepening how this may affect target recognition at great working distances.
The data acquired made it possible to produce complete architectural and urban representations, improving the knowledge needed to prepare the virtual reconstruction of the entire complex area.

Fig. 1 - Spatial framing and approach of the hill and castle from 2 points of view.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.3

CASE STUDY AND HISTORICAL BACKGROUND

The Castle of Canossa is located in the Reggio Emilia Apennines on a hill of white sandstone (Fig. 1). The Castle is known for the famous "Walk of Canossa," an event involving Emperor Henry IV, Pope Gregory VII, and Countess Matilda of Canossa. The building is part of an articulated system of fortifications in the Reggio Emilia Apennine territory. The hill of Canossa has a peculiar morphology, composed of rocky areas (south and northeast slopes) and parts covered by vegetation. The altitude is about 68 meters, starting from an elevation of 510 m to 578 m for a total extension of about 30,000 square meters. The formidable defensive effectiveness is mainly due to the particular conformation of the rocky cliff on which the Castle stands. In addition, a vast and inaccessible gully area to the west minimized the historic sieges (Fig. 2). The actual shape of the hill is dissimilar to the original. Many collapses have been described over several centuries, mainly due to sieges. The Castle rests on a single layer of sandstone weakly sloping to the east. The exact Castle's perimeter walls has seen numerous changes, adapting to the rock conformation of the period. These transformations occurred mainly in the southwest and northeast walls, which necessitated stabilization through the insertion of sub-masonry works in the 1970s. Since 2018, the Ministry of Infrastructure and Transport has started to permanently monitor the transformations of the hill, ensuring the stability of the cliff walls (Fig. 2). The entrance to the Castle is a narrow asphalt road that climbs among the trees on the southwest side.

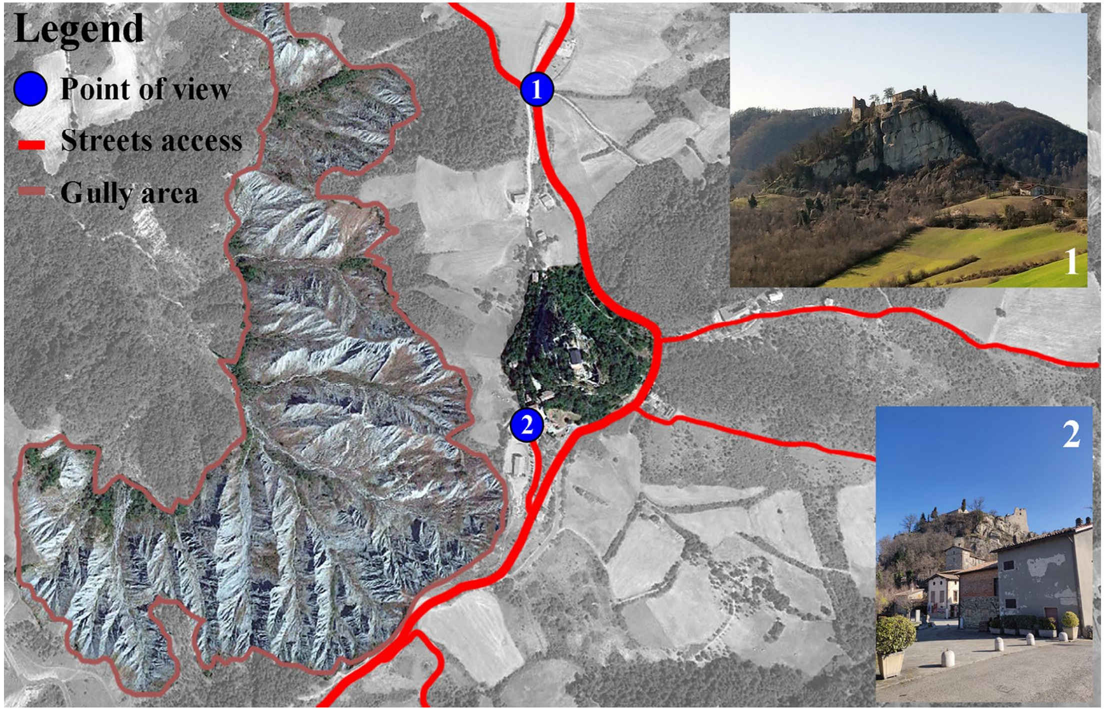

Fig. 2 - Urban schema with the gully area to the west, the main streets and two views: the entire hill (1) and the access road to the castle (2).

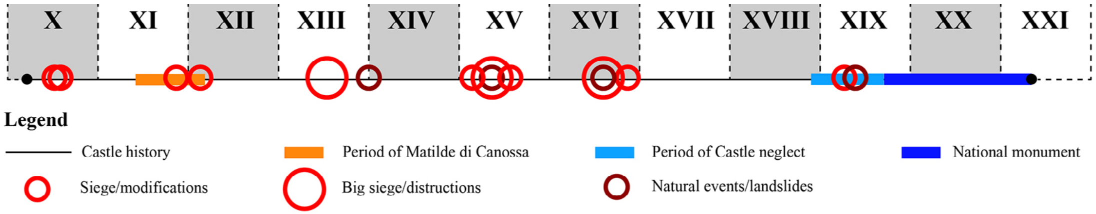

Fig. 3 - Historical schema of the main events characterizing the Canossa system.

The Castle is an architectural complex that stands on the top of the hill, covers an area of 2,000 square meters, and has an altitude varying between about 562 and 583 m (the highest point of the Castle). The foundation of the Castle dates back to the 10th century (Manenti Valli, 1987). Donizone reports that Adalberto Atto prepared a new fortified system on the hill of the Reggio Emilia Apennines (Donizone, 2008). In 1077 there was a meeting between Gregory VII and Henry IV. By that date, the Castle had been expanded to host an important event, accommodating Gregory VII's court (Fig. 3). In 1092, Henry IV attacked the Castle, losing the battle. A few years later, in 1106, the Castle was further expanded by Matilda of Canossa. Upon her death in 1116, the Canossian property came into the possession of Emperor Henry IV, opening new

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claims by the Church (Ferretti, 1884). In 1255, the Reggiani, led by Alberto di Canossa besieged the fortress, reducing it to ruins. A few years later, the Canossa rebuilt it. Between the 13th and 14th centuries, a landslide reduced the hill on the southern side, probably for anthropogenic reasons. Thus, the northern access would later be reinforced for defensive purposes. In 1409, all Canossian castles were part of the Este's plan to strengthen the fortified structures. 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, 1978). The damage caused by this last siege to the architectural system is minimal. Only the walls were seriously damaged. In 1512 the Castelli passed to the Papal State, and in 1523 the Este family reoccupied the Castle of Canossa, carrying out military interventions (Manenti Valli, 1987).

