Ancient Hermione revealed: the contribution of high-performance computing and digital methods to the analysis of a hidden cityscape

Giacomo Landeschi1 | Stefan Lindgren2 | Henrik Gerding1 | Alcestis Papadimitriou3 | Jenny Wallensten4

1Department of Archaeology and Ancient History, Lund University, Lund, Sweden
2Humanities Laboratory, Lund University, Lund, Sweden
3Ephorate of Antiquities of Argolida, Nafplio, Greece
4Swedish Institute at Athens, Athens, Greece

Abstract
This article explores the potential of combining high-performance computing techniques and a set of integrated digital methods to investigate the cityscape of ancient Hermione, Greece. Unmanned aerial vehicles (UAVs), terrestrial laser scanning, image-based modelling techniques and high-performance computing have been combined to provide a fully-three-dimensional (3D) representation of the city landscape, which encompasses both the topography and those still visible archaeological features, which are nowadays annexed into the modern buildings. As a consequence, the resulting geo-located digital platform is now opening up interesting opportunities for research, such as the possibility to analyse spatial interconnections between sacred buildings, to formulate hypotheses about their location and to put them in comparison with the accounts made by historical sources. By taking advantage both of an entirely-3D reconstruction and the analytic tools provided by geographical information systems (GISs), more sophisticated analyses can now be performed and specific issues such as visual perception and movement to and from prominent buildings/spaces can now be investigated.

KEYWORDS
3D GIS, computer vision, high-performance computing, laser scanning, UAV, urban archaeology

1 | INTRODUCTION

This contribution presents the results obtained in the frame of a project related to the multi-disciplinary investigation of Ancient Hermione in Greece. The first part of the article provides a general overview of the combined use of digital methods in the study of ancient urban contexts, pointing out main achievements and critical aspects in connection to the different methods applied. In section 2 the study context is described. In section 3, the methodological framework described is divided in sub-paragraphs presenting the different methods of data collection and analysis, which include unmanned aerial vehicles (UAVs) and high-performance computing (HPC) platforms. In the last section (section 4), the obtained results are presented and discussed. In this context, more long-term research goals are also introduced.
1.1 | Digital methods in urban contexts

Conducting archaeological survey in urban contexts has always been a quite difficult task even when advanced acquisition methods were employed. Among the non-invasive techniques involved, aerial photography and satellite remote sensing have been widely used and discussed (Campana & Francovich, 2003; Kaimaris, Karadodos, Georgiadis, & Patias, 2018; Kaimaris, Patias, & Georgoula, 2017; Mozzi et al., 2016). Geophysics has proven to be one of the more successful and often the only applicable one, due to the presence of physical obstructions and barriers that characterize the urban environment and which prevent the adoption of more traditional approaches (Basile et al., 2000; Papadopoulos, Sarris, Yi, & Kim, 2009). Datasets derived from geophysical prospecting have been sometimes employed as a geometrical reference to make a virtual three-dimensional (3D) reconstruction of the urban landscape (Klein, Vermeulen, & Corsi, 2012). Additionally, geophysics when properly integrated with aerial photography and historical cartography can provide important information to detect new archaeology (Verdonck, Vermeulen, Corsi, & Docter, 2012). The recent advances made in digital archaeology now allow archaeologists to combine different multi-resolution techniques with the purpose of investigating complex urban environments. This raises a broad discussion about the definition and implementation of best-practices to be employed in fieldwork (Vermeulen & Corsi, 2015). The successful integration of ground-based prospecting techniques and remotely sensed satellite data also allowed for a broader and deeper overview of the landscape and its palaeo-environmental evolution in a diachronic perspective (Keay, Parcak, & Strutt, 2014). Another field of application is the monitoring of threatened archaeological heritage, where ground-based prospecting techniques and advanced data post-processing operations have been combined to support archaeologists and planners to identify and prioritize those areas more likely to be damaged by new development (Neubauer et al., 2012).

