LiDAR based investigation of subtle microtopographical proxy indicators: the case of Seluci Castle
(Lauria, Basilicata)

V. Vitale[1], N. Abate[1], A. Minervino Amodio[1], D. Ferdani[2], N. Masini[1]

[1] National Research Council – Institute of Heritage Science, C.da S. Loja, Tito Scalo, 85050 (PZ),
(valentino.vitale, nicodemo.abate, antonio.minervinoamodio*)@ispc.cnr.it*
nicola.masini@cnr.it
[2] National Research Council – Institute of Heritage Science, Area di Ricerca di Roma 1, Strada della
Neve, Via Salaria km 29.300, 00010 Montelibretti (RM), daniele.ferdani*@cnr.it*

Abstract – **The aim of this work is to investigate an abandoned medieval highland fortified site through LiDAR methodology. Much of the evidence that may have been preserved over time at sites of this type turns out to be untraceable for years through on-site survey activities. In the case of Seluci Castel (Lauria – PZ, Italy), the topography of the settlement, exclusively represented by the rectangular-plan tower located on the top of the mountain, was not clearly defined. The possibility of discerning the datum through LiDAR acquisition allowed to clarify and identify some of the fundamental elements that went to make up what can be considered not only a lookout and defense point such as Seluci Castle. Interpretation of the same data were helpful to further understanding of the site.**

I. INTRODUCTION

In hilly and mountainous contexts, the possibility of identifying the presence of ancient settlements is closely linked to the conservation of microtopography which is what remains after centuries or millennia of continuous erosive action.

Microtopography used as archaeological proxy indicator is visible as shadow marks using optical remote sensing imagery, backscattering signal from SAR imaging, and microrelief detectable from LiDAR-derived DEM suitably enhanced based on visualization techniques [1].

Among the three different options, the one based on LiDAR and derived models is the most effective in terms of the ability to distinguish microtopographic archaeological features from those of geomorphological nature.

This is even more true for subtle microtopograhical features, as in the case of the medieval castle of Seluci.

The paper deals with the results of a LiDAR based approach, including the data acquisition, the filtering, and the integration of diverse visualizations techniques the improve the reconnaissance of subtle microtopographic features to facilitate their archaeological interpretation.

II. STUDY AREA

Seluci Castle stands on the mountainous peak at an altitude of 978 m above sea level, isolated in the landscape of the Sinni valley, in Southern Basilicata (Italy). The visibility from the site is extraordinary, widely spanning the side of the Sinni on the center of Latronico (PZ) and that of the upper valley toward Mount Sirino, as well as the valley of Cogliandrino (PZ) in the direction of Grumento Nova (PZ). Seluci is recorded in a bull of 1079, in which it is mentioned among the inhabited centers that Alfano, archbishop of Salerno, recognized as an ecclesiastical fief subject to the jurisdiction of the bishop of Policastro. It is later mentioned with other centers under the name of *Sollucium*, in a document by Charles of Anjou in 1278, which required said centers to "*reparari*" the castle of Rocca Imperiale [2]- [3].

Seluci Castle was investigated by the Archaeological Superintendence from 1990 to 1995, and allowed the recognition of a phase of Lucanian age (6th-5th centuries BC) and a phase of medieval age (11th-14th centuries AD) [4]. Seluci is part of a real network built in the Middle Ages for the defense of the territory, which included settlements, fortified places, and road control points. The top of the mountain is the site of the main fortified keep, stretching southward and occupying its summit; the mountain top then declines toward W-NW, with a wider plateau in marked declivity. The main structure has a rectilinear frontal barrage, consisting of a large wall septum, 25 m approx. long and preserved in elevation for 3 m apporx. (Fig. 1) [5].

