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Smart Eye: An Application for *In Situ* Accessibility to "Invisible" Heritage Sites

CASE STUDY

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ABSTRACT

The Smart Eye Application is an augmented reality app for mobile devices that enables the in-situ 3D visualization of underground and inaccessible to the public archaeological sites and monuments.

Accessibility to excavated archaeological sites and monuments is often hindered for reasons of preservation or urban development. Portable finds are transferred and, in some cases, exhibited in local museums, but the non-portable remains of ancient structures become eventually effaced from the landscape and the collective memory of local communities. The Smart Eye app provides an "x-ray" type view of excavation sites that have been backfilled and are now invisible. While common practice in heritage sites' digital dissemination to the general public uses 2D or 3D reconstructions in augmented or virtual reality environments, the Smart Eye app presents archaeological remains in the shape and form they were found in by archaeologists supplemented with augmented reality markers that provide simplified textual and visual information aimed toward a non-scholarly public. The aim is to re-instate these heritage sites into the interactive relationship that people have with their landscape and their history.

The present paper discusses the chaîne-opératoire of developing the app, from the acquisition of primary documentation data of the excavation sites to the methodology used for the production of the 3D models of the archaeological sites and the development of the app itself and the technical equipment used. Finally, we discuss the results of the preliminary evaluation of the application and future steps to improve it before final testing by the local communities where the archaeological sites are located.

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1. INTRODUCTION

The Smart Eye Application presented in this paper is an augmented reality app for mobile devices that enables the *in-situ* 3D visualization of underground archaeological sites and monuments that are inaccessible to the public.

Physical accessibility to excavated archaeological sites (i.e., any site where archaeological remains have been identified) and monuments is a prerequisite for the public to enjoy it (Grima, 2017). However, accessibility is often hindered for reasons of preservation or urban development. Many archaeological sites are backfilled and, especially in urban areas, given over to other uses, such as public parks, roads, or buildings. Portable finds from these sites are transferred and, in some cases, exhibited in local museums, but the non-portable remains of ancient structures (architectural remains and other features, such as burial structures) become eventually effaced from the landscape and the collective memory of local communities.

Yet, making these sites accessible to the public, and especially to local communities, is highly important as they preserve the material remains of local history and identity, linking people with their land and past. When physical accessibility, however, is severed, digital dissemination is perhaps the only efficient means for making such "invisible" archaeological sites once again accessible to the public.

Since 2000 digital dissemination of heritage sites is increasingly found as an added feature to already public heritage sites and museums aiming to enhance the experience of visitors (Grima, 2017; Bekele et al., 2018; Bekele & Champion, 2019; Liang, 2021). Over the last decade, however, cultural heritage institutions have started to move from the interface of a 2D screen to the more realistic 3D environment of immersive technologies, that is augmented reality (AR), virtual reality (VR), and mixed reality (MR). Augmented reality is used to enhance our perception of the real world by anchoring digital content (text, images, video, and/or 3D models) within the physical world (Azuma, 1997). While in AR and MR users can interact with the digital content in real time, in VR users are transported to a totally virtual environment, without any or little contact with the physical world (Carmigniani et al., 2011; Bekele et al., 2018; Bekele & Champion, 2019).

The Smart Eye application is an augmented reality application wherein users can see the 3D model of an "invisible" excavated archaeological site beneath their feet. There are already two things in this description of the Smart Eye app that differentiate it from other similar apps. The vast majority of immersive technology cultural heritage applications have been developed for archaeological sites and monuments that are visible and physically accessible to the public. Most commonly, further, their content includes 3D reconstructions of how the archaeological sites and monuments would have looked like or would have been used during distinctive moments of their biography (see, for example, Vlahakis et al., 2001; Vlahakis et al., 2002; Reilly et al., 2006; Schöning, Krüger & Müller, 2006; Paelke & Sester, 2010; Eggert, Hücker & Paelke, 2014; Pierdicca et al., 2015; Galatis et al., 2016; Pierdicca et al., 2016; Morandi & Tremari, 2017; Pedersen et al., 2017; Bekele et al., 2018; Bruno et al., 2019; Dragoni et al., 2019; Liritzis, Volonakis & Vosinakis, 2021). Applications for non-accessible sites and monuments are limited in number and they too provide 3D reconstructions of the "invisible' antiquities they promote (Capone, 2011; Martínez et al., 2015; Pierdicca et al., 2015; Unger & Kvetina, 2017). The reasons behind the reluctance of developing immersive applications for "invisible" sites can be found in the difficulty of creating 3D digital content from legacy data (that is, documentation data collected with traditional methods), the partiality of the remains that renders them incomprehensible when viewed by the public without the interpretive mediation of expert archaeologists, and the complexity of the stratigraphy and the architectural setup of the archaeological remains when multiple building phases intersect each other in the same site (Capone, 2011; Martínez et al., 2015; Rösch, 2021).

The Smart Eye application, on the contrary, recreates in an Augmented Reality environment the experience of an archaeological site as the latter was discovered by archaeologists and as it would have been presented to the public if it had been physically accessible. The experience of the visit is enhanced with AR pop-up markers that provide simplified textual and visual information suitable to a non-scholarly public to interpret and contextualize (understand the wider historical context) the remains featured. The aim, thus, of the Smart Eye app is to re-instate these "invisible" heritage sites into the interactive relationship that people have with their landscape and their history by providing an "x-ray" type view of the antiquities that lie beneath the ground.

