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Visualization of military heritage in the current landscape by comparing LIDAR features

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Abstract **– The present paper belongs to a line of research known as aerial archaeology and compares some specific visualizations of LIDAR data (hill-shading, openness, and sky view factor) to understand which of them can provide the best approach to suitably identify and unveil some archaeological permanences as function of different boundary conditions. In the present case, such permanences belong to the very special material heritage consisting of the "physical traces" of the Great War, although latent, they persist in the present landscapes at different states of preservation and visibility, waiting to be unearthed to express their cultural potential. They represent an indispensable palimpsest of "minor signs" such as, for example, fragments of entrenchments, gun emplacements, shelters, bomb craters, and temporary shelters. Such elements made the war machine work at that time while, nowadays, if properly recognized and enhanced, could foster the revitalization of the territories where they are placed.**

I. INTRODUCTION AND STATE OF THE ART

The morphological features of the land have always played a fundamental role in the perception of the landscape since they not only testify to changes in land use and land cover in relation to the needs of anthropogenic development, but also constitute the place where the "signs of history" have been imprinted and stratified. Therefore, being able to precisely know the topographic conformation of a territory means having a rich information potential at one's disposal that can prove useful in many application fields.

In recent years, remote sensing techniques have evolved, allowing not only faster and more systematic data acquisition, but also developing more specific interests in automatic image matching, interferometric synthetic aperture radar (InSAR), airborne or ground-based laser scanning (ALS and TLS), through the use of thermal chambers, georadar, and other instrumentations. Among these, Light Detection and Ranging (LIDAR) is the most commonly used technique for the creation of digital elevation models (DEMs), derived from the segmentation of point clouds obtained through measurements of the ground's distance from the laser emitter.

Numerous studies focused on the study of these different ways of interpreting spatial datasets: Horkn et al. [1] mainly discussed the potential related to the visualization of shading as a useful tool for the elevation differentiation of surveyed features; Keith Challis et al. [2] began to study different techniques by proposing a "toolbox" that includes, in addition to shading, the study of ground slope and irradiance models; Hesse [3] specifically analyzed the LRM (Local Relief Model); Yokoyama et al. [4] focused on the investigation of topographic aperture modes; Kokalj et al. [5] introduced the Sky view factor and its related applications for the analysis of soil microtopography.

From the study of the bibliography, it emerges that no single technique alone can extract the totality of the information contained in the source datasets, and therefore a proper combination of them is needed to make DTMs "express" the best.

Concerning the contribution that these interpretations can provide in the archaeological field, it is also evident that not all techniques are equally useful since they vary in relation to boundary conditions such as, for example, the morphological nature of the context or the different conformation of the structures surveyed (concave or convex) [6].

II. STUDY AREA AND DATA ACQUISITION

To better understand the comparisons proposed in this contribution, it is more effective to discuss their application to specific study areas. The fortified territory of the Trentino-Tyrolean Salient is particularly suited to this purpose as an archaeologically dense landscape of material remains deposited and stratified, more than a hundred years ago, by the First World Conflict, now largely "submerged" within current landscapes [7].

In the European context of the 19th century the Austro-Hungarian monarchy fortified the entire area wedged between the Alps in defense of the southwestern borders with the construction of multiple defensive works. These lines consisted of multiple permanent fortifications well connected by a dense network of temporary and field works conceived and designed to make the most of the orographic characteristics of the places (Fig.1). The implementation of the militarization plans, combined with the destructive impact that the conflict itself caused on the various territories, led to a radical transformation of the overall landscape: on the plateaus of Folgaria, Lavarone and Luserna, in particular, the first phase of the war (1915) was particularly violent and profoundly disrupted the morphological conformation of those territories. A hundred years after the end of the conflict, the current landscape still preserves some material traces of this part of history, but their recognizability is compromised by the state of degradation in which they are found and by the natural and anthropic transformations that have occurred over time, as shown in the shots in Trentino Alto-Adige.

Fig. 1 – Monte Piana trenches (Trentino-Italy)

For these reasons it was decided to analyze these places through the comparison of different ways of visualizing LIDAR data to compare the results and understand their actual contribution to the recognition of these "latent signs" in the landscape; if rediscovered and enhanced, they could become an interesting driver of development for cultural tourism in these areas [8][9].