Fig. 1. Seluci Castle (Lauria - PZ): general oblique views from UAS acquired by drone from V. Vitale

The complex, with an elongated rectangular shape oriented in the NS direction, is divided into at least four rooms with undefined functions between them. A first large building (27x14.5 m approx.) is divided internally into three rooms. The construction technique, but especially the layout of the complex at the summit with a barred keep, would support a chronology of the first facility between the 11th and 12th centuries AD [5]. In the SW portion, a few meters lower than the top tower, a small rocky ridge, 60x20 m approx. in width could be indicated as the area where the settlement related to the medieval fortified site of Seluci must have stood.

On it are scarcely visible leveling of the rock and some areas of accumulation consisting of limestone drafts that would possibly document the presence of rooms. Following the edge of the ridge along the southern slope, the base of a quadrangular tower was identified, consisting of a smaller room measuring 2x2 m (small tower?) and a larger room measuring 4x4 m per side.

The orography of this area becomes steeper in succession, and just downstream from these latter structures, a slight ravine in the rocks allows passage along a path made in the rocks [5].

III. MATERIALS AND METHODS

A. Data photogrammetric acquisition

The aerial proximity footage acquisition phase was performed using DJI Matrice 210 multirotor UAS equipped with a high-resolution (20MP) RGB X5S camera. The area acquired is about 8 ha (hectares) and is characterized by strong elevation changes with considerable slopes developing from E to W.

In order to carry out a high-precision photogrammetric survey with a drone, the flight software was used *UGCS®* (https://www.ugcs.com/). This software enables the creation of a flight plan for the drone to follow by setting parameters of (i) flight height, (ii) flight speed, (iii) camera shutter speed, and (iv) lateral/frontal overlap between acquired photos. In addition, UGCS enables the autonomous flight function called "terrain follow", which allows the user to fly at a constant height following the orographic profile of the ground (height A.G.L. - Above Ground Level) and obtain, in this way, the same resolution on the ground for each frame acquired.

Taking advantage of this function, the user can implement a DTM (Digital Terrain Model) or DEM (Digital Elevation Model) within the platform, or use those already present in UGCS such as the SRTM (Shuttle Radar Topography Mission) model. The area under investigation was acquired by a flyover at an A.G.L. height of about 100 m, which produced 143 RGB photos. The images were then processed within Agisoft Metashape® three-dimensional photogrammetry software.

The processing process included the following steps: (i) photo alignment and creation of the scattered point cloud, (ii) insertion of GNSS coordinates on the relevant ground markers, (iii) correction of photo alignment based on known GNSS coordinates, (iv) creation of the high-density cloud (115 mln points ca.), (v) creation of the three-dimensional model without and with textures, and (vi) creation of DEM and nadiral orthophoto (2.6 cm/pixel).

B. LiDAR Survey

The methodology used for the analysis of the Seluci Castle site can be summarized in three distinct and separate phases: (i) field data acquisition and processing (Fig.2), (ii) data post-processing, and (iii) interpretation of features of archaeological interest.
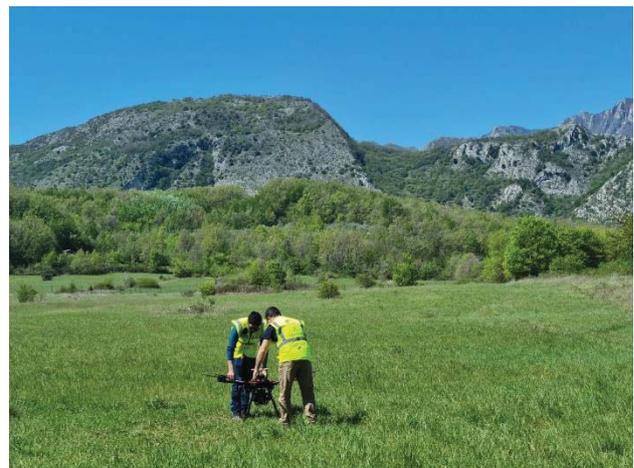

Fig. 2. Phases of field acquisitions (UAS operator N. Abate, V. Vitale).

The LiDAR (Light Detection And Ranging) survey, in this particular highland context, was carried out using a

269

Riegl MiniVux-3 laser scanner which employs the measurement technique called "on line wave form processing" which allows the complete analysis of the laser signal waveform and its digitization, on line and directly on board the scanner, with 5-echo measurements.

