Digital surface models of crops used in archaeological feature detection – a case study of Late Neolithic site Tomašanci-Dubrava in Eastern Croatia

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ABSTRACT

This paper presents the results of a study on the neolithic landscape of the Sopot culture in the area of Đakovština in Eastern Slavonija. A vast network of settlements was uncovered using aerial archaeology, which was further confirmed and chronologically determined by magnetometry, excavations, and field surveys. The study focuses on the site Tomašanci-Dubrava, where a drone was used to acquire vertical photographs to capture a detailed orthophoto of the feature in a maturing crop. The captured data revealed the subsurface archaeological features that affect the rate of plant growth, as observed on detailed digital surface models. The implications of this observation are discussed in the paper, including its potential use on a larger level with ALS data or aerial photographs taken by the state geodesic service to create DSM models of wider areas.

Keywords: Neolithic, enclosure, remote sensing, aerial imagery, magnetometry, DSM

Introduction

The late Neolithic landscape of the area of Đakovština in Easter**n Slavonija has in recent years** been intensively studied through various research projects. A vast network of settlements situated 3-5 kilometers apart was uncovered thanks to aerial archaeology (Kalafatić et al., 2020, Šošić Klindžić et al., 2019). The most striking common characteristic that all of these sites share is the presence of at least one, but usually double or multiple circular ditches that encompas~~se~~s part of the settlement and are 80-180 m in diameter (Šošić Klindžić et al., 2019). The sites were further confirmed and chronologically determined by magnetometry, excavations and field surveys. These sites are attributed to the Sopot culture, a part of a wider late Neolithic group in the Balkans, present in eastern Croatia with most C14 dates placing it between 5200 and 4400 cal BC. By using an integrative approach, new patterns were identified while previous research as well as observed phenomena at selected sites was re-evaluated. The attribution to the late Neolithic period was confirmed by archaeological excavations on the sites of Gorjani Kremenjača, Gorjani Topole, Preslatinci – Ugljara and the site which is the subject of this paper, Tomašanci Dubrava. On other sites, the presence of late Neolithic artifacts ~~were~~ was confirmed by field surveys (Šošić Klindžić et al., 2019). Due to the large number of potential settlements, some of the sites were studied in more detail than ~~the~~ others, and the geophysical surveys with a magnetometer proved crucial in providing an additional layer of detail to the archaeological interpretation of the individual "sites". Suddenly, the overlaying datasets revealed not only vast settlement areas but also individual features within the data, which could potentially be attributed to ditches, houses, pits and multiple other undefined features. The data presented in this paper concerns one of the sites from this vast late Neolithic settlement network, the site of Tomašanci – Dubrava.

Methods

Aerial ~~recoinassance~~ reconnaissance

The site Tomašanci Dubrava was first observed as a part of an aerial survey project of Eastern Slavonia conducted in 2015~~–~~ using an aeroplane and a UAV. (Šiljeg & Kalafatić, 2016). After the initial observation (Fig. 1), the analysis of the avalilable satellite images from Google Earth and orthophotos from the Croatian State Geodetic Administration showed that the Enclosure 1 is visible on almost all available images, and is even recorded as a slight elevation on the Croatian topographic map 1:5000. Additonal analy~~i~~sis of images confirmed the presence of two additional enclosures. Source material is available at https://moprens.ffzg.unizg.hr/. The typical late Neolithic pottery and lithic artifacts collected during the archaeological field survey confirmed the attribution of the site to the late Neolithic period (Šošić Kliindžić et al., 2019).