Fig. 2 – War landscape between Vezzena

Fig. 3 - Surroundings Serrada Fort

In particular, two sample areas with different morphological characteristics were compared: the mountain slope between Forte Busa Verle and Forte Cima Vezzena (Fig.2), characterized by irregularities and a steep slope of the terrain, and the flat area around Forte Serrada (Fig.3) that, being a plateau, does not show particular differences in elevation.
For the analyses, raw LIDAR data acquired by the Autonomous Province of Trento with remote sensing performed between October 2006 and February 2008 were used. These data were supplemented with other ASL surveys in 2014 and 2018, and now freely accessible and downloadable online in ascii-grid format with a 1x1-meter cell grid, with a planimetric accuracy of 1/2000 of flight altitude, and with an altimetric accuracy of 15 cm.

III. METHODOLOGY

The importance that LIDAR is increasingly assuming in the study of the dynamics of archaeological transformation of the landscape is foremost due to its ability to overcome the interference caused by the presence of vegetation. In addition, LIDAR is able to provide a digital surface model, inclusive of every element surveyed (the DSM, Digital Surface Model), and a digital model of the orography of the terrain (the DTM, Digital Terrain Model), built exclusively with the points that belong to the ground. This is declined in the possibility of analyzing the current topography of the territory in all its parts through a non-invasive and remote method, capable of overcoming the visibility limitations inherent in the study of single orthophotos. However, the informative potential constituted by LIDAR data is greatly amplified by the implementation of advanced visualization modes (Hillshading, Ske View Factor, Openness) specifically developed for archaeological purposes and partially borrowed from other scientific fields, thus overcoming the traditional views of "grayscale" terrain elevation models, that avoid to lose important archaeological features [8].

A. Hillshading

Shading certainly represents the most common way of visualization of LIDAR data as it returns a plastic and illustrative representation of ground topography that can be easily interpreted. As shown in Fig.4, the basic assumption is that the surface under analysis is illuminated by direct light from a fictitious light source placed at an infinite distance.

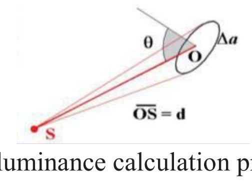

Fig.4 – Illuminance calculation principle [1]

The algorithm calculates a reflectance value for each terrain pixel and is based on the Lambert's formula:

$$E = \frac{I}{d^2} \cdot \cos\theta \quad (1)$$

which postulates how this value is directly proportional to the light intensity I of the source S, the cosine of the angle ϑ between the direction of incidence and the normal to surface dA, and inversely proportional to the square of the distance d between S and dA. Since the color change from white to gray and black enhances the perception of the relief morphology, the result of the algorithm is usually returned in grayscale, although this limits the visibility of fully illuminated or totally shaded areas. In addition, each specific direction of the illumination angles may be parallel to specific evidences on the ground that, when hit by a light beam in the same direction, would not become visible as they are shadowless. To solve this initial gap, one strategy is to produce multiple results by illuminating the surface from multiple light sources at different angles. The most interesting visualizations are usually obtained by combining together between 8 and 16 directions and filtering the resulting processing to derive RGB images, which are more readily understood. In this specific regard, the best settings consist of visualizations implemented from three different directions, preferably at 60° intervals, to which the different color bands are associated, for example, the red band at 315°, the green band at 15°, and 75° in the blue band.

B. *Sky View Factor*

A viable alternative to hillshading is the sky view factor analysis, achieved with an algorithm that simulates diffuse illumination on each DTM pixel coming homogeneously from all directions above, as if a uniformly illuminated hemisphere were above each point analyzed and centered in it (Fig.5).