The present paper presents the chaîne-opératoire of developing the Smart Eye app, from the acquisition of primary documentation data of the excavation sites (legacy and three-dimensional) to the methodology used for the production of the 3D models of the archaeological sites to the development of the app itself and the technical equipment used. Finally, we discuss the results of the preliminary evaluation of the application and future steps to improve it before final testing by the local communities where the archaeological sites are located.

2. THE ARCHAEOLOGICAL SITES USED AS CASE STUDIES FOR SMART EYE

The Smart Eye system is implemented and tested at a variety of heritage sites in Northern Greece, namely at the archaeological site of Thessaloniki Toumba, in Thessaloniki, and at four sites in the town of Thermi, near Thessaloniki (Figure 1).

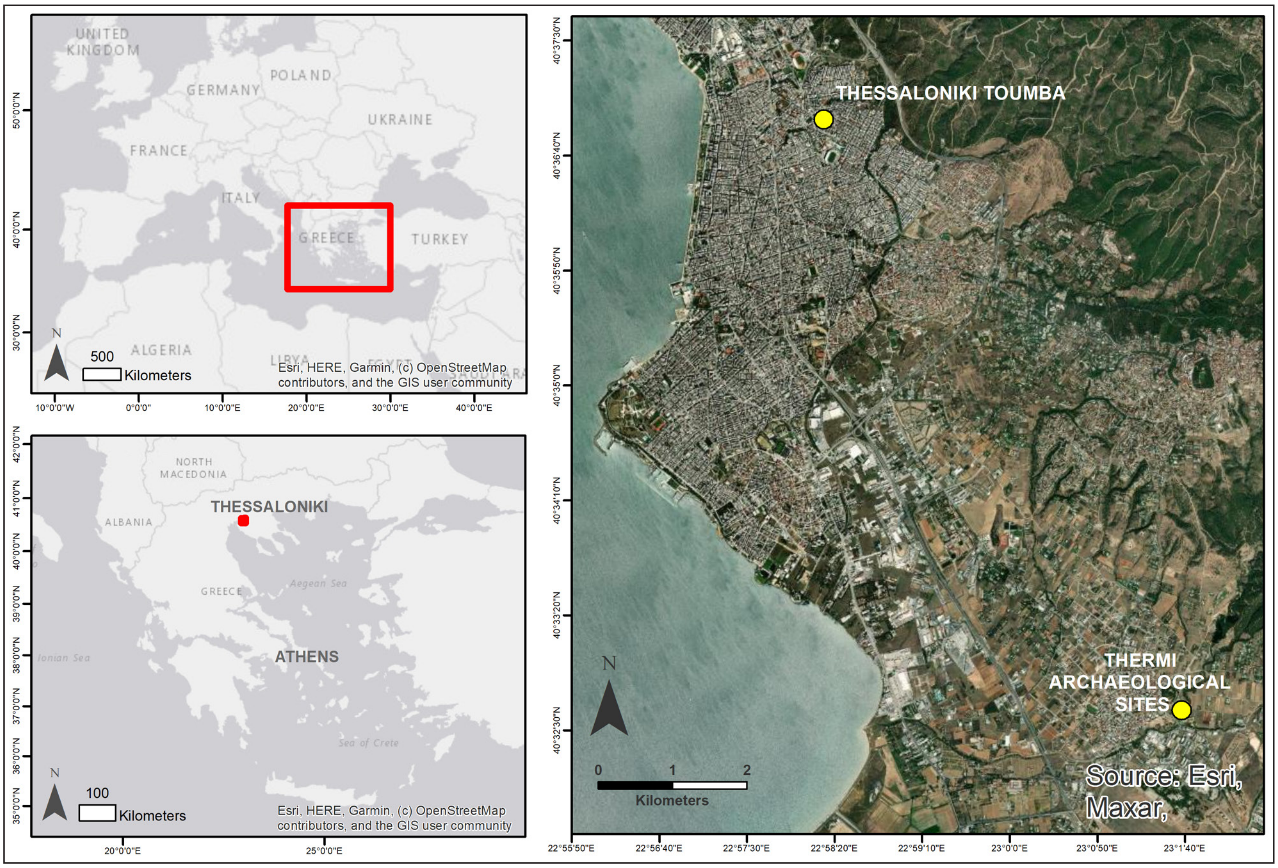

Figure 1 The location of the archaeological sites integrated into the Smart Eye prototype system.

The archaeological site of Thessaloniki Toumba (Figure 2) is currently being investigated by the School of History and Archaeology at the Aristotle University of Thessaloniki. The site is a Bronze Age mound settlement, characteristic of which is the intentional rebuilding of houses and streets on the same restricted location (at the top of a natural rise), each time directly above the remains of the previous settlement phase (Andreou, 2010; Andreou, 2019; Andreou, Triantaphyllou & Efkleidou, 2022). The site is presently covered with a temporary shelter and inaccessible to the public to avert the deterioration of structural remains.

The archaeological sites in the town of Thermi, Prefecture of Thessaloniki, are all located within the urban grid (Figure 3). After their investigation by the Ephorate of Antiquities of Thessaloniki Region, all sites were backfilled and given over to urban development. The sites include an Iron Age to Classical period settlement at the table (locally known as Trapeza) of Thermi, part of the Hellenistic settlement of Thermi, part of the Roman period cemetery of Thermi, and part of the Byzantine era settlement of Thermi.

The settlement at Thermi Table was established at the end of the 9th century BC. The settlement was continuously repaired and rebuilt within the limits of the original habitation and on top of the remains of earlier structures. This process resulted in the formation of a multi-phase flat-topped partially artificial mound of ca. 18 m in height (Skarlatidou, Stagkos & Touloumtzidou, 2015). The site of the table-top has now been converted into a park. Occupational remains (a large storage space with seven pithoi standing in situ) dating to the same period were also located at the foothills of the nearby Bronze Age mound (locally known as Toumba) (Pappa et al., 2019).