1.2 | A 3D-based approach

More recently, significant technical advances made 3D technology and 3D-based multi-resolution sensors a valuable option to perform high-detailed on-site documentation, making it possible to acquire even extremely complex urban contexts such as the Mayan city of Copan, which could be analysed and communicated through an interdisciplinary, collaborative approach (Remondino et al., 2009; von Schwerin et al., 2013). Analogously, laser-scanning and image-based modelling techniques have been employed to digitally acquire portions of still preserved Roman cities (Barsanti et al., 2012, 2013; Fiorillo et al., 2013; Guidi et al., 2009) so as to produce high-resolution 3D models to be used in some cases as a geometrical reference for reconstructing the architectural space as it was discernable in ancient time (Dell’Unto et al., 2013). An additional refinement in the field of 3D acquisition methods is constituted by the massive increase of air-based computer vision techniques, which was made possible by the widespread of low-budget aerial platforms, such as UAVs. These allow for a faster and more accurate documentation of large archaeological landscapes and urban complexes (Ostrowski & Hanus, 2016; Smith, Passone, Al-Said, Al-Farhan, & Levy, 2014; Stal, Lonneville, Nuttens, De Maeyer, & De Wulf, 2014; Verhoeven, 2011). There is undoubtedly great potential in the use of 3D models and they are deemed to play a major role in the archaeological documentation process although more experiments need to be conducted. Indeed, as some recent scholarship has proven (Earl, 2007; Opitz, 2017; Paliou, 2011; Paliou, 2013; Paliou, Wheatley, & Earl, 2011), three-dimensionality has a clear ‘heuristic’ value in the way it can dramatically improve the quality of data interpretation through the adoption of statistically-oriented spatial analysis techniques, combined with a highly accurate representation of the space in all of its dimensions. Research conducted at Lund University has recently proven the potential of 3D technology in combination with a geographical information system (GIS) to analyse and interpret archaeological data (Dell’Unto et al., 2015; Landeschi, 2018; Landeschi et al., 2018). The results obtained both on a single site and on a landscape scale provided archaeologists with interesting solutions to address different types of questions, concerning: (a) the perception of the ancient space (Landeschi et al., 2016); (b) the structural degradation of ancient architectural structures (Campanaro, Landeschi, Dell’Unto, & Leander Touati, 2015); (c) the damage evaluation in the context of a site threatened by human action (Landeschi, Nilsson, & Dell’Unto, 2016). On a broader scale, heuristic 3D models have been employed for example in the analysis of the Mayan city of Copan, and the virtual reconstruction provided the geometrical reference to measure visibility and accessibility as a means for better understanding how the spatial settings were defined by different socio-political groups in the city (Richards-Rissetto, 2017).

2 | STUDY CONTEXT AND PREVIOUS RESEARCH

The location of ancient Hermione (today’s Ermioni in the Argolid) has long been known through the lengthy testimony of the ancient traveler Pausanias (2.34.4–2.36.3). The city lay positioned on a peninsula with two excellent natural harbours (Figure 1) and the fact that the first mention of Hermione in the literary sources can be found already in Homer (Hom. Il. 2.560) stands as testimony of the city’s importance. Its citizens fought in the Persian wars: Herodotos informs us that Hermione had resources enough to send three ships to the battle of Salamis and 300 men to the land battle at Plataia (Hdt 8.43, 9.28) The city had received riches in the Archaic period from the selling of a nearby island (Hydra) and was later possibly made affluent by trade in purple (Hdt. 3. 58–59; Plut. Vit. Alex. 36.2). Although the Athenians attacked Hermione during the Peloponnesian war, and in spite of repeated raids and destruction by pirates in the first century ac, when Pausanias centuries later visited Hermione (in the second century ac),
he found a city which still ‘afforded much to write about’ (Paus. 2.34.11).

