heritage

MDPI

Article

An Innovative System for Enhancing Archaeological In Situ Excavation through Geospatial Integration

Asimina Dimara [1,2,*], Sotirios Tsakiridis [3], Doukas Psarros [2], Alexios Papaioannou [1], Dimitrios Varsamis [3], Christos-Nikolaos Anagnostopoulos [2,*] and Stelios Krinidis [1]

1 Management Science and Technology Department, Democritus University of Thrace (DUTh), 65404 Kavala, Greece; alpapa@mst.ihu.gr (A.P.); krinidis@mst.ihu.gr (S.K.)
2 Intelligent Systems Lab, Department of Cultural Technology and Communication, University of the Aegean, 81100 Mytilene, Greece; ctd19001@aegean.gr
3 Department of Computer, Informatics and Telecommunications Engineering, International Hellenic University (IHU), 62124 Serres, Greece; sotitsak@ihu.gr (S.T.); dvarsam@ihu.gr (D.V.)
* Correspondence: dimara@aegean.gr (A.D.); canag@aegean.gr (C.-N.A.)

Abstract: The field of archaeological excavation has seen enormous developments as a result of the quick development of digital technologies. It is critical to acknowledge the long-term benefits of new approaches. In this regard, this study intends to suggest a system that provides archaeologists with digital tools that allow them to fully and effectively document their excavations in real time while in the field, which is specifically designed for classical and Byzantine archaeology. The system not only facilitates traditional documentation practices but also integrates advanced geospatial technologies and augmented reality, enhancing the accuracy and depth of archaeological research and preservation. This dual functionality enables both the efficient recording of excavation data as experienced by excavators on-site and the detailed documentation processed by researchers post-excavation. The objective of the application is to generate a sophisticated system that will enable the excavation data and experience that the excavator gains on the site of work to be recorded in real time, as well as the documentation that is subsequently processed and accomplished by the researcher or by other researchers. The system saves detailed images and 3D models of artifacts and excavation sites. This ensures that every detail is recorded while preserving the data for future analysis and reference. Lastly, the application was tested in realistic use case scenarios and real-world settings, which increased the system's credibility and demonstrated its capability to enhance the procedures involved in archaeological excavation and documentation.

Keywords: geospatial integration; digital archaeological excavation; real-time data capture; GIS; mixed reality

check for updates

Citation: Dimara, A.; Tsakiridis, S.; Psarros, D.; Papaioannou, A.; Varsamis, D.; Anagnostopoulos, C.-N.; Krinidis, S. An Innovative System for Enhancing Archaeological In Situ Excavation through Geospatial Integration. *Heritage* **2024**, *7*, 2586–2619. https://doi.org/10.3390/heritage7050124

Academic Editor: Nicola Masini

Received: 15 April 2024
Revised: 14 May 2024
Accepted: 15 May 2024
Published: 17 May 2024

1. Introduction

The foundation of our knowledge about previous civilizations and their artifacts is provided by archaeological records. Upon a closer review of all aspects of this crucial process, it becomes apparent that this assignment is not straightforward [1]. Documenting excavations requires complicated techniques that require extreme precision and frequently require manual recording and annotation in the field [2]. However, the digital era presents an excellent opportunity to overcome these limitations [3]. With its many benefits, digitalization might be crucial to archaeological study. It makes documentation procedures more effective and guarantees that historical data are accurately preserved. Furthermore, digitization fosters dynamic knowledge sharing within the archaeological community and improves expert collaboration. Beyond its utility as a process, digitalization may serve as a means to engage the broader public. It enables the widespread dissemination of archaeological findings, promoting a stronger connection to our collective historical heritage.

This transition to digital methods represents a significant advancement in archaeological research, making it more efficient, inclusive, and impactful.

During the past few decades, notable advancements have occurred in the digitalization process in the field of archaeological research. The way scientists explore and preserve our historical heritage has been revolutionized by innovative efforts that have prepared the path for the integration of digital technologies into archaeological practices. Significant work by renowned archaeologists and researchers, such as the pioneering use of geographic information systems (GISs) for site analysis [4], and the advent of 3D modeling techniques have illuminated the path of digital transformation in archaeology [5]. Coupled with increasing the accuracy of data gathering and site analysis, these techniques—among others—have made it possible to create thorough virtual reconstructions of archaeological sites, which has increased our knowledge of past civilizations. These notable approaches continue to influence and inspire the field's ongoing digitization as the modern world navigates archaeological study.

Archaeological excavation is a methodical and complex process essential for uncovering historical and cultural remains buried beneath the earth's surface [6]. Comprehensive preparation and site selection are the first steps and depend on the likelihood of important findings. On-site, excavation teams and researchers employ various tools and techniques, ranging from hand tools for precise artifact recovery to heavy machinery for larger-scale excavations. Earth's layers reveal historical information about architecture, geological layers, and artifacts. Meticulous documentation is essential, and measurements, photos, and thorough notes are used to capture context. Simultaneously, the identification and understanding of the unearthed items are assisted by laboratory analyses and scientific approaches. The challenge in archaeological excavation lies not only in physical tasks but also in deciphering fragmented evidence, requiring the construction of coherent narratives to enhance our knowledge of past civilizations [7].

With the development of digital tools, archaeological excavation has evolved substantially; nevertheless, it is important to acknowledge the long-term relevance of some of the most recent methods. Our understanding of ancient civilizations has advanced significantly thanks to techniques such as photogrammetry (SfM), terrestrial laser scanning, UAVs for documentation, 3D reconstruction, mixed reality visualization, and virtual tours of archaeological sites [6]. These have made it possible to share our very accurate historical reconstructions with the rest of the world. But despite all of these developments, an obvious gap still exists: there is no application that combines in situ excavation documentation with real-time data effortlessly [8]. A breakthrough like this could fill the role of complicated manual documentation procedures, increasing productivity and data accuracy.

Bridging this gap is the core of our research: to create a system that empowers archaeologists with real-time in situ digital tools to document their excavations comprehensively and efficiently. Within this context, this study introduces a system specifically designed for classical and Byzantine archaeology, providing archaeologists with digital tools that allow them to fully and effectively document their excavations in real time while in the field. In doing so, the objective is to facilitate the process while introducing new opportunities to share findings, preserve heritage, and advance archaeological research in novel ways. The suggested system offers tools for recording and scientific documentation of archaeological research and cultural heritage. The objective of the application is to develop an advanced system that allows excavation information and the expertise that the excavator acquires on the job site to be collected in real time. Furthermore, it will facilitate the completion of pending documentation by another researcher. In combination with sophisticated human–computer communication and interaction technologies, the archaeologist and excavator may receive support in automating data recording in real time during excavation by utilizing sophisticated technological tools for access and support. These tools include voice recognition systems that enable function activation and comprehensive supervision access and use, as well as the study, processing, and enhancement of spatiotemporal data. As a result, the system is distinctly designed to serve a dual purpose: it not only enhances the precision and efficiency of archaeological documentation but also integrates these enhancements with advanced technological solutions, thereby revolutionizing the field by linking traditional excavation methods with modern digital capabilities.

In summary, the main innovations of the suggested system are the following:

- Integration of various digital technologies into one holistic system, like GIS, Google Maps, interactive user interfaces, 3D modeling, and augmented reality, significantly enhancing the process of archaeological documentation and scientific analysis.
- Dual purpose of the application as a direct result of its sophisticated integration of various digital technologies. The app serves as a powerful documentation tool, enhancing the accuracy and efficiency of recording archaeological findings through advanced geospatial technologies and 3D modeling. Moreover, it revolutionizes the way archaeological data are interpreted and shared by leveraging augmented reality and interactive interfaces.

The remainder of the paper is structured as follows: In the "Literature Review" section (Section 2), the paper explores foundational concepts, including geospatial technologies, augmented reality, challenges in excavation data documentation, and previous solutions. Section 3 details the research approach, and is followed by Section 4, where the outcomes of the study are presented. Finally, in the last section, Section 5, the paper summarizes the findings and delineates the path forward, ensuring a cohesive and insightful exploration of the pioneering system.

2. Literature Review

2.1. Geospatial Technologies in Archaeological Research

The geospatial revolution in archaeology, involving technologies such as geographic information systems (GISs), remote sensing, and laser scanning, has significantly impacted the field. A meta-analysis of over 11,000 literature references reveals a rapid uptake of geospatial technology around 2005, with a concerning geographic bias towards studies centered on Europe [9]. Today, the proportion of archaeological literature concerning geospatial technology is equal to radiocarbon and is expected to continue growing. Geospatial technologies enable us to discover, record, index, and evaluate places at scales that were unthinkable in the analog age in the digital era. Three trends can be identified: expanding the use of remote sensing, making high-resolution field observations using 3D scanning, and balancing site indices to safeguard sites [8].

Archaeological fieldwork often favors archaeological artifacts, while private collections, often containing large numbers, are often overlooked. These collections hold significant value for research but have not been systematically documented. In the study of [10], Portable Antiquities of the Netherlands (PAN) aims to document and publish these private finds online, in particular, metal artifacts found by metal detector users. This increases the amount of archaeological artifacts available for research and object distribution maps while making use of geospatial technology to improve archaeological data. In addition, geospatial technologies offer great potential for accessing historical landscapes and past realities. They provide synoptic and 3D views through interactive visualization tools and enable researchers to explore past settlements through an infrared lens and using evidence from observations. This paper discusses the advantages of applying geospatial technologies to normal human perceptions [11].

Two case studies of architectural surveys using digital documentation through laser scanning and photogrammetry are presented in [12]. The first site, an Ottoman Soap factory in Lod, Israel, and the second, an Ottoman Bathhouse in Apollonia, Greece, faced challenges due to partial collapse or dangerous structural conditions. The digital documentation methodologies allowed for a fast, accurate, and comprehensive survey, enabling the cultural heritage site to become part of the local community. Understanding the past is challenging due to its lack of exploration and geographical aspects. Geospatial technologies offer the potential for accessing historical landscapes and realities through interactive visualization tools and infrared lens observations. These tools enable learners to understand existing information and researchers to find clues to past settlements in unprecedented ways [13].

2.2. Augmented Reality in Archaeology

The digital age has led to an increase in digital maps, but traditional paper maps still exist for tourist information. Augmented reality (AR) technology has been developed to address this issue. The application "ArheVinkovci" aims to explore the possibilities of augmented reality at archaeological sites in Vinkovci [14]. The application tests the technology's advantages and disadvantages with two hypotheses: that it can produce cartographic representations and supplement existing analog cartographic representations with additional content. Furthermore, an AR-based smartphone application that recognizes artifacts at archaeological sites in real time and provides multimedia information is presented in [15]. It uses deep convolutional neural networks to enhance the solution. The study compares the approach with guided and unguided visits using a visitor-centered questionnaire. The findings are discussed and evaluated using statistical methods to highlight their significance.

The work in [16] presents an interactive AR technology application to enhance the communication and fulfilment of cultural heritage (CH). The application allows visitors to view virtual reconstructions of the ancient Roman city of Forum Sempronii, enhancing their understanding of the site's history. The creation of high-poly models is optimized for easy management on mobile devices, enhancing immersive user experiences. Furthermore, the use of gamification in an immersive AR game for architectural heritage focusing on the potential to convey information through the reanimation of ancient cities is explored in [17]. The game uses an Android application for 3D content and camera input.

The research of [18] explores the acceptance of augmented reality technology in archaeological sites, focusing on behavioral intention. The study found the unified theory of acceptance and use of technology (UTAUT) as a suitable model but acknowledged the potential for a broader understanding and considering additional constructs. The use of AR content in museums has increased, but it also raises costs and investments. An app for tourism using 3D modeling, spectroscopy, and virtual reality to study and record archaeological artifacts in the Regional Museum of Lipari and the National Archaeological Museum of Reggio Calabria was developed in [19]. The app will promote and disseminate information on archaeological, architectural, and cultural heritage. Additionally, museums and registered sites are places where art and science creations are preserved and learned. Advancements in technology are improving these spaces, allowing visitors to experience more through online interactive applications. AR enhances the physical environment with digital audio, graphics, and real-life objects, supporting archaeological approaches [20].

2.3. Challenges in Archaeological Excavation and Data Documentation

The article of [21] discusses the lack of emphasis on building databases for quantitative analysis and interpretation within project teams and the need for more formalized data modeling using controlled vocabularies and consistent recording. This would allow archaeologists to fully realize the analytic affordances of digital data. Data management practices will improve if data creators make more data analysis demands on their own databases. The changing landscape of how researchers want to use and reuse data will promote practices that support wider interoperability. Furthermore, as stated in [6], digital data are crucial for understanding the present and past, but they present intellectually demanding challenges. Data management must be integrated into all aspects of archaeological practice, including ethics, teaching, and publishing. Building data literacy among archaeologists is essential for managing and communicating the data their discipline creates. This involves understanding workflows and human roles in data management, as well as reorienting research projects and information systems to consider wider contexts. The changing landscape of data use and reuse will promote practices that support wider interoperability across projects. Identifiers play a central role in data management, enabling the linking and relating of records and reducing ambiguity in describing archaeological observations.

An archaeological site is a palimpsest where depositional evidence is destroyed, leaving only artifacts and documentary evidence like registers, datasets, and reports. Archaeological excavation is a dynamic process that not only continuously reshapes our understanding of the site but also physically alters the field itself as excavations progress and discoveries are made [22]. Furthermore, [23] aims to guide archaeologists in data sharing by addressing challenges in reusing archived data. The authors propose guidelines to improve data management, documentation, and publishing practices, enabling efficient discovery, understanding, aggregation, and synthesization of primary data by wider research communities. Advanced data capture techniques, cost-effective processing, and visualization technologies are now feasible for documenting archaeological heritage and material culture. Work at Çatalhöyük demonstrates the feasibility of 3D data capture, processing, analysis, and curation. Real-time visualization engines simulate site stratigraphy and cultural landscapes. However, more work is needed to address methodological questions, such as using 3D models for archaeological interpretation, integrating 3D virtual scenarios with external databases, and fostering user embodiment in simulations [23].

2.4. Current Solutions and Their Limitations

Archaeological recording involves excavations on prehistoric and historic sites, revealing cultural and biological remains. The process involves dividing the site into grids and recording findings by sketching, drawing, and taking notes. The findings undergo several processes before being published, including assessing their relevance, conducting stratigraphic analyses to understand the sequence of soil layers, cleaning, cataloging, repairing, drawing, photographing, and describing them [24]. The adoption of digital recording technologies, as discussed in [25], significantly improves the speed and detail of 3D documentation processes. Moreover, these advancements are not solely beneficial for efficiency but are crucial for enhancing the depth and accuracy of scientific analyses across the field [2]. Geomatic techniques are essential for accurately representing objects, with image-based and range-based data commonly used for 3D documentation. Combining multiple techniques is necessary due to the complexity of some structures and the lack of a single technique [26].

