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Castelseprio archaeological site: LiDAR and GIS multiscale dataset supporting on-field investigation and enhancing landscape understanding

1. Context and objectives of the project

Castelseprio (in the Varese Province) is a site of exceptional value for the Lombardy Region (north Italy), both for its archaeological and monumental remains and its landscape and environmental context. This research, entitled “Castelseprio. Innovative technologies for the integrated management of enhancing interventions” was funded by Lombardy Region on the “Call for the promotion of enhancement interventions of the archaeological heritage and the UNESCO sites of Lombardy (2014)”.

The call, presented by the Varese Province, saw the Politecnico di Milano - Department of Architecture and Urban Studies (DAStU, Laboratory “Techniques for the Conservation and Management of Architectural Heritage” (TeCMArcH) – as a research consultant for the creation of a specific Geographic Information System (GIS) project for the management of Castelseprio UNESCO site.

Currently, the management and fruition of the site pose critical issues due to the historical events that have caused the loss of the physical unitarity between the upper area of the *Castrum* (with the ancient *borgo* and the Church of S. Maria *foris portas*) and the Torba complex (FAI – Fondo Ambiente Italiano) which formed the downstream limit of the fortified system.

It is important to remark that Castelseprio was inscribed ten years ago in the UNESCO list as a component of the serial site “The Longobards in Italy. Places of the Power (568-774 A.D.)”, following the World Heritage Committee held its 35th session in Paris between June 19th and 29th 2011.

The GIS has been organised into three territorial areas at different scale (Seprio Valley; Middle Olona Valley; Castelseprio Archaeological Area) using dif-

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ferent information layers. Among the cartographic bases that have been used, there are historical, modern and contemporary maps, technical/thematic maps and aerial shots available. Other information layers have been added to these, such as the main elements of the geological/geomorphological interpretation of the terrain (paleo-beds, embankments, escarpments, etc.) and transformations related to environmental engineering interventions as well as hydrography. Of great use were also the elevation data through the definition of contour lines and the processing of a Digital Surface Model (DSM) and a Digital Terrain Model (DTM) of the entire area, based on the point cloud from the LiDAR flight.

Being an archaeological site, the Information System has collected and georeferenced the data from past excavations acquired from bibliographic sources and archaeological reports, and from documents archived at the former Superintendency of Archaeology (topographical, excavations, photographic, drawings/reliefs archive, archival documents relating to the declarations of cultural interest).

The analyses of historical maps have produced various outputs regarding the permanence of artifacts useful for a better understanding of the past landscape. These include the development and transformations of the historical itineraries and road network, religious and monastic buildings, the variation of land use destinations. A crucial thematic section for understanding the degrees of constraint was verifying the census of archaeological, architectural and landscape heritage regarding the current protection laws' limitations.

The GIS's goal was to identify the archaeological potentiality of Castelseprio site and suggest actions for its future knowledge, management and fruition.

To better communicate the results of the work carried out, as mentioned before, a dedicated GIS project has been developed to connect archaeological data, the relative graphic and photographic documentation, the scientific contents resulting from previous research and carried out with surveys during the project.

The case study on Castelseprio is compliant with a comprehensive multidisciplinary approach addressing heritage, management and enhancing interventions. This approach combines theories, methods, tools from humanities and more techniques, 'poly-tecniques', providing new information and a general model that can be applied and replicated in other contexts.

S.B.

2. Archaeological surface investigations: objectives and methodology of the survey

The archaeological field walk research project[1] was set up to contribute to filling the knowledge gap related to the settlement outside the *Castrum* and of

[1] The survey project in Castelseprio was carried out thanks to the resources made available by Varese Province in 2014, together with funding from Lombardy Region (regional calls 2014 and 2015

which the only certain chronological reference is the date of its end, between 1285 and 1287 (cf. lastly Settia 2018).

Before starting the project briefly exposed here[2], the existence of the *borgo* was known from sporadic observations about the presence of remains buried in the woods surrounding the fortified area[3], surveyed for the first time in the 1940s by Mario Bertolone (*Schizzo Topografico della zona Archeologica di Castelseprio*, in Bognetti, Chierici, De Capitani d'Arzago 1948; Bertolone in Sironi 1950, pp. 12-13). Some investigations carried out by the Archaeological Superintendency in the 1980s and 1990s could offer confirmation of the presence of buildings outside the *castrum* (Surace 2002, pp. 59-71); a house had been intercepted west of S. Maria *foris portas* by Carver excavations (Carver 1987, p. 322; Brogiolo 1996, p. 157). The recent cleaning and exposure of some sections of walls and rooms, carried out in correspondence with already known evidence, confirmed the built-up area's consistency outside the fortification walls without obtaining useful elements for a chronological definition of the structures (Giostra 2020).

The dense coverage of vegetation already reported since the 16th century[4] had always made it difficult to identify, systematically check and measure the evidence reported in the Bertolone sketch. Besides, the morphology of the terrain, steep and enlivened by bumps and valleys, had also hindered the use of ground instruments for geophysical surveys to intercept the buried remains.

As part of this project, the use of remote detection tools through LiDAR technology was therefore chosen, which made it possible to quickly acquire a 'digital cast' of the surfaces scanned by the laser during the aerial overflight, obtaining a high-precision model of the terrain, in which some archaeological evidence emerges. These evidences are also correctly positioned and metrically defined[5].

on projects prepared by the authors), as part of a broader project to enhance the UNESCO site in collaboration with the Archaeological Superintendency. Focal points of the 2014-2015 project were the digitization of all existing information material in the archives of the Superintendency (ATS, AFS, Drawings Archive) and in Varese State Archives, the LiDAR over flight and the resumption of excavation tests. It is thanks to these funds that, after an interruption of over thirty years, the excavations of the Catholic University could resume, as well as the awakening of interest in the area outside the castle, previously ignored.

[2] A preliminary report in Bortolotto *et al.* 2017.

[3] In the first half of the 19th century, on the plateau on which stood the church of S. Maria *foris portas*, it was possible to see "molti edifizii distrutti" (Corbellini 1872, p. 47; Sironi 1970, 1973, 2002, p. 15).

[4] Tibiletti 2013, p. 46 and note 15; in particular, the pastoral visit of the delegate of Cardinal Carlo Borromeo in 1566 reports that woods extended for one and two miles around the church of S. Giovanni; in the decree issued by Cardinal Monti in 1640 "a simple benefit founded in ancient times" is mentioned, consisting of 60 perches of woods around and near S. Maria, while arable land is located in the territory of Gornate Inferiore and Vicoseprio: Dejana 2013, pp. 701-702.

[5] For the methodological specifications and processing techniques of LiDAR and topographical data, see Andrea Garzulino and Nelly Cattaneo in this paper.

On the basis of the cartography thus obtained, compared with the historical surveys, we proceeded with the archaeological field walking[6]. As it is well known, the problem of visibility is one of the determining factors both for the strategies and for the results of the archaeological surface reconnaissance and is strongly conditioned by the current use of the land. In general, a greater index of visibility can be found in soils used for agricultural purposes, as regular ploughing activities bring to the surface archaeological finds and/or submerged structures. Visibility decreases in abandoned agricultural areas and is very limited in the presence of extensive and dense forest coverings, as in the case of Castelseprio[7].

