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### LiDAR for Italian archaeology. High-resolution elevation data to enrich our understanding of the defensive circuits of a protohistoric site in Southern Italy

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# AARGnews

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Cover photo:

Not the Roman town you may hope it to be but a WW2 military depot (although I can no longer find the reference/link to that) by Abbotsley Bridge, Cambridgeshire. Photo: Rog Palmer: 10 July 2018.

## **LiDAR for Italian archaeology. High-resolution elevation data to enrich our understanding of the defensive circuits of a protohistoric site in Southern Italy**

Jitte Waagen<sup>1</sup>

### **Abstract**

This paper presents a case study in which LiDAR data has been studied to provide information on the defensive wall-circuits of a protohistoric site in Southern Italy: Muro Tenente. By applying various approaches of relief visualization, in combination with blending techniques, the high-resolution elevation data is used to shed light on the overgrown and partly lost inner and outer walls of the ancient city. In addition to the application of various analytical representations, a more dynamic approach is proposed using 3D modelling software for real-time visualisations using a realistic shading render engine. The results present new insights into the morphology and preservation of the city walls, as well as providing a new hypothesis regarding their layout.

### **Keywords**

LiDAR, Italy, Muro Tenente, Defensive Circuits, Relief Visualisation Techniques, Blending Techniques, Blender, 3D

### **1. Introduction**

Airborne Laser Scanning, or LiDAR (Light detection and Ranging) has become a well-established source for studying archaeology in the last decade. Although its general value as an archaeological resource is widely recognized, methods for analysing and visualising the extremely detailed point clouds, and their potential for identifying specific archaeological features, are still a field of continuous exploration. This entails all kinds of techniques of manual modeling and terrain analysis, such as lighting, morphometry, image fusion, etc. that improve our perception of that data (cf. Costa-García and Fonte 2017; Doneus 2013; Forte & Campana 2017; Kokalj and Hesse 2017; Kokalj and Somrak 2019; Opitz & Cowley 2013), as well as (semi-) automated feature recognition to aid the archaeologist in tracing important features (cf. Lambers and Traviglia 2016).

These developments are fuelled, among other things, by the increasing availability of LiDAR data for regions in which aerial remote sensing has not been part of structural research agendas for studying archaeology. Italy is a case in point, where LiDAR data has been collected as a publicly available service from 2008 onwards, initially aimed at monitoring coast line and main rivers (2008-2009), later at areas with a high hydrogeological risk (2010-2011), and finally coverage has been enlarged by including secondary fluvial networks and areas with a high probability of landslide activity (2013-2015). Although the Italian territory is not yet fully covered (see García Sánchez 2018, García Sánchez & Waagen, forthcoming), data is now available for considerable parts of mainland Italy. A range of projects have since successfully applied LiDAR studies, using both private and public LiDAR datasets for tracing, documenting and monitoring archaeological remains (cf. Cifani et al. 2007a, 2007b; De Cazanove, 2016;

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Lasaponara et al. 2010b; Campana et al 2012; García Sánchez and Fontana 2016, García Sánchez 2018).

The study of LiDAR data is not a means to itself; it is a resource providing clues on the archaeology under study, and should be well-integrated into the broader set of archaeological techniques and strategies. This short case study aims to demonstrate the value of LiDAR data as an additional layer of information for the analyses of the archaeological site of Muro Tenente. By applying various techniques of LiDAR data visualisation the data provides new archaeological insights, gives a picture of the state of preservational aspects of the site, and provides clues for new hypothesis that will be integrated into future field expeditions.

## 2. The site of Muro Tenente

Muro Tenente is an archaeological site in the Apulia region, a complex protohistoric settlement dating from the first millennium BC (FIG. 1). The 52 ha large ancient fortified town is an important site for the archaeology of Southern Italy, with well-preserved remains giving evidence of domestic, burial and ritual practices. The VU University of Amsterdam has been conducting research on Muro Tenente for almost 30 years up to now, ranging from surveys, test-pits, coring and open area excavations, shedding light on key processes such as Greek colonisation and Roman expansion in southern Italy (e.g. Burgers 1998; Burgers & Napolitano 2010; Vermeulen, Burgers, et al. 2012).



**FIG. 1.** Satellite image (ESRI Satellite (ArcGIS/World Imagery) 2019), with some of its most conspicuous topological features: the defensive inner and outer wall circuits, as well as an excavated ancient road.