Over the last years, unmanned aerial vehicle (UAV) applications have played a significant role in various fields, including the 3D documentation of archaeological excavations, recording historic buildings and monuments, surveying sites and landscapes, aerial exploration, and detecting under-canopy archaeology in forested areas. The rapid development of platforms, sensors, and cloud-based data processing has led to the adoption of drones as everyday tools for archaeologists, engineers, and geophysicists. In 2007, a collaboration involving Fabio Remondino and Zenith aimed to develop a workflow for semi-automatic 3D and 4D documentation of archaeological excavations [27]. The workflow aimed to achieve speed, reliability, accuracy, standardization, and user friendliness.

Digital photogrammetry has become a crucial tool in archaeology, as it provides fast and accurate mapping for archaeological sites. This method proves especially valuable in classical and Byzantine sites, where it helps identify and analyze the distinct historical layers of architecture and artifacts, each representing different periods of occupation and use. Time is a valuable factor for archaeologists, and digital photogrammetry offers powerful tools for accurate mapping and recording. An interdisciplinary experimental research project in Crete, Greece, involved photographing and processing excavation areas within designated sectors and sections at three stages, DTMs and orthophotos, and acquiring digital images for small artifacts [28]. Moreover, iDig is an archaeological tool developed and tested at the Athenian Agora Excavations of the American School of Classical Studies in Greece [29]. It produces immediate digital records in the field and is optimized for excavation workflows. It connects wirelessly to Leica Total Stations and keeps excavation data in sync on multiple iPads, allowing for better collaboration. The app allows for quick importation of frozen drawings, plans, custom fields, and data integration. iDig contains unpublished data from two trenches excavated in 2013.

The advantages of using the Qfield app for archaeological fieldwork are highlighted in the paper [30]. Qfield, compatible with Android devices, allows archaeologists to upload .qgis projects onto their mobile devices, facilitating data collection and real-time updates during excavations. Referred to as a 'pocket-GIS', Qfield streamlines data input, eliminating the need for manual digitization and paperwork. The paper showcases practical applications of Qgis and Qfield in various archaeological projects. Similarly, the utilization of low-cost digital technologies in archaeological excavations is illustrated in the paper [31]. The authors introduce a DIY digital workflow developed by the Comparative Kingship Project in Scotland, offering accessibility and flexibility. This approach aims to streamline tasks such as entering paper records and digitizing on-site drawings, benefiting small-scale academic excavations facing challenges like inclement weather and site accessibility.

In the paper [32], the utilization of the ArcGIS Collector mobile app for archaeological survey data collection is presented. The authors detail the implementation of a site survey workflow using Esri's ArcGIS Collector app (version pro 2.5) in the Kasakh Valley Archaeology Survey in Armenia. The Collector app offers a user-friendly interface for recording site locations, entering attribute data, and attaching photographs. Despite limitations, such as the need for an institutional Esri license, the app's integration with the project GIS and collaborative features enhanced in-field decision-making and interpretation across the survey team. Furthermore, the significance of spatiotemporal data in archaeological stratigraphy extraction and management is presented in [33]. The authors propose a system that utilizes these data for recording stratigraphic units in three dimensions along with associated temporal data, enhancing site understanding and management.

Roosevelt et al. explore the concept of digital archaeology and its impact on archaeological practice [34]. The paper presents a case study demonstrating how these systems can preserve the archaeological record. Additionally, the authors discuss the challenges and opportunities of digital archaeology, emphasizing the importance of ongoing training. Correspondingly, the implementation of ArchField software (ArtifactVis2) during archaeological excavations at Khirbat al-Iraq, Jordan, is presented in [35]. ArchField addresses the reliance on analog recording by offering real-time 3D digital recording, enabling real-time data capture in the field.

The use of mobile GIS software (version 10.2) for on-site excavation data recording is presented in [36]. Using a customized ESRI ArcPad, data are recorded and integrated with ArcGIS for analysis. The authors anticipate improved data recording and the widespread adoption of an on-site excavation data registry, outlining key implementation considerations. Lastly, Katsianis et al. introduce a 3D digital workflow for archaeological intra-site research, emphasizing the need for accurate and efficient documentation due to excavation-induced site destruction [37]. They advocate for widespread adoption, highlighting the development of a georeferenced data model and 3D tools for intra-site analysis.

The limitations of the current digital technologies and tools employed in archaeological recording and documentation are multifaceted, as may be observed in Table 1. UAVs offer the promise of efficient 3D documentation but are constrained by weather conditions, airspace regulations, and mainly by the need for skilled operators. Digital photogrammetry, while valuable for accurate mapping, requires expertise in data processing and relies on compatible hardware. iDig, though optimized for field data recording and collaboration, presents a learning curve for users and demands compatible hardware. Furthermore, these technologies entail significant initial investment costs, posing challenges for smaller archaeological projects. Ethical considerations, such as privacy and aviation regulations, also cast shadows over the unrestricted application of UAVs. In addition to these challenges, weather conditions and airspace regulations can hinder the deployment of UAVs, impacting the timely acquisition of archaeological data. Furthermore, the reliance on skilled operators for UAV operation adds another layer of complexity, potentially limiting its accessibility in certain contexts. Addressing these limitations is vital to harnessing the full potential of these digital tools while ensuring their seamless integration into archaeological research and documentation.

Table 1. Summary of current solutions and their limitations.

Study	Methods Used	Applications	Limitations
Archaeological recording [25]	Sketching, drawing, note-taking, digital recording technologies (e.g., 3D documentation), geomatic techniques, digital photogrammetry	Recording cultural and biological remains, accurate mapping, data preservation	Cost, skill requirements, data processing time, weather constraints, airspace regulations
UAV applications [27]	Unmanned aerial vehicles, 3D and 4D documentation workflow	3D documentation of archaeological excavations, historic site recording, landscape surveying, aerial exploration, under-canopy archaeology detection	Weather conditions, airspace regulations, skill requirements, ethical and legal concerns, initial investment costs
Digital photogrammetry [28]	Digital image processing and mapping	Fast and accurate mapping for archaeological sites, recording multiple temporal levels of ruins	Skill requirements for data processing, need for compatible hardware, learning curve
iDig [29]	Digital data recording, wireless connectivity	Streamlining field data recording, better collaboration, data preservation	Learning curve for users, reliance on compatible hardware, initial investment costs, may not fully replace traditional methods, no 3D modeling
Qfield [30] and low-cost digital technologies [31]	QGIS/Qfield app, DIY digital workflow	Field data collection, digital recording	Compatibility, accessibility, weather constraints
ArcGIS Collector [32] and spatiotemporal data [33]	ArcGIS Collector app, spatiotemporal data system	Survey data collection, stratigraphy extraction	Licensing, data processing, skill requirements
Digital archaeology [34] and ArchField [35]	Digital recording, ArchField software	Preservation, real-time recording	Integration, real-time data capture
Mobile GIS [36] and 3D digital workflow [37]	ESRI ArcPad, 3D digital workflow	On-site recording, intra-site analysis	Hardware compatibility, learning curve

As summarized in Table 2, this study aims to integrate a comprehensive fusion of modern technological methodologies, distinctively merging traditional archaeological methods with advanced digital tools to enhance documentation and analysis. Unlike previous studies that have typically focused on specific technologies, such as 3D modeling or digital recording, this study introduces a holistic approach that leverages sketching, drawing, note-taking, geomatic techniques, 3D modeling, digital image processing, and augmented reality (AR). This integration is designed to enhance the precision and accessibility of archaeological data, facilitating a more dynamic and interactive exploration of archaeological sites. By incorporating a wide range of technologies, this study aims to not only improve the efficiency of archaeological documentation but also to foster a deeper understanding and preservation of cultural heritage through innovative digital solutions.

Table 2. Comparison of archaeologic al documentation methods across various studies.

	Integrated Technologies							
Study	**Sketching, Drawing, Note-Taking**	**Digital Recording Technologies**	**Geomatic Techniques**	**3D Modeling, Visualization**	**Digital Image**	**Wireless Connectivity**	**Spatiotemporal Data System**	**AR**
[25]	✓	✓	✓					
[27]				✓				
[28]					✓			
[29]		✓				✓		
[30]								
[32]							✓	
[34]		✓						
[36]								
This study	✓	✓	✓	✓	✓	✓	✓	✓

3. Methodology

In this section, a comprehensive overview of the methodology followed in this research will be provided. This section is structured around key methodological components and strategies utilized to develop the system for enhancing archaeological excavation and documentation through geospatial integration. It focuses on various aspects, including use case scenarios, mobile app development, concept and requirements, platform and technology selection, user interface (UI) design, geospatial integration, integration with Hololens II, and system architecture and design. Through a detailed exploration of these methodological elements, the systematic approach undertaken in the development of this innovative archaeological documentation system will be addressed.

3.1. Use Case Scenarios

In this section, several illustrative use case scenarios are explored to highlight the versatile applications of the innovative system for enhancing archaeological excavation and documentation through geospatial integration. These scenarios provide insight into how the system can effectively address the unique challenges and requirements encountered in different archaeological contexts. The following use cases will be examined: urban archaeological excavation, rural archaeological site, and collaborative research project.

3.1.1. Urban Archaeological Excavation Scenario

In the context of urban archaeological excavation, an archaeologist faces the challenge of exploring historical relics within a densely populated cityscape, where ancient artifacts are intertwined with modern infrastructure. The excavation site is situated in a bustling urban area, complicating the process due to the presence of buildings, roads, and utilities. This complexity requires careful navigation and excavation planning. In this case, ensuring the meticulous documentation of findings is paramount. The precise recording of artifact locations, orientations, and contextual details is necessary for accurate analysis and interpretation. The archaeologist leverages an innovative system tailored for urban excavations. A mobile app, supported by real-time geospatial data, overlays historical maps onto the modern city landscape, aiding in the identification of potential archaeological features. The mobile app streamlines data collection, enabling on-site annotation, photography, and 3D modeling of artifacts. This facilitates efficient and accurate documentation.

3.1.2. Rural Archaeological Site

In the context of remote archaeological excavation, an archaeologist faces the challenge of exploring historical relics in a secluded and challenging environment, far from urban infrastructure and resources. The excavation site is situated in a remote wilderness area, adding complexity to the excavation process due to its limited accessibility and harsh conditions. This scenario necessitates careful planning and adaptability in archaeological methods. The challenging terrain, extreme weather, and lack of resources make this excavation particularly demanding. In such a remote setting, ensuring meticulous documentation of findings is even more critical. The archaeologist must record artifact locations, orientations, and contextual details with the utmost precision to enable accurate analysis and interpretation. To overcome the challenges of remote excavation, the archaeologist relies on an innovative system designed for such scenarios. This system integrates various components to support efficient excavation and documentation. A central part of the system is a mobile app enhanced with real-time geospatial data. This app assists in overlaying historical maps onto the remote wilderness landscape, aiding in the identification of potential archaeological features. The mobile app is instrumental in streamlining data collection. It enables on-site annotation, photography, and 3D modeling of artifacts, allowing for efficient and accurate documentation even in a challenging remote environment. In remote areas, the archaeologist's ability to adapt to unforeseen circumstances and the self-sufficiency of the team are crucial. The system supports these aspects by providing the tools and resources necessary for independent research and documentation.

3.1.3. Collaborative Research Project

In the context of a collaborative archaeological research project, an archaeologist is part of a multidisciplinary team working together on a complex excavation endeavor. This scenario highlights the challenges and benefits of collaborative research efforts in the field. The collaborative project involves archaeologists, historians, geologists, designers, and other experts working together to uncover and analyze historical relics and archaeological sites. The diverse expertise within the team enriches the research process but also requires effective coordination. The project spans multiple excavation sites, each with its own unique historical significance and archaeological challenges. Coordinating activities and data across these sites is a complex task. Collaboration is central to the success of this project. The innovative system plays a pivotal role by enabling real-time data sharing and collaboration among team members, regardless of their physical locations. The system provides a common platform where all team members can access and contribute to a centralized database of excavation findings, photographs, and documentation. This ensures that everyone has access to the latest information. The system prioritizes data security and integrity to safeguard sensitive archaeological information while ensuring access to authorized team members.

3.2. Mobile App Development

The development of the mobile application is a pivotal component of the archaeological documentation system. This chapter describes the development process, platform choices, programming languages, and key insights that shape this essential component. For this project, Android [38] is the chosen platform for the mobile application. The decision to prioritize Android stems from the preference for larger screens, such as tablets, which are often more suitable for fieldwork, providing a better view for data collection and annotation. However, it is worth noting that the selected programming languages and development approach allow for future expansion to iOS [38], should the need arise.

Flutter [39] is selected as the primary development framework for building the mobile application. Flutter is known for its ability to create natively compiled applications for mobile from a single codebase, which aligns with the project's goal of maximizing code reusability and cross-platform compatibility. Furthermore, Laravel [39] serves as the backend framework for the system. It is renowned for its simplicity, robustness, and the ability to create scalable web applications. Laravel provides the necessary server-side support for the mobile app's functionality, including data storage, retrieval, and synchronization.

3.2.1. Concept and Requirements

This section outlines the general idea and specific needs for the creation of the documentation system. This technology intends to transform fieldwork procedures for archaeologists and researchers, enhance data gathering and documentation methods, and enable real-time cooperation. The basic concept underlying the archaeological documentation system is to empower field researchers and archaeologists by utilizing cutting-edge technology. The system improves the effectiveness, precision, and teamwork of archaeological research by overcoming the gap between conventional excavation techniques and contemporary digital instruments. Table 3 presents the concept's essential components.

Table 3. Key concept elements.

Concept Aspect	Description
Digital Transformation	Shift from manual, paper-based methods to digital data collection and documentation.
Cross-Platform Accessibility	Accessibility on Android tablets initially, with potential future expansion to iOS.
Real-Time Collaboration	Enables researchers to collaborate in real time, regardless of physical locations.
Geospatial Integration	Integrates historical maps onto the modern landscape for contextual reference.
Efficient Data Collection	Facilitates on-site data collection, annotation, photography, and 3D modeling within a user-friendly interface.

