

# UAS-based capacity building for enhancing minor archaeology

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**Abstract** – Modern remote sensing techniques from Unmanned Aerial Vehicle (UAV) platforms provide high-precision survey tools for recognizing and measuring minor archaeological remains scattered across the contemporary landscape at risk of loss. In particular, the digital terrain model (DTM) obtained through the classification of the different signal returns of point clouds acquired with LIDAR (Light Detection And Ranging) technique favors a clear identification of archaeological features through the implementation of some specific visualization techniques (Hillshading, Sky View Factor, Openness). Conversely, acquiring raster datasets allows the elaboration of detailed three-dimensional models that are useful for knowing the geometric conformation, construction type, and state of preservation of archaeological remains. In this paper, we present the contribution that these remote sensing techniques have provided for the elaboration of capacity-building models for the enhancement of some remains of minor military archaeology dating back to the Great War present in Val Belviso, in the province of Sondrio in northern Italy.

## I. INTRODUCTION

The link between archaeology and remote sensing began in the early 1900s with the first experiments on aerial photography carried out by O.G.S. Crawford [1] in the interwar years and by J. Bradford in the 1940s and 1950s [2]. However, it is especially from the second half of the 20th century that these applications rapidly begin to spread as both remote acquisition and documentation systems (satellite systems and Unmanned Aerial Vehicle - UAV) and sensors used (very high resolution RGB cameras, near- and mid-infrared and thermal sensors, multispectral and hyperspectral scanning, radar systems and Light Detection And Ranging -LIDAR) develop [3] [4]. In more recent times, the rapid increase in the accuracy of acquired digital images and the increasing accessibility in the use of unmanned aerial platforms have favored the acquisition of informative datasets with very high spatial, spectral, and temporal resolutions not obtainable with satellite or aircraft systems, thus bridging the gap between satellite and/or aerial surveying and terrestrial archaeological prospecting. Some research have improved the recognition of archaeological signs on the ground by direct comparison

between multispectral and hyperspectral images [5]; conversely, the study of Lidar data through multiple visualization techniques has greatly increased the recognizability of morphological irregularities in the ground (archaeological features) [6][7][8]. The integration of LIDAR sensors, radar, and magnetometers has made an important contribution to the detection of completely buried historical remains by measuring the quantization of the contrast detected [11]. More specifically, some studies have shown how the integration of radar sensors with thermal imaging can facilitate the recognition of ceramic remains due to the different spectral signature of different materials [9]. Conversely, RGB imaging from UAVs has proven to be very useful in detecting the permanence of archaeological remains through the study of differential light/shadow effects and color differentiation due to the different degrees of moisture absorption as a result of melting glaciers or widespread flooding [10].

Currently, remote sensing archaeology is undergoing a further transformation facilitated by the unstoppable spread of artificial intelligence. Indeed, the powerful predictive capabilities of machine learning (ML) and deep learning (DL) algorithms, based on the use of complex neural networks, can contribute to a more effective management of large amounts of archaeological data and to the possibility of automatically and/or semi-automatically identifying the most ideal excavation points within complex landscapes, facilitating faster and more cost-effective workflows [12].

One of the most challenging aspects with respect to the preservation of archaeological heritage is the so-called “landscape archaeology,” or the ability to identify and catalog minor archaeological remains that are historical memory even though they are not monumental. Such assets are often at high risk of loss due to anthropogenic transformations such as urban expansion and/or uncontrolled agricultural exploitation. If a photogrammetric survey by drone with RGB cameras allows three-dimensional reconstruction of archaeological assets with associated photographic mapping of surfaces, LIDAR is an active remote sensing technique that allows distances to be derived by measuring the time elapsed between the emission of a laser pulse and the capture of the backscattered signal [13]. The great potential of LIDAR technology in the archaeological field is due to the

