A holistic solution for the analysis of excavation and specialist data in a 3D GIS framework

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Introduction

This paper seeks to summarise the development and showcase the uses of a 3D GIS-based tool used by the Keros Project in our work at the Early Bronze Age site of Dhaskalio, Keros. While reflexivity and born-digital tools were built into the design of the 2016-2018 excavations,[1] the issue of how appropriately to use, analyse and make accessible the vast quantities of digital data, especially the over one thousand 3D SFM photogrammetric models, came to the forefront of the post-excavation programme. This tool aims to be a 'one-stop shop' for the interpretation of the excavation, including multi-layered 3D views of the site and all geo-located data resulting both from the excavation and from subsequent specialist studies. This is a true 3D GIS system, encapsulating all the abilities of a traditional GIS, including data entry, database management, data analysis and manipulation, while giving access to all excavation and specialist data within a single platform, making the tool data-driven and research-oriented.

The site of Dhaskalio, Keros and the digital recording strategy

The today-uninhabited island of Keros was the thriving heart of multiple networks of connectivity, creativity and innovation during the mid-third millennium BCE.[2] It is situated in the centre of the Aegean, in the Small Cyclades, a minor archipelago framed by the larger islands of Naxos, Amorgos

[1] Boyd *et al*. 2021.
[2] Renfrew *et al*. 2022.

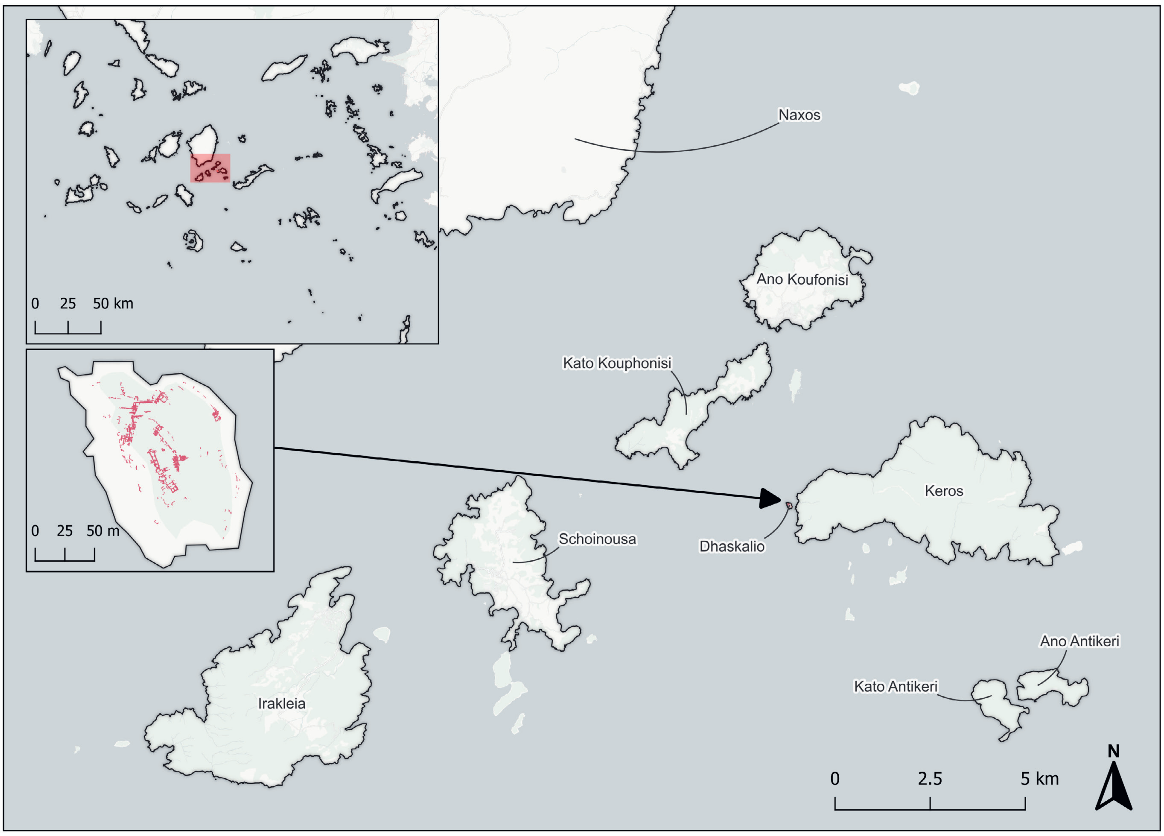

Figure 1. Map of the Southern Aegean with an overview of the Small Cyclades and Dhaskalio.

and Ios (Figure. 1). The small islet of Dhaskalio lies opposite the narrow coastal strip of Kavos at the western side of Keros, today about 90m offshore. (Figure. 2). In the Early Bronze Age (ca. 3300 BCE to 2200 BCE) these two areas were joined by a narrow causeway, so that Dhaskalio was a promontory, and the causeway created a harbour suitable for beaching boats coming from north or south.

Excavations were carried out in the 1960s in one part of Kavos (subsequently designated the Special Deposit North) which had been subject to significant looting. These uncovered the remains of an unusual archaeological deposit characterised by the deposition of broken choice material: marble figurines, stone vessels, obsidian, and particular ceramic vessels (such as sauceboats and conical necked jars) perhaps related to feasting.[3] Excavations between 2006 and 2008 in a second, unlooted and intact archaeological deposit, similar to the first in its nature (and now referred to as the Special Deposit South), confirmed the suspicion that all breakages had occurred in antiquity, and showed that as joins between fragments can only rarely be found, only selected fragments of each object were brought to Kavos.[4] This implied ritual activity on a surprising scale, taking in surrounding islands and perhaps points of origin further afield.[5]

The steep Dhaskalio promontory, overlooking the two special deposits, was first investigated in 2007-08.[6] Larger scale excavations in 2016-2018 aimed to clarify the chronology of the site, the extent and density of the architecture uncovered, and the nature of the activities undertaken

[3] Doumas 1964, 2007; Zapheiropoulou 1968, 2007a, 2007b; Sotirakopoulou 2005.
[4] Renfrew *et al.* 2015, 2018.
[5] Renfrew *et al.* 2012; Renfrew 2013.
[6] Renfrew *et al.* 2013, 2018; Sotirakopoulou 2016.

