

DOI: 10.5281/zenodo.1214569

# MOBILE AUGMENTED REALITY GAMES AS AN ENGAGING TOOL FOR CULTURAL HERITAGE DISSEMINATION: A CASE STUDY

Theodora Ekonomou<sup>1</sup>, Spyros Vosinakis<sup>2</sup>

<sup>1</sup> Junior High School of Amfissa, Gidogiannou 16 Amfissa 33100, Greece

<sup>2</sup> Department of Product and Systems Design Engineering, University of the Aegean, Syros 84100, Greece

Received: 20/02/2018

Accepted: 29/05/2018

Corresponding author: Spyros Vosinakis ([spyrosv@aegean.gr](mailto:spyrosv@aegean.gr))

## ABSTRACT

In recent years, plenty of novel educational tools using mobile augmented reality (mobile AR) have been developed, altering the way students interact with a cultural heritage environment. Nevertheless, the relevant literature still lacks studies exploring the usability, effectiveness and acceptance of the technology by users, and there is still need for in-depth research to better understand the way students interact with mobile AR interfaces in this context. This study explores the use of mobile-AR technology in an open-air archaeological site and the results of this study are aimed at increasing the current literature on the digital enhancement of open spaces of cultural interest. This study also seeks to provide cultural heritage administrators and teachers with some key elements and factors that should be taken into account when deciding on the methods used to guide students to archaeological sites to develop new and more effective digital approach strategies. The paper describes the design, development and evaluation of the pilot application "Oracle of Delphi app", an educational augmented reality application for the Delphi outdoor archaeological site. It is a location-aware portable game aimed at secondary school students and aims to involve them in a playful exploration of the area through which they will learn about the most important monuments of the sacred site of Delphi and discover their history. This study is the only attempt so far to create an educational game using mobileAR for a guided tour of the archaeological site of Delphi which is then tested and evaluated by the students.

---

**KEYWORDS:** augmented reality, mobile applications, cultural heritage, location-aware applications, serious games, archaeology, Delphi.

---

## 1. INTRODUCTION

Augmented Reality (AR) is the technological approach that allows users to view an 'enhanced' version of the real world, in which digital objects are combined with physical ones, ideally in a seamless manner. The main advantage of this technology is that it allows users to receive information, to browse media and to experience stories that are 'naturally' embedded in their surrounding environment. Thus, they can access information relevant to their current location, they can easier link the digital media with the physical context, and they have a more fun and direct way to interact with the contents of the application. From a technological point of view, AR solutions have been applied using a variety of devices, from expensive head-mounted displays and worn eye-glasses with projected imagery, to modern smartphones that take advantage of their integrated cameras and sensors. The fact that a regular mobile device can deliver AR experiences to its users without extra cost or equipment, an approach usually termed as mobile AR, has made the technology widely available and led to a vast number of applications in various areas, such as education, entertainment, tourism, commerce, etc. A notable case of a widespread AR application is *Pokemon GO*, a game that attracted over 65 million users worldwide within one week of its launch in 2016 (Serino et al., 2016).

The field of Cultural Heritage presentation and dissemination has benefited from the wide adoption of AR through a range of informative or educational apps for museum visitors and tourists (Haugstvedt, & Krogstie, 2012). Especially in the case of tangible heritage, e.g. constructions, monuments and artifacts, the AR approach seems to be a very good fit. This is because users need to be focused on items and places of the real world, which is the actual cultural object, and simultaneously in order to appreciate what they are looking at, they need to be informed about their context, their story, their importance, etc. This augmentation of real-world objects with additional contextual information has been traditionally done through human guides or pre-recorded audio narration, but digital technology has much more to add. First it can present the context through a variety of media not limited to narration, such as images, videos, and especially static or animated 3D content. Second, it can be more personalized, adapted to the location and needs of the user and presented on demand. AR apps have the capacity to integrate these features and serve as the next-generation guides for cultural sites and institutions (Yovcheva et al., 2013).

Despite the availability of numerous AR applications for cultural heritage, the scientific research on design approaches and factors influencing their ef-

fectiveness is still limited. There are numerous cases of cultural heritage sites that would potentially benefit from AR approaches, and each one of them has its own limitations and peculiarities. E.g. there are indoor and outdoor environments, where the tracking technology is different; there are places where the addition of markers to support AR tracking is possible, and others where any intervention is prohibited; the objects of focus might be different in terms of size (from small artifacts to buildings), current condition (from ruins to well-preserved constructions), accessibility, etc. Furthermore, the needs of the visitors are not always the same and they have to be carefully studied in order to deliver optimal experience. Characteristics such as age, previous knowledge about the subject, intrinsic motivation and competence with technology need to be taken into account. Finally, there are various design approaches for AR experiences, and their effectiveness needs to be validated. Some approaches simply deliver relative content, others let users actively interact with the application, others include storytelling and narrative features, and in other cases the application has been designed as a game, posing challenges to the user and letting him/her interact in a playful manner. All the aforementioned dimensions and respective solutions create a large design space, which is recently new and fairly unexplored, at least in terms of scientific research. The effectiveness of the various design approaches and solutions needs to be further studied through a series of focused user experiments and evaluations, which will hopefully lead to useful conclusions.