## 3. Analysis of the LiDAR data

The recently available LiDAR data provide an excellent opportunity to explore yet another layer of evidence on the ancient town, hopefully shedding light on features that are otherwise difficult to observe or analyse. It must be kept in mind of course that there are methodological limitations to LiDAR data and archaeological features on the ground may dodge a clear expression in the collected datasets. In the case of Muro Tenente, one can expect subtle features to escape notice due to thick low vegetation through which the LiDAR pulses only moderately penetrate and are

difficult to filter (Holata et al 2018: 2). On the other hand, the general morphology of the terrain should be well visible, as well as the still standing but overgrown parts of the defensive wall circuits. The latter provide indeed a nice example of the application of LiDAR analysis. In the following paragraphs, a couple of striking features of the LiDAR data on the defensive circuits of the site will be highlighted, using various methods for visualisation optimized for the specific archaeological features under study. Finding the optimal visualisation technique has been a rather experimental undertaking, informed by knowledge on the various representation methods (Kokalj and Hesse 2017; Kokalj and Somrak 2019); after all, no single method outperforms all others when it comes to archaeological feature recognition (cf. Roman 2016; Costa-García and Fonte 2017). In addition to relief visualisation techniques, image fusion (blending modes), i.e. pixels ascribed new values by an equation between overlapping cells of two or more raster layers, have been applied to enhance representations (cf. Kokalj and Somrak 2019: 10).

#### **4. From pulse to DTM**

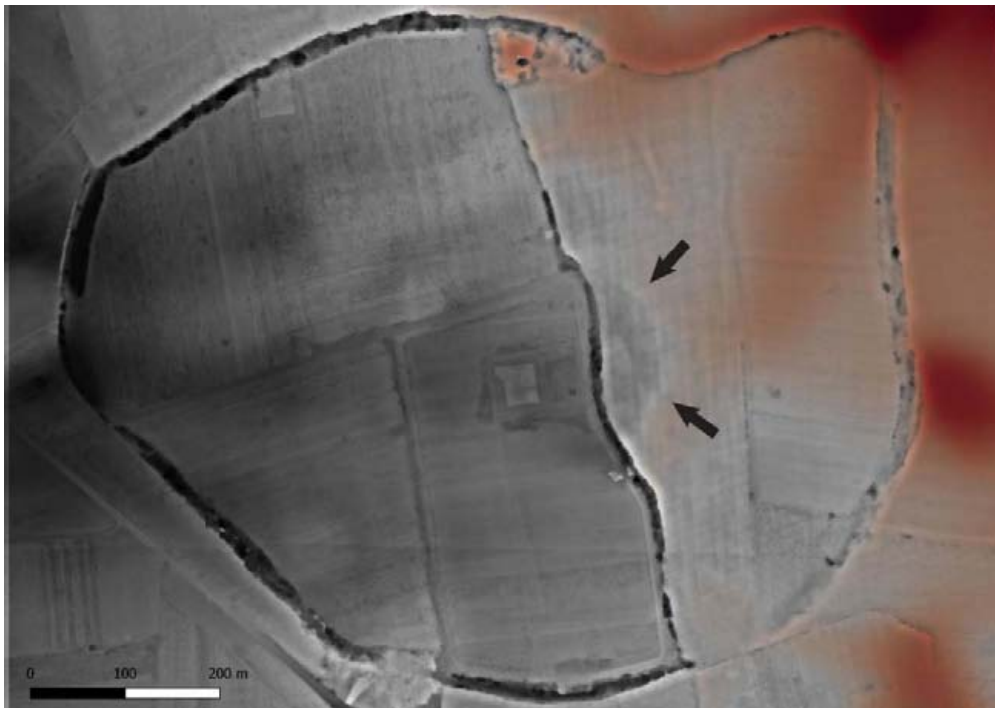
From the LiDAR data provided by the Ministero dell'Ambiente e della Tutela del Territorio e del Mare, the .xyz points have been converted to the .las format and projected to the WGS84 UTM33N CRS using lastools. Subsequently, the measurements in the .las file have been classified using the lasground algorithm from the lastools to generate bare-earth classified points. Then, the resulting points have been imported into SAGA where they have been gridded using an Inverse Distance Weighting (IDW) interpolation, search radius 10 mt, max. number of points 20 and IDW power 2, as well as cellsize, i.e. resolution, 20 cm. The resulting Digital Terrain Model (DTM) has been used for all further analyses.

#### **5. Inner city walls, trajectory**

The original layout of the site as drawn in the early phases of the survey of the site shows the trajectory of the inner wall circuit that has been based on the general topography and a general notion of higher densities of archaeological finds. It generally follows the course of an old dirt road that ran in a circle in the centre of the site. It has been excavated in various parts, showing indeed archaeological evidence of wall structures with towers, built in various phases from the late 4<sup>th</sup> to the beginning of the 3<sup>rd</sup> C. BC. Looking at various visualisations of the LiDAR data, it is possible to assess the exact course of the wall in a bit more detail. Examining the simple digital terrain model (DTM) of the ground classified points, resolution 20 cm, a slight circular elevated area can be detected in the eastern central part of the site.