Preserved knowledge of ancient Hermione attracted western scholars to visit the site early on. Michael Fourmont, came in 1729 and among other 19th century antiquarians and topographers who discuss the history and remains of the city can be mentioned Gell in 1804, W. Leake in 1806, A. Blouet and E. de Boblaye in 1828, E. Curtius in 1840, A. Conze and Adolf Michaelis in 1860. Geographers A. Miliarakis and A. Philippson arrived in Hermione in the late 19th century and certain topographical surveying (for example, Frickenhaus & Müller, 1911; Jameson & Jameson, 1950; Pharaklas, 1973) and archaeological work, notably in the extensive necropolis of Hermione, was carried out in the 20th century (Philadelpheus, 1909; Papadimitriou & Spathari, 1991; Papadimitriou, 1994; Spathari et al., 1991). Furthermore, the remains of a large temple were investigated by A. Philadelpheus and M.H. McAllister (Philadelpheus, 1909; McAllister 1969) and a significant corpus of inscriptions was collected and published in Inscriptiones Graecae IV (cf. Jameson, 1953, 1959; Stamires, 1960). E. Stickas of the Archaeological Society identified an important Christian Basilica and surrounding buildings during excavations in 1955–1956, including extensive mosaic floors. Restoration work on the mosaics, most recently dated to the late fourth or early fifth century AD and with a second sixth century phase, was moreover carried out in 1973–1974 and 1980 (Asimakopoulou-Atzaka, 1998; AD 29, 35). Moreover, the city area of Ermioni is regularly investigated by the Greek Archaeological Service since the 1970s; noteworthy is a find was made in 1988–1990: the discovery of a large Roman tomb monument in the area of the Ermioni entry road.2

1The publication of the archaeological work conducted by the Ephorate of Antiquities of the Argolid and the Swedish Institute at Athens in 2015–2017 is under preparation.

2An extensive history of research will be published by Dr A. Papadimitriou in a forthcoming volume of Opuscula, the journal of the Swedish Institutes at Athens and Rome.
In 2014, the Swedish Institute at Athens was contacted by the Greek Ministry of Culture, with the proposition of a joint study between the Institute and the then Fourth Ephorate of Prehistoric and Classical Antiquities (Argolis). This invitation for collaboration was gladly accepted and a three-year research programme was conducted between 2015 and 2017: A Greek Cityscape and its People: A Study of Ancient Hermione, continued in 2018 as Hermione: A Model City? The overall aim of the study was an understanding of the fabric of social life in a Greek polis in a long-term perspective (Archaic to Imperial times) and to allow for a first focused in-depth study of Hermione. This goal was approached by an integrated study of Hermione’s built environments, family and other social structures of the city, its prosopography and demography and finally religious practices, including funerary rituals. The innovative idea of the project was to proceed from the creation of a high-density digital terrain model (DTM), combined with 3D models of previously known and documented archaeological features and displayed within a GIS environment, to the ‘humanizing’ of this platform through archaeological, osteological and paleopathological examinations as well as studies of rituals and religious beliefs. Thus, traditional excavation methods and archival studies were combined with modern technology, allowing for crossover benefits and much experimentation with new technologies. The various milieux of the modern city of Ermioni, from densely built living quarters with winding narrow streets without clear sightlines or global positioning system (GPS) signal to open flat fields, from steep coastlines to hills with heavy vegetation literally created a field laboratory for the kind of methodological innovation that lies at the heart of the present article. In particular, following such an approach, the project was trying: (a) to recreate the original spatial relations among different areas of the city; (b) to make an assessment of the way the ancient space of the city was used and regulated by its inhabitants. The results presented in this contribution address sub-goal (a).

3 | METHODOLOGICAL FRAMEWORK

3.1 | Field data collecting

Concerning the collection phase, multiple data sources, including 3D data and traditional maps and plans, have been combined with the purpose of examining the evolution of the city landscape in a diachronic perspective (Figure 2). Along the way, different acquisition techniques have been integrated in order to provide a deeper insight into the archaeological heritage of the city, including preserved features, documented archaeological traces and observable ground anomalies (Figure 3).