Our research is along this line. We have designed and developed a prototype mobile AR game and we performed a user study to evaluate its effectiveness. The game is called "Oracle of Delphi app" and aims to educate students visiting the outdoor archaeological site of Delphi in an entertaining manner. It is a treasure hunt game in which students are participating in groups and follow a story presented to them using digital characters. In order to proceed with the game, they have to observe the environment and answer quizzes related to the archaeological site and the respective museum. To the best of our knowledge, the "Oracle of Delphi app" is the first mobile app for the Delphi outdoor archaeological site, which has been declared as a World Heritage Site by UNESCO<sup>1</sup>. The user study aimed to assess the performance of the AR game in terms of student motivation and learning, as well as provide more insight on the suitability and efficiency of the various design choices we made.

<sup>1</sup> See <http://whc.unesco.org/en/list/393>

## 2. RELATED WORK

AR technology has evolved significantly in the last decade, and nowadays there are plenty of available approaches in terms of system configuration. Generally, an AR system needs to be able to track objects or locations in the real world, to calculate the appropriate position, orientation and size of the digital enhancements, and to combine the two images (physical and digital) in a single visual output that is shown to the user (Schmalstieg et al., 2011). There are various methods that can be utilized for real-world tracking, including GPS, inertia sensors, Bluetooth beacons, visual markers, depth cameras, etc. The devices through which the user experiences AR are usually worn or handheld. In the first case, the user wears glasses or a head-mounted display and in the second, he/she holds a mobile device, such as a smartphone or tablet. In the case of worn glasses, the user directly sees the real world through them and the digital enhancements are projected on the glasses, whilst in handheld technologies the real-world image is received from their camera and the combination is rendered on-screen (e.g. see Fig. 1, Liritzis et al., 2015).



*Figure 1: Augmenting the Tholos of Delphi (Liritzis et al. 2015)*

Until about a decade ago, AR applications for cultural heritage sites required the use of special equipment. One of the first notable applications of AR in this domain was Archeoguide, an impressive system that could present animated 3D objects on top of the real-world view based on high-end tracking and rendering technology of the time (Vlahakis et al., 2002). The application offered visitors of Olympia the opportunity to see related content based on their position and viewpoint, such as a digital reconstruction of an ancient temple replacing the current ruins, or digital ancient athletes running in the stadium. Unfortunately, the necessary use of heavy and expensive equipment due to the technological limitations of the time has prevented the wide spread and adoption of similar approaches worldwide.

Today, the advancement of modern mobile devices' processing and rendering abilities and their enhancement with multiple sensors has led to the development of a number of mobile AR applications for museums and outdoor sites of cultural interest that augment the image of natural exhibits and monuments with additional information material (Koutsoudis et al. 2014; Angelopoulou et al. 2011), making them a useful tool for the dissemination of cultural heritage (Casella and Coelho 2013; Mohammed-Amin et al., 2012) and creating a more enjoyable experience for the visitors (Galatis et al., 2016). An indicating example is KnossosAR, an Android app designed to support the guided tour of secondary school students in an educational visit to the open-air archaeological site of Knossos (Galatis et al., 2016).

Furthermore, the mobile AR approach is considered by the scientific community as a valuable tool for learning, a dimension which is directly linked to the field of cultural heritage (Liarokapis et al., 2017). It has been recognized that informal learning is just as important as formal one, and mobile devices can serve as a bridge between these two types of learning (Gikas and Grant, 2013). Additionally, a considerable number of modern studies argue that the use of mobile AR applications has a positive impact on the student participation and the cultivation of various skills (Koutromanos and Avraamidou 2014; Koutromanos et al., 2015), and also that the interaction between visitors of a cultural heritage site and AR systems contributes to a richer experience (Han et al. 2014) and "positive learning outcomes and emotions" (Harley et al., 2016).

In the recent years, the gaming dimension has been added to mobile AR applications resulting into serious games with AR and location-based capabilities. Serious games, a class of digital games designed for educational purposes, have a number of advantages that turn them into effective learning tools (Mansour and El-Said 2008; Michael and Chen 2006). Mobile AR games designed for non-formal learning take advantage of user actions in both the digital and the physical world and create rich experiences adopting a more motivating and experiential approach to learning (Cheng and Tsai, 2013; Avouris and Yiannoutsou, 2012; Ardito et al., 2007). A number of these games, known as serious heritage games, aim at cultivating cultural awareness and acquainting the player with the archaeological monuments of a place (Mortara et al., 2014).

Finally, a variety of authoring tools have been deployed in recent years to develop mobile AR applications that can be used or designed for the cultural heritage sector and exploit the user's location-based technologies such as Hoppala, LoCloud, Tag-

gingCreaditor, TaleBlazer and Aris (Fidas et al., 2015). In this work, the ARIS 2.0<sup>2</sup> open source platform created by the University of Wisconsin was selected to support the creation of Augmented Reality and Interactive Storytelling applications and concern mobile devices with operating system iOS.

### 3. DESIGN AND IMPLEMENTATION OF THE MOBILE GAME

The design of a mobile AR game poses a number of challenges. First of all, being a serious game, designers have to ensure that it maintains a good balance between its playful character and the cognitive effect sought (Flanagan, 2009; Bellotti, 2010). Researchers also argue that the design team of these games should include specialists in mobile AR and educational technology to ensure that a number of factors are taken into account in the process, such as focus attention, satisfaction, mixed fantasy, interaction, challenge etc (Permadi and Rafi, 2015). Especially in the cultural heritage domain, one important challenge in designing a mobile app is to ensure that it covers the needs of the user, allowing him/her to focus mostly on the exhibits rather than the application itself (Kuflik et al 2011).