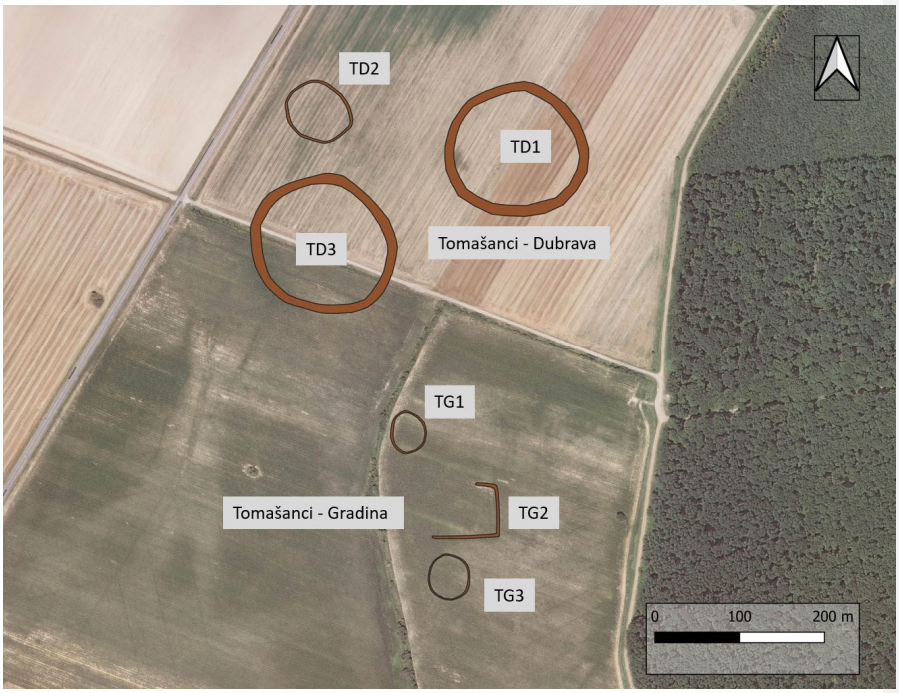

Figure 1 - Archaeological features visible as crop marks and soil marks in the area of Tomašanci – Dubrava and Tomašanci – Gradina; Interpretation~~-~~: Šiljeg & Kalafatić 2016; Šošić Klindžić et~~-~~ al.,2019

Magnetic survey

The aim of the magnetic survey was to confirm the presence of the enclosures as well as to collect data on the internal structure and organization of this late Neolithic site. The company Cmp prospection from Berlin in cooperation with Archeologická Agentúra s.r.o., Bratislava conducted the magnetic prospection of the site in February 2021 and May 2022. The first survey in Tomašanci included an area of 10.8 ha using the 10-probe fluxgate gradiometer array LEA MAX combined with a GNSS-RTK positioning system and moved by an ATV. The Förster FEREX CON650 fluxgate gradiometer probes register the vertical gradient of the vertical component of the Earth's magnetic field with an accuracy of 0.1 nT (Nanotesla) (Meyer, 2021). The survey in 2022 continued with a 7-probe fluxgate gradiometer mounted on a cart and moved by the operator. The magnetic surveys successfully confirmed the presence of the two enclosures~~–~~ (TD1 & TD3) and ~~mutliple~~ multiple other features, such as pits, postholes, houses and even a large ellipsoidal ditch stretching across one of the enclosures (Figure 2). Further work should include a GPR survey, as work on similar structures in lower Austria has shown promising results (Wallner et~~-~~ al. 2022).

Figure 2 – Interpretation of the magnetometer survey on the site of Tomašanci Dubrava

Archaeological excavation

The large ellipsoidal ditch raised suspicions about its attribution to the late Neolithic period because it was cutting through one of the enclosures, and its shape resembled features common in later periods and usually attributed to Roman times. To provide precise chronological attribution, a small-scale test excavation was conducted in May 2022 on a segment of the ellipsoidal ditch. The V-shaped ditch feature was confirmed through excavations, and the material recovered from the ground was exclusively from the late Neolithic period. Although the larger ditch feature appears to be superimposed over the circular enclosures (Figure 2), the nature of the magnetometer surveys makes it hard to differentiate features stratigraphically (Fassbinder 2016), and this fact should be considered in future research.

