Mobile Augmented Reality Guides in Cultural Heritage

Panagiotis Galatis
School of Science & Technology
Hellenic Open University
Patras, Greece
galatisp@gmail.com

Damianos Gavalas
Department of Cultural Technology and Communication, University of the Aegean, Mytilene, Greece
&
CTI, Patras, Greece
dgavalas@aegean.gr

Vlasios Kasapakis
Department of Cultural Technology and Communication, University of the Aegean, Mytilene, Greece
&
CTI, Patras, Greece
v.kasapakis@aegean.gr

Grammati Pantziou
Department of Informatics, Technological Educational Institution of Athens, Athens, Greece
&
CTI, Patras, Greece
pantziou@teiath.gr

Christos Zaroliagis
Department of Computer Engineering & Informatics, University of Patras, Patras, Greece
&
CTI, Patras, Greece
zaro@ceid.upatras.gr

ABSTRACT
Mobile augmented reality (MAR) technology creates unprecedented possibilities for delivering engaging, immersive experiences to the visitors of cultural heritage sites. Despite the proliferation of available prototypes, the relevant literature still lacks studies investigating the way that users interact with MAR interfaces as well as identifying major usability problems and technology acceptance factors. Herein, we present KnossosAR, a MAR guide implemented for the archaeological site of Knossos (in Crete, Greece) which serves as a testbed for pursuing the abovementioned research objectives while also comparing the (dis)advantages of MAR vs. map-based mobile interfaces in outdoor cultural heritage sites. Among other technical contributions, KnossosAR addresses the occlusion problem, which is commonly encountered in location-based AR applications; that is, it employs an efficient method for estimating the field of view (FoV) of the user in order to handle situations wherein a point of interest is occluded by a physical obstacle (e.g. building). We have conducted field trials which provide preliminary evidence of the efficiency, effectiveness and utility of KnossosAR (including the incorporated FoV estimation approach).

CCS Concepts
• Software and its engineering→Software creation and management • Information systems→Information systems applications • Human-centered computing→Human computer interaction (HCI) • Human-centered computing→Ubiquitous and mobile computing.

Keywords
Augmented reality; mobile guide; cultural heritage; archaeological site; Knossos; occlusion; user evaluation.

1. INTRODUCTION
The diffusion of smartphones and tablets has paved the way for a multitude of mobile augmented reality (MAR) applications in cultural heritage, most of which are museum guides, visually augmenting physical exhibits with background or interpretive information [1, 13]. Several among the known storytelling-driven projects, which use AR to convey the history of a place in the context of a guided tour, are mainly implemented for the outdoors [1, 2, 16]; those use the device's GPS receiver and inertial sensors, typically, to superimpose virtual objects on the physical environment framed by the camera's display. For instance, the mobile device may be used to display AR views of a building, to receive additional location-based information, or to listen to audio and 3D-enhanced narrations [6, 25].

Despite the proliferation of the available prototypes, the relevant literature still lacks studies about usability and technology acceptance factors as regards the effective use of MAR technology in outdoor cultural heritage applications. Our main focus is on comparing the MAR interface in location-based guides against alternative options like map-based or audio interfaces. The research questions addressed in this article are: (a) whether the MAR paradigm indeed involves a more natural and intuitive interface than that of conventional two-dimensional maps; (b) what is the actual quality of experience perceived by mobile users; (c) what are the most desired characteristics of MAR and map-based paradigms, i.e. what makes a practical, intuitive, and stimulating user interface. To address our research objectives, we have implemented KnossosAR as a case study. This is an outdoor MAR guide for the Unesco world heritage site of Knossos, the largest Bronze Age archaeological site on Crete (Greece) which is considered as the oldest city in Europe.

On the course of the iterative development process pursued for KnossosAR, we have encountered a critical usability problem dealt with in numerous AR applications. This is the partial or full occlusion of points of interest (POIs) by physical obstacles (e.g. buildings). Those POIs are treated indiscriminately by mobile location-based AR frameworks, regardless of whether they are actually within the field of view (FoV) of the user or not. However, displaying occluded objects (e.g. overlaying a marker or any sort of interpretive information about a hidden POI) often results in misconceptions and wrong pursuance of tasks amongst users [19,

22] thereby compromising the clarity and explicitness of AR applications. Practically, the occlusion problem has been addressed so far only in indoor environments. Although not being part of our original research plans, occlusion handling represented a major design consideration for KnossosAR. Namely, the feedback received on early prototypes of KnossosAR (by the members of a focus group) revealed the need for real-time FoV estimation in MAR applications developed for outdoor archaeological sites. KnossosAR has undergone field trials which provided preliminary evidence of its efficiency, effectiveness and utility (including the incorporated FoV estimation approach).