3.1.1 | GPS survey

In 2015 the field campaign was conducted with the purpose of documenting those still visible archaeological features that are now partially annexed into the modern buildings. To accomplish this goal, a combined approach of acquisition and data-processing techniques was employed (Figure 3). The main objectives of that survey included: (a) to 3D map the urban context of the ancient city along with its

![Figure 2](image_url)
necropolis area; (b) to set up and implement an efficient 3D GIS allowing the management of a multiscalar and multitemporal dataset; (c) to integrate different methods of digital survey in a heterogeneous and diverse landscape.

During the first campaign, data were collected and georeferenced using terrestrial laser scanning, image-based 3D modelling and real time kinematic (RTK) GPS. Due to the necessity of importing the collected datasets in a GIS environment, using a GPS was a fundamental requirement to get the features properly located in the space. An ALTUS APS 3 Carrier-Phase enhancement GPS was hence employed to measure all the ground control points (GCPs) to be used as markers for georeferencing the derived 3D models of the archaeological structures. The fast time of data acquisition together with a good degree of spatial accuracy made the RTK GPS the most-suitable option to conduct the survey. Although, the particular conditions in the acquisition area, characterized by narrow streets and a high density of modern buildings, in most cases prevented us from getting an accurate satellite signal, GCPs were acquired in a restricted area south of the church of Aghioi Taxiarches, where the presence of a courtyard enabled a good signal reception from the GPS base. More points were collected in the southernmost part of the modern town, in close proximity to a portion of still-visible stone blocks, probably connected to the ancient city wall. Less problematic was the GPS survey in the area of the necropolis, located about 600 m northeast of the modern town, where the absence of buildings let us easily and quickly acquire GCPs all around the burial area.

In addition, during the last field campaign more GCPs were acquired throughout the city as we had the possibility to employ a more sensitive RTK device (Leica GS18 T) that is capable of getting the correction signal even in locations with poor sky visibility and is completely immune to any electromagnetic interference.

3.1.2 | 3D data capturing

To three-dimensionally acquire the still-visible archaeological features, including portions of city walls, temple foundations, embankments, a combined approach of methods was employed, including active and passive sensors. To collect some of the features, a terrestrial laser scanner (TLS) (Focus3D 120, Faro Technologies Inc. Lake Mary Florida, USA) was considered the best-suited option, due to the particular light conditions and the excessive darkness encountered in certain spaces that would have prevented the use of digital camera and so the use of computer vision-based processing techniques. Additionally, more features, including portions of walls and isolated stone blocks were identified and located in different areas of the modern town and needed to be included in the acquisition campaign. Owing to the lack of a sufficiently accurate GPS signal, where the RTK correction was missing, a different strategy was employed to georeference those features. Instead of anchoring GPSs directly on the structures, a seamless number of scans was acquired to spatially connect the area around the Aghioi Taxiarches church, which was previously georeferenced through the GPSs placed next to the building, in a position where it
was possible to get a proper RTK correction resulting in an accuracy of 3 cm. The road connection TLS acquisition consisted of 15 aligned point clouds resulting from around 300 scan positions with an average of 1,207,766 vertices per point cloud after a decimation to 1 cm point density. This approach allowed us to generate a single 3D mesh that could be geo-located based on the points located close to the church area, and which subsequently provided the right position for all the connected archaeological features (Figure 4). In connection to this laser scanner acquisition, the remaining part of the streets which included archaeological objects to be documented was acquired with an SLR digital camera (Canon EOS 550d) and the photographs were processed through image-based 3D modelling (IBM) techniques in order to derive a polygon mesh to be properly re-scaled and connected to the previously-described mesh. As a result, a set of 3D meshes was imported and properly georeferenced in 3D GIS. To deal with both textured and meshed 3D models and to add new layers as 3D vectors, ESRI ArcGIS was employed.