UAV Ortophoto

During recent field-work conducted in the first half of 2022 on the site Tomašanci- Dubrava, we aimed to get a more detailed aerial view of the area and ~~of~~ the archaeological features identified by previous aerial archaeology interpretations. A drone was engaged to acquire a set of vertical photographs over a large area where two distinct neolithic enclosures were visible. The goal was to capture a detailed orthophoto of the feature in a maturing crop, since the area was targeted for further geomagnetic surveys later in the season.

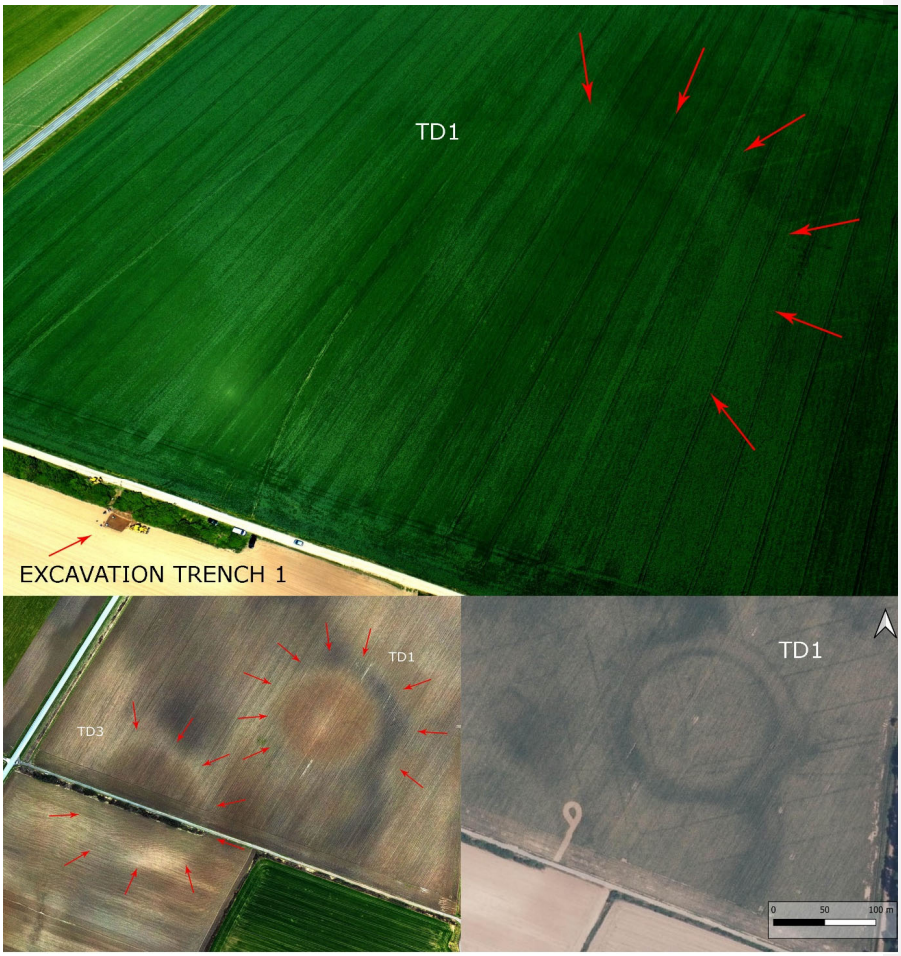

Figure 3 – above: oblique aerial photo of the TD1 enclosure as a soil mark taken during the 2022 survey; below left: orthophoto of TD1 and TD3 soil marks during the 2023 survey; below right: enclosure TD1 on a~~the~~ state geodesic archival photograph~~s~~, taken in 2021.