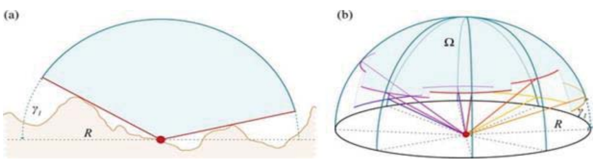

Fig.5 – SVF calculation principle [5]

The SVF represents the measurement of the portion of the sky visible from each specific point on the surface; it corresponds to the measure of the solid angle calculated with the following analytical relationship:

$$\Omega = \sum_{i=1}^{n} \int_{\gamma_1}^{\pi/2} \cos\varphi * d\varphi = 2\pi * \left(1 - \frac{\sum_{i=1}^{n} \sin\gamma_1}{n}\right) \quad (2)$$

in which φ corresponds to the latitude and λ to the longitude angle of the hemisphere, i.e. a function of the vertical elevation angle γ in the n directions of analysis. Normalizing the formula by 2π shows that, in the limiting cases, the formula returns a dimensionless parameter between 0 (γ_1=90°, SVF=0, no visibility - black color) and 1 (γ_1=0°, SVF=1, all-clear view - white color) that makes the irregularities of the terrain morphology obvious. Such a visualization is particularly effective in clearly identifying the concavities present in the terrain: as seen in Fig.6 this made possible to bring out a rich palimpsest of previously latent and barely visible "material signs" that can be recognized as remains of Great War vestigia, including entrenched paths and depressions with an almost circular course that can be traced back to the negative interfaces produced by bomb blasts.

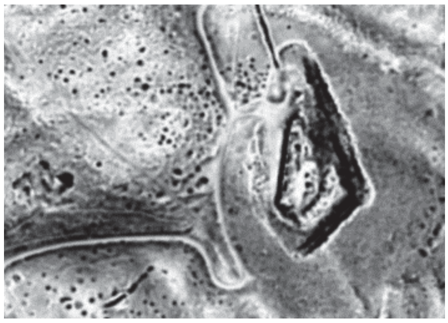

Fig.6 – SVF visualization: the unveiling of a rich palimpsest of military traces around Verle Fort

Briefly analyzing in depth the variables of the computational algorithm, it becomes clear that the main factors influencing the outcome of SVF visualization are essentially the number of scanning directions and the maximum search radius. If the setting of the first parameter to 8, 16, 32, or 64 directions almost exclusively influences the accuracy of the definition of the edges of the detected objects, the choice of the maximum radius according to which to "scan" the microtopography depends on the scale of the features that will be detected. In other words: large survey features when a large search radius is chosen, and detailed features when a small radius is used. In the case study, for example, given the need to verify the permanence of remains of the minor vestiges of the Great War, a search radius estimated at about 5 m (10 pixels) was chosen to have a size comparable to that of the elements to be identified.

C. *Openness*

Another way of visualizing LIDAR data is topographic aperture analysis, that aids the detection of surface concavities and convexities in a totally independent way of the presence/absence of a light source. Aperture is defined as the average of several zenith or nadir angles (expressed in radians) within a predetermined horizontal distance (L) (Fig.7). To obtain the aperture value for a given context, profiles along at least eight directions (N, NW, W, SW, S, SE, E, NE) within a defined radial distance must first be obtained from the DEM; hence, for each of them, the zenith angles:

$${}_D\emptyset_L = 90 - {}_D\beta_L \quad (3)$$

and nadir:

$$_D\psi_L = 90 + {_D\delta_L} \quad (4)$$

can be determined [4].

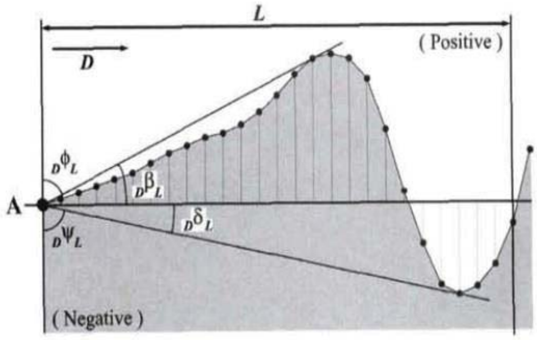

Fig.7 – Principle of calculating Openness [4]

The mean value of all zenith angles corresponds to the positive aperture, while the median of the nadir identifies the negative aperture. As with the SVF, the accuracy of visualization is a function of the number of analysis directions and, most importantly, of the maximum search radius: this type of visualization allows to well identify with clearly visible dark tones not only recessed paths and bomb crater depressions but also the edges of features in relief, thus convex. Being independent of the illumination factor, topographic openness highlights any morphological features of the terrain and the presence of both natural and artificial obstacles to the exclusion of general topographic information. In both openness images, in fact, neither slopes nor shadows are shown, but for each point the maximum aperture value with respect to zenith (positive-light values) or nadir (negative-dark values) is returned, and not with respect to a hemispherical canopy horizontally centered at the point itself as in the SVF calculation. As demonstrated by application to the case study, this will be particularly advantageous in the recognition of archaeological evidence in areas where the slope of the terrain is particularly steep.