In 1557/58, the most destructive event was Ottavio Farnese's cannonades, which caused a landslide in the northern area, destroying the entrance structure in the northeast corner (Ferretti, 1884; Aceto, 1978; Confortini, 2001). A year later, the Este family fortified the walls and restored the palace. Beginning in 1570, the Castle changed hands several times, starting with the Ruggeri family, who turned it into a stately home and ending in 1642 with the Valentini family of Modena, who held it until 1796. After this date, the fortress remained neglected and fell into disrepair. 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. Finally, in 1878, the Italian state acquired the hill and declared it a national monument. On the site of the fortress, the National Museum of Canossa was opened in 1893 and reorganized in 2002. To this day, little remains of the Matilda-era fortress (Fig. 4). The ruins include the remains of a monastery and some palace walls built by Ruggeri in the late 16th century. At the center of the archaeological area, there is the Canossa National Museum, which contains numerous remains and a valuable historical reconstruction of the Castle by the Reggiana Society of Archaeology (Patroncini, 2002) represented a possible Canossa first configuration. Since 2017, the Matilde di Canossa Cultural Association has been managing the entire area and its maintenance, promoting its presence in the territory. 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 (Russo et al., 2023).

Fig. 4 - Photograph of the best-preserved portion of the castle and the dominant environment.

3D DATA ACQUISITION AND PROCESSING

An integrated survey campaign based on active and passive 3D acquisition methodologies at different scales was planned. It included three different acquisition campaigns, suitable for multi-scale analysis and representation. Data redundancy allowed metric validation, checking global and local accuracy. In the first phase, a photographic campaign related to the archaeological area and the Museum was carried out. The first step was devoted to defining an absolute reference network to support the survey through passive and active techniques. Then proceeded to plan and implement an aerophotogrammetric survey of the territory and detail. Finally, the last step considered a range-based approach limited to the archaeological area. The various steps included intermediate and progressive validation to ensure the reliability of the data moving toward larger scales.

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TOPOGRAPHIC NETWORK

The network had the role of framing both the photogrammetric survey and the laser scanner acquisition in the same reference system. Twenty targets of A3 and A2 size and thirty natural points were used to materialize such a system, for a total of 50 framing points distributed over the entire area with the highest density in the archaeological area on the top of the hill (Fig. 5). These targets, laid on the ground, defined the initial reference network of points acquired by GNSS. They were also used as control points in the photogrammetric survey (GCP) and 3D laser scanner. Natural points, i.e., points well materialized by existing artifacts, served the dual purpose of performing as check points for the photogrammetric survey and GCPs for the laser scanner survey. In particular, numerous natural points were surveyed along the access road to the Castle for better alignment of the laser scanner survey of the road

Most GNSS stations showed sufficient satellite coverage but low or non-existent data signal. Therefore, the Network Real Time Kinematic (NRTK) configuration (Sokkya GCX3) was initially replaced with GNSS in static mode (Topcon GR3). The master station was placed in the center of the survey area, using a rover station with a minimum acquisition time of 10 minutes (1 epoch per second) for each target (Fig. 6). Next, the NRTK acquisition problem was solved by 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. This mode was adopted for surveying natural points along the ascent to the Castle.

Three points were acquired for each hairpin bend of the paved road leading to the Castle, demarcating each change of direction of the staircase. This arrangement of landmarks was planned for two reasons. On the one hand, to contain the global alignment error within the 10 cm. error highlighted at the base of the hill. On the other, to define a network of landmarks to avoid misalignment of the field scan due to the small number of vertical surfaces.

Fig. 5 - Distribution of targets (yellow) and natural landmarks (red) in the area.