ability of the emitted signal to pass through vegetation and reach down to the ground, thus being able to scan the real morphology of the ground. Indeed, the laser pulses are not completely absorbed by leaves and branches, allowing the system to detect underlying objects as well. As the signal is emitted by the sensor, if any object interposes itself in its path, part of the radiation is reflected back to the emitter generating the first return signal (echo), while the remaining part of the original pulse continues toward the ground and, if it intercepts other obstacles, produces further returns. The first and last returns are the most important ones: the first allows to generate the Digital Surface Model (DSM), the last one allows to define the Digital Terrain Model (DTM), i.e., the three-dimensional model of the terrain morphology, which is particularly useful in the archaeological field. The latest generation LIDAR sensors allow the acquisition of multiple returns, thus succeeding in greatly improving the quality of the acquired point cloud. Through mathematical algorithms and filtering processes, it is possible to perform precise classification of point clouds by categorizing multiple echoes so as to distinguish, for example, vegetation, soil and archaeological evidences. In addition to the different ways of classifying returns, numerous research have highlighted the potential of some specific DTM visualization techniques for improving the visibility of different archaeological features [14]. These are mathematical algorithms that allow highlighting the elevation differences of the detected point cloud by means of fictitious illumination modes (simple Hillshading or Hillshading from multiple directions [15], irradiance models, and Sky View Factor [16]), through the study of ground slope models or based on the analysis of local topographic aperture [17]. This paper highlights the fundamental contribution that modern archaeological remote sensing techniques can make in the development and application of capacity building models for the enhancement of minor cultural heritage. Specifically, the paper presents the outcomes of the application of these archaeological remote sensing methodologies conducted with a UAV platform equipped with RGB and LIDAR sensors for the identification, survey, and three-dimensional modeling of some minor military fortifications dating back to World War I present in Val Belviso, in the Lombardy territory, near Aprica, in the province of Sondrio in northern Italy.

## II. STUDY AREA

The Belviso Valley, located at the junction between the Camune and Orobic Pre-Alps, is situated in the easternmost part of the province of Sondrio and, more precisely, on areas falling within the municipalities of Aprica and Teglio (Fig.1). From the orographic point of view, the valley cone develops in a north-south direction, with the valley floor at about 1250 meters above sea level from which, almost symmetrically, the slopes of the Frot

Valley, to the east, and the Magnolta Valley, on the opposite side, develop. In this context of high naturalistic and landscape value, an integral part of the Orobic Valtellinesi Park, there are some abandoned military remains dating back to World War I, grouped in 4 different macroareas (Valle di Frot, Valle Magnolta Bassa, Valle Magnolta Alta, Puncera).

It is a set of minor fortifications that is part of the system called the Northern Frontier Advanced Works, now better known as the Cadorna Line, built starting in 1916 to protect the northern border of the Italian Kingdom and consisting mainly of cave works, open-air or rock-cut defensive emplacements, trenches and military connecting infrastructure. The impressive apparatus never experienced any wartime episodes and fell mostly into neglect at the war conclusion (Fig.2).

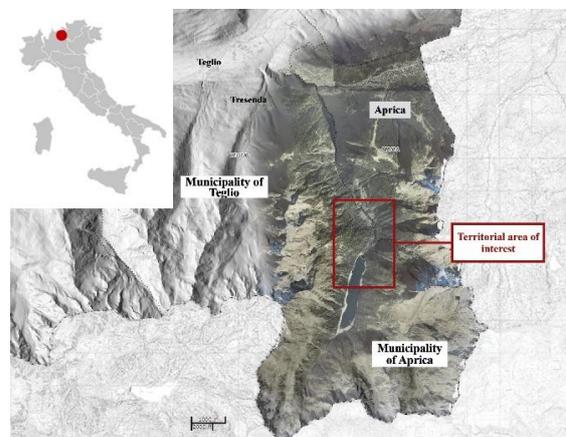


Fig. 1. Territorial framework

After a little over a hundred years, what remains of these “minor works” are only a few isolated fragments, difficult to locate and, for this very reason, often not considered in the many projects that, on the occasion of the Great War Centenary, have developed at the European level. Law 78/2001, however, recognizes their historical and cultural value by promoting their “reconnaissance, cataloguing, maintenance, restoration, management and valorization with a light, low-regime, guardianship approach” [18]. Indeed, these works are still pregnant with significance as historical testimonies capable, if recovered and enhanced, of re-activating memory and a sense of identity in the present and for future generations.

In 2024, the Orobic Valtellinesi Park, in collaboration with a team of researchers from the University of Bergamo and in synergy with the municipalities of Aprica and Teglio and the other involved stakeholders, participated in the Lombardy Region's call for proposals “Avviso Unico Cultura 2024” receiving funding to draw up an integrated project for the study, analysis, restoration and enhancement of this military archaeological heritage.



