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Archaeology of archaeology at Heloros: Re-interpreting the urban layout of a complex Greek settlement in Sicily using proximal sensing and data fusion

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ABSTRACT

Heloros lies on a low hill situated along Sicily's Ionian shore. Archaeologists believe this city was the first subcolony of Syracuse. Despite its long history and prowess, Heloros is and therefore less known. This article answers crucial questions regarding the site's chronology, architecture, and topography. This involves digitizing and verifying legacy data and fusing them in a Geographic Information System with newly acquired 3D and geospatial documentation that we collected using global positioning, digital photogrammetry, drones, terrestrial and airborne Light Detection and Ranging, and ground penetrating radar. Our results present new insights into Heloros' history, including information about its pre-Greek occupation and revisions to the interpretation of important buildings and fortifications. Our research demonstrated that the Archaeology of Archaeology investigation we carried out at Heloros, when enhanced by our 'digital excavation' approach can generate new knowledge on archaeological sites without requiring new excavations.

1. Introduction

The site of *Heloros* (EPSG 32633: 509569.86 4077370.22), located along Sicily's Ionian coast about 30 km south of the city of Syracuse, is among the island's less-known Greek settlements (Fig. 1). While briefly mentioned in ancient literature, the site's significance is often only linked to the nearby Heloros river, now called the Tellaro, which gave the settlement its name. Archaeologists have determined that Heloros was Syracuse's initial subcolony, likely established in the late 8th century BCE. This conclusion was drawn from examining the site's archaeological artifacts and assessing the strategic importance of its topography (Copani, 2010). Heloros is situated on a low plateau of about 12 ha (20 m above sea level) and strategically positioned close to sandy beaches north of the Tellaro river.

Heloros is slightly higher than the surrounding landscape, providing visual control of a large stretch of coastline from Capo Murro di Porco in the north to Capo Passero, the southeasternmost tip of Sicily. Due to its geographic location, Heloros' harbour must have played a crucial role for Syracuse's economic and military standing. While significant archaeological excavations were carried out at Heloros between 1899 and the 1980s, there needs to be more documentation available despite the extensive collection of excavated materials. These excavations revealed a thriving city during the Hellenistic period, featuring impressive fortification walls, a North Gate, a theater, several temples, and a Sanctuary of Demeter with a monumental stoa and a well-planned urban layout (Orsi et al., 1965; Voza, 1999). Although the site features remarkable monuments, it has never been explored using modern archaeological methods and surveying techniques. The results of previous excavations were not fully published, and the preliminary reports raised more questions than they answered. As a result, there are still many open issues about ancient Heloros, even over a century since the first excavations.

In this paper, we aim to answer a crucial question regarding the development of the site's architecture and topography, starting from its uncertain foundation in the late 8th century BCE to the Late Hellenistic/Early Roman Republic era when it gradually disappeared from written sources. Although Heloros is known as an Archaic city built on a pre-existing Sikel settlement, the archaeological evidence found at the site

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mostly belongs to the Classical or Hellenistic period, making its archaeological dynamics complex to understand. Although in recent years new studies on the landscape archaeology of Southeastern Sicily have shed light on the cultural development of many indigenous and Greek sites, they did not focus in detail on Heloros (Brancato, 2019; Brancato et al., 2019).

Furthermore, the absence of any scholarly work in English on the archaeology of Heloros has made the site virtually unknown outside of the Italian scientific community. Against this scenario, the University of South Florida's Institute for Digital Exploration (IDEx www.usf.edu/idex) and the LMU Munich's Institute for Digital Cultural Heritage (IDCH https://www.dkes.fak12.uni-muenchen.de/index.html) teamed up with the *Parco Archeologico e paesaggistico di Siracusa, Eloro, Villa del Tellaro e Akrai* (Parco Archeologico), the Sicilian authority entrusted with the preservation of the site, to improve the understanding of Heloros' cultural significance and address the issues affecting its sustainability and protection. The Parco Archeologico has given us a three-year research permit for 2021–2023 to develop the Heloros Advanced Digital Exploration and Surveying (HADES) project (https://www.usf.edu/arts-sciences/institutes/idex/research/hadesproject.aspx) to gather new information about the site using digital archaeology techniques and combine it with existing legacy data to produce new knowledge. As part of the HADES project, we looked at legacy data from the 20th century to better understand the provenience of excavated materials and improve the documentation of architectural elements at Heloros. Next, we combined the available information with recently obtained geospatial data and 3D documentation on a GIS platform. This helped us better understand the site's topography and urban layout, revealing new insights into its history. We argue that using a 'digital excavation' methodology at Heloros can enhance the success of the '*Archaeology of Archaeology*' research we were invited to perform by our partners at the Parco Archeologico.

The digital excavation workflow we used in the HADES project is a multilayered process that enhances the archaeological investigation without needing physical excavations (Abate et al., 2023; Dorninger and Nothegger, 2012; Shaohua and Qingwu, 2014). This involves all the steps shown in Fig. 2, which can be summarized as follows: 1) research design and planning; 2) work with legacy data; 3) produce 3D and geospatial documentation; 4) fuse all data in the GIS; 5) analyze data in the GIS, formulate interpretative hypotheses, and ground truth results; 6) curate, archive, and disseminate the data; and 6) publish results.

Additionally, the HADES project has adopted an *Archaeology of Archaeology* approach, which Murray and Spriggs Field initially proposed (2017). This approach views a site as a laboratory where prolonged archaeological investigation produces data and knowledge while leaving physical evidence on the site. To better understand and protect Heloros, we propose incorporating a digital excavation component into this approach. The HADES project used various remote and proximal sensing techniques, including satellite imagery, low-altitude photography, digital photogrammetry, terrestrial Light Detection and Ranging (terrestrial LiDAR), airborne Light Detection and Ranging (airborne LiDAR), Global Navigation Satellite System (GNSS), and Geographic Information System (GIS) techniques. This helped us gather valuable data and insights about the traces left at Heloros by past archaeological excavations. Thanks to this approach, we created new 3D and geospatial documentation that brought attention to Heloros from local authorities, such as the municipality of Noto and the Parco Archeologico. We believe this increased public awareness about Heloros' significance will help to ensure its future use and protection. As part of our research at Heloros, it is essential to note that we initiated the first investigation of the site using Ground Penetrating Radar (GPR) and drone-based airborne Lidar. However, the presentation of our GPR and LiDAR survey results is not within the scope of this article. These new data will be the focus of future publications in specialized journals.

