DRONES AT ÇATALHȮYŪK: A NEW SURVEY FOR LANDSCAPE INTERPRETATION

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This third volume in the *Archaeology of Anatolia* series offers reports on the most recent discoveries from across the Anatolian peninsula. Periods covered here span the Epipalaeolithic to the Medieval, and sites and regions range from the western Anatolian coast to Van, as well as the southeast. The contributors offer nearly real-time updates on their ongoing excavations and surveys across the Anatolian landscape. A new section in this third volume, "The State of the Field," presents the latest findings in critical areas of Anatolian archaeology. The *Archaeology of Anatolia* series represents a forum for scholars to report their most recent data to a global audience, allowing for productive engagement with others working in and near Anatolia. Published every two years, it is an invaluable vehicle through which working archaeologists may carry out their most critical task: the presentation of their fieldwork and laboratory research in a timely fashion.

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DRONES AT ÇATALHÖYÜK: A NEW SURVEY FOR LANDSCAPE INTERPRETATION

MAURIZIO FORTE, NEVIO DANELON, AND ARKADIUSZ MARCINIAK

INTRODUCTION

Despite many years of archaeological excavations at the Neolithic site of Çatalhöyük, the standing explanation for economic, social, and ritual activities of the inhabitants is based solely upon a wide range of evidence originating from deposits found in different parts of the densely-occupied settlement. The immediate environs of the settlement have never been systematically studied, creating a significant void in a comprehensive understanding of the existence of local community in its different forms, and leaving the interpretation of the settlement's original deposits largely one-sided and unbalanced. These research questions require new methods and very extensive surveys and landscape analyses by non-invasive technologies. For these reasons, in 2015, a remote sensing project involving the use of drones was initiated. The plan was to map in 2D and 3D the East and West mounds and to generate high resolution models and georeferenced orthophotos of the site. The device was the UAV DJI S900 hexacopter, equipped with a Panasonic GH4 digital camera.

This chapter aims at presenting the results of the first drone survey at Çatalhöyük that produced over 3000 digital photos. This allowed the creation of a very detailed DTM (digital terrain model) and DSM (digital surface model). The 3D visualization of the East mound clearly shows the existence of a third small mound, very likely related to the latest phase of the site's occupation. On the West Mound, on the other hand, the archaeological feature-tracking made by digital filtering and image processing displays several crop marks and foundation walls related to the Early Chalcolithic village. The combined use of drones with RTK (real time kinematic) GPS (by using targets on the ground) allowed for the creation of a very accurate model of the entire site in terms of resolution and geolocation. This discussion also attempts to integrate the received results with the settlement layout and spatial organization, as revealed by the long-term excavations, as well as geophysical prospection, and provides the first integrated picture of the site and its immediate environs.

INTRODUCTION TO DIGITAL PHOTOGRAMMETRY AT ÇATALHÖYÜK

Studies of the Neolithic in the Near East have been and continue to be decidedly focused upon investigating settlements and their constituent elements. These settlements have a form of distinct mounds (tepes, höyüks, magulas), clearly dominating the landscape, some of them up to 25 m in height and up to 30 ha in size. The character of the immediate environs of these settlements remains largely unexplored. This is clearly manifested by a dearth of studies focused on understanding the immediate surroundings of the settlements and the complex relations of its inhabitants with its natural elements, such as rivers, streams, forests, or open spaces, which comprise the primordial dimension of existence of any Neolithic community. This biased nature of Neolithic research is quite common, and clearly present in the studies carried out in past years on many large Neolithic settlements in the Near East (e.g. Byrd 2005; Özdoğan 1999; Rosenberg and Redding 2000). A prime example is the large Neolithic settlement at Çatalhöyük East in central Anatolia, intensively investigated in the years 1993–2017 by an international team of scholars forming the Çatalhöyük Research Project (cf. Hodder 2014).

The use of remote sensing technology at Çatalhöyük and at other Neolithic sites in Anatolia in past decades mainly focused on satellite imagery (Corona, for example; Kennedy 1998) and aerial photos. All these data can be extremely useful for large-scale surveys and for the historical reconstruction of the landscape, but the lack of high resolution optical data and digital elevation models prevents a more detailed analysis of crop marks, soil morphology, and archaeological features.

The problem of these previously hidden data can be solved by the use of drones and digital photogrammetry, and by integrating high resolution orhophotomosaics with 3D visualization tools. Therefore, in the summer 2015, a team from Duke University-Dig@Lab started a new aerial survey by drone in the areas of the East and West mounds at Çatalhöyük and their immediate surroundings. The capacity of UAVs, or drones, to fly under 50 m of height and to produce images with 0.5-1 cm of resolution can completely change research perspectives and offers a different methodological approach to non-invasive technologies. In our case the data processing of over 3000 drone photos released very detailed RGB imagery, DSMs (digital surface models), and DTMs (digital terrain models), which are able to give new interpretations of the site. Finally it is important to note that we use a drone built in 2014, with some restrictions in terms of flight duration and camera tracking, if we compare it with the latest generation of multispectral copters.

This chapter presents preliminary results of the combined drone prospection and digital photogrammetry in the area of the East and West mounds at Çatalhöyük as well as their immediate surroundings. These will be discussed in relation to the results provided by archaeological excavations as well as different types of geomorphological prospections.

THE NEOLITHIC LANDSCAPE

Areas beyond and at the edge of the settlement zone were unquestionably important for social and economic activities for any Neolithic community. A distinction between the occupation of settlement versus the use and exploitation of these zones at Çatalhöyük has been implied but never investigated in any detail.

There are suppositions implying that the Neolithic settlement was divided into sectors, for which there appear to be radiating lines that start at the top of the mound and extend outwards. The lines separate groups of houses that are distinctive. Some of the radial zones include more elaborate houses than others, and some form midden areas at certain points during the occupation of the mound. This interpretation of social geography of the local community was restricted to the settlement itself (e.g. Hodder 2013: 152, Fig. 10.1). Considering that houses comprised the major architectural structures on the mound, communal practices most likely might have been performed away from but in close proximity to the settlement, as reported at other Neolithic settlements in the Near East, such as at Çayönü, Jerf el-Ahmar, or Aşıklı Höyük (Özdoğan 1999; Stordeur 1999; Özbaşaran 2012). These settlements arguably had a form of special purpose buildings, located usually a short distance from the settlement. However, the work carried out at Çatalhöyük to date provided no evidence of either ritual and administrative centers nor chiefly residence.