In 2016 field season, two additional goals were set: the first one consisted of the digital acquisition of the topography of the entire peninsula of Ermioni and the subsequent creation of a high-resolution DTM; the second goal was the testing of an advanced supercomputing system for processing a large dataset of information. To completely acquire the whole peninsula area a UAV DJI Inspire 1 RAW with a Zenmuse x5 digital camera was employed and different sets of photographs were acquired in order to cover the entire area and obtain a point cloud to be georeferenced and imported in GIS. More laser scanner acquisitions were also performed in order to collect additional features to be integrated into the geodatabase.

FIGURE 4 A portion of street connections, linking different archaeological features still visible in situ but hard to be georeferenced through GPS, has been digitally captured through the use of laser scanner and SLR cameras (a) and then visualized as a set of meshed 3D models in a GIS environment (b). Such operations allowed adjusting the position of the 3D models of the archaeological objects for which it was not possible to put down any marker (c). As reference GPS station, the area around the church of Aghioi Taxiarches (P) was considered [Colour figure can be viewed at wileyonlinelibrary.com]
3.1.3 | UAV-based data acquisition

As for the drone acquisition, a couple of dedicated applications (DJI and Pix4D) were installed on the tablet personal computer and connected to the remote controller in order to define the desired camera settings and flight parameters to be used. Ideally, the flight plan should be set up so as to cover the whole area to be modelled in the form of a regular grid, taking pictures with a sufficient level of overlap to make them usable for image-based 3D modelling. The total surface to be covered being 0.974 km² and with a drone’s battery autonomy of ca 20 minutes, the best-suited option was to acquire the whole area in eight separate flights, which resulted in eight chunks of approximately 300 photographs to be processed (Figure 5). Each flight height was defined trying to find the right balance between a reasonable distance between the camera and the ground surface and the need of keeping the drone within a safety distance from the more proximal buildings and/or any other physical barrier. As an average value, 62.9 m above the taking off surface was determined to be sufficient to capture details that could enable the reconstruction of a spatially accurate point cloud to be used as a basis for the DTM.

3.2 | Data processing: image-based 3D modelling reconstruction

Considering the huge amount of data collected during the UAV-based data acquisition campaign, consisting of 2265 raw images, it was essential to define novel methods for performing image-based 3D modelling in an efficient way. By taking advantage of high-performance computational resources available through the Lund University Center for Scientific and Technical Computing (LUNARC), the entire dataset has been processed and a high-resolution 3D model produced (Figure 6). Agisoft Photoscan Pro software was installed to run a parallel processing on multiple compute nodes by
taking advantage of all the available cores across the nodes. Using remote visualization it was possible to connect any local computer to two different compute clusters named ‘Aurora’ and ‘Erik’, enabling to perform respectively more CPU (central processing unit) and GPU (graphics processing unit) demanding processing pipelines. ‘Aurora’ consists of 240 compute nodes in total. Each node has in turn two Intel Xeon E5-2650 v3 processors (Haswell), offering 20 compute cores per node. The nodes have 64 GB of DDR4 ram installed. ‘Erik’ is based on 16 SL250 nodes and eight SL270 nodes each with dual 64-bit, 8-core Intel Xeon E5-2650 2.00 GHz processors, resulting in a total number of 384 processor cores. The system includes 68 Nvidia Tesla K20m GPU cards (two in each SL250 node and four in each SL270 node) which make its performance very suitable for GPU-demanding tasks. To make it accessible for demanding interactive remote graphics tasks, Erik has been reconfigured as an ‘On Demand’ solution that uses a queueing system named Slurm to allocate a full graphics node to each user on an on-demand basis. As demonstrated through some preliminary tests, when using Agisoft Photoscan software, the point alignment typically takes advantage of CPU resources while the dense point reconstructions heavily relies on GPU to generate the dense point cloud. For this reason, the entire process was split in two separate chunks that were processed through Aurora for the point alignment and through Erik for the point dense reconstruction. Through a user-friendly graphic user interface (GUI) users had