2. Site background

2.1. Interactions with nearby indigenous settlements

According to a previous review of the available Greek literary and

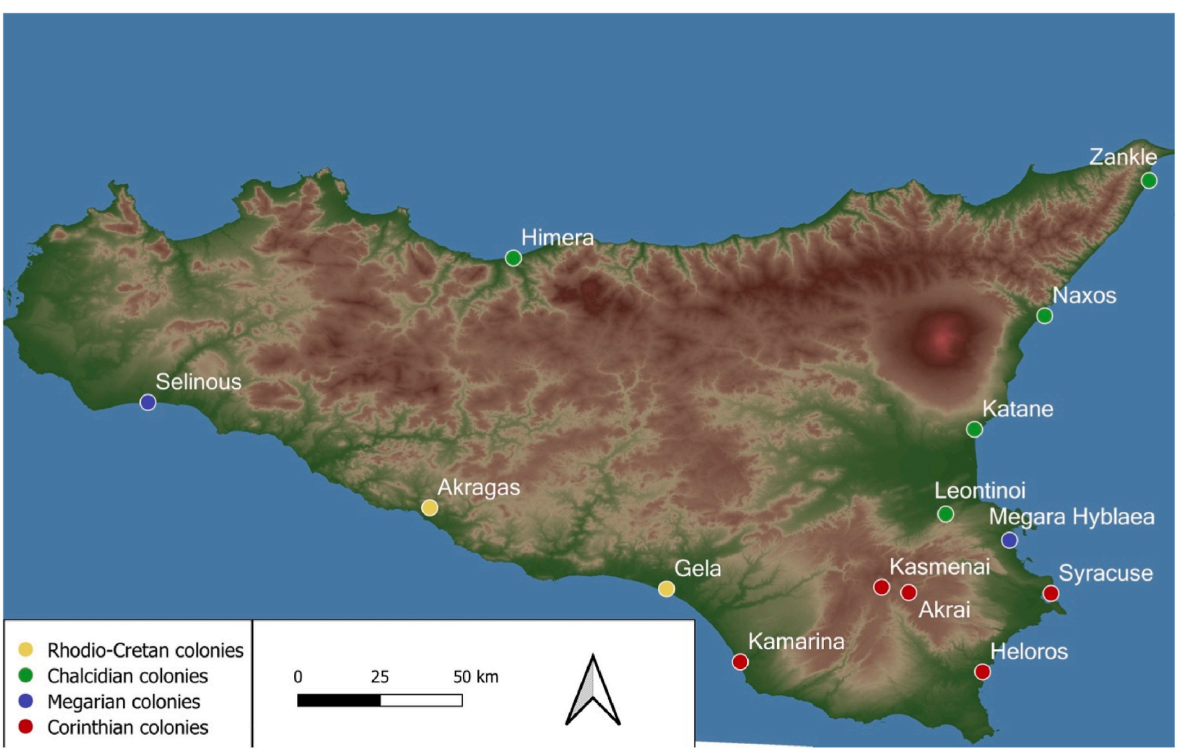

Fig. 1. Map of Sicily showing the location of Greek cities and Heloros. Colorized version generated from *Tinitaly DEM* made available by Sezione di Pisa Istituto Italiano di Geofisica e Vulcanologia. Map by Dario Calderone.

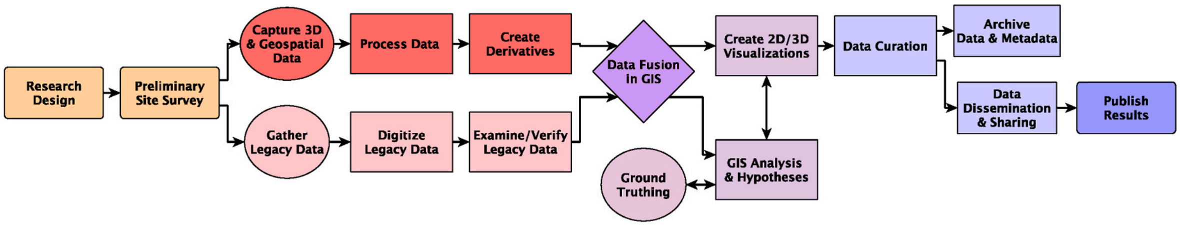

Fig. 2. Diagram showing the digital excavation workflow used in the HADES project. Diagram by Nicola Lercari.

epigraphic sources related to Heloros (Corsaro and D'Agata, 1989), Pindaros was the first to mention the settlement (Pindaros, *Nemee*, IX, 40). At the same time, Herodotus referred to its harbor in 493 BCE (Herodotus, *The Histories*, VII, 154). The Helorine *hodòs* (Helorine Road), the ancient road that connected the settlement to Syracuse, was mentioned multiple times by Thucydides (Thucydides, VI 66, 3; VI, 70, 4–5; VII, 80, 5. Archaeological research has shown that a Sikel community inhabited the site before the Greek city of Heloros was established in the late 8th century BCE (Pelagatti and Voza, 1973; Voza, 1978). This community probably belonged to a more extensive indigenous network that included several other contemporaneous centers situated within an eight-mile radius along the upper western course of the Tellaro River (Fig. 3). Some of these centers include Tremenzano, Cozzo delle Giummare, Grotta delle Murmure, Monte Alveria-Noto Antica, and Monte Finocchito. Among them, Monte Finocchito was the most impressive fortified Sikel citadel in southeastern Sicily (Frasca, 2016; Nicoletti, 2022). However, previous research on Monte Finocchito did not provide much information about its connection with Heloros, the only Greek city nearby. According to one interpretation, the citadel of Monte Finocchito was built between 850/800 and 700/665 BCE. This suggests that the settlements of Finocchito and Heloros existed at the same time and probably had some interaction with each other. This is supported by their proximity and intervisibility (Fig. 4) (Frasca, 1981).

Other previous work provides a second interpretation that links the abandonment of Monte Finocchito to the establishment of Heloros, implying a possible historical relationship between the two events (Steures, 1980). Recent archaeometric data from a comparative study of indigenous pottery from Monte Finocchito and early Greek pottery from Heloros revealed the presence of two local imitations of Greek Proto-Corinthian cups at Heloros, which were probably crafted at Monte Finocchito. Scholars interpret this as evidence that the two sites interacted and were part of the same network at some point (Raudino, 2021; Raudino et al., 2017).

2.2. Relationships with other Greek cities

Interestingly, Thucydides' account of the Greek colonization of Sicily and the Corinthian colonial efforts does not mention how Heloros was established (Thucydides, *The Peloponnesian War*, 6.3, 5). Archaeologists are surprised by the lack of information regarding Heloros' foundation, which was historically recognized as the first Syracusan subcolony (Voza, 1999; Copani, 2005, 2010). The city's name appears to have

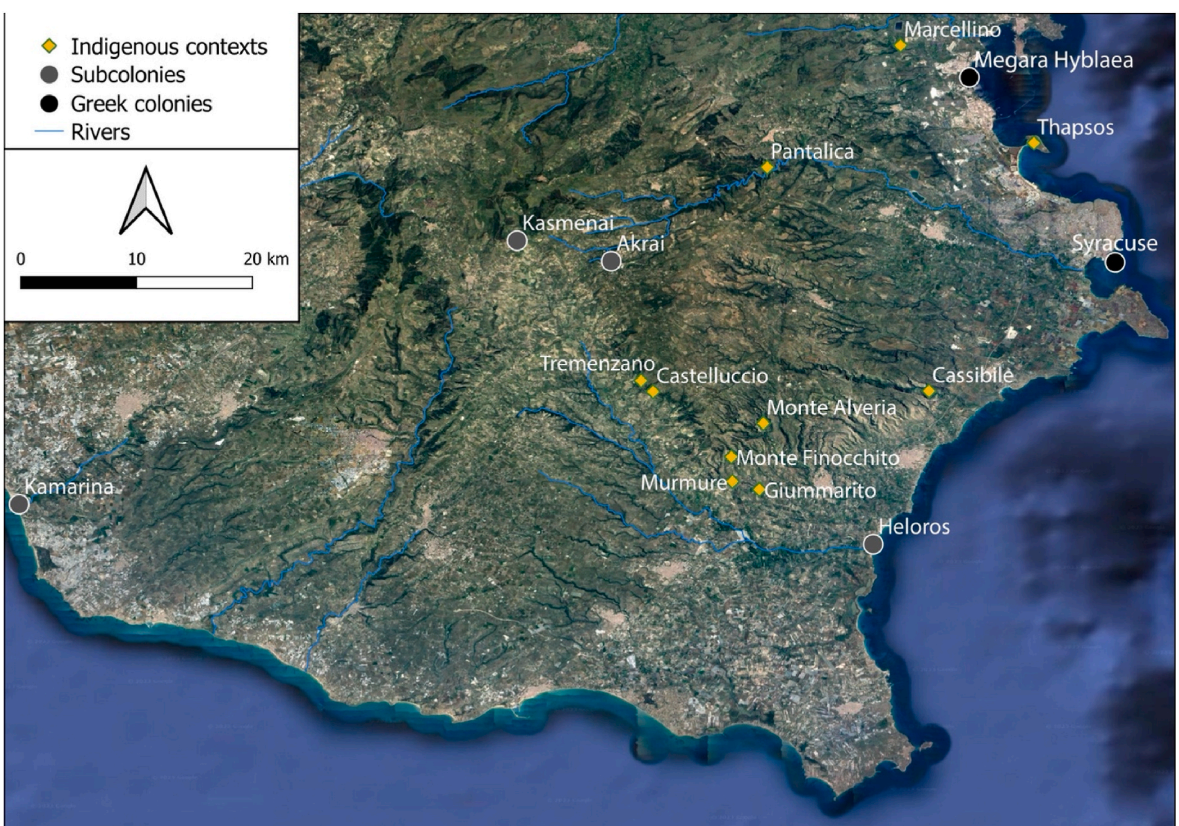

Fig. 3. Map of Southwest Sicily showing the location of indigenous settlements and Greek colonies near Syracuse. Generated from Map data ©2015 Google. Map by Dario Calderone.