Fig. 2. Val Belviso fortifications

The proposed masterplan consists of the creation of a new historical-cultural hiking trail that becomes a kind of open-air museum in which the enhancement of the archaeological permanencies of the Great War becomes a flywheel for the revitalization of the territory also from an economic and touristic point of view.

The university research team provided in-depth advice in the elaboration of a specific capacity building model for the enhancement of minor cultural heritage by fostering an interdisciplinary methodological and operational approach that can be shared among the different stakeholders involved (municipalities, local authorities, communities) and can also be replicated in similar but different contexts.

### III. METHODOLOGY

The proposed capacity building model is based on a few key elements: the definition of objectives and involved actors ; the assessment of existing competencies and the resources available to increase them; the systematization of interdisciplinary operational contributions useful for defining a solid and precise knowledge base of the heritage to be managed; the need to create opportunities for cooperation between different realities by facilitating the transfer of knowledge and the sharing of good practices; the definition of tools and economic resources needed to support the enhancement objectives; the active involvement of communities also through opportunities for discussion; and the need to monitor and evaluate the activities carried out according to the results obtained.

The planning of a survey campaign by acquiring the information datasets through UAV platforms equipped with RGB camera and LIDAR sensor became indispensable since the in-depth historical-archival research conducted in several historical and military archives (including the ISCAG - Historical and Cultural Institute of the Corps of Engineers and the AUSSME - Archives of the Historical Office of the Army General Staff) did not provide useful information about the precise location of the individual military artifacts present in the Belviso Valley due to the scale of representation of the

historical maps found and the systematic visualization errors inherent in them.

#### A. Data acquisition

The analysis of the spatial context made it possible to optimize the data acquisition phase by defining the flight plans of the employed UAV platform with respect to the 4 macro-areas within which to locate the archaeological remains (Fig.3).

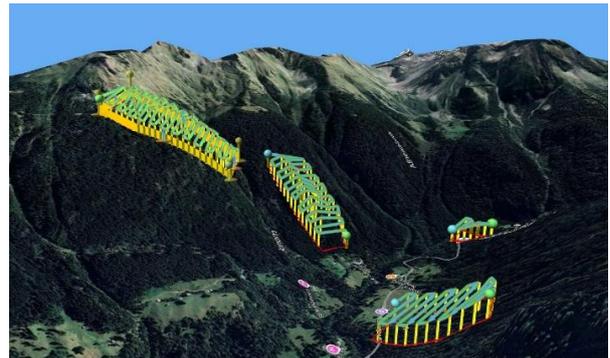


Fig. 3. UAV Flight plan

Specifically, a DJI mod. Matrice 300 RTK drone equipped with an RGB camera, a high-precision IMU platform and a state-of-the-art LIDAR module was used. The use of the Zenmuse L1 LIDAR sensor, in particular, made it possible to acquire point clouds with high density (recording more than 240,000 pt/s effective) and high precision (5cm in altitude and 10cm in the plane, with flight height of 50m), supporting as many as 3 returns (double and triple with a point cloud density of 480,000 pt/s) with measurement intervals of less than 450 meters (80% reflectivity 0 klx). Thanks to the all-in-one solution mounted on the UAV platform, it was possible to acquire, simultaneously with the Lidar data, also very high resolution raster datasets, i.e. RGB images useful for subsequent 3D-processing of some specific archaeological artifacts existing in the areas not characterized by substantial forest cover.

#### B. Data processing

After making appropriate sensor orientation corrections to ensure the correct location of the points and verifying the alignment of the scans so as to have accurate overlaps, the raw datasets of the 4 different macroareas were uploaded into CloudCompare software to generate the digital terrain model, which is useful for learning about the soil morphology and extracting contour line trends.

To obtain the morphology of the terrain without vegetation, several automatic filtering algorithms were applied to the point cloud: in particular, the S.O.R. (Statistical Outlier Removal) filter for the elimination of general noise, and the Cloth Simulation Filtering (CSF) for the recognition of the last echo among the three recorded by the Zenmuse L1 Lidar sensor.