**FIGURE 7** Different stages of the 3D model reconstruction: (a) the sparse point cloud was obtained from the camera alignment through the use of a structure-from-motion (SfM) algorithm and after the gradual selection and this consisted of 669 810 xyz points; as a following step (b) the dense point cloud, resulting from the multi-view stereo (MVS) matching that allowed to increase the number of points up to 233 639 780, has been georeferenced (c) with 38 GCPs previously acquired through the RTK GPS. Finally (d) a special filtering tool has been used to classify terrain surface points and separate them form the points belonging to buildings and vegetation cover [Colour figure can be viewed at wileyonlinelibrary.com]
the possibility to set the numbers of nodes and the walltime for both the point alignment and the dense cloud reconstruction, which are typically the more demanding stages in terms of hardware performance.

After this process a dense point cloud was produced and the entire dataset was georeferenced based on 38 GCPs, acquired during the previous field campaigns (Figure 7). Ten additional check points (CPs) were then added in order to evaluate the overall accuracy of the model and such an operation gave us a total root mean square error (RMSE) of 26.18 cm, similar to the one observed and described by Jebur, Abed and Mohammed (2018), where an RMSE of cm 31, 27 and 29 resulted respectively from x, y and z coordinates (Figure 8). As a result, the point cloud was filtered in order to keep only the points belonging to the ground surface and use them to build up the raster DTM (Figure 9). Since the priority was to reconstruct a high-resolution terrain model of the city area, special filtering tools available in Agisoft Photoscan were applied to remove redundant point data information, such as buildings, walls, roofs and vegetation elements. Some additional ‘background noise’ due to points not correctly triangulated in Photoscan were manually cleaned up at a later stage. As a final result, a DTM with a spatial resolution of 5.75 cm/pixel and a point density of 302/m² was obtained.

3.3 | GIS data implementation

To better manage all the spatial information collected during the field campaigns and to effectively use these datasets to analyse the archaeological record, ESRI ArcGIS software was chosen as the best-suited solution to manage in the same digital environment both two-dimensional and 3D data. For this purpose, a geodatabase was set up in order to manage different types of contents. WGS84 UTM 34 N was defined as the coordinate system to locate all of the imported objects. As part of the base map, a digital elevation model (DEM) of

| Point | X error (cm) | Y error (cm) | Z error (cm) | Total (cm) | Image (pix) |
|------|--------------|--------------|--------------|------------|-------------|
| label | X error (cm) | Y error (cm) | Z error (cm) | Total (cm) | Image (pix) |
| point 69 | -0.775143 | 3.22408 | -1.74101 | 3.74522 | 0.100 (10) |
| point 70 | 10.6722 | -6.26416 | 2.67447 | 12.3564 | 0.143 (11) |
| point 71 | 20.175 | 4.26016 | -0.022843 | 20.6199 | 0.226 (15) |
| point 72 | -6.30311 | 7.37707 | -0.999499 | 9.77192 | 0.089 (12) |
| point 73 | -5.59525 | 11.4421 | 2.82813 | 13.0471 | 0.123 (19) |
| point 74 | -7.15719 | -3.87978 | 5.33114 | 9.73134 | 0.110 (9) |
| Total | 10.9225 | 8.92807 | 4.49638 | 14.807 | 0.801 (a) |

| Point | X error (cm) | Y error (cm) | Z error (cm) | Total (cm) | Image (pix) |
|------|--------------|--------------|--------------|------------|-------------|
| label | X error (cm) | Y error (cm) | Z error (cm) | Total (cm) | Image (pix) |
| point 75 | 29.9637 | 1.90503 | 24.2226 | 38.577 | 7.945 (13) |
| point 76 | -14.4021 | 1.98218 | 17.5186 | 22.7651 | 6.787 (18) |
| point 77 | -4.08586 | 4.47673 | -29.0862 | 29.7109 | 6.417 (21) |
| point 78 | 20.5589 | -1.55284 | 19.6778 | 28.5008 | 2.050 (9) |
| point 79 | 1.79515 | -2.63214 | -18.562 | 18.8343 | 2.696 (17) |
| point 80 | 22.7033 | -13.7051 | 20.4244 | 33.4728 | 5.834 (13) |
| point 81 | -9.54465 | 14.3732 | 0.87121 | 17.276 | 0.888 (12) |
| point 82 | 20.7022 | -7.54161 | -12.2096 | 25.1899 | 1.799 (9) |
| point 83 | 8.69444 | -14.159 | -1.71165 | 16.7033 | 3.039 (6) |
| point 84 | -15.7758 | 11.5101 | 9.22721 | 21.5986 | 4.390 (78) |
| Total | 17.0512 | 9.06197 | 17.6819 | 26.1823 | 4.905 (c) |