#### 3.1. Framing the problem

The mobile AR game we designed and implemented attempts to address two problems. First, from the observation of students during school visits to archaeological sites, it seems that groups of students are randomly wandering around looking at the monuments, sometimes refrain from reading their inscriptions, and usually it is difficult to focus on a single human guide. Second, visitors of the open-air archaeological site of Delphi cannot connect the natural space in which they tour to the monuments, statues and artifacts from the votive offerings exhibited in the Museum.

Therefore, the aim of this app is to enhance the students' visiting experience in the archaeological field through their active participation in a gaming environment. It attempts to help them focus on the important aspects of their visit in an entertaining manner and help them recall the museum exhibits and link them to the natural space. Ideally, to make them acquire a more positive stance towards archaeology and to abandon some of their possibly negative stereotypes about these visits.

#### 3.2. Target group and design goals

The target audience of the application are schools visiting the Delphi archaeological site during an educational field trip. In most cases, users will be stu-

dents between 12 and 15 years. As such, they are expected to have a certain degree of familiarity with mobile applications and digital games, and also to have the physical capability to walk a relatively long distance during their experience in the outdoor site.

The main design and pedagogical goals set out for the users of the application are:

- to learn the history and architecture of the most important monuments of the archaeological site and some historic figures whose name is associated with Delphi
- to link important exhibits of the Delphi Museum with the natural space where they have been buried for centuries, as well as the present setting of the archaeological site with the village that had been once there, named Kastri
- to develop their cooperative and teamwork skills
- to have fun during the visit to the site
- to have a positive attitude towards the experience of visiting an archaeological site
- to become familiar with augmented reality applications and mobile location-based technology in general.

#### 3.3. Initial survey

Before the detailed design of the mobile AR app, we decided to perform a survey to help us gain a broader understanding of the subject. We contacted prospective users of the application and asked them to fill a questionnaire and to participate in follow-up interviews. The goals of the survey were: a) to identify behaviours and attitudes of the students-visitors of the archaeological site based on their previous experiences, b) to learn about their preferences and needs regarding the type of information included in the app and the its connection to the physical site, and c) to have their opinion about special features and affordances that could be included in the design. The questionnaire we used included 10 questions and was filled by students of the school year 2016-2017 of the high school of the town of Delphi. In total, 23 students participated (10 girls and 13 boys).

The processing of the questionnaires and the follow-up discussion led to the following conclusions:

- Most of the students were familiar with the use of modern mobile phones, since they had a smartphone (83%). Their dominant operating system was Android, with almost twice as many users as iOS.
- The percentage of students who had experienced a tour of a site of archaeological interest using a mobile app was low (22%).
- Although a visit to an archaeological site was considered to be useful for almost half of stu-

<sup>2</sup> See <https://fielddaylab.org/make/aris>

dents (57%), for one out of four students it has been rated as a boring experience.

- All students had visited Delphi's archaeological site and were willing to take part in a future user study of the app under design (the study would help them compare different approaches to presenting a site and thus to draw useful conclusions).
- The majority of students would choose a portable device to tour an archaeological site (70%) instead of the traditional approach (such as a professional tour guide) and would like the application to include information on the exhibits of the Delphi Museum (91%).
- The media with which students would like to learn about the archaeological site were mainly videos with three-dimensional representations (74%) and past photographs of the monuments and the site.
- Only one student would prefer to participate individually in the game, while everyone else would prefer to take part in small groups sharing a single device.
- The characteristics of a mobile cultural game that have been rated as the most interesting by the teenagers were, in order of preference:
  - a. surprises, tests and puzzles, features of a treasure hunt game (21%)
  - b. mystery and adventure in the game scenario (20%)
  - c. competition through score and declaration of a winning team (17%)
  - d. the need to carefully observe the physical space as part of the game challenges (13%)

e. to evaluate the players' speed (5%).

### 3.4. Requirements analysis

Along with the survey, a series of visits to the archaeological site as well as meetings with an archaeologist of the Delphic Institute were carried out. The discussions with the archaeologist were about the aims and objectives of the educational application, the existence of similar applications or approaches, the planning of an optimal route within the space, the choice of monuments of interest, and the related spatial and historical information.

Taking into account the results of the above activities, as well as the findings of the initial survey, we reached to a number of requirements (technical, functional, aesthetic) and a set of constraints for the application. The first set of requirements concerns the game itself. The game rules should be intuitive and easy to follow, and the game should contain clear, unambiguous instructions on what players should do each time. The second set is about the spatial and environmental features of the open archaeological site, such as the distance that students have to cover, the number of possible routes, and the exposure of the visitors to difficult climatic conditions (such as long exposure to direct sunlight). These restrictions led to a number of requirements, such as that the game should be competitive only in terms of knowledge and quiz-answering and not in terms of player speed, and that duration of the game should not exceed 60 minutes. A third set of requirements concerned the educational aspects of the game, which led to the design of the game scenario and challenges.



Figure 2. The three landmarks of the game: Treasury of the Athenians (a), Temple of Apollo (b) and ancient theatre (c)

### 3.5. Game concept

The open-air archaeological site of Delphi includes two sanctuaries, the sanctuary of Apollo and the sanctuary of Athena. This application was restricted to the sanctuary of Apollo, and specifically to three monuments of this sanctuary, so that the game's duration is within the expected limits. The

landmark monuments chosen in the game were the Treasury of the Athenians, the Temple of Apollo and the ancient theater of Delphi (Fig. 2).