The importance of the social networks through which resources could have been obtained by the Çatalhöyük inhabitants has been stressed elsewhere (Hodder 2013). Many of the sodalities may have had a spatial geography not based on contiguity or proximity of habitation, but on other factors. Relationships based on some degree of specialization of production or participation in hunting wild animals and feasting may have been dispersed across the mound and beyond. Other relationships may have been localized and spatially contiguous. These different larger scale social groupings may have performed their activities in spatially separated sectors of the settlements and beyond, separated by empty spaces or areas of midden, similar in character to those identified at Aşıklı Höyük (Özbaşaran 2012).

Some indications of the off-site occupation at Çatalhöyük were provided by the Konya Basin Palaeoenvironmental Research (KOPAL) programme carried out in the early 1990s. A small off-site trench was excavated in 1997 and expanded in 1999, located in the fields to the north of the North Area. The aim was to excavate the top of the lake marl to record the off-site formation processes, the Neolithic ground horizon, and buried soil horizons of subsequent periods. The work provided some evidence of the organization of economic activities in the vicinity of the settlement (Hodder 2007; Roberts et al. 1999).

A substantial amount of work has been successfully completed as regards the reconstruction of local environments and the development of the Çarşamba water system. The first significant contribution was made by the KOPAL programme, mainly aimed at investigating the Late Quaternary litho-, bio-, and chronostratigraphy of the large former lake basin on the Anatolian plateau. The past environmental changes recorded in these sediments have been used as proxies for the human occupancy of south central Turkey, and in particular for the origins and development of agriculture and settled village life at Çatalhöyük (Hodder 1997), Aşıklı Höyük (Özbaşaran 2012), and Can Hasan III (French et al. 1972), dating from ca. 9000 14C BP onwards (Roberts et al. 1999). Other work focused on the regional scale and involved a comprehensive programme of vibro-coring in the area at a considerable distance from the settlement site, providing a reference sequence for the Çarşamba fan more generally (Roberts et al. 1996).

A tributary of the Çarşamba River ran between the West (Chalcolithic) and East mounds of Çatalhöyük prior to recent artificial modification of the drainage system. The local landscape was thereby broken up into dry and wet patches offering a diversity of uses. Within this complex environment the site was located at a low point in a broad shallow depression bordered by low marl ridges to the north and south. This heterogeneous mosaic of open space and changing water resources itself creates resilience and stability. The water system around the site has undergone significant transformations, as convincingly documented by the studies conducted to date (e.g. Ayala et al. 2017).

Contrary to the palaeoenvironmental reconstruction based on the geoarchaeological work that situated Çatalhöyük within a palaeolandscape dominated by wet conditions (Roberts et al. 1996; Boyer et al. 2006), the high-resolution coring carried out in the years 2007–2015 has been able to demonstrate that the landscape of the Konya Plain was highly variable and has shown evidence of increasingly dry conditions since the early Holocene. This new evidence forces us to review the established landscape model and related interpretations of the land use in the region. The earlier idea that a large single channel flowed past the site in a high-energy meandering river system (Roberts and Rosen 2009: 395–96, 399; Roberts et al. 1996: 39) was indicated, but it was firmly placed later in the Chalcolithic.

Except for the KOPAL project from the late 1990s, the only off mound area at Çatalhöyük excavated to date is a circular and regular eminence ca. 50 m in diameter located very close to the main part of the settlement and excavated for the first time in the 2018 season (Marciniak et al. 2018).

The East Area, along with the entire eastern part of the East mound, has been subjected to a range of non-invasive methods related to the beginning of the Çatalhöyük Research Project in the years 1993–1995 and the geophysical survey in 2012. The scraping project was carried out in its selected parts. Two squares were investigated (1090/1040 and 1040/1040) and led to the discovery of Neolithic features comprising east–west walls constructed of large fine-textured pale orange bricks, some over 1 m in length, as well as a semi-circle of laid bricks. In addition to Neolithic structures, a large number of post-Neolithic pits, some of them likely to be burials, along with scattered heavily burnt deposits, were also found. One burial in the northwestern part of square 1090/1040 was fully excavated, and revealed the burial of a small infant without grave goods capped by two terracotta tiles (Matthews 1997: 88).

The pottery survey of the East Area from the early 1990s resulted in the discovery of a large amount of Neolithic and post-Chalcolithic pottery. However, considering the post-Chalcolithic architecture and depth of topsoil covering the Neolithic features, Last (1997: 139) argued that most likely the material originated from upper parts of the South eminence and was washed down to the East Area.

The geophysical survey conducted in 2012 did not reveal many features in the eastern part of the East mound. It exposed some rectilinear structures, which may be interpreted as Neolithic walls. Furthermore, a positive linear anomaly cuts across the mound from northeast to southwest for a distance of 53 m. Numerous positive linear and discrete anomalies and faint traces of structural remains were also revealed in the western part of the area (Campana et al. 2012: 112–13).

The excavation work in the 2018 season was carried out in the 10 × 50 m longitudinal trench. A significantly distinct Neolithic occupation was revealed, comprising four Neolithic buildings and associated midden deposits as well as unspecified dwelling structures. They represent at least three phases of the Neolithic occupation represented by a range of different dwellings: (i) four regular buildings, (ii) a special purpose room inserted into one of the earlier buildings, and (iii) four unspecified structures made of white regular bricks. The 2018 season brought about a recognition of numerous post-Neolithic features including inhumation burials as well as ovens and pits of different character (Marciniak et al. 2018).

DRONE TECHNOLOGY

Structure from motion (SfM) photogrammetry is a well-established technique increasingly used to generate high resolution 3D models in archaeology. It is used at different spatial scales ranging from a small artifact to a landscape level. SfM processing is based on specific algorithms applied to a set of overlapping, offset digital images taken from different positions. The automated workflow consists of image matching (alignment) to estimate 3D geometry and camera positions, and bundle adjustment to refine the model and minimize the reprojection error (Smith et al. 2016).

When combined with drone-based survey, SfM offers a wide range of capabilities such as the generation of high resolution georeferenced imagery, namely orthophotos and digital elevation models (DEMs) as well as 3D models and dense point clouds. The desired resolution depends on the distance from the ground and the camera's sensor. SfM works best when dealing with the bare ground rather than vegetation. In the latter case, much more expensive LiDAR techniques are more suitable for producing useful data able to penetrate forest canopy and detect the underlying soil. In the case of Çatalhöyük, the mostly sparse and patchy low-scrub vegetation covering the two mounds allowed for a slope-based classification of the ground surface. In this way buildings, trees, and isolated bushes can be weeded out from the photogrammetric digital surface model (DSM) in order to produce a digital terrain model (DTM).