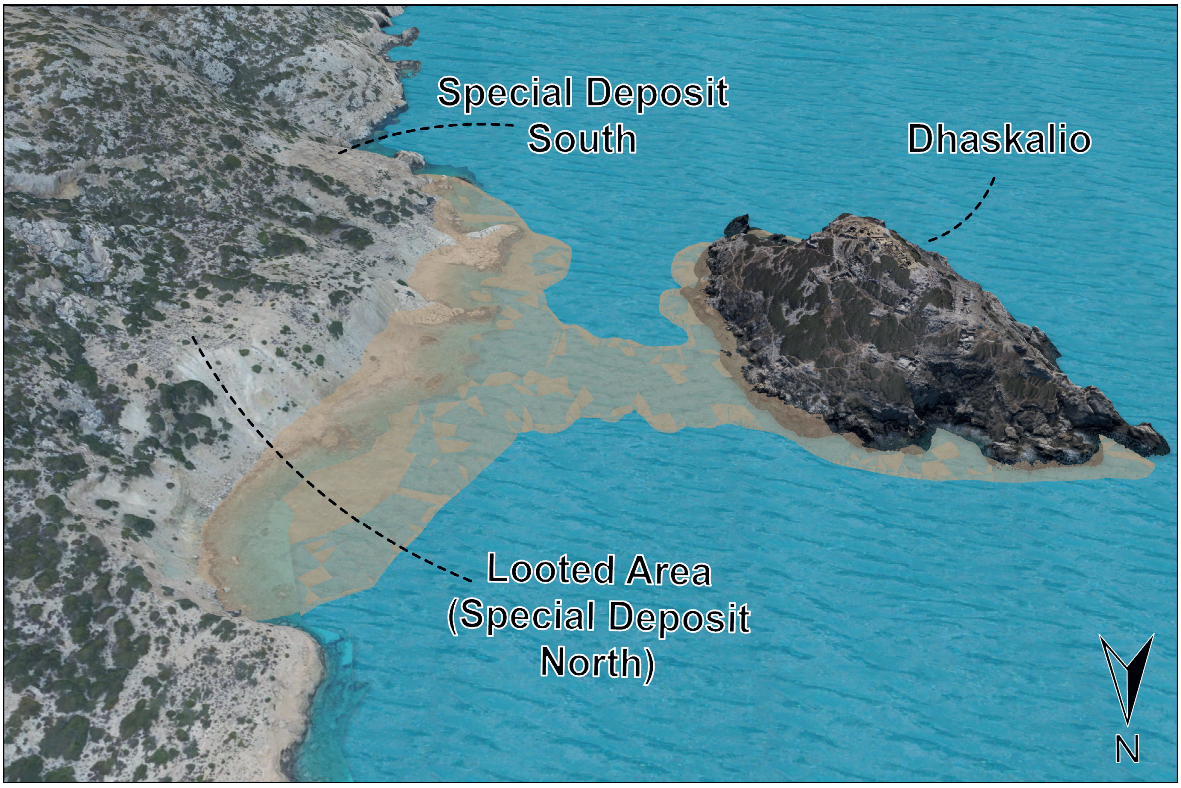

Figure 2. Special Deposits North and South on Keros joined to Dhaskalio with a reconstruction of the Early Bronze Age causeway in the 3D GIS environment.

there.[7] In designing a methodology suitable for the research questions of the project, we not only focused on rethinking work in the field (including excavation technique, sampling and in-field scientific approaches[8]), but also on data management, information flow and reflexivity. One aspect of this was to design an all-digital recording process based on the iDig iPad app in the field and using photogrammetry to replace field drawings (sections and plans).[9]

Data recording in iDig was designed to replace all paper-based forms and notebooks, as well as to capture 2D imagery and 3D geospatial data (connecting wirelessly to total stations or dGPS units). The photogrammetric process (described elsewhere[10]) was intended to record in 3D the pre- and post-excavation state of each individual context (with occasional mid-context recording as well). During the initial season we worked to integrate the iPad-based recording with many of the activities taking place in the field laboratory, chief among them the analysis of pottery, the most ubiquitous form of material culture. It was clear that we had begun to create a significant dataset, and it became imperative to imagine how these data might be made accessible and viable as an analytical dataset. In particular, the large number of photogrammetry models were not linked with the rest of the data, and having chosen to use them as the primary visual and metric record, it was essential to imagine how to reintegrate them with the rest of the data. We therefore began to envisage the possibility of an overarching system for data management and analysis that could encompass the entirety of the project's datasets within a single platform, allowing scalar and multivariate analyses of the project's data in its contexts. Drawing on the work of Hodder and Andrews *et al.* more than two decades ago,[11] the thinking behind this approach was fully to integrate the field team and specialists into a flattened hierarchy, whereby information could flow

[7] Renfrew *et al.* 2022.
[8] Boyd *et al.* 2021.
[9] Boyd *et al.* 2021.
[10] Boyd *et al.* 2021.
[11] Hodder 1997, 1999; Andrews *et al.* 1997.

both vertically and horizontally within the team structure.[12] This paper discusses how we used the 3D capabilities of ArcGIS Pro to create such a system, how it has worked in practice, and the transformative possibilities it offers for future research.

Archaeological 3D GIS

The landscape of digital archaeology has evolved significantly with the widespread adoption of photogrammetry as a cost-effective and efficient tool for generating accurate 3D models of archaeological remains.[13] While debates surrounding its usefulness over manual recording may persist, recent advances in computing power have democratised 3D modelling, making it widely accessible for archaeologists. In recent years, many projects have begun to experiment with 3D GIS in the site recording and analysis process with great success, and the limits of what is possible are constantly being increased.[14]

The application of spatial technology in archaeology is typically classified into three categories: visualisation, data management, and spatial analysis.[15] Gonzalez-Tennant[16] stressed the need for archaeologists to organise their GIS systems in a more structured manner that would allow for the easy dissemination of site data, and the adoption of GIS as a 'living document', while early on Merlo noted that 3D GIS should be used by archaeologists not just to analyse data, but to also reflect on how we excavate and what types of data we include.[17] Organisation and reflexivity in the use of GIS as an intra-site 'living document' have become staple concerns of several current methods that incorporate 3D GIS.[18] The two initial classifications of GIS as a visualisation and data management tool are well represented in the use of image-based 3D models in archaeology. A true 3D GIS system should encapsulate all of the abilities of traditional GIS, that is for data entry, database management, data analysis and manipulation,[19] however there is generally an underrepresentation for their use as a technique for spatial analyses. While several well-known, free GIS software packages such as QGIS and GRASS GIS support the use of 2.5D (i.e. an orthophoto draped over a DEM), high quality, reliable 3D GIS is not yet mature outside of proprietary software, with the main contenders being ESRI's ArcGIS ArcScene and ArcGIS Pro.[20] Some projects have had success in building their own web-based platforms (notably the systems based on a combination of Omeka-S and CNR-ISTI's 3DHOP developed at DARKLab at Lund University[21]), but it should be acknowledged that this is not an accessible method for many projects, which may lack the financial resources or technical expertise required for such a task.