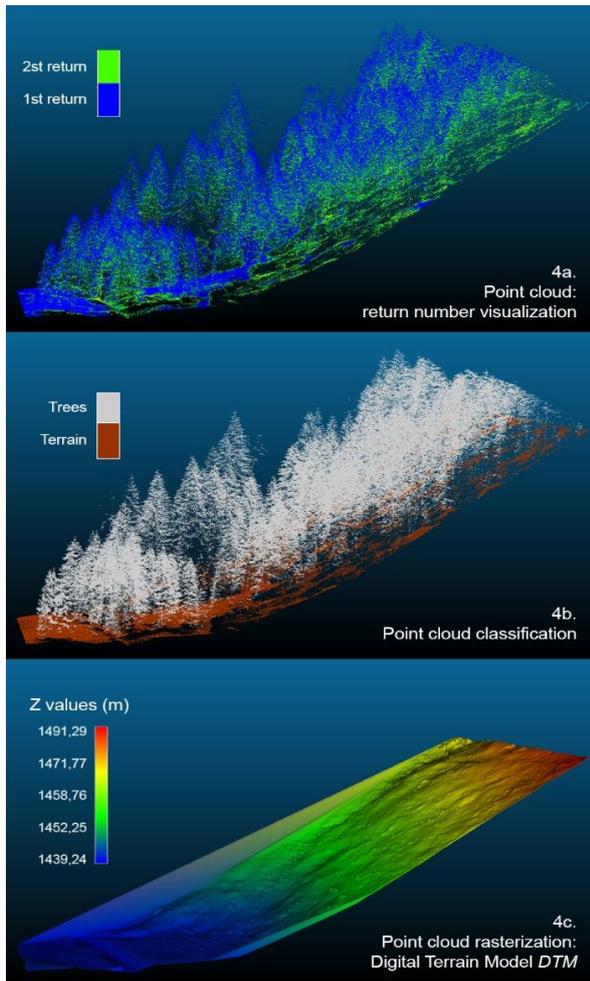


Fig. 4. Classification phase in CloudCompare Software

Despite the calibration of the CSF algorithm parameters in relation to the density of the acquired point cloud (Cloth resolution=0.3; Max iterations=500; Classification threshold=0.5), many vegetation points were incorrectly classified as “last returns”, leading to a rather inaccurate DTM and confirming the critical issues regarding CSF already identified by other research [19]. To improve the effectiveness of the automatic filtering tools, the identification of ground points was implemented with a manual classification based on the use of specific attributes called “scalar fields”, which allow additional data to be stored for each point, in addition to the geographical coordinates, such as the number of returns or signal intensity. As can be seen in Fig.4a, in this way it was possible to classify the point cloud by distinguishing the first return from the last echo, allowing, therefore, a marked improvement in the quality of the DTM at the same spatial resolution, determined by the density of points recorded per unit area.

By analyzing the different returns, it was possible to manually classify the surveyed points: out of the total of

576,517,923 points acquired, a dataset of 7,902,280 was classified as “Terrain” (brown color in Fig. 4b), from which, after further filtering, 491,268 points were used for the generation of the DTM with a pitch of 5 meters or elevation difference greater than 20 cm (Fig. 4c). The DTM thus obtained returned the actual model of the land morphology devoid of vegetation and was, finally, processed and analyzed in detail in the QuantumGIS environment using the specific visualization techniques previously mentioned, designed to highlight precisely the archaeological features. Thanks to a combination of Hillshading, Hillshading from multiple directions, Sky view factor, and Openness visualizations, it was possible to precisely locate a series of linear irregularities etched into the ground at different depths, later recognized as the military remains of ancient entrenchments (Fig. 5).