The remainder of this article is structured as follows: Section 2 presents previous research related to our work. Section 3 discusses the design and implementation details of KnossosAR. Section 4 introduces the FoV estimation method incorporated in KnossosAR. Section 5 discusses our main user evaluation findings. Finally, Section 6 concludes our work.

2. RELATED WORK

Recent developments in mobile computing (such as the wide penetration of mobile devices equipped with camera, GPS receiver and inertial sensors) shaped a favorable technology landscape for MAR applications. MAR services provide a novel interface to the ubiquitous digital information in the physical world, hence serving in great variety of application contexts [5].

Among others, MAR technology opens up unprecedented possibilities to cultural organizations and institutions like museums and archaeological societies/services which do not necessarily need to invest in buying dedicated hardware infrastructure, but rather take advantage of devices own by visitors. As a result, the MAR-based guides developed for cultural heritage sites have proliferated in the recent years. So far, the majority of relevant prototyped applications are tailored to indoor environments employing computer vision [13] or some sort of fiducial markers [7, 8] to recognize exhibits.

However, the literature specifically focusing on outdoor MAR without the use of bulky or cumbersome wearables [4, 23] is still scarce. Moving a MAR application outdoors is particularly challenging, especially when considering archaeological sites and excavations where interactive storytelling and environmental context could play a significant role in the user's experience. Such a system would require an intuitive human-computer interface based on metaphors, hotspots, logical clues, delivered on mobile device screens. The users would interact with augmented information of the excavated objects and would be able to compare artifacts over different historical periods [1].

Along this line, Mohammed-Ammin, et al. [16] presented a MAR tour guide for visitors of the archaeological site of Arbela, Iraq. The guide presents the complex and multifaceted history of the site, including superimposed 3D models of buried layers left by successive civilizations which inhabited the area. The user's location and nearby geo-tagged content is shown through a two-dimensional map interface.

Ardito et al. [2] presented a MAR system designed to support young students in learning history in the archaeological site of Egnathia, in the Apulia region, Italy. The proposed system employs a gamification approach to stimulate students in acquiring historical notions, thereby making the archaeological visit more effective and exciting.

Angelopoulou et al. [1] presented a multi-user MAR educational iOS application for the archaeological site of Sutton Hoo (UK), offering interpretive information for a group of Anglo-Saxon burial mounds. The site combines indoor and outdoor POIs that need to be connected. The AR tour is delivered in the form of a team-oriented puzzle game. A number of teams of children visitors are cast into the role of investigators trying to solve a number of puzzles that involve finding specific exhibits from the excavation site.

The aforementioned projects have demonstrated the potential of MAR technology as a means for delivering stimulating experiences to the visitors of archaeological sites. Nevertheless, thorough investigation is still needed to understand the way that users interact with MAR interfaces, address usability problems and identify technology acceptance factors. Even more so to compare the relevant (dis)advantages of MAR vs. map-based mobile interfaces in outdoor cultural heritage sites.

3. KNOSSOSAR: ITERATIVE DESIGN PROCESS

The primary purpose of KnossosAR is to utilize MAR technology to support guided tours of secondary school students (either alone or in groups) while on educational visit on outdoor archaeological sites. In particular, the educational and learning objectives for students supported by KnossosAR have been specified in consultation with educators and archaeologists, as follows:

- Become acquainted with the palace of Knossos (architecture, decoration, art of pottery and frescoes) and compare its complexity with that of the Minotaurous maze.
- Acquire basic knowledge about the Minoan Crete, its sovereignty in the sea and the spread of the Minoan civilization through trade.
- Become acquainted with characteristic elements of life in the Minoan Crete: occupations, housing, food, clothing and toilette.
- Comprehend the causes that led to the destruction of the Minoan civilization.

Contemporary theories of learning suggest that the above listed educational objectives should be pursued through approaching the historical context revealed in Knossos experientially [14]. Namely, KnossosAR could serve as a technological assistant to locate POIs in the archaeological site and derive contextual interpretive information via various media.