However, the reliability of the LiDAR survey's indications has allowed the almost systematic identification and recognition – except in some impenetrable points due to the brambles – of the area traditionally assigned to the Borgo for an extension of about 4 hectares. Some cases are already reported in the Bertolone map, to which hitherto unknown evidence has been added.

The cataloguing of the artefacts observed during the surface survey was carried out, taking into account the following parameters:

- typology of evidence
- constituent materials
- distribution density
- dimensions
- vegetation

The data have been structured in a database, joined to the webGIS archive (Nelly Cattaneo and Rosa Maria Rombolà in this paper).

S.M.

3. Archaeological surface investigations: results of the survey

The first survey of the *borgo*, as already mentioned, is the work of Mario Bertolone, of which the preliminary sketch before publication (Bognetti, Chierici, De Capitani d'Arzago 1948) is kept in the Topographical Archive of the Superintendency (fig. 1); shortly after the update published by the same author in Sironi 1950.

Based on the topographical sketch, the built-up area outside the *castrum* is arranged on some reliefs to the west of the fortified precinct. Regarding the archaeological consistency of it, three categories of evidence are distinguished: remains 'to be detected', 'buildings', 'defences' (fig. 2).

[6] Carried out on some days during the spring and autumn of 2016, jointly with the team of the Politecnico di Milano, which took care of the positioning of the artifacts with the GNSS device.

[7] On the development of a surface reconnaissance methodology centered on the geomorphological specifications of the sites and on the GIS elaborations see Massa, Melis 2006.

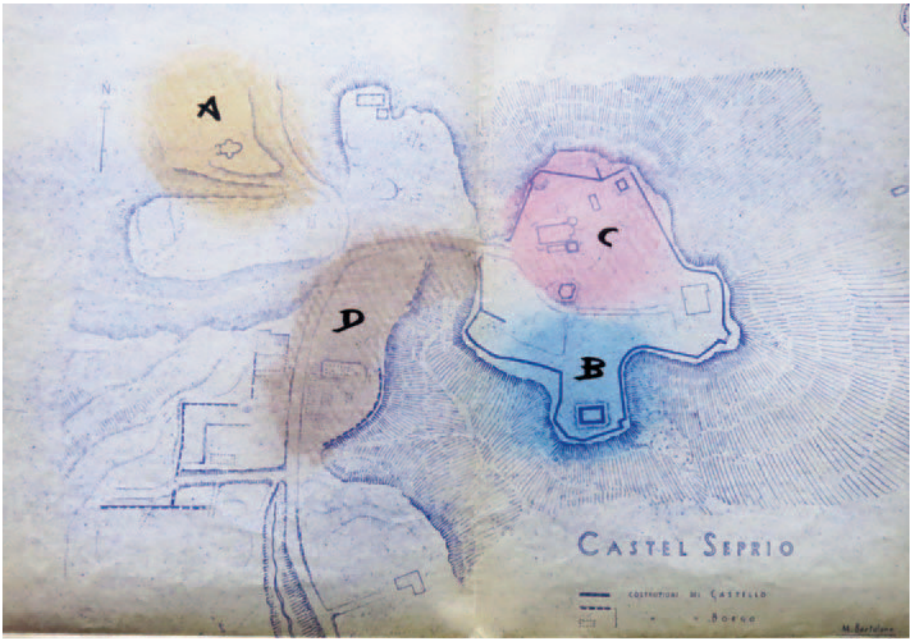

Fig. 1. ATS, copy of the sketch of M. Bertolone, 1946-1947.

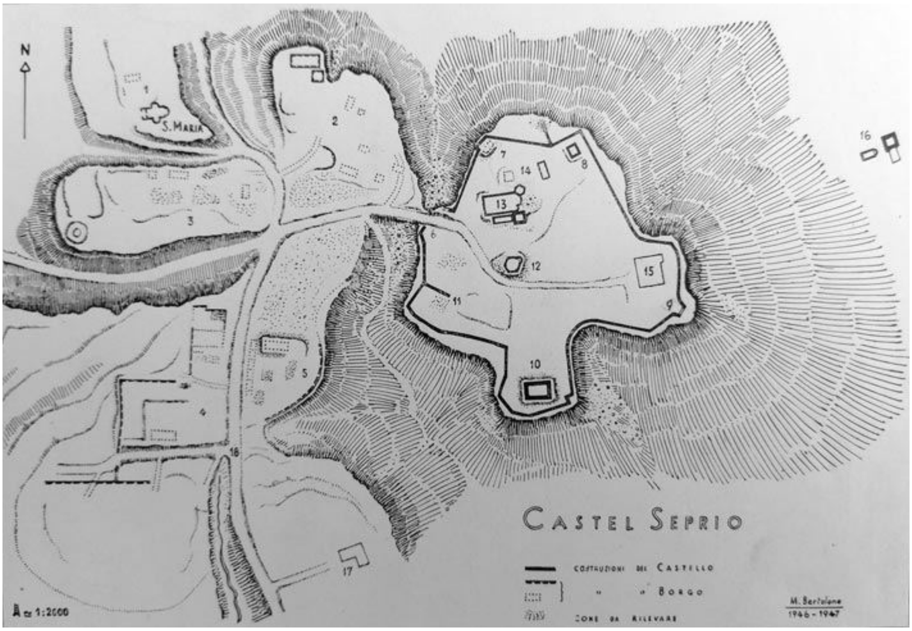

Fig. 2. Topographic sketch by M.Bertolone 1946-1947 (from Bognetti, Chierici, De Capitani d'Arzago 1948).

As it has been noted, this is a considerable density of buildings, where, based on the few test pits carried out for emergency situations, it seems that burials have also been found, believed to be dated before the houses (De Marchi 2011, p. 48).

Thanks to the LiDAR survey carried out in 2015, we acquired the following evidence:

- possibility to distinguish between the signs determined by the geomorphology and/or by interventions of an arrangement of the terraces, which are widespread on the west slope, and traces of presumed buildings. It is to be verified whether the terraces are the result of ancient cultivation or slope regularisation works for the settlement: the absence of ceramic materials, observed during the survey, would suggest the second hypothesis;
- reliable positioning of the buildings and relative orientation: while bearing in mind that the uneven conformation of the land has undoubtedly shaped the location of the buildings, it can be noted that the church could have influenced the alignment along the west-east axis, the only building of the *borgo* preserved in elevation[8], because spared, like the other religious buildings inside the fortified precinct, from the destruction of the late 13th century;
- density of the stone artefacts, also verified by fieldwalking.

The systematic fieldwalking of the explorable areas led to the discovery of numerous remains of stone structures emerging on the surface and/or in exposed sections of the slope to identify morphological features of the slope probably attributable to an artificial regularisation. In contrast, the total absence of archaeological finds emerging on the surface has been noted. The remains do not always coincide with the perimeters drawn on Bertolone's sketch.