The laser is, in addition, equipped with a GNSS PPK positioning system, which is used as a payload on a DJI Matrice 600 drone [6]-[11]. The LiDAR acquisition covered a useful area of about 8 hectares, i.e., free of disturbances due to beam scattering [12]-[17] . The flight was conducted at an altitude of 70 meters A.G.L. (above ground level) at a constant speed of 3 m/s, in dual-acquisition grid mode, through the use of UgCS pro software, using the DEM provided by Tinitaly (http://tinitaly.pi.ingv.it/) for the Italian peninsula [18]. Data acquisition was followed by the data processing step, as described by Riegl for his instrument.

The processing steps to go from the LiDAR-acquired data to the georeferenced raw point cloud were (i) acquisition of GNSS RINEX data from fixed stations located in the Italian peninsula; (ii) correction of the route acquired by the PPK antenna based on the fixed station data, in Applanix POSPac UAS software; and (iii) use of Riegl's RiPROCESS® suite for creating and exporting the point cloud to the WGS 84 UTM 33 N system.

According to LiDAR specifications, under ideal conditions, each individual acquisition generated a point cloud with a density of 142 points/m2.

However, the acquisition was done in dual grid mode, a factor that allowed for greater density in the final product. The density was found to be uneven due to a number of determinants such as (i) the sum of points/m2 of the two individual point clouds generated by the individual acquisitions, (ii) drone speed subject to micro-delays/accelerations due to wind, and (iii) the morphological discontinuity of the recorded environment [12],[14].

Once the georeferenced point cloud was obtained, extraction of the terrain profile (ground points) was obtained using Global Mapper® v.22 software. The filtering operations of the point cloud to obtain the DTM were: (i) filtering of high-noise points (isolated and aerial points); (ii) classification of ground points from those belonging to other elements (e.g., vegetation, structures) using the software's automatic classification algorithm; and (iii) removal of low-noise points (i.e., points too far away from the points classified as terrain).

Finally, the refined point cloud was created and then exported. The resulting point cloud was then subjected to spatial resampling interpolation using the open source software Cloud Compare to obtain a cloud with a constant point density, set with a GSD (Ground Sample Distance) spacing of 0.02 m. Finally, the DTM was created and then exported.

The obtained DTM was then subjected to several operations to improve the rendering and visibility of the archaeological features. The operations were of two types: (i) noise reduction of the DTM and (ii) creation of DTM models derived from different visualization techniques. Noise and speckle reduction was performed using the GRASS GIS operator, in QGIS software. The algorithm used was an Enhanced Lee filter. The second operation

performed on the DTM after filtering with the Enhanced Lee filter was the creation of different derivatives, based on visualization techniques. These techniques are generally based on how the illumination interacts with the points in the DTM. The open source tool RVT (Relief Visualisation Toolbox) was used for this task. The data thus produced were subsequently analyzed in a GIS environment (Figg. 4-5), from which the resulting produced a dedicated archaeological cartography.
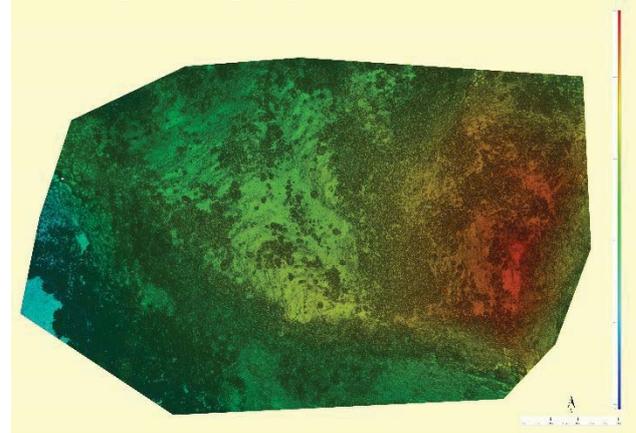