IV. RESULTS AND DISCUSSION

As shown in Fig.8 and 9, the experimentation of different visualizations on the fortified surroundings of Fort Serrada and Fort Cima Vezzena made it possible to identify, with centimeter precision, the microtopography of these historical landscapes revealing numerous concavities of almost circular shape and long depressions in the ground with a more linear trend. Using 8 analysis' directions and calibrating the maximum scanning radius of 5 meters (10 pixels), i.e. a dimension compatible with the dimensions indicated in military manuals regarding entrenchments and gun emplacements, the identified irregularities turned out to be precisely the "physical signs" related to what remains of the imprint left by the Great War more than a century ago.

Analyzing the obtained elaborations, it is immediately evident how the visualizations concerning the flat context around fort Serrada appear more immediately understandable. In fact, the local morphology of the area is more homogeneous and consequently also the identification of some of the existing irregularities is already possible through the shading of the DTM (Fig.8a). However, the SVF and topographic aperture provide more interesting data for a more precise definition of the geometric features of such "signs", especially concerning the sharpness of edges, the configuration of convex elements, and the relative depth of depressions, which can be identified with gray-scale displays where black corresponds to greater depth and white to maximum exposure (Fig.8b-c-d). On the other hand, as far as the mountainous area is concerned, the shaded visualization facilitates the understanding of the degree of terrain slope and highlights only the most markedly incised paths in the terrain (main roads), but it is not equally effective for the recognition of "minor" signs imprinted in the local microtopography. Analyzing Fig.8b is evident that even SVF makes only a partial contribution because the visualization of the results obtained by the algorithm is largely influenced by the degree of terrain slope that limits the visible portion of the sky. Therefore, the most suitable visualization is the topographic aperture, which allows for the accurate detection of archaeological remains even in areas where shading and SVF are not particularly useful. This becomes clear by comparing Fig. 9c/d with Fig.9b/c. This simple comparison is not only related to the analyzed case study, but it also allows to understand potentials and criticalities of different LIDAR data visualizations in relation to the type of morphological context of reference. Specifically, the reasons for the greater readability provided by the topographic aperture versus SVF (Fig.9) stem directly from the setting of the computational algorithm underlying the respective visualizations. Indeed, as is evident in Fig.10-11, the SVF uses only the zenith angles above a fictitious horizontal plane centered on the point under analysis. Therefore, the maximum angle derived during processing cannot be larger than a hemisphere (zenith of 90°). On the contrary, topographic aperture also includes angles of larger amplitude. In other words, this means that positive and negative aperture does not consider the slope factor, returning the same value regardless of whether it was determined on a horizontal (Fig.10) or inclined (Fig.11) surface. Although this reduces the understanding of overall topography, sharper views of topographic structures are obtained, not masked by slope values as in the SVF. Therefore, it can be seen that while in flat contexts SVF and topographic openness essentially provide comparable results (at least with respect to concave elements), in mountainous contexts where slope values are considerable, topographic openness provides a more significant contribution to the recognition archaeological remains.