Orthophotos and DTMs are complementarily useful for identifying unseen topographic features. The combination of spatial (elevation) and spectral analysis provides a double feedback for the interpretation of the clues. Crop marks that are hard to identify in the visible spectrum (RGB) can be enhanced with the additional aid of the near-infrared (NIR) spectral band. Slight differences in ground elevation can be exaggerated in order to highlight the micro-morphology of the terrain. In this way it is possible to identify unseen building footprints and wall foundations which are not visible on the ground.

THE 2015 AERIAL SURVEY

The aim of this survey was the generation of high-resolution georeferenced imagery and 3D terrain models of the ground surface within the archaeological site of Çatalhöyük. We carried out a UAV-based photogrammetric survey with the twofold purpose of providing a more precise cartographic base as well as to investigate the micro- and macro-morphology of the site, not easily understandable from the ground level. All these data have been georeferenced both in local and global (WGS84 – UTM 36N) coordinates using a total station in the first case, and a differential GPS antenna in the latter. In order to collect all the photos needed for the aerial photogrammetric survey, we used a Panasonic GH4 camera mounted on a DJI S900 high-power hexacopter.

The first stage of the work consisted of engaging in accurate topographic planning that involved placing a number of ground control points (GCPs) on the site for georeferencing the model. We created a shapefile in ArcGIS with 19 topographic points evenly distributed over the entire area with the twofold goal of controlling their spatial density as well as avoiding unwanted alignments (Fig. 12-1). We printed 19 checkerboard targets on A3 format paper sheets that must be clearly visible in photos of 4608 × 2592 pixels taken from a distance of 75 m above the ground. To retrieve the location of the planned GCPs on the ground we relied on the support of a GPS handheld device.

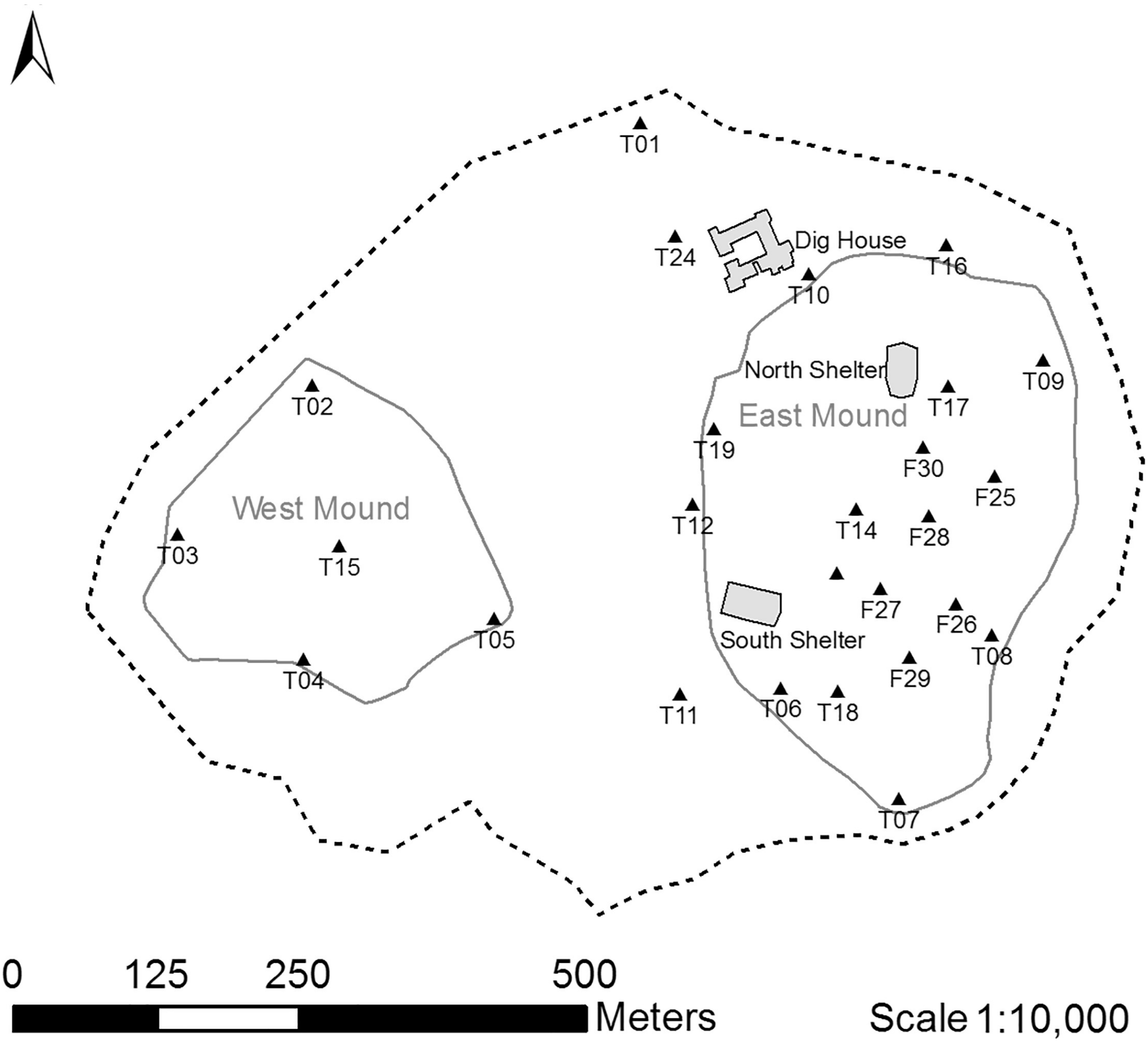

Figure 12-1. Çatalhöyük, distribution of the ground control points.

The GCP positions were accurately measured in the following days, regardless of the flight planning. To this end, we used the Archer2 handheld device running ArcPad in conjunction with an SX Blue II GNSS receiver. We took advantage of a subscription for a GPS service (OMNI Star) which uses real time differential correction based on a triangulation from a multitude of different satellite networks. This real time correction allowed us to receive GPS coordinates in the field with an average accuracy of 20 to 40 cm, compared to the average of 1.5 m accuracy we would have had without any differential correction. GPS readings were recorded in a shapefile using the datum WGS 1984, projected into UTM zone 36 North. The GCP positions were also measured by triangulation with the support of a total station with an accuracy of 2 to 4 cm. Since the total station survey was based on the local coordinate system, we provided data both in the local and global systems.