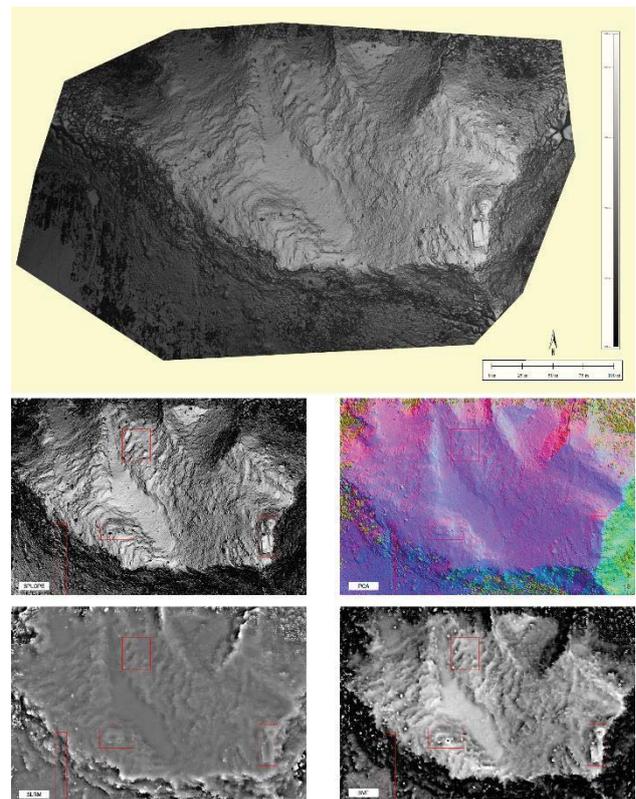*Fig. 3. DSM (Digital Surface Model) colour.*

Fig. 4. Example of data obtained from operations to improve yield and visibility: digital terrain elevation model (DTM), SLOPE, Principal Component Analysis (PCA), Simple Local Relief Model (SLRM), Sky-view-factor (SVF).
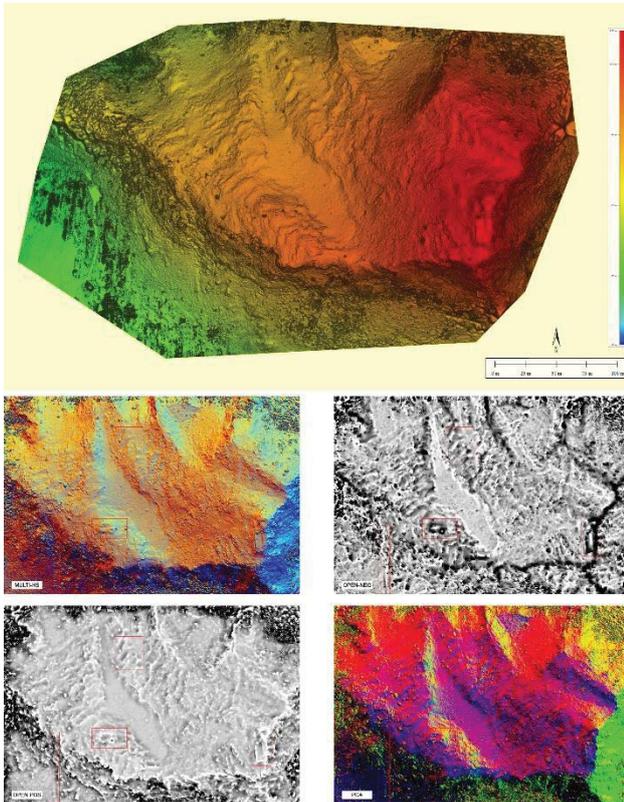
Fig. 5. Example of data obtained from operations to improve yield and visibility: digital terrain elevation model (DTM), Multi-Hillshading (MULTI-HS), Openness Negative (ON), Openness Positive (OP), Principal Component Analysis (PCA).

Fig. 6. Seluci Castle (Lauria - PZ): structures of the summit tower.