In some cases, it has been possible to identify segments of walls relevant to collapses/foundations, with a recognisable alignment (fig. 3 A, B, E).

In numerous cases, consistent outcrops of pebbles and stones have been recognised, sometimes with the presence of brick fragments, identifiable as collapses/destruction of walls, despite the presence of vegetation (fig. 3 C).

Elsewhere it was only possible to record the presence of not very compact and inhomogeneous outcrops of pebbles, for which it is premature to propose a functional or typological identification (fig. 3 D).

The remains of stone structures documented by the field walking, at present and with caution, since it was not possible to proceed with the simultaneous cleaning and survey, seem comparable with masonry techniques already known within the castle walls, whose systematic analysis has allowed a periodization (Scillia 2013). Even the surveys carried out by the Superintendency outside the

[8] One other church, currently no more visible, has been seen by Sironi 1970, p. 186, its identification with the one mentioned in the *Liber Notitiae Sanctorum Mediolani* is not sure, Brogiolo 2018, p. 437 footnote 8.

Fig. 3. Example of the types of evidence documented during the 2016 survey, positioned on the LiDAR basis and with reference to previous knowledge (elaboration TeCMArcH Laboratory).

precinct walls, in the area between the ancient roads to S. Maria and S. Giovanni, west of the valley that separates the plateau of the *castrum* from the *borgo*, have brought to light the remains of three buildings (Surace 2002, pp. 59-71 and tav. 1, p. 60, with elaboration of the map of Bertolone 1946). These are built with small and medium-sized cobblestone walls (from 10 to 25 cm), with the canton in rough-hewn slabs, such as *building 1* (Surace 2002, tav. 3), or with cobblestone walls and rough-hewn stones, such as *building 3* (Surace 2002, fig. 3), in some cases of considerable thickness. *Building 2* instead featured pebbles arranged in a herringbone pattern, alternating with horizontal courses of split pebbles and stones (Surace 2002, tav. 4).

The masonry technique of *building 1* seems to be comparable with the TM4 of the Scillia classification, dated to the 9th century, while for *building 2,* a parallel can be proposed with TM3 variant B, dated to the 11th century (Scillia 2013).

Therefore, also for the *borgo* the existence of different masonry techniques is highlighted, probably attributable to a hierarchy of the buildings – indicated by the work of more or less specialised workers – and/or to different chronological phases, similarly to what was found for the houses excavated inside the precinct walls and outside, close to its southwestern section, which have documented construction phases referable to the early Middle Ages, with renovations and modifications in the following centuries (Dabrowska *et al.* 1978-79; Sedini 2013; De Vanna 2017).

S. Maria has been called *foris portas* since the 13th century, an indication that could be connected to the *castrum*, outside of which it is evidently located and therefore remember a period in which there was no *borgo*. Alternatively, it could refer to a location outside the *borgo* itself, as the results of the excavations carried out in the 1980s, which confirmed the isolated location of the church on the edge of the settlement, might suggest (Carver 1987, pp. 315-316).

It is evident that the date of construction of S. Maria constitutes a chronological reference of great importance for the evolution of the settlement or the surrounding landscape. However, the building's construction sequence and its dating are controversial, oscillating between the mid-6th and 9th-10th centuries (Brogiolo 2013, pp. 221-254).

The excavations conducted by Martin Carver and Gian Pietro Brogiolo at S. Maria *foris portas* in the years 1981-1983 and 1985 have particular significance in setting the main questions about the origin and the archaeological consistency of the *borgo* (Brogiolo, Carver 1982; Brogiolo, Carver 1983; Carver 1986, 1987).

Excavations revealed a ditch in front of the façade and along the eastern side of the church, while its continuation to the north and south has been verified after the removal of the vegetation in the adjacent woods. The ditch, according to Carver, was dug in the 13th century, but it likely follows the line of a previous border, or, based on comparisons with similar realities, it may be dated from the 9th century (Brogiolo 1996, p. 157).

Beyond the ditch, the traces of a building and a probable water basin have been identified, pertinent to the settlement in connection with the church and its cemetery, reserved for the aristocracy of the castle, in a phase subsequent to the use of the cemetery of S. Giovanni, probably coeval to the foundation of the *castrum* (Brogiolo 2013, pp. 253-254).

As Carver points out, understanding the function of S. Maria also means recognising more generally the urban history of the site, which probably represents, according to the archaeologist, the urban reorganisation phase of Castelseprio, coinciding with the great period of medieval urbanism, between the 10th and 13th centuries (Carver 1986, p. 573).

However, despite the conspicuous literature existing on S. Maria *foris portas*, there is still a lack of knowledge about some fundamental aspects to clarify the relationship between this building and the religious complexes that arose in the central sector of the castle (S. Giovanni with baptistery) and in the fortified appendix of Torba at the foot of the hill, that is, if they were built isolated or inserted in inhabited space. In particular, as regards S. Maria *foris portas*, "… we completely ignore the context" (Brogiolo 2013, p. 214; Brogiolo 2018, p. 437).

It is possible that by accepting the higher chronology of Santa Maria *foris portas*, the *borgo*'s development may coincide with the expansion of the houses close to the southwestern portion of the walls in the early Middle Ages (Brogiolo 1996, p. 40). However, it could also be connected to a later phase, when the *curte castri Sebrii* is mentioned, probably outside the *castrum*[9].

Furthermore, the potential relationship between the medieval *borgo* and the earliest settlement poles, signalled by the Golasecchian burials intercepted by Carver excavation, by the materials of the Iron Age found in the excavations at the door of the *castrum* (Dejana, Mastorgio 1973), for the Roman era by the copious stone materials reused in the constructions of the castle and Torba (Mentasti 2013), is not clarified yet.

Turning the attention from the architectural typoogies to the functions, we may wonder about the entity of the population resident in the *borgo* and which kind of relationship they had with the aristocracies who occupied the castle: was it a predominantly productive or military role, or more probably both? (De Marchi 1999; Brogiolo 2017).

Further, systematic micromorphological investigations are necessary, in addition to the stratigraphic excavation, to answer these questions. In any case, we believe that the information gathered thanks to this project is useful for planning future interventions, with the awareness that the systematic destruction carried out starting from 1285, which was followed by the probable long-term despoil of reusable materials, has irremediably deprived us of lots of information relating to the last stages of the life of the *borgo* (Settia 2018).

S.M.

4. LiDAR data

As part of the project, given the territorial morphology and dense vegetation, to identify and investigate the archaeological remains in the UNESCO site of Castelseprio, it was decided to conduct a laser scanner survey with LiDAR technology (Light Detection and Ranging)[10].

Its main advantage is to provide a direct method for the acquisition of three-dimensional data, and, unlike other survey methods[11], the geometric information recorded by the instrument can be immediately used for an initial knowledge of the current morphology.

LiDAR technology uses a set of measurement systems mounted on aircrafts, that scan the overflowed field, storing valuable information for the knowledge and

[9] Document issued in 992 by Otto III in favor of the estates owned by the bishop Olderico, Brogiolo 2018, p. 437.