For the flight planning we relied on DJI Ground Station software. Even working offline, it allows for the visualization of Google Earth imagery as a base map as long as it has been previously loaded. Ground Station generates a route for the drone given some input parameters and a rectangular shape directly drawn on the Google Earth base map. Considering an average flight time of about 8-10 minutes, we divided the entire area of interest in 7 longitudinal rectangles for each flight. Then the software calculated the route and the waypoints according to the flight parameters entered. The flight altitude was set to 75 m, the forward velocity was set at 10-12 m per second and the photo overlap to 75%. Due to a defect in one axis of the gimbal, the overlap percentage was not always precise. Given that recharging each battery pack took up to 40 minutes, we needed to concentrate the flights in the central part of the day, avoiding sharp changes in light conditions and shadows between one flight and the other that could prevent the photos from being aligned in PhotoScan.

We selected a total of 729 vertical photos taken from the drone at a resolution of 4608 × 2592 pixels. The images were uploaded and processed in Agisoft PhotoScan. After a first alignment and the generation of a rough 3D model, we placed markers in correspondence with the targets visible on the model and entered the coordinate values for each

Figure 12-2. Çatalhöyük, orthophoto.

of them with the support of the GIS. After this step we adjusted their position, image by image, centering the markers on the target and launched a new adjustment process. In this way the model was georeferenced according to the coordinate system while the reprojection error was minimized. A dense point cloud was generated and subsequently classified in order to separate the ground from the vegetation and the low points (noise). Two different geometric models were generated depending on whether we wanted to obtain a DSM—including vegetation and buildings – or a bare DTM. After processing the data in PhotoScan we exported different kinds of georeferenced imagery for the GIS (Figs. 12-2 and 12-3) and 3D models in different formats, both in local and global coordinates.

Simultaneously, we carried out two detailed surveys in specific areas that could reveal predictable morphological features. The first was located on the eastern side of the East mound, where the drone flew at a lower height of 35 m above the ground in order to detect more geometric detail of the ground surface. The second area was located in the surrounding countryside, just north of the site. Here we sought to detect any possible clue of a possible palaeo-channel of the local river, slightly visible in some satellite imagery. Unfortunately the surrounding landscape was cultivated and covered with high levels of vegetation that prevented us from investigating the ground surface. The digital terrain model of the site was uploaded in ERDAS Image, a remote sensing application for geospatial data processing. By manipulating shaders and lighting parameters in the viewer, data imagery can be rendered in a number of different ways in order to enhance the visibility of features that would not normally be detected. The raster graphics editor is provided with automatic or semiautomatic feature extraction algorithms that provide the capability of vectorizing and mapping the interpreted features. After a preliminary elaboration, Çatalhöyük's elevation data revealed interesting features related to the ground micromorphology, such as the presence of the so called "third mound," slightly visible, and the shallow squared notches related to the previous archaeological prospections carried out by James Mellaart.

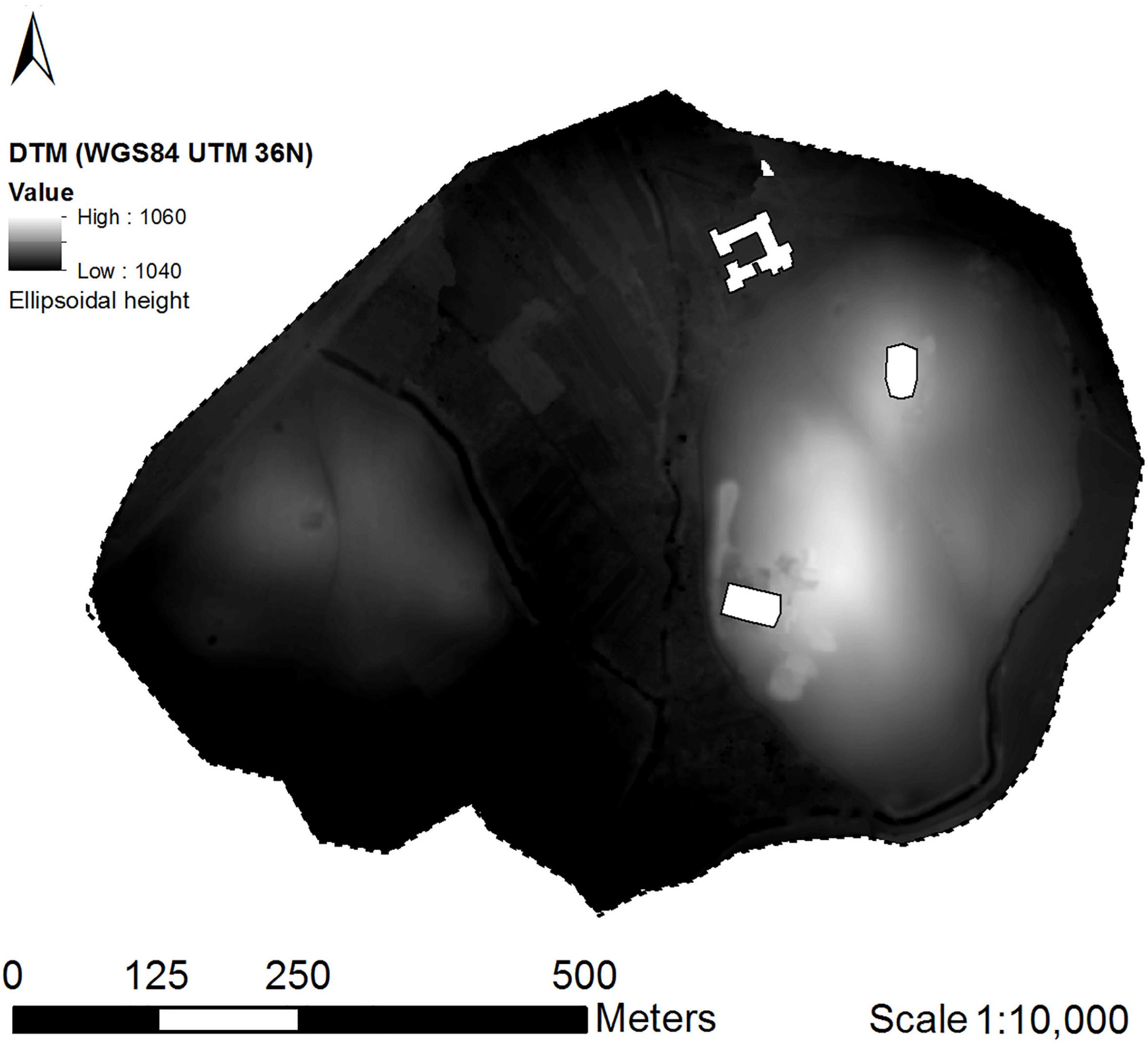

Figure 12-3. Çatalhöyük, digital elevation model (DEM).