The types of media we decided to use in the game are texts with relevant historical information on each monument, video with three-dimensional digital representations of the monument, or theatrical acts that had been played at specific points in the area a

few decades ago, and past photographs or drawings of the monuments and space, from antiquity to before or during the excavation.

The fun element in serious games depends on the player's involvement with the story and the challenges, and also by factors such as narration, graphics, usability, cooperation / competition mechanisms, etc. (Mortara M. et al., 2014). To ensure that the application will be engaging for visitors, we included a variety of activities, such as puzzles to locate the landmarks, quest for hidden places (marked with QR codes), and rewards when players managed to answer a question successfully.

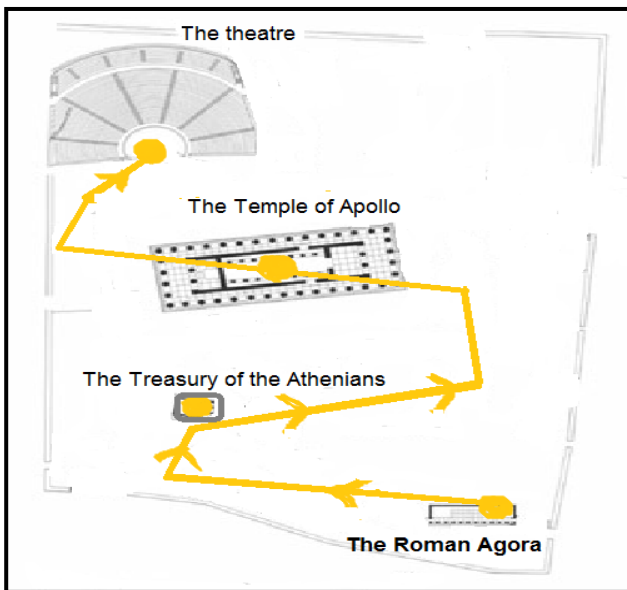


Figure 3: Route of the players in the game

Also, due to the importance of digital characters for the dissemination of cultural heritage and for the fun element (Vosinakis, 2017), we decided to include them as well. Digital characters have been designed to appear on landmark monuments and interact with players when they are in a particular location. The role of these characters was to provide information, guide the players, and ask or answer questions. The digital characters of this game were chosen to be:

1. *Pausanias*, a traveler who visited Delphi in the 2nd century AD.
2. *Plutarch*, the elder of the Apollo priests in the Delphi Delusion,
3. the poet *Angelos Sikelianos* and his wife *Eva Palmer*, whose names have been associated with the revival of the Delphic feasts in the ancient theater in 1927 and 1930,
4. *the group of French archaeologists* who participated in the "Great Excavation" of Delphi and
5. *Pythia*, the high priestess of Apollo at the Oracle.

Finally, the storyline on which the game was based was as follows:

*"We are in the 2nd century. B.C. in the Sanctuary of Delphi. Each player belongs to a group that has come to Delphi in order to receive an oracle from Pythia. But Pythia will give the oracle to the group that will be able to gather the greatest amount of money to pay the tax to the oracle".*

The scenario will be rolled out linearly, that is, each player has to follow a specific path (Fig.3) and, from one step to the next one, he/she will have to do perform an activity, such as reading a story, seeing a video or solving a quiz.

### 3.6. Interface and scenario

The game interface includes four tabs shown on the left of the screen which leads to respective selections for the player during the game. The selections are: 1) "Map", showing the map of the area and the current position of the player; 2) "The Treasury", a digital inventory where players can store the virtual items they collect during the game 3) "Scan", allowing users to scan a QR code tag with the camera of their portable device and 4) "Notes", where users are able to share different forms of feedback with the rest of the group.

The steps that capture the game flow as series of acts based on the landmarks are the following:

Initially, the players gather at the entrance of the archaeological site, the Roman Agora, divided into groups of 2-3 people and are presented with the basic game rules to play safely and efficiently. Each team downloads the application and creates an account in the ARIS platform.

The game starts. By choosing the "Oracle of Delphi app" (Fig. 4a), the group sees a short description of the game scenario on their home screen. The map of the archaeological site (Fig. 4b) is then displayed and the icon of the application's operating instructions (Figure 4c) appears in the player's current position.

Then the first digital character appears, Pausanias, who "introduces himself" and "explains" that their mission is to find three monuments of the sanctuary, where there are hidden quizzes, with questions of escalating difficulty. Each correct answer will give the players 5, 10 or 20 overs respectively, while each wrong answer will remove the same points. Then they will have to search around them for a QR code tag, which after scanning with their device, will display the data that will lead them to the first monument. The puzzle includes a photo of the monument as it was in 1906, at the time of its restoration (Fig. 4 d).