[10] The survey was carried out by the Compagnia Generale Riprese Aeree CGR spa of Parma.

[11] E.g. aerial photogrammetry, territorial topographic survey.

representation of the territory and its features. The aerial survey's first output is a point cloud defining terrain altimetry and the elements, e.g., vegetation, buildings, roads, etc. The points contributing to forming the cloud are arranged according to the instrument's scanning pattern and provide planimetric coordinates, altimetry, intensity of reflection, and can be classified based on the intercepted surfaces (Cowley, Opitz 2012). Generally speaking, the laser scanner is a tool used for surveying objects and artefacts and consists of a device that automatically drives, directs and records the impulses of the attached laser range finder that determines the distance between the point of emission of the impulse and the point of reflection on the surface of the intercepted object (Shan, Toth 2009; Remondino, Campana 2014). The set of intercepted points helps to form a point cloud since the impulse origin position is known, and the angle of direction and the distance are recorded. In the case of airborne laser scanner, an inertial system and a GNSS device are integrated to trace the flight paths and know the coordinates of each point of emission of laser pulses and the direction of the emitted beams[12].

In the case of Castelseprio, although thick vegetation characterises some portions of the area, it was possible to obtain a valid result in the acquisition and representation of the underlying terrain's morphology. This result was obtained thanks to applying appropriate algorithms and selection criteria[13]. The method enabled the generation of a Triangulated Irregular Network (TIN) to describe the 2.5-dimensional trends and in which it was possible to create contour lines with an interval up to 15-20 centimetres, depending on the needs. Therefore, the resulting model has differentiated from any other 2.5-dimensional product from the cartography or available aerial image. The quantity and quality of the data collected by the laser scanner also made it possible to realise a high precision DTM and a digital elevation model (DSM), aiming at supporting the census of archaeological emergencies on large areas since anthropogenic features standing out from the level of the ground might be detected. A further advantage is creating an updated and metrically correct cartographic base on which the identifiable archaeological structures have been placed, thus being correctly positioned.

In this way, problems connected to archaeological structure identification and positioning were overcome. It is essential to underline that the available maps (regional and provincial technical maps and municipal cartographies) could not act as unique support for such elaborations for two main reasons: first, because they represent already interpreted data with a purpose different from the one needed for the project; the second reason concerns all the criticism of maps' nominal scale and accuracy. Data relating to the archaeological remains

[12] For laser scanning techniques used in LiDAR technology and for processing see Shan, Toth 2009; Cowley, Opitz 2012; Remondino, Campana 2014.

[13] Geometric parameters such as maximum gradient and acceptable height differences in Cowley, Opitz 2012.

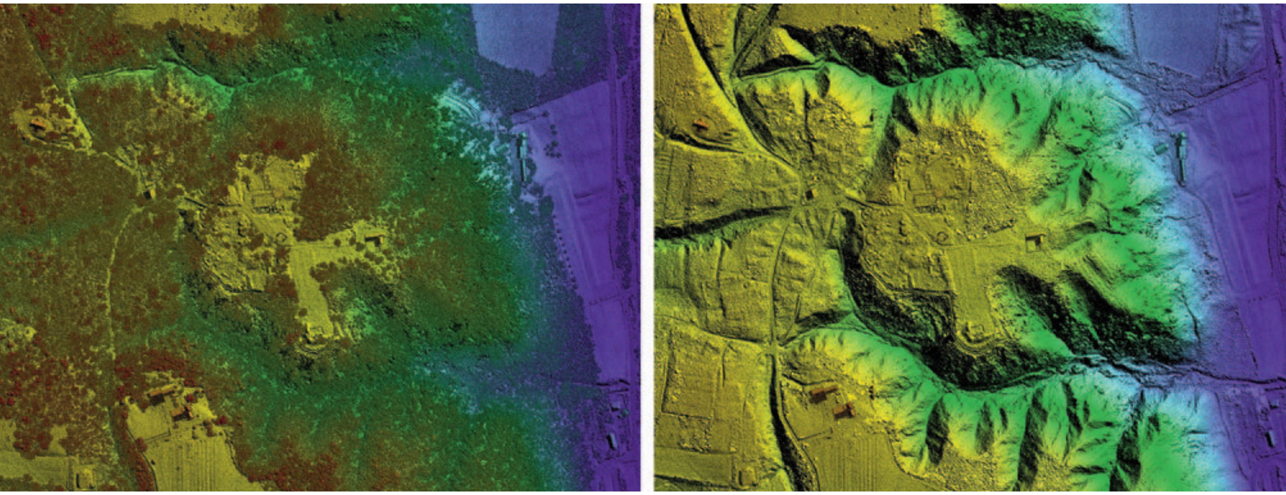

Fig. 4. Digital surface model (DSM) obtained from LiDAR data processing. In both views, the area is the same. All the objects' classes were represented on the left, while on the right, only vegetation was excluded (elaboration TeCMArcH Laboratory).

are often represented in a general way (1:5.000, 1:10.000 and 1:25.000) which does not match their geometric consistency. Finally, the area has been archaeologically investigated in past survey campaigns. The remains are now not easily recognisable except for limited portions that are not represented in the currently available maps.

For greater immediacy of consultation and representation of the data, it was preferred to assign each point its category through semi-automatic processing systems[14], specially calibrated for the case of Castelseprio[15]. Despite dense vegetation, it was still possible to obtain numerous spatial data relating to the underlying ground thanks to applying appropriate algorithms and appropriate selection criteria[16] able to extract from the point cloud only the information deriving from the ground surface (fig. 4).

The surfaces' analytical functions[17] have proved profitable for the census of archaeological emergencies and highlighted morphological characteristics and elements of the territory.

[14] These are the categories identified using the TerraScan software: terrain, low-medium-high vegetation, buildings, water, roads, railways, power lines, overlap points, noise points and non-classifiable points.

[15] For further information on the use of LiDAR technology in the archaeological field: Garzulino 2019.

[16] Geometric parameters such as maximum admissible slope and acceptable height differences.

[17] For example, Shading, Hillshading, SkyViewFactor able to increase the shading effect to bring out the discontinuities more, to accentuate changes in elevation and better understand the course of the ground, to highlight concavity and convexity of the ground and structures.

A digital photogrammetric camera was also equipped on the airplane and allowed to perform numerous aerial shots of the entire archaeological area. These images were processed using image-based photogrammetric systems and Structure from Motion techniques (SfM) to obtain a three-dimensional texturised model with high-definition details. From the perspective of dimensions, proportions, and precision, the model has been verified thanks to the LiDAR point cloud. Therefore, the results obtained have allowed creating new cartographic support to ground all the analytical elaboration of the project.

Therefore, the results obtained made it possible to create new cartographic support to base all the project's analytical readings.

A.G.