DATA INTERPRETATION

The relevance of the preliminary interpretation and the meaningful digital content of the imagery is due to the fact that remote sensing technologies by drone have now been used experimentally at Çatalhöyük for the first time. The range of scale, details, and photogrammetric survey is particularly revolutionary in Neolithic archaeology and in the future should be combined with other remote sensing methods such as targeted excavations, geophysical prospections, and multispectral drones, to investigate both on-site and off-site areas. Large-scale remote sensing is the best way to approach the study of very complex territories and to contextualize sites and settlements in their original environment. This process requires substantial effort, which has to take into account several analyses by direct and indirect empirical studies.

The digital processing of the East mound has particularly highlighted the morphological and archaeological features of the area. The orthophoto shows the oval extension of the anthropogenic deposit (Fig. 12-2), and in the South Area the extent of previous archaeological excavations.

In particular, the 3D sharpening and visualization of the DTM of the East mound in pseudo-colour shows two large ovoid hilly surfaces separated by a depression and a third small mound visible in the Eastern side of the whole East mound, known as the East Area (Figs. 12-4, 12-5, and 12-6). The RGB drone's photos show a concentration of the archaeological deposit in this region, which is much more visible in three dimension (the DTM resolution is 1-2 cm). Based on this evidence and former archaeological surveys of the area (Last 1997; Matthews 1997), it is possible to interpret it as the latest Neolithic settlement. This was clearly much smaller than the rest of the earlier settlement, and it indicates a different spatial reorganization of the site, before the occupation of the West Mound.

The digital processing of the DTMs and of the RGB orthophotos of the West mound has produced new maps and interpretations of the settlement. Also in this case it is important to overlay the features recognizable in the DTM with

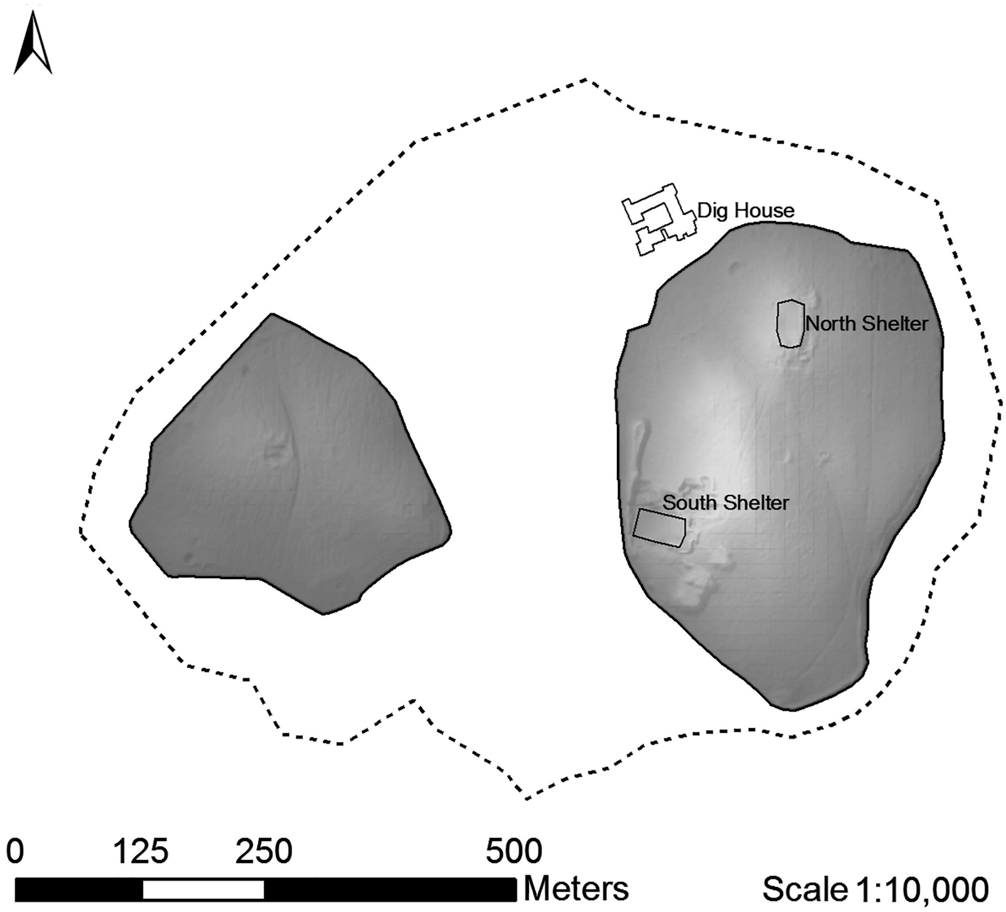

Figure 12-4. Çatalhöyük, hill-shaded DEM of the two mounds.

