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Enhancing Cultural Sustainability: Making Rescue Excavations Accessible through Educational Applications and Virtual Reality

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Abstract: The key questions of this article concern the extent to which digital documentation, 3D scanning technologies, and VR/AR technologies contribute to the preservation, enhancement, and sustainability of cultural heritage. The purpose of this research is to present an innovative methodology through which a platform for the diagnosis, management, and documentation of findings, progress, and reports and projections of rescue excavations in the area of Euboea, Greece was implemented. A holistic approach is proposed with a comprehensive system of archaeological documentation and visualization, which integrates the use of digital technologies in all steps of the archaeological process, enhances the tools of the scientific community, and provides immersive experiences for both researchers and the public. The results of the method include (1) a complex toolbox of innovative technologies that allow archaeologists to plan and execute a rescue excavation in an efficient and concise manner and (2) a VR installation at the Diachronic Museum of Chalkida "Arethousa", which allows the public to participate in virtual rescue excavations and explore archaeological sites that are no longer accessible. Through this project, the impact of new technologies on cultural heritage and, in particular, on issues of sustainability, accessibility, education, and visitor participation is highlighted.

Keywords: rescue excavations; educational applications; virtual reality; sustainability; museum; Euboea

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1. Introduction

Chalkida, as an important urban center over time, boasts a plethora of archaeological remains, and especially during the great residential development of recent decades, several architectural structures and movable findings were revealed. The area includes a wider geographical unit defined by the coastline and hill of Vatrovouni. Within these limits, several rescue excavations have taken place in the past and, undoubtedly, several will take place in the future. The archaeological information that has already emerged from the excavations, combined with what is still emerging, highlights the fact that their management requires a holistic approach, which will combine rescue excavations with technological means. In the context of this research, significant progress is offered in the diagnosis, documentation, and analysis of the following rescue excavations: The Prehistoric settlement of Manika in Chalkida and the rural complex of the Middle Byzantine era at the location "Roumani-Rachi" area of Kastella, in the Municipality of Dirfya-Messapia [1–3]. More specifically, the ability to manage three-dimensional information from rescue excavations and documentation of findings in three-dimensional space was offered in a specially designed database through a corresponding 3D application. Existing efforts in Greece are limited to the documentation at the database level of mobile findings. The documentation scheme developed for the platform for the diagnosis, management, and documentation of findings, progress, and reports and projections of rescue excavations (PDRE) in combination with the subsystem for the development of digital virtual rescue excavations

(SDRE) are unique tools that increase the possibilities for easily creating original innovative educational virtual tours with impressive results. Within the framework of the project and the use of innovative tools, excavation teams can directly disseminate the results of excavation works and research to the public, while the optimal management, mapping, and documentation of the excavation material allow for the future exploitation of the content. In the future, when a sufficient number of rescue excavations of an area are included in the system, utilizing the classification of stratigraphy, the scientific community will present a model of the residential development of the area to the general public. Additionally, the public and the educational community will be able to visit archaeological sites that are no longer accessible.

2. State of the Art

Rescue excavations, also known as "rescue archaeology" or "emergency archaeology," arose in response to the impending destruction or alteration of sites due to construction, development projects, or natural disasters. They aim to mitigate the loss of cultural heritage by documenting and recovering objects, structures, and archaeological features before they are irreparably damaged.

The primary goal of rescue excavations remains constant: to preserve archaeological information before it is lost forever [4]. In Greece, although there are laws on antiquities, they do not adequately protect them, resulting in antiquities being trafficked or destroyed during the excavation process [5]. In the 1970s in Great Britain, the efforts of rescue archaeology focused on raising public awareness through publications on the importance of preserving cultural heritage [6], demonstrating archaeologists' continued commitment to protecting cultural heritage from the threats posed by development and global crises. Rescue excavations often require cooperation between archaeologists, heritage professionals, and competent authorities. Technology plays a critical role in facilitating collaboration and data sharing, especially in rapidly evolving rescue scenarios. Cloud computing and digital databases allow many stakeholders to access and contribute to excavation data, ensuring seamless communication, effective decision-making, and a coordinated rescue effort. This collaborative approach also encourages interdisciplinary research, allowing experts in different fields to share their expertise and enhance their general understanding of the archaeological context [7].

When conducting rescue excavations, various methods and techniques are used to maximize efficiency and minimize damage to the archaeological record. The importance of rescue excavations extends beyond cultural preservation and protection. Such interventions can contribute to research on social dynamics and behavior, community involvement promotion, and thus, sustainability of cultural heritage. By documenting and recovering archaeological remains, rescue excavations ensure that valuable information will be accessible for future exploitation [6].

In these time-sensitive and high-pressure scenarios, technology plays an important role in maximizing the efficiency, accuracy, and preservation of archaeological data. Archaeology is now characterized by the widespread presence of digital technologies. The most significant transformation in recent decades can be attributed to the information technology revolution, which has ushered in novel digital and statistical approaches, fundamentally altering the landscape of archaeological practices. Moreover, these tools are designed to increase archaeologists' capacity to derive meaningful insights from raw data, making the analytical process more efficient [8]. Primarily, since 2000, cultural heritage documentation has utilized laser scanning methods and digital photogrammetry techniques for metric data acquisition. Especially aerial photogrammetry and close-range or terrestrial photogrammetry have found extensive application in this context. 3D scanning techniques have become prominent as they represent a new model for a systematic approach to acquiring various data related to cultural heritage, as well as creating precise documentation of an archaeological site. This represents a computer-controlled approach that can incorporate GNSS and unmanned aerial vehicle (UAV) photogrammetry to generate 3D models. Furthermore, to

streamline excavation recording, subsequent analysis, interpretation, and publication procedures, digital excavation recording systems have been developed to document, analyze, and publish archaeological data. This methodology provides the benefit of consolidating all information into a cohesive, cross-referenced repository, exemplified by software such as iDig—Recording Archaeology, which serves not only for data storage and presentation but extends its capabilities to various additional functions [9].

In rescue excavations, time constraints require data recording to capture as much information as possible before its probable destruction or loss. Technological tools such as digital mapping software (GIS), data loggers, and mobile devices equipped with specialized applications allow rapid and efficient real-time data collection and accurate measurements [7,10]. This ensures that valuable archaeological data are recorded systematically, reducing the chances of critical information being overlooked or lost due to time constraints. This technology offers advanced imaging techniques that significantly improve the documentation and preservation of artifacts and archaeological features during rescue excavations. High-resolution photography, three-dimensional scanning, and photogrammetry allow for detailed digital documentation of objects, architectural elements, and even entire excavation sites [11,12]. Studies show that these advantages become particularly critical in archaeological environments facing time and cost constraints, such as in cases of rescue archaeological excavations [13]. These digital files not only provide accurate representations but also facilitate post-excavation analysis, interpretation, and virtual representations, preserving archaeological data for future research and informing the public.

Ground penetration radar (GPR), electromagnetic prospecting, and geophysical methods can detect buried structures and objects without the need for extensive excavation. GPR can be applied in urban areas where the presence of potential noise sources, such as metal bodies, prevents the application of other geophysical methods, such as magnetic and earth resistance methods [14]. In addition, this technology allows archaeologists to quickly assess the extent and importance of archaeological sites in rescue excavations.

Remote sensing techniques such as aerial photography, satellite imagery, and Light Detection and Ranging (LiDAR) can help archaeologists identify potential archaeological features, site boundaries, and areas of importance [11,15]. The effectiveness of the use of LiDAR, a sensor that detects the light and distance carried by an unmanned aerial vehicle (UAV), is valuable for revealing artificial structures hidden by vegetation and quickly documenting the topography of the ground surface [16]. The wide availability of 3D models created using this technology facilitates easier access and further contributes to its increasing adoption [17].

Concerning accessibility to sites and monuments revealed by rescue excavations, virtual reality (VR) and augmented reality (AR) provide immersive and interactive experiences, making them accessible to the public [18,19]. People can visit virtual sites, explore historical reconstructions, and engage with artifacts, regardless of physical constraints or geographical distance [20]. This accessibility extends the reach of cultural heritage beyond natural boundaries, making it available to researchers, educators, and the general public. Virtual reality (VR) contributes to sustainability by offering virtual experiences that reduce the need for physical trips to heritage sites. VR enables heritage preservation by providing immersive and interactive experiences. Virtual reconstructions of historical environments or lost structures allow visitors to explore and understand cultural heritage without physical intervention and minimize damage to fragile sites and artifacts [21].

In conclusion, technology has revolutionized the field of excavation, allowing archaeologists to collect data quickly, efficiently, and non-invasively as they are required for rescue excavation [22]. By adopting technology, archaeologists can streamline the process, preserve cultural heritage, and ensure that the information resulting from excavation is provided for future research and utilization [12].

