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PAPER

Enhancing Tourist Experiences in Crowded Destinations through Mobile Augmented Reality: A Comparative Field Study

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ABSTRACT

Mobile augmented reality (MAR) has gained significant attention in the tourism sector as a way to enhance the visitor experience. The rapid advancements in mobile computing and sensor technologies have facilitated the widespread use of geospatial augmented reality (AR) applications by tourists when exploring popular destinations. To analyze the impact of AR technology on the tourism experience, we developed the FEZAR mobile application. This application serves as the focal point of our study, allowing us to evaluate user performance using a comparative experimental approach. To ensure the usability of the FEZAR application, professionals with expertise in mobile technologies, including AR, performed rigorous testing and evaluation of the application. Through their evaluations, significant usability issues were identified and resolved, resulting in the application being well-received by the experts. Subsequently, a comparative field study was conducted in Fez's old medina, a crowded UNESCO heritage site, involving users (N = 40) who were randomly assigned to experimental and control groups in equal distribution. The results of the study revealed that the proposed AR model had a significant positive impact on user visits. Compared to other forms of media, AR offers more informative and enjoyable experiences. Additionally, it effectively helps locate monuments in crowded tourism settings. The findings of this research make a valuable contribution to the ongoing discussion regarding the impact of evaluating MAR user interfaces on increasing visitor engagement with tourist destinations.

KEYWORDS

mobile augmented reality (MAR), human-computer interaction, cultural tourism, user performance, UNESCO heritage, crowded tourism setting

1 INTRODUCTION

The use of augmented reality (AR) research is already widespread, with examples including marketing, education, medicine, and maintenance. To enhance visitors'

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experiences, it is also used in the tourism sector. In order to bridge the gap between the virtual and physical worlds, mobile augmented reality (MAR) was developed as a potential technology [1]. The development of smartphones, along with advancements in mobile computing (CPU, GPU, motion sensors, position sensors, and cameras), has led to an increase in the creation of much richer experiences [2]. Applications for geospatial augmented reality have been increasingly adopted, such as the Pokémon Go craze [3].

Tourism is one of Morocco's two most important sources of economic income and social development. The old medina of Fez, located in the north of Morocco, was classified as a UNESCO world heritage site in 1981 and is considered a popular destination for international tourists. The old medina of Fez is characterized as a very crowded tourist destination due to its high density of religious, civil, and military monuments, narrow roads and alleys, and overpopulated area[1].

Nonetheless, new visitors to the old Medina of Fez usually rely on brochures provided by official tourist agencies or official guides to obtain cultural information about the monuments they visit. Tourists also use printed maps or generic localization systems that are not specifically designed for tourism purposes to navigate and orient themselves through the different tourist circuits. Hence, the visitor experience is negatively impacted. In the technology-driven tourism industry, future employees must be tech-savvy and skilled in order to thrive in the competitive field [4].

To support the planning requirements of the tourism industry, it has become increasingly important to provide new solutions that intelligently guide tourists and facilitate access to tourist information [5]. One industry that can benefit the most from augmented reality research is tourism. Geo-based mobile AR technology offers several advantages for users, including the ability to display real-time information on the user's location and points of interest[2]. Additionally, it allows for the simultaneous display of virtual images alongside real-world images, which is highly valued by users [6]. It can also integrate content from various social networks to enhance awareness of the visited region [7] and provide a more user-friendly interface, simplifying the search for historical locations.

In order to comprehend the potential impact of AR systems on tourism in a densely populated historical city, it is necessary to conduct real-world testing of the technology [8]. Since AR applications differ significantly from typical applications in terms of interaction modalities, it is necessary to conduct a usability test to verify if they meet their objectives and user expectations before proceeding with user evaluation [9]. Thus, this paper aims to explore the impact of MAR on providing support to tourists navigating through crowded urban areas. The study involved evaluating user performance using two distinct experimental protocols: a MAR application and a localization and navigation system. Prior to conducting the study, several hypotheses were formulated to guide the research.