To realize the concept of this documentation system, a set of comprehensive requirements guided its development. These requirements cover various aspects of the system, including functionality, usability, scalability, and security. The key requirements included are presented in Table 4.

Table 4. Key requirements elements.

Requirement	Description
Platform Compatibility	The mobile app must be compatible with Android tablets initially, with potential future expansion to iOS devices.
User-Friendly Interface	The user interface (UI) should be intuitive and efficient, catering to the needs of archaeologists and researchers conducting fieldwork.
Data Collection and Annotation	The app should allow for on-site data collection, annotation, and photography of artifacts. It should also support 3D modeling capabilities for precise documentation.
Real-Time Collaboration	The system must enable real-time collaboration among team members, allowing for simultaneous data entry and sharing.
Geospatial Integration	Integration with geospatial data is essential to overlay historical maps onto modern landscapes for contextual reference.
Data Security	Robust data security measures must be implemented to protect sensitive archaeological information, ensuring access is restricted to authorized users.
Scalability	The system should be designed with scalability in mind to accommodate future enhancements and expansions.
Training and Support	Comprehensive training and support materials must be provided to ensure users can effectively utilize the system.

Table 4. *Cont.*

Requirement	Description
Quality Assurance	Rigorous testing and quality assurance procedures are necessary to identify and rectify any issues or bugs.
Deployment	The app should be deployable on the Google Play Store for Android devices and prepared for potential deployment on the Apple App Store in the future.

3.2.2. Platform and Technology Selection

The selection of certain technologies, such as database management systems, cloud computing services, and geospatial tools, that are necessary for the app's operation is explained in this section. To guarantee the system's resilience, scalability, and efficiency in assisting with data administration and archaeological study, these technologies must be chosen carefully. MySQL has been chosen as the relational database management system (RDBMS) for the back-end of the system because of its well-established track record of performance, scalability, and dependability. A strong foundation for organized data storage is offered, fulfilling a crucial need for the effective management of archaeological data. To reduce data redundancy and guarantee data integrity, a well-designed normalized database schema was also put into place (see the database schema at https://drive.google.com/file/d/1nqpWTni1KUSlqXjBc1sVc4aXzO5ZrO0d/view?usp=sharing, accessed on 20 March 2024). This strategy is in line with the goals of the system and follows best practices for database design in the management of archaeological data.

The provided database layout and the relationships described within reflect the complexity of a database structure tailored for archaeological research. The entities "Sector", "Space", and "Section" suggest a layered approach to data categorization, where each physical layer or section of an archaeological site is recorded and interlinked. This helps in maintaining the context and spatial relationship of finds and observations within the site. Specific IDs are given to the entities to indicate primary keys that uniquely identify each record within their respective tables. These IDs are used to establish relationships between different entities. The relationships between the entities are managed through a junction table that records connections between sections and spaces/rooms, with each record including the IDs of both the section and the space/room. This hierarchical and spatial setup ensures the meticulous documentation and management of the excavation site, from broad sector overviews down to specific details of individual spaces, facilitated by a relational database that tracks these complex interrelationships efficiently.

The main relationships in the archaeological site database are hierarchical and interconnected, reflecting the physical and functional structure of an excavation site. A one-to-many relationship exists between sectors and sections, where each sector is subdivided into multiple sections for detailed study. Sections contain spaces or rooms, exhibiting a many-to-many relationship since a single space can span multiple sections and vice versa, which is managed via a junction table that records the links between sections and spaces. Additionally, a finding artifact is usually located on a specific layer but can belong to multiple sections if it is large, constituting a many-to-many relationship. This is crucial for artifacts that straddle the boundaries of sections, necessitating meticulous record-keeping to ensure every part of the artifact is accurately documented and associated with all relevant sections. These relationships enable the precise tracking of archaeological data across different layers of spatial organization, enhancing both the efficiency of data retrieval and the integrity of the site's archaeological record.

Because of its extensive range of cloud services, Amazon Web Services (AWS) (https://drive.google.com/file/d/1nqpWTni1KUSlqXjBc1sVc4aXzO5ZrO0d/view?usp=sharing, accessed on 1 April 2024) has been selected as the cloud services provider. This offers alternatives for data storage, scalable computer resources, and potent analytical tools. Because of AWS's extensive worldwide reach and strong security protocols, reliable data processing and storage are guaranteed. Furthermore, because of AWS's flexibility, the system may be scaled both vertically and horizontally, as needed. This feature is crucial for meeting changing user needs and increasing data volumes, especially when it comes to archaeological research initiatives.

The geographical features of the Google Maps API (https://developers.google.com/maps, accessed on 3 April 2024) have been utilized to offer precise and current mapping data. This is a highly valuable resource since it makes it easier to superimpose old maps over modern terrain, which is in perfect harmony with the goal of geospatial integration inside the system. The cross-platform framework Flutter has allowed for the seamless integration of Google Maps into the mobile application. A wide user base can profit from the system's geospatial capabilities thanks to this calculated decision that guarantees consistent geospatial functionality across Android devices and paves the way for possible future expansion to iOS. The real-time geospatial data that Google Maps provides greatly improve the user experience. It provides users with dynamic and up-to-date information through features like live position tracking and map references to archaeological features. Moreover, Google Maps' built-in geospatial features enable archaeologists to conduct geographic analysis right within the program. By simplifying the research process and assisting in the identification and contextualization of archaeological features within excavation sites, this functionality helps to produce more accurate archaeological interpretations.

3.3. User Interface (UI) Design

In this chapter, the design principles and considerations that guide the creation of an accessible and user-friendly interface for the mobile app and other system components within the system are addressed. The UI design is a crucial aspect of the system as it directly impacts the user experience and the effectiveness of data collection and documentation processes. This user-centric approach is guided by several design principles and is presented in Table 5. Moreover, the considerations covered by the app are presented in Table 6.

Table 5. Design principles.

Principle	Description
Consistency	Consistency in layout, navigation, and visual elements is maintained throughout the app and other system components. This consistency ensures that users can easily navigate and interact with the system without encountering unexpected changes.
Efficiency	Efficiency is a key principle. The design streamlines data collection and documentation processes, reducing the time and effort required for tasks. Intuitive interfaces and logical workflows contribute to efficiency.
Accessibility	The design prioritizes accessibility, ensuring that all users, including those with disabilities, can interact with the system. Features such as text-to-speech, adjustable font sizes, and clear contrast are integrated to enhance accessibility.
Feedback and Guidance	Providing clear feedback and guidance to users is essential. The UI offers informative prompts, tooltips, and feedback messages to guide users in performing tasks and understanding the system's status.

Table 6. UI Design Considerations.

Consideration	Description
Device Compatibility	Given the system's initial compatibility with Android tablets, the UI is optimized for larger screens. Adequate spacing, touch-friendly elements, and layouts that make the most of tablet real estate are considered.
Intuitive Navigation	The navigation structure is designed to be intuitive, allowing users to access different features and sections of the app easily. Navigation menus and hierarchies are structured logically.
Data Entry	Data entry forms are designed with simplicity and efficiency in mind. User-friendly input methods, such as dropdown lists and checkboxes, reduce data entry errors and enhance user productivity.
Visual Aesthetics	Visual esthetics play a role in user engagement. The UI design incorporates a visually pleasing and cohesive color palette, icons, and imagery that align with the system's archaeological context.
Real-Time Updates	In scenarios where real-time collaboration is essential, the UI accommodates real-time updates and notifications to keep users informed about changes made by team members.
Orientation and Context	The UI provides orientation and context, especially when overlaying historical maps onto modern landscapes. Features like markers and legends clarify the user's position and the relevance of archaeological features.
Testing and Iteration	Usability testing is conducted with archaeologists and researchers to gather feedback on the UI design. Iterations are made based on user feedback to enhance the design's effectiveness.
Cross-Platform Consistency	While the system is initially developed for Android tablets, consideration is given to maintaining consistency should the system expand to iOS in the future. Design elements that translate well across platforms are prioritized.

3.4. Geospatial Integration

Essentially, geolocation [40] is the basis on which the functionalities of the system are developed. This method collects accurate geolocation data for archaeological excavations in both urban and rural environments by using GPS technology found on mobile devices. This system acknowledges the typical limitations of standard GPS accuracy on mobile devices, which is generally a few meters. To enhance precision, which is especially crucial in archaeological contexts, our platform integrates supplemental location data from Wi-Fi and cellular networks by integrating Google Maps [41]. As a result, the location indicated by Google Maps is less than 2 m from the actual point.

Additionally, the system employs a layered approach on a Google Maps base, incorporating manually inserted geometric points to refine spatial accuracy. These enhancements allow for sub-centimeter precision in data recording, aligning with the rigorous standards required for detailed archaeological documentation and analysis. This data integration has several significant benefits. With the integration of enhanced geolocation techniques, archaeologists can now accurately associate each piece of data with precise physical coordinates. This precision ensures that features, artifacts, and entire excavation sites are meticulously documented within their true geographic contexts, thereby enriching the detail and reliability of archaeological records. Furthermore, this method simplifies the initial creation and subsequent refinement of site segmentation. By simply adjusting points on the map by mere inches, researchers can efficiently outline and modify smaller segmented areas, facilitating a swift and accurate mapping process on the ground.

Furthermore, archaeologists may overlay ancient maps on modern landscapes due to the system's integration of geolocation data with mapping services like Google Maps.

A thorough contextual understanding is made possible by this fusion of temporal layers, which also helps to identify prospective archaeological elements and their contextual links within the surrounding environment. Geospatial data lay the foundation for spatial analysis, providing archaeologists with the capability to perform sophisticated assessments of artifact distributions, site layouts, and spatial patterns. Such analytical prowess contributes significantly to insights into ancient societies, settlement patterns, and cultural behaviors. Finally, the system extends real-time geospatial updates, enabling archaeologists to continually monitor their positions and make reference to archaeological features on the map while conducting excavations. This live tracking heightens situational awareness, facilitating on-site decision-making.

The integration of geographical data and technologies significantly enhances the documentation process of excavations in multiple ways. Archaeologists may acquire a comprehensive contextual understanding of excavation sites through the use of geolocation and mapping. The ability to clearly perceive the spatial linkages between objects, artifacts, and maps improves the accuracy of archaeological interpretations. By offering a visual reference for item documentation and excavation progress, the inclusion of geographical features simplifies the data collection process. Because of their increased efficiency, archaeologists can spend more time analyzing their findings and less time documenting them.

Moreover, precise geolocation data significantly contributes to data integrity by minimizing the risk of errors in artifact placement or recording. The meticulous accuracy achieved in documenting archaeological findings enhances the reliability of research outcomes. Finally, real-time geospatial data sharing promotes collaboration among team members, whether they are on-site or working remotely. Multiple researchers can concurrently contribute to excavation documentation, fostering teamwork and data synchronization. The overall geolocation foundation is depicted in Figure 1.

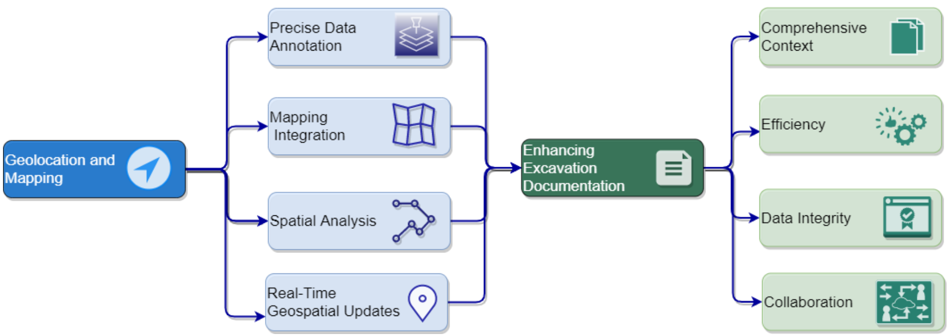


Figure 1. Geolocation foundation.

3.5. Integration with Hololens II

An important step forward in providing archaeologists with advanced capabilities for data visualization and interaction during excavations is the integration of Microsoft Hololens II into the archaeological documentation system [42]. Through the use of Unity, a 3D development platform, and direct interaction with the project repository, archaeologists will be able to view an extensive variety of data formats in situ within the context of the excavation, including files, pictures, videos, and 3D models.

The primary framework for integrating Hololens II's functionalities is Unity. It provides a flexible and robust setting for creating engaging augmented reality (AR) applications [43]. The project repository's archaeological data can be easily accessed and instantly visualized using Unity, which improves the understanding and study of excavation sites. The seamless experience for archaeologists is made possible by the intimate integration of Hololens II with the project repository. This connection guarantees that any pertinent data may be instantly accessed and viewed in the augmented reality environment, including academic papers, historical records, photos, videos, and 3D models. Because of this level of accessibility, archaeologists can work more efficiently and save time by not having to transfer between different tools and platforms.

The capacity of Hololens II's integration to observe data in situ, inside the context of an excavation, is one of its main benefits. On the actual excavation site, archaeologists might overlay old maps, 3D models of artifacts, or documentation files. This helps with decision-making during excavation and offers a thorough understanding of the archaeological elements. Integration with Hololens II extends beyond simple visualization. It makes interactive data interaction possible. Within the augmented reality environment, archaeologists can annotate findings, alter 3D models, and access multimedia resources. By adding an interactive element, data analysis and interpretation become more in-depth, which promotes a more dynamic and knowledgeable archaeological process.

3.6. System Architecture and Design

Within the meticulously designed framework of the system's architecture (Figure 2), the top level serves as a complete collecting area for all excavation data, including text, audio, videos, recordings, photos, and 3D models. The system's core is this multi-modal data storage area, which offers a vast and varied collection of data. The data repository, which has a strong database and effective data access and services, is located just below. This configuration allows it to make seamless API calls, which expands the capacity to communicate with external apps like augmented reality (AR) glasses and mobile apps in addition to enabling internal communication between components. The architecture is carefully designed to guarantee open accessibility, scalability, and flexibility, allowing users to fully utilize the excavation data.

The architecture is divided into two distinct components at a lower level: a mobile app and Hololens II, both of which were developed using cutting-edge technology. Users can explore the excavation data in a three-dimensional format and with a fully immersive experience due to the Hololens II component, which was designed using Unity. However, the Flutter-developed mobile app appeals to users who want a portable and flexible interface. Users' overall experience is improved by the easy access to excavation data from Hololens II and mobile applications made possible by the integration of these components. Additionally, the architecture is made to be expandable, allowing for the integration of additional third-party applications and promoting a cooperative and networked ecosystem for investigating and taking advantage of the enormous potential provided by mobile and Hololens II platforms.