3. Materials and Methods

The present methodology that was developed, apart from the technological dimension of recording and documenting rescue excavations, also refers to the field of educational cultural tourism applications using virtual reality and gamification. The platform for the diagnosis, management, and documentation of findings, progress, and reports and projections of rescue excavations offers the ability to create applications that use virtual reality (VR) and gamification to produce educational gamification scenarios. The information recorded on this platform is the basic material for the development of educational digital applications for pupils, students, and "excavation" tourists in the form of a narrative with gamified elements utilizing VR virtual reality technology. There is also the possibility of developing educational narratives in the virtual space of the excavation where the methodology of rescue excavation will be presented with real examples.

Initially, it is important to present and analyze the educational context in which the development of educational applications was included and, in particular, the games and narratives they contain. The main axis of pedagogical philosophy is the theory of discovery learning of J. Bruner, according to which it is considered necessary to have stimuli for the subject of the learning process (pupil, student, or "visitor") to be able to discover new aspects in an already existing form of knowledge [13]. Through an exploratory process, which is based on searching, finding alternatives, and generally participatory educational activity by the subjects of the learning process, the substantial acquisition of new knowledge will be achieved. The constructive theory (constructivism) of the approach to knowledge was chosen as a continuation of the above perception regarding the pedagogical process. According to this, the effectiveness of learning is inextricably linked to the ability of the individual to understand and assimilate knowledge creatively, through a process of interaction with different stimuli [23]. Proponents of this educational model consider that when the subjects of the learning process are actively involved in the reception and construction of information and knowledge, they can understand it in depth as well as maintain it [24]. At the same time, experiences with VR allow full interaction within a dynamic and autonomous environment [25]. Therefore, an attempt is made to utilize virtual reality technology to achieve the construction of information and knowledge by the user-subject of the learning process for a fuller and more in-depth understanding of them.

This research aims to cover what is missing from traditional learning environments with the use of mixed reality, virtual reality, and gamification techniques through an integrated platform for creating applications that use new realities (VR, AR, and MR) and gamification. The educational applications of the platform support the holistic acquisition of knowledge, as they allow a variety of explorations to access the required information through interactive storytelling using virtual reality [26,27], the prospect of creating an entertaining user experience with AR [28,29], and gamification [30]. The aim is for users to be able to participate in active learning processes [31] through new realities and the creation of scenarios and stories and enriched material to enhance the experience [32], as well as alternative narratives in case the user chooses to form them [33–35].

The central scenario of the application is based on the logic of identifying the modern "visitor" (pupil, student, or tourist) with an "amateur archaeologist" who visits Chalkida and the Diachronic Museum of the city "Arethousa" full of wonder and research. The protagonist visitor entering the site and utilizing the platform uses the map on which the archaeological findings are placed. They can also tour a real site of a rescue excavation in progress, following the options below, which are not hierarchical but rather parallel:

- Virtual reality tour through the space of the Diachronic Museum of Chalkida "Arethousa". The tour is carried out with the help of an audio narration by a personal guide-archaeologist in rescue excavations, based on the reconstruction of the excavation and the course of its history. In addition, it is possible to search for information about the history of the excavation of the site through a field where the information will be organized as Wikipedia articles, with the required quality, multimedia, and references.

- Realization as a game of digital virtual excavation utilizing virtual reality (VR) technology. With the help of the narration of a personal guide-archaeologist and visualization of findings at the point of their discovery as well as their continuously updated documentation on the history of the site, the information will be organized in the form of Wikipedia articles, with the required quality, multimedia, and references.
- Tour with VR virtual reality technology and with the help of the narration of a personal guide-archaeologist in the real place where the rescue excavation was carried out concerning findings of antiquity or another era and witnesses of the timeless human presence in the area (e.g., the part of the ancient market of Chalkida in the new building of Green Bus Station Euboea, or excavation remains in another basement of a current building of the city, such as the section of the medieval wall in the building of the Chamber of Commerce and Handicrafts of Euboea).

The user participates in scenarios concerning:

- Role-playing: as archaeologist or conservator participating in the excavation team, etc.
- The first steps of the young amateur archaeologist: the preparation of works and the discovery of the first find in the excavation.
- The technique of sorting and naming excavation finds.
- Use of educational games simple at the beginning in the form of puzzles, crossword puzzles, or mazes and more complex along the way, such as the "treasure hunt" between visitors or groups to search and find a "lost" object and place it in the appropriate place, etc.

In this context, applying two of the most important teaching principles, namely the direct utilization of the experiences of pupils/students and visitors and the "time start", it is important to refer to the past of each visited monument with specific data from primary and secondary sources of the period. In this way, pupils/students/visitors perceive historical time through historical understanding, the different conditions, and modes of action of people [36]. Thus, the teaching scenarios do not present the past of an area as a linear representation over time but rather create a complex reality enabling the person involved to understand the ways of utilizing the data provided by the platform. The platform's contribution is defined by the experience gained through experiential engagement and ultimately a form of "immersion" in the creation and operation of the monument in the past, the understanding of excavation methods in the present, the achievement of communication and cooperation goals, and the understanding and transfer to third parties of the current situation. The above will be validated using formative and final evaluation processes. At the end of the tour, a special evaluation questionnaire will be completed [37].

The main systems of the research project are the platform for the diagnosis, management, and documentation of findings, progress, and reports and projections of rescue excavations (PDRE) and the subsystem for the development of digital virtual rescue excavations (SDRE), which are the basis on which the educational applications were developed. The digital platform was designed after analyzing the requirements of both researchers and visitors through a collaborative methodological approach to identify the needs for the development of the platform.

The architecture model chosen for the platform for the diagnosis, management, and documentation of findings, progress, and reports and projections of rescue excavations (PDRE) is that of n-tier architecture.

The proposed solution is based on 4 layers that each perform specific functions and can only communicate with the layer directly below it. These levels are (see Figure 1):

- Application layer.
- Communication layer.
- Business logic layer.
- Data tier.

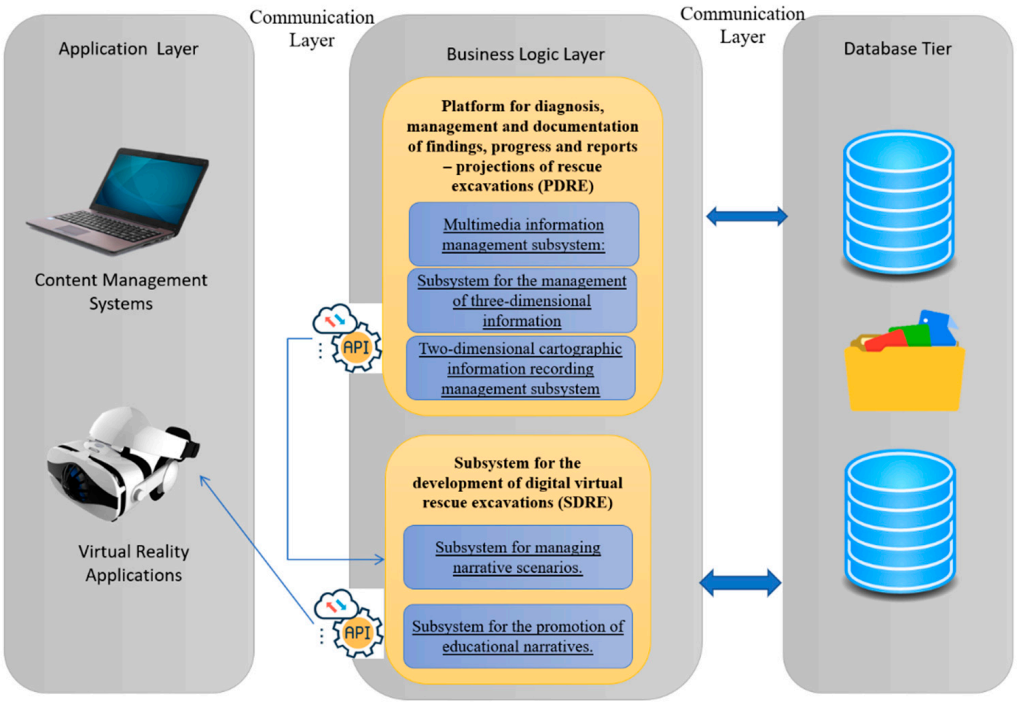

Figure 1. Four-tier application architecture.

The Content Management Systems consists of PDRE and SDRE. Virtual Reality applications obtain virtual rescue excavation data via the API of SDRE. SDRE accesses three-dimensional and multimedia content for constructing narratives by accessing the API of PDRE. PDRE consists of three subsystems for recording information:

- Multimedia information management subsystem.
- Subsystem for the management of three-dimensional information.
- Subsystem for managing the recording of two-dimensional cartographic information.

The descriptive and three-dimensional information stored in PDRE is the primary material for the development of educational digital applications (apps) for pupils, students, and "excavation" tourists. These applications are developed through the subsystem for the development of digital virtual rescue excavations (SDRE) in the form of storytelling with gamified elements utilizing virtual reality technology. The elements of the virtual rescue excavations are the actual recorded data of the discoveries in PDRE so that the interested parties can experience moments of rescue excavation. Developing educational narratives in the virtual space of the excavation, where the methodology of rescue excavation is presented with real examples, creates another possibility for the subsystem to develop digital and virtual rescue excavations.