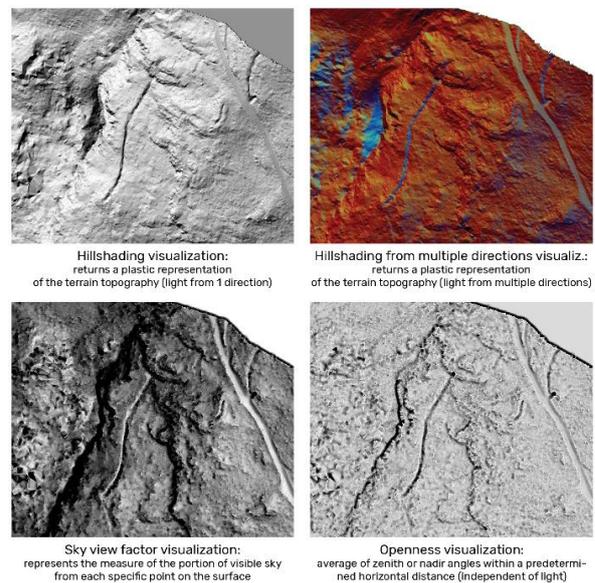


Fig. 5. Visualization techniques of Lidar data

Parallel to the creation of the DTM, the RGB images remotely sensed by a drone, and partially supplemented by some raster datasets acquired from the ground with a Reflex camera, were processed through the Agisoft Metashape software to elaborate 3D models of some defensive emplacements still recognizable today but in an obvious state of degradation. After the alignment of the images, through the “batch processing” phase, the raster data were processed by calculating the geographical position of each point in 3D and generating a point cloud representative of the external surface of some defensive emplacements. Finally, to generate surface meshes, this point cloud was imported into Rhinoceros 3D modeling software from which it was possible to derive architectural plans and sections, which are essential for geometrically describing the archaeological remains for subsequent recovery interventions (Fig.6).

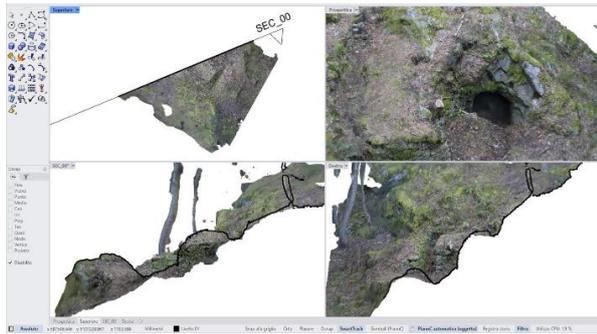


Fig.6. 3D-modelling in Rhinoceros environment

#### IV. RESULTS

The integration of measurements by LIDAR, photogrammetric images, and 3D processing allowed, almost unexpectedly, the identification of 17 fortified works still present in the analyzed area at different degrees of preservation (Fig.9).

	Trenches detected by DTM [m]	Trenches detected by DTM – to be verified [m]	Historical paths to be verified [m]
Macroarea 1	70,20	/	227,00
Macroarea 2	52,10	52,40	118,30
Macroarea 3	83,90	90,75	477,85
Macroarea 4	35,60	21,30	98,50

Table 1 – Entrenched systems detected by DTM

Specifically, 9 rock-cut caves were geolocated, accessible but with obvious problems of moisture and presence of deposits, 5 open-air defensive positions, and 3 main entrenched routes characterized by the presence of dry-stone walls still well preserved. Moreover, the detailed study of the LIDAR data has made it possible to map with certainty more than 241 meters of minor entrenched routes connecting the different emplacements, now almost entirely hidden below the forest cover and made recognizable exclusively through the analysis of SVF+Hillshading from multiple directions visualizations (Table1).

In addition, the possibility of extracting specific sections from the DTM right at the ancient tracks made it possible to delineate the current elevation profiles with centimeter accuracy, while also recognizing and quantifying the presence of debris and shrubs to be removed by the recovery project (Fig.7).

In fact, having detected an average thickness of about 25-30 cm of debris (rubble, soil and weed vegetation) above the probable original trampling level obtained from the comparison with the military manuals of the time represented by Design Aids and Manual of the Engineer

Corps [20], the removal of more than 36 cubic meters of deposits along the certain tracks was planned, in addition to the other 21 cubic meters concerning the entrenched paths to be verified in situ.