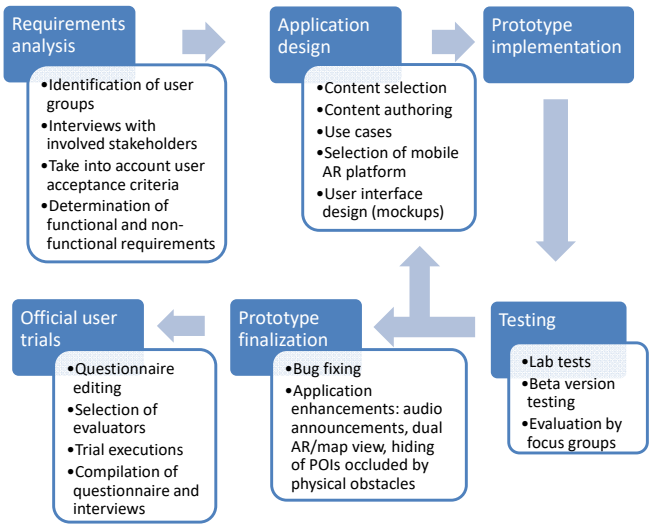


Figure 1. Illustration of KnossosAR development cycle.

Through using the application, students should be able to build sufficient knowledge background by undertaking the role of explorer, based on the principles of discovery and exploratory learning. Collaborative and cooperative learning should also be encouraged so as to capitalize on one another's resources and abilities and enable the development of social skills. Finally, the application should cater for the emotional development of students. Dominant emotions are expected to be the tension resulting from the action, the joy of discovery, the fulfillment of achievement.

KnossosAR has been developed following an iterative software development cycle (see Figure 1): requirements analysis; design; prototype implementation; testing; prototype finalization; official user evaluation.

3.1 Requirements analysis

The requirements analysis of KnossosAR adopted the Volere methodology [17]. The application requirements have been elicited by involved stakeholders (archaeologists experts in Knossos, professional guides and curators from local cultural heritage institutions, educators, students). Our requirements analysis also consolidated 'good practices' derived from similar MAR projects and general principles for usability design [3, 9]. The main functional and non-functional requirements identified for KnossosAR are as follows:

- The application should support the autonomous tour guidance of users in the archaeological site; users should be able to follow their own explorative routes with their preferred pace and be able to retrieve information about POIs/landmarks under a variety of augmentation forms, including textual descriptions, audio narrations, images and 3D graphics.
- The application design should make no assumptions on any kind of supportive infrastructure (e.g. WiFi installation, attachment of fiducial markers on POIs); hence, it should be developed upon a sensor-based AR framework and be able to function as a standalone application so as not to be sensitive to network disconnections and avoid roaming charges.
- User input should be rare and limited.
- The application should offer an intuitive interface so as not to distract the user from his/her main visiting purpose, namely the experiential exploration of the archeological site.
- The application should support educational objectives as to motivating students to discover information about specific elements of the site.
- The guided tour should be offered in a playful manner (i.e. incorporate gamification elements) aiming at increasing the user commitment and engagement in the exploration of the site.
- The application design should be easy to replicate and port to other cultural heritage sites.

3.2 Application design

The application content has been dictated by archeologists and educators based on the rationale of selecting a set of POIs regarded as being most important while also serving the learning objectives of educational visits, as discussed earlier. Those POIs are:

- The Throne Room with the famous alabaster throne and frescoes, where it is speculated that King Minos met with the priesthood.
- The Stepped Portico (covered stairway) leading to the palace complex.
- The South Entrance, where the plaster relief "Prince of lilies" or "Priest-king Relief" has been discovered.
- The royal apartments where one can admire the natural lighting system and air conditioning of premises and frescoes like that of dolphins and sea urchins in the queen's room.
- The compartments with the giant storage jars, used in trade shipment with other peoples in the Middle East, Egypt and the Aegean.
- The Sewer System, leading rainwater away from the palace complex. In the same area there are signs of the great destruction of the palace.

Upon the selection of POIs, we then proceeded to content authoring: text (POI description) authoring, recording of audio clips (narration of textual description), editing of photographs, videos, etc.