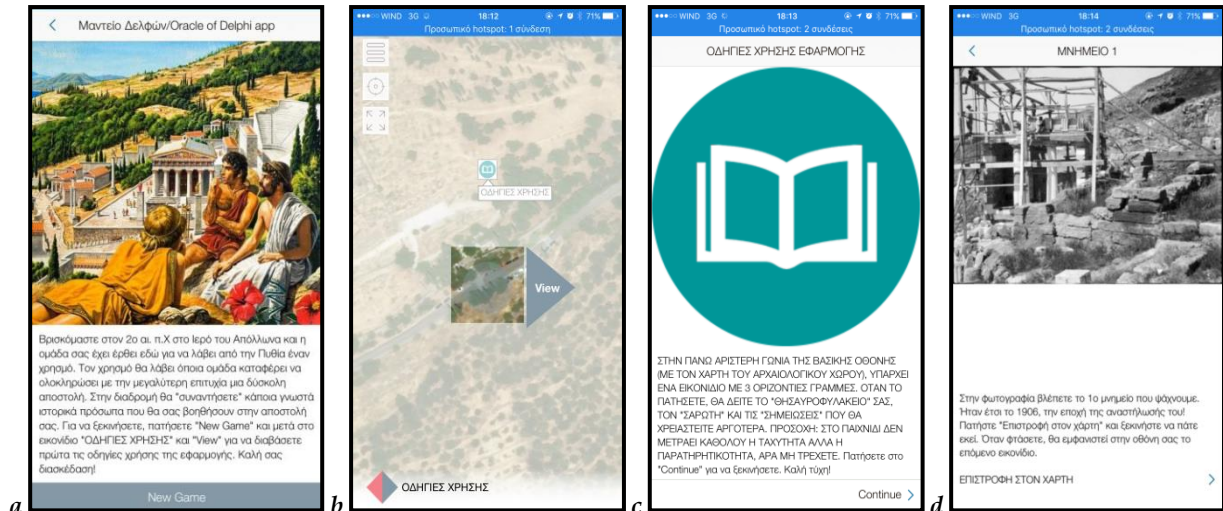


Figure 4: Screenshots of the "Oracle of Delphi app"

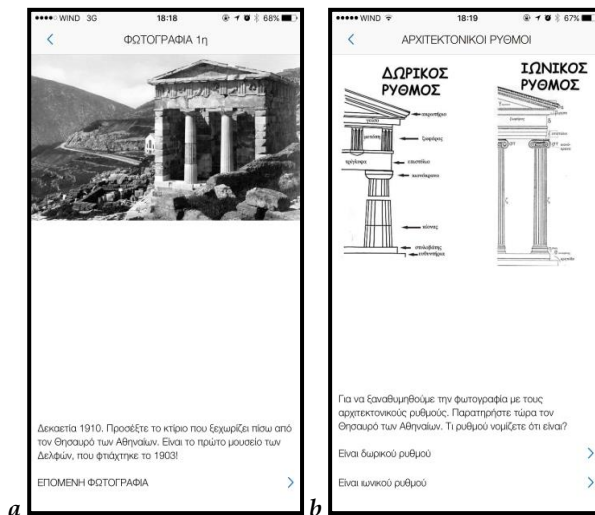


Figure 5: A sequence screenshots in in the Treasury of the Athenians (© EFA L'École française d'Athènes)

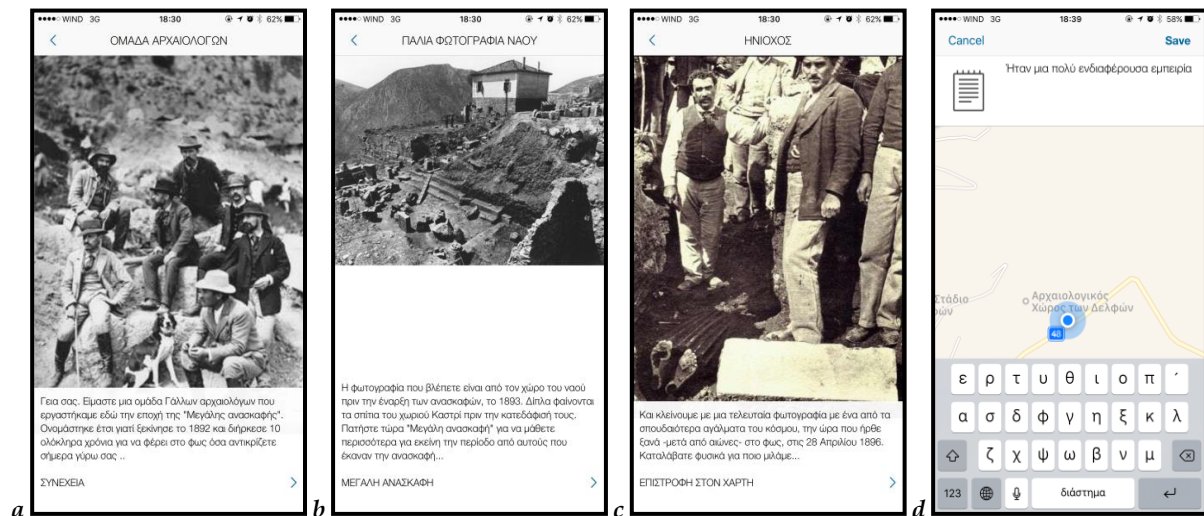


Figure 6: screenshots from the Temple of Apollo and the Roman Agora (a,b,c) and the Notes tab (d)

When the player approaches The Treasury of the Athenians, the following icons will appear sequentially on the map of the screen:

- a brief text with the most important information about the monument, a picture of the architectural styles of antiquity, so that the players can then be asked to recognize the rhythm of the monument, and its photographs as it was during the 1900s and 1940s (Fig. 5)
- a short three-dimensional video with the representation of treasury in antiquity
- a quiz of three questions of multiple choice and a degree of difficulty, as well as a puzzle to guide the player to the next monument (a photograph of the monument found during his excavation by the French Archaeological Society in about 1890).

