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PRELIMINARY RESULTS OF THE CASTELMONARDO PROJECT

1. Introduction

The medieval remains of Castelmonardo near Filadelfia (Calabria, Italy) play a very important role for the local community in terms of cultural memory and identity. In the 18th century a catastrophic earthquake (de Dolomieu 1784; Sarconi 1784) totally destroyed the ancient town of Castelmonardo. The inhabitants moved a few kilometers away and founded the new town Filadelfia. People continued to be emotionally linked to the remains of the ancient town. Local historians and scholars have demonstrated their interest in the remains of Castelmonardo, giving the input for archaeological explorations and excavations in selected areas (Maestri 1978, 1982). In the 1990s and during the last years explorations and archaeological excavations were undertaken by volunteers ("Gruppi Archeologici d'Italia") under the directions of archaeologists in cooperation with local institutions. Despite the interventions above mentioned, Castelmonardo is largely archaeologically unexplored and a specific scientific documentation about the site is still lacking.

The recent development of advanced technologies in archaeology, such as non-invasive archaeological prospections (e.g. Trinks, Neubauer, Doneus 2012; Corsi, Slapšak, Vermeulen 2013; Rzeszotarska-Nowakiewicz 2015) allow the efficient exploration of large areas with high accuracy in a cost-efficient way. On the other hand, Virtual Archaeology (e.g. Forte, Siliotti 1997; Neubauer *et al.* 2014), which is focused on the scientific virtual reconstruction of archaeological contexts and historical landscapes, plays an increasingly important role in the enhancement and communication of archaeological sites. Combining the scientific documentation, which is generated from archaeological prospection, excavations and virtual reconstructions, with appropriate story-telling techniques the efficient and scientifically correct dissemination and communication of Cultural and Archaeological Heritage can be achieved.

The considerations above could appear fairly trivial if we think in theoretical terms. However, in practice, the application of such strategy is not often implemented, especially in the Italian context. Without embarking on the specific topic of Italian policies concerning cultural heritage, which is an argument beyond the scope of this article, we have generally observed a lack of systematic strategies specifically focused on the enhancement of the archaeological site through the integration of advanced technologies, from the non-invasive survey (archaeological prospection) to the 3D reconstruction and communication. From this point of view, the un-explored Castelmonardo offers a good opportunity to test and develop innovative strategies of enhancement of the archaeological site, starting from the very early stage of the research.

2. The ongoing project

The Department of Art, History and Performing Arts of the Sapienza University of Rome in cooperation with the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) has recently initiated the pilot project "Castelmonardo: From Remote Sensing to 3D Reconstruction. An example of technological research and humanities synergies for the development and communication of the territory" with the goal to explore, document and disseminate the historic-archaeological heritage of Castelmonardo. The project is based on the assumption that the historic-archaeological research applied to a specific territory should be conducted through the use of cost-efficient advanced techniques and integrated to a high quality level of dissemination and communication. The accessibility for the local community to its own historical and archaeological heritage is a fundamental aspect for the development of sustainable strategies for the preservation and valorization of cultural heritage. For that reason, an international cooperation has been established between the above mentioned institutions, with the goal to develop a good practice for the scientific investigation and communication of the historic-archaeological heritage of Castelmonardo. The Italian company OBEN s.r.l., which is specialized in remote-sensing technology, and the Virtutim srls working on communication techniques for cultural heritage have cooperated in the project. The local "Istituzione Comunale Castelmonardo" is also actor in the project, cooperating in logistic aspects and communication.

The present paper describes the first step of the project, which has been focused on the high resolution large-scale exploration of the archaeological site through the use of advanced remote-sensing techniques.