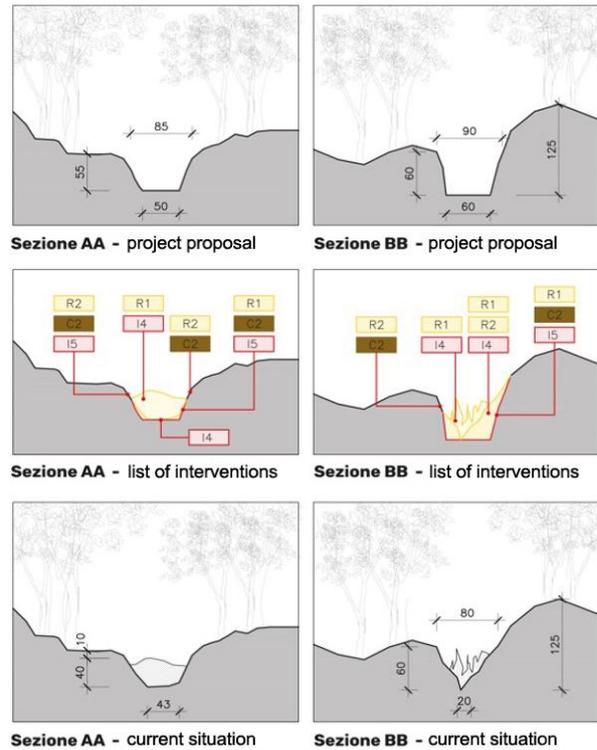


Fig. 7. Trenches: current situation, list of interventions and project proposal

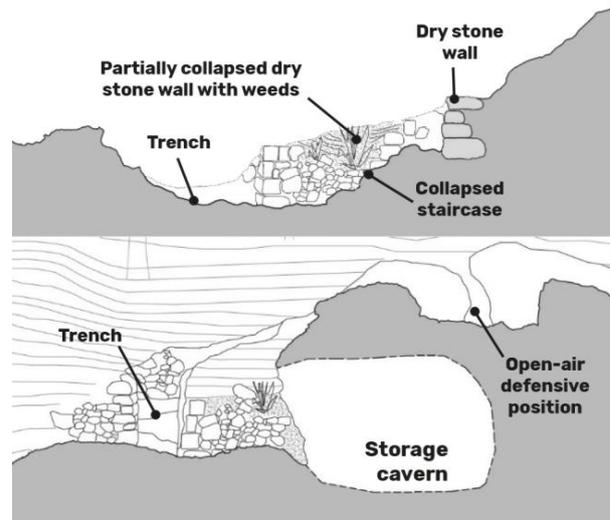


Fig.8. Open-air defensive position (remain nr. 20): longitudinal and cross-section of the current state