In a similar manner the flow of the game continues in the ancient theater and the Temple of Apollo (Fig. 6 a, b, c), to finish in the Roman Agora, where Pythia "tells" a story with her most famous oracles and urges players to see in their treasury the set of items they managed to collect during the game. Then they read on their screen the words of Pythia, which is addressed to them, giving them, instead of the oracle, the verses of Cavafy's poem "Ithaca"?

*"Ithaka gave you the marvelous journey. Without her you would not have set out. She has nothing left to give you now. And if you find her poor, Ithaka won't have fooled you. Wise as you will have become, so full of experience, you will have understood by then what these Ithakas mean".*

Finally, players are allowed to choose the tab "Notes", to write a comment, to make an audio recording, to photograph something, or to see notes of other players (Fig. 6 d).

#### 4. USER STUDY

The goal of the user study was to examine the extent to which the main design goals have been achieved, as well as to identify any weak points in the game in order to make the necessary improvements and redefinition in the future. Furthermore, we expected to reach further insight about the suitability of this kind of technology for school field trips in cultural heritage sites, and possible aspects of improvement.

The evaluation method used was a field study, since the best way to understand the function of a spatially sensitive game is to test it in real conditions (Sterros et al., 2012), and to evaluate the technical performance, functionality and learning efficiency of the application.

The study was conducted in May 2017 with the participation of the students of the last two grades of

Delphi Junior High School (N=13 pupils: 9 boys-4 girls), with duration of approximately 30 minutes for each group of students, using four mobile devices with iOS (Fig. 7).



Figure 7: Students playing "Oracle of Delphi app"

During the game, three evaluators followed the students, observing them discretely. After completing the game, participants were asked to fill in a questionnaire to capture the overall quality of their experience and add any free comments they may have. A follow-up discussion with the students allowed us to take further notes about their experience.

#### 4.1. Evaluation results

The questionnaire had thirteen (13) questions asking students to rate their experience with the game, that were answered on a 5 point Likert scale (1 – not at all; 5–very much). Table I shows the questions and the respective number of answers in each step of the scale. Furthermore, it asked them to rate the individual elements of the game and the results are shown on Fig.8.

Table I: Rating results

Question	1	2	3	4	5
Game satisfaction	0	0	0	6	7
Difficulty to learn the game	11	1	1	0	0
Difficulty to use due to device size	11	2	0	0	0
Difficulty to understand instructions	1	4	2	1	5
Having technical problems	5	7	1	0	0
Entertainment during the game	0	0	0	7	6
Agony for victory	1	2	4	2	4
Desire to use mobile AR again	0	0	3	4	6
Immersion in the game	1	2	1	8	1
Difficulty of quizzes	3	6	4	0	0
Observation of the monuments during the game	1	2	3	3	4
Reading the in-game info	0	1	4	6	2
Acquiring new knowledge	0	0	1	7	5

The processing of the questionnaire answers led to the following conclusions.

The students generally received a very positive impression of the game and would like to relive this experience with another similar game in the future.



The majority of students thought the game was very easy to operate (85%), that the small screen of the device did not limit the experience (85%), and that the game helped them gain new knowledge (92%).

There was heavy competition between the teams, which reinforced their interest in the game and the effective cooperation among the team members.

The elements of the game most liked by the students were in order of preference: the quizzes with the questions (85%), the old black-and-white photographs (77%), the puzzles of locating the monuments (70%) and the texts with the short story of each monument (54%).

However, the evaluation process has brought to light some drawbacks of the application, which in the future will have to be reconsidered:

For a significant percentage of students (38%) it was unclear at some points in the game what to do or where to go to, which highlights the important of providing clear goals in an AR game, and raises the need to re-check the game's navigation instructions in the future.

Most students (77%) were moderately or heavily stressed during the game, prioritizing winning of the game and less to observe the monuments. Thus, they have been focusing much more on game quizzes and less on historical and archaeological information. This negative element was eliminated at those points where the text contained expressions such as *"read carefully the following, because they will be useful to solve the puzzles later"* or *"observe the point of the monument because you will need it below."*

Finally, from the observation of the behavior of the students and of the dialogues between the members of each team during the game, we reached the following findings:

1. the enthusiastic involvement and the high degree of immersion of all students in the "Oracle of Delphi app" game, as demonstrated by the subjective perception of the sense of time and the lack of perception of the presence of other visitors in the space
2. the development of a strong group spirit among the members of each group
3. the great ease of managing the AR approach by the students "looks like the pokemon go, perfect!"
4. the difficulties that certain characteristics of the physical space caused to the game, e.g. difficulty of viewing the content due to the large number of visitors, and
5. individual technical problems, which resulted in delayed start of the game for certain groups due to low GPS signal at the starting point of the game and the inability to run the game on

one of the devices because it did not have a required software update.