- H1: The visit will be more entertaining and enjoyable with the use of the experimental visual MAR application.
- H2: The MAR application will be more user-friendly than other available guidance tools, but handling errors will also be more important.
- H3: In the trial setting of the MAR application, users will find it easier to orient themselves to historical landmarks.
- H4: Access to tourist information will be made easier by the MAR application.

[1] Medina of Fez, UNESCO World Heritage Centre: http://whc.unesco.org/en/list/170/
[2] Wikitude: Augmented Reality: https://www.wikitude.com/blog-geo-ar-location-based-augmented-reality/

Section 2 offers a discussion of related work and an overview of the field of AR research, as well as a look at various types of AR evaluation. The remaining sections of the paper are organized as follows: Section 3 presents the methods used in this study to gather pertinent data. Then, in Section 4, more specific results from both the expert and user evaluations are provided. We discussed the results, our conclusions, and some recommendations for improvement in Section 5.

2 REVIEW OF LITERATURE

This section focuses on the transition from technology-centered evaluation to user-centered evaluation as observed by researchers. In the second step, we will narrow down the scope of AR applications to focus specifically on those related to tourism. Additionally, we will demonstrate the evaluation process of AR applications in the context of tourism, and we will demonstrate how AR applications in the context of tourism. At the conclusion, we will outline the various types of AR evaluation and the appropriate evaluation methods.

2.1 Toward a user-centered evaluation of augmented reality

Even though the first early prototypes were shown forty years ago [10], the academic community only started to take an interest in augmented reality research in the 1990s [11]. More recently, AR technology has been used in a wide range of industries, including marketing, medicine, education, entertainment, tourism, and more [12]. The challenge here is to create AR systems that are usable. Developments should prioritize user needs over technology in order to provide solutions and identify the target users of the application [13].

Swan and Gabbard [14], recognizing the importance of user-centered evaluation, conducted a survey in this field. They examined 1104 articles from prestigious conferences and journals (ISMAR, ISWC, IEEE virtual reality, and Presence) and discovered that only 21 (or 2% of all papers) explain formal user-based experiments, while 266 publications (or about 24%) are focused on AR research. In light of these findings, the authors acknowledge the necessity of continued development of AR systems by shifting from a technology-centric to a user-centric approach.

Three years later, Dünser et al. [15] conducted a similar survey to evaluate the methods used in AR research between 1993 and 2007, building upon previous research. As a result, out of the 3309 articles, 161 were AR user evaluation publications, accounting for 28.9% of the total after KW selection and 10.4% of the total AR papers after KW selection. However, only 120 of these articles described formal AR user evaluation, making up 21.5% of the total after keyword selection and 7.8% of the AR papers after keyword selection.

In 2008, Zhou et al. [16] also conducted a review of the ten-year evolution of the work presented at ISMAR, a prominent and inaugural AR meeting. They divided the previous AR research from 313 papers into eleven categories, one of which was "evaluation." Only 1.8% of the most referenced papers evaluated AR systems, and only 5.8% of papers (18 out of 313) were devoted to this topic.

Findings indicate that, until 2008, there was not enough engagement from the AR research community in the area of evaluating AR interfaces and conducting user-based experiments. However, statistics confirm that there has been an increasing understanding of the importance of evaluating augmented reality.

In 2018, Kim et al. [17] published a review of the second decade of ISMAR, similar to Zhou et al.'s comprehensive survey [16]. The authors added four new categories to the original list: perception, collaboration, reconstruction, and modeling. According to the average number of citations per year, one of the top five most cited research topics was "evaluation." This indicates a significant rise in AR evaluation research, with 16.4% of all papers being related to AR evaluation. Kim et al. interpreted this significant increase as the result of the requirement for papers in ISMAR to include some form of evaluation when a new application or method is introduced. This requirement was not always present in the first decade of the conference.

2.2 Evaluation of augmented reality in the tourism context

When examining the current state of augmented reality research, we observe a scarcity of studies that have implemented and discussed user-based or expert-based experiments specifically in the field of tourism and outdoor navigation systems. On the other hand, there is a growing trend to develop more innovative applications aimed at enhancing tourist experiences and promoting the cultural heritage of historic cities [18].