As emphasised by Katsianis *et al*,[22] 3D GIS shows tremendous potential for its use as a 3D archive and for post-excavation study (see also Katsianis in this volume). 3D solutions are increasingly incorporated into cultural heritage data repositories, facilitating the development of FAIR management for 3D GIS data.[23] However, existing projects often operate on a small scale. They focus on one or two small trenches with arbitrary excavation units (such as Kämpinge and Västra Vång in Sweden[24] or Kaymakçı in Turkey[25]), or record single spaces (such as building 89 at Çatalhöyük[26]),

[12] Boyd with Renfrew 2021.
[13] Balletti *et al*. 2015; Dell'Unto and Landeschi 2022.
[14] For example, see Balletti *et al*. 2015; Dell'Unto *et al*. 2017; Opitz and Nowlin 2012; Richards-Rissetto 2017.
[15] Ebert 2004; McCoy and Ladefoged 2009.
[16] Gonzalez-Tennant 2009.
[17] Merlo 2004.
[18] Katsianis *et al*. 2008; Wilhelmson and Dell'Unto 2015; Dell'Unto and Landeschi 2022.
[19] Wheatley and Gillings 2002.
[20] See, however, discussion on proposed F/OSS frameworks in van Leusen and Nobles 2018.
[21] Derudas 2023, 57-69.
[22] Katsianis *et al*, 2021.
[23] Moore, Rountrey and Scates Kettler 2022; Pantos *et al*. 2023; Ponchio *et al* 2016.
[24] Derudas *et al*. 2021; Derudas, Nurra and Svensson 2023.
[25] Nobles and Roosevelt 2021.
[26] Berggren *et al*, 2015.

limiting the full potential of 3D GIS. Those who do employ large-scale photogrammetric or 3D recording strategies do not generally record models of each stratigraphic unit, instead recording end of season changes or focusing on high-resolution details as in burials.[27] As noted by Nobles and Roosevelt,[28] true 3D archaeological work requires a holistic approach that integrates spatial and non-spatial data manipulation and analysis. In this spirit, our work at Dhaskalio demonstrates the feasibility of a holistic 3D workflow across an entire excavation site, covering approximately 560m^2, with each stratigraphic unit recorded in 3D.

System design - the central information framework

Designing a reflexive and 'open' system

A key aspect of this project has been to develop a 'living' database. This means that the database should be able to grow and be modified over time[29], while at the same time allowing access to multiple users working on various aspects of the dataset and with different workflows.

On the one hand, team members should be able to use their preferred software, with which they are familiar and which offers the tools needed for their respective modes of analysis. On the other hand, it is important to ensure data integrity and data flow between specialists, which is best accommodated with a single 'source of truth'. The framework must function well enough to be the preferred data store of the entire team, in order to avoid multiple out-of-sync versions of the same information and the propagation of 'old data'. The current project has been working towards a separation of data storage - a backend built on a PostgreSQL with PostGIS server accompanied by additional file and object storage, and multiple frontend services to read and manipulate the data. The data available in the 3D GIS can also be accessed in a traditional GIS using QGIS, as tables and forms using Microsoft Access, LibreOffice Base or PgAdmin, used in Python and VBA scripts, or presented in a browser-based web frontend through an API (Figure 3). While the 3D GIS is still reliant on proprietary software, access to the data is not.

In the first iteration of the CIF, the project provided an online endpoint for database and object storage access. While technically functional, this revealed a number of practical issues with usability, performance and security. Meanwhile, a solution that relied on every team member

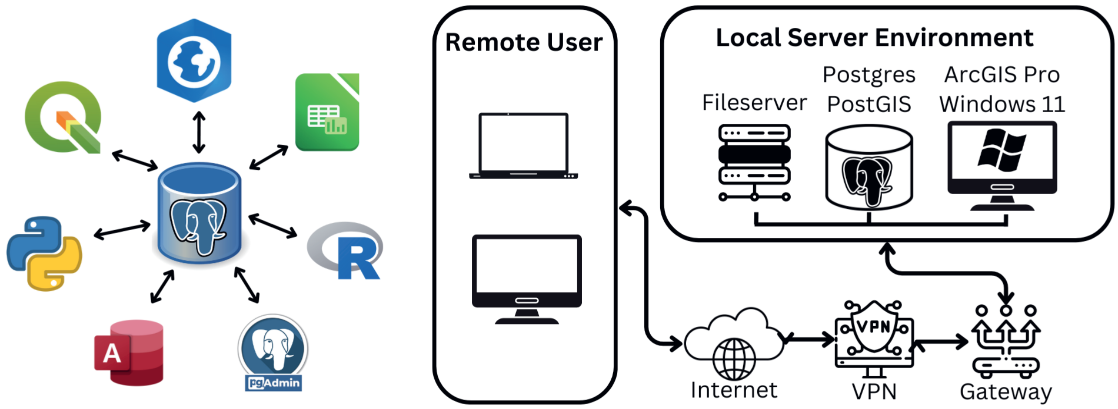

Figure 3. a) A selection of programs used to access the data in the PostgreSQL backend database' and b) 'Hardware configuration of the Central Information Framework'.

[27] Berggren *et al.*, 2015.
[28] Nobles and Roosevelt 2021
[29] Katsianis *et al.*, 2021.

having the software skills, powerful hardware and bandwidth required to manage and run the 3D GIS on their own computers, would not meet the goal of providing accessibility to all. Thus, it was decided to go one step further and set up a centrally managed turnkey system minimising the requirements on the individual user. In this setup both data storage and pre-configured frontend software is hosted in a local server environment, on performant hardware with high-bandwidth connections. Each team member is given an individual VPN login to the local network (a VLAN set up specifically for the CIF), and when connected can choose to log on via remote desktop to computers with all necessary software readily available and configured, or to access the data with their own software of preference. Licence restrictions limit the number of concurrent users of ArcGis Pro on the Windows machines, but virtual Linux desktops with QGIS, Base and other F/OSS software configured with data access can easily be cloned to scale as required.

Data in the GIS

3D data

The Keros Project established a documentation workflow centred around the consistent and rigorous use of structure-from-motion photogrammetry, where the documentation workflow was kept consistent throughout excavation campaigns.[30] This resulted in a textured 3D mesh of each context's opening surface, which also represented the bottom of the context above. After processing in Agisoft Metashape, each 3D model was imported into CloudCompare, where it was cropped to the context's boundaries. Each 3D model was then imported into ArcGIS Pro and organised stratigraphically into the areas of each trench.[31] In total, 1760 3D models were imported into the GIS, which contained the models of the trenches at the end of the 2018 excavation, including all structures as individual elements, and each stratigraphic context including fills and deposits, surfaces, and cuts. These 3D layers were joined with their corresponding context data from the PostgreSQL table. Field photographs were also joined to stratigraphic layers and architectural models.

Other data types

A large number of other general files make up a significant part of the project's data from the 2016-2018 seasons. These include field photographs and photographs of the Special Find artefacts from each trench, various documents such as end of season reports, trench notebooks, and finalised Harris matrices, digital polyline plan drawings of the site's architecture drawn by the site architect using CAD, as well as literature published about the site (see Figure 4). All of these files can be accessed within the 3D GIS environment.

Standard Polyline and Polygon data can be viewed in 3D using the site's DEM, but can also be used in their original 2D format if desired. This enables the user to access different data types that may have been created using standard GIS, and opens the potential to view plans from older excavations at the site where Z coordinates have not been taken in a projected 3D environment. Figure 5 illustrates the ability to use data projected in both 3D and in a 2D format. A common issue for archaeologists collecting spatial data is poor integration with non-spatial data.[32] This not only stifles the development of standards of digital recording, but also drives a wedge between data types, discouraging researchers from exploring all of the datasets available. Our workflow aims to mitigate this issue by bringing all available data types together to be accessed in a single holistic environment.

[30] Boyd *et al*., 2021.
[31] For a complete overview of the workflow see Campbell 2021.
[32] González-Tennant 2009; Jensen 2018.