Results

DSM 2022

A DJI Mavic 2 Pro was used to acquire 595 vertical photographs (~~-~~5472 x 3648 pix) from a flight altitude of 260 m, the overlap between images was 90%, and the final 3D model was georeferenced using a GNSS device on the ground. The images were processed in Agisoft Metashape using the Reference preselection mode in the Align~~e~~ment phase, and the generated DSM (digital surface model) has a resolution of 3.7

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cm/pix. The captured data revealed the targeted feature as a crop mark in a field of maturing industrial peas, but the ~~surface of the model itself~~model's surface revealed small differences in the height of the growing crops. The different levels of plant growth correspond to subsurface archaeological features, which in turn perfectly correspond to the archaeological features recognized previously on different aerial photographs.~~.~~

DTM 2023

A second drone survey and a DTM (digital terrain model) generation was conducted in early March 2023. The crops were at this point removed from the fields. The goal was to get a good orthophoto of the soil mark for the enclosures. Because of the potential photo orientation~~alignment~~ problems due to the fact that in some cases images with no distinct features can yield poor results, we decided to sacrifice some of the resolution for a good result. The soil marks visible on the orthophoto are one of the best representations of the enclosures at Tomašanci – Dubrava on aerial images. We used a DJI Mavic 2 Pro to acquire 354 photographs from a flight altitude of 340 m, the overlap between images was 90% and the final 3D model was georeferenced using a GNSS device on the ground. The resulting DTM has a ~~resuliton~~ resolution of 3.7 cm/pix. The DTM of the fields without crops also revealed the distinct ditches surrounding the features TD1 and TD3, with the same slight elevations visible in the middle of the enclosures as was the case with the earlier DSM recorded when crops were present in the field.

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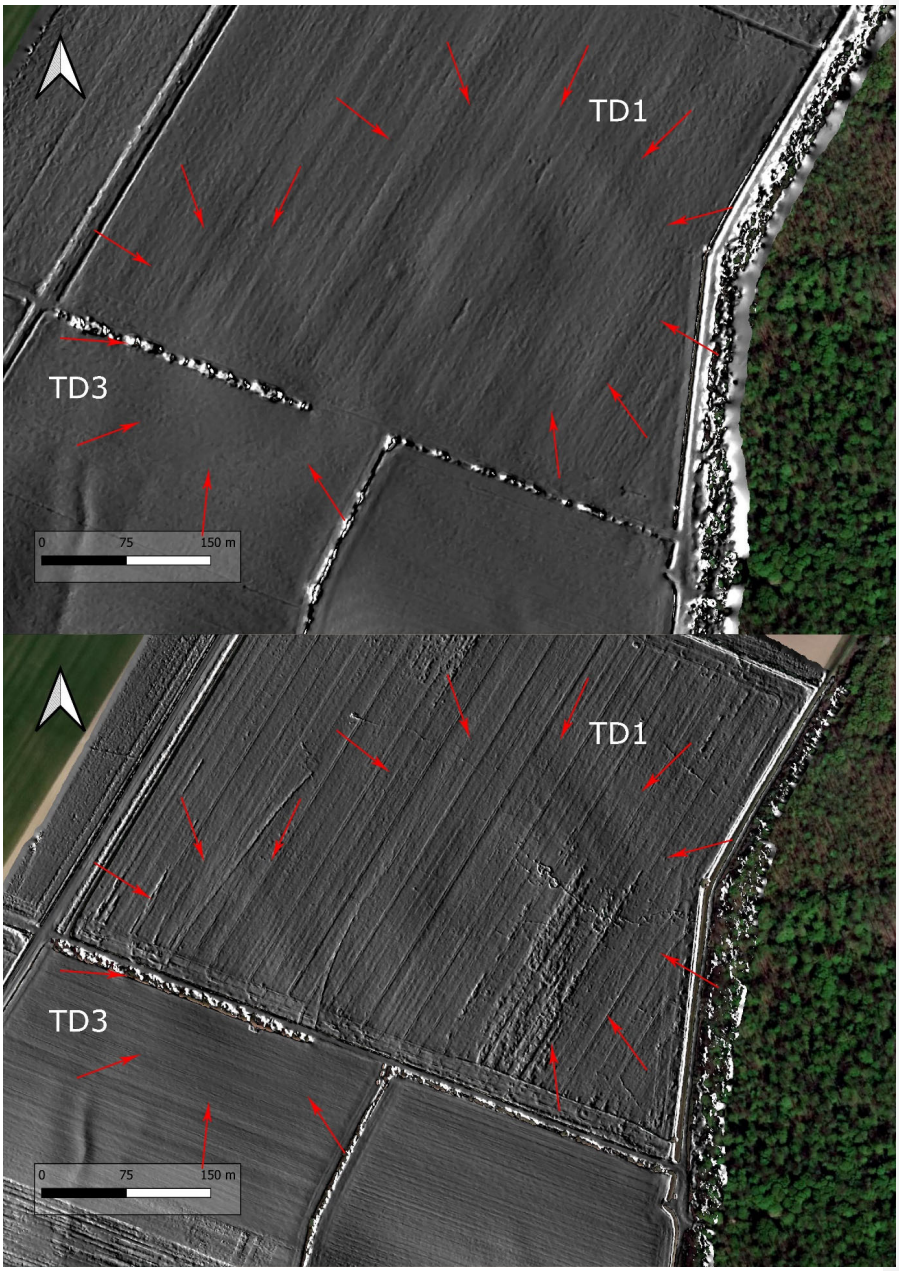