The SDRE consists of two subsystems:

- Subsystem for managing narrative scenarios. In this subsystem, the creator of the scenarios for the virtual environment creates educational narratives.
- Subsystem for the promotion of educational narratives. The educational virtual tours are displayed within the museum and will be evaluated in the context of a specific experimental layout. Visitors will use the integrated virtual reality computer systems (computers, virtual reality helmets, controllers, etc.) that will be placed in specially designed areas of the Museum. The evaluation will be completed by the target groups of the project, i.e., by the target audience of the educational activities who seek the knowledge and the "enhanced" experiential experience that will be offered to them by the open view workshop in which they will participate in a real rescue excavation. Based on the evaluations, the educational virtual tours will be improved to meet the real needs of the demonstration facility.

The scenarios are based on actual rescue excavations and their main objective is to highlight the procedures described in the respective actions in previous chapters and the challenges, difficulties, and positive outcomes they can offer.

4. Results

After the design was specified, the project team proceeded to the development of the platform for the diagnosis, management and documentation of findings, progress, and reports and projections of rescue excavations (PDRE) and the subsystem for the development of digital virtual rescue excavations (SDRE) along with the corresponding APIs.

PDRE is a web application, developed to run on LAMP stack (Linux: CentOS v7.9.2009, APACHE: 2.4.58, MySQL: 5.7, PHP: 7.4) and web browsers using JavaScript, HTML, and CSS for the user interface 2.3.2.5 Unity WebGL. The term LAMP refers to three key components that work extremely well together to host a powerful website with a database. The term LAMP is an acronym for Linux, APACHE, MySQL, and PHP. These four technologies are used to create a server where the connection to the network is implemented, and communication is achieved using a web browser.

4.1. PDRE

The platform for the diagnosis, management, and documentation of findings, progress, and reports and projections of rescue excavations (PDRE) is based on the three basic subsystems mentioned above, through which the following tasks can be performed:

- Excavations: The user enters the system and is directed to the page of excavations available to him. From this page, they can select an excavation and see the details concerning it (Figures 2 and 3).
- Excavation details: They can also edit the details of the excavation, upload photos and drawings, and set a position on the map (Figures 4 and 5).
- Location on the map: The original location for each excavation must be defined on the map, as well as a coordinate polygon, which briefly describes the form of the excavation. The map of the excavation will always be at the point specified by the user enabling them to depict polygons and points for the excavation among other elements.
- Excavation layers: In addition, the user can select an excavation layer for viewing and editing. They can upload image files for photos and drawings and set the location on the map or create a new layer (Figures 6 and 7).
- Finds: The user can edit or create a find or monument by adding details, image files for photographs and drawings, and locations on the map (Figures 8 and 9).
- Provisional recording of findings: On this page, the user can create or select and edit a provisional record per layer and category for the findings.

The detailed and three-dimensional information presented above, which has been stored in PDRE, is the primary basis for the construction of educational digital applications for pupils, students, and tourists with an interest in archaeology. These applications are created through the subsystem for the development of digital and virtual rescue excavations (SDRE) and are presented as a kind of narrative using virtual reality technology. In the central area of the virtual rescue excavations, the real data of the discoveries are recorded in PDRE. This will allow users to experience moments from a rescue excavation through the comfortable and secure platform of virtual reality. Among the features that the subsystem for the development of digital rescue excavations provides is the creation of educational narratives in the virtual environment of the excavation. Here, the methodology of rescue excavation through real cases will be presented, thus allowing users to gain a more complete understanding of this process beyond the experience of discovering archaeological finds.

Figure 2. PDRE. The list, in Greek, of excavations registered in the system.

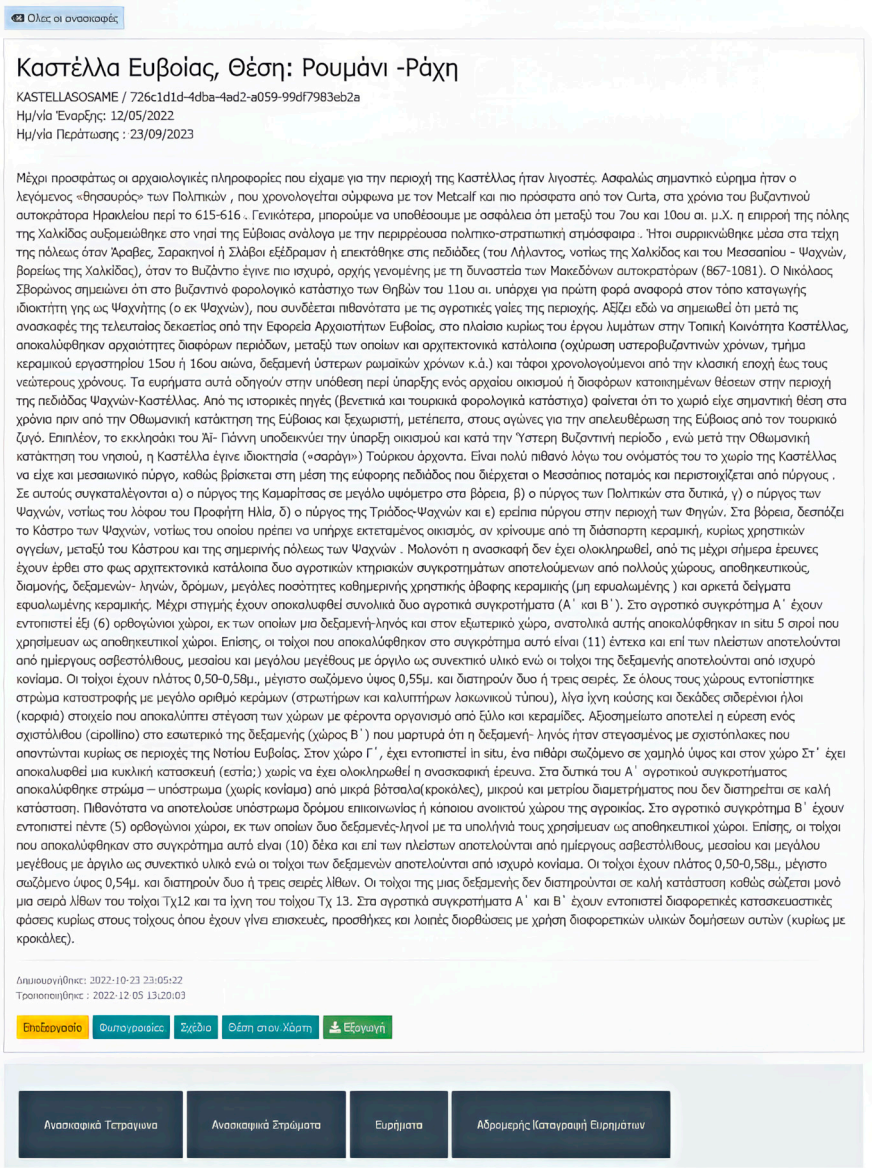

Figure 3. PDRE. General information about Kastella excavation, in Greek.