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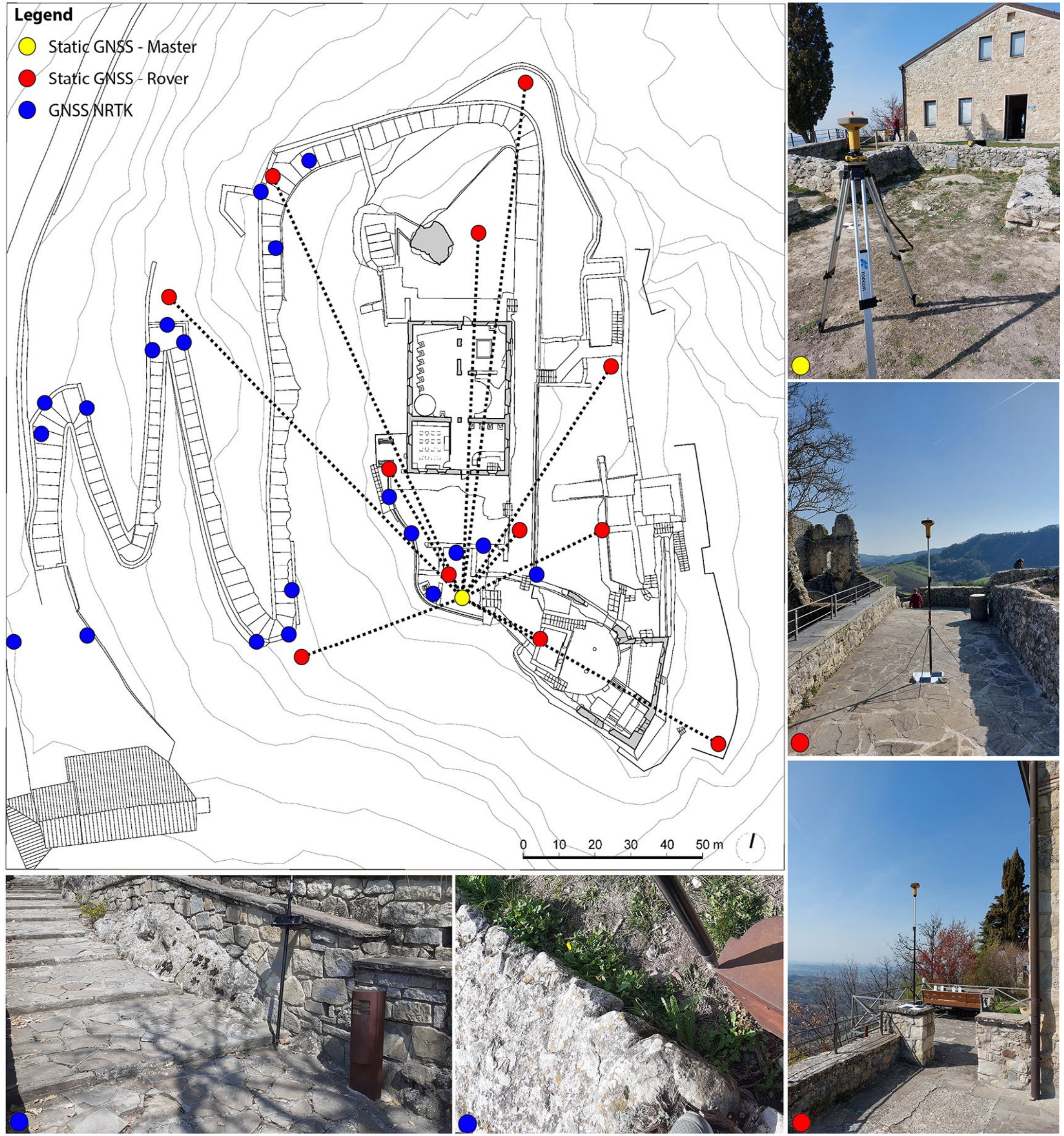

Fig. 6 - Diagram of the different topographic stations.

The absolute coordinates of the master GNSS were first determined by downloading data from two permanent stations of the TopNet network. Then, the coordinates acquired from the rover system were processed with short baselines and integrated with NRTK coordinates.
All elevations were transformed from ellipsoid to geoid elevations within IGM grids, ITALGEO2005 ripple model, obtaining the final list of coordinates framed in ETRF2000(2008.0)-UTM32 and geoid elevations in the national elevation system (Genova, 1942). The standard deviation of the GNSS static points considered in the project was less than 3 cm, while an error within 10 cm was accepted for the NRTK coordinates.

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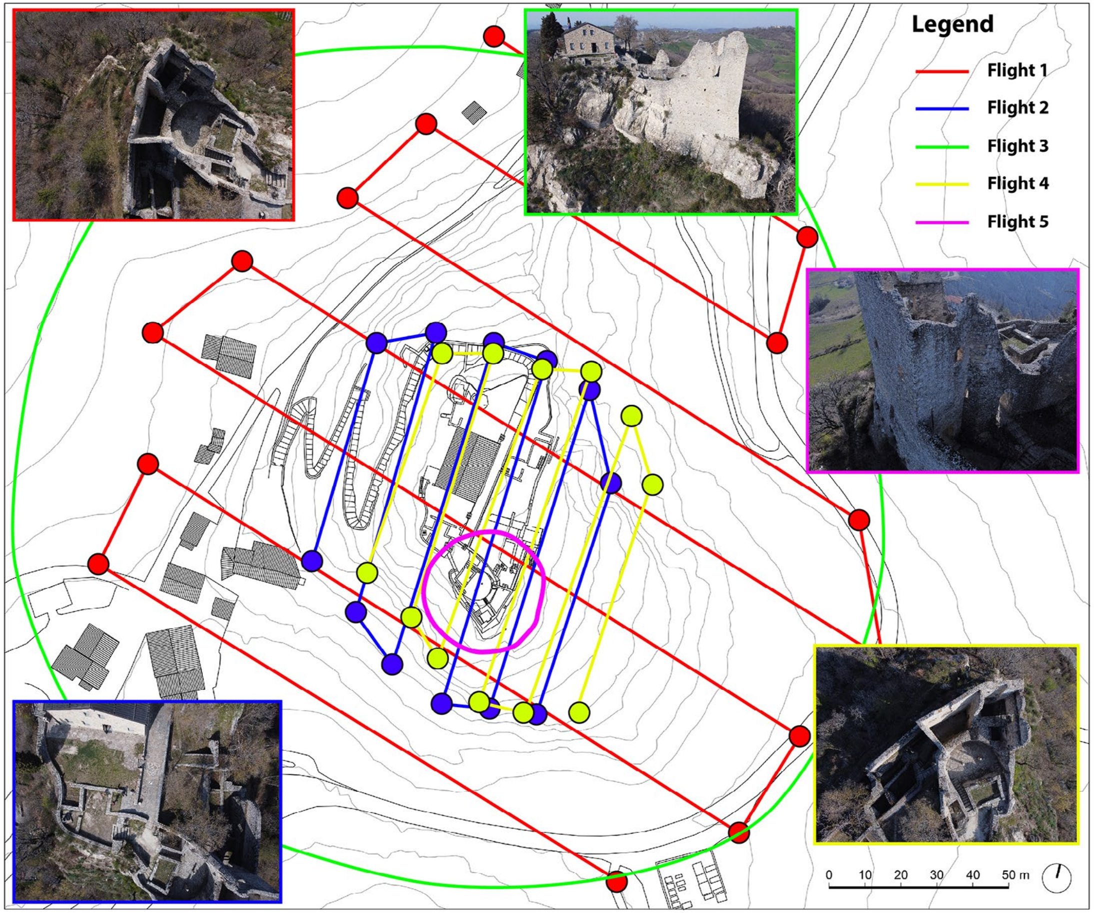

Fig. 7 - Diagram of the 5 flights by RPAS: 3 planned with waypoints (flights 1, 2, 4) with nadiral axis, 2 (flights 3, 5) as manual flights with tilted camera axis.