| Count | X error (cm) | Y error (cm) | Z error (cm) | Total (cm) | Image (pix) |
|------|--------------|--------------|--------------|------------|-------------|
| Count | X error (cm) | Y error (cm) | Z error (cm) | Total (cm) | Image (pix) |
| 38 | 10.9225 | 8.92807 | 4.49638 | 14.807 | 14.807 (d) |
| 10 | 17.0512 | 9.06197 | 17.6819 | 19.3096 | 26.1823 |

FIGURE 8 RMSE observed in 38 GCPs evenly distributed all over the model’s surface and 10 check points not previously used in the georeferencing process. Table a and b show the error rate measured respectively for each single GCP and CP while table c and d present their total RMSE. Interestingly, results show that the total RMSE on check points (26.18 cm) reflects what has been recently observed in analogue case studies (see Jebur et al., 2018)
the city topography was provided by the Greek cadastral agency (KTIMATOLOGIO, 2020) in the form of a raster dataset with a point density of 0.2 points per square metre (PPSM). In this sense, the idea behind the drone acquisition was to generate an improved version of the terrain model with a higher level of point density which would allow us to raise the spatial resolution up to 400 PPSM. The idea was that a high-resolution model would allow us to better understand the original topography of the ancient city of Ermioni and to possibly detect ground anomalies that might be related to the presence of buried archaeological features (Figure 10).

More datasets were then imported into the GIS. All the 3D models, irrespectively of technique employed for their production, are usually managed by the 3D Analyst module as 'multipatch' feature classes, which represent a file format that describes surface boundary
FIGURE 10  DTM derived from the dense point cloud and imported into the GDBMS. The spatial resolution is set to 5.75 cm/pixel with a point density of 302 points/m². Field 3D-acquired archaeological features have been imported as multipatch feature classes and correctly located based on the GCPs measured both with RTK GPS and total station. Interestingly, image (a) shows the original dense point cloud without any filter applied where it is almost impossible to see the spatial relations between archaeological objects and the original topography of the study area whereas in (b) the removal of the redundant point information (i.e. modern buildings) allow for a better understanding of such relations in a way that would not be possible through traditional field surveys methods [Colour figure can be viewed at wileyonlinelibrary.com]
3D models (ESRI, 2008). Portions of temple foundations, wall structures and terrace embankments were therefore turned into shapefile entities and connected to the relational structure of the geodatabase management system (GDBMS). More data were supplemented by the Fourth Ephorate of Prehistoric and Classical Antiquities (Argolis) in the form of digitally scanned plans of archaeological features brought to light in the past decades in the urban area. These were converted into raster files to be used as an additional data source for the reconstruction of the original city grid of ancient Hermione. Additionally, the original aerial images acquired by the drone have been linked to the GDBMS in order to allow deeper insights into the ground anomalies not detectable in the general orthophotomap due to the comparatively lower resolution.