The application design phase also involved the specification of a number of use case scenarios. Namely, the detailed formal (UML) definition of the interactions between the involved actors and the application components to achieve specific goals (tasks).

Based on the use case diagrams we then derived the UI mockups which exposed the basic functionality of the envisioned application and served as a tool to solicit early feedback from archeologists and educators as well as from the end users (students). This feedback has been take into account so as to adjust several UI and interaction elements prior to prototyping the application.

3.3 Iterative prototyping and testing

KnossosAR has been developed as a standalone application for the Android platform. The Android Augmented Reality Framework[1] has been chosen to support the projection of AR views as it also facilitates the implementation of several desired features such as a visual metaphor of a 'radar' used to display the location of POIs (represented by dots) relatively to the user's location and direction. The development of KnossosAR comprised iterative prototyping and testing phases. The output of each prototyping phase has undergone extensive 'lab' tests as well as evaluation by focus groups. The focus group comprised a team of three technologically literate individuals who provided analytical feedback as regards spotted software bugs as well as usability flaws and missing functionality.

The first prototyping phase comprised the implementation of a fully functional prototype. The interpretive information edited for the selected POIs (see Section 3.2) has been incorporated into the AR framework. In addition to the AR view, a standard map view has been developed to offer users an alternative means for locating POIs (the map view indicates both the current location of the user and POI locations by color-coded markers). The most important remarks and suggestions for improvements highlighted by the focus group members during the first testing phase have been:

- At some points, the AR view included markers for POIs hidden from certain viewpoints as this has been the default function of the AR framework. This often resulted in confusion and misconception, therefore, it has been suggested to allow hiding markers associated with occluded POIs[2].

[1] https://github.com/phishman3579/android-augment-reality-framework

[2] Some of the focus group members argued that the display of AR markers based on proximity would be sound in a city guide wherein, for instance, the user would like to know the restaurants located up to a certain distance from his/her current location. Nevertheless, this is undesirable in the functional context of KnossosAR where the main purpose of the user is to recognize POIs as s/he walks around the archaeological site.

- While the application has been configured to automatically display visual indications about annotated POIs when the user came close to them, this often remained unnoticed as the users typically walked around the site only occasionally checking their device's screen.

(a)

(b)

Figure 2. (a) Displaying and (b) hiding an AR marker associated with an occluded POI.

Based on the elicited feedback, the original prototype has been adapted as follows:

- The markers corresponding to occluded POIs have been hidden. Essentially, this has been realized through the incorporation of the FoV determination technique presented in Section 4. To compensate for the hidden information, we have opted to implement a third view (further to the AR and the map views): a dual view which comprises a split screen combining the AR and map views. This allows users to have a broader perception if the site; namely, to locate POIs (in the map section of the screen) which could otherwise remain unspotted due to being out of the user's FoV, thus, hidden in the AR view.
- On the event of approaching a POI in less than 5 m distance, the user is optionally notified via an audio announcement and/or device's vibration.

The hiding of AR markers associated with occluded POIs is demonstrated in Figure 2. Figure 3 illustrates the ground plan of Knossos designating POIs and obstacles.