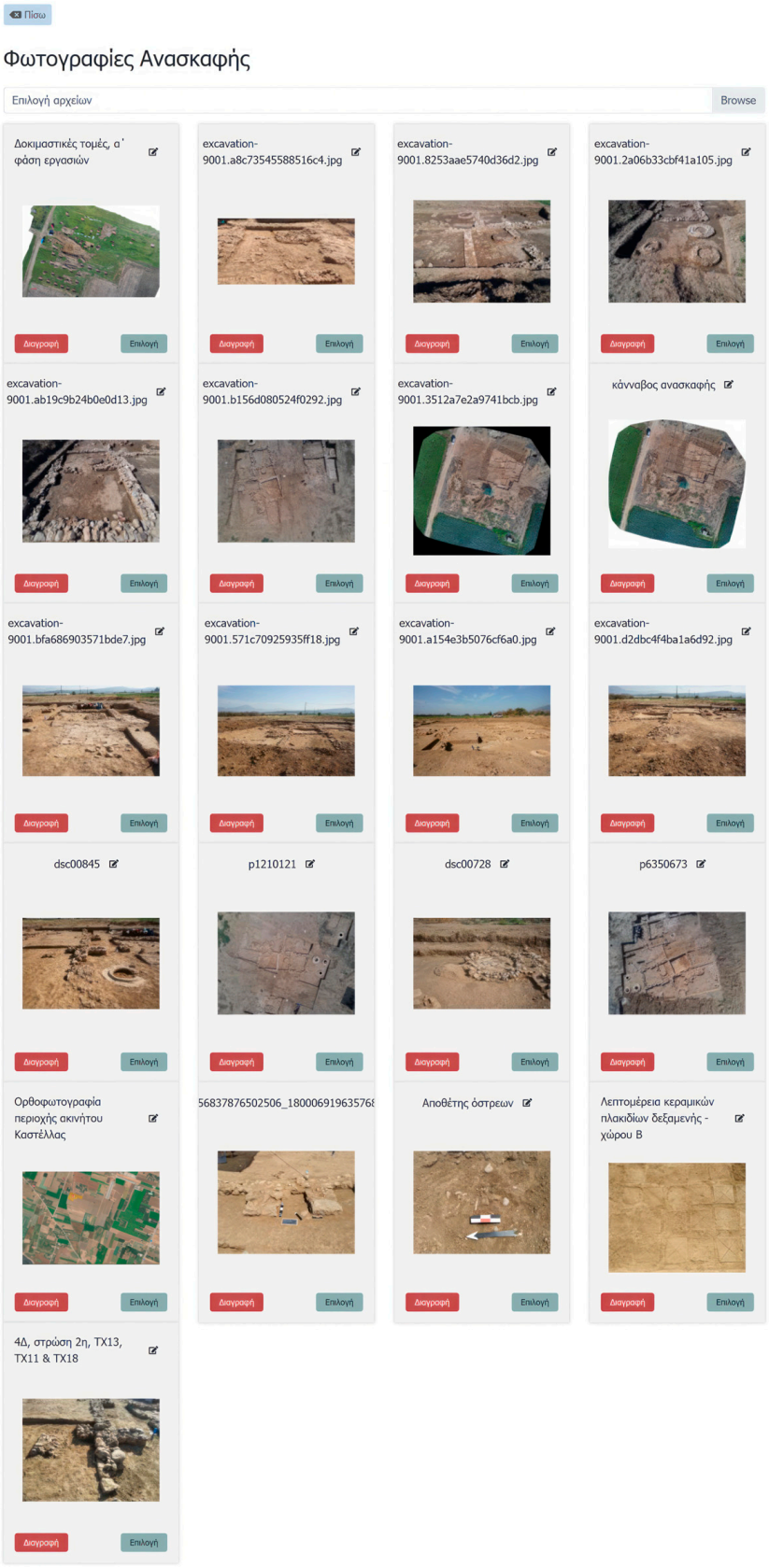

Figure 4. PDRE. Photos of the Kastella excavation, with labels in Greek.

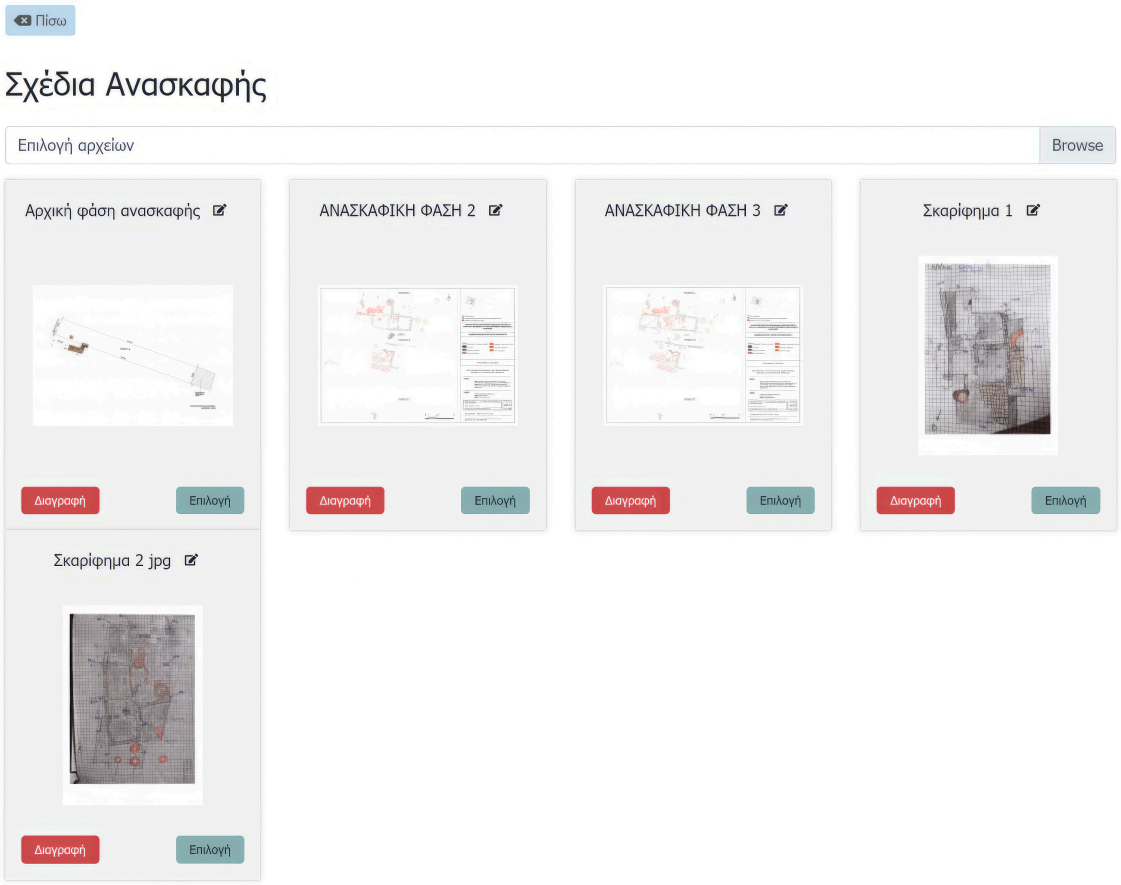

Figure 5. PDRE. Drawings of the Kastella excavation, with labels in Greek.

Figure 6. PDRE. List of the excavation layers of the Kastella excavation, in Greek.

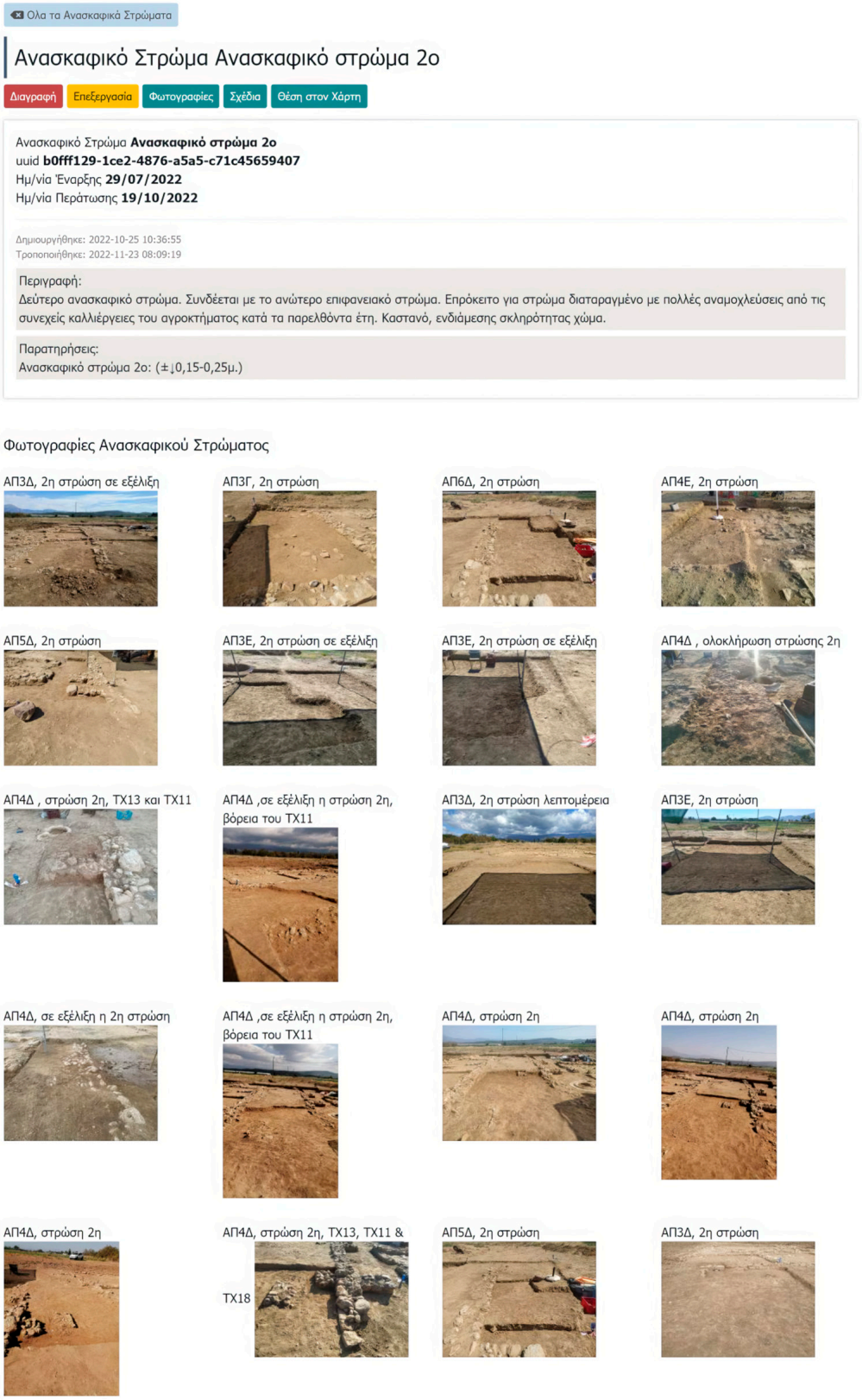

Figure 7. PDRE. Information in Greek, and photographs of one of the excavation layers of the Kastella excavation.