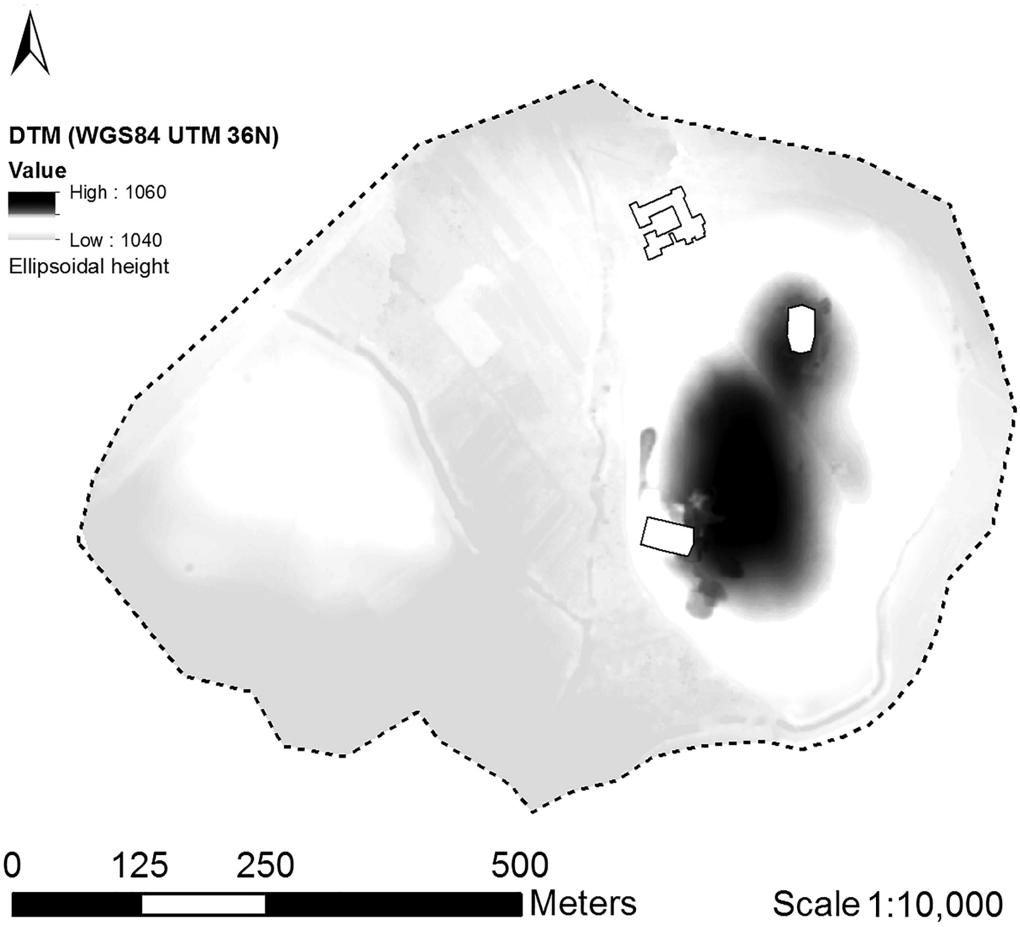

Figure 12-5. Çatalhöyük, stretched DEM.

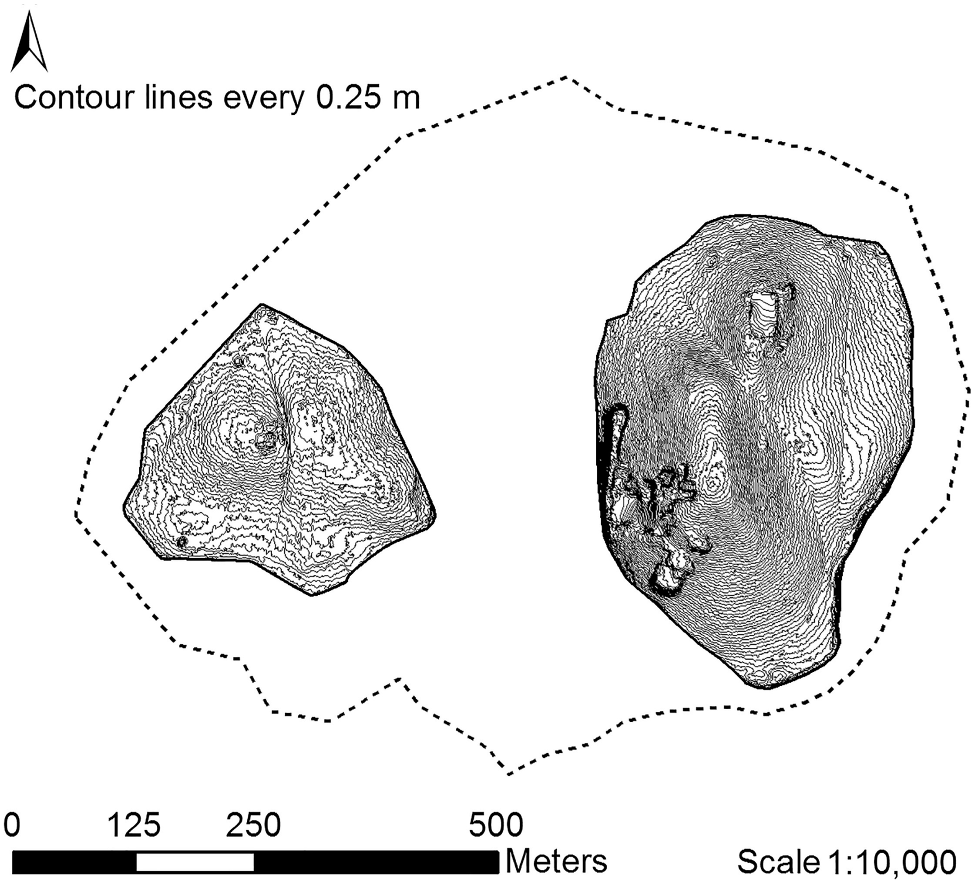

Figure 12-6. Çatalhöyük, contour lines.