4 | RESULTS AND DISCUSSION

As a preliminary result, the data post-processing gave us the possibility of collecting and displaying in a GIS environment a high-density DTM which provided the geometrical reference to adjust 3D models of the previously-documented archaeological features along the z axis, such as the temple foundation, sections of the Classical and Hellenistic city walls, terraces and isolated wall blocks. All of these elements can be visually and spatially interrelated and compared against the topography of the modern city in a way that could not be possible in reality, due to the presence of visual obstacles (modern buildings, vegetation, etc.) preventing any intervisibility between the archaeological elements. Hopefully, the high resolution of the DTM in terms of point density will allow us to detect and investigate more thoroughly ground anomalies that can be associated to the presence of terraces and buried wall structures, especially in the easternmost part of the study area, not covered by modern buildings.

So far, the project on ancient Hermione has proven the potential of employing 3D data information to recreate lost topographic relations among archaeological and natural features that characterized the ancient urban space: this is an essential prerequisite to define and geo-locate areas of the city linked to specific functions, such as sanctuaries or public squares. As an example, the topographic location of the Roman aqueduct, in which the verticality plays a significant role for defining its original path through the landscape, can be more effectively addressed through a fully-3D data representation (Cambray, 1993), while a deeper understanding of the settings of artificial terraces as attested in other Greek cities (Bintliff & Evelpidou, 2002) can be more easily obtained through the setup of a spatially high-resolution DTM of the study area.

In a similar way, additional questions relate to the way those portions of land that were more exposed to external attacks and therefore more demanding of defensive structures.

Based on such premises we need to carefully re-discuss the role of three-dimensionality and its centrality in addressing questions on the ancient urban space and the way it was experienced by its original inhabitants. Still, as in any simulation process, some degree of uncertainty must be taken into consideration. In this sense, recent studies have tested procedural 3D modelling as a valuable option to perform an accurate and critical reconstruction of ancient urban areas, by introducing procedural rules that contribute to add transparency to the overall workflow and to map uncertainty in a more solid way (Piccoli, 2016). Additionally, an important source of information lies in the so-called ‘legacy data’ (Allison, 2008), consisting of archival sources that can often provide significant clues about transformations and changes occurred in the landscape and can therefore contribute to the development of a diachronic representation of the city evolution drawing upon important sources such as historical photographs, unpublished excavation drawings or field reports. By integrating such data in GIS it will be possible to build up an interpretative framework that can allow us to gain new knowledge about the way space was structured and used in antiquity. As recent scholarship has proven, by combining vertical and horizontal map representations together with 3D models it is possible to virtually reconstruct the original context in a way that would not be possible through traditional approaches of documentation (Landeschi et al., 2018). In an urban context it would be interesting also to test volumetric analysis for engaging at a deeper level with the study of visual connectivity, following theories on space syntax analysis (Hillier & Hanson, 1989), to cope with that empty space often disregarded from archaeological enquiry (Campana, 2017) and possibly to add new meaning to the use of the landscape, trying to explore concealment and hiddenness as additional properties (Gillings, 2015).

As this contribution has sought to demonstrate, there are new openings for a more comprehensive study of the urban space in antiquity thanks to advances occurred in digital technology and the use of high-performance computing. Using 3D technology as a heuristic tool for data analysis is still at a very basic stage, and its contribution can be crucial to allow archaeologists to define the original topography of an ancient urban space. More importantly, the analysis of an ancient space as a lived, dynamic environment in which people moved and interacted remains an objective for future research. Data modelling in archaeology has already proven the importance of providing data representations that ‘simplify’ complex phenomena in order to make them more easily understandable (Lock, 2003): it is about time now to make any simulation process more transparent so that it can afford the possibility to build up different scenarios of reconstruction to test several hypotheses on the use of space. It is therefore essential to generate representations that tend to provide a more accurate picture of the reality, so that they can be effectively used as an integral part of the interpretative process. The massive diffusion of 3D technology within archaeological practice must be encompassed within a theoretical framework where new questions are raised and addressed through the use of dynamic solutions where three-dimensionality
plays a key-role and multi-resolution approaches to data analysis are explored.

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CONFLICT OF INTEREST
The authors have no conflict of interest in relation to this work.

ORCID
Giacomo Landeschi https://orcid.org/0000-0002-7463-1935

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