In their paper, Chen [6] introduced a mobile AR application that showcases historical images of heritage sites. The author conducted two usability evaluations to assess the effectiveness of the application: a heuristic evaluation using Nielsen's ten heuristics [19] and a hallway test conducted using the Think Aloud Protocol. The results revealed a generally positive reception among users, indicating the application's favorable usability.

Kourouthanassis et al. [20] published an interesting paper in which they reported on the development process of a mobile AR travel guide called CorfuAr, which supported personalized recommendations. In addition, they conducted fieldwork with the assistance of 105 participants who completed the evaluation questionnaire to study the adoption of MAR applications and their impact on user emotions. The results of the study show that the interaction features of CorfuAR elicit feelings of enjoyment and excitement, which subsequently influence the intention to use the application.

In their study, Schaeffer [21] focused on adapting and applying usability evaluation techniques to assess four AR applications, including the Wikitude navigational application. The published work describes two evaluation methods: a modified heuristic evaluation where the researchers adapted Nielsen's ten heuristics [19] to fit AR evaluation, and usability testing in a real environment through observation and note-taking. Many usability issues were revealed, such as overall instability and a limited number of points of interest (POIs).

Phithak et al. [22] designed and developed the "Korat Historical Explorer," a mobile AR application aimed at promoting historical tourism in Korat province, Thailand. The province is known for having more than 2000 temples. The application underwent a usability evaluation by nine experts who assessed its efficiency, effectiveness, flexibility, learnability, and user satisfaction. Subsequently, the authors recruited 35 users to use and evaluate the application using the same parameters as the experts. We believe that the evaluation of AR in the context of tourism should encompass more aspects than just usability, including navigation and enjoyment. Additionally, we acknowledge that the feedback from experts and novice users may be interpreted differently. Therefore, we recommend conducting separate evaluations for each group.

A study conducted by Han et al. [23] examined the influence of AR experiential value on heritage tourism. The findings revealed that the different aspects of AR experiential value, such as visual appeal, entertainment, and enjoyment, make a significant contribution to destination authenticity and AR satisfaction. The study involved 355 participants who were randomly selected using Amazon Mechanical Turk as the recruitment platform. While online surveys provide valuable user data, we assert that field experimentation is a more effective approach for gathering relevant data on user performance.

2.3 Evaluation methods and types for augmented reality

Swan and Gabbard [14] proposed a categorization for user-based evaluation in AR. This classification is primarily along three dimensions: "human perception and cognition," "user task performance and interaction techniques," and "user interaction and collaboration." This provides a multidimensional approach to understanding how users engage with AR. In the process of their classification, Dünser et al. [15] identified a fourth category they called "interface or system usability studies." This category emphasizes the significance of usability in AR, a crucial aspect that is frequently disregarded in the development of these advanced systems.

Usability inspection has emerged as a critical evaluation method. This is a collection of cost-effective methods for evaluating user interfaces to identify usability issues [24]. Such inspections allow AR researchers to critically evaluate AR user interfaces and gather expert feedback for technical improvements. The field of AR currently lacks general guidelines or heuristics for visual augmented reality [11]. Nevertheless, AR system designers have the responsibility to apply the general principles of human-computer interaction (HCI) identified to date [25]. This underscores the evolving nature of this technology and the need for continuous adaptation and learning in its implementation.

Furthering the discussion on user-based evaluation methods, Dünser et al. [15] also proposed another set of classifications. These include objective measurements, such as error rates, task completion time, and the number of actions, as well as subjective measurements, such as questionnaires and user judgments. They also recognized the value of qualitative analysis, such as conducting formal user observations or interviews. Additionally, usability evaluation techniques such as heuristic evaluation, the TAP method, and expert feedback were recommended. Finally, they suggested the benefit of informal evaluations, such as the informal collection of user feedback.

3 METHODOLOGY

In this paper, we will evaluate the FEZAR augmented reality mobile application and the 2D digital geolocation map to study user task performance and the impact of AR technology on tourist visits. Two evaluation techniques are used for this purpose: heuristic evaluation for usability testing and user evaluation using both subjective and objective measurements. After a brief presentation of the two devices, we will first discuss the usability tests conducted by experts in the laboratory of the University of Fez. Following that, we will present the field experiments carried out by representative users in the historical medina of Fez. The research workflow is described in Figure 1.