Fig. 7. Seluci Castle (Lauria - PZ): structures of the southern tower defending the main access to the site.

IV. RESULTS AND CONCLUSIONS

The result of this approach has been the possibility of discerning archaeological elements that are otherwise barely visible and difficult to reach through conventional archaeological survey techniques, providing the possibility of studying the very diachronic evolution of the fortified site of Seluci Castle [5].

Following up on earlier terrestrial survey activities, the LiDAR data specifically allowed for the definition of spaces and clarification of their topographical function in the general organization of Seluci Castle [19]-[24].

A LiDAR-based approach allowed the vegetation (or part of it) to be filtered, and the visual enhancement created through the derived LiDARs allowed the identification of microtopographic proxies of archaeological interest as shown in Figures 4 and 5.

Prior to this, the area from which the site was accessed in ancient times and much of the area on which the small settlement that served as the fortified center stood was partly completely unknown.

The defensive structures, clearly legible on the summit of the rise, were also part of a system that was in part more complex than a simple fortified summit turret (Fig. 6), assisted in their specific function by the redoubt located at SW of the summit, close to the access to the site, consisting of two rectangular rooms and probably intended as lookout and first defense turrets (Figg. 6-7) [5].

REFERENCES

[1] N.Masini, R.Lasaponara. "Sensing the Past from Space: Approaches to Site Detection". In: N. Masini, F. Soldovieri (Eds). Sensing the Past. From From artifact to historical site. Springer International Publishing, 2017, pp. 23-60, doi: 10.1007/978-3-319-50518-3_2.

[2] G.A.Magini, "Italia. Carta della Basilicata dei primi anni del Seicento", 1691-1692.

[3] E.Winkelmann, "*Acta Imperii inedita seculi XIII*, I", Innbruk, 778, rr. 34-37, 1880.

[4] P.Bottini, "Castello di Seluci e la viabilità antica nell'alto Sinni", in Carta archeologica della Valle del Sinni,

Fascicolo 7: da Episcopia e Latronico a Seluci e Monte Sirino, a cura di L. Quilici, S. Quilici Gigli, Roma, 2003, p. 259.

[5] V.Vitale, "Il paesaggio medievale nella Basilicata meridionale. Le forme del potere laico ed ecclesiastico nella media valle del Sinni tra X e XV secolo d.C.", BAR International Series 3042, 2021.

[6] M.Danese, D.Gioia, V.Vitale, N.Abate, A.M.Amodio, R.Lasaponara, N.Masini, "Pattern Recognition Approach and LiDAR for the Analysis and Mapping of Archaeological Looting: Application to an Etruscan Site". *Remote Sens.* 2022, *14*, 1587, doi:10.3390/rs14071587.

[7] N.Masini, F.Gizzi, M.Biscione, V.Fundone, M.Sedile, M.Sileo, A.Pecci, B.Lacovara, R.Lasaponara, "Medieval Archaeology Under the Canopy with LiDAR. The (Re)Discovery of a Medieval Fortified Settlement in Southern Italy". *Remote Sens.* 2018, *10*, 1598, doi:10.3390/rs10101598.

[8] B.Štular, E.Lozić, "Comparison of Filters for Archaeology-Specific Ground Extraction from Airborne LiDAR Point Clouds". *Remote Sens.* 2020, *12*, 3025, doi:10.3390/rs12183025.

[9] S.Buján, M.Cordero, D.Miranda, "Hybrid Overlap Filter for LiDAR Point Clouds Using Free Software". *Remote Sens.* 2020, *12*, 1051, doi:10.3390/rs12071051.

[10] C.Briese, N.Pfeifer, "Airborne Laser Scanning and Derivation of Digital Terrain Models, Proceedings of the 5th Conference on Optical 3D Measurement Techniques". In Proceedings of the GRASS, Proceedings of the GRASS Users Conference 2002; 2001, pp. 80–87.