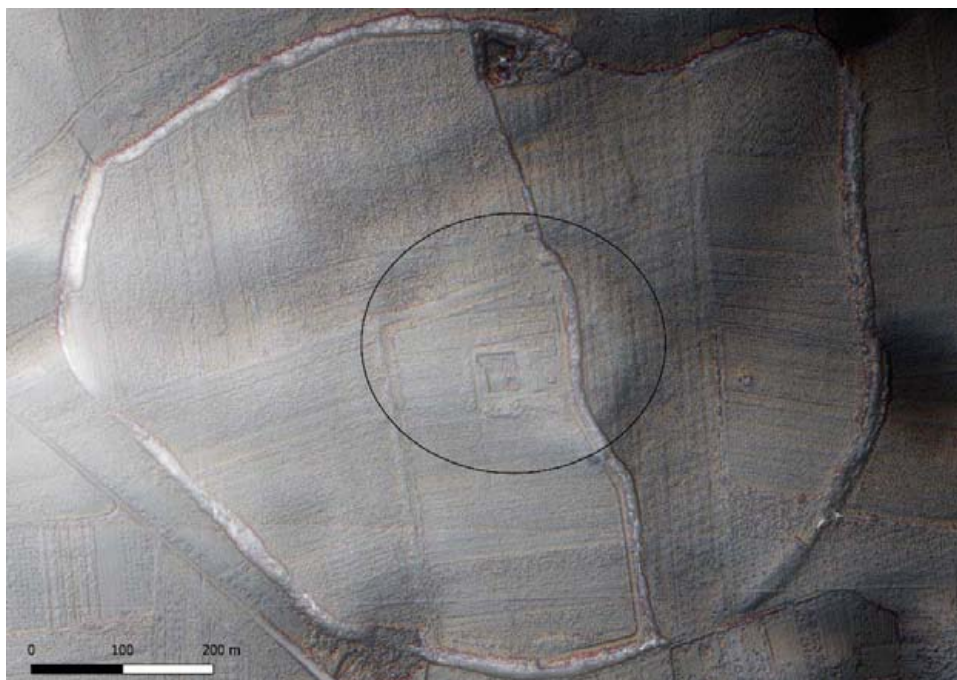
The elevation difference amounts to ca. 20-30 cm height difference, that, due to a gradual transition, is nigh undetectable in the field. The circular elevation is especially crisp on a rendering of the DTM blended with an optimized colour ramp blended with a local dominance model (FIG. 2). A local dominance model calculates the relative dominance, i.e. angle between an 'observer' looking down at surrounding pixels, and is optimized for very subtle positive and negative features (Kokalj and Hesse 2017: 25). It has been calculated here using a search radius of 20 mt and an observer height of 1.7 mt. The multiply blending mode literally multiplies pixel values from the DTM and local dominance, resulting in a strengthening of the visibility of the elevation difference.

To get a good view at the general morphology of the terrain, a resampling filter made with SAGA GIS software (Conrad et al. 2015, see Costa-García and Fonte 2017 on its application)



**FIG. 2.** DTM generated from LiDAR data with lastools, local dominance model produced in the Relief Visualisation Toolbox, rendering created using the blending mode 'multiply' in QGIS. Circular elevation difference in central area indicated.

on an exaggerated hillshade (3x) blended with the DTM provides a very useful image (FIG. 3). The resampling filter acts as a trend-removal technique that emphasizes local small-scale differences, which multiplied with the general image of the hillshade does a great job at representing both local and global morphology. A soft light blend with the DTM then subtly



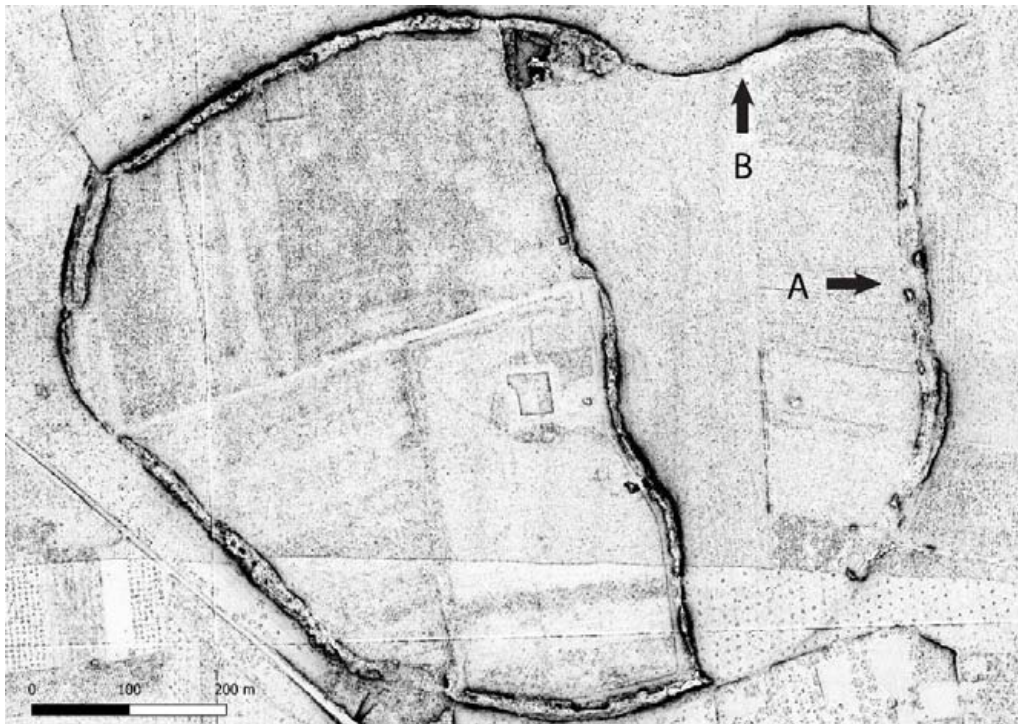
**FIG. 3.** DTM generated from LiDAR data with lastools, combined with a resampling filter of an exaggerated hillshade (generated with SAGA), combined in QGIS with the 'soft light' blending mode on the resampled hillshade. Trajectory inner city wall indicated.