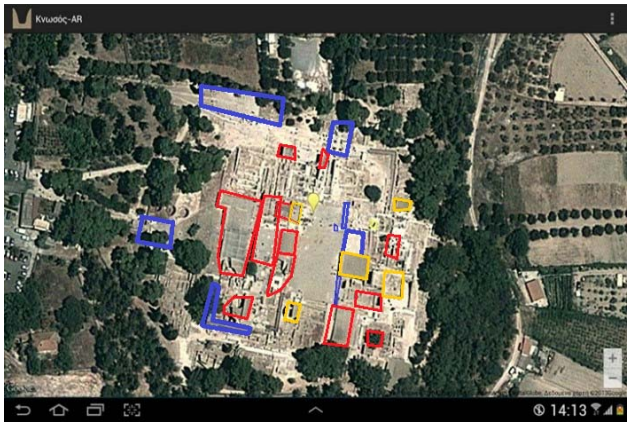
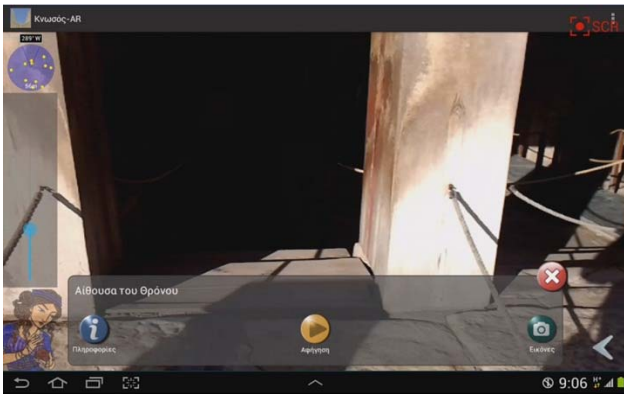
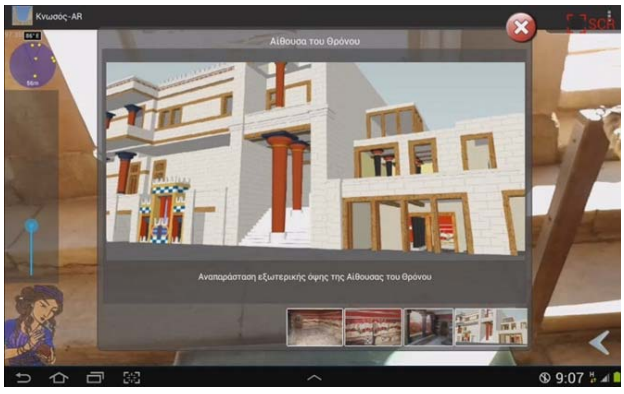


Figure 3. Ground plan of Knossos with color indication of POIs (yellow), buildings obstructing the users' view (red) and ruins of zero height, hence, not regarded as obstacles (blue).

In order to implement audio announcements we have adopted methods commonly practiced in acoustic spaces [20]. Upon approaching a POI the user listens to a short audio message announcing the POI's identity (title). As a result, the users are disengaged from continuously looking up their device's screen. Thus, they are left to focus on the actual exploration of the archeological site and pursue a more relaxed visit style. In addition to receiving audio notification, a popup panel provides the user access to POI-relevant information (textual description, audio narration, slide show) (see Figure 4). This panel also appears when the user taps on a marker in the AR view.



(a)



(b)

Figure 4. (a) Popup panel providing access to interpretive information relevant to a POI; (b) slide show.

Last, the dual AR/map view of KnossosAR is shown in Figure 5.

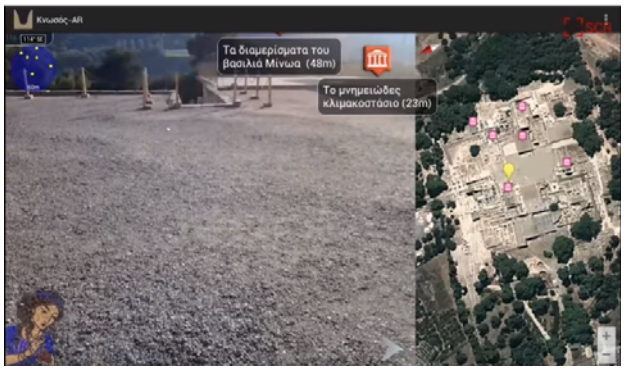


Figure 5. The dual view which combines the AR and map views.

4. FIELD OF VIEW DETERMINATION

Höllerer et al. [10] have recognized the problem of POIs occluded by physical obstacles (such as buildings) and argued that AR projections should be appropriately adjusted to convey correct depth information. The literature dealing with the occlusion problem in AR mainly considers the occlusion of virtual objects by real ones. Along this line, several works have focused on providing depth perception through employing computer vision methods, such as edge-based tracking [15, 21, 24] or marker-based tracking [12]. These approaches either require (offline) registration of the physical environment (therefore, they cannot be easily relocated elsewhere) or involve computationally hard image-processing tasks.

However, typical outdoor AR applications entail far stricter requirements: real-time performance; anytime/anywhere execution (hence, support for consuming open geodata, especially topography/building data); suitability for executing on average mobile equipment. Moreover, many applications would benefit from accurately estimating the user's FoV, which is a problem more generic than occlusion estimation: FoV refers to the whole area being within the user's view in the 2D or 3D space, while occlusion detection refers to testing the Line of Sight (LoS) condition between the user and a specific point. Unlike existing methods, our focus has been on methods for determining LoS/FoV while also satisfying the above listed requirements of outdoor AR applications.