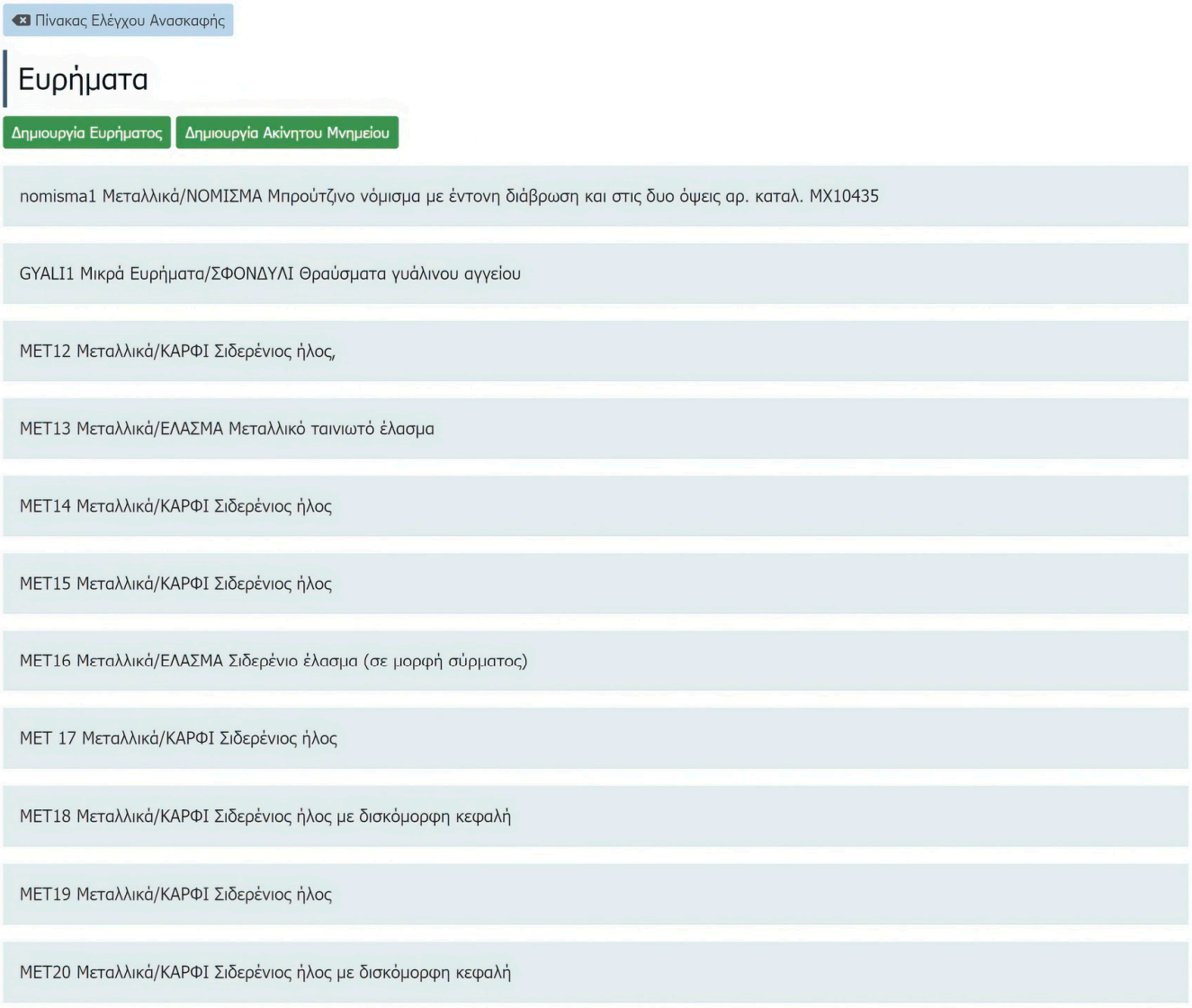

Figure 8. PDRE. List from findings of the Kastella excavation, with labels in Greek.

The information presented in the digital virtual excavations is stored in the three-dimensional information management subsystem and includes texts, sounds, audio narrations, excavation layers, three-dimensional finds, photographs, and graphics that enhance the user experience. The user will create the excavation in this subsystem, upload any information they want, and then run the SDRE executable file on the computer, which will have all the necessary tools for composing the scripts.

The user runs the application locally, logging in with a username and password. After entering the data, the user displays the list of virtual rescue excavations made by the user in the PDRE subsystem. From the list, they select the script they want to work on and expect all the materials to be loaded from the PDRE. The user through the menu can:

- Preview a scenario in virtual reality glasses.
- Save the changes made to the virtual excavation.
- Create different scenes of rescue excavations.
- Add a new scene and name and edit it.
- Define the three-dimensional environment of the scene.
- Enrich the presentation with different types of elements that can be added (images, text, sound, or 3D objects), as well as a library with selections of photos and other graphic material uploaded to the platform.

- Combine elements from the above and add them to the scene they created.

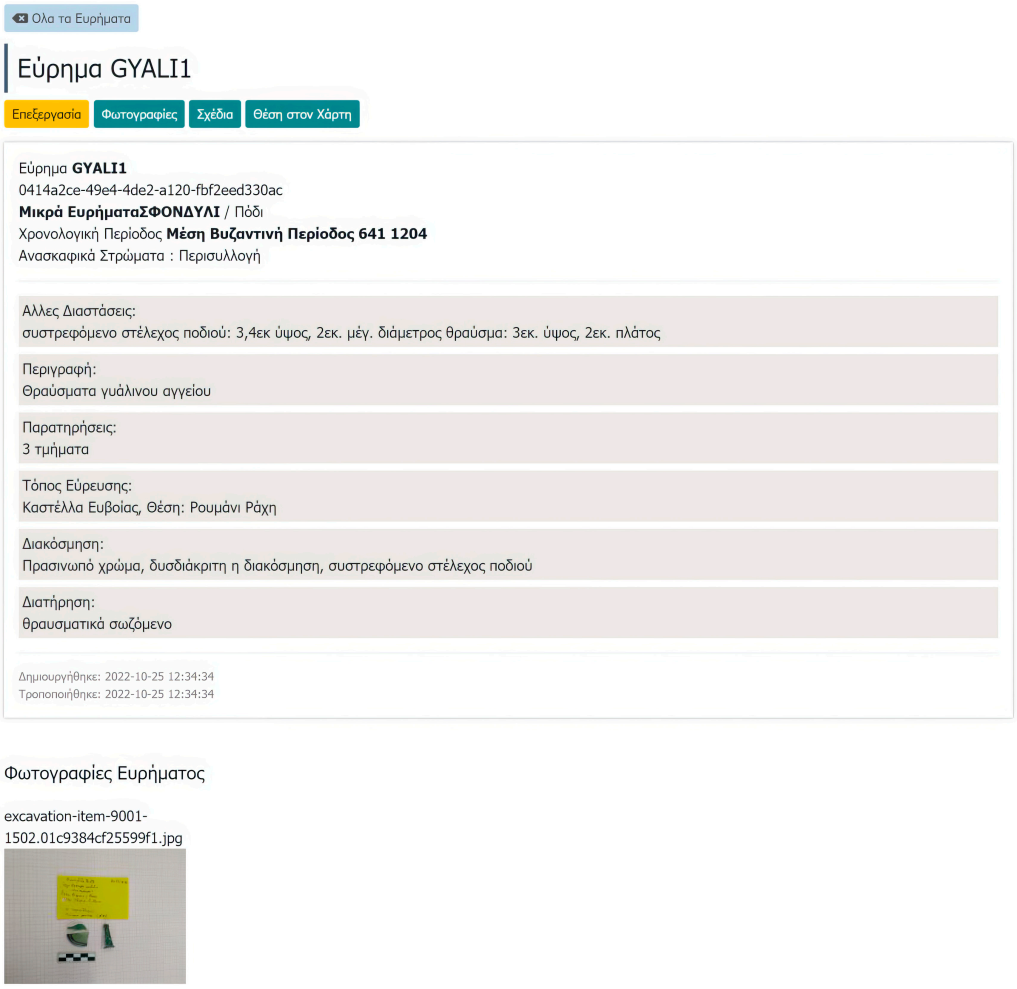

Figure 9. PDRE. Documentation information, in Greek, of one of the findings of the Kastella excavation.

Data collection was carried out from the two rescue excavations at:

- Manika-Georgiou Plot: Prehistoric settlement of Manika in Chalkida [1].
- Kastella, Euboea, Location: Roumani-Rachi: A rural complex of the Middle Byzantine era at the location "Roumani-Rachi" area of Kastella, in the Municipality of Dirfya-Messapia [2,3].

These data were then processed, and a classification system was developed, documented, and entered into the PDRE. The rescue excavation data added to the PDRE are shown in the images in Figures 2–9.

4.2. SDRE

The subsystem for the development of digital virtual rescue excavations (SDRE) consists of two subsystems, one for managing the narratives and one for their display in the virtual reality application.