3. The area of interest and specific research aims

The archaeological area of Castelmonardo is located on a sandstone hill in Calabria, a few kilometers SE of the modern town Filadelfia (Vibo Valentia, Italy). The hill rises from the height of about 300 m to about 560 m and is bordered, respectively to its north-western and south-eastern sides, by two narrow valleys where, respectively, the two water streams Prantari and Greto flow. On the south-eastern side of the hill there are the evident traces of large landslides likely directly related to the catastrophic earthquake, which destroyed Castelmonardo in 1783 (de Dolomieu 1784; Sarconi 1784). The whole area is characterized by fairly dense Mediterranean vegetation and by small-size agricultural areas, mainly used for olive trees cultivation.

The archaeological remains in the site mostly belong to the medieval settlement. A few archaeological finds dating back to the Neolithic period also were detected (V. Rondinelli, personal communication), demonstrating that it was also inhabited in the Prehistory. Our focus is mainly addressed to the medieval town and the possible presence and detection of prehistoric traces will be not treated in this article.

The most evident remains of Castelmonardo consist in the foundations of a fortress ("Rocca"), on the top of the hill, and the remains of a large church. A few underground rooms (*ipogea*) and fountains located on the slopes of the hill also characterize the site. The archaeological evidence indicates that the area was fortified since the Byzantine period (Maestri 1978). The oldest written sources about the site date back to 1000 AD. It is known that Castelmonardo was provided of a large number of churches, public buildings, fountains and mills. Based on the distribution of the remains and the topography of the site we can assume that the town covered an area of about 15-20 ha.

The archaeological area, with regard to the "Rocca" and church, is reachable through a NE/SW road, partially set on an ancient path, which presumably crossed the town approximately in the same direction. The structures situated on the slopes of the hill are not easily reachable.

Considering the irregular topography, the hardly reachable areas and the presence of remains, which are partially hidden by vegetation, we have addressed our attention to remote sensing techniques with the goal to perform a preliminary exploration of the site. Due to the lack of high resolution topographic data concerning the area of interest, we focused our efforts in the production of a high resolution Digital Terrain Model (DTM), with the specific goal to perform a preliminary mapping of the site in the GIS environment. The high resolution DTM was also created with the goal to use it in further steps of the project, for which high resolution geophysical surveys (Ground Penetrating Radar, GPR) in selected areas are planned.

For the high resolution measurements of the ground surface, the Light Detection and Ranging (LiDAR) technology has been preferred to the aereo-photogrammetric techniques, which are based on aerial imagery and are not efficiently usable in the presence of vegetation cover.

4. The LiDAR survey

Airborne LiDAR is an active remote sensing technology allowing the efficient collection of highly accurate elevation measurements of above-ground features and ground surface topography (e.g. Kraus, Otepka 2005; Doneus, Briese 2006). The distance to the target is measured by illuminating it with a pulsed laser light and recording the reflected pulses through a sensor. LiDAR measurements allow the creation of accurate DTMs even in forested areas due to the capability of the pulsed laser light to partially penetrate the vegetation and reach the ground (e.g. White *et al*. 2010; Esposito *et al*. 2014; Balsi *et al*. 2016).

In archaeology, high resolution DTMs derived from LiDAR data are being increasingly used in the preliminary detection and mapping of archaeological features like buried structures, paths and roads. However, LiDAR data and derived products are not always easily available, especially for Italian archaeological projects. The most common problems occurring in the collection of LiDAR data in archaeology come from the following reasons: for mapping over large areas, LiDAR data are traditionally collected from aircraft, which represents a fairly expensive methodology, not always supportable in the frame of archaeological projects. Even if LiDAR data are usually made freely available by Italian regional Institutions ("Regioni"), not all Italian regions are totally covered by LiDAR surveys and it can happen that no LiDAR data are available for a specific archaeological site. If LiDAR data and derived products are available, they are generally the result of surveys conducted with environmental purposes and are not specifically focused on archaeology.

The Unmanned Aerial Vehicles (UAV) LiDAR technology is a relatively new technology based on high precision laser scanners that are integrated with internal Global Positioning System (GPS) and Inertial Navigation Systems. The data collection is performed by means of a UAV or RPAS (Remotely Piloted Aerial System), commonly known as "drone". Compared to the more traditional Airborne LiDAR, the advantages in performing UAV LiDAR acquisition is represented by the possibility to obtain higher point density, more flexibility and a cost-efficient survey. This appears a more accessible and suitable technology for archaeological purposes.