Data	Format	Acquisition Method	Storage Location	Files/ Attributes
Photogrammetry	OBJ	Photographs/Agisoft Metashape	Local HDD > 3D GIS	1760
Excavation Database	SQL	Exported from iDig	PostgreSQL with PostGIS	c. 50,000
Special Finds Data	PointZ	Total Station/Exported from iDig	PostgreSQL with PostGIS	5921
Specialist Data	MultiPolygonZ PointZ	Compiled from iDig/CSV and excavation polygons/points	PostgreSQL with PostGIS	10,824
Field Photographs	JPG	Field recording	Local HDD > 3D GIS	11,560
Special Find Photographs	JPG	Lab recording	Local HDD > 3D GIS	12,020
Plan Drawings	PolylineZ	Orthophotos/drawn	PostgreSQL with PostGIS	131
Related Literature	TXT/PDF	Table from reference management software	Local HDD > 3D GIS	

Figure 4. Table summarising the data types within the Central Information Framework and available in the 3D GIS and number of files/attributes.

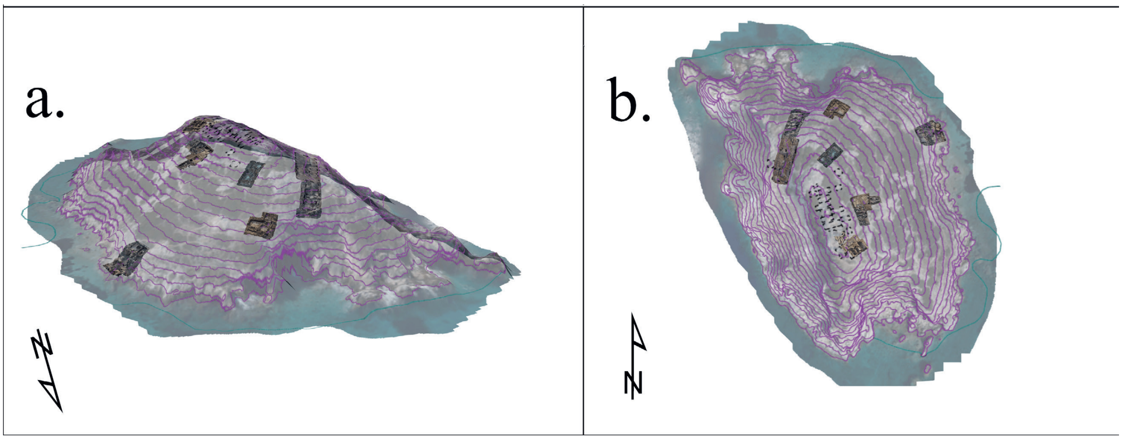

Figure 5. Showing data accessible in both 3D (a) and 2D (b) in the same GIS environment.

A 'living' 3D GIS database

While accessible on many platforms, perhaps the most important aspect of the Keros Project's Central Information Framework is its integration of 3D data. ArcGIS Pro has excellent support for 3D data types and has many in-built 3D analysis tools, which have proven invaluable in the project's post-excavation phase. For example, it is possible to run queries on the point, polygon and 3D data and view them together, which allows for a more comprehensive analysis of the site. Queries can be saved and quickly switched between.

Exploration and interaction

All spatial objects can be interacted with by clicking, which produces a pop-up showing the excavation and context information from the field, specialists' interpretations, and all photographic attachments. This comprehensive interactivity is a key feature of the system, leading to exploration of the data on top of more typical statistical and GIS based analyses.

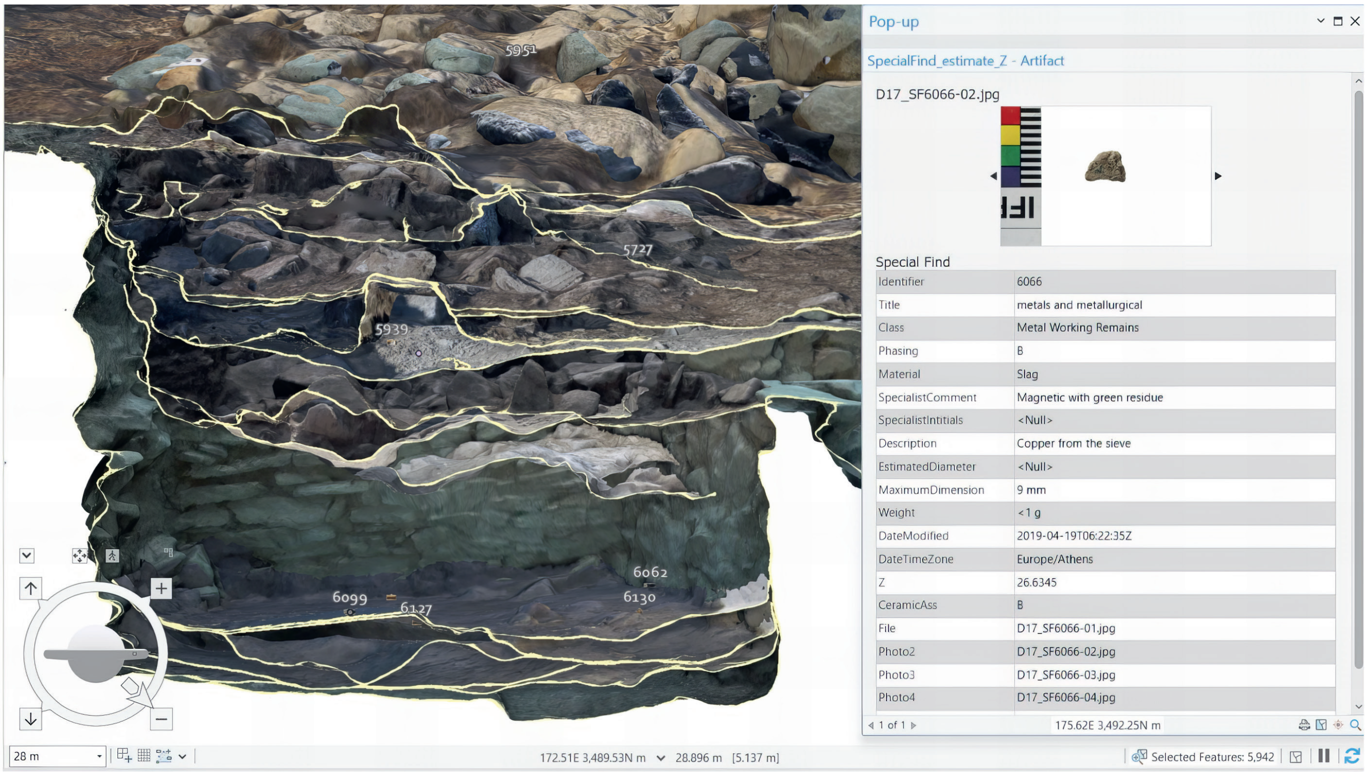

Figure 6. Section of Trench L with a query showing special find artefacts from Phase B and ceramic baking pans from Phase B, with pop-up of artefact 6066.