AEROPHOTOGRAMMETRIC ACQUISITION

In the second step, an RPAS survey was planned to cover the whole area, overcoming the accessibility bottlenecks. At this stage, the purposes of the survey were to:

- frame at a territorial scale the representation of the Castle in the territory by surveying the entire hill, including the Castle itself, the village, and the immediately surrounding region;
- complete the survey of the Castle by laser scanner, acquiring the areas inaccessible from the ground, thus achieving an integrated survey.

For the photogrammetric campaign, the use of a DJI Mavic mini 2 RPAS, equipped with a camera with a focal length of 4.49 mm (nominal value), f/2.8, ISO 100, and 1/1250 sec exposure, was planned. As a result of the acquisition step, a calibrated focal length value of 4.85 mm was fixed. Because of the complex morphology of the survey object and the need to have both high-density data for integrating the architectural survey with the scanner and lower-density data for the urban-scale representation of the complex, five

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flights were performed (Fig. 7), both in manual and programmed mode (waypoints). The images obtained from the flights were processed together within the Metashape program (Agisoft) and then grouped into two projects: territorial survey and detail survey. Image pre-processing was developed to reduce the light variation between rocky areas and vegetation by working on the brightness value of the photogrammetric block.
As for the first project, three flights with a total of 286 images have been carried on: two scheduled flights with 13-15 waypoints, a nadiral axis of the camera, and near-orthogonal stripes. On the other hand, the third flight was performed in manual mode with a tilted axis and a nearly circular trajectory around the hill (Fig. 7). The first two flights presented an average altitude of 605 m, the third 620 m. The ground elevations, which varied between 510 and 578 m, resulted in a GSD varying between 4 cm and 1 cm. The ortho-image extracted within the Metashape program provided an average GSD of 2.24 cm. Regarding image orientation (Table 1), 18 GCPs and 9 check points were used, resulting in the following values:

Type of points	Point #	XY error (cm)	Z error (cm)	Total (cm)
Control points	18	3.0	3.5	4.6
Check points	9	6.5	8.2	10.5

Table 1 - Table with the error of control points and check points extracted from the territorial photogrammetric block.

On the other hand, concerning the second project, both a planned flight with nadiral and tilted axes and a manually executed flight at a very close distance around the most preserved part of the Castle, with horizontal and tilted grasping axes, were planned for a total of 356 images. Some of these images, obtained at a very close distance, were preliminarily lightened, limited to those of the shaded part.

Fig. 8 - View from above with all artificial and natural points used in photogrammetric blocks.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.3

ISSN 1828-5961

In the manual flight around the Castle, the RPAS's altitude varied between 575 and 593 m, while in the planned flight, the altitude remained stable at around 630 m. The images in the flight around the Castle show a minimum GSD of 3 mm. In the programmed flight (nadiral axes), a GSD varied between 3 cm and 1.8 cm. The average GSD indicated by Metashape was 7.1 mm. Regarding image alignment (Table 2), 11 GCPs and 13 check points were used, obtaining the following values.

Type of points	Point #	XY error (cm)	Z error (cm)	Total (cm)
Control points	11	2.5	1.9	2.8
Check points	13	5.1	4.8	7.

Table 2 - Table with the error of control points and check points extracted from the detailed photogrammetric block.

CONGRUENCY CHECK BETWEEN THE PHOTOGRAMMETRIC PROJECTS

Since the two projects were aligned entirely independently of each other, it was considered appropriate to check the congruence between the two projects (Fig. 8). For this purpose, 8 natural points were considered, except for 7a, in both projects by obtaining their X, Y, and Z coordinates. The values (Table 3) were obtained by comparing the coordinates of the homologous points, demonstrating excellent congruence between the two projects.
From settings point of view during image orientation, considerable importance was given to the marker accuracy present within the Metashape program, with particular reference to control points. The image of targets under the most favourable and unfavourable conditions (Figg. 9-10) was analysed because several parameters affected the target recognition: the morphology of the terrain and the rock, the flight plans with nadiral and inclined axes, and the varying altitudes.

The results are images with appreciable variations in scale between and within the same image. Multiple flights were conducted, again with the same drone and camera. They result in distances between the camera and terrain/masonry varying from a few meters to a maximum of about 140 meters.
By estimating a collimation error of one pixel, uncertainty (accuracy) varies from 1 to 4 cm. The error of determining the plano-altimetric position (GNSS) must also be considered. Therefore, in the detailed project, an accuracy of 3 cm was assumed. For the territorial project, 5 cm of accuracy has been considered.
A single value was adopted since it does not appear that the uncertainty increases with increasing camera-target distance. Once the consistency between the different point clouds was verified, they were combined into a single project, going on to define the textured polygonal model of the entire Canossa system (Fig. 11).

Points	Coordinate variation (m)		
	ΔX	ΔY	ΔZ
1	-0.046	-0.015	0.08
2	0.067	-0.005	0.045
3	-0.043	-0.015	0.039
4	0.002	0.007	-0.004
5	-0.014	0.005	-0.016
6	0.035	-0.021	0.048
7	-0.029	-0.013	0.028
7 BIS	-0.008	0.007	0.022
Δ Mean (m)	-0.005	-0.006	0.034

Table 3 - Variations between the same coordinates extracted in the two projects.

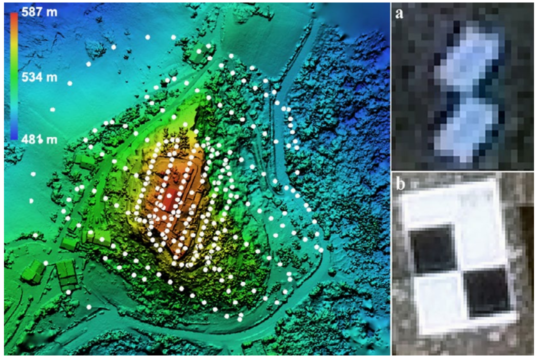

Fig. 9 - The DSM on the left is obtained from the land survey project and shows the variability of land elevation in relation to the location of the camera centers. On the right comparison between the image of an A2-format target (a) at 110 m relative altitude (GSD 0.04 m) and the image of an A3-format pin target (b) at 27 m (GSD 0.01 m).