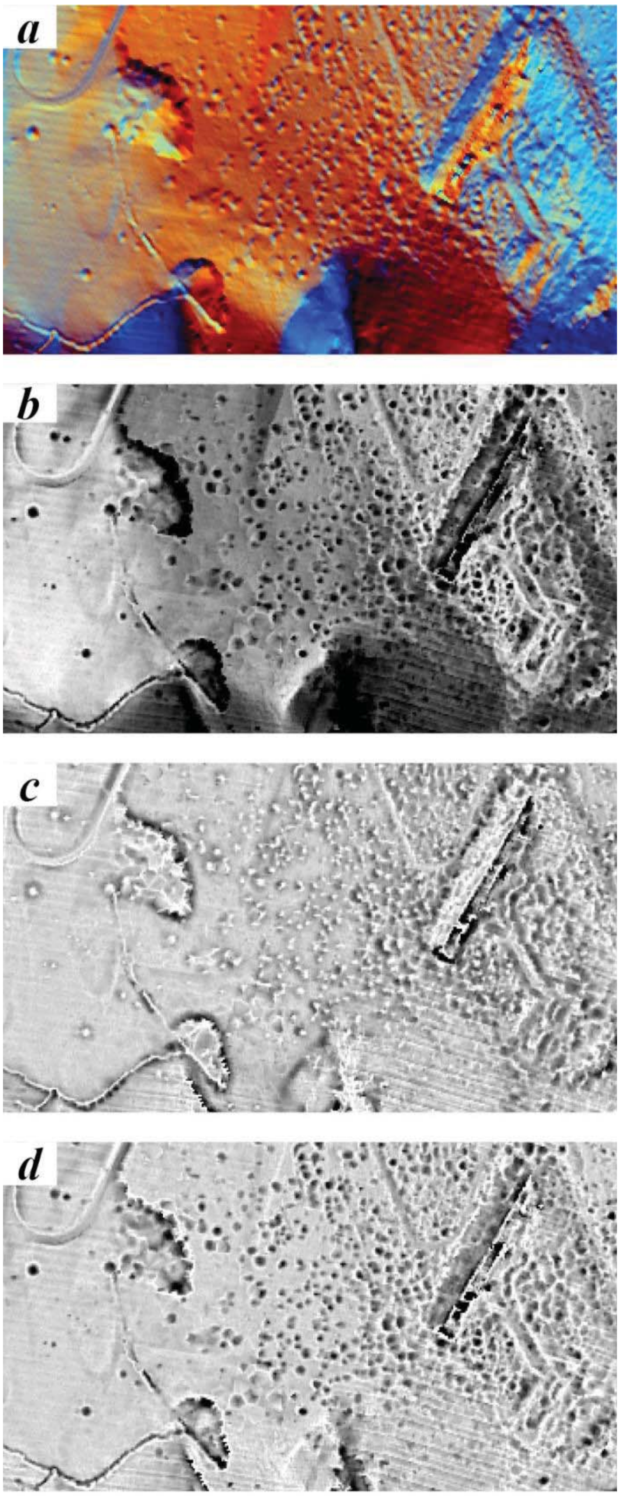

Fig. 8 - Entrenched system around Serrada Fort (lowland context), Lidar data visualizations comparison: a. Hillshading from multiple directions; b. Sky View Factor (8 directions - 5m max radius); c. Negative Openness (8 directions - 5m max radius); d. Positive Openness (8 directions - 5m max radius)