emphasizes the lighter and darker areas, resulting in a smooth but very clear representation. Not only does this visualisation provide a good view of the eastern course of the inner wall circuit, but it also nicely shows the complete trajectory with exception from the southwestern part.

The exact nature of the elevation is hard to determine, but it may be a result of a local strong luting of sand and sand-lime bricks (Burgers 1998: 57), that defines a tough layer that gave shape to the central walled area and impeded a complete flattening of the terrain in subrecent times. A further clue is provided by projecting the Hellenistic pottery densities from the archaeological fields surveys that shows a nice spatial correlation (Burgers 1998: 53-94). The orientation of the most prominent features found in the Italian and Dutch excavation trenches appear to confirm the spatial arrangement as well; the trajectory indicated by the DTM is consistent with the Soprintendenza excavations from the 70s, that show an ancient road in roughly the same orientation (FIG. 1). We can safely redraw the central wall circuit according to the trajectory visible on the LiDAR data as it can consistently argued to be an accurate representation.

## 6. Outer city walls, morphology and preservation

The site of Muro Tenente is surrounded by the outer city walls. Although parts are preserved, they are not visible because they are covered by rubble and are heavily overgrown. Some small sections of it have been laid bare, which have shown an emplectrum wall building with various phases and probably towers, dating from the late 4<sup>th</sup> to the of the beginning 2<sup>nd</sup> c. BC. The major part of the trajectory has not been studied, and we had no clear picture of the degree of preservation of all of the probably partly upstanding structures. The canopy penetrating capacities of the LiDAR pulses however allow a rather sharp image, even enabling precise measurements of the actual structures. They are effectively visualised with a sky view factor (SVF) rendering of the LiDAR data, that shows the degree to which a location has an



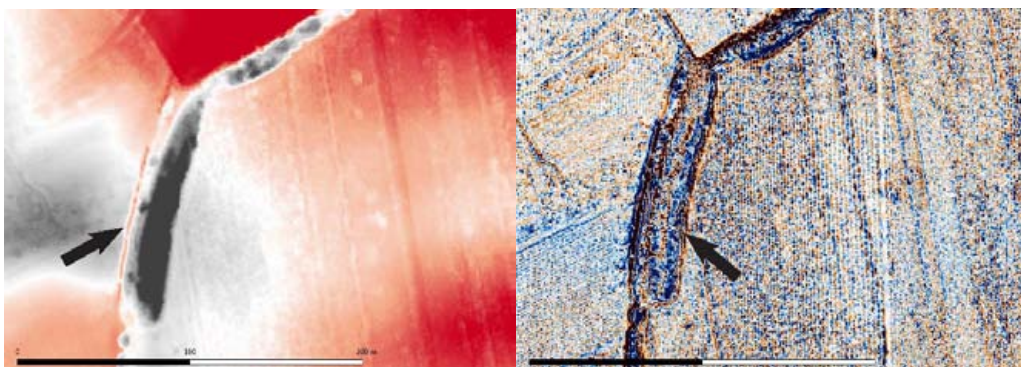
**FIG. 4.** Sky View factor rendering of the LiDAR data (generated with SAGA). Preserved parts of inner and outer emplectrum walls in the eastern area (A), plateau ridge in the northeastern area (B).



unobstructed hemisphere above it. The advantage of such a model is that it provides a sharp image of local differences in elevation. Where a hillshade shows the effect of directional sunlight over a terrain as modeled shadows, a SVF resembles the shadow effect in case of diffuse illumination, i.e. an overcast sky (Kokalj and Hesse 2017: 22). Although less subtle than the local dominance, the SVF has the advantage of the 'plasticity' of hillshade models and features are comprehensible to perceive (Kokalj and Hesse 2017: 22). It has here been produced with SAGA, settings default with the maximum search radius (FIG. 4).