One perceived disadvantage of an open area system of excavation is that, as baulks are not maintained, stratigraphic sections may only be drawn at trench edges. Our project went further and dispensed with section drawing altogether. A major benefit of recording each stratigraphic layer using photogrammetry is that an accurate section of any excavation sector, of any size and orientation, can be created with ease and with greater spatial accuracy than a field drawing. Using the 'Exploratory 3D Analysis' tool provided in ArcGIS Pro, a cross-section can be drawn anywhere. This allows for a view of the stratigraphic sequence in any area of the trench and at any angle, and

Figure 7. Using 'Measure Distance' tool to measure the length of wall 52 in Trench B, compared with measurements taken in the field as seen in the pop-up.

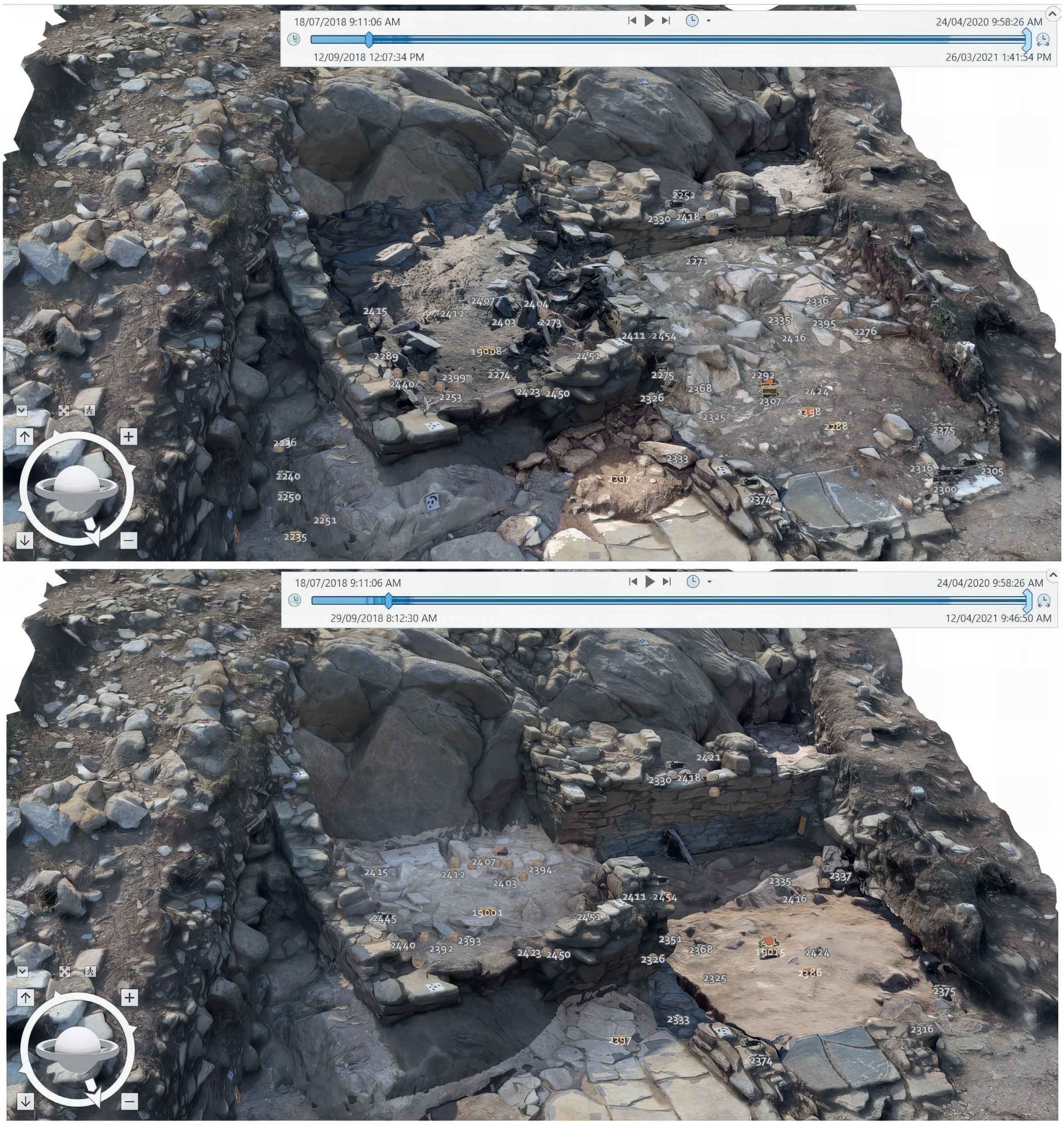

Figure 8. Showing the use of time to pinpoint which contexts were open and which Special Finds were collected on a specific day, on 12/09/2018 (above) and 29/09/2018 (below).

is not restricted to baulk or trench edges. An accurate and movable representation of the vertical stratigraphy of any area of interest can be generated at will (Figure 6). Artefacts and specialist data, including micromorphology sections, can thus be viewed in their stratigraphic contexts. While this is different from traditional representations of strata, any 2D representations could be added to the dataset as attachments, providing the ability to cross-reference.

Measuring geometry within the system is of great value in checking field measurements or in taking measurements that were not separately taken in the field. Figure 7 shows the reliability of the 'Measure Distance' tool being utilised for measuring architectural remains, with an example from Trench B. The tool calculates the length as 2.8 m which is the same measurement taken by the excavators in the field of the maximum length of the structure. Heights can also be measured, meaning that where walls heights are varied due to the number of courses preserved, the topography, or where height data may be missing, they can better be recorded and understood in post-excavation.

Reflexivity, time and phasing

One of the most powerful features of the system is the ability to visualise contexts, finds and other data based on date and time of excavation, offering a view on the excavation as it was at a particular point in its timeline. Utilising the temporal tools within ArcGIS Pro, artefacts and stratigraphic layers can be toggled on and off, based on the moment the iDig entry was created in the field at the time of their excavation (Figure 8). This allows for a reconstruction of how the site was excavated as it was interpreted by the excavators, which adds elements of reflexivity to the excavation process itself. Furthermore, future researchers can follow the process of excavation digitally and see why and how decisions were made by the original excavators, for use in future projects or site conservation. In essence, while the physical material may be lost, a geospatially accurate model of it continues to exist digitally, albeit as excavated (and interpreted stratigraphically) in the field. This offers an unparalleled ability to understand the relationships spatially between contexts as well as to remove them in excavation order or indeed in any other order. Combined with the spatially accurate placement of finds, samples and analyses, this is a powerful toolset for site interpretation.