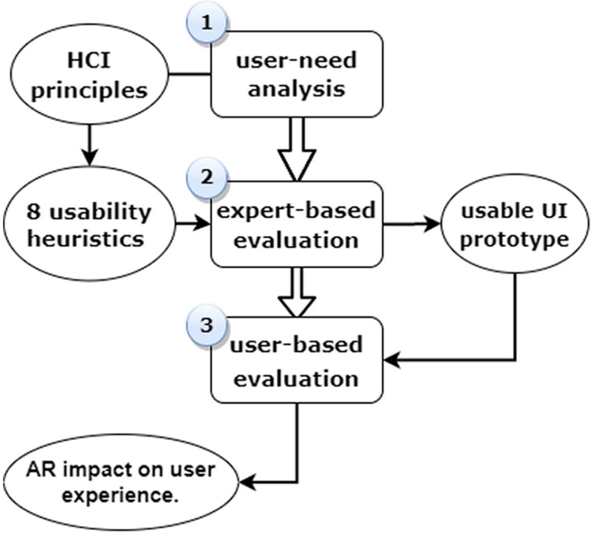

Fig. 1. The research workflow adopted for this study

3.1 System overview

FEZAR, a mobile geo-based AR application, and GMAP, a 2D digital geolocation map, are the two devices evaluated in this paper, as illustrated in Figure 2.

FEZAR augmented reality mobile application. In order to analyze and compare user task performance across multiple experimental configurations, we designed and developed a mobile augmented reality application named FEZAR. This application was created to assess users' proximity to historical sites in the Fez medina as well as the angle at which their phone cameras are positioned. It also provides relevant information about these landmarks. By simply modifying the database, which includes 38 historically or logistically significant locations in the Fez medina, the application can be adapted to work in different cities. The program was developed using the Wikitude platform, which offers a variety of fascinating augmented reality features, such as geolocation-based 3D rendering (see Figure 2b).

A detailed explanation of how to create this application is not provided in this paper because the development approach has already been discussed in prior work [18]. The focus of the current paper is solely on user performance evaluation. The overall architecture of the application remained unchanged. It is worth mentioning that several user interface designs were improved, and several features were added or adjusted based on the usability test conducted by the experts.

GMAP: 2D geolocation map. A two-dimensional geolocation map, or digital map, is a mobile application or system that provides users with navigation and routing services, as well as relevant information about places of interest. This includes images, distance, descriptions, and hyperlinks. For the purpose of our experimentation, we needed to compare the FEZAR application with a 2D geolocation map using only 2D positioning content without incorporating any virtual 3D elements. Every map that met these requirements was valid for the experiments. All users, however, utilized the Google maps platform[3] as their 2D geolocation system (refer to Figure 2a).