Fig. 4. Heloros' location as seen from the Southern Necropolis of Monte Finocchito. Figure by Davide Tanasi derived from Steures 1980.

originated from the Greek word for the Heloros river (currently known as Tellaro), the region's most prominent feature. The transportation axis connecting Syracuse with the city of Heloros was called the Helorine Road by the Greeks, as noted by Uggeri (2004). According to ancient sources, Heloros and his brother Aktaios were the sons of the river god Istros in Skythia. They came to help Telephos when the Achaeans accidently attacked his kingdom on their way to Troy. Ajax killed the two brothers during the battle. This scene is depicted on a panel of the Telephos frieze of the Pergamon Altar (Flavius Philostratus, *On Heroes*, 2.15; Lulli, 2016). The Greeks possibly named the river after Heloros because of his father's divine nature. However, there is not much available information about why a location near the Tellaro river was chosen as the city's location. During the late 2nd century CE, the Roman author Claudius Aelianus mentioned that Heloros was "once a Syracusan fortress." This is the only known connection between Syracuse and Heloros, indicating that the subcolony had a significant military role (Claudius Aelianus, On the Characteristics of Animals, 12.30). Heloros is situated on a coastal plateau with easy access to the sea, dominating a flat and fertile area adjacent to the Tellaro river and its abundant freshwater resources. Furthermore, the rocky shore beyond the two beaches that surround Heloros could be easily quarried for construction material. Indeed, numerous limestone quarries have been documented near the site (Felici, 2012; Idà, 2020) (Fig. 5). The silence of the literary sources and the absence of significant epigraphic documents complicates the interpretation of the initial architectural development of Heloros, leaving it as an essential open issue.

Equally important is to shed light on the relationship between Heloros and Neaiton, the closest Greek city and Syracuse's subcolony. Neaiton was built over the indigenous settlement of Noto Antica-Monte Alveria. However, this task is challenging due to our limited knowledge of Neaiton's earliest history. According to ancient sources and archaeological data, the primary evidence about Neaiton (or *Netum* in Latin) is from the age of Hieron II when the Romans assigned the city to the king in 263 BCE as part of the Syracusan kingdom. This was alongside Akrai, Leontinoi, Megara Hyblea, Turomenion, and Heloros (Guzzardi, 2001).

2.3. Archaeological evidence and chronological issues

Excavations have been conducted at Heloros for over a century, with work done in 1899, 1927, 1958–1959, 1961 (Orsi, 1899; Orsi et al., 1965), and again in multiple stages between 1967 and 1980 (Voza, 1972, 1973, 1976, 1999). These excavations uncovered a wide range of archaeological features and imposing architectural evidence within Heloros' surroundings (Fig. 6) and the city itself (Fig. 7). The *Colonna Pizzuta* (Pizzuta Column) is a massive funerary monument that stands outside the Heloros hill already mentioned by Grand Tour travelers visiting Sicily in the 18th century (Houël, 1785). It marks a wealthy burial from the Hellenistic era and dominates a large cemetery area located west and northwest of the city. This burial ground includes four main areas for graves, labeled A-D, which date back mainly to the 6th and 5th century BCE. To the north of the city, on the beach, there is a small sanctuary complex thought to be an Archaic *Koreion*, the only known extra-urban cult place identified so far at the site.

Additionally, several quarry sites are located on the hill's eastern slope and north and south of Heloros, as identified by Idà (2020). The North Gate and Northeast and West fortification walls are the most impressive archaeological features in the city. They include seven square defense towers, one circular tower, and a sizeable quadrangular bastion. These structures were likely built in two phases during the Archaic and Classical periods. Archaeologists discovered various public and religious buildings on the southern and southwestern sides of the hill. These include the Sanctuary of Asklepios, or *Asklepieion* (2nd – 1st century BCE), the so-called Sanctuary of Demeter (4th to the 2nd century BCE), which was enhanced with a large stoa in its final phase, and a theater believed to be from the Hellenistic era. An excavated *insula* of houses, only briefly mentioned in preliminary reports, is also thought to have originated during the Hellenistic period.

Furthermore, excavators speculated that there was once a South Gate located on the southeastern slope of the hill. As a matter of fact, this gate was never documented and its existence it's merely speculative. Additionally, if it ever existed it was very likely obliterated in the 1920s by the excavation of the irrigation canal that severely damaged the theater. The agora is the most significant and least known part of Heloros' urban context. It is situated at the center of the hill, on higher ground. Here, archaeologists discovered a trapezoidal market area surrounded by buildings with colonnades. The Helorine Road runs across this area from the North Gate to the South Gate. To the west of the Helorine Road and south of the agora, an urban area was delimited by a secondary East-West road. Little information is available regarding this district's chronological and architectural evolution, except that it was utilized during the Archaic and Hellenistic periods.

Based on our examination of the legacy documentation, we inferred that most of the archaeological findings in Heloros are not from the Archaic period. Through our surveying and ground truthing, we observed that at Heloros, there are more structures from the Hellenistic period than from other eras. This situation presents a challenge in interpreting the data, highlighting the need for new approaches to answering our research questions. To address this, we initiated the HADES project, whose methods and findings are detailed in the following sections.

3. Methods and materials

Our team began the HADES project adopting an *Archaeology of Archaeology* approach, which entailed collecting all the available field notes, legacy data, drawings, and maps of Heloros produced by various teams of archaeologists in the nineteenth and twentieth centuries. We then conducted a thorough walking survey of the site using advanced

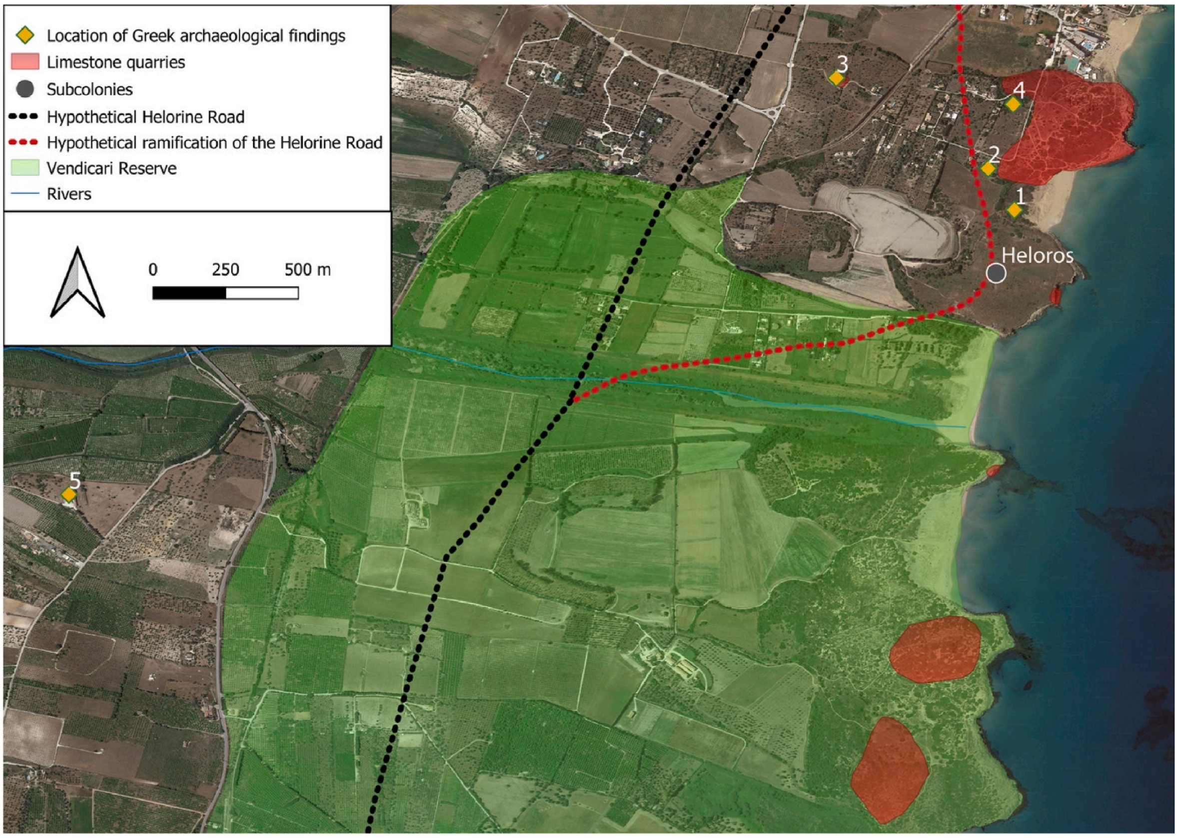

Fig. 5. Satellite view of Heloros' landscape showing the site's proximity to the Vendicari Reserve, the location of Greek archaeological findings and quarries, and the paths of the Helorine road as proposed by Uggeri (Uggeri 2004). Generated from Map data ©2015 Google. Map by Dario Calderone.