4.1. Outcomes from different LiDAR datasets

When approaching the wider territorial context of an archaeological site and questioning about its unexcavated features, resorting to aerial surveys is often considered a good starting point and a support for focused fieldwalking and topographic surveys. Nevertheless, the current availability of different technologies and datasets and their fast development and updating suggests that clearly defining objectives and analysing local conditions is of paramount importance in order to select the most effective technology, being at the same time aware of the limits that affect each kind of dataset.

The project carried out in Castelseprio posed methodological issues related to the understanding of the unexcavated areas, in particular of the consistency of the *borgo*, on the western side of the plateau. Past investigations, mainly carried out by archaeologist Mario Bertolone between 1946 and 1950, offer important hints about the borgo, but a general layout of the settlement has yet to be outlined. Both this part of the plateau and the north-eastern area of the *castrum* are woodland. This is the reason why a dataset based on LiDAR data has been considered the proper base for a map supporting visual survey and fieldwalking: LiDAR data have been successfully used in the past decades for detecting remains located under canopy trees, which are therefore not visible in aerial photos, and often even difficult to be identified during fieldwalking and located by means of a traditional topographic survey. In a LiDAR data acquisition, the width of the pulse hitting the ground, which – depending on the flight height – can reach several decimetres, and the possibility of laser devices to register multiple responses of the same laser beam, provide the recording of the portions of the signal that not being stopped by leaves and branches, reached the ground, thus suggesting a common impression that "the signal has penetrated the canopies".

Therefore, the general idea is that a good collection of ground-points can provide a Digital Terrain Model (DTM) to evaluate the local morphology and, when accurate enough, to point out the presence of artefacts. Scientific publications deal mostly with successful results of LiDAR in archaeological applications, so the present contribution prefers to point out some critical steps in the use of these data in contexts, quite common in Italy, like the one in Castelseprio. As a flight was carried out by CGR in 2015, it is also possible a general assessment outlining the main differences between a customised dataset and the one already available, which was acquired by 2010 by the Italian "Ministero dell'Ambiente" and supplied through the infrastructure "Geoportale Nazionale". The Ministerial LiDAR data are available for the entire national territory – mapped mainly for hydrogeological purposes –, thus constituting a source with an enormous potential for archaeological research nationwide, once their proper fields of application have been clarified.

First, it is important to remark, though quite obvious, that local conditions can affect significantly the output of a LiDAR flight; the conditions can be mainly referred to as: 1. kind of woodland and 2. consistency of the expected archaeological remains. The case of the Castelseprio area poses some of the worst conditions: dense deciduous trees compose the woodland with medium to dense low vegetation, making it necessary to plan the data acquisition in winter to maximise the number of ground points. According to the metadata, the Ministerial point cloud on Castelseprio was acquired on June 1st 2009, and that (which was probably necessary to avoid snow layers on the north faces of the close Alps) reduced the density of ground points acquired in the woodlands. The result is that 0.5 points per square metre are available. This dataset is very useful for general geomorphological information, such as slopes, impluviums, detection of past landslides etc., and can support the investigation on mounds at least 4 metres wide, but, of course, it has not been planned to support the investigation on smaller scattered remains.

As 8 points per square meter are considered the minimum threshold for archaeology-tasks (Opitz pers. comm. 2011), a specific LiDAR flight was planned and carried out in the Castelseprio area in 2015 December 5th (fig. 5). It was scheduled in winter with an acquisition parameter aimed at maximising data in the area of interest, mostly woodland.

Point cloud density is determinant for the Digital Terrain Model's accuracy (DTM), which is the output generally used for preliminary archaeological investigation as it displays an easy-to-read and intuitive image of the ground. As many experts and scholars often remark, looking clear and intuitive and being the output of a laser-based technology does not mean that a DTM is an objective data and a perfectly corresponding cast of the ground surface: the process from raw data to DTM goes through a noise reduction and a classification process that can be based on different filter algorithms, each generating a different result (Pfeifer, Mandlburger 2009, pp. 307-333). Depending on the kind of forest (deciduous or evergreen, coppiced or wild, dense in understory canopies or clear), the proper algorithms should be used to provide the most suitable classification process or different steps in data processing might be required (Opitz, Nuninger 2014).

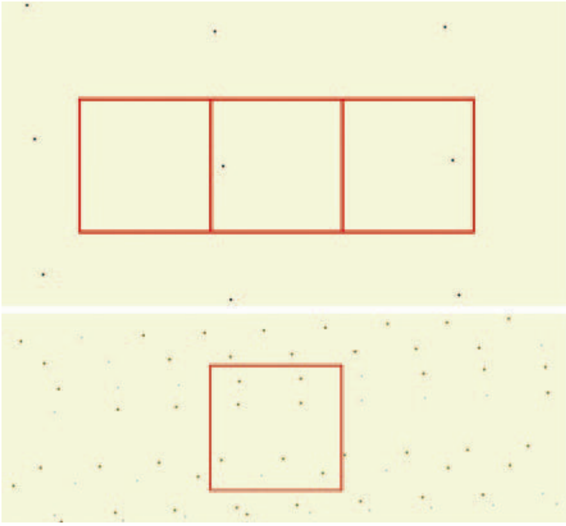

Fig. 5. Comparison between 2009 (above) and 2015 (below) point clouds on the same spot within a 1-meter square: the point density is 0.75 points/sqm in 2009 data and 8 p/sqm in 2015 data (elaboration TeCMArcH Laboratory).

It is important to remark that woods have been present in the Castelseprio area at least since the 16th century, and a thick layer of humus now covers most of the evidences that may emerge only a few decimetres from the ground level. As the objective is to detect also small elevation anomalies of the ground surface, any predefined and standard algorithm creating a DTM by smoothing the surface should be avoided.

The surface model generated with the 2015 point cloud is not a DTM, but a Triangulated Irregular Network (TIN), which makes use of all the points acquired and classified as ground points without decimating or oversampling points according to the DTM cell size. As a TIN is a 2.5D surface, effective hillshading visualisations can be applied to point out anomalies. Another tool to detect anomalies is to apply a Sky View Factor calculation to a high precision DTM (cell size below 1 metre), which can be generated only from a dense point cloud (fig. 6).

The outputs obtained from the 2015 LiDAR acquisition have been included in a database managed in a GIS environment, and, combined with a wide set of information coming from past archaeological investigations, it provided a significant base for 2016 activity on the field.

N.C.