Among the sites integrated into the Smart Eye system are also the site of a Hellenistic period farmstead (Skarlatidou, 2016), part of the Byzantine period (late 12th–early 13th centuries AD) settlement with remains of partially preserved walls and a stone-covered terrasse (Pappa et al., 2019), and part of the Late Roman period (late 2nd–4th centuries AD) cemetery. The latter comprises predominantly of pit graves covered with stones and/or schist slabs containing few grave goods (three or four ceramic vessels at most and occasionally a coin or other artefacts) (Pappa, Vliora & Nanoglou, 2018).

The sites were chosen for the prototype Smart Eye app based on the type, quantity, and quality of their documentation data, the variety of preserved remains, and the presence or lack of multiple habitation phases. The aim was to allow Smart Eye researchers to address a wide range of issues concerning the quantity and quality of the archaeological data necessary for the implementation of the Smart Eye app's content and the different types of data required and curated in the AR platform.

In fact, all sites have been documented with traditional means and methods (terrestrial photography and hand-drawn 2D maps and sections of deposits and features preserved in situ). This legacy-type data required the preparation of a protocol for their acquisition, selection,

Figure 2 The archaeological site of Thessaloniki Toumba, in Thessaloniki, Northern Greece (Photo by J. Apostolou; Courtesy of Thessaloniki Toumba excavation archive).

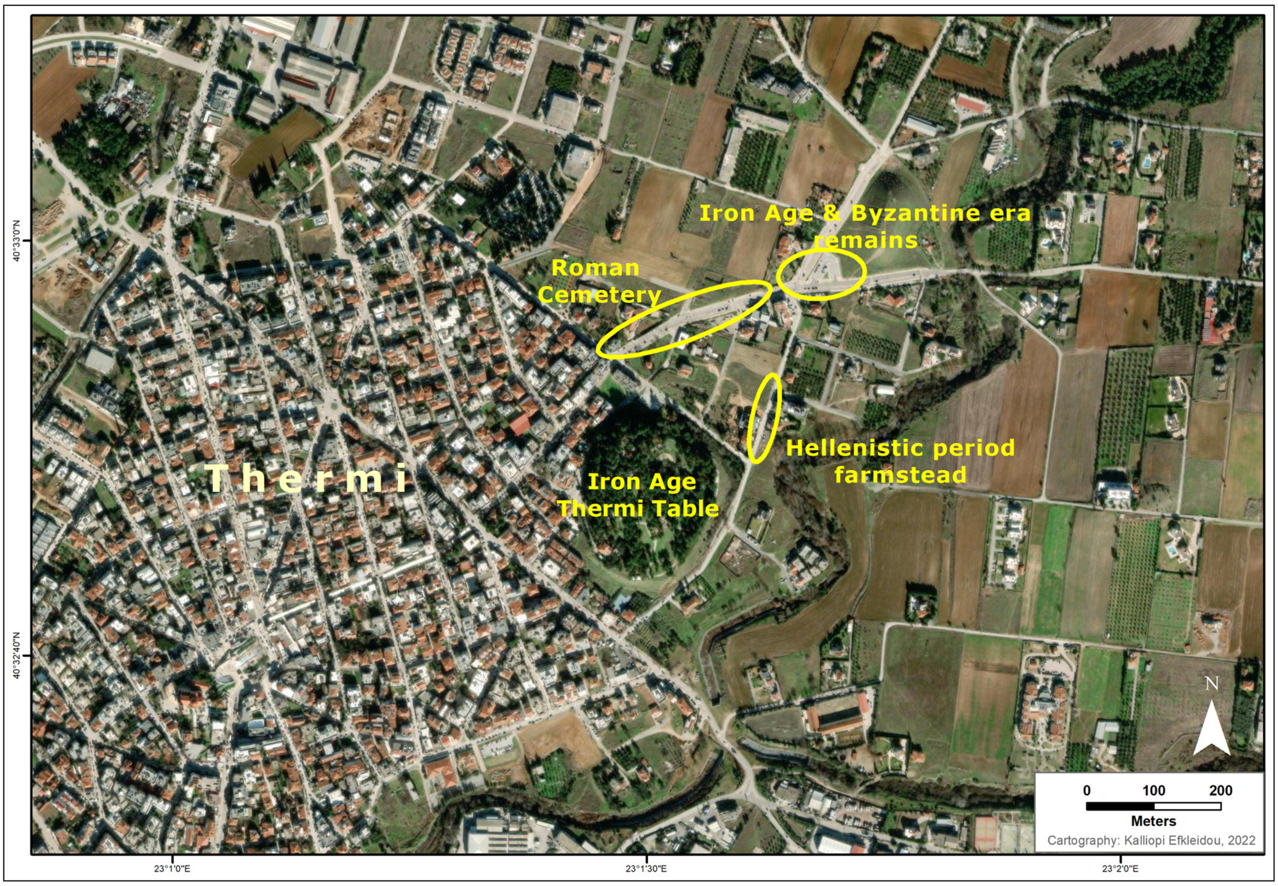

Figure 3 Map of the archaeological sites in Thermi, Northern Greece.

and transformation into a format that can be integrated into an AR system.

Thessaloniki Toumba was additionally chosen because part of it is still under investigation. There, 3D documentation methods are being implemented (photogrammetry, laser scanners, and UAVs) producing highly accurate, cost-effective, and relatively intuitive 3D models of the excavated space and features.