GNSS technology, with a 1-cm real-time kinematic (RTK) correction, to locate previously excavated buildings, structures, and roads situated in overgrown areas (Fig. 8a). This initial work helped us recognize the limitations of the existing archaeological documentation and the challenges of interpreting such a complex site. Between 2021 and 2023, we used various remote and proximal sensing techniques to gather new geospatial data and 3D documentation of the site. Our goal was to better understand the legacy data and uncover more information about the history and significance of the area. By examining satellite imagery on Google Earth Pro, we identified specific locations on Heloros Hill that our digital excavation could focus on. These areas include the Northeastern and Western fortifications, the Sanctuary of Asklepios, the Sanctuary of Demeter, and the agora with its commercial district and nearby streets. We used various digital archaeological methods to understand the complexities of Heloros' occupation (Dennis, 2020; Forte, 2016; Morgan, 2022). This involved creating 3D maps of the site using ground and drone-based digital photogrammetry and terrestrial LiDAR (Campana, 2017; Ebrahim and Mostafa, 2014; Lercari, 2019; Russo, 2012) (Fig. 8b–d). We used the ground control points we collected with the GNSS to georeference the legacy site plan and drawings of excavated areas, as well as the digital surface model (DSM) and orthophotos we obtained from our 3D documentation. Fusing all the data into our site GIS was a success, allowing for thorough analysis and re-interpretation of the site (Campiani et al., 2023; Dell'Unto et al., 2017; Dell'Unto and Landeschi, 2022; Lock and Pouncett, 2017; Richards-Rissetto, 2017; Scianna and Villa, 2011). In the following sections, each technique will be explained in more detail.

3.1. Drone-based digital photogrammetry

To improve our investigation of Heloros' topography, we used a DJI Phantom 4 PRO V2.0 UAV to capture thousands of at-nadir, low-altitude aerial images of the site (Verhoeven, 2009) (Fig. 8b). The UAV was equipped with a 20-megapixel RGB camera, which had a 1-inch CMOS sensor and an 8.8 mm/24 mm (35 mm format equivalent) f/2.8 lens. Using the DJI Pilot app, we automated and flew several UAV missions as we gradually cleared the vegetation covering the excavated areas (for details, see Table 1).

We set the UAV fly paths at different heights to balance site coverage and detail. The photographic datasets were processed following a standard image-based modeling (IBM) workflow optimized for archaeological drone-based applications (Aicardi et al., 2018; Fernández-Hernandez et al., 2015; Ferrari et al., 2015; Stal et al., 2014). To generate the 3D map of the entirety of the hill of Heloros, approximately 12 ha, we flew at 70 m a.g.l. and produced a detailed derivative DSM and an orthophoto we used to verify the information included in the legacy site plan (for detail see Table 1). To analyze in depth the excavated areas, we took pictures from an elevation between 9 and 22 m a.g.l., generating derivative data (for detail see Table 3). We georeferenced these 3D maps and derivative data using ground control points recorded by GNSS (Hill et al., 2019).

3.2. Close range photogrammetry

To create more precise 3D documentation of the previously excavated buildings, structures, and architectural elements, we used ground digital photography and a standard archaeological IBM workflow (Dellepiane et al., 2013; Sapirstein and Murray, 2017) (Fig. 8c). We captured thousands of photos using a Canon Eos 2000D camera and a Sigma 10–20 mm f/4–5.6 EX DC HSM lens (for detail, see Table 2). We set the wide-angle lens at 10 mm with a focal aperture of f8 to achieve the desired results.

To make the process more efficient, we used a wide-angle lens to capture fewer images that covered all the important buildings and

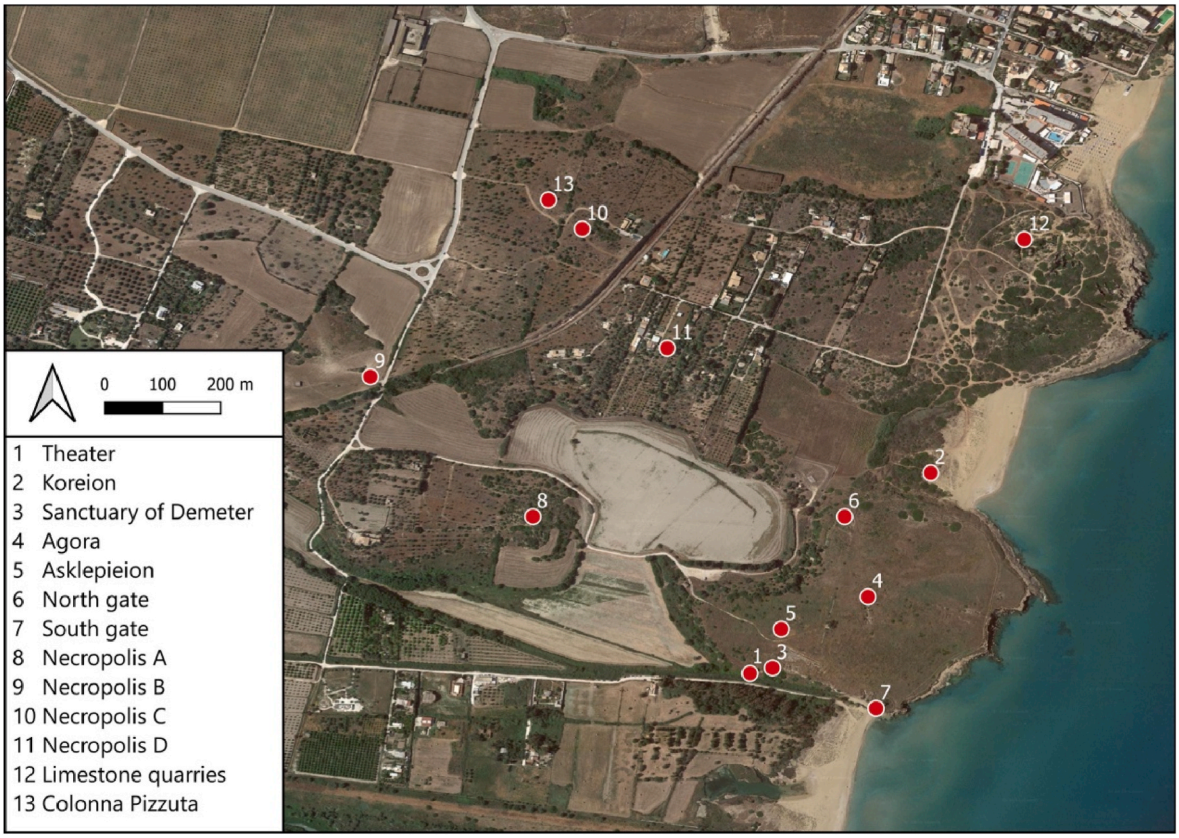

Fig. 6. Satellite view of Heloros' landscape, showing the location of excavated areas and archaeological features. It was generated from Google Maps data from 2015. Map by Dario Calderone.