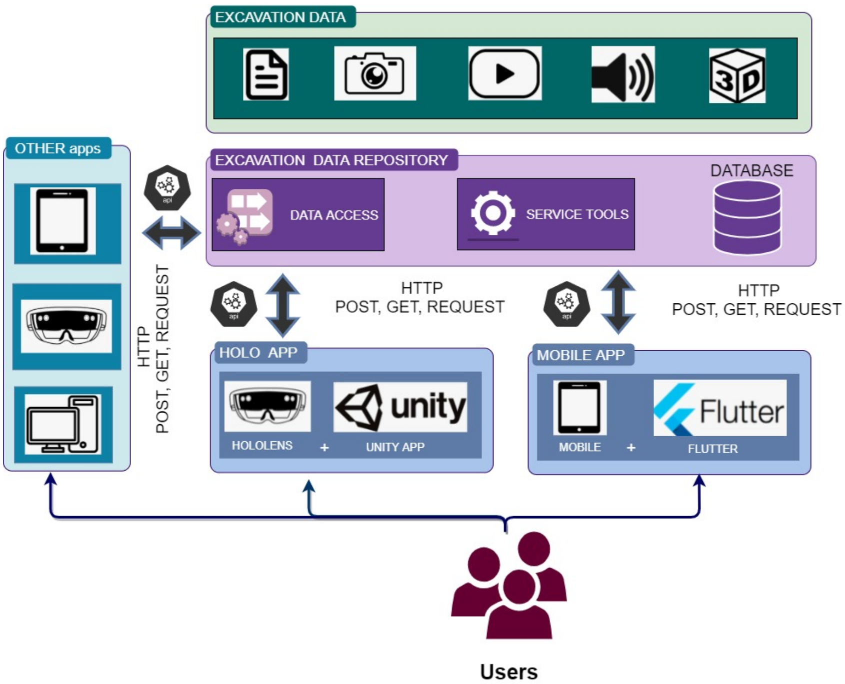


Figure 2. System conceptual architecture and design.

4. Experimental Results

4.1. Experiment Set-Up

The proper selection of excavation sites is essential to testing an application when exploring archaeological landscapes. The three archaeological environments that have been selected not only demonstrate a diversity that reflects the diverse range of difficulties that researchers encounter, but they are also ordinary and highly representative for classical archaeological research, especially in regions such as Greece and Italy. These sites were chosen because they embody the typical challenges and opportunities found in classical archaeological settings, offering an ideal context for demonstrating the efficacy and adaptability of our digital tools. The three use cases, urban and rural archaeological excavations and a collaborative research project, are depicted in Figure 3.

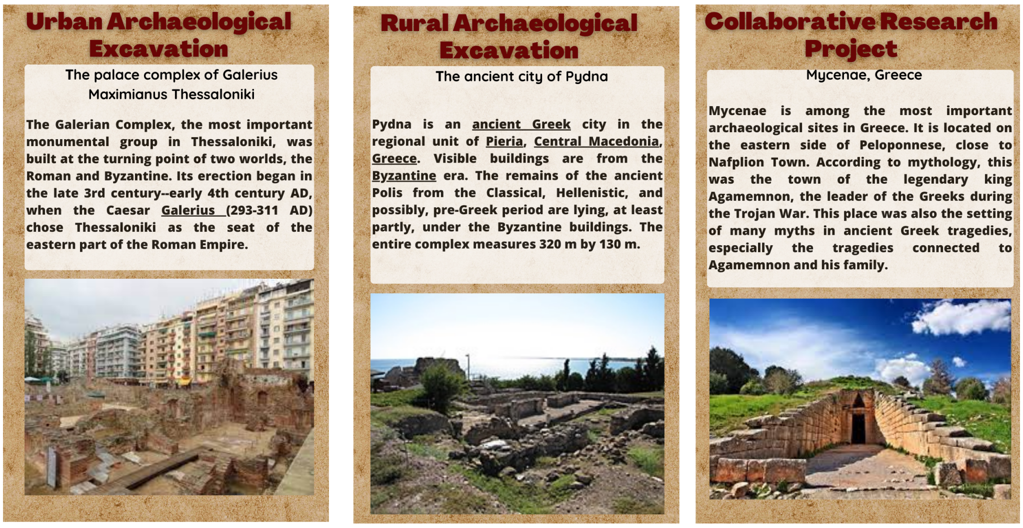


Figure 3. Simulation environments for application testing.

4.2. Mobile App

4.2.1. Auxiliary Menu

The mobile app auxiliary menu is designed to facilitate the addition of crucial information required for the management of excavation data. Emphasizing user-friendly principles, the menu minimizes the need for extensive typing by enabling selection-based inputs, therefore accommodating the practical needs of users in the field. As depicted in Figure 4, the auxiliary menu comprises several key components, like the type of excavation, artifact types, roles of the teams, and others. Upon selecting a sub-menu, for instance, "Excavation Types", users are presented with the opportunity to input new information or select from existing options. This design choice supports the iterative addition of data, allowing for dynamic database expansion over time. Furthermore, any new information added through this sub-menu is saved for later use, ensuring that the app's database grows in both detail and utility with each entry. This feature not only streamlines the data entry process during subsequent uses but also enhances the overall efficiency of the excavation documentation workflow.

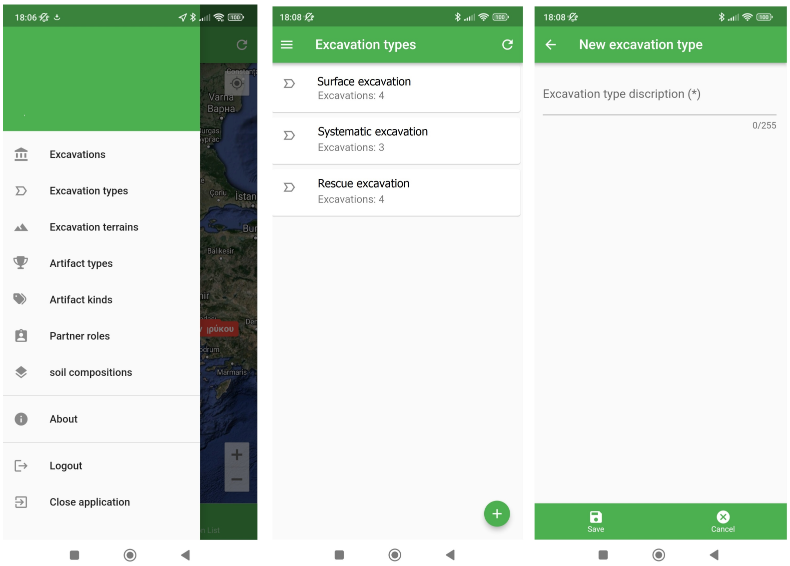


Figure 4. Auxiliary menu.

4.2.2. Excavation Main Menu

The main menu items in the archaeological excavation application after selecting a specific excavation site, such as "Rural Pidna", are excavation data, excavation map, excavation team, artifacts, excavation diary, media files, orthomaps, and global notes, as depicted in Figure 5. Each of these menu items is designed to provide comprehensive and organized access to all aspects of the excavation, enhancing both the efficiency and depth of archaeological research and documentation.

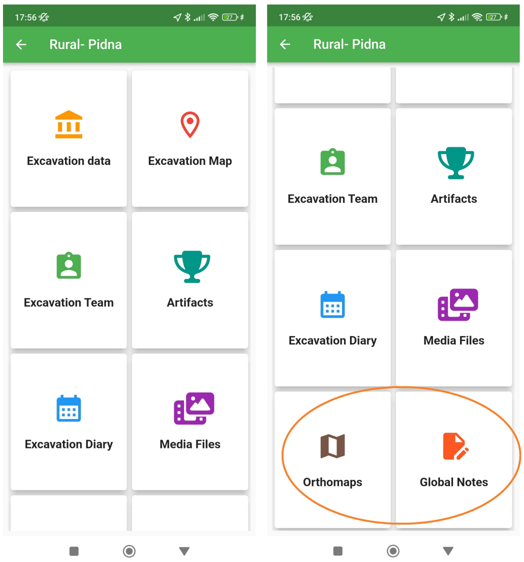


Figure 5. Main menu components.

4.2.3. Excavation Data

The excavation data section acts as the central hub for all primary information related to the selected archaeological site, as depicted in Figure 6. This comprehensive module contains essential details that are crucial for the effective management and understanding of the excavation.

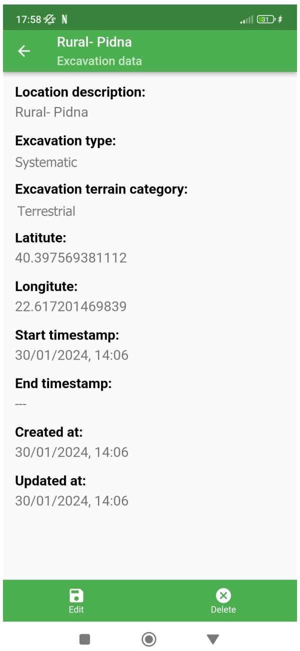


Figure 6. Excavation data dashboard.

The location description field provides a narrative description of the excavation site's location, offering insights into the surrounding environment and its historical significance. The exact location field provides precise geographical coordinates (latitude and longitude) of the excavation site. This ensures that users have accurate location data, which is essential for GIS mapping and any related navigational needs. The excavation terrain category categorizes the site's terrain, such as terrestrial, underwater, forested, desert, urban, or coastal. Understanding the terrain is vital for preparing the appropriate excavation techniques and equipment. The field excavation dates are a field to record the start and end dates of the excavation. If the excavation is ongoing, the expected end date can also be noted. This helps in planning and tracking the progress of the excavation over time.

4.2.4. Excavation Map Exploiting GIS

A geographic information system (GIS) is integrated into the archaeological excavation management application, as depicted in Figure 7. The main screen of the application presents a map, which is the primary interface for visualizing the excavation sites. Each site is marked with a pin on the map. These pins could be labelled with either a code (like "KE34") or a descriptive name (such as "Rural Pidna"). The naming can vary according to specific project requirements or naming conventions (Figure 7-1). Furthermore, alongside the map, there is a list view of the excavation sites for easy reference and selection. This dual presentation (map and list) enhances user navigation and selection efficiency within the application (Figure 7-2). Users can add new excavation sites directly on the map by pressing a specific location. The application automatically captures the longitude and latitude of the new site, simplifying the process of adding new data points (Figure 7-3). After confirming the location of a new excavation site, users can input detailed information about the excavation. This may include specific characteristics of the site, historical relevance, planned excavation dates, and other pertinent details (Figure 7-4). The system is designed to streamline the data entry process, reducing manual input by automatically saving geographical coordinates. It also allows for quick updates and additions, enhancing fieldwork efficiency.

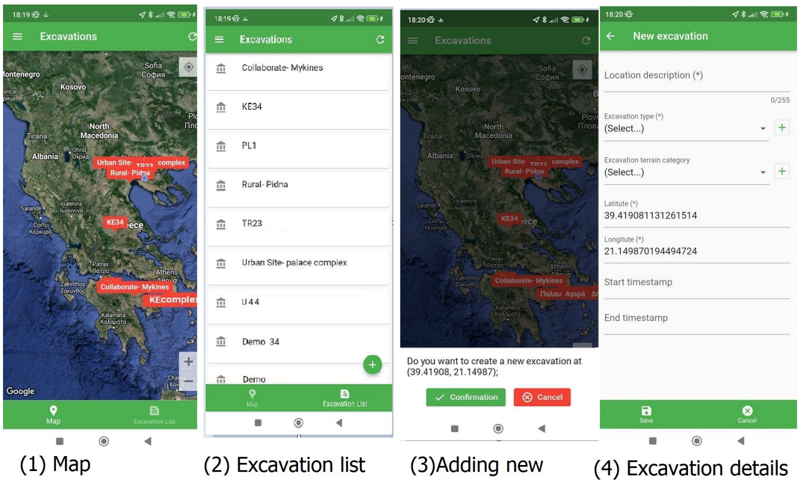


Figure 7. GIS map and excavation list.

The excavation map serves as an interactive GIS tool tailored to each specific archaeological site. It provides a detailed view of the site's layout, which is crucial for both planning and ongoing management of excavation activities, as shown in Figure 8. The map displays a comprehensive layout of the excavation site, marked into grids or sectors that delineate different areas of interest. This structured approach aids in systematic exploration and documentation. Users can access overlays showing different geological strata or layers as well as the locations of significant finds. These overlays can be toggled on and off for clarity and are invaluable for understanding the site's archaeological context. The map is fully interactive, allowing users to zoom in and out for detailed or broad views, respectively. This feature is essential for both detailed examination and general site overview planning.

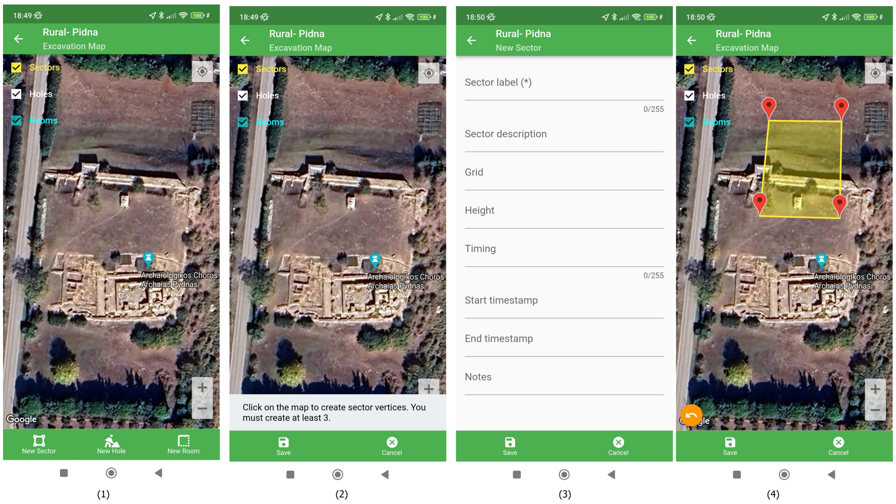


Figure 8. Main menu of the excavation based on GIS.