[3] Google maps platform: https://mapsplatform.google.com/intl/en/

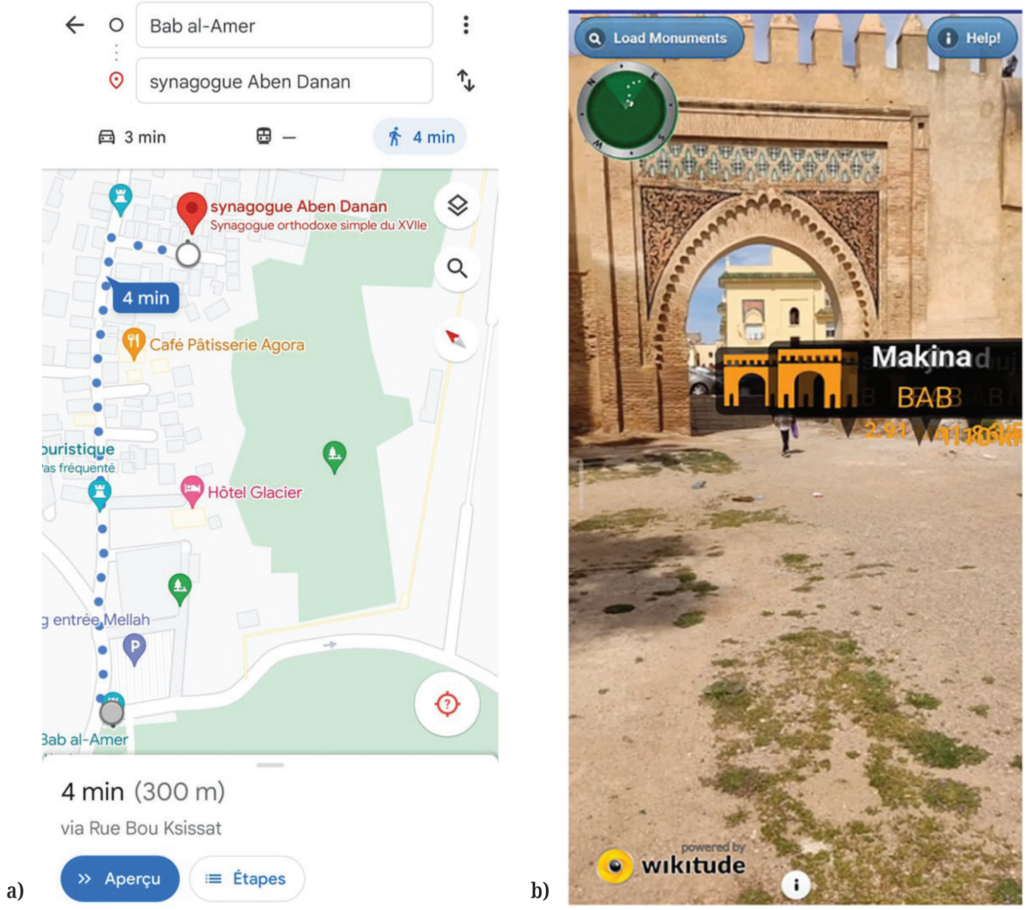

Fig. 2. Screenshots for the two systems used in the user evaluation. (a): 2D digital map view (b): AR application view

3.2 Laboratory-based experiment

The first assessment of an interaction design based on user task analysis can be a heuristic evaluation [26]. The HCI literature contains a number of usability heuristics and design guidelines [19] [25] [27–29].

Eight HCI design principles were defined by Dünser et al. [25], and their application to the development of AR systems was discussed. The suggested need for improvement, and the provided principles are merely a concise overview. We developed eight reliable heuristics for assessing the usability of our application by expanding the rules based on the specifications of geolocation-based MAR interfaces.

1. Affordance: The functional properties and interaction metaphors of the application should effectively communicate to the user the purpose of the system.
2. Reducing cognitive overhead: The application should enable the user to focus on the actual activity. The interaction techniques used must minimize the cognitive overhead required to locate the selected destination (POI).
3. Low physical effort: The user should be able to find points of interest with minimal interaction steps. The application should minimize "unnecessary" actions and minimize the risk of fatigue and discomfort.

4. Learnability: The user interface should facilitate easy and efficient learning of how to consistently and effectively use the application. Graphic symbols should be clear and intuitive.
5. User satisfaction: The application must engage the user in finding the POI they were looking for and provide sufficient data (such as images, distance, and description) to facilitate the search.
6. Flexibility in use: Users should be able to control the navigation distance and choose which types of POIs to display on the interface. The application should support various modes of interaction.
7. Responsiveness and Feedback: Inform users about the current status of the system through appropriate feedback. The effect of the user's actions on the virtual layer should be immediately noticeable.
8. Error tolerance: The application's design should aim to minimize errors. Nevertheless, the application should notify the user, recover from errors, or present reasonable solutions if any errors occur.

Experimental protocol. In terms of participants, we followed the recommendations of Nielsen and Molich [30], who suggested that this type of evaluation should be conducted with three to five evaluators. Therefore, five evaluators with strong backgrounds in computer vision, mobile user interface, and AR were chosen. There were four men and one woman present. They ranged in age from 25 to 30.

Nine tasks were assigned to the five evaluators to complete using the FEZAR application. The purpose was to examine the user interface and identify any usability issues. The next step was for the evaluators to identify which height heuristics the detected usability issues violated.