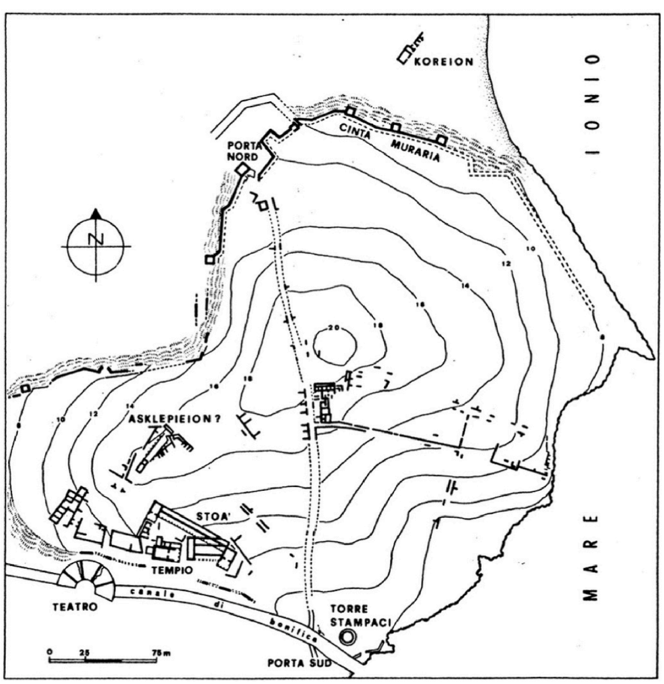

Fig. 7. Voza's map of Heloros detailing all the excavated archaeological features and areas (Voza 1999).

structures. We then used Adobe Lightroom Classic to adjust the white balance, colors, and distortions before processing the photos in Agisoft Metashape. Additionally, we utilized ground digital photogrammetry to capture 51 architectural elements from the Sanctuary of Demeter area, such as column drums, cornices, foundation blocks, and parts of a coffered ceiling that may belong to the Great Stoa.

3.3. *Terrestrial LiDAR and structured light 3D scanning*

To ensure accuracy in documenting larger archaeological structures or features in the shadow of walls, photogrammetric 3D models resulting from low-altitude photography may not be sufficient (Chapman et al., 2013). To address this, we used terrestrial LiDAR to document excavated areas with walls taller than 2 m or complex masonry structures (for detail, see Table 3). TLS point clouds are sets of data consisting of points with x, y, and z coordinates. They are used in archaeology and heritage preservation for on-site documentation, digital preservation, and site monitoring (Lercari, 2019). TLS point clouds capture not only the surface of buildings but also the color and intensity of the reflected laser signal, which gives us more insights into the texture and material of the scanned environment (Tan et al., 2018). Using TLS, we captured with millimeter-level accuracy the Northeastern and Western walls, the North Gate (see Figs. 9 and 10), and the buildings in the Sanctuary of Demeter with its intricate overlay of architectural phases.

We also used a structured light laser scanning method to record 102 architectural features in the agora and Sanctuary of Demeter, producing colored point cloud datasets with millimeter-level accuracy. This technique allowed us to document the traces of Greek inscriptions and quarry marks that can still be seen on the scanned architectural elements and stone blocks.

3.4. *Geographic Information System*

To answer our main research question about Heloros' architecture and topography development, we integrated the newly produced

Fig. 8. **a)** HADES project team members are seen collecting GNSS survey points inside Tower 3; **b)** a team member is seen setting up a drone to gather low altitude aerial photographs of the agora district for 3D mapping purposes; **c)** a Team member is seen capturing photos of North Gate's Tower A for 3D mapping purposes; **d)** Team members are seen reviewing Terrestrial LiDAR data of the Northeast Wall in the field using a tablet. Photographs a-c) by Davide Tanasi, photograph d) by Dario Calderone.

Table 1
Details on our drone-based digital photogrammetric datasets.

Dataset	Capt. Year	Area (m2)	Alt. (m)	N. Pics.	Georef.	N. of GCPs	DEM Res. cm/pix.	Orthoph. Res. cm/pix.
Heloros Hill	2021	140,000	70	700	Yes	6	6.02	1.07
Sanctuary of Demeter	2021	4500	22	236	No	N/A	1.1	0.54
North Gate	2021	645	16.7	180	No	N/A	0.82	0.41
Sanctuary of Asklepios	2022	1600	15	182	Yes	5	3.47	0.45
Agora	2022	5300	13.4	366	Yes	6	3.48	0.34
Pizzuta Column	2023	40	22.1	202	No	N/A	1.22	0.52
Northeast & West Walls	2023	4000	9.5–12	665	Yes	10	1.21	0.30

geospatial information and derivative data, such as the DSM generated from drone-based photogrammetry shown in Fig. 11a into a GIS environment (QGIS 3.30). Firstly, we brought all the legacy data into the GIS and aligned them with the correct geographic coordinates. Then, we transformed the existing drawings into a digital vector format. We created a new site plan using the DSM, our GNSS data, and observations from our walking surveys of the site. We carefully examined the legacy data and cross-checked them with the physical remains still visible on the surface. We also identified new remains that had not been recorded and corrected any errors.

4. Results

Using the geospatial and digital archaeological techniques discussed above, we gathered valuable topographical and archaeological data on Heloros. This helped us make sense of a fragmented archaeological record spanning over a century and better understand the site's urban layout and surroundings. We produced a cache of new digital archaeological and topographical data on Heloros. This includes new 3D documentation of all the excavated areas and monumental fortifications and a new catalog of their architectural and planimetric features. We used the open-source 3D viewer CloudCompare to analyze the latest 3D data and the GIS to fuse our derived geospatial data and legacy data. Then we created an online open-access collection on the web viewing platform Sketchfab to store and share the 3D data obtained during the HADES project (https://sketchfab.com/usfidex/collections/hades-project-2021-2023-8d343371f7d14582b67a979adcd44e45) (Fig. 12b). This collection includes mesh 3D models of the entire archaeological site, all the excavated areas and a large part of the fortifications, and hundreds of architectural *disiecta membra*, including column drums, cornices, foundation blocks with mason's marks, and paneled ceiling elements, scattered in the Sanctuary of Demeter and agora (Fig. 12a). To

Table 2
Details on our close-range digital photogrammetric datasets.

Dataset	Capture Year	Area (m^2)	N. of pictures	Sparse Cloud Point	Dense Cloud Points	Mesh Poly Count	Texture Res.
Stoa	2021	683.45	939	971.223	65.822.226	1.572.672	8.192
North Gate	2021	905.61	363	5.656.780	35.678.162	3.871.403	4.096 × 4
Sanctuary of Asklepios	2022	82.50	316	1.772.862	152.344.404	4.732.892	16.382
Agora-North Complex	2022	337.02	785	1.290.636	70.002.325	4.297.404	16.382
Agora-South Building	2022	123.43	431	748.082	360.017.928	1.913.568	16.382
Secondary Road & North Builds.	2022	327.07	1.525	9.333.106	157.752.093	2.067.702	16.382
Room with Well	2022	32.27	238	321.668	87.140.224	2.500.000	16.382
Building next Asklepieion	2022	29.96	352	10.338.897	94.653.446	2.299.262	16.382
Theatre	2022	66.68	620	483.482	121.639.437	24.922.116	16.382
West Wall Inscription	2023	3	45	67.995	43.789.380	3.895.083	16.382
North Gate's Left Wall	2023	94.64	191	330.505	68.236.430	8.195.579	16.382
West Wall	2023	227.87	930	1.603.145	274.067.620	4.999.999	16.382
Tower West	2023	53.61	134	173.040	54.186.438	4.325.428	16.382
Secondary Door	2023	139.59	559	924.848	49.527.657	5.308.006	16.382
Northeast Wall towers 1–3	2023	578.11	1.395	1.903.044	98.328.022	8.944.455	16.382

Table 3
Details on our terrestrial laser scanning datasets.

Dataset	Year	N. Scan	Point distance in mm @10 m	N. of pts. in million/scan	Scanner model
Sanctuary of Demeter	2021	45	7.7	28.0	Faro Focus m70
North Gate	2021	17	6.1	43.7	Faro Focus m70
Sanctuary of Asklepios	2022	23	7.7	28.0	Faro Focus m70
Agora	2022	45	7.7	28.0	Faro Focus m70
Northeast & West Walls	2023	90	6	102.0	Leica RTC360

further address the research question related to the chronological development of the city, we will focus the following discussion on the results obtained in two specific contexts: the North Gate and the Sanctuary of Demeter.

4.1. The North Gate

Our team used a combination of digital mapping technologies, on-site observation, and visual analysis in the GIS to create orthophotos and plans for the excavated fortifications (Fig. 13). This includes an updated plan for the North Gate, which differs significantly from previously published versions (Fig. 14a) (https://youtu.be/CeaytE16cYM).