[11] N.Masini, R.Coluzzi, R.Lasaponara, "On the Airborne Lidar Contribution in Archaeology: From Site Identification to Landscape Investigation". In *Laser Scanning, Theory and Applications*; Wang, C.-C., Ed.; InTech, 2011 ISBN 978-953-307-205-0.

[12] B.Štular, E.Lozić, S.Eichert, "Airborne LiDAR-Derived Digital Elevation Model for Archaeology". *Remote Sens.* 2021, *13*, 1855, doi:10.3390/rs13091855.

[13] A.F.Chase, D.Z.Chase, J.F.Weishampel, J.B.Drake, R.L.Shrestha, K.C.Slatton, J.J.Awe, W.E.Carter, "Airborne LiDAR, Archaeology, and the Ancient Maya Landscape at Caracol", Belize. *J. Archaeol. Sci.* 2011, *38*, 387–398, doi:10.1016/j.jas.2010.09.018.

[14] Ž.Kokalj, R.Hesse, "Airborne Laser Scanning Raster Data Visualization"; Prostor, kraj, čas; ZRC SAZU, Založba ZRC, 2017; Vol. 14; ISBN 978-961-254-984-8.

[15] N.Masini, R.Lasaponara, "On the Reuse of Multiscale LiDAR Data to Investigate the Resilience in the Late Medieval Time: The Case Study of Basilicata in South of Italy". *J. Archaeol. Method Theory* 2021, *28*, pp. 1172–1199, doi:10.1007/s10816-020-09495-2.

[16] J.-S.Lee, "Digital Image Enhancement and Noise Filtering by Use of Local Statistics". *IEEE Trans. Pattern Anal. Mach. Intell.* 1980, *PAMI-2*, pp. 165–168, doi:10.1109/TPAMI.1980.4766994.

[17] D.S.Davis, M.C.Sanger, C.P.Lipo, "Automated Mound Detection Using Lidar and Object-Based Image Analysis in Beaufort County", South Carolina. *Southeast. Archaeol.* 2019, *38*, pp. 23–37, doi:10.1080/0734578X.2018.1482186.

[18] S.Tarquini, L.Nannipieri, "The 10m-Resolution TINITALY DEM as a Trans-Disciplinary Basis for the Analysis of the Italian Territory: Current Trends and New Perspectives". *Geomorphology* 2017, *281*, pp. 108–115, doi:10.1016/j.geomorph.2016.12.022.

[19] R.Lasaponara, G.Leucci, N.Masini, R.Persico,G. Scardozzi, "Towards an Operative Use of Remote Sensing for Exploring the Past Using Satellite Data: The Case Study of Hierapolis (Turkey)". *Remote Sens. Environ.* 2016, *174*, pp. 148–164, doi:10.1016/j.rse.2015.12.016.

[20] *Satellite Remote Sensing: A New Tool for Archaeology*; R.Lasaponara, N.Masini, Eds.; Remote sensing and digital image processing; Springer: Dordrecht ; New York, 2012; ISBN 978-90-481-8800-0.

[21] J.R.Jensen, "Introductory Digital Image Processing: A Remote Sensing Perspective"; Pearson series in geographic information science; Pearson Education, Inc: Glenview, IL, 2016; ISBN 978-0-13-405816-0.

[22] T.M.Lillesand, R.W.Kiefer, J.W.Chipman, "Remote Sensing and Image Interpretation"; Seventh edition; John Wiley & Sons, Inc: Hoboken, N.J, 2015; ISBN 978-1-118-34328-9.

[23] Remote Sensing for Archaeology and Cultural Landscapes: Best Practices and Perspectives Across Europe and the Middle East; D.G.Hadjimitsis, K.Themistocleous, B.Cuca, A.Agapiou, V.Lysandrou, R.Lasaponara, N.Masini, G.Schreier, Eds.; Springer Remote Sensing/Photogrammetry; Springer International Publishing: Cham, 2020; ISBN 978-3-030-10978-3.

[24] S.H.Parcak, "Satellite Remote Sensing for Archaeology"; Routledge: London ; New York, 2009; ISBN 978-0-415-44877-2.