5. Data collection and processing

The UAV LiDAR survey was conducted in late winter, with relatively low vegetation growth. Survey and data processing were performed by OBEN s.r.l., an Italian enterprise, spin-off of the University of Sassari (http://www.oben.it/).

An area of 32.6 ha was scanned by using a YellowScan LiDAR, mounted on a RPAS as shown in Fig. 1. The RPAS is 1.8 m-diameter octo-copter, permitting GPS waypoint navigation, auto take-off and landing, a payload of over 4 kg and 20 minutes cruise-range.

The LiDAR is integrated with internal Inertial Navigational System (INS) and GPS receiver enhanced by Real Time Kinematic (RTK). Dimensions, weight and autonomy of this LiDAR are about 17×21×15 cm^3, 2.1 kg, and 3 hours respectively. Such characteristics make this LiDAR a good solution for

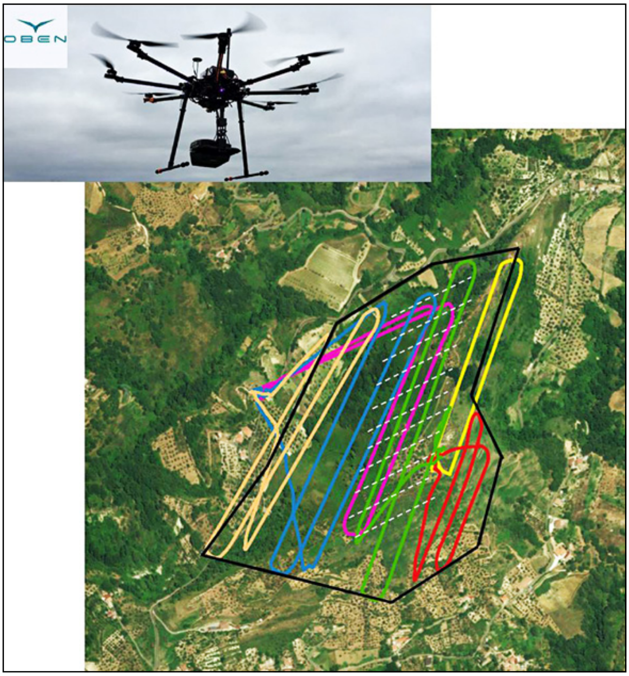

Fig. 1 – UAV LiDAR survey in Castelmonardo: the six flights performed by OBEN s.r.l. through RPAS (Remotely Piloted Aerial System) (above, in the figure) are indicated by continuous lines. Dashed lines indicate the area of overlapping, where the highest density of archaeological structures is expected.

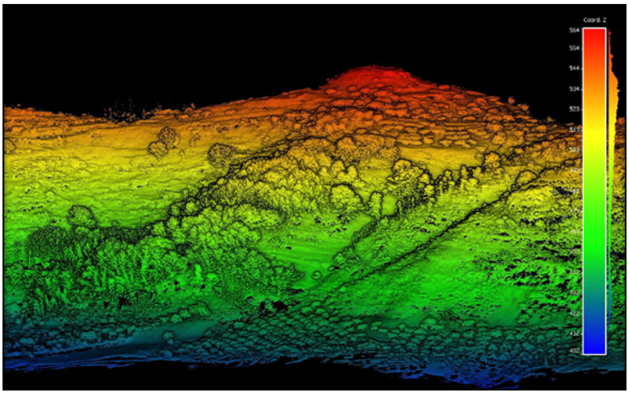

Fig. 2 – 3D visualization of the LiDAR point cloud clearly showing the vegetation (trees) above the ground surface. Graphics: S. Esposito.

light UAV applications. The LiDAR operates up to 100 m above ground level. It provides high density measurements with average positioning accuracy of 40 cm and typical products scale of 1:1000. Scan angle range is ±50°. The system provides up to three echoes per shot, allowing to also obtain returns from ground under vegetation cover, exploiting gaps that are present even in dense canopies (Fig. 2). The site was surveyed by carrying out six flights collecting seventeen strips (Fig. 1). Strips overlap in the central and eastern part of the survey area, where the highest density of urban medieval remains is situated.