Using this visualisation, we are able to assess the walls' general state of preservation, and locally study its construction. E.g. the eastern trajectory of the outer wall circuit is almost completely removed (mechanically), but it is still possible to follow its course, along which line there are still pieces left of the inner and outer emblectum construction. In areas where the wall is completely gone, such as in the northeastern part of the outer wall circuit, we still find clues about the trajectory. For the original reconstruction of the wall trajectory the subrecent road has been followed, which is now corroborated through the LiDAR analysis. The SVF presents a sharp contrast on the outer side of the road, showing that the road lies on the edge of a slightly elevated platform, which is the geological stratum known as the 'Gallipoli formation' (Burgers 1998: 57). The known wall structures make use of the elevation drop at the edge of this geological formation, to abut the wall. It is very plausible to suggest that the elevation drop indicated on the edge of the plateau is indeed the outer wall trajectory.

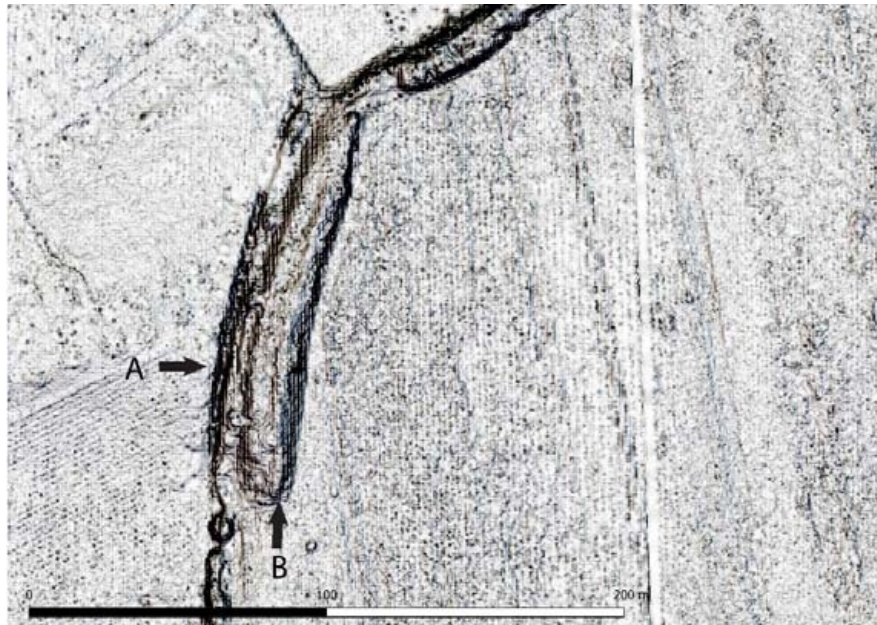
Of the northwestern preserved trajectory, a section of about 125 mt in the northwestern outer city wall is fairly conspicuous; parallel to the remains of the emblectum structure runs a stretch of about 5 m wide, demarcated by an apparent drop in elevation, which appears to be a 3 m wide, 1 m deep ditch, clearly visible on the DTM, with a local histogram stretch applied, stretching the colour ramp over the range of values visible in the extent of the map (FIG. 5A). Although the general shape is discernible on the SVF, a high pass over the resampling filter on the hillshade gives a slightly sharper image (its usefulness mentioned by Costa-García, personal communication). The high pass emphasizes the local small-scale differences, showing what is very likely the outer wall of the emblectum construction (FIG. 5B).



**FIG. 5A.** Local histogram stretch over the DTM rendering of the LiDAR data (generated with QGIS), parallel ditch indicated.  
**FIG. 5B.** High pass over the Resampling Filter (generated with SAGA), inner emblectum wall indicated.

Yet another rendering, this time a multiplication of a multiple hillshade and a Sobel edge detection provides the best overall image (FIG. 6). A multiple hillshade solves the problem of linearity (features lying parallel to the cast shadows) and loss of detail in areas with shadows cast over them (Kokalj and Hesse 2017: 16) by combining the results of 16 hillshade projections from different azimuths on a regular interval. The combination with a Sobel edge detection,

which is basically an image segmentation technique, emphasizes the edges without the effect of darkening adjacent pixels as with a SVF.