To address the aforementioned issues, we prototyped an efficient geolocative raycasting method which allows to detect buildings in location-based AR applications, thereby reliably resolving the object occlusion issue. Our method is inspired by the raycasting technique utilized in video games to estimate the visibility of virtual objects. Raycasting refers to the act of casting imaginary light beams (rays) from a source location (typically the point of view of the character or object controlled by the player) and recording the objects hit by the rays [18]. Herein, we extend this idea in outdoor AR applications wherein, unlike video games, the virtual space is integrated with the physical one, which is not pre-registered and occlusion is typically caused by surrounding buildings. Our geolocative raycasting technique, titled Ray-Polygon Intersection (RPI), suggests a portable scheme which may be incorporated in any outdoor AR application and be utilized at any urban setting, provided that sufficient topographical data exist.

[3] Bearing refers to the angle of a moving object's direction from the North.

It is noted that, in addition to the device's exact location, RPI requires the calculation of the device's orientation (bearing[3]) based on measurements taken from the accelerometer and magnetometer sensors of the device. Thereafter, the bearing is set as the center of the player's FoV. The precise estimation of the player's FoV (i.e. the exact 2D polygon which delimits the player's sight) may then be undertaken by the approach discussed in the sequel.

Our FoV determination approach employs an efficient, geometric ray intersection method. Initially, building polygons are deconstructed to pairs of vertices, each referring to a polygon side (line segment). We then generate a sequence of ray segments (consecutive rays are $angle_s$ degrees far from each other) from the leftmost to the rightmost FoV's angle ($angle_l$ and $angle_r$, respectively) considering the current bearing of the device as the bisector of the FoV's angle. The edges of each ray segment are set to the device's location and the ray's endmost point being d_{max} far (maximum FoV distance). To determine FoV we then calculate the intersection points among each ray segment and the building polygon side lines. For each ray segment, the intersection point which is nearest to the device is regarded as the furthest FoV point along this particular ray. It is noted that, since no open geodata have been available for the archaeological site of Knossos, the building (polygon) coordinates in KnossosAR (both for the POIs and the buildings that may possibly occlude POIs) have been manually edited.

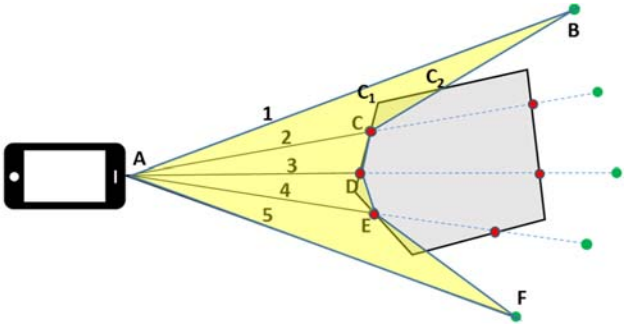


Figure 6. FoV determination utilizing the ray intersection approach.

Figure 6 demonstrates our method through a simplified scenario which involves five rays and a building polygon. The green circles denote the endmost points of the five ray segments while the red circles denote the intersection points of the rays with the building polygon sides. The yellow-shadowed area (ABCDEF) represents the estimated FoV polygon. Note that the accuracy of FoV estimation depends on the density of rays (i.e. their in-between angle). For instance, the triangle CC1C2 is erroneously considered to be within the player's FoV (the triangle's area would be smaller if rays were denser).

In KnossosAR, the intersection points among blocked rays and their nearest polygons (or the endmost points of the non-blocked ray segments) are saved in a vector; utilizing the Google Maps Android API library, the application easily inspects whether a particular location lies inside the FoV's polygon. When considering polygon-shaped POIs, those are regarded as non-occluded when any of their vertices lies within the user's estimated FoV.

It is noted that a detailed description of our RPI algorithm appears in [11].

5. FIELD TRIALS

Elementary and secondary education schools often organize educational visits to cultural institutions and heritage sites. However, stimulating and retaining the interest of students often proves a rather hard exercise. Archaeological sites are especially challenging in the sense that students are guided around ruins of ancient settlements that hardly reflect their original appearance and purpose. The utility of MAR applications in answering 'how did it used to look like' questions and engaging users in the educational process appears as a reasonable hypothesis. However, evidence is missing as user acceptance studies of MAR applications with cultural heritage resources are rare [9].