Furthermore, most sites at Thermi are flat with remains extending over a single habitation period but the sites of Thermi Table and Thessaloniki Toumba are artificial mound settlements, where deposits of multiple superimposed habitation phases have been located. At the flat sites, a singular 3D model of the excavated space is projected onto the visitors' screen. At the artificial mound settlements, however, a different 3D model needs to be projected for each habitation phase of the excavated space providing visitors with the ability to explore the sites over two planes: the horizontal (geographical — where all remains shown are synchronous to each other) and the vertical (chronological — where the user can stand in the same place and explore a different 3D model for each habitation phase of the site in chronological order).

3. THE SMART EYE SYSTEM IMPLEMENTATION

The Smart Eye system consists of three parts: the acquisition and suitable transformation of the primary archaeological data into 3D models, the implementation of a content management system based on Web GIS technology to store and organize all the information (3D models and information for the AR hotspots), and the mobile application design and development featuring an AR environment and a 2D Web-GIS component.

3.1 PRIMARY ARCHAEOLOGICAL DATA

As mentioned already, from the onset of the Smart Eye research project's design, it was decided to use both legacy and real-time 3D excavation documentation data.

3.1.1 Legacy data acquisition and adaptation

The term "legacy data" refers to excavation documentation data produced and collected or captured without the use of technology that is available today after the digital revolution and/or without having any prior insight into their subsequent use in producing 3D models of the excavated space (Allison, 2008). This is the type of documentation available from the vast majority of rescue and systematic excavations to date in Greece. The protocols followed in this case often prove lacking in the accuracy or the level of detail necessary for the production of accurate 3D models of archaeological features (Efkleidou et al., in press).

The legacy data from the sites integrated into the Smart Eye app consist of ca. 150 hand-drawn trench top plans and sections, more than 2000 photographs (analogue or digital depending on the date captured) and textual documentation (excavation diaries and reports). The procedure of making the legacy data operational involved first their digitalization (through scanning in high-resolution raster format) and then their digitization in a format that could be subsequently translated into 3D. Digitization was performed in CAD software, where all hand-drawn features were traced into vector geometric graphics (points, lines, and closed polygons) and classified in different layers according to feature type, function, and material (details of the procedure can be found in Kaimaris et al., 2022; Efkleidou et al., in press) (Figure 4). The procedure resulted in the production of 16 habitation phase top plans for the site of Thessaloniki Toumba and 13 habitation top plans for the sites around Thermi.

3.1.2 Real-time 3D data acquisition

Real-time 3D data, as mentioned above, were obtained during two excavation campaigns at the site of Thessaloniki

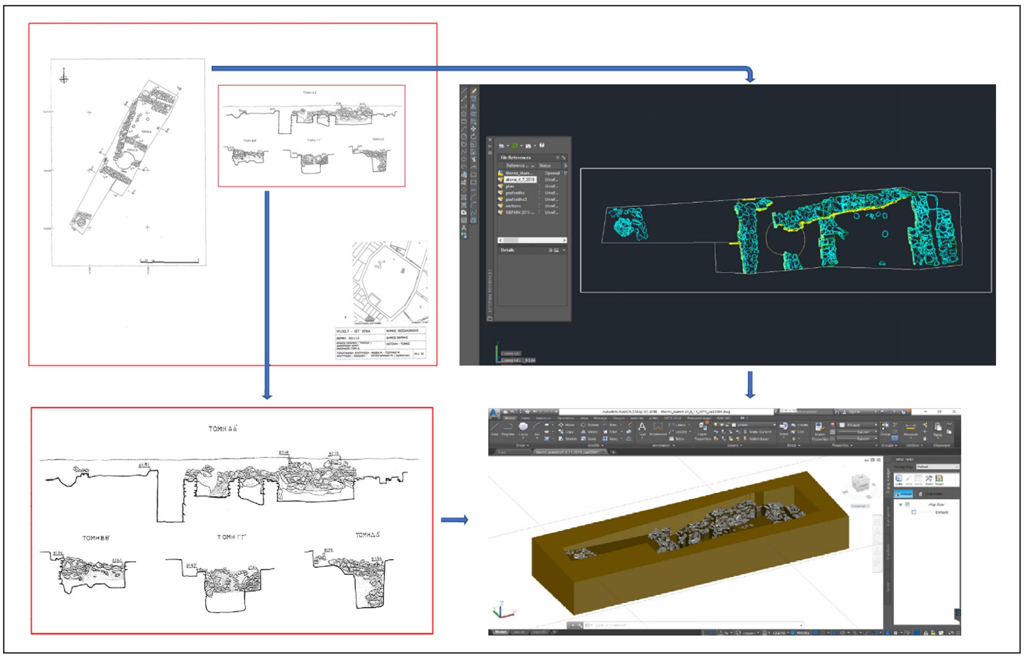

Figure 4 The transformation of the 2D legacy top plans and sections (top and bottom left) into 2D CAD drawings (top right) and finally into 3D models of the excavated archaeological sites in 3ds MAX (bottom right) for the Smart Eye app.

Toumba (2019 and 2021). Different 3D documentation techniques were tested to ascertain labour and time-cost effectiveness, as well as the size and quality of the final product (cf. Galeazzi, 2016; Ferdani et al., 2019; for a comparison between the techniques used at Thessaloniki Toumba, see Stamnas et al., 2021). The first technique involved the use of a laser scanner; the second technique involved structure-from-motion (SfM) photogrammetry using a custom-made Unmanned Aerial Vehicle (UAV) and a hand-held digital camera (Figure 5).