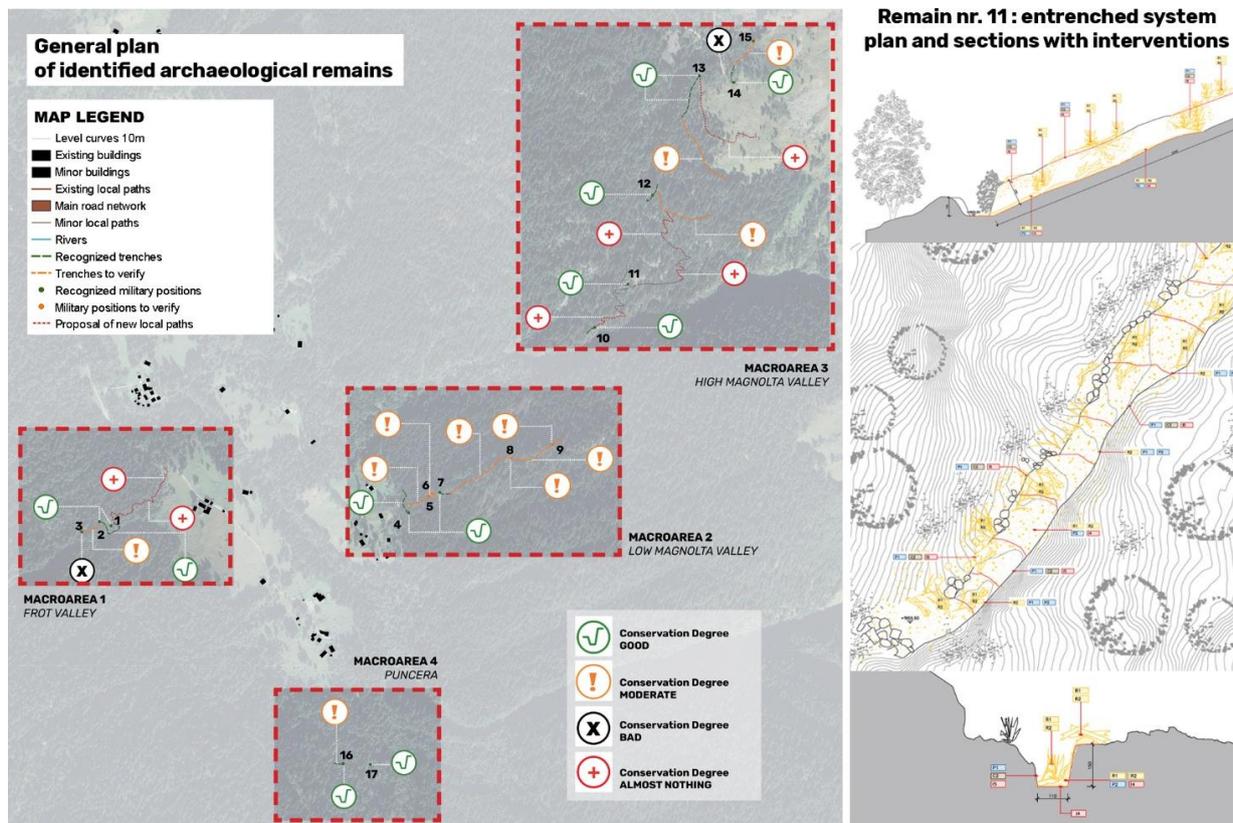


Fig. 9. General plan of identified archaeological remains and detail of remain nr. 11

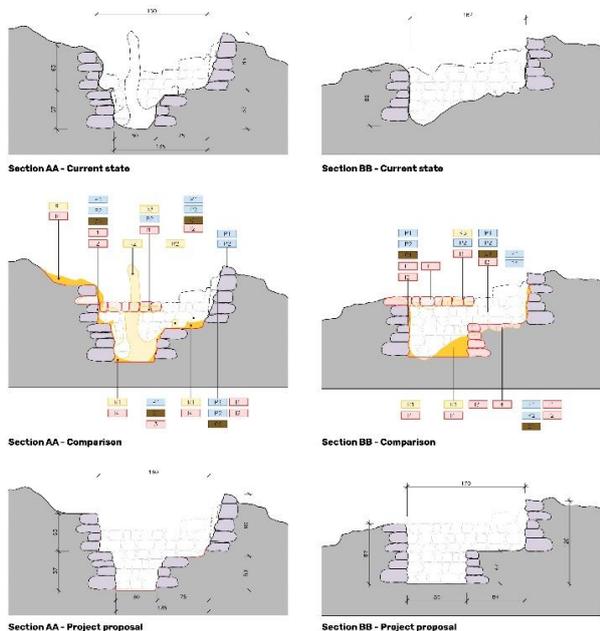


Fig.10. Open-air defensive position (remain nr. 7): current state, comparison, and project proposal

Three-dimensional modelling made it possible to virtually reconstruct the 5 outdoor defensive

emplacements, thus recognizing the traditional building types of the period also reported in military manuals found in the archives. By processing the geometric data extracted by Rhinoceros software in a CAD environment, in fact, representative architectural plans and sections of the actual state were obtained, which, with millimetric precision (scale of representation 1:50), made it possible to describe the wall textures of the drystone walls, circumscribe the collapses, identify the weedy vegetation and recognize, also dimensionally, some characteristic elements of the defensive works such as the firing steps inside the emplacements (Fig.8-10).

Vector files obtained in the QuantumGis and Rhinoceros-CAD environment were used as representative design drawings of the actual state of the sites, against which the graphic elaborations concerning the state of comparison and simulations of future interventions were produced, distinguished into 3 specific removal actions (R1-R3), 2 types of cleaning (P1-P2), 2 modes of consolidation (C1-C2), and 5 different types of integration (I1-I5).

## V. CONCLUSIONS

This article states how specific visualisation techniques (hill shading, sky view factor, openness) of the DTM can contribute to develop capacity building models for the enhancement of certain minor military archaeological

remains. With particular reference to the remains dating back to the Great War in Val Belviso, in the province of Sondrio, the metric and geometric knowledge of the archaeological remains, obtained thanks to remote sensing techniques, provided an essential contribution to set up the technical-economic feasibility of the recovery and enhancement project of the aforementioned works, in accordance with the protocols of the Superintendence of Archaeology, Fine Arts and Landscape of the province of Sondrio. A future integration with additional datasets that can be recorded with TLS or SLAM (Simultaneous Localization and Mapping) survey techniques could provide additional information for precision 3D-modelling of the interior of the cave works.

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