In the narrative scenario management subsystem, the creator of the scenarios for the virtual environment creates educational narratives by defining the:

- Order and location of the three-dimensional models of the excavation layers.
- Order and location of three-dimensional models of excavation finds.
- Order of the visual two-dimensional information presented (photos, videos, graphics, and maps).
- Order of the audio narrative.

- Order, the way of interaction, and the creation of educational quizzes that will be presented to the user and will offer points and sometimes additional rewards.
- The logic of displaying the above through a time series view in which the order in which the elements of the narratives will be presented is displayed.

The screens from the management app are shown in Figures 10–13.

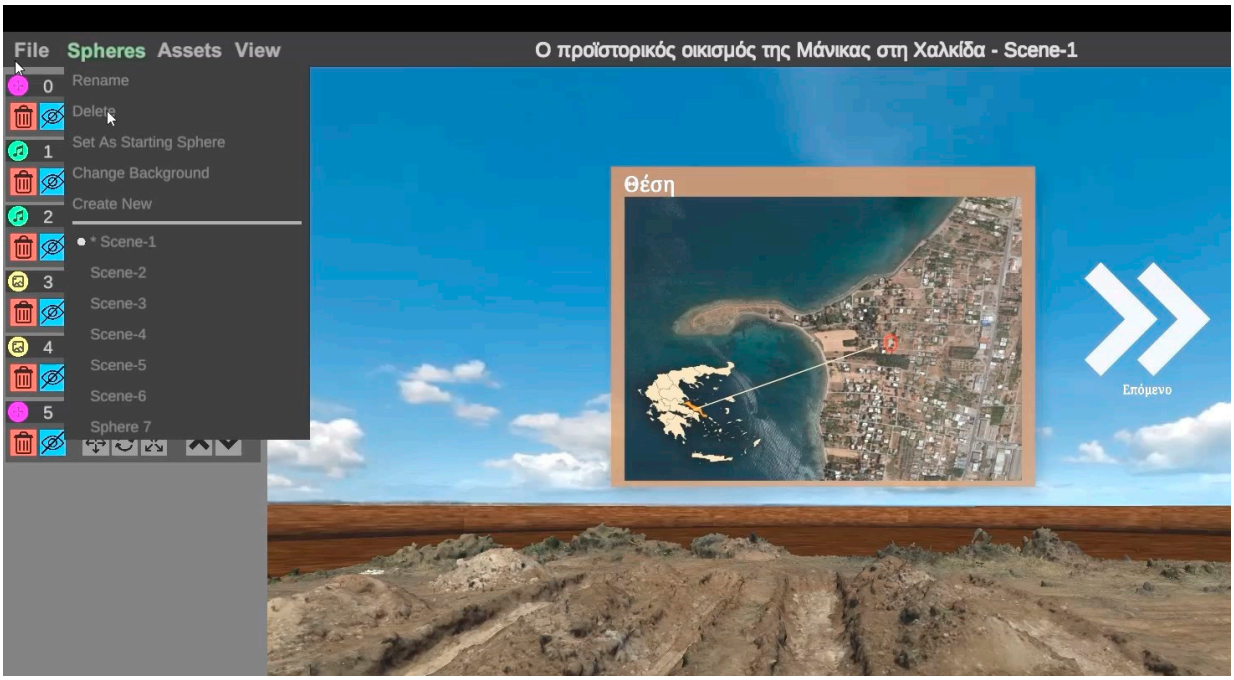

Figure 10. Scene creation screen. The red circle marks the location of the site.

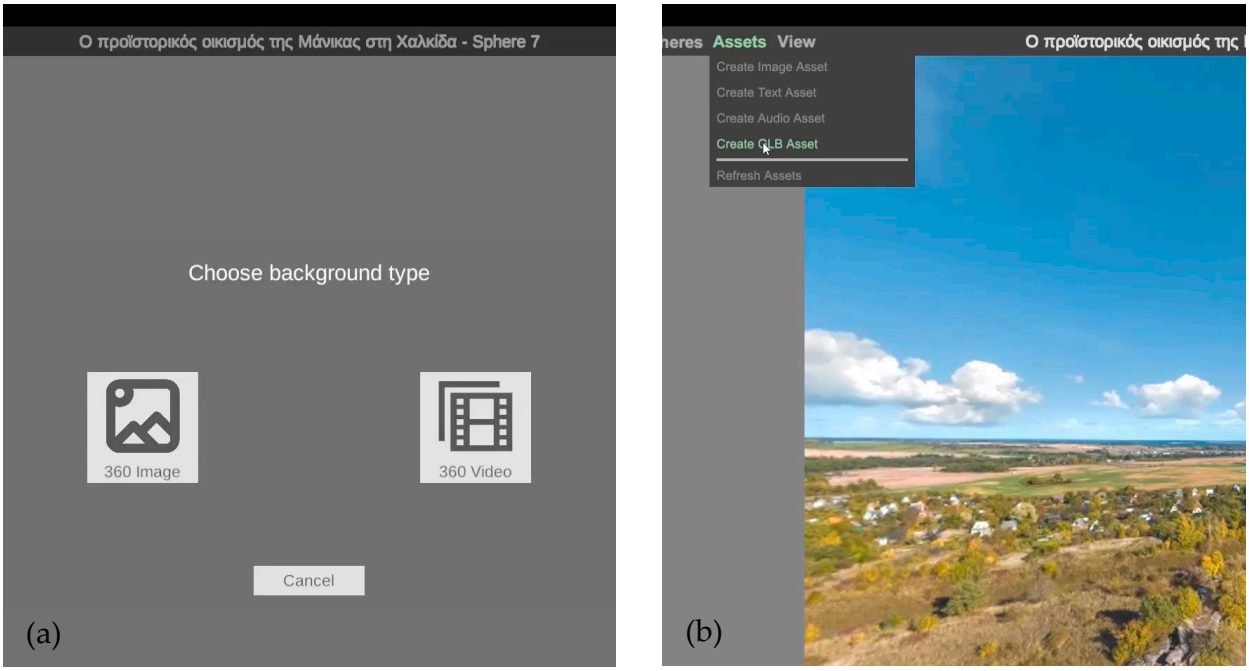

Figure 11. Environment input screen (**a**) and option to load GLB file (**b**).

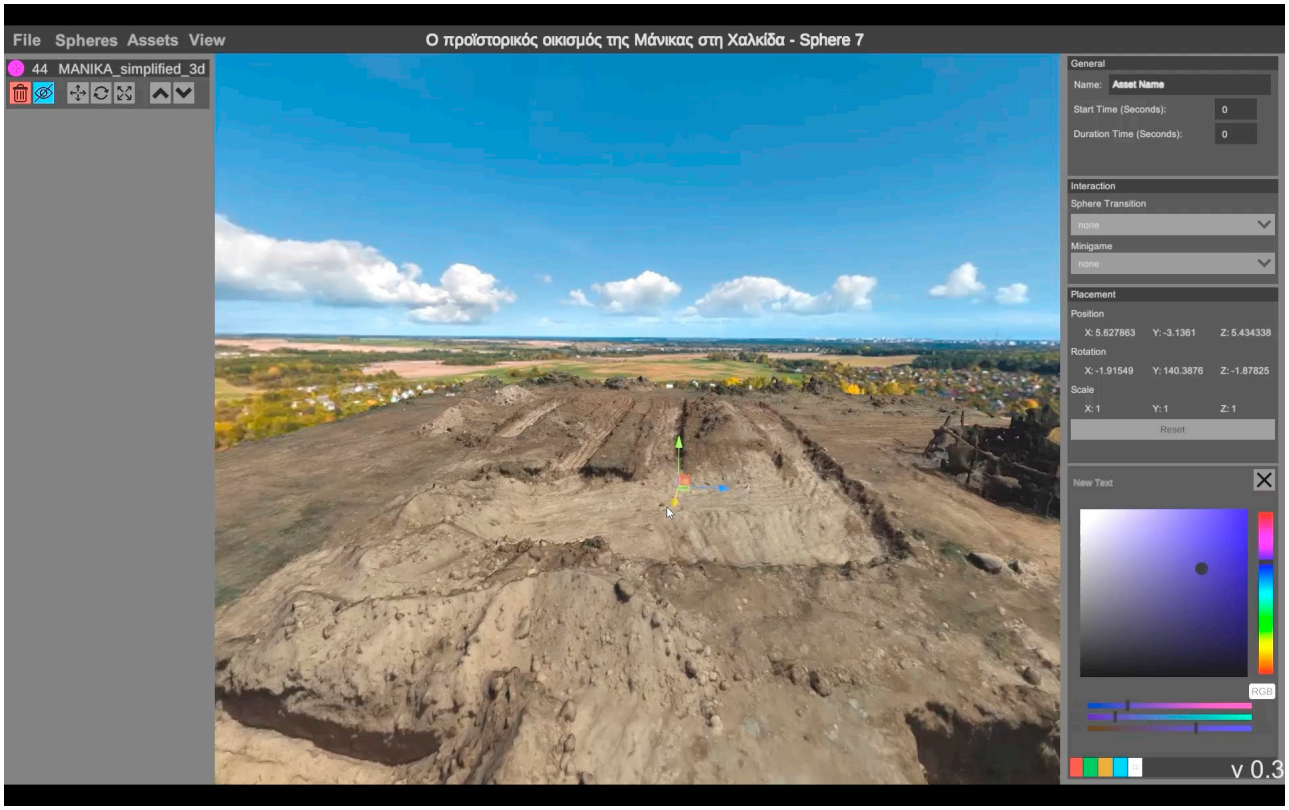

Figure 12. Screen of a loaded three-dimensional environment file with editing capabilities.