The raw product issuing from LiDAR scanning is a point cloud, i.e. a dense set of points organized in 3D space and accurately georeferenced. The cloud can be viewed from any angle using appropriate software (e.g. CloudCompare, Fugro), and sections can be extracted. Raw data were post-processed using a QGIS plugin provided by the LiDAR manufacturer. Average (all returns) point density and spacing are about 67.33 pts/m² and 0.12 m respectively.

Semi-automatic analysis and classification of the point cloud has been performed with the goal to separate points belonging to ground and those belonging to vegetation. A 0.40 m resolution DEM (Digital Elevation Model), including all elements (i.e. ground and above-ground elements) has been generated. From the ground points a 0.40 m DTM representing the elevation of "bare earth", including morphology, has been created.

In both DEM and DTM the particular morphology of the hill is well enhanced in the high resolution LiDAR data. Even though most of archaeological remains like the fortress, the church and other buildings are not directly under dense vegetation cover, the DTM offers nevertheless a clearer image of the morphology, allowing a better archeological interpretation of the site. In specific areas of interest, direct examination of the point cloud, or of a high-resolution mesh derived from it, can give even more detailed information.

6. GIS-based visualization

Visualization techniques (e.g. Kokalj, Hesse 2017) for raster data, like relief shading and slope (gradient), allow the presentation of the LiDAR data in a more readable way, greatly helping in their archeological interpretation. Relief shading, also known as hillshading, describes how the relief surface reflects incoming illumination based on physical laws or empirical experience. Illuminating the surface from different directions a better interpretation of the morphology can be obtained (Kokalj, Hesse 2017, 16-19).

Slope also represents in most circumstances an excellent visualization technique (Challis, Forlin, Kincey 2011). It represents the maximum rate of change between each cell and its neighbors. If presented in an inverted

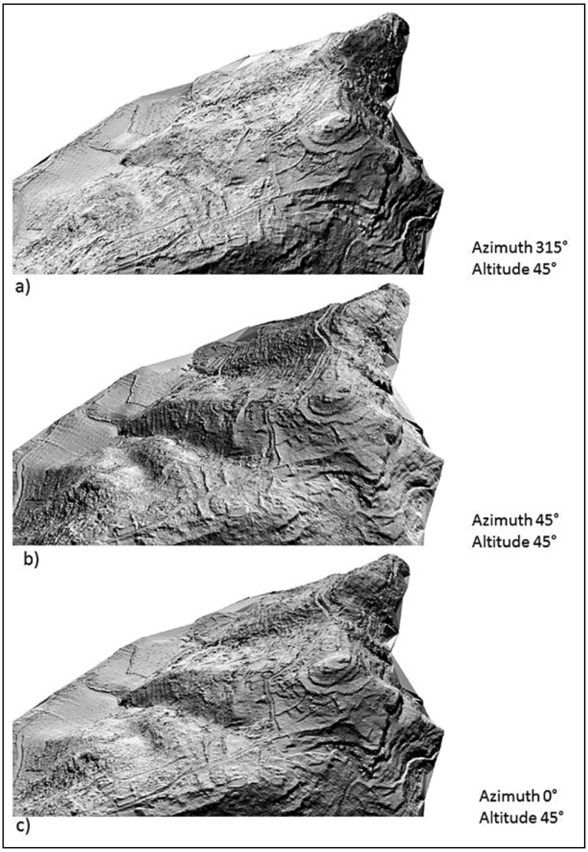

Fig. 3 – Hillshading visualization (DTM) in the 3D GIS environment (ESRI ArcScene) from three different directions of illumination. Graphics: V. Poscetti.

greyscale (steep slopes are darker), slope offers a very plastic representation of morphology (Kokalj, Hesse 2017, 19). Both hillshading and slope have been applied to our data, with regard to the DTM.