By pressing on a specific point on the map, users can start the process of creating a new sector, excavation section (hole), or room (Figure 8-2). The application requires the selection of at least three points to define a new sector, ensuring accurate and practical area demarcation. Upon pressing a point, the user receives a prompt informing them of the need to select a minimum of three points to create a sector. This guidance helps prevent errors and supports the user in correct data entry. Once a sector is defined, the user is automatically directed to a form to add detailed information about the sector. This includes the sector's name, a detailed description, grid dimensions, start timing, and any pertinent notes (Figure 8-3). These details are critical for proper record-keeping and contextual understanding of each sector. After creation, the new sector is highlighted on the GIS map in yellow (Figure 8-4). This visual distinction makes it easy to identify newly added sectors, enhancing the map's usability and the user's ability to navigate through various site components. This interactive GIS-based excavation map is designed to be a central tool in the excavation management system, enhancing the accuracy and efficiency of archaeological documentation and planning.

Users can further subdivide the map by creating smaller excavation areas, referred to as "holes", within the already defined sectors, as depicted in Figure 9. This is particularly useful for detailed exploration and documentation of specific site features. Similar to sector creation, the user begins by selecting at least three points on the map within a sector. This point selection is crucial for accurately defining the boundaries of the hole. Once the points are selected and the boundary of the hole is defined, the system automatically creates the hole. This process mirrors the sector creation, ensuring consistency and ease of use. Immediately after the hole is created, a form opens, prompting the user to enter specific details about the hole (Figure 9-1). This includes a description of the hole, its dimensions, and any relevant observations. Crucially, the user must also select the sector to which the hole belongs from a dropdown menu, thereby directly associating the hole with its corresponding sector. After the details are submitted, the hole is marked on the GIS map in white (Figure 9-2). This distinct marking differentiates holes from sectors and provides visual cues to users navigating the map. By pressing on the hole marked on the map, the user can visualize the form containing all entered descriptions and details (Figure 9-3). This feature allows quick access to data and facilitates easy updates or reviews of specific hole information.

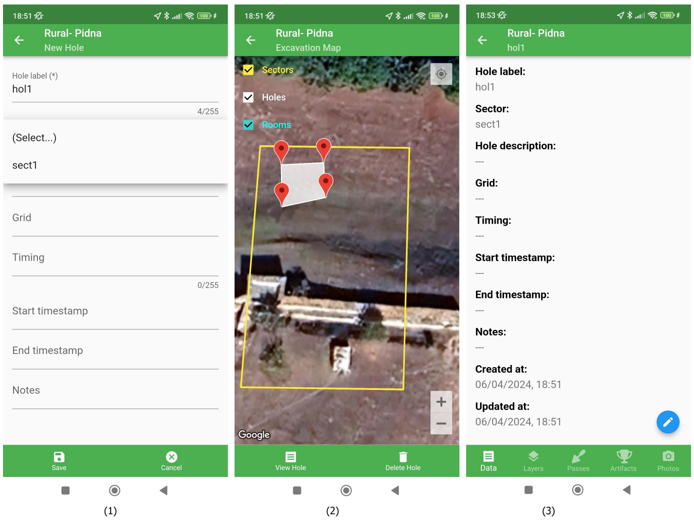


Figure 9. Adding sectors (holes) dashboard.

It is important to underscore the specialized integration of manually inserted geometric points with the Google Maps platform. This method is not merely an application of existing geospatial technologies but an enhancement tailored to the nuanced needs of in situ archaeological research. Allowing archaeologists to manually adjust and refine these points, the proposed system significantly improves the precision of georeferencing archaeological finds. Moreover, the capability to layer archaeological strata and findings dynamically over these refined points represents a significant advancement over traditional GIS applications used in archaeology. This innovative approach provides a more accurate, interactive, and user-friendly tool for documenting and analyzing excavation sites, making it particularly valuable in managing the complex data associated with classical archaeological sites. Furthermore, the system allows archaeologists to effortlessly save and visualize matrix segmentation by simply walking through the excavation area with enabled GPS devices. This feature not only enhances the ease of capturing site-specific data but also ensures that the segmentation of the excavation matrix is consistently updated and visualized in real time, further enhancing the accuracy and utility of the geospatial data in archaeological research.

Expanding the excavation map's functionality to include rooms provides even more granularity and control for archaeologists to manage and analyze different excavation areas thoroughly. Like sectors and holes, rooms can be added to the excavation map to represent smaller, more specific areas of interest within the site. This might be used to indicate distinct rooms within a larger structure or defined areas within a sector or hole. The user defines a room by selecting at least three points on the map, which is necessary to establish the precise boundaries of the room. This method is consistent with the creation of sectors and holes, maintaining a uniform user experience. Once the points are defined, the system automatically creates the room. A unique color code (blue) is applied to these areas on the map, which helps to distinguish rooms from sectors (highlighted in yellow) and holes (marked in white). A form pops up requiring the user to input details about the room. Information such as the name of the room, its purpose, dimensions, and any significant findings are entered here. Importantly, the user can associate the room with both a sector and a hole, establishing a clear hierarchical relationship within the data structure. After the room's details are confirmed and saved, it appears on the map in blue, providing a visual representation of all rooms relative to other divisions. This color distinction helps users easily identify different types of divisions at a glance.

To manage the complexity of information displayed on the map, users can toggle the visibility of sectors, holes, and rooms. Checkboxes allow users to select which elements to display, as depicted in Figure 10. This flexible visibility feature is crucial for users who need to focus on specific details without the distraction of other layers, or for those who require a comprehensive overview when planning or analyzing the site. By implementing such features, the excavation map becomes a powerful tool for detailed spatial analysis and documentation, allowing archaeologists to manage their excavation sites with high precision and clarity. This interactive approach not only aids in the immediate needs of the excavation process but also contributes significantly to the long-term management and study of archaeological sites.

Figure 10. Change excavation data visualization.

4.2.5. Excavation Team

The excavation team area lists all team members involved with the specific excavation (Figure 11). It includes roles that address the specific responsibilities of each team member and their names. This facilitates easy communication and coordination among the team.

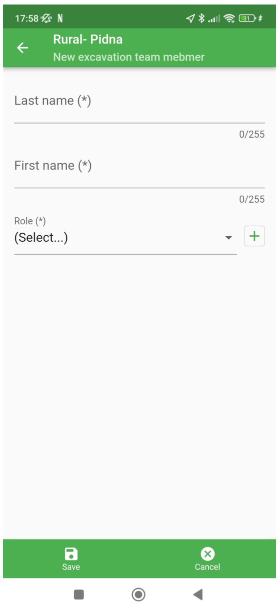


Figure 11. Excavation team dashboard.

4.2.6. Excavation Artifacts

The artifacts section of the archaeological excavation management application plays a crucial role in cataloging and documenting each artifact uncovered during the excavation. This section ensures that all relevant data about the artifacts are systematically captured and accessible for analysis, research, or exhibition purposes, as depicted in Figure 12. Each artifact is assigned a unique label or identifier, which helps in tracking and referencing within the database. This label is critical for managing the inventory and linking artifacts to specific documentation, such as reports or publications. Users can categorize artifacts by type and kind from dropdown menus, which are populated based on predefined classifications (i.e., the auxiliary menu), such as "tools", "jewellery", or "ceramics". Each artifact entry includes a detailed description covering its historical context and peculiarities, precise dimensions, documented color, and material constitution. This structured data capture is essential for accurate documentation, analysis, conservation, and educational display purposes.

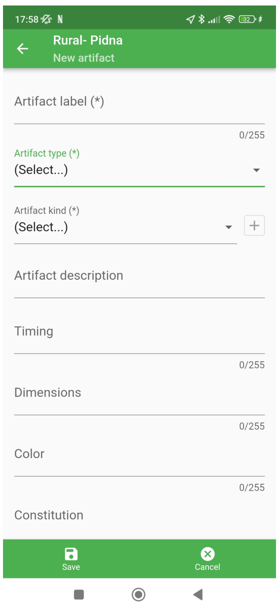


Figure 12. Excavation artifacts dashboard.

As depicted in Figure 13, the process for managing artifacts within the archaeological site system must be both intuitive and comprehensive. Initially, users select the desired sector, hole, or room on the excavation map to add, view, or edit an artifact (Step 1). Subsequently, a dashboard displaying detailed information for the selected area appears, where users can click on the artifact icon to engage with artifact-related information and data. This opens a list displaying images of existing artifacts for viewing or editing, and an option to add new artifacts. In this dashboard, users can upload photos of new findings and enter essential data and information, such as labels, descriptions, types, dimensions, and other relevant details (Step 2). Additionally, artifacts can be edited or deleted as needed (Step 3). In the final step, (Step 4) by scrolling down on their mobile device's screen, users can specify the depth at which the artifact was found and associate it with the selected sector, hole, or room through a menu selection, ensuring that each entry is directly linked to specific database fields. As a result, although the map interface does not provide depth information, this method ensures comprehensive documentation of each artifact, including its exact position and associated details. This method is meticulously aligned with the database relationships, facilitating streamlined queries for later scientific analysis, such as retrieving all artifacts found in a specific sector. This integration ensures efficient data management, allowing researchers to access and analyze archaeological information with ease and precision.

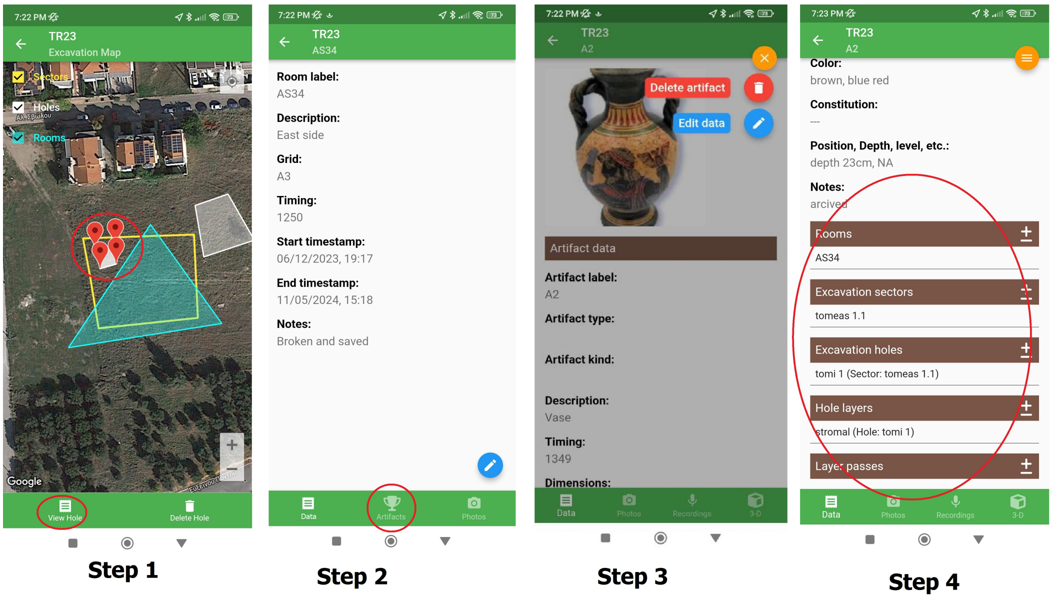


Figure 13. The process of adding, viewing, or editing artifacts in the app.

4.2.7. Excavation Diary

The excavation diary is a part of the archaeological excavation management application that serves as a chronological log of daily activities and observations (Figure 14). It records key details, such as weather conditions and equipment issues, which influence excavation methods and artifact preservation. Users can select specific dates to view or add entries, ensuring comprehensive and consistent record-keeping (Figure 14-2). This tool not only preserves the excavation's history but also supports decision-making by allowing team leaders to access and analyze past activities and outcomes. Overall, the excavation diary is vital for documenting and managing daily operations on-site. While diaries are no longer universally employed in contemporary archaeological excavations, they remain a valuable tool in certain countries, such as Greece, where they are still used extensively [44]. These excavation diaries serve as a primary method for documenting daily activities, observations, and decisions on-site, providing a detailed historical record that is invaluable for both current analysis and future reference.

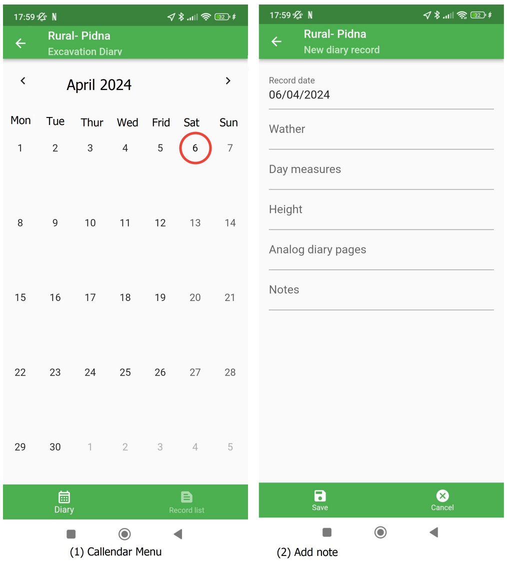


Figure 14. Excavation diary dashboards.

4.2.8. Media Files

The media files section of the archaeological excavation management application is an integrated multimedia repository designed to enhance the documentation and analysis of the excavation site. This section acts as a centralized repository for storing and organizing all forms of media related to the excavation, including photographs, videos, audio recordings, and 3D models. Each file can be tagged with specific locations or artifacts, linking the media directly to the relevant site data. For photographs and videos, users have the option to upload photographs and videos from existing files stored on their devices, allowing for the integration of previously captured media (Figure 15-1,3). The application also supports live capturing capabilities, enabling users to take photos and record videos directly through the app using the mobile device's camera. This feature is particularly useful for capturing real-time findings and activities at the excavation site. Moreover, similar to photos and videos, users can upload pre-existing audio files. Additionally, the app allows for on-the-spot audio recording, facilitating the immediate documentation of oral notes, interviews, or ambient sounds at the site. This real-time recording is crucial for capturing spontaneous insights and descriptions that are easier to communicate verbally.