The integration of architectural reconstructions, in tandem with queries on artefacts based on their phasing within the GIS environment, shows great potential for pulling together the interpretations

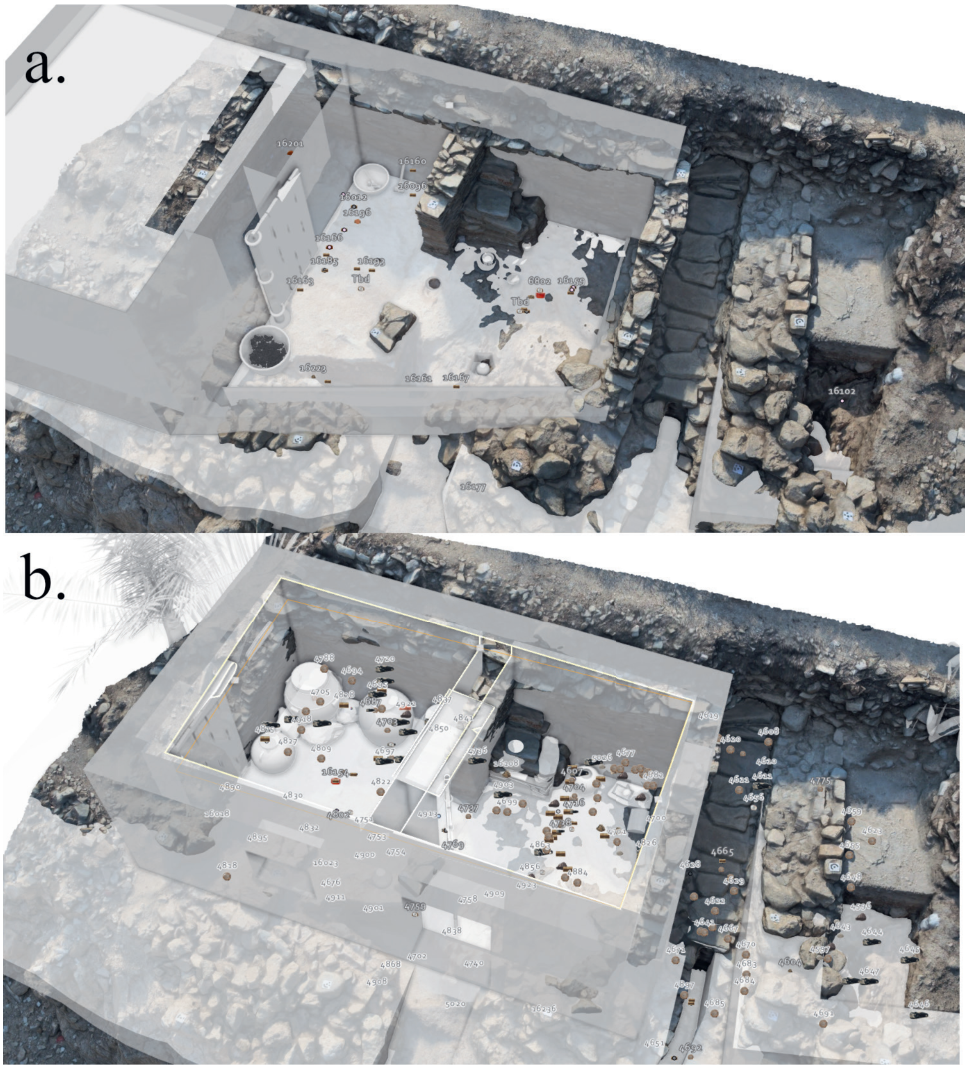

Figure 9. 3D reconstructions of buildings in Trench H. Earlier Phase A (top) and Phase B (below) and their corresponding Special Finds artefacts displayed. Architectural reconstructions by Marie Floquet.

of specialists and giving a picture of the function of spaces on Dhaskalio. This has use cases not only for better understanding the phasing of the site and how different areas may have functioned by contextualising finds in their architectural spaces, but also the potential to be utilised as a learning tool. Figure 9 shows a preliminary architectural reconstruction of Trench H in Phase A (above) and Phase B (below) with the Special Find artefacts corresponding to each phase visible.

Discussion

The payoffs

In the post-excavation phase of this project in particular, the adoption of a 3D GIS-based 'living' database has proven to be an exceptionally useful tool. This section outlines the key advantages of the system, emphasising its role in interpretation, data management, and its potential to become an essential tool for future archaeological endeavours.

Holistic data and universal data access

The set up of the Central Information Framework to be a single 'point of truth' for the project has been a large payoff of the system. Having only one version of data and a centralised backup has meant that up-to-date data are instantly available for all project members, accessing the CIF via a remote desktop connection, most of whom would not have had hardware powerful enough to run the system on their own computers. Similarly, the emphasis on exploration and interaction of the 3D GIS, in tandem with saved queries, lowers the user threshold, to encourage non-GIS specialists to analyse their data in its wider context. For those who do not require or are uncomfortable with using 3D data, having a single database with many points of access remains invaluable.

Enhanced interpretation and analysis

The 3D GIS aspect of the CIF has proven a crucial facilitator in the interpretation and analysis of archaeological data, by bringing together all specialist and excavator work in a single environment. This enables an unprecedented level of detail in recording trench data from multiple excavation seasons. With centimetre-level accuracy in all three dimensions, the system offers a comprehensive overview of the site's stratigraphy, allowing researchers to create detailed sections at any location and angle, so as to visualise artefacts and specialist analyses in context. The detailed volumetric data opens the way for accurate mapping of find densities on a context level, allowing for distribution analyses more commonly employed in surface survey and direct comparisons between contexts of different size and composition. Moreover, the ability to visualise the site and analyse data at different levels of granularity with such ease has given exceptional insight into the site functionality over time and across spaces. Data can be viewed at context, trench or building level, and even at a site level, as exemplified by Figure 10. The contextualisation of every part of the excavation process in its site-wide context in a visual, intuitive way cannot be overstated.A further layer of value is provided by the contextualisation of past excavations, in this case those conducted on Dhaskalio from 2006-2008. This feature allows for a seamless integration of past data (Figure 11), and a view of the site with all trenches open at the same time, something that has never occurred in reality. Similarly, it is hoped that the implementation of architectural reconstructions will aid in site interpretation and conceptualisation of the site across its phases of occupation, providing a holistic view that extends beyond individual artefacts and trenches.

One example of effectiveness here is the combination of old and new site data with old and new excavation approaches. The earlier excavations relied on baulks and section drawings to record and interpret stratigraphy. While the open-area approach of the new excavations put much less emphasis on trench edge stratigraphy, the ability to use the volumes created by 3D recording to construct virtual sections anywhere in the trench allows for direct comparison between section stratigraphy in adjacent trenches from the two excavation periods.