For the relief shading (Fig. 3) we have tested three different directions of illumination by setting the azimuth to 315°, 45° and 0° respectively. The sun elevation has been maintained to 45°. We have then compared the three images in the 2D (ESRI ArcMap) and 3D GIS environment (ESRI ArcScene). In particular, the comparison between the first two images (Fig. 3, a-b), where the morphology of the north-western and south-eastern sides of the hill is shown with different characteristics, greatly helped in the interpretative mapping of the area of the fortress.

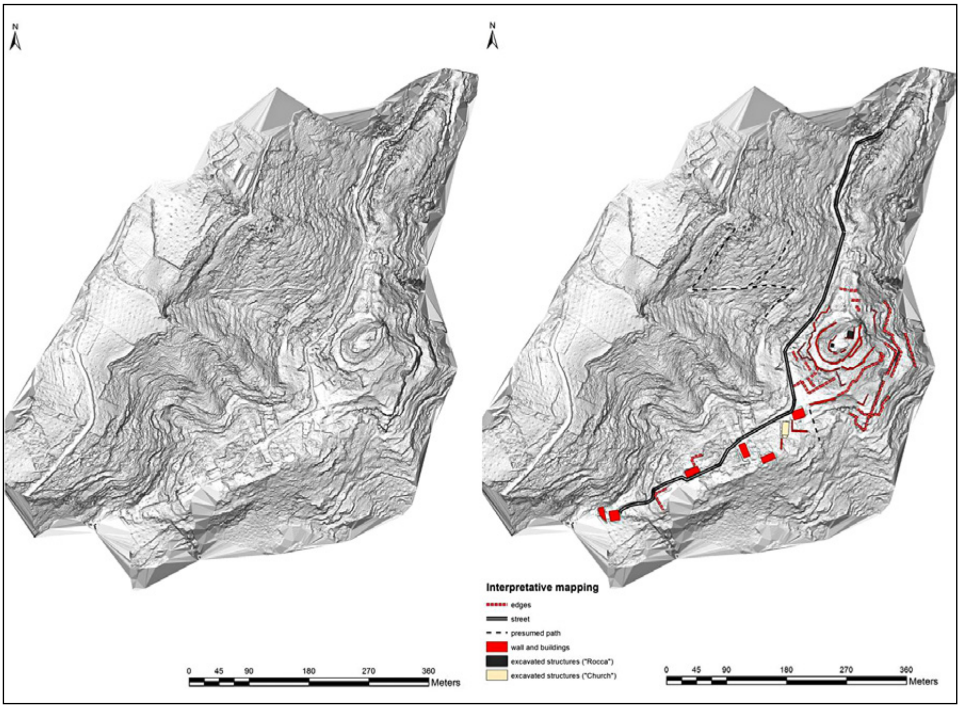

Fig. 4 – Left: slope visualization by means of an inverted greyscale (steep slopes are darker). Right: Archaeological interpretation of the features. Dashed lines on the top of the hill (edges) hypothetically indicate the structures of the fortress with enclosure walls located at different elevations. The NE-SW modern street crossing the site is partially set on an ancient road. Graphics: V. Poscetti.

All the three greyscale images have been then used to create a RGB colour composite image by assigning the images to the red, green and blue colour channel (Devereux *et al.* 2008; Hobbs 1999). The resulting image seems nevertheless not to offer in our case a great advantage in data interpretation. We found the simple and interactive comparison of the three images in the 3D GIS environment a better solution to analyze the data.

The applied slope algorithm combined with inverted greyscale visualization describes at best the particular morphology of the site (Fig. 4). However, small features like the walls of the church and other buildings are better detected in the hillshading visualization.