3.2 THE PRODUCTION OF 3D MODELS FOR THE AR APPLICATION

The procedure of transforming the digitized top plans into 3D models took place in Autodesk 3ds Max© software. The 2D vector features were extruded and their geometry was modified or smoothed using the re-topology tools available in the software based on the shape of the features and the elevation data provided in the top plans produced during excavation (Figure 4).

Lack of sufficient or suitably rendered information on the shape (concavities, weathering, or erosion) or the elevation fluctuations on the surfaces of archaeological features was commonly observed in the 2D top plans. To achieve better accuracy in the 3D models, we increased the density of elevation information by making optimal use of textual descriptions and photographs available in the excavation archives.

3D texturing was based on sample images taken from various objects, surfaces, and archaeological features in the field and applied to the surfaces of corresponding features in the models of the excavated spaces. The result reached a high level of accuracy and photorealism. In total, we produced 10 three-dimensional models of an equal number of excavated habitation phases for the site of Thessaloniki Toumba and 13 models for the sites of Thermi which are gradually being integrated into the Smart Eye prototype system (Figure 6).

The 3D models captured in the field with laser scanners or photogrammetric techniques do not need any adaptation before they are integrated into the AR application. We produced 20 models of the excavated space at Thessaloniki Toumba during the course of the excavation but only six were integrated into the Smart Eye app, as differences with the rest were minimal (owing to the progress of the excavation) and not always meaningful.

3.3 THE CONTENT MANAGEMENT SYSTEM

A Content Management System (CMS) with the ability to manage geographical information was designed to support all the storage and processing needs of the Smart Eye system. The CMS was designed and developed on top of a GIS Subsystem that consists of a central geodatabase, to store the primary archaeological documentation data, integrated with a content management infrastructure to store 3D models and multimedia data used in the mobile AR application. Two sets of geospatial point data were also included in the GIS Subsystem's geodatabase attached with attributes that provide visitors with information relevant to the archaeological sites and their history (info-points) or to particular features and artefacts recovered from these sites (hotspots). The user interface of the CMS component was provided to the data management team to organize and maintain content.

3.4 THE MOBILE WEB-GIS COMPONENT

Based on the CMS and the content, a Web-GIS user interface was implemented allowing visitors to view the archaeological site and its wider region as a 2D map with point markers indicating the location of available AR models and info-points (Figure 7). Visitors can then use this interface to navigate the site before they turn to the AR application interface and start interacting with the AR model of the excavated site and the AR hotspots already mentioned.

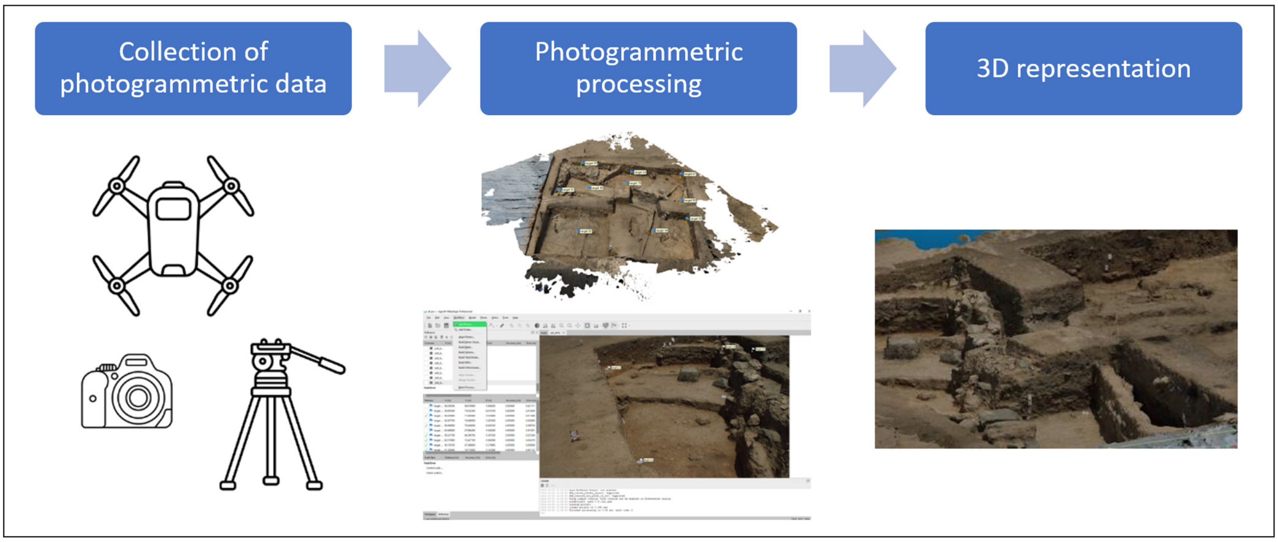

Figure 5 The process of 3D documentation and modelling of the excavation at Thessaloniki Toumba.