Figure 4 – above: DTM 2023, enclosures TD1 and TD3 visible as slight elevations and ditches as depressions in the soil on the digital terrain model; below: DSM 2022, enclosures TD1 and TD3 visible as slight elevations and ditches as depressions in the crops on the digital surface model

Discussion

The DTM and the DSM models generated at the Tomašanci – Dubrava site revealed that although the archaeological features are situated in ploughed fields, the microtopography is not ~~completely~~ entirely wiped out. The ~~presence of~~ slight differences in ground elevation (20 – 60 cm) ~~are a reflection of~~reflect the big earthwork and building activities of the Neolithic society which dwelled in the area roughly 6000 years ago. Cropmarks are commonly explained as inconsistent plant growth affected by buried archaeological features. It seems that the ~~microtopgraphy of the area could be a factor as well, as our example demonstrated that the plants which~~area's microtopography could also be a factor, as our example demonstrated that the plants that grew higher ~~are the plants that~~ were situated in higher terrain, with ~~and the plants that were~~ shorter plants ~~are the ones that were~~ growing over lower terrain (ditches). ~~It is our conclusion~~We conclude that detailed terrain models can be used to detect large archaeological features such as enclosure ditches and other ~~large~~ extensive earthworks associated with prehistoric communities. It is a fact that magnetometric surveys are still the best method for mapping out these types of archaeological traces~~, but~~. However, one large setback in this area remains ~~with the fact~~ that magnetometers still can no~~'~~t reliably be used in large aerial surveys, but LiDAR and photogaphy~~rammetry~~ can. A ~~smiliar~~ similar approach utilizing multiple archaeological prospection techniques and overlaying them to achieve the best result was recently completed on a similar structure from lower Austria (Wallner et~~.~~ al. 2022).

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Detailed terrain models of extremely large areas can thus be used to detect new enclosures and help with the archaeological interpretation of these vast arcaheological landscapes. This fact has ~~wider~~ broader implications because it can serve as a basis for future research in this area, especially if we consider application on a wider~~larger~~ level where ALS data or aerial photographs taken by the state geodesic service can be used to create DSM or DTM models ~~of wider areas~~.

Acknowledgements

We are gr~~e~~ateful to Marin Mađerić, who made the second drone survey, C. Meyer for the magnetic survey and all the participants in the 2022 excavation.

Data, scripts, code, and supplementary information availability

Supplementary information is available online: https://moprens.ffzg.unizg.hr/

Conflict of interest disclosure

The authors declare that they comply with the PCI rule of having no financial conflicts of interest in relation to the content of the article.

Funding

This research is funded by the Croatian Science Foundation, project Modelling Prehistoric Networks in Slavonia IP-2019-04-5344.

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