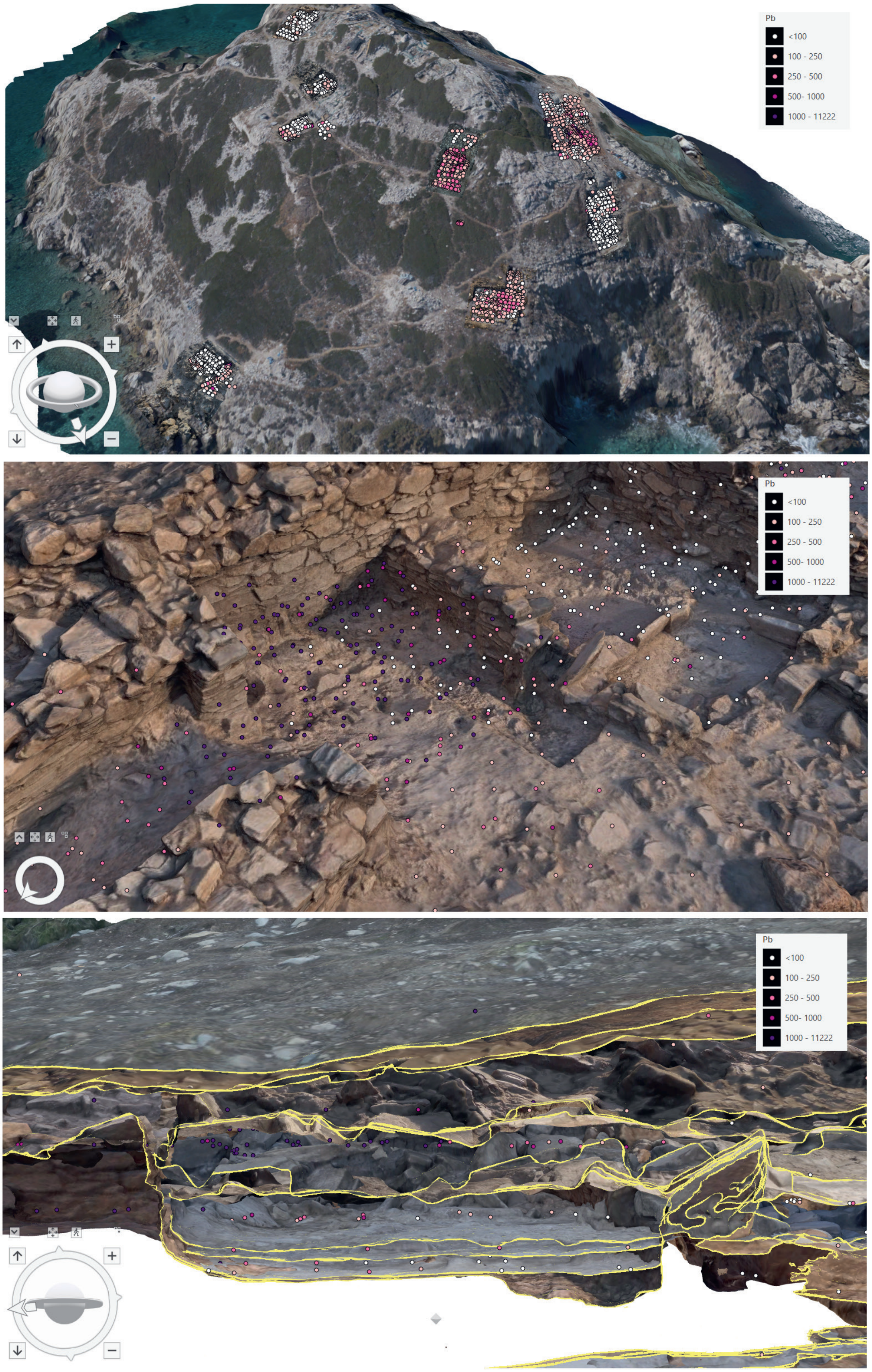

Figure 10. Resolution of data - from context level (top), trench and building level (middle), to site level (bottom). Interaction of specialist data (soil chemistry readings) and 3D photogrammetric models of each context in section aid in the interpretation of building functionality.

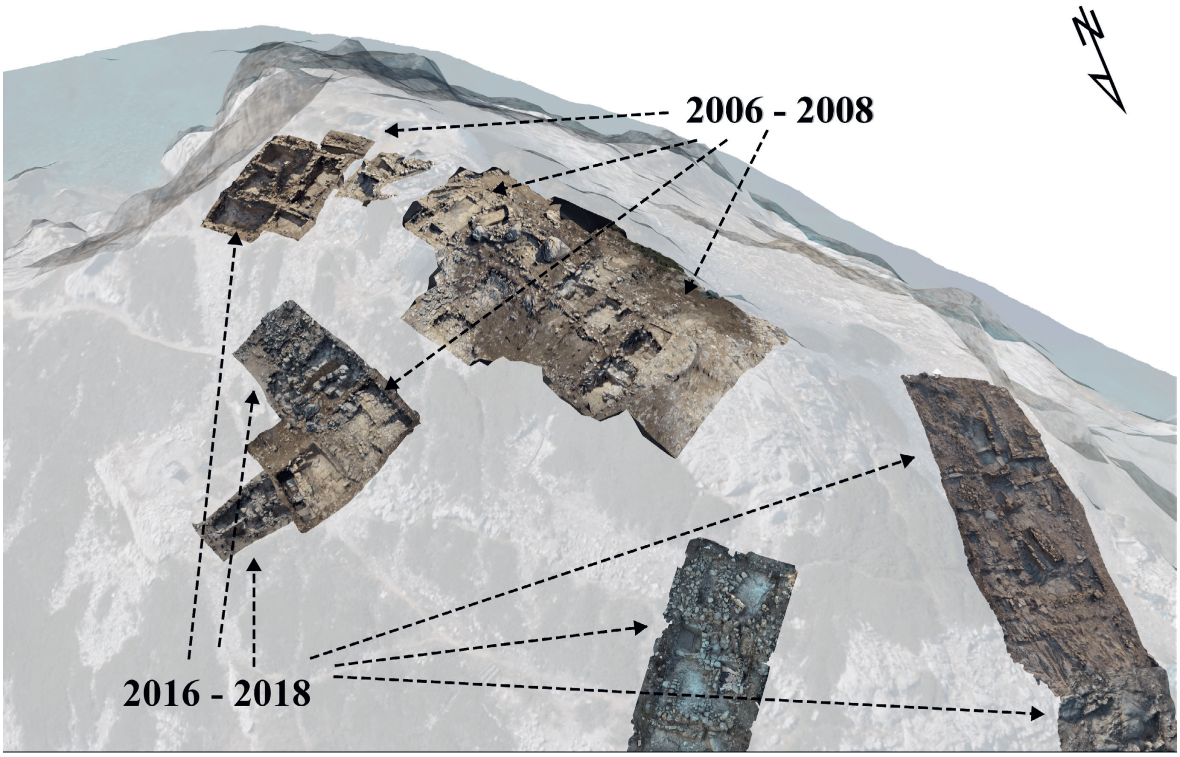

Figure 11. Screenshot of GIS showing excavation trenches from both 2006-2008 and 2016-2018 together. During the 2016-2018 seasons, the earlier excavations had been backfilled and were not visible.

A tool for reflexivity and archiving

Beyond its immediate project applications, the 3D GIS system holds promise as an archival and re-interpretive tool. This functionality brings us some way closer to achieving (digitally) repeatable excavations, allowing future researchers to re-examine field decisions, challenge interpretations and test hypotheses. The system supports the creation of digital reconstructions of contexts and find spots, contributing to the contextualization of past excavations. This archival capability, combined with its potential for future reinterpretation, adds a layer of longevity and adaptability to the system.

The benefits derived from our 3D GIS system extend from enhancing on-site analyses to streamlining data management through the CIF and giving equal access to data to members of the project. Additionally, its potential as an archival and re-interpretive tool positions it as a valuable asset for future archaeological research. We believe that these payoffs exemplify this system's role as an intra-site 3D GIS for comprehensive data integration, visualisation, and analysis.