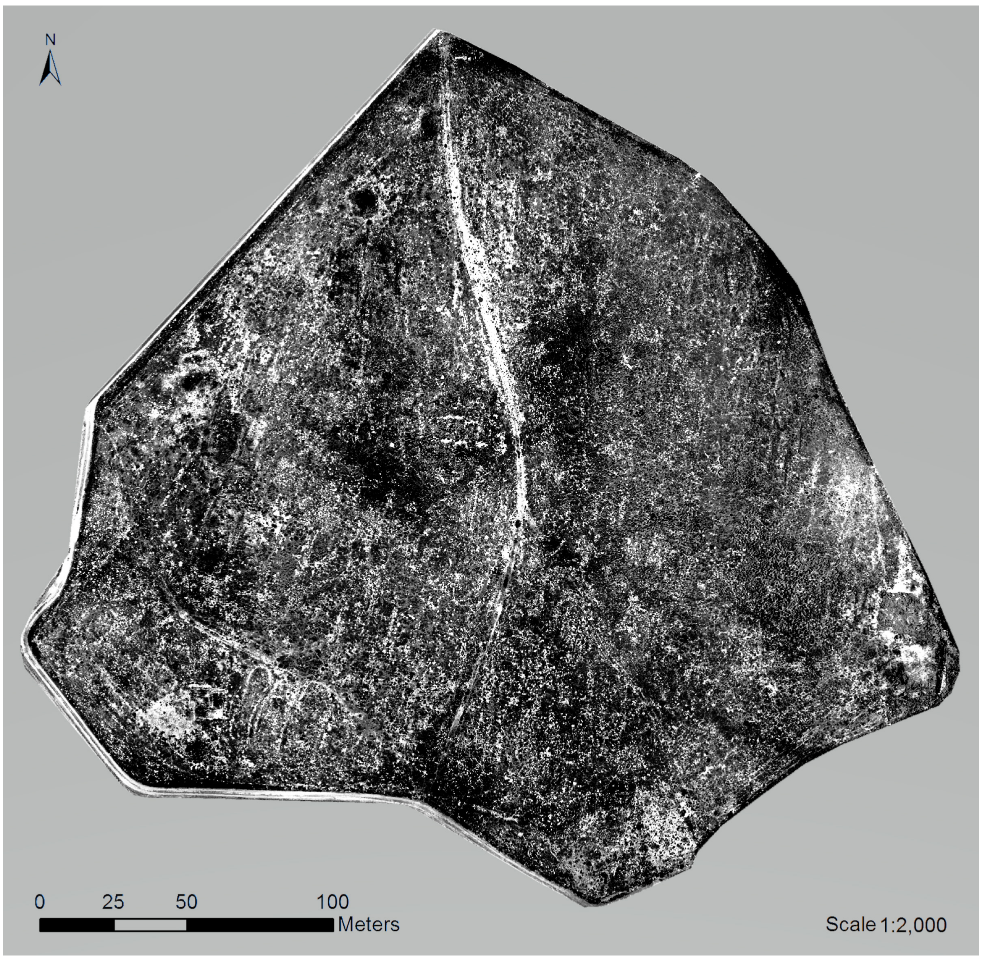

Figure 12-7. West Mound, orthophoto.

Figure 12-8. West Mound, cropmarks.

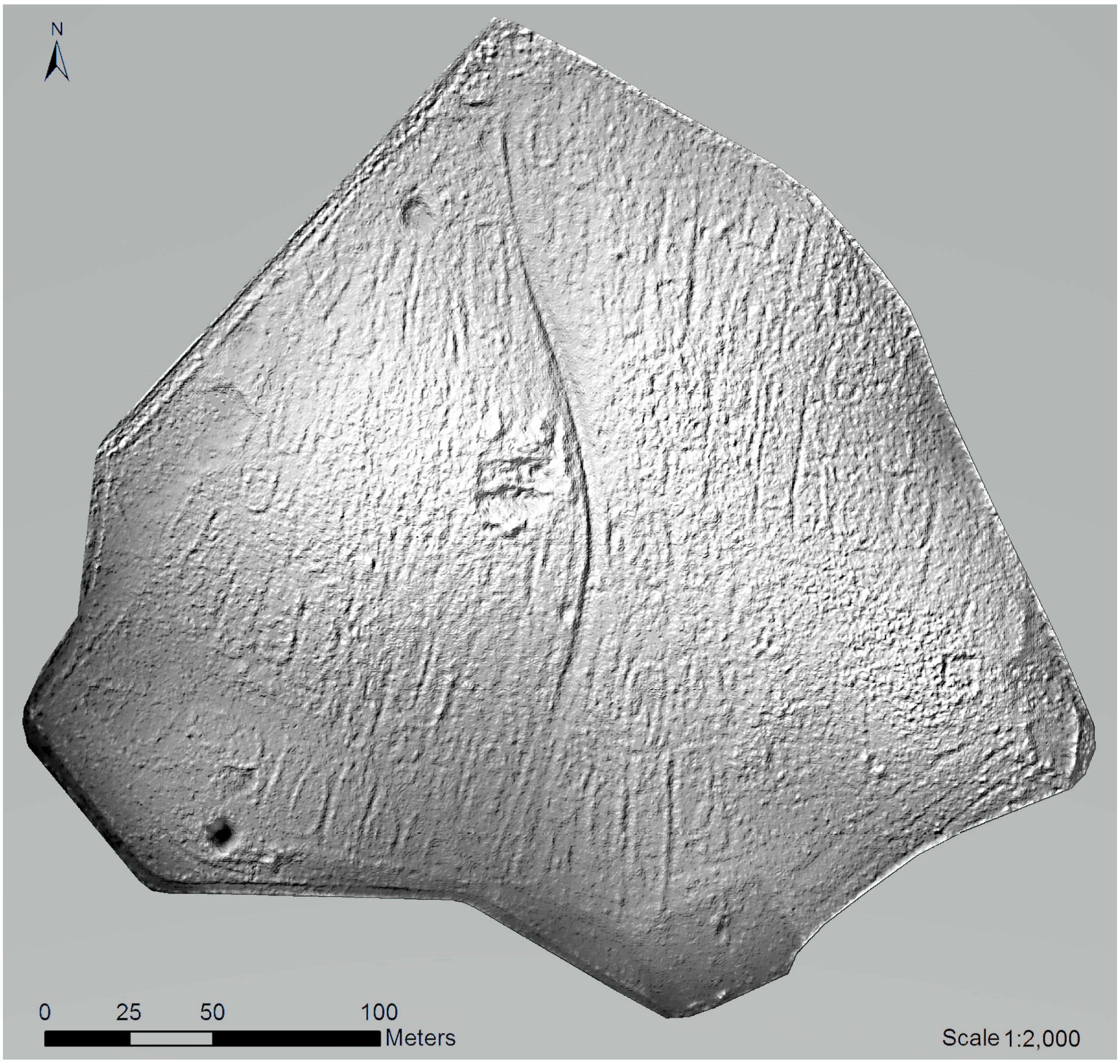

Figure 12-9. West Mound, hill-shaded DEM.

the ones identifiable in the RGB optical data. In the 2D and 3D visualization of the DTM, after applying a sharpening filter, it is possible to see a large number of rectangular foundations of buildings, most of them oriented NE–SW (Figs. 12-9 and 12-10). The same result, with less recognizable features, is visible in the RGB imagery (Figs. 12-7 and 12-8); here the iso-orientation of linear and rectangular features toggles with circular shapes and some apparently empty areas, which may be related to public/shared spaces. One cannot rule out the presence of a system of streets and passages able to connect the entire village with external roads.

The interpretation of all these features attributable to the Late Neolithic and Early Chalcolithic settlements implies a very consistent urban plan of the village, at least in the latest phases of occupation. Similar structures have been revealed at the contemporaneous sites in northwestern Anatolia, such as at Aktopraklık (Karul and Avcı 2011) and Ilıpınar (Roodenberg 1995). It would be important to integrate this layout's interpretation with a deeper knowledge of the vertical stratigraphy of the site.

Figure 12-10. West Mound, interpretation based on the DEM.