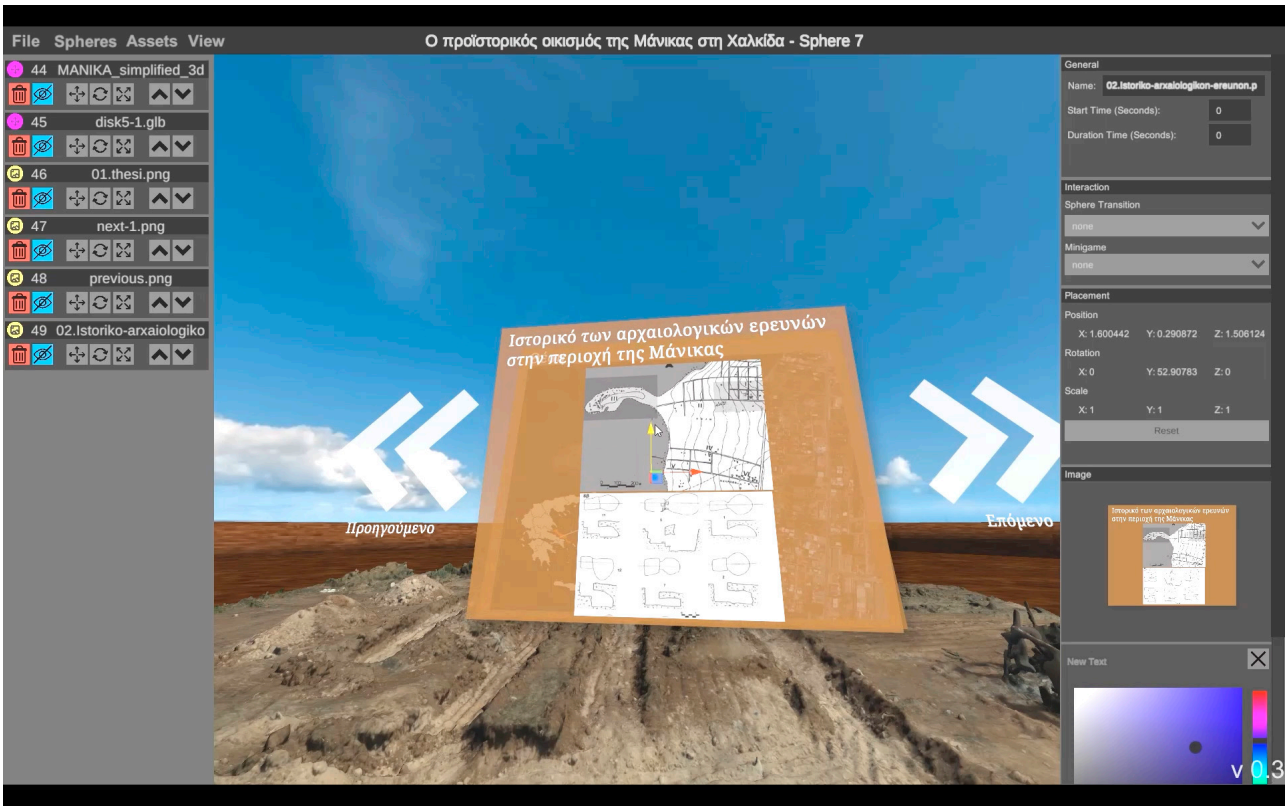

Figure 13. Screen loaded with image file with editing features.

Subsystem for the promotion of educational narratives: The educational virtual tours were created by the managers of the educational programs of the Archaeological Museum of Chalkida "Arethousa". Visitors use the integrated virtual reality computer systems (computers, virtual reality helmets, controls, etc.) placed in specially designed areas of the Museum. The scenarios are based on actual rescue excavations, and the main objective is to highlight the procedures of rescue excavations.

The screens from the virtual reality app are shown in Figures 14–17.

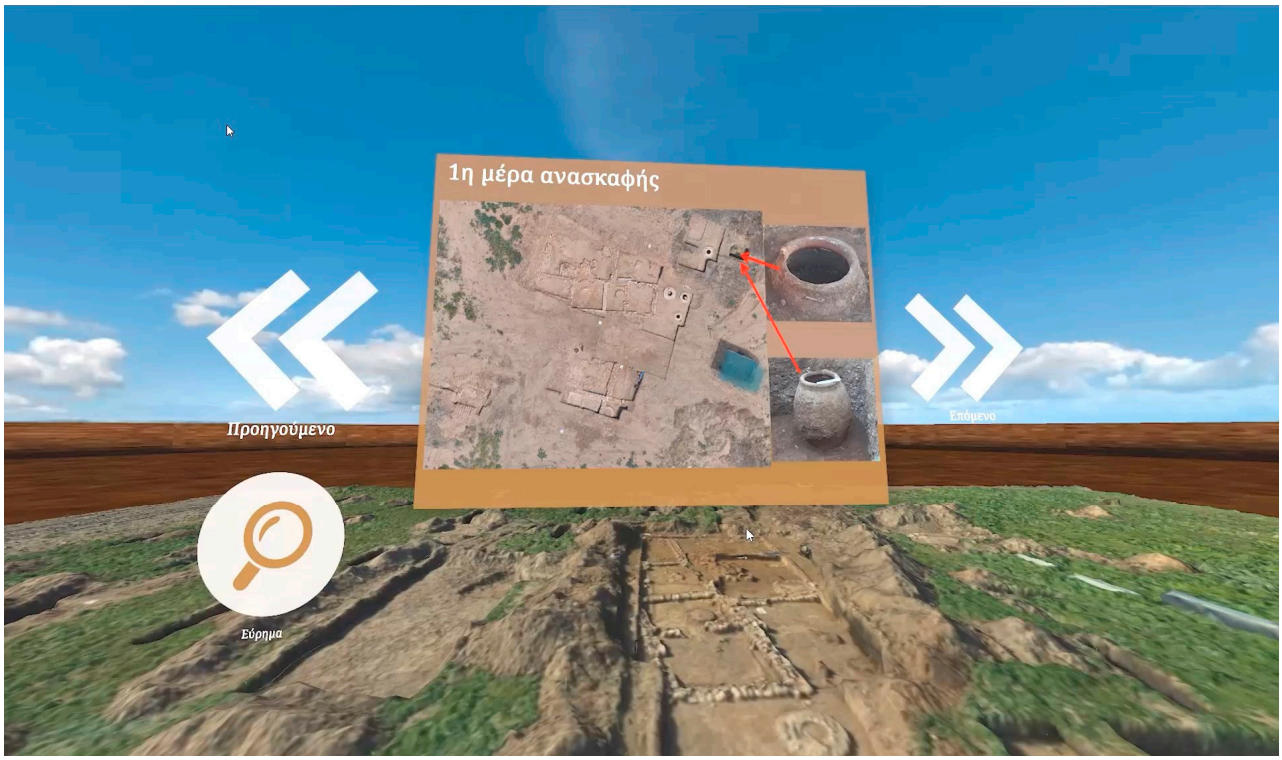

Figure 14. Interactive screen of the interactive virtual reality educational application.

4.3. Pilot Study

The recent emergence of innovative technologies has promoted virtual reality (VR) as a powerful tool for adopting a unique approach in the world of archaeology. Applied to the Kastella and Manica rescue excavations in Euboea, virtual reality not only transformed the way these locations are experienced but also provided useful information through the results of a pilot study presenting participants' experience of virtual reality, the educational impact of this technology, and the demographic data.

This pilot study was conducted in the form of a questionnaire to be completed inside the Museum during the period from July to September 2023. In total, 41 people participated, 68.3% of whom identified as women and 31.7% as men. The age disparity was broad, with the majority (41.5%) representing people under the age of 18 and 19.5% people aged between 25 and 44, while both age groups between 35 and 44 and 55+ shared a common participation percentage (17.1%). The occupation range was equally broad: 41.5% of the participants were pupils/university students, while 19.5% and 14.6% worked as public and private officials, respectively. The respondents belonged to a range of educational levels, from graduates of a higher education institution/university (29.3%) and Master's degree holders (19.5%) to primary school graduates (29.3%).