The plan provides a visual representation of several features that, after their discovery, were buried back or were subject to significant alterations, including the moat. Furthermore, our new North Gate plan confirms the existence of a Classical phase first discussed by Karlsson (1992), characterized by an external curtain wall with rusticated blocks and by Tower A. AdAdditionally, it allowed us to identify two Archaic phases we labeled as Phase I (as shown in Fig. 14a) and Phase II (as shown in Fig. 14a). In Phase I, the North Gate's passage looked bigger compared to Phase II, where the wall on the west side of the Gate was extended. This extension included a small side door and a rectangular tower (Fig. 15a). The side door was sealed in Phase II. The tower was integrated into a larger trapezoidal structure (Fig. 15b). Later on, Tower A was built around this structure during the Classical period, as proposed by the authors in a previous publication (Tanasi et al., 2023). In addition, our research revealed a secondary road that has cart ruts. This road intersects with the Helorine Road near the North Gate. We also discovered a previously unknown and unrecorded set of interconnected vats that are likely linked to rustic structures (Fig. 14b). Our findings shed light on the periods of life on the site that came after the Greek era. These installations are interpreted as a grape-pressing facility, and numerous comparisons are found elsewhere in the Sicilian countryside. Facilities of this type were excavated and used with minimal architectural and technical changes from the end of the Greek Classical period to the eleventh century CE. Orsi's reference to the Roman poor huts, or '*casupole romane*' he discovered near Heloros' North Gate can provide valuable context for understanding the grape-pressing facilities we identified along the Helorine Road as belonging to the late Roman era (Orsi et al., 1965). Similar production facilities, such as a grape press located on the ruins of the Hellenistic fortification walls, were also observed at Megara Hyblaea in the context of the reconstruction following the destruction of 211 BCE (Vallet et al., 1983).

4.2. The Sanctuary of Demeter

One of the most significant public and religious areas in Heloros is the so-called Sanctuary of Demeter, near the theater (https://youtu.be/Lwv3yaboR1Q). Regrettably, there is limited knowledge and

Fig. 9. View of the Northeast Wall terrestrial LiDAR point cloud showing Towers 2 and 3. 3D models by Dario Calderone and Nicola Lercari.

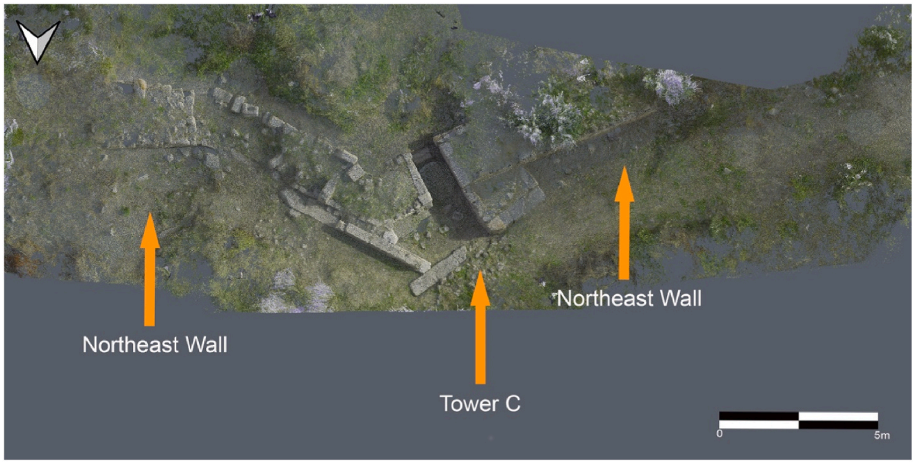

Fig. 10. View of the Northeast Wall terrestrial LiDAR point cloud showing the location of Tower C. 3D models by Dario Calderone and Nicola Lercari.

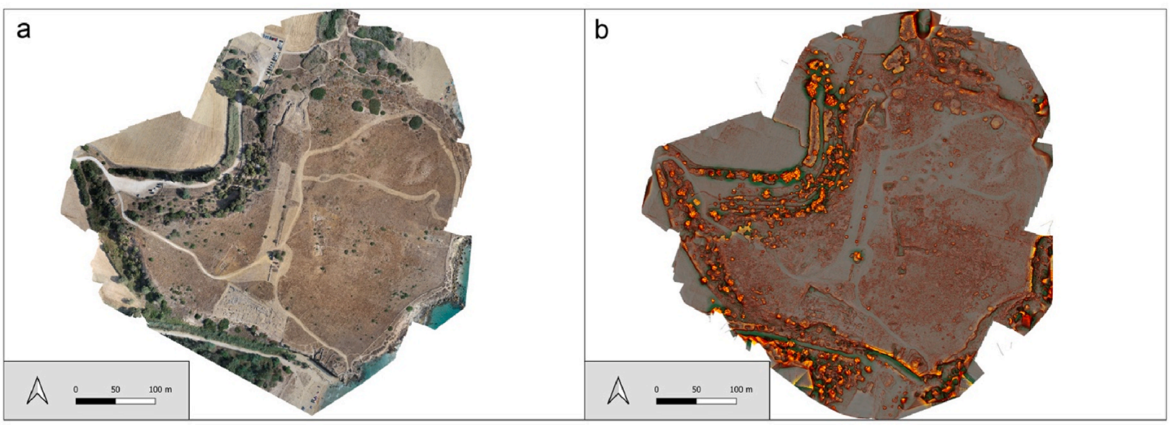

Fig. 11. **a)** Heloros' Digital Surface Model derived from drone-based photogrammetry data and **b)** Heloros' DSM Local Relief Model visualization. Visualizations a) by Dario Calderone and b) by Gerardo Jiménez Delgado.

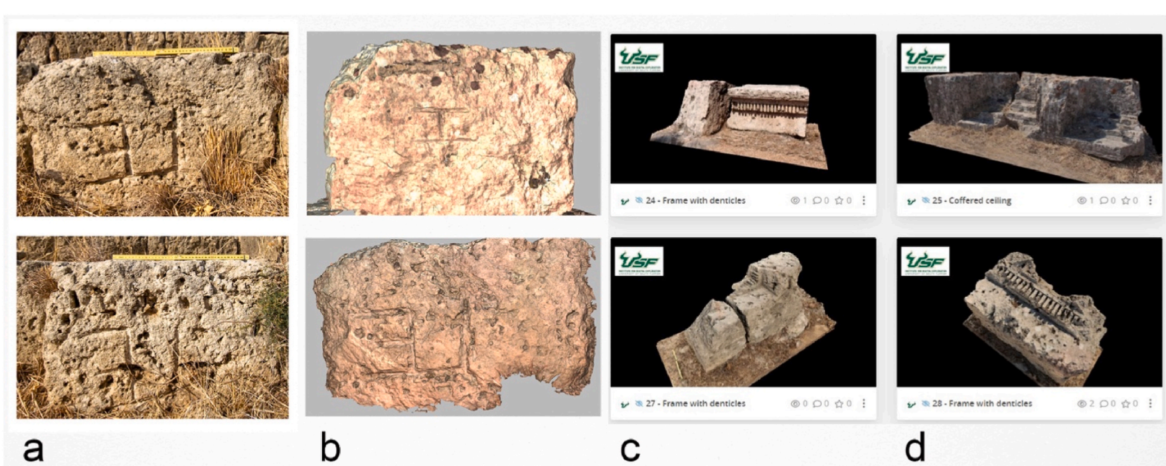

Fig. 12. **a)** Photographs of foundation ashlar blocks of the stoa displaying masons' marks; **b)** view of the blocks' structured light point clouds; c-d) 3D models of disiecta membra documented in the Sanctuary of Demeter are seen in the HADES Sketchfab collection; Photographs a) by Paolino Trapani, 3D models b) by Lena Ruider; 3D models c-d by Paolino Trapani.

research on the chronological evolution of this monumental area. However, a preliminary report has been published providing an outline of this sanctuary, revealing at least six distinct construction phases dating between the end of the 8th/beginning of the 7th century BCE and the 7th to 8th century CE. The peak of its development was reached between the 4th and 2nd century BCE, marked by the construction of the Temple of Demeter (phase 4) and the stoa (phase 5) (Fig. 16) (Voza, 1980). The plan for the sanctuary is challenging to understand due to the lack of descriptive information in the report and the significant changes made to the area during the construction of a large overlaying Byzantine Basilica in phase 6. Additionally, the excavators' use of reconstructive and interpretative methods to draw its plan further complicates our effort to reconcile the legacy documentation and publications about the sanctuary with the physical evidence we observed at the site. For instance, the interpretation of the stoa (Fig. 18), showing a U-shaped structure with an additional, differently aligned building towards the east and the reconstructed tetrastyle temple devoted to Demeter, must be revised.