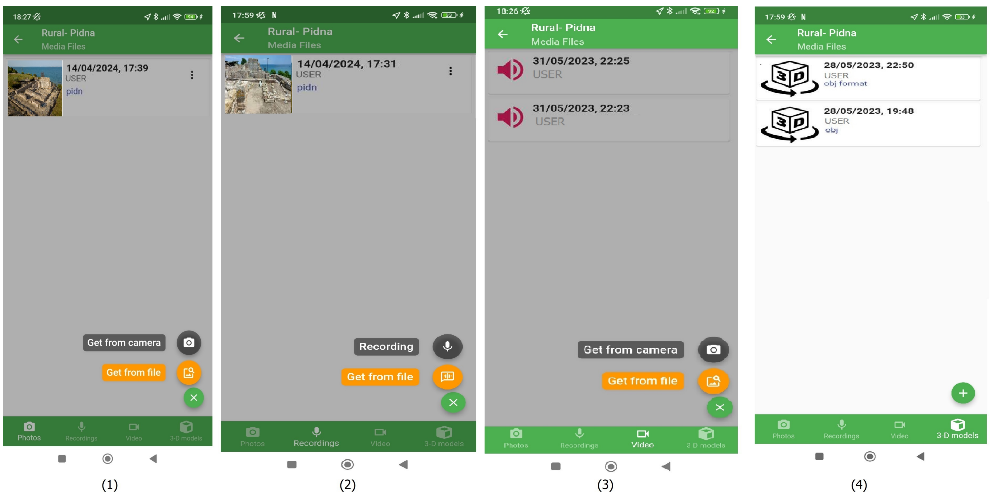


Figure 15. Media files dashboards.

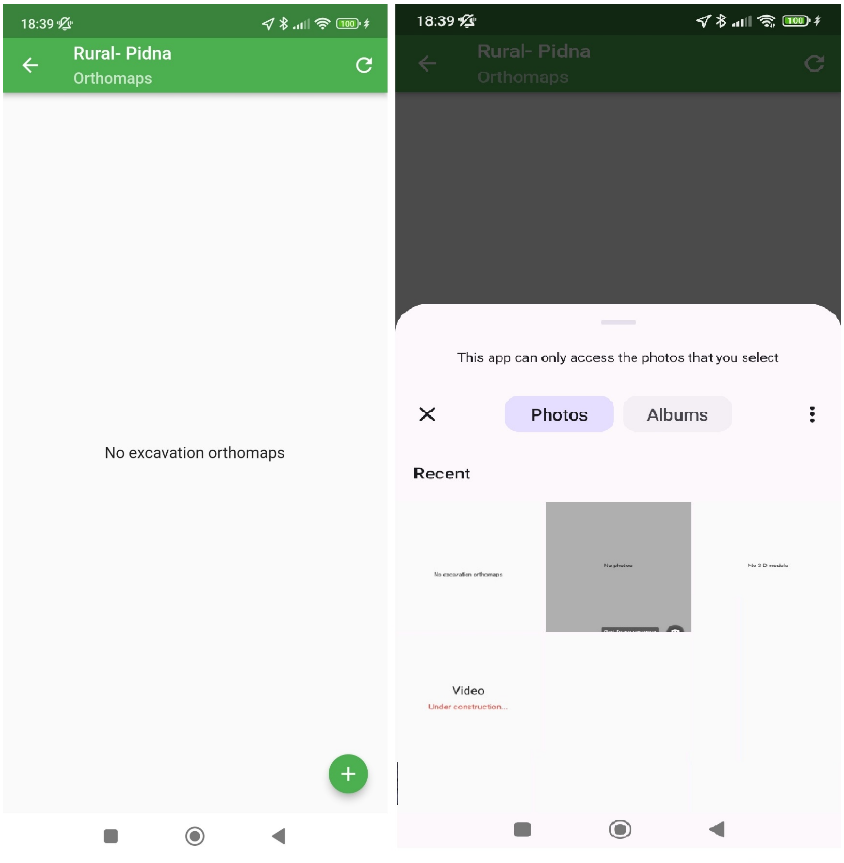
Unlike photographs and videos, 3D models can only be uploaded. Users can upload 3D model files that have been created externally, such as through 3D scanning processes or digital reconstruction software. These models are important for providing a three-dimensional perspective of artifacts, structures, or landscape features. The application supports common 3D model file formats, such as OBJ, STL, and PLY, which are widely used for their compatibility with various 3D software applications. For orthoimages, standard image file formats like JPEG, PNG, and TIFF are accepted alongside GIS-specific formats such as GeoTIFF for geospatial accuracy. The system supports uploading 3D models and orthoimages via URLs or direct links from databases where these files are hosted. Users can input the URL in the provided field, and the system will fetch and integrate the file directly into the database, streamlining access to externally hosted resources. When selecting a 3D model to ensure smooth performance on standard mobile phones and tablets, the application utilizes standard file compression and optimization techniques [45].

It is important to note that 3D models created directly with a standard smartphone or tablet camera could be embedded within the system but would inherently possess less accuracy. This is due to the limitations of mobile device cameras compared to dedicated scanning technology. Methods to create 3D models from phone cameras are available and can be integrated into the system for convenience [46]; however, for rigorous archaeological work where precision is paramount, models generated by more accurate tools are recommended. This approach ensures that the application can accommodate both quick, preliminary visualizations and detailed, precise reconstructions, as required by the project's demands. The media files section is thus a vital part of the excavation management application, adding depth and richness to the archaeological documentation and providing a dynamic tool for the analysis, presentation, and archiving of the site's findings.

4.2.9. Orthomaps

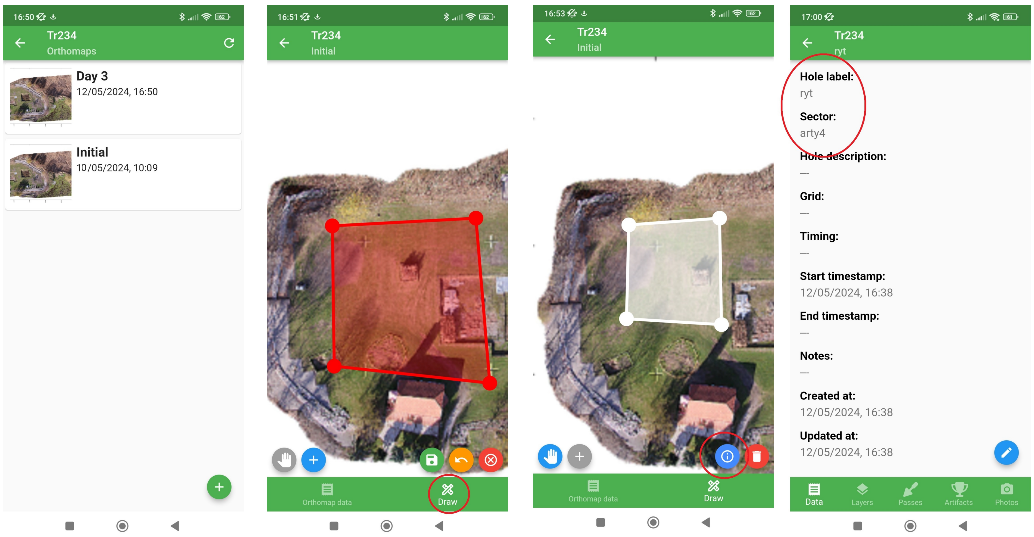
The orthomaps section of the archaeological excavation management application is a specialized tool that utilizes high-resolution, geometrically corrected aerial photographs to provide detailed, accurate representations of the excavation site from an aerial view. This feature plays a crucial role in understanding the topography and planning the excavation strategies effectively (Figure 16). Users can import orthomap files that have been prepared beforehand. These files are typically generated through processes involving drones or other aerial survey methods that capture extensive data over the excavation area.

The orthomaps section of the archaeological excavation management application not only utilizes pre-existing aerial photographs for initial planning but is also designed to integrate updated orthomaps as the excavation progresses (Figure 17). As new layers are uncovered and more detailed information becomes available, updated orthomaps are generated and imported into the application periodically. This dynamic capability allows users to continuously refine their understanding of the site's topography and adjust their excavation strategies accordingly. Within the app, users can access a catalog of these orthomaps, selecting the most current or relevant map for their needs. They can then use this map to visualize changes, plan new excavation areas, or update existing ones (Figure 17-1). Moreover, the application provides functionality for users to draw and define new sectors, sections, or rooms directly on these orthomaps and save these modifications (Figure 17-2). Once an area is created or modified, it can be directly linked to the corresponding records in the database, ensuring that all spatial data remain synchronized with physical site changes (Figure 17-3). This integration not only enhances the accuracy of the geographical data but also allows for the immediate visualization and analysis of information related to specific areas directly from the app, streamlining both fieldwork and data management processes.



(1) (2)

Figure 16. Orthomaps dashboard.



1. Menu of historical orhtomaps

2. Select draw and make a sector, section, etc.

3. The area is created and it is associated with the database and entries.

4. By selecting the area to visualize,the data associated with the entries are visualized.

Figure 17. Orthomaps dashboard and new entries.

4.2.10. Global Notes

Users can access and add general notes that may not fit into the other specific categories but are still important for the excavation's overall management, as depicted in Figure 18. These notes could include observations, hypotheses, or reminders.

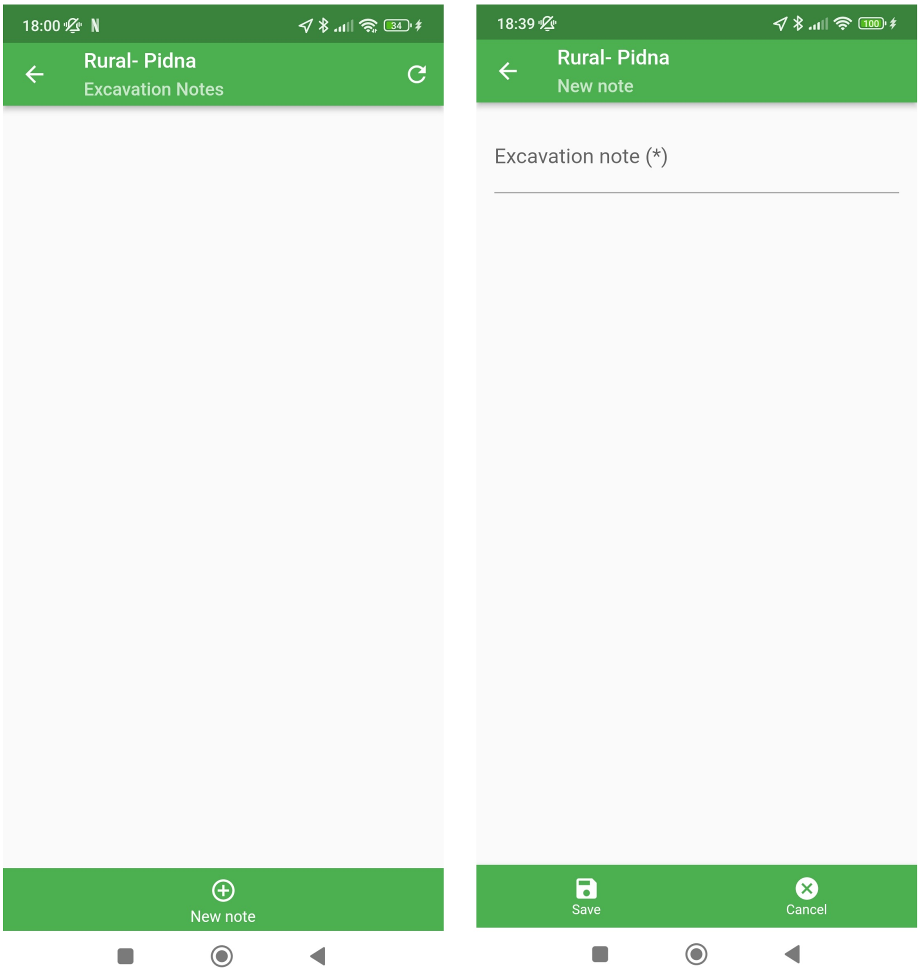


Figure 18. Notes dashboard.

4.3. Hololens II

Integrating Microsoft Hololens II into the archaeological excavation management application provides an innovative and immersive way to interact with and visualize excavation data using augmented reality (AR). This technology not only enhances the capabilities of our application by allowing users to see and interact with historical data layered directly onto the current excavation site but also facilitates the sharing of knowledge and aids in the preservation of sites. By using AR, archaeologists can provide immersive educational experiences and detailed site analyses that were not previously possible, making complex data more accessible and engaging. While the cost of Microsoft Hololens II is considerable, it is in line with similar AR and VR technologies and represents an optional enhancement that enriches the user experience and extends the application's educational and preservation capabilities without being mandatory for its fundamental operations.

4.3.1. Menu

The Hololens II menu, as depicted in Figure 19, offers a user-friendly interface that presents a list of all the available excavations. Each excavation is represented in an interactive list format within the augmented reality environment. Users can interact with the menu using hand gestures or voice commands, which are fundamental features of Hololens II.

This allows for a hands-free and intuitive navigation experience, enhancing the accessibility and ease of use in field conditions. Users can select an excavation by performing a specific gesture, such as pointing or air tapping, directed at the desired excavation entry in the virtual list. Alternatively, users can initiate a selection by using a voice command, such as saying "Select Urban site- palace complex". This voice interaction further simplifies the user experience, making it more efficient when physical interaction is impractical.

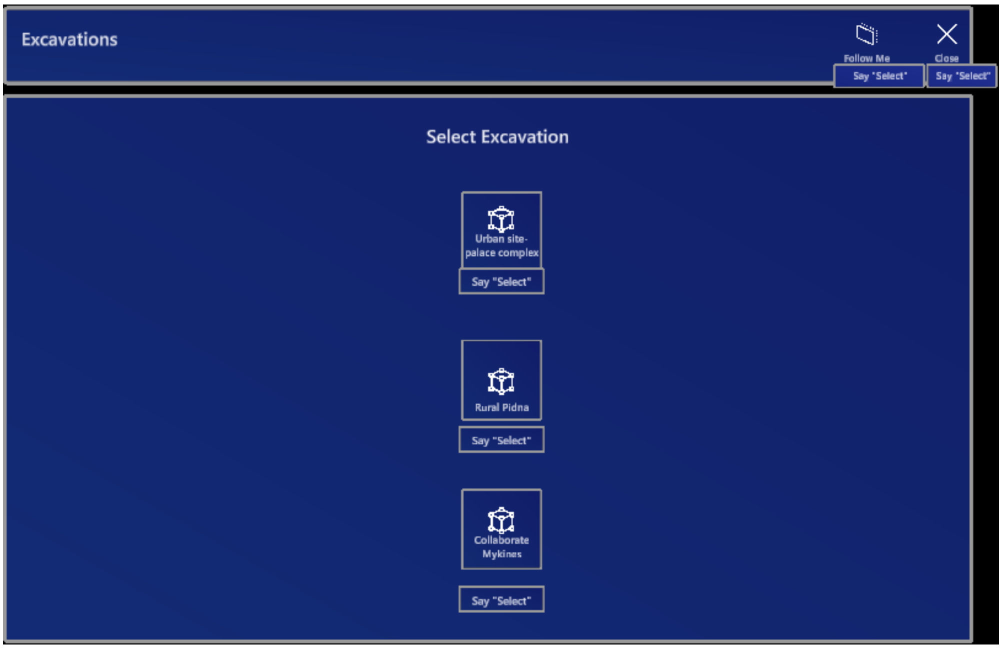


Figure 19. Hololens II excavation list main menu.