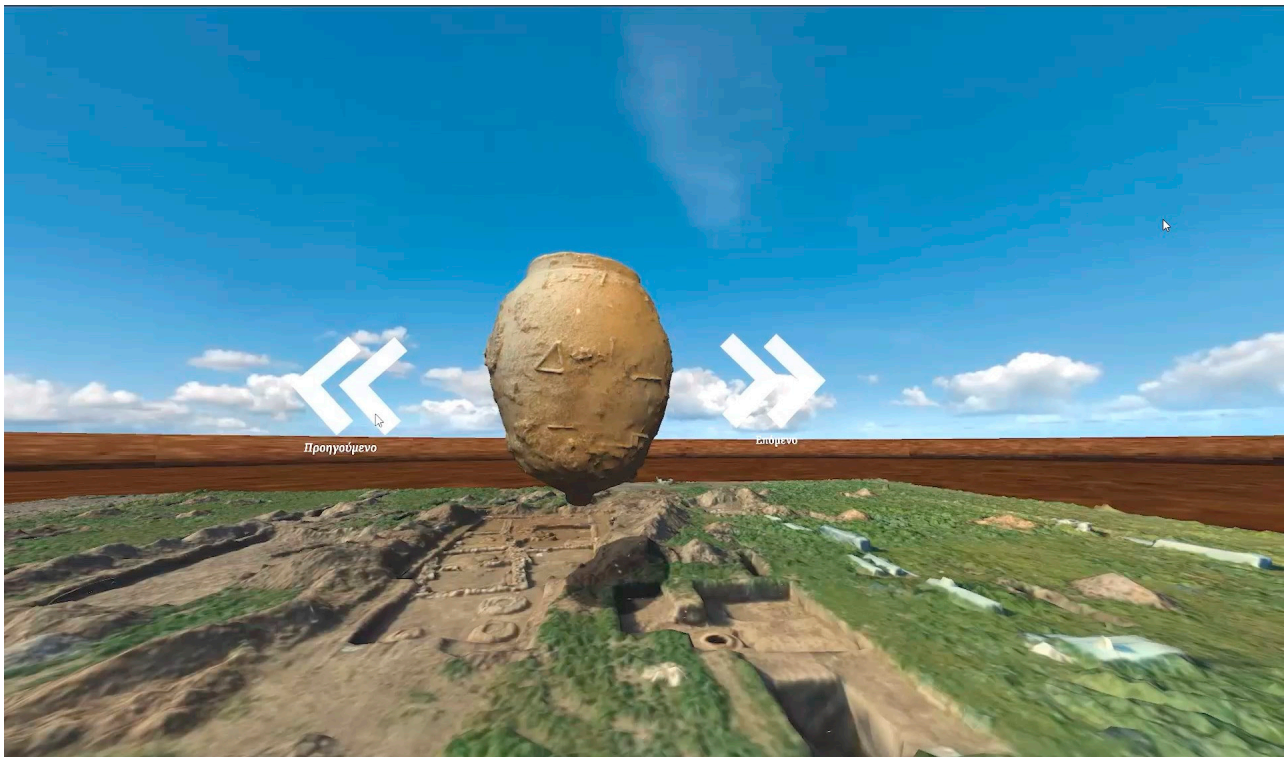

Figure 15. Virtual reality educational application screen—view finding.

Figure 16. Virtual reality educational application interaction screen.

Figure 17. Virtual reality educational application screen—view findings. The arrow indicates the finding place of the objects.

In the questions regarding the VR application, the majority (78.9%) of the respondents rated the overall experience of using VR in the Kastella and Manica rescue excavations in Euboea as excellent, indicating the effectiveness of this tool for drawing in different audiences. Moreover, 28.2% of the participants stated that there were occasional technical issues, 7.7% reported that the technical performance was below their expectations, and a small percentage chose not to answer. The level of interactivity in the VR experience was characterized either as very interactive by the majority of the respondents (59%), having total control of their exploration and actions, or as moderately interactive by the remaining 41%, stating that there were some interactive elements but that they had limited control. It is worth mentioning that this specific question received no negative answer whatsoever. Among other options, 59% of the participants showed a preference for the traits of optical quality and realism, 48.7% for those of educational narration and information, and a significant percentage (28.2%) chose interactive features and controls that virtual reality provided.

Using a series of multiple-choice questions, the participants expressed valuable comments for the improvement of the application itself as well. Specifically, 40% preferred more detailed visualization of the excavation sites, 31.4% wanted additional historical context and background information about the site, and 25.7% proposed more interactive quizzes or games integrated into the VR experience.

Through this pilot study, the educational impact of the virtual reality experience was also assessed, with 80% answering that the educational content perfectly complemented the virtual reality experience and 51.3% stating that the VR experience significantly improved their knowledge of rescue excavations. It is of substantial interest that 62.5% of the participants considered the content of the VR as effective for the historical and archaeological significance of the excavations, while a percentage as high as 85% did not find any specific points confusing or difficult to understand during the virtual reality experience.

Although the VR experience received positive feedback and 64.1% of the respondents noted that the technical performance met or exceeded their expectations, some of the respondents chose not to answer. Regarding the level of inspiration to learn more about the history and archaeology of the Kastella and Manica sites, 57.5% answered that they were inspired, 5% that they were not particularly inspired, while a significant 7.5% said that they were already interested, stating through this that VR tools were not a prerequisite for them. Moreover, by answering multiple-choice answers, the respondents expressed their interest in further improvements, such as more interactive quizzes or games (25.7%) and more opportunities for multi-player collaboration or interaction (15.4%).

To conclude, the results of this pilot study notably emphasize the effectiveness of VR technology in making the archaeological experiences approachable and appealing to special audience categories. The overall feedback and the useful proposals can provide more and more opportunities for the continuous advancement of virtual reality applications aiming at archaeological education. As archaeology and technology unite, the aforementioned findings underline the constantly expanding role of virtual reality in enriching our understanding of the past.

5. Discussion and Conclusions

This study highlights the significance of innovative technologies in rescue archaeology and the development of educational applications using virtual reality. Specifically, we present a platform for diagnosing, managing, and documenting the findings, progress, and reports and projections of rescue excavations (PDRE). Moreover, we built a web application and a subsystem for the development of digital virtual rescue excavations (SDRE), through which we achieved advancement and increasing importance of virtual and augmented reality technologies in historical and archaeological research, particularly for educational purposes. Adopting archaeology within an information system workflow entails thorough digital integration encompassing data acquisition, storage, and analysis. The merits of this process are significant, offering the capability to efficiently gather extensive data and conduct further analysis [9].

The emergence of new technological tools, such as photogrammetry, 3D modeling, and advanced data management systems plays a vital role in the preservation, accessibility, education, and participation of the public in various aspects related to cultural heritage [38]. As shown in the current study, these tools provide reliable, multifaceted, and high-spatial-resolution results, making inaccessible or geographically challenging areas accessible to both scientists and the general public [9]. In the context of our research, the establishment of the "Arethousa" Museum VR tour installation in Chalkida can be considered an important step forward in this direction, allowing for the exploration of archaeological sites, namely, in our case, from Greece, the Prehistoric settlement of Manika in Chalkida, and the rural Middle Byzantine complex at the location "Roumani-Rachi" area of Kastella, in light of new technological advancements such as the VR/AR ones and gamification.

The value of virtual-reality-based educational applications for archaeological education was also evident in this study, highlighting the need for more interactive and visually rich learning methods in archaeology. This aligns with the findings of Kyrlitsias et al. [39] regarding the effectiveness of VR in enhancing user experience and learning at archaeological sites. Liu et al. [40] introduced an innovative VR game to explore archaeological relics, enhancing learning motivation and outcomes.

The platform and subsystem developed in the context of our research, namely PDRE and SDRE, not only succeed in presenting and providing valuable archaeological information in a virtual way but also contribute to sustainability, a vital aspect of life today, which fundamentally goes hand in hand with education. The outcome of this combination is the formation of a new model, based on the notions of preservation, accessibility, and participation [38].

In particular, VR and AR technologies preserve cultural heritage sites by enabling the reduction in physical trips, thus the human footprint when visiting a site in person, as well

as the operation of certain machines and objects [41]. In this way, remotely located people of different backgrounds gain access to and, subsequently, become acquainted with the virtually presented and precisely historically and archaeologically documented cultural history and material culture in Manika/Chalkida and Kastella, regardless of how remote or inaccessible they are. This inclusiveness in the form of participation without borders has a socio-economic impact on the sustainability of the community itself and its reinforcement as this procedure promotes community-based tourism, digital storytelling, and the imparting of significant cultural knowledge [42]. The immersive and interactive virtual reality that has subsequently emerged introduces a new way of approaching and interpreting various aspects of cultural heritage [43].

Our findings, complementing the work of Borodkin [44] and Bakaoukas [45], offer new perspectives on the integration of technology in the educational aspect of archaeological research and underscore the necessity of incorporating virtual reality and other digital technologies in archaeology. Future research should explore further technological applications and assess their effectiveness in various educational settings. Additionally, investigating the impact of virtual reality on students' perception and understanding of archaeological sites and history presents another potential direction for future research. The work of Venditti and Mele [46] on virtual reality in archaeology communication and Harkema and Rosendaal [47] on the didactic potentials of VR in education, particularly in enhancing hands-on learning experiences, provide valuable insights into these areas.

Supplementary Materials: The Supplementary Material for this article can be found online at: https://sosame.eu/en/ (accessed on 27 December 2023).

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