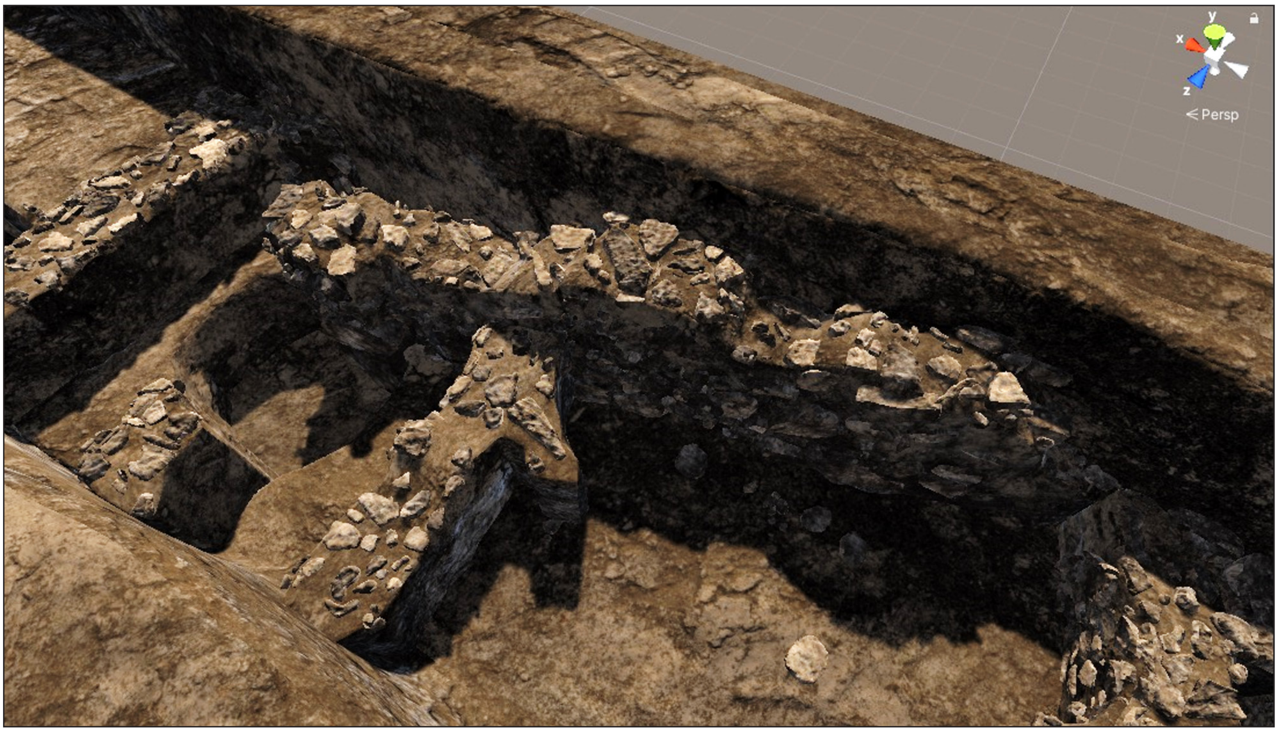

Figure 6 The final textured 3D model of an excavation trench at the archaeological site of Thermi Table.

Figure 7 The Smart Eye system's Web GIS user interface.

3.5 THE MOBILE AR COMPONENT

The Smart Eye AR component was implemented in the Unity 3D game engine, where all 3D models of the archaeological sites produced in 3ds Max were imported as .fbx files. Apart from the 3D models, the info-points and hotspots stored in the Smart Eye geodatabase were also imported into the renderer as a point-cloud file.

The AR component is designed to constantly "read" the location of visitors so that once they approach a site integrated into the Smart Eye system, AR digital markers come up on the screen of the mobile device indicating the location of info-points, 3D models, and hotspots. Visitors can then walk towards these markers and energise them to see their content (Figure 8).

When visitors select the AR functionality of the app, the system dynamically "reads" the direction and angle of the mobile device sensors and brings on the screen the part of the modelled archaeological site that lies in front and beneath the feet of the visitor (Figure 9). A square grid surface on top of the 3D models in the AR interface assists users to gain a better understanding of the depth at which antiquities lie while simulating a walking surface (much like a glass floor) that prevents viewers from having the impression of walking in mid-air (Figure 10).

While visitors immerse themselves in the AR model of the archaeological sites and explore their different features, AR markers come up indicating the location of hotspots. These hotspots represent locations where features and artefacts of interest have been found during excavations. When these markers are selected by users, a pop-up window appears on the screen of the mobile device providing information, such as multimedia files (photographs, drawings, or videos) and a textual description of the relevant feature or artefact, aimed at enhancing the learning outcomes of the visit. More than 400 points of interest will be added to the AR system for the site of Thessaloniki and approximately 200 points for the archaeological sites of Thermi (Figure 11).

At archaeological sites where multiple habitation phases have been excavated (i.e., at Thessaloniki Toumba), visitors are also given the ability to choose the habitation phase or chronological period they want to explore based on their interests or the progress of their visit.