The tests took place at the faculty of science Dhar El Mahraz in Fez, either inside the informatics laboratory or in public areas where the evaluator could move about freely. We asked testers to independently examine the interface before starting the tests in order to familiarize themselves with the program. Each issue is assigned a severity rating between 1 and 5, based on Nielsen's framework [31], to prioritize the most critical problems for resolution. High-priority issues should be addressed promptly, or an alternative approach should be considered. Evaluators were asked to recommend improvements for each task, in addition to pointing out usability issues, as depicted in Table 3.

3.3 Field-based experiment

User experience questionnaire. Elzakker [32] distinguishes four main categories for collecting primary data from representative users: interviews, questionnaires, observation, and product analysis. The primary data varies depending on the user's preferences, opinions, rankings, and comments.

Because written questions provide greater data comparability [33] and questionnaires are more cost-effective than video/audio recording or observation, which would require following each group of users, questionnaires are often more convenient and consistent than personal interviews [26]. Written questionnaires were utilized in previous studies to analyze various user experience parameters in the context of augmented reality. These parameters included measuring users' immersion in location-based AR environments [34], evaluating the task performance of users during AR prototype testing [6], and assessing the usability of AR systems [8].

The calculation of presence scores in augmented environments [35] and the comparison of presence scores in real and virtual spaces [36] can both be successfully done using questionnaires. In light of these findings, the methodology for testing the hypothesis in this study is a quantitative survey.

Nevertheless, questionnaires have a number of limitations. The participants may be influenced by the researchers' predictions [33]. The quality of the data largely dependent on the effort and cooperation of the subjects [5]. Combining subjective and objective approaches can overcome this constraint. Data recording will provide us with quantitative information, such as the number of users who arrived at the correct locations or the time it takes for a user to complete a task (refer to Table 2).

Experiment participants. We randomly selected 40 users as a sample for user testing, consisting of 24 men and 16 women (see Figure 3). With a mean age of 26.82 and a variance of 4.97, the individuals in the group ranged in age from 18 to 40. We conducted an online survey that included questions about users' previous experience with AR applications and their level of familiarity with tourist activities to ensure that these users were not experts. Out of the total users surveyed, 20% had prior experience with AR applications, 55% were unfamiliar with AR applications but had a basic understanding of them, and 25% had no knowledge of what an AR application was. We divided the participants into two equal groups: an experimental group for the AR prototype and a control group for the geolocation map. We used a randomized approach for the group assignment. It is important to highlight that the sample selection procedures did not take into account the ability of sample members to recognize or access certain test monuments without the use of assistive technology.

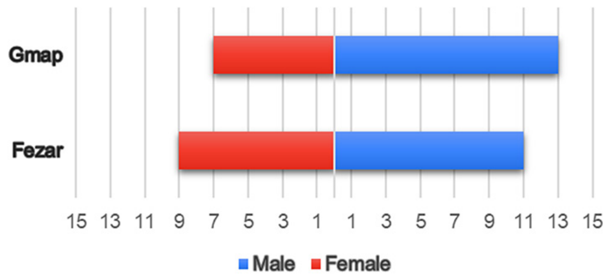

Fig. 3. Gender distribution of participants for the experimental groups

Experiment scenario. Both tourists and handicraft vendors frequent the selected circuit. The Mellah neighborhood consists of approximately seven ancient monuments and is a 500-meter passageway between two gates. Participants from both groups were individually invited, and we carefully explained the entire procedure. We provided participants with smartphones and instructed them to use them to complete a series of scenario-based tasks. These tasks involved exploring five landmarks in the Mellah alley, as depicted in Figure 4. Prior to reaching the target location (Semmarine Gate), each participant started from a designated starting point (El Amer Gate) and aimed to visit three landmarks along the way (Aben-Danan Synagogue, Fassiyine Synagogue, and Magana Gate). Users completed a questionnaire after completing the circuit and the activities. The neighborhood itself is a historical landmark and is frequently congested, making it a suitable location to test the performance of our geo-based AR prototype in a crowded situation (see Figure 5).