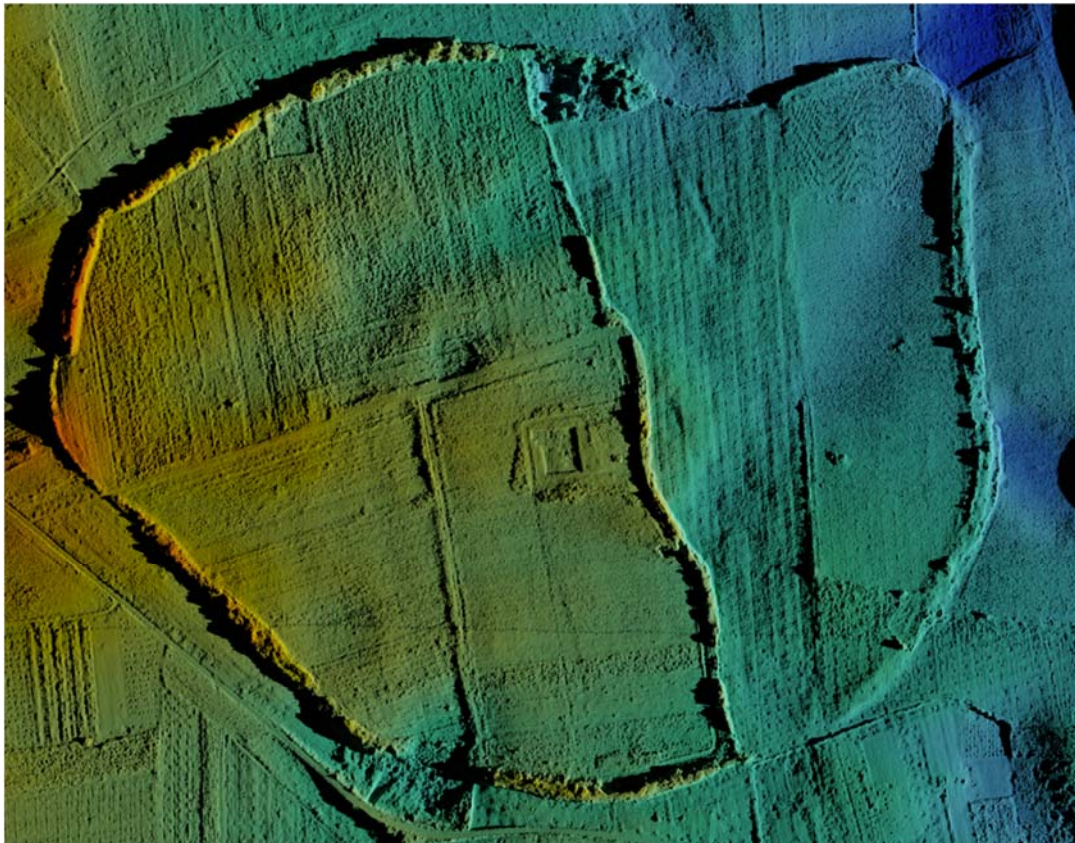
**FIG. 6.** Sobel edge detection (generated with Orfeo Toolbox, Monteverdi) combined with a multiple hillshade (generated with SAGA), rendering created using the blending mode 'multiply' in QGIS. Indicated are the ditch (A) and the inner emblectrum wall (B).

The resulting image clearly shows the inner wall of the emblectrum structure, the outer edge of the fortification, and the parallel stretch of terrain that rises from north to south to about 1 m in relation to the fields to the west of the walls (FIG. 6). The interpretation is however difficult; if this is the difference between the Gallipoli formation and the surrounding geological formation, why was that boundary not followed here? Is this ditch excavated purposely to make the approach to the wall more difficult at this location? If it is modern, and the 'elevated' stretch parallel to the walls consisting of rolled down rubble from the walls, what is it, since such a broad and deep ditch is not found elsewhere? In any case, the ditch and its particular context has gone unnoticed so far in the research and warrants some further investigation. Obviously, observations made on the basis of an inductive study of the LiDAR data must be checked on the ground, by means of a thorough inspection of the locations, as far as possible, i.e. ground-truthing. This has not yet been part of a dedicated fieldwork effort.

### 7. Towards a dynamic 3D analysis of LiDAR data

A large part of this case-study into the value of the LiDAR data for understanding the walls of Muro Tenente has actually been a continuous production and recombination of various analytical renderings. Whereas informed by their particular qualities, the actual effect for the identification of interesting features is still often one of experimentation. Standardised visualisation workflows have recently been proposed (Kokalj and Hesse 2017; Kokalj and Somrak 2019). A supplementary approach that could make this process more dynamic, is to insert the generated elevation models into 3D modeling software. In applications such as Blender, various types of shaders can be cast over the projected data realtime. Instead of generating a multitude of hillshade models, or using multivariate modeling with a range of hillshades, such as the PCA method, it is possible in this way to directly change the position of the light source and examine the effects. As a trial in this study, in collaboration with the 4D