Along this line, KnossosAR has been tested on site, through 'formal' field trials. The objectives of the field trials have not only been to test the innovative functional elements of the application (such as our occlusion handling method), but also to offer insights on the way that similar applications are actually used and how the AR views compare to alternative visualization means, such as the map and the dual AR/map views.

(a)

(b)

(c)

Figure 7. Field trials: (a) Briefing of participants; (b) browsing interpretive information about a POI; confirmation of the 'discovery' of 4 (out of 6) POIs.

KnossosAR has been evaluated by 16 students (12 male, 4 female) 17-19 years old (average 17.6), in the context of an educational visit in the archaeological site of Knossos[4]. The participants have tested the application in four groups (of four individuals each) in order to facilitate their live observation by the developers. The testing sessions have been executed using tablet devices supplied by the development team. Most (68.8%) of the students had visited the archaeological site in the past, either privately or in the context of an educational (school) visit. All of them have been experienced mobile application users and familiar with mobile interactive map interfaces. 62.5% have been aware of the existence of electronic guides in museums and cultural heritage sites; however, only 12.5% had actually used one in the past. Notably, none of them has been aware of the capabilities and usage of the AR applications.

Initially, the students have been briefed by the developers about the main functional elements of KnossosAR. Students have been then invited to participate in a 'treasure hunting'-like game wherein the objective has been to 'discover' (i.e. approach) the 6 selected POIs (see Section 3.2) in a 30 min session. Upon the completion of the evaluation session, the participants have been requested to fill in a questionnaire so as to convey their overall quality of experience and document any remarks. Finally, a semi-structured interview followed in order to offer participants the opportunity to clarify any issues and suggest further improvements. Figure 7 shows snapshots from the KnossosAR field trials.

The questionnaire comprised two sections. The first section (seeTable 1) aimed at eliciting the perceived value and quality of experience of the participants about the application as a whole as well as its individual functional elements. The participants experienced no difficulty to get acquainted with the usage of the application (S1). The incorporation of the AR views and the gamification of the guided tour increased the fun element (S2). The interpretive information consumed though the application allowed participants to acquire new knowledge about then archaeological

[4] A video recorded during the field trials is available from: https://www.youtube.com/watch?v=RnohY2JdkzI

site (S3), while the visualization of the POIs assisted in locating important points which otherwise would likely remain unnoticed (S4). The occlusion handling technique (participants have been informed during the briefing session that AR markers associated with non-visible POIs would be hidden) has been positively valuated (S5). Besides, some participants argued that they could receive hints about the existence of occluded POIs through inspecting the 'radar'; this displayed visual indications of all 'in-range' POIs regardless of their visibility. The participants have found useful most of the means provided for locating POIs within the archaeological site (S6). Among them, the AR markers and the audio messages announcing proximity to POIs have been most highly appreciated. As regards the means for consuming interpretive information, audio narration and images/photographs have been the most commonly used (S7); reading textual information has been less popular as it was claimed to distract the user's attention from looking at the POI itself. The overall valuation of KnossosAR has been positive with respect to the perceived quality of experience (S8). When prompted to characterize the AR interface of the application in one sentence, the verbalization has been around the concepts of entertainment and innovation (e.g. 'fun', 'interesting', 'original', 'groundbreaking') as well as usefulness (e.g. 'helpful', 'nice to have').

Table 1. Overall valuation of KnossosAR using a likert scale: 1-5 (1:Not at all, 5: Very much).

Statement		Median	Average
S1	The application has been easy to use.	5	4.6
S2	The application has been pleasant to use.	5	4.4
S3	The usage of the application allowed me to acquire knowledge about then archaeological site (that I would miss otherwise).	4	4.1
S4	The application assisted me to locate points of interest within the archeological site (that I would miss otherwise).	5	4.8
S5	I have appreciated the hiding of AR markers representing POIs out of my field of view.	4	3.9
S6	The following application elements assisted me in locating points of interest within the archaeological site:		
a	Floating (AR) markers	5	4.4
b	Radar	3	3.5
c	Interactive map (including visual indication of the user's current location)	4	3.8
d	Audio (POI proximity) announcement	5	4.8
S7	The following application elements assisted me in eliciting interpretive information about points of interest:		
a	Audio narration	4	4.3
b	Textual information	3	2.9
c	Photographs	4	4
S8	The overall quality of experience with the usage of the mobile guide has been positive.	4	4.2