We created a precise 3D model of the sanctuary using terrestrial LiDAR and drone-based photogrammetry. This helped us map out the structures in their current conservation state. We also created a 3D model of the stoa using ground photogrammetry to increase the resolution of our data. Furthermore, using ground photogrammetry, we have cataloged and digitized 51 *disiecta membra*, or separate architectural features of the sanctuary, precisely 13 foundation blocks with mason marks and 38 architectural elements (Fig. 12a-b, above). Through GIS analysis, we observed the displacement of these *disiecta membra* from their original structures. This dislocation extended throughout the sanctuary area and towards the north. This helped us understand how natural disasters, likely earthquakes, or human activities, such as quarrying for cut materials, greatly impacted the Sanctuary of Demeter's structures. These events probably occurred in the post-classical era, adding to the complexity of interpreting the site. We utilized Sketchfab to combine all the 3D documentation of the sanctuary. Through this online visualization platform, we were able to create a comprehensive visual representation of the entire sanctuary in which each 3D model of the existing architectural structures was connected to their respective location within the area model using Sketchfab's annotation feature. We shared this annotated 3D model on the HADES Sketchfab collection (https://skfb.ly/oHyAW) (Fig. 17) (Bennoui-Ladraa and Chennaoui, 2018). The 3D models of this group of *disiecta membra* will help our virtual reconstruction of the stoa, which was likely the most significant building in the Sanctuary of Demeter during the Hellenistic period.

Overlaying the digitized legacy documentation of the sanctuary's six phases and new drawings we derived from the area's 3D model, we carefully investigated each archaeological feature. This resulted in an updated area plan, showing a series of significant new elements (Fig. 18). Comparing the new plan with the one created in the 1980s (Fig. 16), it becomes clear that the sanctuary's legacy documentation does not reflect the actual orientation and dimensions of the structures. As discussed by the authors in another publication (Lanteri et al., in press), we found that in some instances, the draftsperson in the 1980s took the liberty of proposing structures or alignments that do not exist. To keep things brief, we will only cover a few of the latest discoveries below.

We discovered a post-hole system dug in the bedrock (as marked in red in Fig. 18). The post-holes are situated on the western side of the stoa and arranged in a circular pattern around a cistern. Similar installations have been found in different areas of Megara Hyblaea, and they are thought to be remnants of a prehistoric settlement or the campsite of early Greek colonists (Guzzardi, 2020). It is thus possible that these post-holes are related to native hut structures that existed before the Greek phases of the site since Heloros offered evidence for occupation already in the Middle Bronze Age. Additionally, our data contradict the hypothesis from the 1980s that the stoa had two side-buildings. Specifically, as it appears in Fig. 18, there is no evidence of the elements that prior publications claimed were evidence of a second *paraskenion* located asymmetrically on the east side (Fig. 16). Our results show that near the eastern edge of the stoa, multiple structures are related to different phases, some occurring earlier and some later than the stoa. This is highlighted by a significant variation in the structures' masonry. Specifically, there is a row of eight rectangular blocks aligned in a north-south direction that was believed to be the eastern wall of the second *paraskenion*. We think we must reconsider these blocks in the context of a pre-existing phase, which still needs to be investigated through ground truthing. This new evidence may suggest that the stoa was L-shaped rather than U-shaped. Of note is that the legacy documentation shows that during the excavation of the stoa, a group of residential buildings was discovered west of the sanctuary. Archaeologists dated this residential area to the pre-Hellenistic period before backfilling it. While little is known about these structures, future excavations in the area may provide more information about their chronology and contribute to a better understanding of the city's overall urban development, as these pre-Hellenistic structures are among the few

Fig. 13. Orthophoto of Heloros' fortifications derived from drone-based photogrammetry data showing the location and details of Towers A, B, C, and 1, 2, 3, 4 (the towers are visualized as renders from terrestrial Lidar point clouds). Orthophoto and 3D models by Dario Calderone.

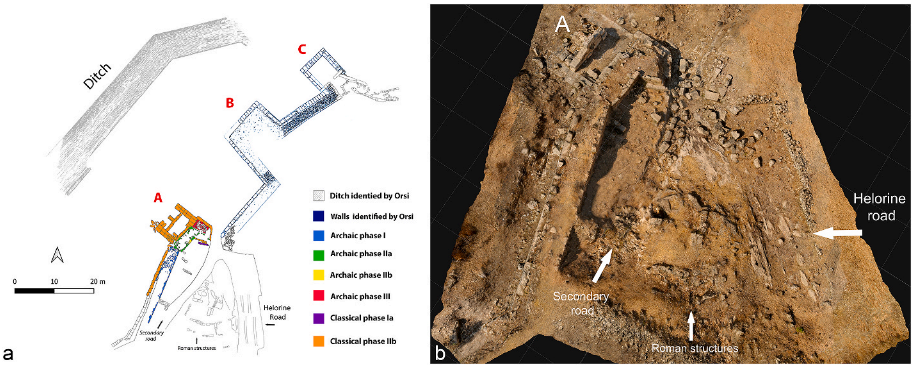

Fig. 14. **a)** Plan of the North Gate showing its main chronological phases and new relevant features; **b)** view of a 3D model obtained through drone-based photogrammetry showing the Roman structures discovered between the Helorine Road and a secondary road. Drawings by Davide Tanasi.

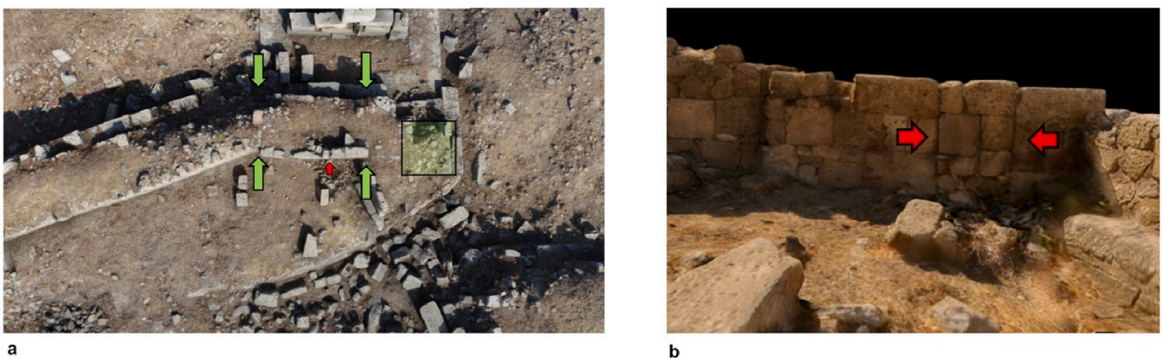

Fig. 15. **a)** View of the North Gate 3D model obtained through drone-based photogrammetry showing a detail of Tower A of Archaic Phase II. 3D model by Paolino Trapani and **b)** view of the North Gate 3D Model obtained through ground photogrammetry showing a detail of a wall of Archaic Phase II including a sealed door. 3D model by Paolino Trapani.