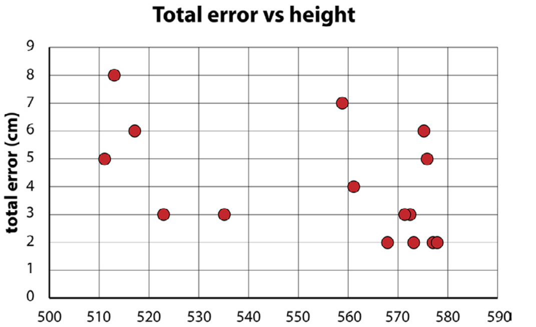

Fig. 10 - Total error in control points in relation to camera-target distance for the territorial survey project.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.3

Fig. 11 - Two different views of the textured polygonal model obtained from the photogrammetric point cloud.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.3

3D SCANNING SURVEY

The last step in the acquisition pipeline involved using 3D laser scanning from the ground as an instrument to achieve a sampling step compliant with the whole representation of the archaeological area. The survey was carried out with a Focus M70 (Faro). Its small size and light weight allowed it to cope efficiently in different environmental conditions and sloped terrain. The first scan was located in a barycentric position. A resolution of 3 mm@10mt was set, acquiring a vast archaeological volume and four targets with great accuracy. The acquisition campaign was defined by 154 scans (Fig. 12), ranging a resolution of 6 to 24 mm@10mt. This variation depends on the specific environmental conditions and the level of architectural detail encountered. The range-based approach allowed sampling of all the archaeological surfaces except the top of the wall, the museum roof, and the Castle's outer wall.
The range-based clouds were aligned in JRC Reconstructor (Gexcel), alternating a cloud-to-cloud ICP alignment with bundle adjustments to optimize some intervisible blocks. Each scan was filtered at 30 meters distance, eliminating all outliers by reducing the measurement uncertainty. The global alignment error is only a few millimetres, consistent with the instrument's standard deviation (1 sigma). The entire system was then roto-translated in the absolute reference system with an average and distributed orientation error of 3.7 cm. A separate discussion deserves the ascent to the Castle (Fig. 13). The paved entrance was oriented separately from the rest to control better the scans' position for each bend in the road relative to the visible targets. The other scans were then aligned by leaning against the constrained scans and using bundle adjustment to minimize the shift effect of range data.

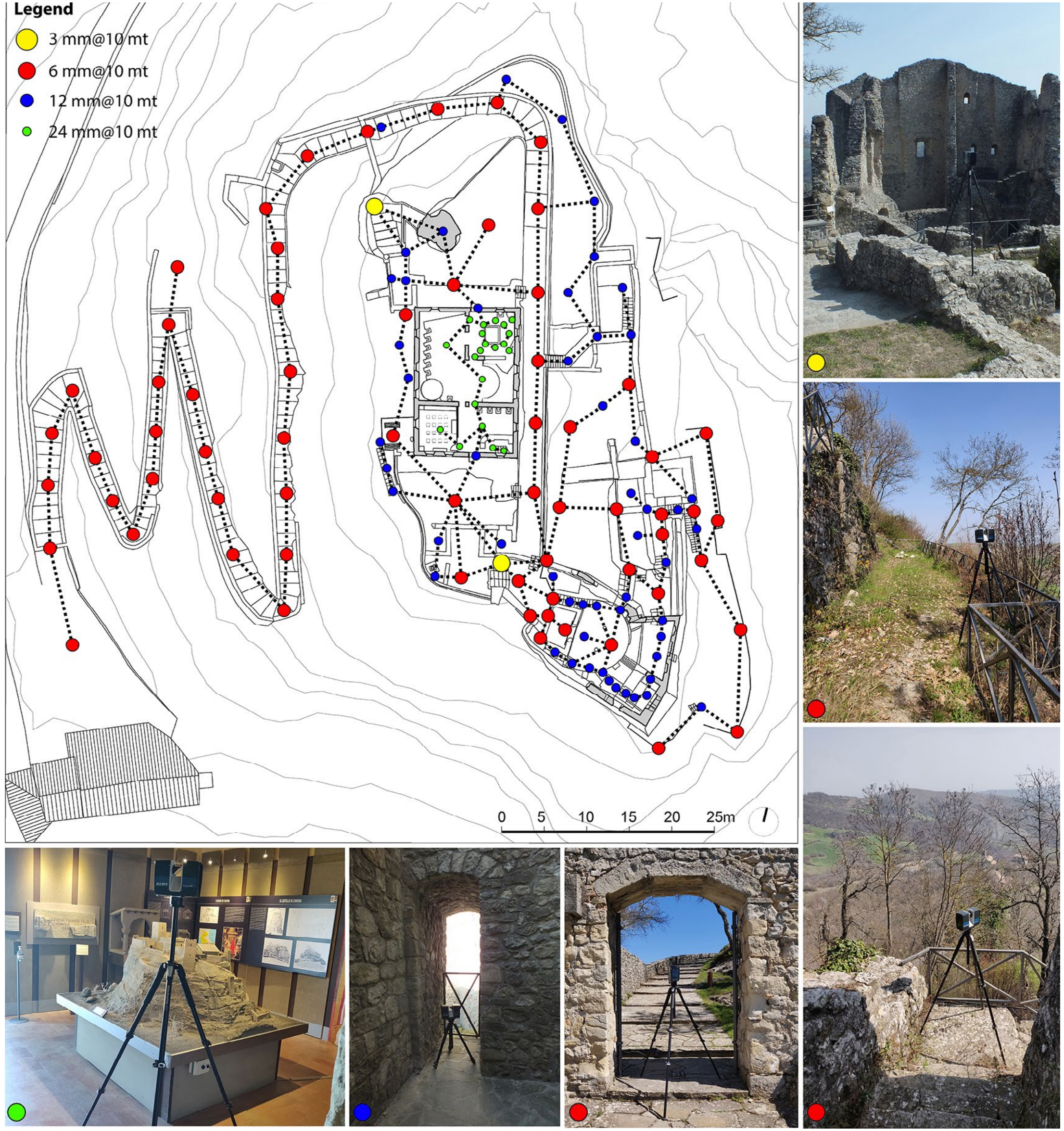

Fig. 12 - Location schema of the 3D laser scanner stations, the different types of settings, and some field images.