5. Understanding the area: data collection, selection and processing in GIS environment

The research aimed at enhancing and systematise most of the datasets generated in decades of archaeological investigation and excavation in Castelseprio. Along the time, different outputs of subsequent campaigns have been archived

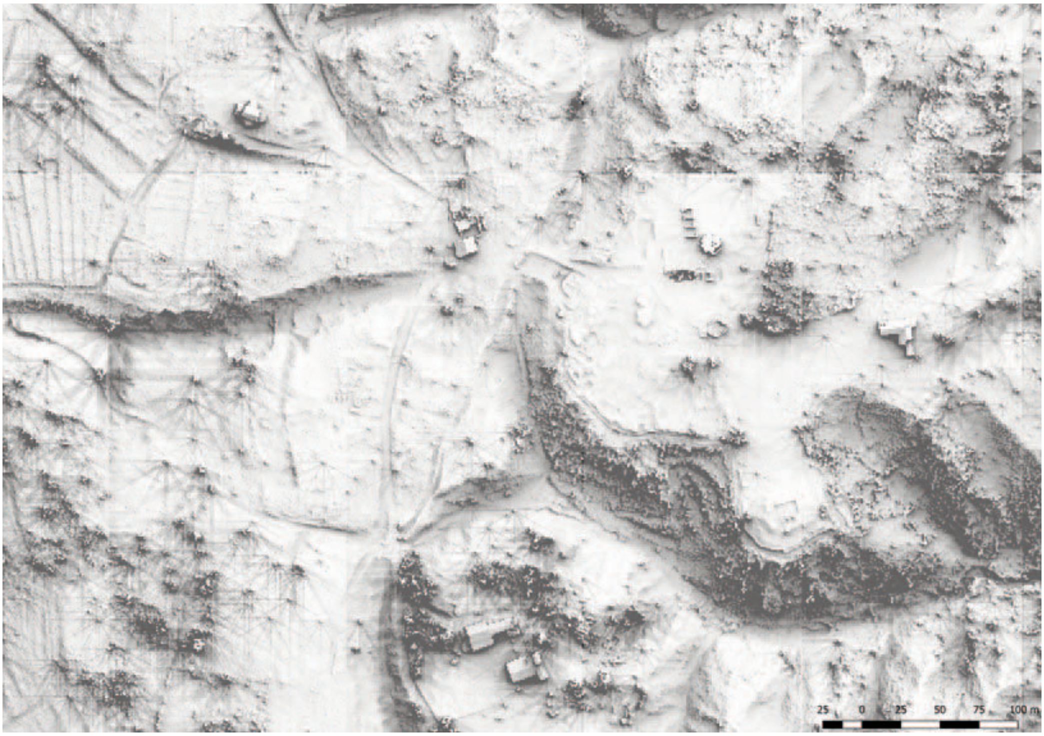

Fig. 6. Example of a Sky View Factor calculation provided by a 0.5 m cell-size DTM based on 2015 LiDAR data (elaboration TeCMArcH Laboratory).

on various supports, in forms of metrical surveys at different scales, photos, maps, descriptions and reports etc. The possibility provided by a GIS environment to collect all these different formats into a unique database made it possible to put in relation all the outputs, properly organised and classified, and to create a new starting point for a better understanding of the site. GIS has therefore been used as a tool to study the *castrum*, the *borgo* within Castelseprio and retrace the multiscale relations between the wider area and the archaeological site.

The GIS project set up is composed of vectorial, raster and textual data that have been collected and selected from previous datasets or created specifically for the task.

Collected data include open geographical data[18], which provided a wide thematic variety of datasets, and historical maps. All these data have been georef-

[18] Data can be downloaded from the websites of the following institutions: Regione Lombardia (Geoportale and Open Data), Provincia di Varese, Comune di Castelseprio, Comune di Gornate Olona, Parco della Media Valle Olona and Parco Rile Tenore Olona, Statistique Suisse, UNESCO World He-

erenced on a second dataset, based on the Carta Tecnica Regionale at different scales – 1:50.000 and 1:10.000 – as a base for information at the regional scale, and, for a more accurate georeferencing of data concerning the archaeological area and its immediate surroundings, on the processed layouts of the LiDAR dataset acquired on purpose in 2015.

As the GIS environment and the collected dataset enable multiscale investigation, three territorial levels, at different scales, have been focused on, as it was possible to detect and point out a set of relations (physical, functional, historical, cultural, visual, symbolic, etc.) intertwining the three ranges, maintaining Castelseprio as a central point: the Seprio Valley; the Olona Middle Valley; Castelseprio Archaeological area.

Seprio Valley dataset

The dataset referring to the Seprio Valley, analysed at a nominal scale of 1:250.000, focused on the system of relations between territorial morphology, lakes-watercourses and waterways, and the area's road-network between the 1st and the 6th century, as defined by the current research outputs (De Marchi 2013, pp. 16-22). For its geographical location, in the high Middle Age, the Seprio Valley started being a crucial intersection and intermediate point between the plan, the morainic hills and the valleys leading to the alpine passes. The road layout was a unique network with the waterways and adapted to the territorial morphology, relying on a system of defensive and control strongholds with different functions and ranges (*ibidem*).

Starting from the bibliography and basing on cartographic data describing soil, hydrogeologic and morphological characteristics of the area, the position of important places has been pointed out, and the three main historical routes in use in the valley between the 1st and the 6th century have been retraced (fig 7).

A shapefile (named *viabilita_antica.shp,* polyline) records these routes: 1. Milan - Sesto Calende - Angera - Alpine passes; 2. Milan - Ceresio; 3. Como - Vico Seprio - Novara. This file matches with a second one (*localita_in_epoca_longobarda.shp*, point) which displays the main inhabited and urban centres along the routes. The Milano - Ceresio route followed the Olona river and crossed Castelseprio. Another important route was the Como - Vico Seprio - Novara, based on an axis orientation from North-East to South-West crossing the territory and the two other ways.

Middle Olona Valley

The second area of investigation in the GIS environment is defined by the Middle Olona Valley, a portion of the Seprio Valley. It has been analysed at

ritage Sites; see sitography. More than 400 files have been collected during the first part of the research.