4.3.2. Excavation Media

Upon selecting an excavation, the user is presented with a detailed 3D visualization of the excavation site. This model can include layers, grids, and specific findings, all rendered in three dimensions within the user's current environment (Figure 20). Users can explore the 3D model by moving around in the physical space, zooming in and out, and interacting with specific elements of the model using gestures. This spatial interaction is particularly useful for understanding the layout and depth of the excavation layers.

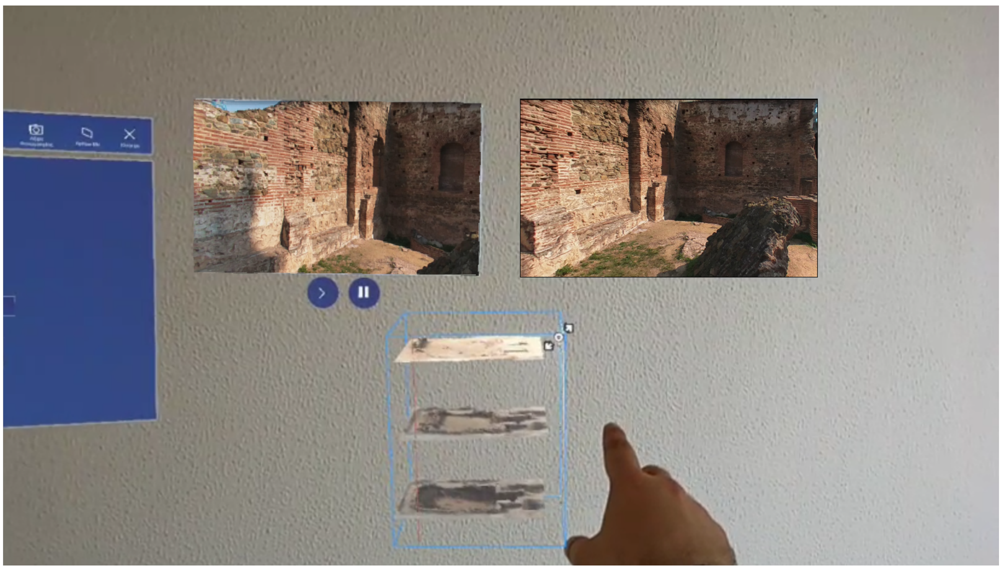


Figure 20. Excavation media.

Building on the already robust capabilities of Hololens II for viewing and interacting with 3D visualizations of excavation sites, the system can be further enhanced to provide an even richer and more detailed experience by incorporating various types of detailed visual data. Users can view 3D models of artifacts directly within the Hololens II environment. This feature allows for close-up examinations of artifacts in three dimensions, offering insights into their shapes, textures, and potential uses that might not be as apparent in two-dimensional images. The 3D models can be scaled to their real-life size or enlarged to enhance detail visibility, facilitating a better understanding of the artifacts' physical attributes and craftsmanship (Figure 21).

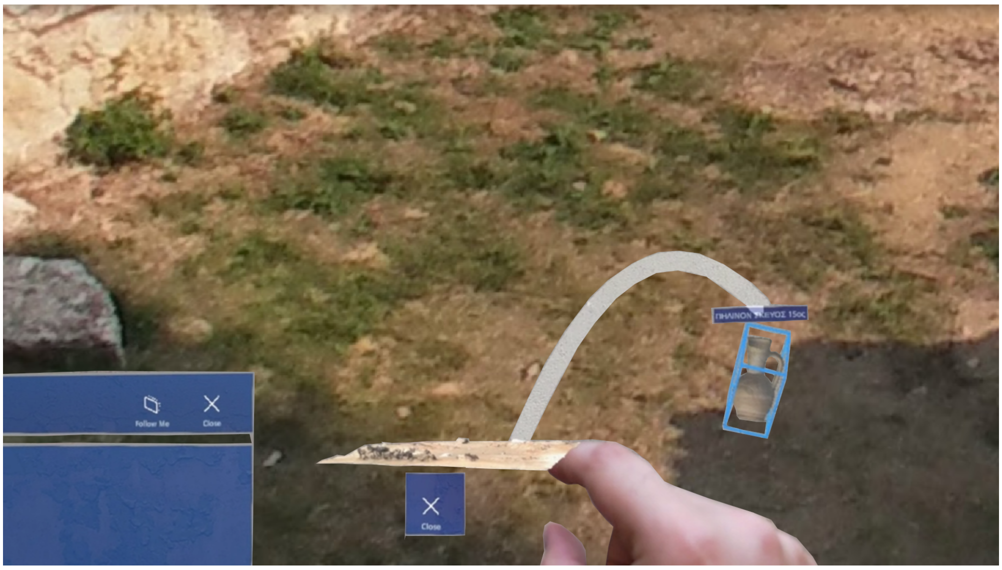


Figure 21. Excavavation artifact 3D view Hololens II.

Moreover, 3D visualizations of the excavation site can be augmented with orthomaps, providing a real-world geographic context (Figure 22). Orthomap overlays on the 3D model help users visualize the site's topography and landscape features accurately. Integrating orthomaps with the 3D models allows for a comprehensive understanding of the site layout relative to its surrounding environment, aiding in the strategic planning and analysis of the excavation areas.

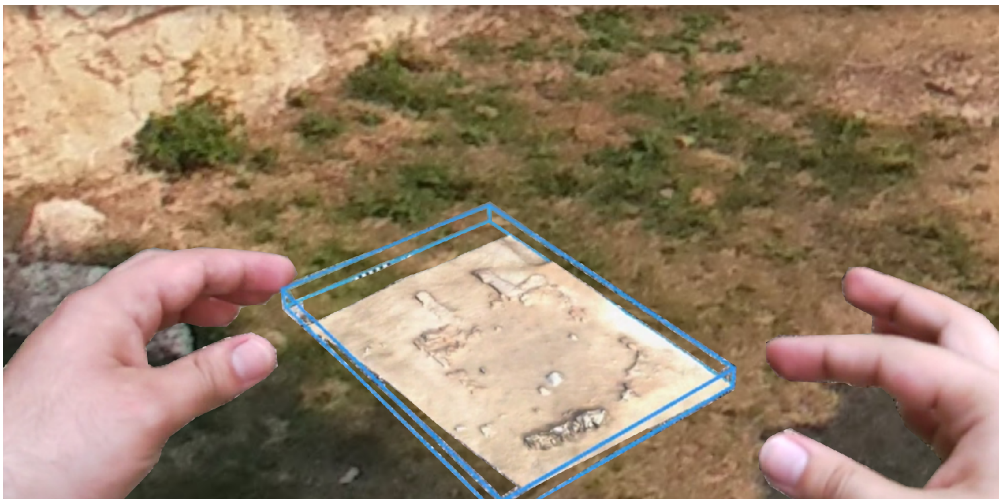


Figure 22. Excavation orthomap in 3D view Hololens II.

Through intuitive gesture controls, users can navigate through different components of the 3D model, switching between artifact views, layers, and even different sections of the site. This mode of interaction not only examines complex excavation data more easily but also significantly enhances the user experience by making it more engaging and interactive. Hololens II allows for shared viewing sessions where multiple users can simultaneously view and discuss the 3D model, regardless of their physical location. This feature is invaluable for collaborative reviews and decision-making processes involving teams of archaeologists, historians, and educators.

4.4. Mobile App and Hololens II Performance during Real-World Excavation Scenarios

The team physically visited the three distinct archaeological sites to test the application in real-world excavation circumstances and assess how well the technology functioned in real-world settings. During our extensive assessment of the smartphone app and Hololens II in authentic archaeological sites, the system proved to be remarkably effective and useful in a variety of circumstances. The incorporation of geolocation has emerged as the fundamental element of the system's capabilities, furnishing precise positioning information that is vital for the documention of archaeological sites. The tests and the respective results per site are presented in Table 7.

In the urban archaeological excavation scenario, the time spent navigating to artifacts is recorded at an average of 90 s. This was assessed over multiple test cases involving 30 distinct artifacts distributed across a simulated urban dig site. This metric highlights the application's streamlined navigation capabilities, significantly reducing the time typically required to locate artifacts between potential urban obstacles such as buildings and paved surfaces. The location accuracy deviation of ±2 cm from the designated point on the map underlines the high precision offered by the application's geospatial technology in urban settings, where such accuracy is critical due to the dense arrangement of potential finds. Furthermore, the on-site annotation completion rate of 85% was calculated based on the successful documentation of 43 out of 50 attempted entries, including notes, photographs, recordings, and videos directly in the field. This completion rate emphasizes the application's robustness in facilitating real-time data recording, enhancing the documentation process during excavations.

Table 7. Mobile app and Hololens II performance metrics.

Scenario	Key Metrics	Performance Evaluation
Urban	- Time spent navigating to artifacts: 90 s - Location accuracy deviation: ±2 cm - On-site annotation completion rate: 85%	- Navigation was quick and obstacles were managed efficiently. - High precision in artifact location pinpointing. - Annotation process was completed effectively in most cases.
Rural	- Time to collect data per artifact: 2 min - Stability of system under harsh conditions: 92% uptime - Accuracy of geospatial overlays: within 5% of satellite data	- Efficient data collection demonstrated under remote conditions. - System maintained high uptime even in challenging environments. - Geospatial overlays closely matched satellite data, confirming accuracy.
Collaborative	- Delay in data sharing between devices: <5 s - Team satisfaction score: 95%	- Near-instantaneous data sharing facilitated smooth collaboration. - High team satisfaction indicates effective collaborative tools and features.

For the rural archaeological site, the data collection time of 2 min per artifact, observed over a series of 35 artifacts, indicates the efficiency with which the application handles data in less-accessible, remote locations. This efficiency is crucial in rural excavations, where resources and time are often limited. The system's stability, recorded at 92% uptime during continuous operation under various harsh environmental conditions, demonstrates the application's reliability and resilience. The 92% system uptime was measured by monitoring the operational status of the application over a defined test period (6 h), typically during active fieldwork conditions. The accuracy of geospatial overlays, within 5% of the corresponding satellite data, was verified by comparing the application's data overlay with Google Maps, confirming the application's capability to produce accurate spatial analyses in varied terrains.

In the collaborative research project, the delay in data sharing between devices was less than 5 s, tested across 10 devices in the networked environment involving 10 team members sharing data simultaneously. This minimal delay ensures that information is swiftly and efficiently circulated among team members, facilitating effective collaboration. The team satisfaction score of 95%, derived from a survey of the participating members, reflects the high regard for the application's collaborative tools and overall system performance. This fact indicates strong user approval and the utility of the application in supporting team-oriented archaeological projects.

4.5. Discussion

4.5.1. Limitations

It is crucial to address the limitations of our application to provide a balanced view and outline potential areas for future development. One significant limitation is the application's specificity to classical and Byzantine archaeology, which inherently restricts its utility across other sub-disciplines of archaeology such as archaeozoology, archaeomalacology, and archaeobotany. The current configuration and functionalities of the app are tailored to the documentation and analysis of physical artifacts and excavation sites typical of these particular historical periods and do not directly support the specific data recording and analysis needs associated with the study of animal bones, shells, or plant remains found at archaeological sites.

Moreover, the application relies on the integration of advanced geospatial technologies and augmented reality, which, while providing enhanced user experience and data visualization, may not offer the sub-centimeter precision required for some specialized archaeological tasks. This precision issue is particularly pertinent when using the app's GPS functionalities based on standard mobile device capabilities, which may not meet the rigorous demands of all archaeological fieldwork scenarios. Additionally, the app's reliance on Google Maps and manually inserted geometric points, although innovative, may present challenges in regions with restricted Google services or in environments where high-resolution satellite imagery is not readily available or is out of date. These factors could potentially limit the app's effectiveness and accuracy in certain geographical areas.

4.5.2. Future Work

In the future, we aim to enhance archaeological excavation documentation and analysis. While our application has made significant strides in utilizing a mosaic of technologies, like geospatial technologies and augmented reality, for classical and Byzantine archaeology, there is considerable potential to expand its utility to other sub-disciplines within archaeology. To address this, future developments will focus on collaborating with field experts in archaeozoology, archaeomalacology, and archaeobotany. These collaborations are essential to adapt and extend the application's functionalities to accommodate the unique data requirements and analytical processes specific to these fields, such as the precise recording of organic material distributions and conditions at excavation sites.

Moreover, while our app currently offers innovative solutions for site mapping and data integration through Google Maps and manual point insertion, enhancing geolocation precision remains a priority. Future updates will explore the incorporation of more advanced GPS technologies that can provide sub-centimeter accuracy, which is necessary for detailed spatial analysis in complex archaeological excavations. This will involve not only technical upgrades but also adjustments to the application's interface and data processing algorithms to handle more precise geospatial data effectively.

Additionally, we plan to make the app more adaptable to various global regions, including those with limited access to Google services. This will require the development of alternative mapping solutions that can be integrated within the app, ensuring its functionality and reliability across different geographic and regulatory environments. By addressing these limitations and setting a clear roadmap for future enhancements, our application is poised to become a more versatile and indispensable tool in the field of archaeology.

The ongoing development of the app will continue to embrace novel technologies and methodologies, ensuring that it remains at the forefront of archaeological research tools. With sustained innovation and expert collaboration, our goal is to transform the app into a more generic platform that not only supports a broader range of archaeological disciplines but also sets new standards in archaeological data recording and analysis.

5. Conclusions

The integration of advanced geospatial technologies and augmented reality within archaeological excavations offers a revolutionary leap in how we understand and preserve our historical heritage. The capabilities of these digital tools to provide detailed, interactive, and accurate representations of excavation sites ensure that every artifact and feature can be meticulously recorded and analyzed. This not only enhances the precision and efficiency of archaeological research but also opens new pathways for educational and public engagement, making the wonders of ancient civilizations more accessible and comprehensible to a wider audience.