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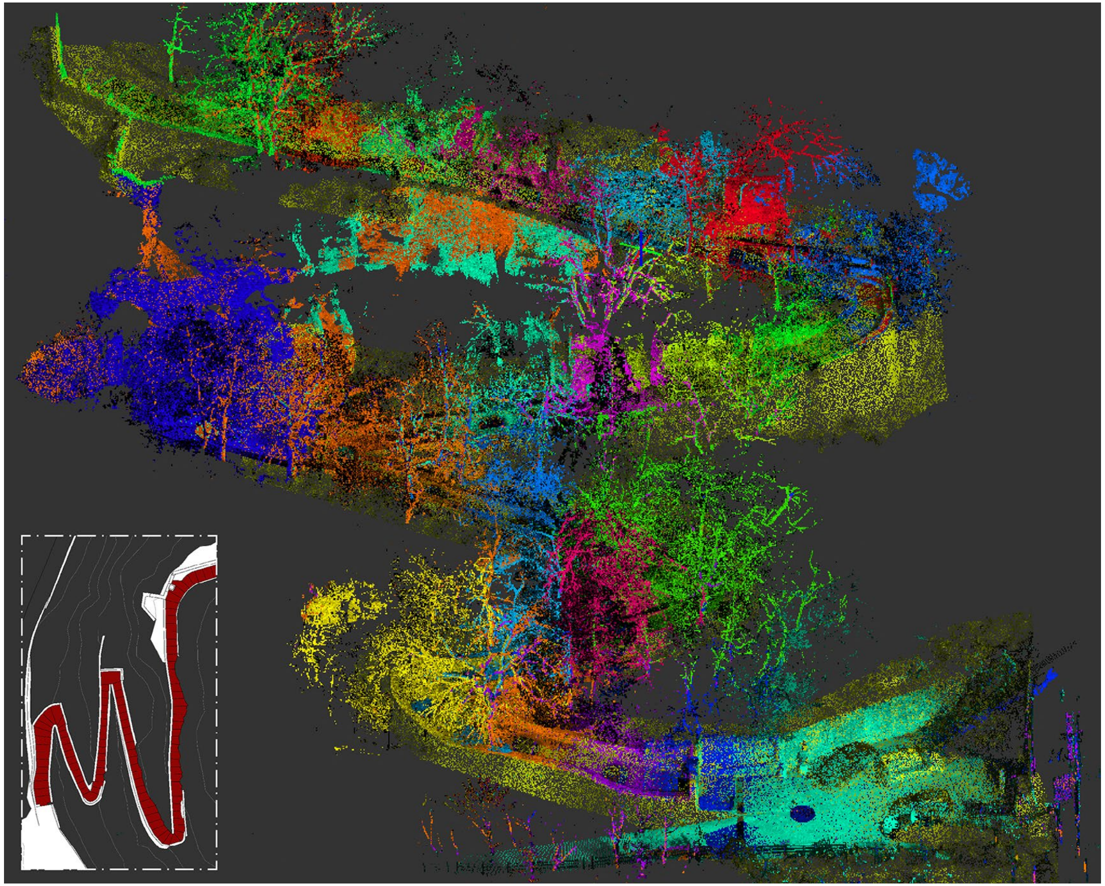
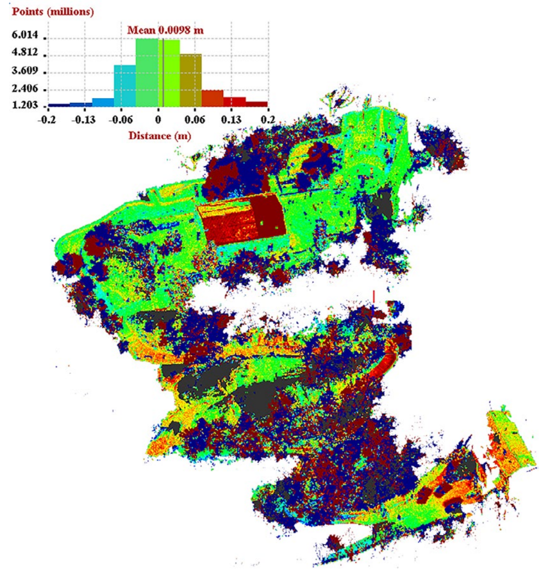


Fig. 13 - Axonometric view of the aligned range maps of the paved path between the base of the hill and the top. On the bottom a focus on the plan.

Fig. 14 - Comparison between range-based and image-based data.



RELIABILITY CHECK BETWEEN THE RANGE AND IMAGE-BASED DATA

Since this survey project foresees an integrated system among heterogeneous data, it is critical to plan local and global data validation to identify the degree of data reliability, starting with the geodetic data. At the local level, the relative orientation phase of the individual scans or images and the deviations from the topographic network targets supplied values consistent with the instruments' capacity and the aim of the representation. Therefore, what should be checked instead is the global cloud consistency, identifying possible deviations between point clouds. Therefore the comparison between the photogrammetric point cloud and the range-based one was planned. To make the two clouds more consistent, they were resampled with a 1 cm step to have two systems with similar resolutions. Then they were brought into both CloudCompare and JRC software, identifying the deviation map between the two clouds. The analysis showed an average deviation of less than 1 cm (Fig. 14). The values obtained show how the most significant variations are related to vegetation since the two acquisition methodologies (active and passive) detected tree geometries from two different viewpoints, not having the same overlap with archaeological surfaces. Instead, it is essential to point out a distributed and consistent deviation over the surveyed area, from the top of the hill to the lower part of the Castle access. This behaviour and the acceptable deviation values demonstrate the successful absolute orientation process between the different point clouds and their level of reliability. It must consider instrumental error and relative and absolute orientation error.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.3