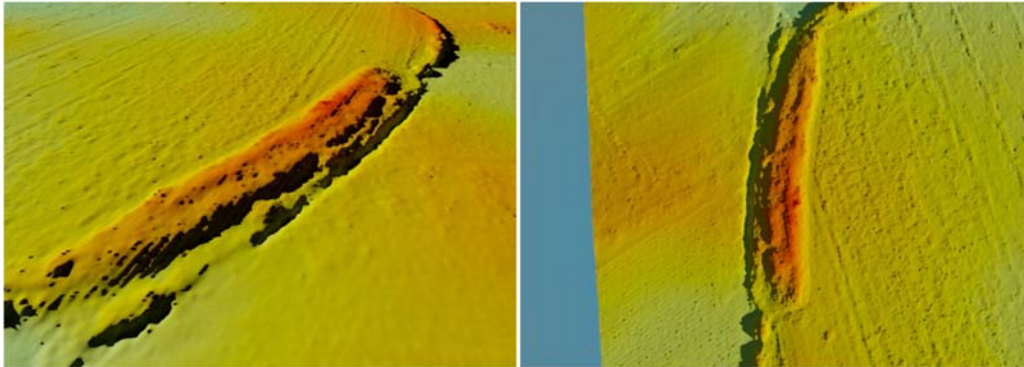
Research Lab at the University of Amsterdam (help and advice from T. Lanjouw), the Muro Tenente data were reworked into a mesh in Blender (with the plugin BlenderGIS). With the visualisation of the LiDAR data in Blender, it was possible to add a light source of which we could determine the position, type and intensity and move it around the model to see the effects for identifying archaeological features. It is these visualisation possibilities of 3D software with, for example, very realistic shadows, or multiple light sources for multispectral visualisation, in combination the real-time dynamics of changing lighting conditions that made this a very powerful tool.



**FIG. 7.** Render of the DTM in a Blender scene with one sunlight at a small angle using the cycles physically based rendering engine.

Of course, that process of real-time lighting cannot be shown in a single illustration, but hopefully a render can already give a good impression of the advanced dynamics in shadow modelling (FIG. 7). To give an impression, an animation of the sunlight rotating around its central axis can be found here <https://doi.org/10.21942/uva.7996022> (made by T. Lanjouw).

The representation in Blender was made by adding the DTM produced with lastools as a texture in Blender, after which the values of the DTM in the texture are interpreted by Blender's 'displacement modifier' as elevations. By adding 'subdivision modifiers', it is possible to increase detail up to the original DTM resolution. The data has subsequently been visualised by adding a sun casting sharp shadows over the DTM with a modified colour ramp, and rendered using the cycles physically based render engine.



**FIG. 8.** DTM in Blender using BlenderGIS, rendered with a light source casting sunlight as well as diffuse skylight, using the cycles rendering engine, A (left) viewed from the north, B (right) from the south. Both clearly show the ditch as a continuation of the edge of the plateau of Muro Tenente.

Detailed renders of parts of the DTM cast more light over the conspicuous wall arrangement of the northwestern part of outer city walls (Fig. 8AB). Studying these visualisations, the inner emplectrum wall is well visible, but more importantly, the direct continuation of the terrace formed by the Gallipoli formation into the ditch, is evident. This strengthens the idea that the ditch has locally been dug as part of the fortification system, where for some unknown reason the emplectrum wall structure was built a bit more towards the inside than elsewhere.

## 8. Conclusions

The study of the LiDAR data by means of various types of visualisations has brought to light several interesting features of the inner and outer wall circuits of the site of Muro Tenente. In case of the trajectory of the inner wall circuit, this has concretely led to an important new archaeological insight into the spatial organisation of the site. The areas in between the walls have not been explicit part of this investigation, since the expectation of observing traces of archaeology is very low due to the intensive agricultural development of the area combined with the problem that low vegetation poses for LiDAR measurements. This problem could potentially be mitigated by a dedicated campaign of Low Altitude Aerial Photogrammetry, i.e. drone missions. These could be performed flexibly in seasons where the ground is mostly bare and, due to the close range collect photos for subsequent Image Based Modelling, resulting in much higher resolution 3D data than LiDAR (García Sánchez and Waagen, forthcoming). Furthermore, drone flights could also be planned to collect high resolution aerial pictures in various stages through the year for a study of cropmarks, which may very well show up on a site like this. Surely, incorporating 3D rendering software into a LiDAR analyses is well worth the effort, and holds promise for future LiDAR data exploration.

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**Conflicts of Interest:** The author declares no conflict of interest.