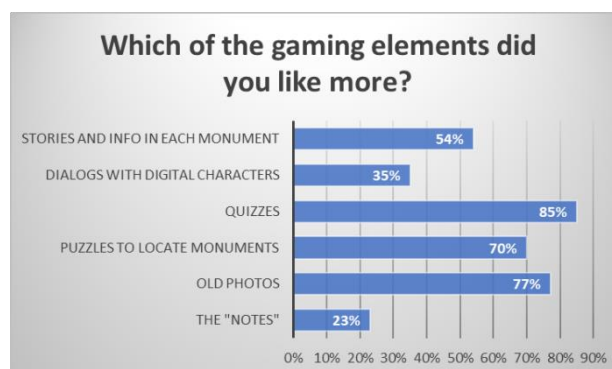


Figure 8: Preferences of game content elements

## 5. CONCLUSIONS

This article presented the mobile AR application "Oracle of Delphi app", implemented for the archaeological site of Delphi. The application was tested with the main research goal of revealing usability, efficiency and learning efficacy issues in outdoor heritage sites. The study results provided positive indications regarding the utility and ease of use of the application, as well as the enthusiastic involvement of the players. The combination of natural monuments and virtual information has inspired curiosity and stimulated students' interest in exploring the archaeological site. Also, the use of mobile AR technology exposed students in a different way of interaction, which they easily understood.

The evaluation process has also resulted in a number of possible extensions and improvements for the mobile game. These include its development for android mobiles, enriching it with more types of "Quests" for students, and using richer and more detailed multimedia content, the addition of other languages for foreign visitors, additional player options, such as selecting the amount of information to be provided, receiving help, and selecting a sequence that will be played in the game so that not all players follow the same route, and finally extending the game to more locations and ancient monuments (such as the temple of Athena Pronaia, the treasury of the Massaliots, the Gymnasium and the Tholos and the Castalian Spring).

An important element that needs to be taken into account in general is the complexity of the problem space and of the features to be considered and balanced in the design of edutainment applications for archaeological sites. A multidisciplinary approach and the cooperation of experts from various fields, such as archaeologists, educators, usability experts, etc, is a necessity. Unfortunately, in Greece and internationally - according to the study of existing literature and searches on official sites of archaeologi-

cal sites - there have been no major steps to exploit mobile-AR and space-sensitive games for outdoor heritage sites visitors.

As mobile AR technology is underway and smart devices are the dominant technology with which students come into daily contact, useful educational

applications such as the one studied in this paper can be a new way of approaching archaeological sites of young people, offering them a fun and yet rich learning experience, avoiding expensive high-end solutions.

## ACKNOWLEDGEMENTS

We would like to thank the Archaeologist of Delphi, Mr. Tsaroucha Anthoula for her useful advice and the former Director of the Delphi Junior High School, Mr. Cornezos Charalambos, for his support in the process of testing the application in the archaeological site by the students of the school. The copyrights of the photographs used for the purposes of the application that was implemented belonged to the French Archaeological School and were drawn from official websites<sup>3,4</sup>. Finally, it should be mentioned that this thesis is part of the diploma thesis elaborated by the author of the work Ekonomou Theodora in the framework of the master "Applied Archaeological Sciences" in the Department of Mediterranean Studies of the Aegean University<sup>5</sup>.

## REFERENCES

- Angelopoulou, A., Economou, D., Bouki, V., Psarrou, A., Jin, L., Pritchard, C., Kolyda, F. (2011) "Mobile augmented reality for cultural heritage", *Proceedings of the 4th International Conference on Mobile Wireless Middleware, Operating Systems, and Applications*, Springer, pp. 15-22.
- Ardito, C., Buono, P., Costabile, M.F., Lanzilotti, R., Pederson, T. (2007). Mobile games to foster the learning of history at archaeological sites. *Proceedings of the IEEE Symposium on Visual Languages and Human-Centric Computing*, pp. 81-86. DOI Bookmark: <http://doi.ieeecomputersociety.org/10.1109/VLHCC.2007.54>
- Avouris, N., & Yiannoutsou, N. (2012). A Review of Mobile Location-based Games for Learning across Physical and Virtual Spaces. *Journal of Universal Computer Science*, Vol, 18, Issue 15, pp 2120-2142.
- Bellotti, F., Berta, R., & De Gloria, A. (2010). Designing Effective Serious Games: Opportunities and Challenges for Research. *ijET*, 5(SI3), pp. 22-35
- Casella, G. & Coelho, M. (2013) Augmented heritage: situating augmented reality mobile apps in cultural heritage communication, *Proceedings of the International Conference on Information Systems and Design of Communication*, pp. 138-140.
- Cheng, K. H. & Tsai, C. C. (2013). Affordances of augmented reality in science learning: Suggestions for future research. *Journal of Science Education and Technology*. Vol. 22, Issue 4, pp 449-462.
- Fidas, C., Sintoris, C., Yiannoutsou, N. & Avouris, N. (2015) A survey on tools for end user authoring of mobile applications for cultural heritage. 6th International Conference on Information, Intelligence, Systems and Applications (IISA), Workshop on Mobile Hipermedia Applications for Culture, Corfu, July 2015, pp. 1 - 5.
- Flanagan, M. (2009). *Critical Play. Radical Game Design*. Includes bibliographical references and index. ISBN 978-0-262-06268-8
- Galatis, P., Gavalas, D., Kasapakis, V., Pantziou, G. & Zaroliagis, C. (2016). Mobile Augmented Reality Guides in Cultural Heritage. *MobiCASE'16 Proceedings of the 8th EAI International Conference on Mobile Computing, Applications and Services*, pp. 11-19.
- Gikas, J. & Grant, M. (2013). Mobile computing devices in higher education: Student perspectives on learning with cellphones, smartphones & social media. *Internet and Higher Education*, Vol. 19, pp 18-26.
- Han, D., Leue, C., & Jung, T. (2014). A tourist experience model for augmented reality applications in the urban heritage context. In: *APacCHRIE Conference*, 21-24 May 2014 Kuala Lumpur. Manchester: Manchester Metropolitan University.
- Harley, J. M., Poitras, E. G., Jarrell, A., Duffy, M. C., & Lajoie, S. P. (2016). Comparing virtual and location-based augmented reality mobile learning: emotions and learning outcomes. *Educational Technology Research and Development*, 64(3), pp. 384.