7. Interpretative mapping

The typical morphology of the site, which is strongly related to the remains of the fortress, is well enhanced in the DTM. The features (Fig. 4) seem indicate at least three enclosure walls, which are located at different elevation on the highest part of the hill, in the range 510-560 m. The excavated remains of the "Rocca", including a 9×10 m building-tower and a squared tower of about 4×4 m, are relatively well detected in the DTM. However, comparing the area of the "Rocca" with aerial images (2016), we observe more details in the aerial images. This could be related to the fact that in the LiDAR data points from small bushed and low vegetation, that partially hid the structures of the "Rocca" in the period of the survey (2017), were not perfectly separated from the archaeological remains in the automatic classification process. Also in other few cases the direct comparison of the DTM with aerial images in the GIS environment helped us in the interpretation of the features, especially on the border of the investigated area, where the raster does not present a good interpolation due to the lack of the data.

We have observed that most of archaeological features are located on the top of the hill and on its partially collapsed eastern side. In the small forested area in the sloping north-eastern side, the DTM did not detect relevant archaeological remains. A zig-zag linear feature could be interpreted as path, maybe in relation with the ancient town.

8. Conclusions and future directions

The application of the UAV LiDAR technology in Castelmonardo was very satisfactory, allowing a preliminary investigation of the whole site in a very efficient way. The applied LiDAR system permitted a good penetration through the vegetation allowing the generation of an accurate high resolution DTM, which was efficiently used in the GIS-based interpretative mapping. The applied visualization techniques performed in the GIS environment allowed an immediate visual perception of the relevant archaeological features in the DTM.

At the state of the research, the interpretation regarding enclosure walls and paths still remain hypothetical, until verification on site is made. Most linear features, very probably related to the remains of medieval buildings, have been also hypothetically interpreted. Except for known excavated structures, like the remains of the "Rocca" and the excavated remains of the church (Fig. 4), most of the detected features should be further investigated in detail. Despite the good quality of the LiDAR data, the comparison with aerial images effectively contributed for a better data interpretation.

For the future, geophysical surveys like GPR in selected areas are planned. Considering the irregular topography of the site, only a few small and relatively flat areas can be investigated by means of GPR.

Based on the results of all archaeological prospections and historical documents, a virtual 3D reconstruction of the site will be realized. The possibility of exploring and analyzing the ancient site of Castelmonardo within an interactive virtual 3D environment, which includes 3D reconstructions of buildings embedded in the historical landscape, is a fundamental aspect of the project. The analysis and documentation of environmental elements, like water resources, in relation to anthropic interventions also will be part of our future work. The final output of the work will consist in multi-media presentations through storytelling techniques, which represent a very suitable method for effective communication, allowing the public to perceive, understand and learn about their own cultural heritage in an immediate way.

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ABSTRACT

The remains of the medieval town of Castelmonardo (Calabria, Italy) are located on a hill, a few kilometers SE from the modern town of Filadelfia (Vibo Valentia). Since the 1970s archaeological excavations have been carried out in selected areas of the hill. However, a systematic archaeological investigation of the whole archaeological site has never been conducted before. The paper presents the preliminary results of the first archaeological prospection conducted in Castelmonardo by means of advanced remote sensing techniques, with the goal of achieving a first GIS-based digital mapping of the archaeological site. The recently developed UAV LiDAR technology, consisting in the use of high precision laser scanners mounted on Unmanned Aerial Vehicles (UAV), commonly known as drones, was applied to realize a high resolution digital terrain model (DTM) of the site. Integrating the LiDAR data with web GIS based aerial images,

a preliminary archaeological interpretation of the whole archaeological site was conducted, offering a suitable base for further analysis and virtual reconstructions. The work presented here was conducted as part of a recently initiated research project focused on Castelmonardo, led by the Department of Art History and Performing Arts - Sapienza University of Rome, and conducted in cooperation with DigiLab Research and Services - Sapienza University of Rome, Istituzione Comunale Castelmonardo - Filadelfia (Italy), the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology - Vienna (Austria), Virtutim srls and the Italian company OBEN s.r.l.