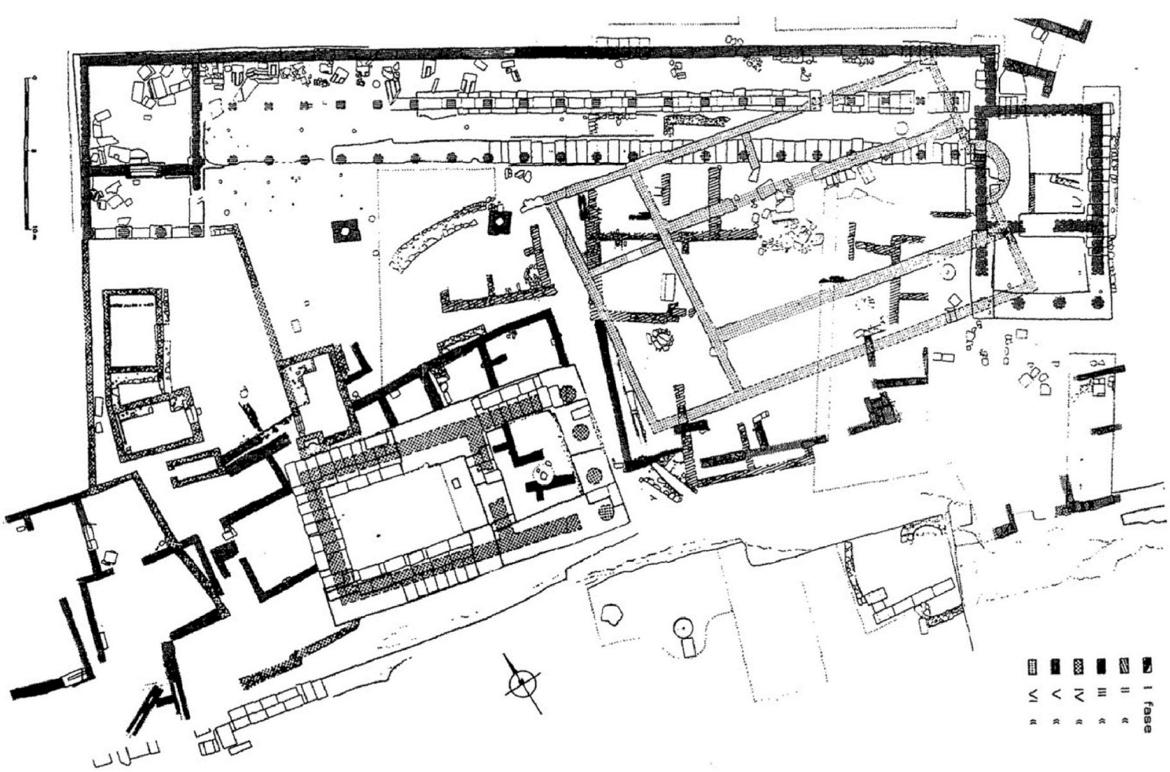

Fig. 16. Plan of the Sanctuary of Demeter as drawn in the 1980s (Voza, 1980).

Fig. 17. Annotated 3D model of the Sanctuary of Demeter in Sketchfab showing hyperlinks to documented disiecta membra (https://skfb.ly/oHyAW). 3D model by Dario Calderone.

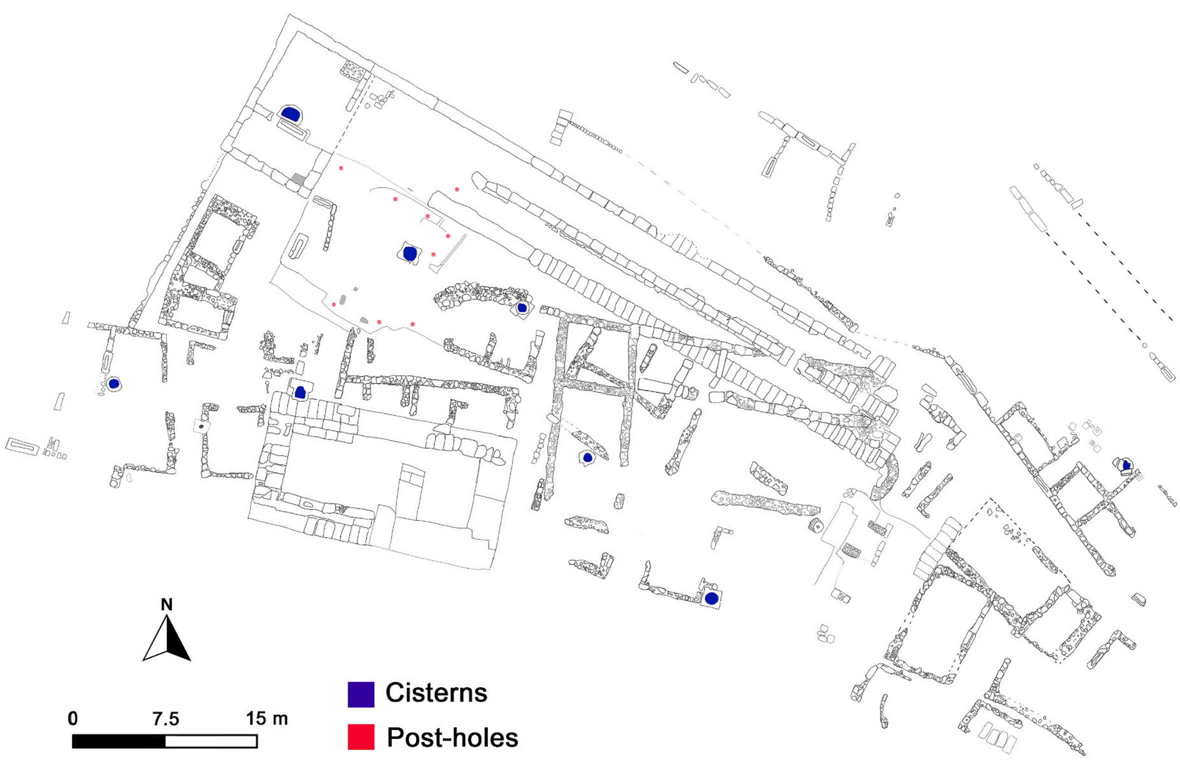

Fig. 18. Updated plan of the Sanctuary of Demeter generated from an orthophoto produced by integrating terrestrial LiDAR point cloud and drone-based photogrammetric data. Plan by Davide Tanasi.

remaining from that period.

5. Conclusion

A robust and reliable investigation process must be established when applying an *Archaeology of Archaeology* approach to reinterpreting a complex archaeological site like Heloros. This article explained how the HADES project achieved this goal by creating a digital excavation workflow that involved gathering, digitizing, and validating legacy data generated over a hundred years, capturing and processing new 3D and geospatial data using multiple digital documentation and proximal sensing techniques, creating derivatives, fusing all data in the GIS, analyzing data through the GIS, creating 2D/3D visualizations, curating and archiving the results, and sharing the data through a Sketchfab online digital collection (Fig. 2). We used this workflow to create detailed documentation of previously excavated areas and test new hypotheses about Heloros' impressive fortification system and the monumental Sanctuary of Demeter.

To conclude, our research at Heloros has yielded new insights into its history, including previously unknown information about the pre-Greek occupation and revisions to the interpretation of significant buildings and fortifications, including the Sanctuary of Demeter, agora (https://youtu.be/IMDTvek6eUs), and North Gate. This proves that the Archaeology of Archaeology approach, when enriched by the digital excavation methodology used in the HADES project, can generate new knowledge on archaeological sites without requiring new excavations. Moving forward, we plan to further investigate Heloros by reinterpreting other areas of the site, exploring the nearby quarries, and surveying the surrounding landscape using airborne LiDAR techniques to find traces of the ancient path of the Helorine Road, especially towards the Oasi Faunistica di Vendicari (Vendicari Reserve), situated just south of Heloros along the mouth of the Tellaro river (Fig. 5). Given the size of this area and the complexity entailed in detecting archaeological contexts beneath the dense Mediterranean vegetation, this involves using drone-based LiDAR mapping to obtain new high-resolution 3D and geospatial data to be analyzed in our GIS. To further enhance our understanding of the site's topography, we plan to conduct additional GPR prospections of the Heloros hill north of the agora and towards the North Gate. These activities will be carried out during our 2024 fieldwork.

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CRediT authorship contribution statement

Nicola Lercari: Conceptualization, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Davide Tanasi:** Conceptualization, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Till Sonnemann:** Investigation, Visualization, Writing – original draft. **Stephan Hassam:** Data curation, Investigation. **Dario Calderone:** Data curation, Investigation, Methodology, Visualization, Writing – original draft. **Paolino Trapani:** Data curation, Investigation, Visualization. **Lena Ruider:** Data curation, Investigation. **Rosa Lanteri:** Resources, Supervision, Writing – original draft, Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Grammarly Premium's generative AI function to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.daach.2024.e00327.

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