Fig. 4. The selected itinerary for the study

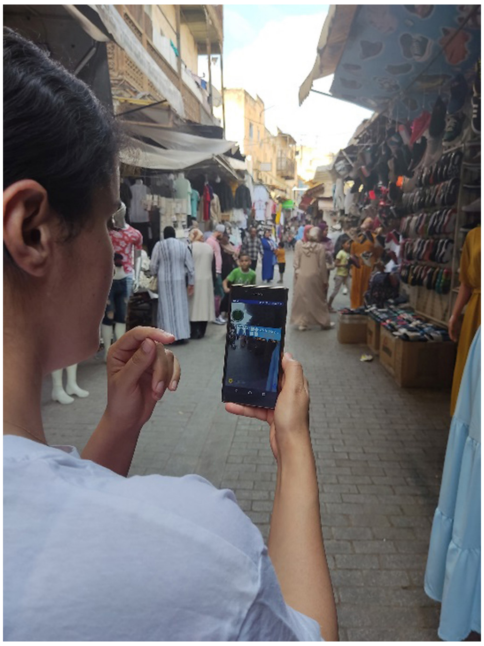

Fig. 5. A user from experimental group in the Mellah Alley during the experiment

Questionnaire measures. A preliminary observation is that there is a lack of research studies in this area that utilize a unified, ready-to-use model. Therefore, researchers must make an independent effort to develop specific questionnaires tailored to the case under investigation [37]. Having said that, the literature review stage was followed by a team discussion to determine and predefine the dependent variables for this study, as shown in Table 2. There were additional team discussions after determining the variables of the experiment. The goal was to transform the four dependent variables into specific formal questions that would comprise the questionnaire. This would enable us to test the theoretical hypotheses.

The questionnaire was divided into five sections. The first four sections allowed users to evaluate the four dependent variables, while the fifth section was reserved for concluding overarching thoughts and suggestions. Since the majority of the questions are closed-ended, we decided to use a 4-point Likert scale to avoid any confusion that may arise from neutral responses. To facilitate individuals in expressing their opinions or comments, we included a few open-ended questions. Direct, conditional, and dichotomous questions are also provided.

Experiment variables and metrics. Bowman et al. argued in [26] that, in the context of virtual environments (VEs), time and accuracy are two important quantitative metrics. Additionally, there are various subjective performance values to consider, such as user comfort, perceived ease of use, and ease of learning. As the device used in this experiment serves as the independent variable, the experimental group used the FEZAR device, while the control group used the GMAP device. The independent variables of the study are presented in Table 1.

Table 1. The independent variables of the study

Test Sample	Independent Variable	Abbreviation	Participants (n=)
Experimental group	Geo-based AR prototype	FEZAR	20
Control group	2D Geolocation Map	GMAP	20

As described in Table 2, the dependent variables include usability, POI localization, informativeness, enjoyment, speed, and accuracy. The logging method was used to capture, in real time, the visit's traces. From these logs, we were able to determine the number of errors made by the visitor during their visit, as well as the amount of time spent.

Table 2. The dependent variables under study

Dependent Variable	Short Definition
Usability	The measure of how effectively a product can be used by users to accomplish specific tasks [9].
Informativeness	The provision of concise and relevant information about the POI, including a brief description, distance, helpful links, address, and contact information [38].
Enjoyment	The content must amuse the visitor and make the experience more pleasant and interesting [39].
POI localization	The capability to obtain directions and navigate to a selected POI in AR view [40].
Time	The duration of time required to complete a task.
Accuracy	The measure of the number of errors made during the execution of a task.

4 RESULTS

We employed two evaluation methods for data collection: heuristic evaluation for usability testing and user evaluation utilizing both subjective and objective measurements. We begin by presenting the results obtained from the experts' evaluation. Following that, we report the users' responses collected through the questionnaire and logging method.

4.1 Heuristic evaluation

The results of the heuristic evaluation are presented in Table 3. The table displays the problems identified by the evaluators (E1 to E5), the violated heuristic, the severity rating, and any comments or solutions provided by the evaluators to address each specific problem. The heuristic evaluation allowed us to identify 20 usability issues with an average severity rating of 3.5. We were able to solve 80% of the issues found, with the remaining problems mostly related to device compatibility with the AR API. Issues with a severity higher than two were prioritized.