The pitfalls

One major challenge encountered in the implementation of this system is the time-consuming setup process, characterised by the numerous components involved. The ad hoc development of the system post-excavation exacerbated this issue. However, with proper pre- and post-excavation preparation, this process can be significantly streamlined.

Infrastructure and resource constraints

The requirements for all trenches to have access to the technical equipment needed for a satisfactory high resolution of recording are certainly not feasible for all projects. Additionally, a dedicated IT team is essential for managing the workflow effectively: as a minimum, we would suggest that two persons is likely to be the viable minimum for a project of this scale, one handling 3D data and GIS integration, the other overseeing all other data and the database back end. The financial implications of such prerequisites certainly raise concerns about the accessibility of this approach for teams operating under tight budgetary constraints or lacking the necessary resources.

Knowledge threshold

While much has been done in this project to limit the specialist skills required to work with the Central Information Framework and 3D GIS, the successful implementation of the system depends on personnel with a robust database, GIS and 3D data skillset. This creates a potential barrier for archaeological projects lacking access to such expertise, limiting the broader applicability of this workflow.

Proprietary software

Another challenge is the dependence of the 3D GIS component of the CIF on proprietary software. Though many universities and research institutes have access to ESRI licences, the associated costs may pose a considerable barrier. The project intends to migrate to a F/OSS form of GIS once one with equivalent 3D capabilities is available.

Data quality concerns

Some concerns relating to data quality should also be addressed. There is undoubtedly irregularity of colours between the textured 3D models of contexts due to uncontrollable variables, particularly the time of day that the image sets were taken. While some projects[33] have attempted to minimise these disparities, they often involved daily drone captures of the site at a set time daily and thus do not capture each excavated layer in the stratigraphy. This project was more ambitious, creating models of each excavated stratum, meaning that waiting for the ideal lighting was not an option, and nor would it be for most projects. This meant that the photo sequences were taken as soon as the new context was exposed, regardless of the lighting. Further steps in grading the photogrammetry models would be possible, but constitute an additional overhead.

Future directions and suggestions

Reflecting on the challenges and successes of this system, several avenues for future improvements and development in archaeological 3D GIS have become apparent. Firstly, a pivotal step towards workflow optimisation involves the implementation of a semi-automated process, where building, aligning, cropping, and importing 3D models occur seamlessly throughout the excavation season[34]. This continuous workflow would ensure the (near) real-time integration of excavation data within the GIS, promoting efficiency and potentially reducing the time between fieldwork and data analysis. Second, to further expedite field and laboratory processing, the integration of iPad LIDAR technology should be adopted in the field. Leveraging this technology could significantly reduce the time required for the processing of 3D models and general data collection in the field. Further, while continuing with the PostgreSQL back end, another future direction may involve the development or adoption of a web front end for field or specialist recording, accessible from any browser. This shift would eliminate a number of processing steps between initial data entry and integration in the database, establishing a direct field-to-database system. Not only would this streamline data processing, but it would also ensure that past and current data are readily available on-site. Creating a front end to rival the many advantages of iDig is, however, a considerable

[33] See Galeazzi 2016; Sapirstein and Murray 2017; Waagen 2019.
[34] As outlined by Indgjerd 2024 with accompanying Python code.

challenge. This ongoing development aligns with the broader goal of creating a more seamless and integrated data management system for archaeological research.

Addressing a current data gap in our system, the integration of 2006-2008 excavation data presents an opportunity to enrich our understanding of the site. Building on the success of other 3D GIS projects[35] in transforming 2D archival data, such as section drawings, into 3D polygons and points, our system could incorporate such earlier excavation material. This expansion ensures a comprehensive and holistic representation of the site for those using the system, incorporating both recent and past excavations. Another aim for this project is the integration of volumetric data into the workflow. Building on recent promising workflows described by Nobles and Roosevelt[36], the integration of 3D surfaces into solids offers an exciting avenue for enhanced analysis. This approach would enable detailed studies of artefact densities per deposit and volumetric assessments of the excavation. Such advancements may contribute to a more nuanced understanding of the spatial distribution of artefacts within the site, allowing for more targeted interpretations of archaeological contexts.

To mitigate the dependency on proprietary software, a strategic shift towards Open Source software is recommended once this becomes available. This approach aligns with the broader principles of accessibility and sustainability within archaeological research. By transitioning to Open Source tools where feasible, we can reduce costs, enhance collaboration, and promote a more inclusive environment for researchers with varying levels of technological resources.

Conclusion

The applications of this 'living' 3D GIS archive for an extensive excavation has transcended the realm of a mere proof of concept, evolving into a dynamic and integrated tool that reshapes the way we handle our data. The positive outcomes of this system are not merely confined to its capacity for visual representation, but extend to its functionality as a comprehensive and interconnected database for intra-site analysis. As we delve into the possibilities of holistic approaches to 3D GIS, this workflow addresses the need for all-encompassing methodologies that bridge spatial and non-spatial dimensions.

This system's potential is underscored by its utilisation of a substantial data source including open-area trenches and single contexts. The notion that 'if we can, anyone can' prevails, though we acknowledge the requirement of time, financial investment, and patience. Nevertheless, the payoff is evident – a system that consolidates all site data from an excavation into a singular environment, eliminating the need for multiple programs or intricate coding.

By retaining 3D models within the excavation database as part of the GIS, researchers can filter, view, and assess them alongside other datasets, tabular data from specialists' analyses, and photographs. This integration highlights the potential of 3D models to move far beyond visual aids, demonstrating their capacity to significantly contribute to the post-excavation process of intra-site analysis. This system represents a departure from the static uses of three-dimensional data, offering a flexible and fully integrated solution that promotes reflexivity and the effective use of spatial data in archaeological practices. We are truly only beginning to appreciate the value of the holistic integration of data and the platform it provides for innovative analyses. This system was built with the aim of being used as a long-term excavation database, and we hope that its success will be further demonstrated as it becomes an integral part of future excavation seasons. Moreover, there is clear potential for non-project researcher and general public access to the database in future iterations. The continuous evolution of this system holds the promise of reshaping the project's

[35] For example, Katsianis *et al.* 2008; Gavryushkina 2018.
[36] Nobles and Roosevelt 2021.

archaeological data management practices for years to come, fostering a more dynamic and insightful approach to understanding Dhaskalio, Keros.

Acknowledgements

Excavations on Keros 2016-2018 were directed by Colin Renfrew and Michael Boyd, with Irini Legaki as associate director, and assistant directors Evi Margaritis and Giorgos Gavalas. Ioanna Moutafi was field director on Dhaskalio and Giorgos Gavalas field director on Keros. The excavations were conducted with the permission of the Greek Archaeological Service and with the support of the British School at Athens, the McDonald Institute for Archaeological Research, University of Cambridge and The Cyprus Institute. We are grateful for the support of the Director of the Cycladic Ephorate, Dr Demetris Athanasoulis, and to our colleague Stefanos Keramidas.

Developing the system would not have been possible without the hard work of the members of the Keros-Naxos Seaways Project. Dr Karsten Lambers contributed with valuable insights supervising Rosie Campbell's MSc thesis at the University of Leiden, where the first version of the 3D GIS was developed.

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