CONCLUSION

The new mapping of the site by drone technology and remote sensing applications provided new insights on the character of the landscape and gave some hints about the spatial organization of Late Neolithic and Early Chalcolithic settlements. As we are at the very preliminary stage of the project, the conclusions are tentative, and the interpretation of both settlements, as well as different parts of the immediate environs, lacks necessary detail and precision. However, these preliminary results clearly show the outstanding potential of this approach for off-site, and in the future, large-scale, landscape spatial analyses. The drone prospection is particularly effective due to the immediate response of data processing, the high resolution of all the datasets, and the total control and management of the flight by the archaeological team. In the future, we intend to fly again over the site with a multispectral copter, so that we can analyze different spectral signatures and archaeological anomalies.

The success of the methodology stems mainly from the integration of different modes of processing, such as optical data enhancing, digital surface modelling, and digital terrain modeling (elaborated by sharpening, high pass filtering). This is because most of the foundation walls and archaeological structures beneath the topsoil are identifiable by crop marks, colours, and/or the morphology of the terrain. The possibility of operating software applications in 2 and 3 dimensions multiplies the potential of the simulation of the archaeological landscape and produces comparative views of the site features. In fact, optical anomalies on the ground (i.e. crop marks) can be different from morphological features identifiable in a digital elevation model of the same area. Of particular significance is the stretching of the digital terrain model in the 2D and 3D visualization. Due to the high resolution of the photogrammetric datasets, a large number of archaeological remains beneath the topsoil is clearly visible and trackable.

In more general terms, the three-dimensional visualization of the East mound's DTM-DSM (Fig. 12-11) revealed the presence of a circumscribed eminence in the central-eastern part of the site known as the East Area, most likely dated to the Late Neolithic. This little mound is the result of the anthropogenic and natural accumulation of soil over the foundation walls of the buildings.

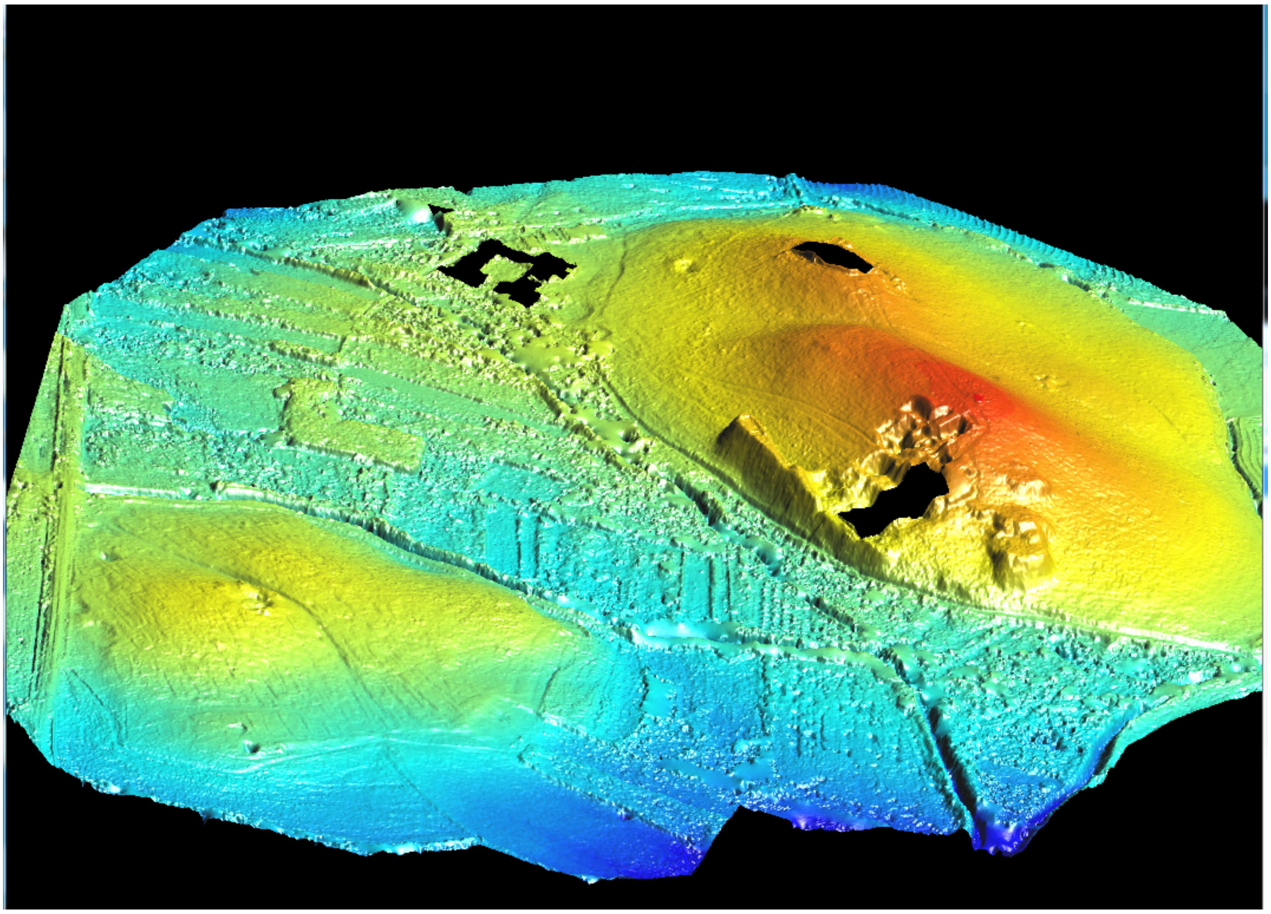

Figure 12-11. 3D view of the DEM.

On the West mound the interpretation of the drone's optical data and post-processed digital terrain models is particularly impressive. In fact, the identification of multiple rectangular-oriented shapes over the entire mound displays, for the first time, the complexity of the settlement and its organization, quite different from the Neolithic village of the East mound.

The applied methodology made it possible to reconstruct a very articulated "urban" plan with a clear iso-orientation of rectangular buildings in NE–SW alignment as well as some circular and linear shapes in between. The layout seems to be a combination of circular arrangements of houses around a large plaza and rows of houses placed along some kind of passageways or streets. The site architecture is dominated by detached and semi-detached houses—a pattern characteristic of the Late Neolithic and Early Chalcolithic.

As this is a preliminary analysis, this methodology opens up new perspectives on the investigation of the site and surrounding landscape by non-invasive technologies, aligned with archeological and geophysical studies.

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