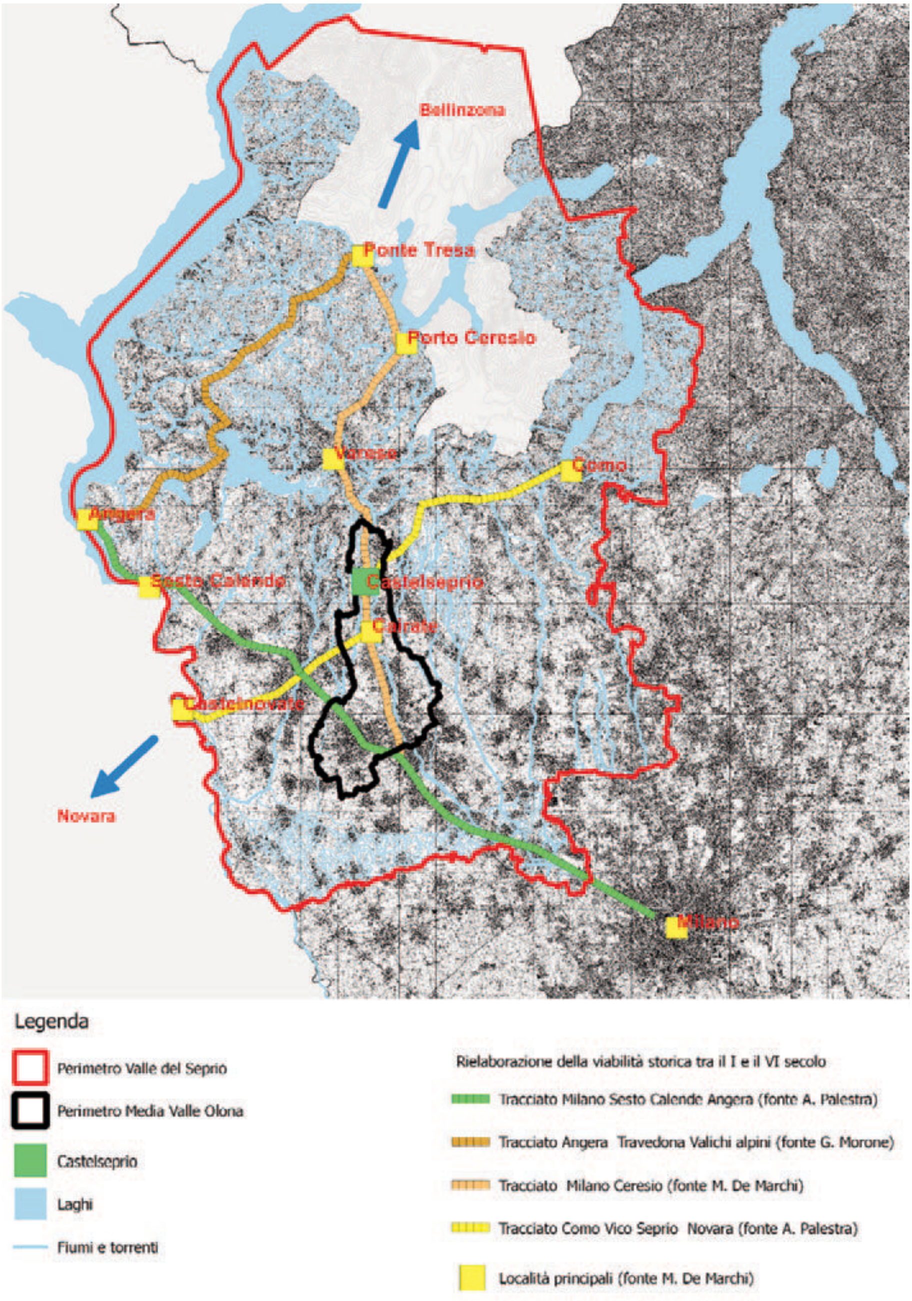

Fig. 7. The relation between road network from the 1st to the 6th century, watercourses and lakes, and geomorphology in the Seprio Valley territory (TeCMArcH Laboratory).

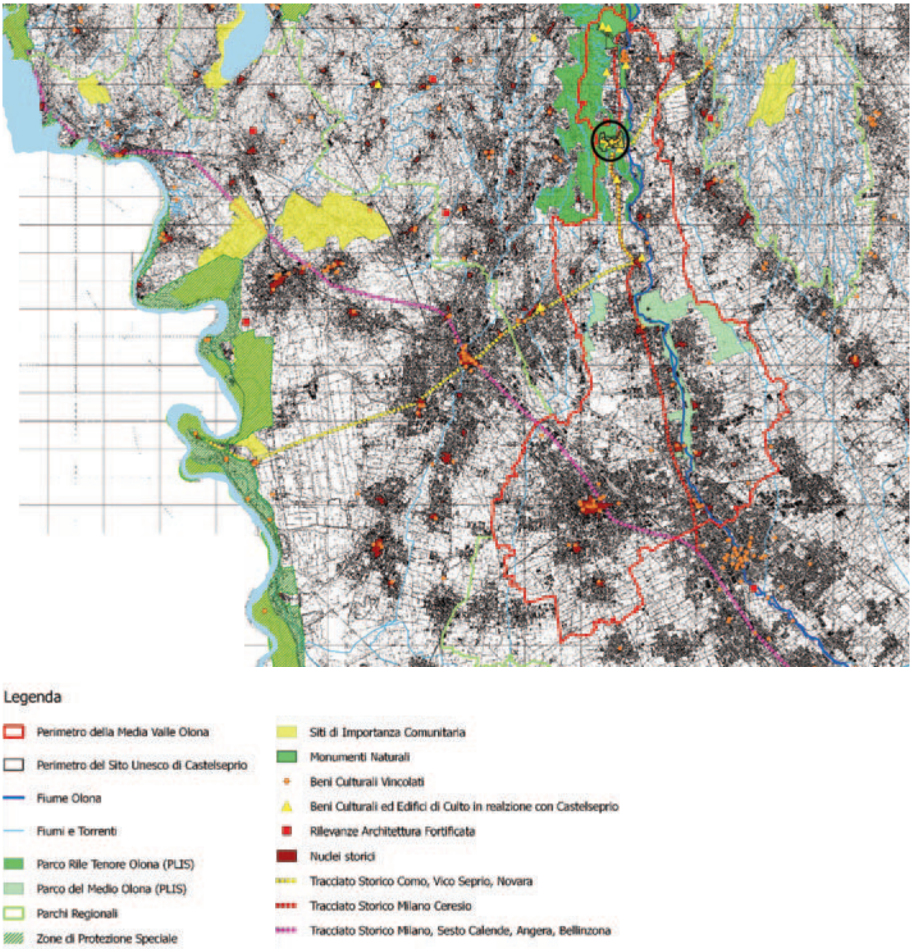

Fig. 8. The Middle Olona Valley: data to focus on the relation between Cultural Heritage and Natural Protected areas (TeCMArcH Laboratory).

1:50.000 – 1:25.000 nominal scale; as this scale is the one in use by the planning actions of the supra-local institutions (mainly clusters of municipalities, besides the former *Provincia di Varese* and *Regione Lombardia*), the aim was to focus on the current relations between the Cultural Heritage sites, the Natural Protected areas and the Parks, to analyse the possible enhancement of cultural routes and fruition and to position the site in a network of points of interest, that enables the understanding of the cultural landscape. At the same time, this area of interest and its dataset suggested the importance of considering an archaeological site on a broader timeframe, as part of a palimpsest involving traces of past land-scape as well as current territorial planning and land use.

The Olona Valley is rich in cultural and natural elements, which may be understood in their ties providing new key-interpretations of the landscape features: cultural heritage location, urban settlements, road network, hydrological net, natural areas and their peculiarities. Each layer can be read in relation to the others, thus providing keys to detecting past and present phenomena. This part of the research dealt with the check and the screening of data to control the quantity and quality of the strictly necessary information. The most meaningful ones are the perimeter of the Middle Olona Valley (whose definition has been one of the results of the research), UNESCO Castelseprio area perimeters, hydrographic network, natural elements and parks, cultural heritage sites according to the *Regione Lombardia* database (point shapefiles referring to historical settlements, fortifications, listed cultural heritage), the heritage sites and the places of worship strictly related to Castelseprio. By superimposing the layers concerning the cultural heritage and the historical communication network, it is possible to remark how strictly Castelseprio was linked to the surrounding settlements along the Milan - Ceresio and the Como - Novara routes: the location of graveyard churches and places of worship suggests the remarkable role of Castelseprio over the surroundings, thus providing evidence of the wider context and the existence of a unique frame joining apparently scattered sites like the Monastery of S. Maria Assunta at Cairate, S. Giulio church at Cassano Magnago, S. Michele oratory at Gornate Olona, S. Nazzaro church and S. Martino church at Caronno Corbellaro, and S. Michele Arcangelo church at Mornago.