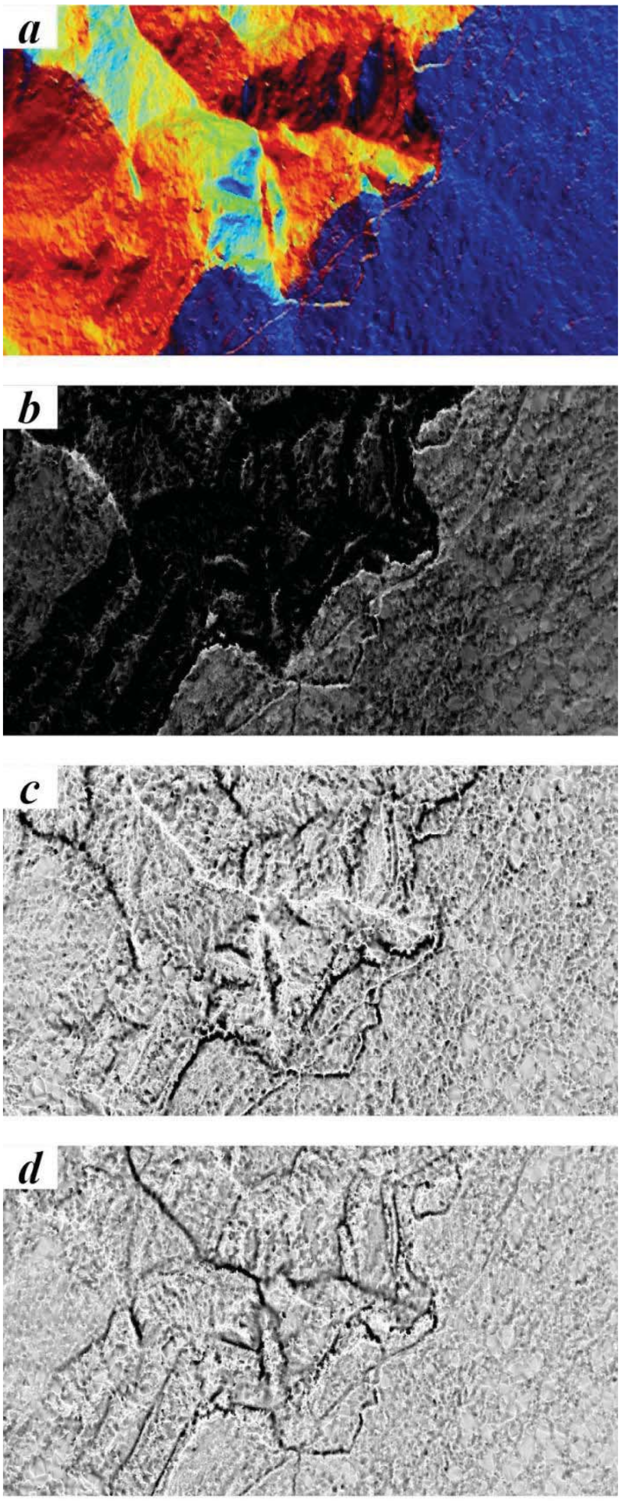

Fig. 9 - Entrenched system around Vezzena Fort (mountain context), Lidar data visualizations comparison: a. Hillshading from multiple directions; b. Sky View Factor (8 directions - 5m max radius); c. Negative Openness (8 directions - 5m max radius); d. Positive Openness (8 directions - 5m max radius)

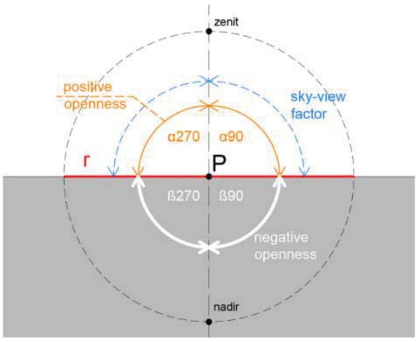

Fig. 10 – SVF VS Openness - sloping context

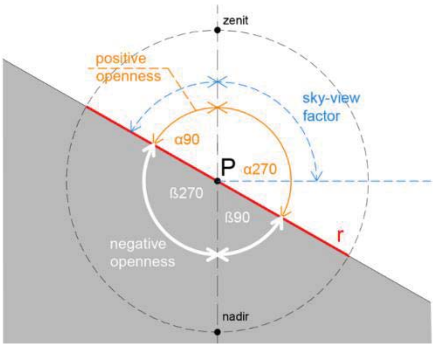

Fig.11 – SVF VS Openness - plain context

V. CONCLUSIONS

It is evident how the interpretation of different ways of visualizing LIDAR data constitutes an important methodological contribution useful in unveling the constituent plots of the evolutionary biography of contemporary landscapes. The experimentation on the two study cases made it possible to unveil what remains of the pregnant cultural heritage related to the Great War and, at the same time, to compare the different visualizations to understand their potentials and criticalities at a general level.

In summary, it emerged how shading from multiple directions is valid for essentially getting a general view but not for specific analyses of local microtopography, with respect to which the contributions of SVF and topographic aperture perform much better. It was also understood how the main criticality of SVF is related to the incidence of terrain slope values that alter the visualization of results thus leading to a preference, for mountainous contexts, for the visualization of topographic aperture as the main tool for the rapid identification of archaeological features.

Ultimately, a careful combination of SVF (which considers general topography) and topographic aperture (focused on differences in micro-relief) represents an essential operational contribution that facilitates the legibility of historical permanences in present-day landscapes, also opening up future research developments, such as, for example, the implementation of semi-automatic recognition and classification processes of archaeological evidence.

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