## References

- Burgers, G.L.M., 1998. *Constructing Messapian Landscapes. Settlement Dynamics, Social Organization and Culture Contact in the Margins of Graeco-Roman Italy*, Amsterdam: Gieben Publishers.
- Burgers, G.L.M., Napolitano, C., 2010. *L'Insestimento messapico di Muro Tenente. Scavi e ricerche 1998-2009*, Roma: Reale Istituto Neerlandese.
- Campana, S., G. Bianchi, A. Fichera, L. Lai & M. Sordini, 2012. 3D recording and total archaeology: from landscapes to historical buildings. *International Journal of Heritage in the Digital Era 1*: 443–60. <https://doi.org/10.1260/2047-4970.1.3.443>.
- Cifani, G., R. Opitz & S. Stoddart, 2007a. LiDAR survey in southern Etruria, Italy: a significant new technique for the study of cultural landscapes. *The European Archaeologist* 2007a: 2–4. <https://doi.org/10.1017/S1047759400005353> – 2007.
- Cifani, G., R. Opitz & S. Stoddart, 2007b. Mapping the Ager Faliscus road-system: the contribution of LiDAR (light detection and ranging) survey. *Journal of Roman Archaeology* 20: 165–76.
- Conrad, O., B. Bechtel, M. Bock, H. Dietrich, E. Fischer, L. Gerlitz, J. Wehberg, V. Wichmann & J. Böhner, 2015. System for automated geoscientific analyses (SAGA) v. 2.1.4. *Geoscientific Model Development* 8: 1991–2007.
- Costa-García, J.M., Fonte, J., 2017. Scope and limitations of airborne LiDAR technology for the detection and analysis of Roman military sites in Northwest Iberia. In Victorino Mayoral Herrera, V. Parcero-Oubiña, C., Fábrega-Álvarez, P. (eds.), 2017. *Archaeology & Geomatics. Harvesting the benefits of 10 years of training in the Iberian Peninsula (2006-2015)*, Sidestone Press, Leiden.
- De Cazanove, O., 2016. Programme Ignobilia Oppida Lucanorum. Fouilles, prospections, études à Serra del Cedro, Civita di Tricarico et Rossano di Vaglio. *Chron. Act. Archéologiques L'École Fr. Rome*.
- Doneus, M., 2013. Openness as Visualization Technique for Interpretative Mapping of Airborne Lidar Derived Digital Terrain Models. *Remote Sens.* 2013, 5, 6427-6442.
- Forte, M., S. Campana. 2017. *Digital methods and remote sensing in archaeology: archaeology in the age of sensing*. London: Springer.
- García Sánchez, J., 2018. Archaeological LiDAR in Italy: enhancing research with publicly accessible data. *Antiquity* 92, 1–10.
- García Sánchez, J., Fontana, G., 2016. In search of Montagna di Gildone: developing an optimal workflow for the application of LIDAR in central Italy. Presented at the Joint Chapter Meeting CAA-DE and CAA-NL-FL, Ghent, Belgium (24 - 25 Nov 2016).
- García Sánchez, J., Waagen, J., forthcoming. Built environment in Satricum. Tracing technology and Archaic society using Remote sensing tools. in Gnade, M. & Revello-Lami, M. (eds.) Proceedings of *Tracing Technology. Celebrating forty years of archeological research at Satricum*.
- Holata, L., Plzák, J., Světlík, R., Fonte, J., 2018. Integration of Low-Resolution ALS and Ground-Based SfM Photogrammetry Data. A Cost-Effective Approach Providing an 'Enhanced 3D model' of the Hound Tor Archaeological Landscapes (Dartmoor, South-West England). *Remote Sens.* 2018, 10.
- Kokalj, Z., and Hesse, R., 2017. *Airborne laser scanning raster data visualization. A Guide to Good Practice*, Založba ZRC.
- Kokalj, Ž. and Somrak, M., 2019. Why Not a Single Image? Combining Visualizations to Facilitate Fieldwork and On-Screen Mapping. *Remote Sens.* 2019, 11, 747. <https://doi.org/10.3390/rs11070747>

- Lambers K., and Traviglia, A., 2016. Automated detection in remote sensing archaeology: a reading list. *AARGnews - The newsletter of the Aerial Archaeology Research Group* 53.
- Lasaponara, R., Coluzzi, R., Gizzi, F.T., Masini, N., 2010. On the LiDAR contribution for the archaeological and geomorphological study of a deserted medieval village in Southern Italy, *Journal of Geophysics and Engineering*, Volume 7, Issue 2.
- Opitz, R., D.C. Cowley, 2013. Interpreting archaeological topography: 3D data, visualisation and observation. Oxford: Oxbow.
- Roman, A., Ursu, T.-H., Lăzărescu, V.-A., Hora, C., Opreanu, T., Farca, S., 2016. Visualization techniques for an airborne laser scanning-derived digital terrainmodel in forested steep terrain: Detecting archaeological remains in the subsurface. *Geoarchaeology* 32. 549-562. 10.1002/gea.21621.
- Vermeulen, F., Burgers, G. L. M., Keay, S., & Corsi, C. (Eds.), 2012. *The Contribution of Urban Landscape Survey in Italy and the Mediterranean*. Oxford: Oxbow.