ISSN 1828-5961

DATA INTEGRATION AND REPRESENTATION

The two image-based clouds (territorial and detail ones) and the range-based point cloud were integrated following three main steps: the systematization of the incoming information, optimization of the overlaid data, and definition of the final cloud. Regarding the first aspect, 1 cm was considered a sufficient resolution to obtain representations at a scale of 1:50. All clouds were carefully cleaned to eliminate residual outliers.
Optimization of the overlapping data required having all the information in the same data management system. The clouds were then imported into the JRC program (Fig. 15), and the overlays were reduced based on the following starting conditions:
• range-based data define the archaeological area (summit part) and the access road to the Castle;
• the detailed image-based data sample the ridges of the walls, the roof of the Museum, and all external wall surfaces, not covered by the range-based data;
• the territorial photogrammetric data describe the rest of the territorial area not covered by the previous two.

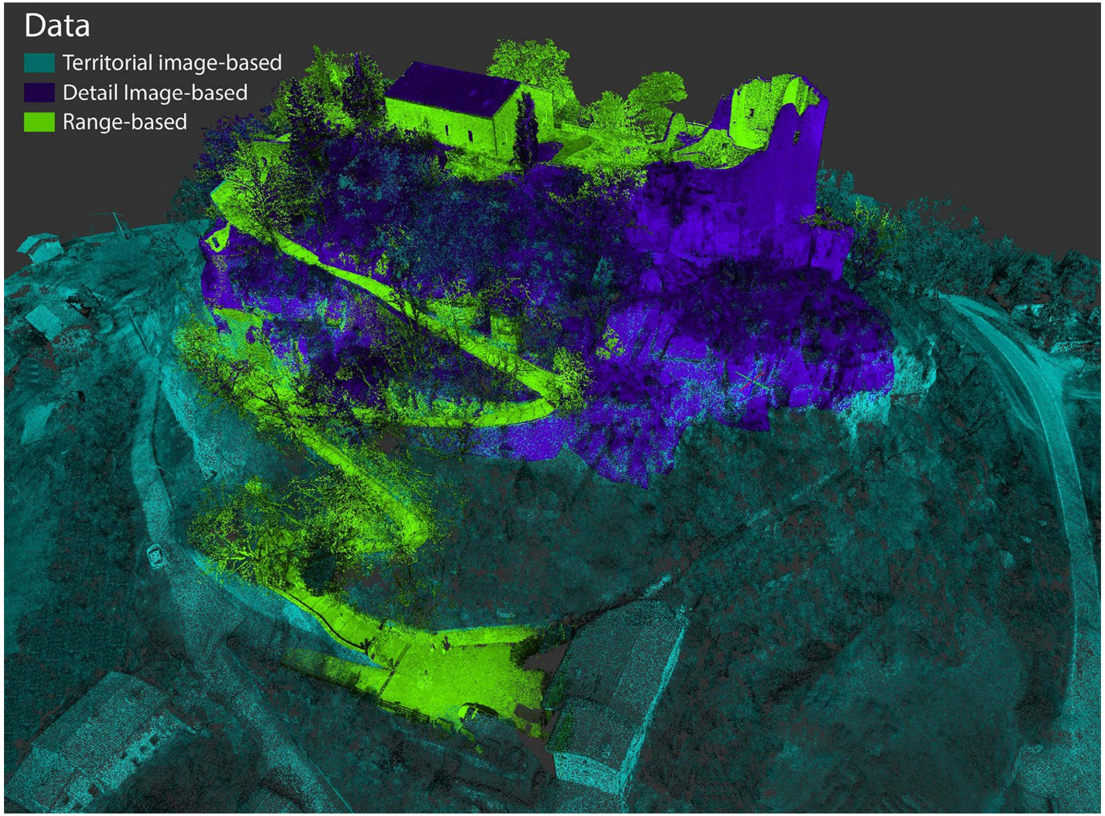
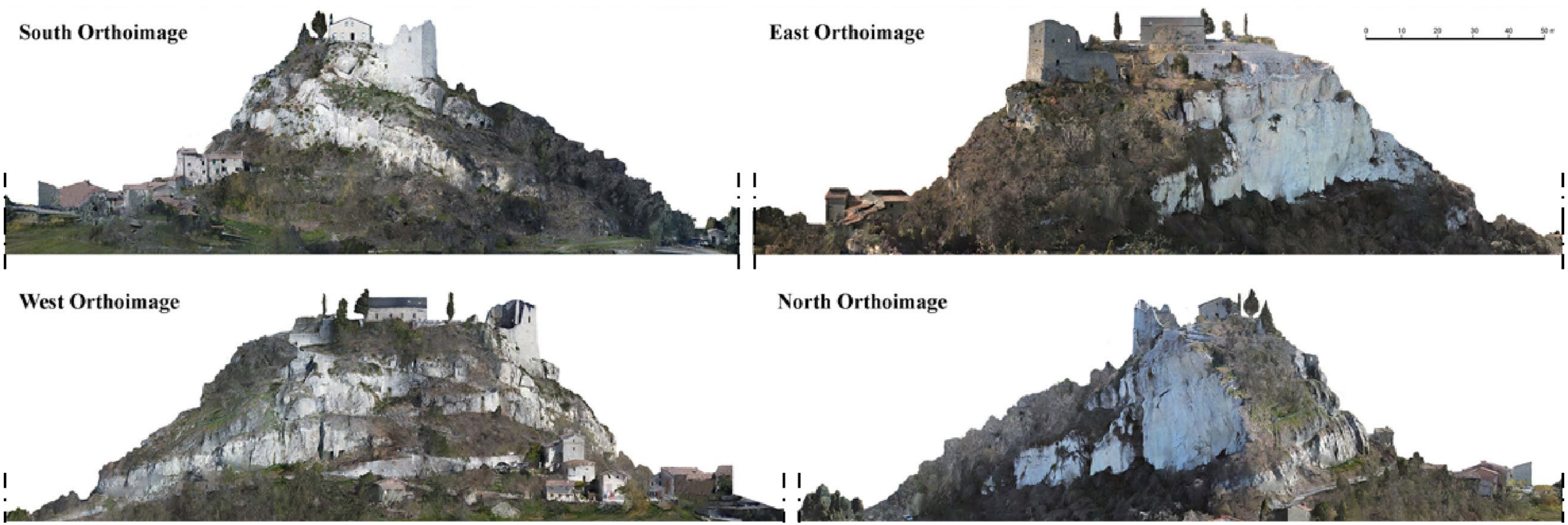


Fig. 15 - Point cloud integration between range-based and photogrammetric data.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.3

Fig. 16 - Reference data for representation: the integrated final point cloud.