The next section of the questionnaire (see Table 2) aimed at comparing the AR against the map and the dual AR/map interfaces with respect to several criteria. Notably, half of the participants indicated preference on the map environment as regards the ease of use (Q1) (mainly due to their higher level of familiarity with alike interfaces) with a 37.5% favoring the AR environment; the dual environment has been the less preferred option as it required more cognitive effort in order to synthesize the visual information projected in the two screen parts. Participants appeared bifurcated as regards the fun element of application usage among the AR and the dual AR/map environments (Q2). However, their preference on the AR view could be regarded somewhat biased due to the fact that it has been new to all users. The participants found the AR markers more functional and conspicuous than map markers (Q3) with some arguing that the former have been more informative (as they additionally included the POI title and distance info) and discernible (due to being more sizeable and not overlapping among them). On the other hand, the participants indicated slight preference on the map environment as regards the ease in interacting with (tapping on) the markers (Q4) with some stressing out their 'stability' as opposed to the floating MAR markers whose positioning has been very sensitive to devices' orientation changes (yet, some opposite views highlighted the significant overlap often noticed in the map interface which required the adjustment of the zoom level in order to distinguish individual markers). The dual AR/map interface has been favored by the majority of respondents as regards to the ease in locating and reaching nearby POIs (Q5) as it combined the best of the two 'worlds': the intuitive orienteering offered by AR (as it directly conveys the direction towards a POI) and the broader view (and layout) of the archeological site offered by the map interface which illustrated all POIs (regardless of their visibility) without requiring any rotation (it has been commented that the radar of the AR environment did not compensate that deficiency). However, it should be noted that the dual environment may be less practical in smartphone devices, due to their lower screen resolution.

Table 2. Direct comparison among the three supported information visualization environments.

	Question	AR (including the radar)	Map	Dual (AR/map) env/ment
Q1	Which environment did you find easier to use?	37.5%	50%	12.5%
Q2	Which environment did you find more pleasant to use?	50%	0%	50%
Q3	Which environment's markers did you find more conspicuous?	75%	25%	N/A
Q4	Which environment's markers did you find most easy to tap on? (AR or map markers)	43.7%	56.3%	N/A

Q5	Which environment did you find more helpful to locate and reach nearby points of interest?	25%	12.5%	62.5%

In the semi-structured interview held in the end of the testing sessions, the participants have made several suggestions for further improvements, such as:

- Incorporation of richer interpretive information: 3D reconstruction of selected ancient ruins; provision of information about the archaeological site as a whole further to the 'fragmented' information about POIs.
- Use of visual clues (e.g. special color codes) to denote already visited POIs.
- Alternative ways to handle hidden POIs (i.e. those being out of the user's FoV): use of transparency for AR markers associated with hidden POIs; provision of audio hints about hidden POIs.

6. CONCLUSION

This article introduced KnossosAR, an outdoor MAR guide implemented for the Unesco world heritage archaeological site of Knossos (in Crete, Greece). KnossosAR seamlessly integrates AR projections of interpretive information in a non-linear storytelling context. The application has served as a testbed to pursue our main research objective; namely, to reveal usability problems and identify technology acceptance factors with respect to the usage of MAR technology as well as to compare MAR vs. map-based mobile interfaces in outdoor cultural heritage sites.

Unlike existing outdoor AR applications, KnossosAR addresses the occlusion problem by appropriately handling occluded POIs/landmarks (commonly dealt with in location-based AR applications) as suggested by members of a focus group who evaluated an early version of our prototype. This is achieved through employing a geolocative raycasting technique which enables real-time detection of surrounding buildings and adapts AR content accordingly.

The execution of user evaluation trials confirmed the perceived usefulness, ease of use and enjoyment of KnossosAR. Our evaluation findings largely match the conclusions of similar user acceptance studies [9]. The combination of the physical objects with the virtual information triggered the curiosity and stimulated the interest of students to physically explore the archaeological site. The use of MAR technology exposed students to an alternative interaction style, which they easily mastered. Initial mistrust, gave its place to a sense of accomplishment when they succeed in locating the 'hidden' POIs.

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