By superimposing the layers concerning the natural environment and the Parks, specifically the Rile - Tenore - Olona Park and the Middle Olona Park, it is possible to set Castelseprio currently among wider opportunities of the fruition of the territory to seize to the complexity of the present landscape, basing on slow and gentle-mobility planning.

Castelseprio Archaeological area

A more detailed dataset concerns the Archaeological area. It aims to link the data collected in archival and bibliographical research and data coming from data processing, thematic analyses, surveys and fieldwalking on-site to provide a complete and detailed overview aimed at safeguarding and enhancing the site. The nominal scale goes from 1:500 to 1:2.000. Among the layers of the dataset, there are the UNESCO core and buffer zone, the active landslides and local hydrogeologic system, the permanent elements of the anthropic environment derived from the historic cadasters, topographic and archaeological surveys of the artefacts and the excavated areas, mapping of the scattered archaeological evidences, interventions carried out on the area.

One of the first issues at the archaeological scale concerns the relation between geomorphology and archaeological evidences. It is clear that the monu-

Fig. 9. Geomorphology and archaeological evidences (by L. Scesi, E. De Finis).

mental complex's location in Castelseprio and the close-by Monastery of Torba are strictly related to the local geomorphology: the *castrum* is located on a fluvioglacial plateau deeply engraved by river erosion and subject to landslides, as a consequence of high and frequent rainfall. Therefore, the safeguard and conservation of the area rely on the control of the geomorphological and forest asset: instability, erosion, and vegetative cover must be managed to reach a sustainable point of balance.

The data used to deal with geomorphological and archaeological issues are both vector and raster. In the first category, there are layers about areas of diffused instability, terrace edges, riverbeds and alluvial mounds, landslides escarpments and landslide niches, small trenches, conoids etc., detected through a local survey (Scesi *et al.* 2016). The cartographical base for the on-site geomorphological investigation is the Digital Terrain Model (DTM) obtained from the Ministry LiDAR data acquired in 2009. An orthophoto with a 10 cm ground sample distance acquired in 2015 has been used as well.

The collection of data referring to the built environment includes an articulated interpretation of historical cadastral maps, and the Istituto Geografico Militare Italiano (IGMI) maps before the advent of aerial photogrammetry. These maps have been georeferenced and, by representing chronological threshold quite recent but still meaningful, they demonstrated to be of some interest to analyse the permanent elements of the territory as well as its transformations:

- *Catasto Teresiano* - 1721/1722;
- *Catasto Lombardo-Veneto* - 1862;
- *Cessato Catasto* - 1905-1960;
- *Catasto terreni vigente* (current cadaster)[19];
- IGMI *serie 25 V* (sheet 31 –II SE), 1884; 1905; 1916.

Four sheets from the *Teresiano* Cadaster[20] and five from the *Lombardo-Veneto* Cadaster[21] have been composed to create two raster layers. The control points used for the georeferencing process have been detected in the 2015 LiDAR output. Superimposing the current cadaster helped in pointing out the permanent elements in terms of buildings, paths, property divisions, cultivation differences etc. Each past cadaster was an instrument for the fiscal census of properties, and the results can be meaningfully different according to the purpose and economic strategies of the entrusting government, that is why in the *Teresiano* Cadaster, the complex of S. Giovanni Evangelista, S. Paolo and two towers along the Southern walls of the *castrum* are recorded. At the same time, no traces of them are reported in the following *Lombardo-Veneto* cadaster. On the other side, the *Lombardo-Veneto* Cadaster maps canals and streams, which are not recorded in the *Teresiano* one. Comparing the two, the texture of the properties is approximately the same; the current property texture still follows the same layout as the historical one, that seems to be the result of the presence of obstacles, like, for instance, archaeological evidences, that often mark the borders between different properties (the defensive walls are an important sign the property system refers to), and the terrain morphology. These observations are

[19] Supplied by the former*Direzione Regionale per i Beni Culturali e Paesaggistici della Lombardia*, now *Segretariato Regionale del Ministero dei Beni e delle Attività Culturali del Turismo per la Lombardia.*

[20] FG -1-B-D - FG -2-A-C - FG -3-B-D - FG -4-A-C.

[21] FG -1-D - FG -2-b - FG -2-D - FG -3-A - FG -3-C.

Fig. 10. *Teresiano* Cadaster and some permanent elements (TeCMArcH Laboratory).

collected in two shapefiles, which are the output of this specific part of the research.

Concerning the *castrum*, a shapefile named *manufatti_500.shp* (polyline) contains the topographic survey carried out in 2002 by the operators from the former *Soprintentenza Archeologica della Lombardia*, Milano offices. Connected to the elements mapped, it is possible to open the forms regarding conservation issues (Gasparoli *et al.* 2016) and the archaeological sheets (Massa 2016), which are all documents issued in the project's frame and are archived as external link accessible from the GIS environment.

The archaeological area of Castelseprio is also characterised by a quite significant amount of evidence and remains in the area referred to as *borgo*, which lies on the western side of the plateau out of the castrum is currently covered by a forest. Another task of the research aimed at collecting data about these remains to provide a general layout of what might have been the past settlement.

A significant part of these remains were mapped by the archaeologist Mario Bertolone during campaigns in 1946 and 1948-50 (Bertolone 1954), but not many of them are visible. The maps published by Bertolone have been vectorised, and georeferenced locally, basing on the field investigation results and on the Triangulated Irregular Network (TIN) obtained from 2015 LiDAR data. The content of *Rilievo_Bertolone_1948.shp* (polyline) has been classified according to the legend attached to the original map to maximise the transfer of information. It provided a significant layer dealing with little known parts of Castelseprio and the possible general relation of the settlement and the local morphology.

The *borgo* areas outlined by Bertolone are actually split into two sub-areas defined by the two different protrusion of the plateau, and they have been object of a fieldwalking and archaeological survey to point out the archaeological risk of the area. All the remains detected during the on-the-spot investigation have been mapped through a GNSS device in RTK mode. The points thus determined, and each remain attribute, as defined by the archaeologist Prof. Serena Massa, populated a shapefile named *survey* containing over 190 points.

The outcomes of this on-site investigation, combined with Bertolone's maps and the TIN, might be a good starting point for planning further archaeological investigation and other activities regarding the site, as they provide a general layout aiming at describing the *borgo* according to the current knowledge.

R.M.R., N.C.

Conclusions

The research activities took advantage of a multiscale and interdisciplinary approach to match fragmentary information and to obtain the most from each technology adopted. From the methodological point of view they helped in general in defining potentialities and limits of the manifold data available (historical maps, cadaster, open access territorial data, LiDAR point clouds, etc.) and their proper field of application. In the specific case of Castelseprio the research activities enhanced the comprehension of the relations between the monumental complex and its context, suggesting new issues to be investigated.

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