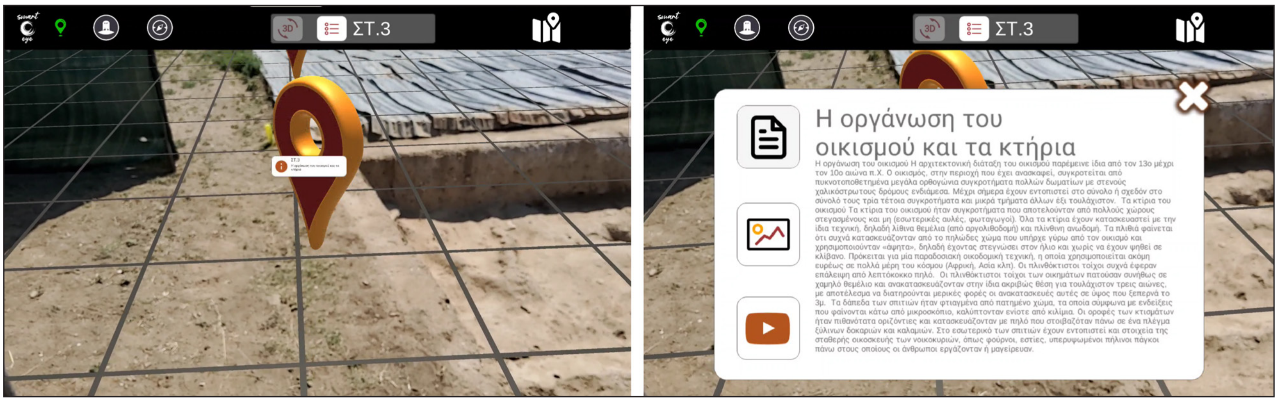

Figure 8 The Smart Eye system's AR interface with AR markers showing the location of info-points and 3D models (left) and the pop-up window displaying textual or media information when an info-point AR marker is selected (right).

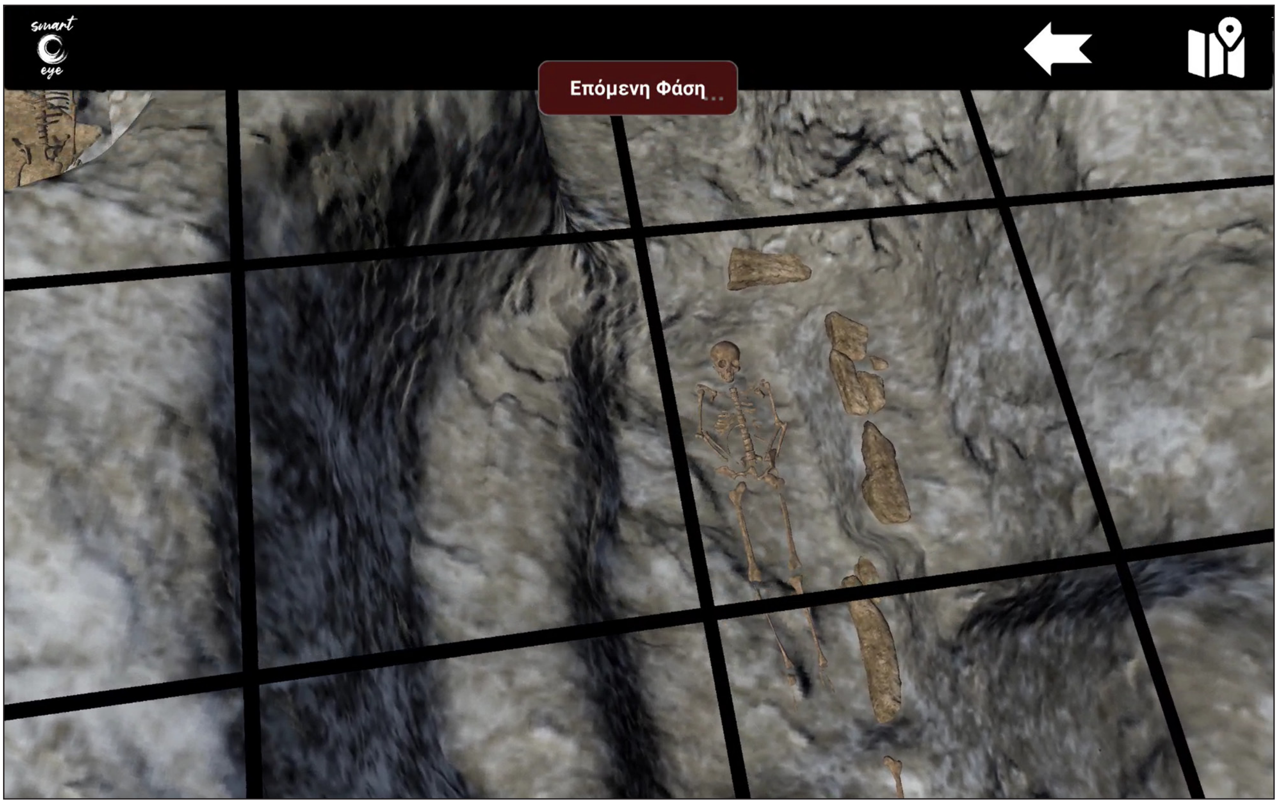

Figure 9 The view of the 3D model of the Late Roman cemetery excavated at Thermi as the screen of the mobile device is turned towards the ground in front of the visitor's feet.

Figure 10 The integration of a square grid surface above the 3D model of the excavated space at Thessaloniki Toumba in the Smart Eye system.