The suggested methodology involved the practical testing of a mobile app and Hololens II system across three distinct archaeological scenarios, urban excavation, rural sites, and collaborative projects, demonstrating the system's adaptability and efficiency. Overall, the field tests across different excavation scenarios highlight the system's capability to enhance archaeological excavations through accurate documentation, efficient data collection, and effective collaborative tools. The integration of geolocation has been pivotal, providing precise positioning crucial for documenting sites accurately and enhancing the overall excavation and documentation process.

The successful deployment of the mobile app and Hololens II system across three varied archaeological scenarios not only affirms the adaptability and operational excellence of our tools but also underscores the transformative impact of integrating advanced technologies in archaeological practices. By facilitating a high degree of precision and interactivity in documentation processes, these technologies empower archaeologists to achieve a deeper and more nuanced understanding of historical contexts. The ability to virtually reconstruct and analyze excavation sites through augmented reality enriches our interpretation of ancient cultures and offers unprecedented opportunities for immersive educational experiences. This enhances public engagement by allowing non-specialists and students to explore historical sites and artifacts in intuitive and informative ways, bridging the gap between expert knowledge and public curiosity.

Looking forward, the conclusions drawn from our field tests suggest significant potential for further refinement and expansion of the system's capabilities. The enhancement of offline functionalities, as previously mentioned, will be a crucial development. Additionally, future iterations will seek to integrate more robust data-handling capabilities to manage the large volumes of data generated during excavations. This includes advanced analytics tools to automatically generate insights and patterns from the collected data, thereby aiding in the hypothesis- and theory-testing phases of archaeological research. Moreover, by extending the system to include support for a broader range of archaeological sub-disciplines, such as paleoethnobotany or forensic archaeology, the application's utility could be significantly broadened.

In essence, the continuous development and refinement of our archaeological tools, guided by field feedback and technological advancements, will ensure that the discipline not only preserves the legacies of the past but also continues to innovate the ways in which these legacies are studied and shared. This proactive approach to adopting and integrating cutting-edge technologies within archaeological workflows exemplifies a forward-thinking mindset that is crucial for the evolution of the field in the digital age.

Author Contributions: Conceptualization, A.D., S.T., D.P. and C.-N.A.; methodology, A.D., S.T., D.P. and A.P.; software, A.D. and S.T.; validation, A.D., S.T., D.P. and A.P.; formal analysis, A.D., S.T., D.P., A.P., S.K., D.V. and C.-N.A.; investigation, A.D., S.T., D.P., A.P., S.K., D.V. and C.-N.A.; resources, A.D., S.T., D.P., A.P., S.K., D.V. and C.-N.A.; data curation, S.T. and C.-N.A.; writing—original draft preparation, A.D., S.T., D.P. and A.P.; writing—review and editing, A.D., S.T., D.P., A.P., S.K., D.V. and C.-N.A.; visualization, A.D., S.T., D.P., A.P., S.K., D.V. and C.-N.A.; supervision, A.D. and C.-N.A.; project administration, S.T; All authors have read and agreed to the published version of the manuscript.

Funding: This work is partially supported by the NERITES project, which is funded by the EU H2020 under grant agreement No. 101132575.

Data Availability Statement: All data used are available in the paper.

Acknowledgments: This work is partially supported by the NERITES project which is funded by the EU H2020 under grant agreement No. 101132575.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Psarros, D.; Stamatopoulos, M.I.; Anagnostopoulos, C.N. Information Technology and Archaeological Excavations: A Brief Overview. *Sci. Cult.* **2022**, *8*, 147–167.
2. Previtali, M.; Valente, R. Archaeological documentation and data sharing: Digital surveying and open data approach applied to archaeological fieldworks. *Virtual Archaeol. Rev.* **2019**, *10*, 17–27. [CrossRef]
3. Morgan, C. Current digital archaeology. *Annu. Rev. Anthropol.* **2022**, *51*, 213–231. [CrossRef]
4. Jebur, A.K. Uses and applications of geographic information systems. *Saudi J. Civ. Eng.* **2021**, *5*, 18–25. [CrossRef]
5. Brutto, M.L.; Meli, P. Computer vision tools for 3D modelling in archaeology. *Int. J. Herit. Digit. Era* **2012**, *1*, 1–6. [CrossRef]
6. Kansa, E.; Kansa, S.W. Digital data and data literacy in archaeology now and in the new decade. *Adv. Archaeol. Pract.* **2021**, *9*, 81–85. [CrossRef]
7. Nobles, G.R.; Roosevelt, C.H. Filling the void in archaeological excavations: 2D point clouds to 3D volumes. *Open Archaeol.* **2021**, *7*, 589–614. [CrossRef]
8. McCoy, M.D. The site problem: A critical review of the site concept in archaeology in the digital age. *J. Field Archaeol.* **2020**, *45*, S18–S26. [CrossRef]
9. McCoy, M.D. Defining the geospatial revolution in archaeology. *J. Archaeol. Sci. Rep.* **2021**, *37*, 102988. [CrossRef]
10. Vos, D.; Heeren, S.; van Ruler, N.; Smallenbroek, K.; Lassche, R. PAN (Portable Antiquities of the Netherlands): Harnessing Geospatial Technology for the Enrichment of Archaeological Data. *J. Geogr. Inf. Sci.* **2018**, *6*, 13–20. [CrossRef]
11. Rajani, M.; Dixit, S. Potential of geospatial technologies as a cognitive and spatio-visual tool for mapping the past. *Natl. Secur. Vivekananda Int. Found.* **2021**, *4*, 63–80.
12. Stylianidis, E.; Evangelidis, K.; Vital, R.; Dafiotis, P.; Sylaiou, S. 3D Documentation and visualization of cultural heritage buildings through the application of geospatial technologies. *Heritage* **2022**, *5*, 2818–2832. [CrossRef]
13. Rajani, M.; Dixit, S. Potential of Geospatial Technologies. *Natl. Secur.* **2021**, *4*, 73–92.
14. Poslončec-Petrić, V.; Vuković, V.; Bačić, Ž.; Kljajić, I. Use of Augmented Reality to Present Archaeological Contents. In Proceedings of the International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies, Tuzla, Bosnia and Herzegovina, 1–4 June 2023; Springer: Berlin/Heidelberg, Germany, 2023; pp. 186–194.
15. Ajili, L.; Louati, H.; Ben Ameur, F. Augmented Reality Coupled with Deep Convolution Neural Networks to Enhance Archaeological Sites Experience. In *New Trends in Intelligent Software Methodologies, Tools and Techniques*; IOS Press: Amsterdam, The Netherlands, 2023; pp. 97–108.
16. Dragoni, A.F.; Quattrini, R.; Sernani, P.; Ruggeri, L. Real scale augmented reality. A novel paradigm for archaeological heritage fruition. In *Proceedings of the 1st International and Interdisciplinary Conference on Digital Environments for Education, Arts and Heritage: EARTH 2018 1*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 659–670.
17. Varinlioglu, G.; Halici, S.M. Gamification of Heritage through augmented reality. *Ecaade Sigradi* **2019**, *1*, 513–518.
18. Marto, A.; Gonçalves, A.; Martins, J.; Bessa, M.C. Applying UTAUT Model for an Acceptance Study Alluding the Use of Augmented Reality in Archaeological Sites. In Proceedings of the VISIGRAPP (2: HUCAPP), Prague, Czech Republic, 25–27 February 2019; pp. 111–120
19. Barrile, V.; Fotia, A.; Ponterio, R.; Mollica Nardo, V.; Giuffrida, D.; Mastelloni, M. A combined study of art works preserved in the archaeological museums: 3D survey, spectroscopic approach and augmented reality. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *42*, 201–207. [CrossRef]
20. Karaarslan, S.V. Application of augmented reality technologies in archaeology. *Engl. Artic.* **2018**, *2018*, 181–200.

21. Faniel, I.M.; Austin, A.; Kansa, E.; Kansa, S.W.; France, P.; Jacobs, J.; Boytner, R.; Yakel, E. Beyond the archive: Bridging data creation and reuse in archaeology. *Adv. Archaeol. Pract.* **2018**, *6*, 105–116. [CrossRef]
22. Henninger, M. From mud to the museum: Metadata challenges in archaeology. *J. Inf. Sci.* **2018**, *44*, 658–670. [CrossRef]
23. Kansa, S.W.; Atici, L.; Kansa, E.C.; Meadow, R.H. Archaeological analysis in the information age: Guidelines for maximizing the reach, comprehensiveness, and longevity of data. *Adv. Archaeol. Pract.* **2020**, *8*, 40–52. [CrossRef]
24. May, K.; Taylor, J.S.; Binding, C. Stratigraphic Analysis and The Matrix: Connecting and reusing digital records and archives of archaeological investigations. *Internet Archaeol.* **2023**, *61*, 64. [CrossRef]
25. Lercari, N.; Shiferaw, E.; Forte, M.; Kopper, R. Immersive visualization and curation of archaeological heritage data: Çatalhöyük and the Dig@ IT App. *J. Archaeol. Method Theory* **2018**, *25*, 368–392. [CrossRef]
26. admin. Innovation in Archaeological Documentation Methods. Available online: https://mycoordinates.org/innovation-in-archaeological-documentation-methods/ (accessed on 18 September 2023).
27. admin. Principal Archaeological Applications. Available online: https://ebrary.net/205884/geography/principal_archaeological_applications (accessed on 19 September 2023).
28. Georgiadis, C.; Tsioukas, V.; Sechidis, L.; Stylianidis, E.; Patias, P. Fast and accurate documentation of archaeological sites using in the field photogrammetric techniques. *Int. Arch. Photogramm. Remote Sens.* **2000**, *33*, 28–32.
29. iDig. Available online: https://idig.tips/ (accessed on 19 September 2023).
30. Montagnetti, R.; Guarino, G. From qgis to qfield and vice versa: How the new android application is facilitating the work of the archaeologist in the field. *Environ. Sci. Proc.* **2021**, *10*, 6. [CrossRef]
31. Masson-MacLean, E.; O'Driscoll, J.; McIver, C.; Noble, G. Digitally recording excavations on a budget: A (low-cost) DIY approach from Scotland. *J. Field Archaeol.* **2021**, *46*, 595–613. [CrossRef]
32. Lindsay, I.; Kong, N.N. Using the ArcGIS collector mobile app for settlement survey data collection in Armenia. *Adv. Archaeol. Pract.* **2020**, *8*, 322–336. [CrossRef]
33. De Roo, B.; Stal, C.; Lonneville, B.; De Wulf, A.; Bourgeois, J.; De Maeyer, P. Spatiotemporal data as the foundation of an archaeological stratigraphy extraction and management system. *J. Cult. Herit.* **2016**, *19*, 522–530. [CrossRef]
34. Roosevelt, C.H.; Cobb, P.; Moss, E.; Olson, B.R.; Ünlüsoy, S. Excavation is destruction digitization: Advances in archaeological practice. *J. Field Archaeol.* **2015**, *40*, 325–346. [CrossRef]
35. Smith, N.G.; Levy, T.E. ArchField in Jordan: Real-time GIS data recording for archaeological excavations. *Near East. Archaeol.* **2014**, *77*, 166–170. [CrossRef]
36. Tripcevich, N.; Wernke, S.A. On-site recording of excavation data using mobile GIS. *J. Field Archaeol.* **2010**, *35*, 380–397. [CrossRef]
37. Katsianis, M.; Tsipidis, S.; Kotsakis, K.; Kousoulakou, A. A 3D digital workflow for archaeological intra-site research using GIS. *J. Archaeol. Sci.* **2008**, *35*, 655–667. [CrossRef]
38. Pradeep, A.; Paracha, M.T.; Bhowmick, P.; Davanian, A.; Razaghpanah, A.; Chung, T.; Lindorfer, M.; Vallina-Rodriguez, N.; Levin, D.; Choffnes, D. A comparative analysis of certificate pinning in Android & iOS. In Proceedings of the 22nd ACM Internet Measurement Conference, Nice, France, 25–27 October 2022; pp. 605–618.
39. AL-atraqchi, O.M. A Proposed Model for Build a Secure Restful API to Connect between Server Side and Mobile Application Using Laravel Framework with Flutter Toolkits. *Cihan Univ.-Erbil Sci. J.* **2022**, *6*, 28–35. [CrossRef]
40. Bähr, S.; Haas, G.C.; Keusch, F.; Kreuter, F.; Trappmann, M. Missing data and other measurement quality issues in mobile geolocation sensor data. *Soc. Sci. Comput. Rev.* **2022**, *40*, 212–235. [CrossRef]
41. Nielsen, K.E.; Mejía, S.T.; Gonzalez, R. Deviations from typical paths: A novel approach to working with GPS data in the behavioral sciences. *Int. J. Health Geogr.* **2022**, *21*, 5. [CrossRef] [PubMed]
42. Park, S.; Bokijonov, S.; Choi, Y. Review of microsoft hololens applications over the past five years. *Appl. Sci.* **2021**, *11*, 7259. [CrossRef]
43. Nieminen, T. Unity Game Engine in Visualization, Simulation and Modelling. Bachelor's Thesis, Tampere University, Tampere, Finland, 2021.
44. How to Do an Excavation. Available online: https://www.athinodromio.gr/%CF%80%CF%8E%CF%82-%CE%BA%CE%AC%CE%BD%CE%BF%CF%85%CE%BC%CE%B5-%CE%BC%CE%B9%CE%B1-%CE%B1%CE%BD%CE%B1%CF%83%CE%BA%CE%B1%CF%86%CE%AE-2/ (accessed on 11 May 2024).
45. Technologies, U. Unity-Manual: Practical Guide to Optimization for Mobiles. Available online: https://docs.unity3d.com/2020.1/Documentation/Manual/MobileOptimizationPracticalGuide.html (accessed on 11 May 2024).
46. Biggs, J. You Can Now Use Your Cellphone as a 3D Modeling Tool | TechCrunch. Available online: https://techcrunch.com/2015/04/01/you-can-now-use-your-cellphone-as-a-3d-modeling-tool/?guccounter=1&guce_referrer=aHR0cHM6Ly9lZGdlc2VydmljZXMuYmluZy5jb20v&guce_referrer_sig=AQAAALvXV663Xid78FISxffFO4X9EiBxkzdFthIUenSOnn41KixSXEN5_hPpjV6JOEHMSov7Q42aeBLzPbcTHwy3HMqq90xQRFu7taeSIt8UHSoSLZ9OTTcHNwU8noPs-hUun6-HBLeuBU36wwcz0R2X5HBnM1Y4ZiobfqWKDQPaunpj (accessed on 11 May 2024).