Fig. 17 - Reference data for representation: orthoimages extracted from the photogrammetric point cloud.



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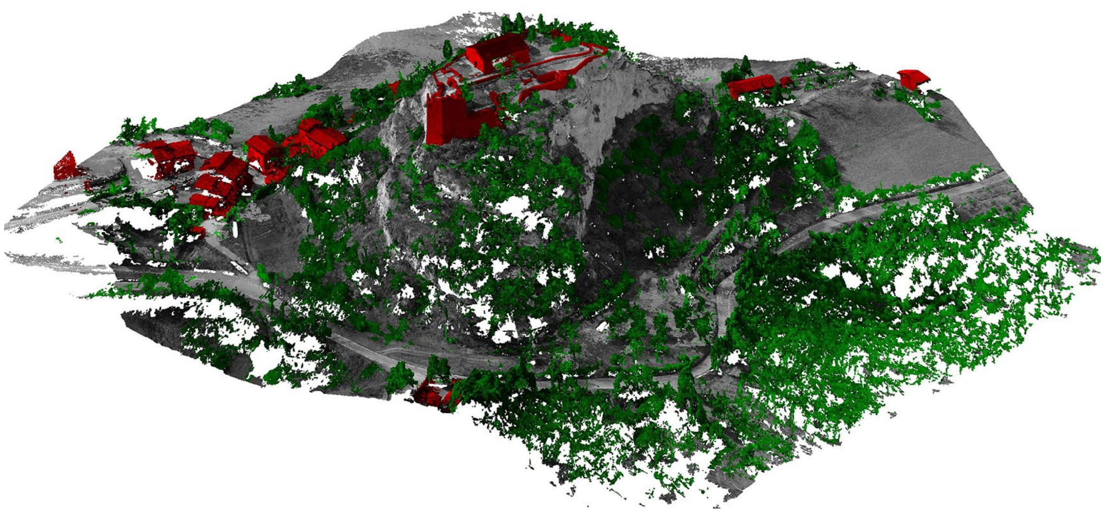
This purely manual cleaning operation took a long processing time, identifying the different overlaps, assigning a group priority concerning the area, and deleting the remaining data.
The last step consisted of merging the three clouds and resampling the cloud at 1 cm, homogenizing the higher data density in the still overlapping areas.
Finally, a cleaning step was performed in sections to identify residual noise near the surfaces of the archaeological areas or any tangential outliers. The cloud defined was the basis for the entire 2D representation phase of the area, preliminary to the reconstruction of the 3D model (Figg. 16-17).
The hill and castle restitution phase required some preliminary steps. The first was to systematize the final cloud and the different views of the castle-hill system within AutoCAD and ReCap software. It combined the visualization of point cloud and ortho-images (Fig. 16) extracted from the photogrammetric data. In addition, the point cloud was divided into different layers, separating the terrain from the architecture and the tree system (Fig. 17). This last step made it possible to manage the information separately and, above all, construct a DTM of the hill alone to extract the contour lines (5-meter pitch) that describe its morphological variation. These were then projected onto a plane and plotted in the CAD to support the representation of the area.
The representation of the area was based on the interpretation of these data, five drawing plans (Fig. 18), and four external facades, providing an exhaustive description of such a morphologically complex system. At the architectural scale, it is planned to define 1:50 scale plans of the summit area only, preliminary to the 3D reconstruction of the Castle (Fig. 18).

Fig. 18 - Point cloud semantically divided into the three levels: terrain, vegetation and architecture.



CONCLUSIONS

The paper illustrates an integrated 3D survey methodology for the geometric acquisition and restitution of the archaeological system of Canossa. The system's complexity is related to the morphological conformation of the hill, the spatial distribution of the archeological site, and the variation in scale between the territory and the Castle details. The research aims to collect geometric and radiometric information to START a 2D restitution and interpretive 3D modeling process. An integrated survey campaign is applied using the GNSS system, photogrammetry from RPAS, and a 3D laser scanner. In particular, RPAS plays a crucial role because it can solve the problem of scale variation and limited accessibility of the site. The use of the different techniques highlighted different bottlenecks concerning the specificities of the area. Different comparison and data validation steps have been planned to check the collected data. The feedback process introduced allowed a priori verification of the quality of the integrated geometric data before moving on to the restitution phase. The restitution imposed a series of data management strategies to control the morphological complexity imposed during the interpretation phase. The good local and global accuracy of the system and the restitution reliability allow starting of a detailed restitution campaign, laying the groundwork for reality-based modeling of the entire archaeological area and the 3D virtual reconstruction of the Castle at the time of Matilda of Canossa.

ACKNOWLEDGMENTS

The authors would like to thank Elvira Rossi, president of the Cultural Association "Matilde di Canossa" for her kindness and helpfulness in the project. In addition, they would like to thank Prof. Paolo Russo for his scientific responsibility over the entire photogrammetric process, the definition of some image-based models, and the preparation of a detailed report of the activities.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.3

Fig. 19 - Representation of the archaeological area: general and detailed floor plan and two elevations/sections.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.3

NOTE

[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, F.P. edited paragraphs 4, G.F. paragraphs 2, A.P. paragraph 3, V.R. paragraph 5 Finally, M.R. had the role of verifying the general content, coordinating all the work.

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