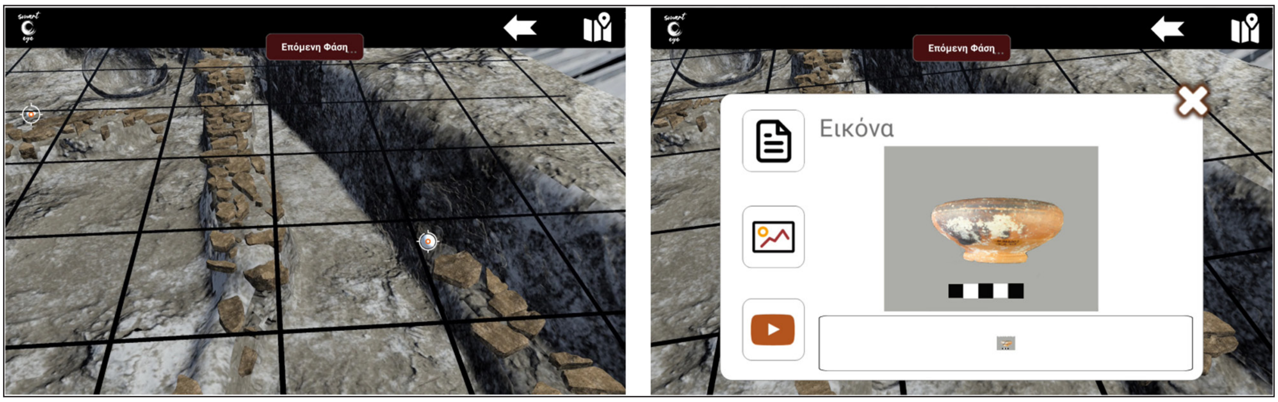

Figure 11 The AR markers in the 3D model of the excavated space at Thessaloniki Toumba showing the location of hotspots (left) and the pop-up window (right) that appears when AR hotspots are energised.

4. DISCUSSION

The Smart Eye mobile application has been tested multiple times in the lab to detect and resolve technical and content-related problems. There have been two field evaluations, further, for which members of the Smart Eye research team were invited to participate with the aim to test the application's effectiveness and user satisfaction. Participants (9 individuals) included engineers and archaeologists who had not been involved in the mobile application's development (software and hardware design and development, coding, etc.) and represent non-expert users (either in terms of cultural heritage knowledge or in terms of computer and technical expertise). Each time, participants were introduced to the functions of the application (interface, menus, capabilities) and then asked to complete two questionnaires associated with specific tasks, and provide answers regarding the application's efficiency and effectiveness as well as user experience. Participants were left free to access and explore the archaeological sites using the Smart Eye application at their own pace and according to their personal interests. As a result, different participants followed different paths in their exploration and spent different amounts of time over various areas and features of the archaeological sites.

During both trials, it was made evident that the accuracy of the in-built devices' sensors (location, angle, direction) could not sufficiently meet the needs of the Smart Eye app users. Location accuracy lies within the range of six to seven meters. Similar errors are present in magnetometer sensors on mobile devices resulting in the AR models "moving" in different directions as visitors move around.

The issue of location accuracy has been overcome since the evaluation by using u-blox technology to develop new and improved software and hardware for an external unit that improved user-location determination to an error margin of ca. 5 cm. The issue of the magnetometer sensors' accuracy remains under investigation.

Other problems identified involved the small size of the fonts used for the informational texts at info-points and hotspots and distortions in the projection of images of artefacts and other archaeological features. Besides these easily amended issues, one out of three users noted the need for "clearer 3D models". This is an issue related to the 3D rendering of the 3D models and the display contrast on the mobile devices' screen under different ambient light conditions rather than the level of resolution in the 3D models. The Smart Eye development team is currently experimenting with different brightness settings for the devices' screen and illumination settings in the 3D models to address the issue.

Other than the issues reported, participants in the evaluation demonstrated positive feelings towards the quality of their visit to the archaeological sites and the effectiveness and efficiency of the Smart Eye system, although one participant noted that some time was necessary for the users to get accustomed to the use of the app and the AR environment. Participants became acquainted with the archaeological sites' overall history and the archaeological remains that were visible on their screen as they walked through the sites.

The results of these preliminary evaluations are currently being addressed by the Smart Eye research team to finalize the app for its evaluation by the general public estimated to take place in the Spring of 2023.

5. CONCLUSIONS

Cultural heritage management institutions have a duty towards both the investigation and preservation of cultural heritage and the education of the public concerning its history and cultural background. Cultural education, however, should not take place only in the organised and controlled environment of a museum or an archaeological site where antiquities are physically accessible. We also need to consider those numerous heritage sites that remain at present "invisible" and inaccessible for reasons of heritage conservation or urban development, because these sites preserve equally important parts of the history and culture of respective regions and communities.

In the case of physically inaccessible sites, the only way to make them "accessible" again is to use digital methods and means, such as augmented or virtual reality applications (Grima, 2017). The Smart Eye app presented here targets exactly this type of "invisible" heritage site. Unlike most immersive technology applications which use 3D reconstructions of archaeological sites and monuments, the Smart Eye app demonstrates 3D models true to the remains' state of preservation at the time of their excavation. The use of accurate 3D models of the ancient remains was an intentional choice as it was considered best to familiarize the public with the true form of the archaeological remains rather than to feed it with a hypothetical reconstruction that covers up and defaces the original remnants.

For the prototype Smart Eye application, the primary archaeological data include both legacy and 3D documentation data from sites that have already been backfilled and that are currently being investigated respectively. A protocol has also been developed for the transformation of the legacy data into 3D models that can be implemented when the Smart Eye app's content is redesigned for use at different archaeological sites. Provision has been made, further, for info-points and hotspots inside the AR models of the sites where the public can find additional textual information and media to improve their understanding of the archaeological site, its history, and important artefacts retrieved from it.

As a result, the Smart Eye app is expected to provide the public with an "x-ray" type view of archaeological sites that are currently inaccessible. What is important is the fact that this can be accomplished at the actual place where the archaeological remains lie buried and not in some geographically and culturally disassociated space, such as a museum or a virtual reality world.

The Smart Eye app, thus, offers an interactive cultural experience that will allow visitors to immerse themselves into the architectonic space of the past, to explore and discover the site at their own pace and based on the archaeological features that interest them the most.

DATA ACCESSIBILITY STATEMENT

The documentation material of the two archaeological sites used for the production of the 3D models and additional media (images, maps, videos) provided for the hotspots have not been made freely accessible to the public because they have not been published yet by the respective cultural heritage institutions and research teams.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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