<sup>3</sup> See <http://www.delphi.diadrasis.net>

<sup>4</sup> See [http://odysseus.culture.gr/h/3/gh3530.jsp?obj\\_id=2507](http://odysseus.culture.gr/h/3/gh3530.jsp?obj_id=2507)

<sup>5</sup> See <http://dms.aegean.gr/en/> [Economou, T. (2017). Development of an educational application Augmented Reality for a conducted tour in the archaeological site of Delphi. The Department of Mediterranean Studies. University of the Aegean, Lab of Archaeometry, Rhodes, Greece]

- Haugstvedt, A. C. & Krogstie, J. (2012) Mobile augmented reality for cultural heritage: A technology acceptance study, *Proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR), IEEE International Symposium on Mixed and Augmented Reality 2012 Science and Technology Proceedings* 5 - 8 November 2012, Atlanta, Georgia pp. 247- 255.
- Koutromanos, G. & Avraamidou, L. (2014). The use of mobile games in formal and informal learning environments: a review of the literature. *Educational Media International*. Vol. 51, Issue 1, pp 49-65.
- Koutromanos, G. , Sofos, A. & Avraamidou, L. (2015). The use of augmented reality games in education: a review of the literature. *Educational Media International*. Vol. 52, Issue 4, pp 253-271
- Koutsoudis, A., Arnaoutoglou, F. & Pavlidis, G. (2014). Passive markers as a low-cost method of enriching cultural visits on user's demand. *Journal of Advanced Computer Science & Technology*. Vol 3, No 1, pp. 12-17.
- Kuflik, T., Stock, O., Zancanaro, M., Gorfinkel, A., Jbara, S., Kats, S., Sheidin, J. & Kashtan, N. (2011). A visitor's guide in an active museum: Presentations, communications, and reflection. *Journal on Computing and Cultural Heritage*. Volume 3 Issue 3, article 11.
- Liarokapis, F., Petridis, P., Andrews, D., de Freitas, S.: *Multimodal Serious Games Technologies for Cultural Heritage, Mixed Reality and Gamification for Cultural Heritage*, Part V, Springer International Publishing, pp. 388, (2017)
- Liritzis, I. ,Al-Otaibi, F.M, Volonakis, P and Drivaliari, A. (2015), Digital technologies and trends in cultural heritage. *Mediterranean Archaeology and Archaeometry*, Vol. 15, No 3. pp. 313-332.
- Mansour, S. & El-Said, M. (2008). The Impact of Multi-Players Serious Games on the Social Interaction among Online Students versus Face-to-Face Students. *7th. WSEAS International Conference on Applied. Computer & Applied Computational Science*, pp 772-778.
- Michael, D. & Chen, S. (2006). *Serious games: Games that educate, train, and inform*. Thomson Course Technology PTR.
- Mortara, M., Catalano, C. E., Bellotti, F., Fiucci, G., Houry-Panchetti, M. & Petridis, P. (2014). Learning cultural heritage by serious games. *Journal of Cultural Heritage*, Vol. 15, Issue 3, pp. 318-325.
- Permadi, D., & Rafi, A. (2015). Developing a conceptual model of user engagement for mobile-based augmented reality games. *Jurnal Teknologi*, 77(29), 9-13.
- Mohammed-Amin, R.K., Levy, R.M., Boyd, J.E. (2012). Mobile augmented reality for interpretation of archaeological sites. *Proceedings of the 2nd International Workshop on Personalized access to cultural heritage*, pp. 11-14.
- Schmalstieg, D., Langlotz, T. and Billinghurst, M. 2011. *Augmented Reality 2.0*. Springer Vienna. 13-37.
- Serino, M., Cordrey, K., McLaughlin, L., & Milanaik, R. L. (2016). Pokémon Go and augmented virtual reality games: a cautionary commentary for parents and pediatricians. *Current opinion in pediatrics*, Vol. 28(5), 673-677.
- Stenos, J., Waern , A., Montola, M. (2012). Studying the Elusive Experience in Pervasive Games. *Simulation and Gaming*. Vol 43, Issue: 3, pp: 339-355
- Vlahakis, V., Ioannidis, N., Karigiannis, J., Tsotros, M. , Gounaris, M. , Stricker, D., Gleue, T., Daehne, P. & Almeida, L. (2002). Archeoguide: an augmented reality guide for archaeological sites. *Computer Graphics and Applications*, Vol. 22, pp. 52-60.
- Vosinakis, S. (2017). Digital Characters in Cultural Heritage Applications. *International Journal of Computational Methods in Heritage Science (IJCMHS)*, 1(2), 1-20.
- Yovcheva, Z., Buhalis, D., & Gatzidis, C. (2013). Engineering augmented tourism experiences. In L. Cantoni & Z. Xiang (Eds.), *Information and Communication Technologies in Tourism*, pp. 24-35.