Table 3. The findings of the heuristic evaluation conducted by five expert evaluators

Task	Evaluator	Problems Encountered	Heuristic(s) Violated	Severity	Suggestions
1	E1	The notification demanding to enable GPS was not visible to me. I reopened the application, chose Help to learn the cause, and then turned on the GPS. I had to click "load monuments" to display their locations on the screen after waiting until I realized this.	Learnability	4	I suggest adding a prompt window instead of the small message that appears briefly and then disappears. Alternatively, you can increase its delay to appear permanently until the user enables the GPS, or when the user clicks Load Monuments a message to appear telling the user that he has to enable the GPS. In addition, you could consider auto-loading of the monuments.
	E2	When I used the app on my Samsung Galaxy Tab 3, I ran into a situation where the map and monuments were both fixed and didn't move, even when I moved. On other devices, the app operated without a problem.	Affordance	3	The app should operate across various devices and platforms in order to guarantee maximum usability.
	E3		Reducing cognitive overhead	1	It is preferable that the monuments load automatically when the GPS is activated.
2	E1	I tried clicking anywhere to close the image panel after they were displayed, but nothing happens, so I clicked 'return' button to dismiss the images.	Reducing cognitive overhead	3	Add a "close icon" to close image or a "click anywhere" function to close.
	E2	No problem has been encountered.	User satisfaction	1	If visitors in Fez are lost in the narrow lanes of the old medina, I think it would be difficult for them to find the monuments because the view does not provide enough information. I think that including Google Maps driving mode will facilitate reaching the destinations.
	E4	The description panel of Jnan Sbil does not scroll down and the distance disappeared.	User satisfaction	3	Add scroll function.
3	E1	Yes, I can easily find my destination but finding my position is challenging because the application provides a coordinate number that gives no indication about where I am.	Responsiveness and feedback	2	A map pop-up should have appeared when I clicked "My position" to give users their positions relative to monuments
	E3	Latitude and longitude by themselves are not useful, it is necessary to display the position in a map or to have path instructions.	Responsiveness and feedback	3	
	E5	It was hard to find my position. Did not receive coordinates inside the building.	Reducing cognitive overhead	1	Add the button to locate user on first activity

(Continued)

Table 3. The findings of the heuristic evaluation conducted by five expert evaluators *(Continued)*

Task	Evaluator	Problems Encountered	Heuristic(s) Violated	Severity	Suggestions
4	E4	There are 6 places in mosque category but I only found 5.	Low physical effort	2	The radar shows 6 dots
6	E4	No update for the distance.	Flexibility in use	4	Show distance on markers
	E5	I missed the update in 2 minutes.	Flexibility in use	3	Add distance to 3D markers
7	E4	I did not find the distance controller easily.	Flexibility in use	1	
	E5		Flexibility in use	1	Distance bar should start with minimum value, take off the percentage values, it's confusing.
8	E5		Low physical effort	1	It would be helpful if the list disappears after selecting a type.
9	E1	The GPS warning message is small to be seen by all users.	Learnability	4	I suggest to make a prompt window instead of the small message.
	E2	No problem has been encountered.	Error tolerance	1	The app quickly (3 or 4 seconds) asks the user to enable GPS, and then restart the app. In my opinion, the message should be displayed as long as the app is running (when the GPS is not activated).

Decreasing cognitive overhead and improving use flexibility were the most frequent issues. The experts stated that the prototype's inability to update the distance in real-time in certain locations necessitated additional cognitive effort to fully comprehend its usage, load the monuments, and interact with the virtual layer depicted by floating AR symbols. A real-time update of the distance between users and points of interest is computed using the GPS positioning system. The narrow lanes of medieval Medina contribute significantly to the lack of accuracy or failure of GPS systems. Although it consumes mobile resources, using a hybrid location system (GPS, Wi-Fi, and GSM) is necessary.

Augmented reality mobile applications are significantly different from other mobile or desktop applications in terms of interaction modalities and user interface design. Because the AR icons are superimposed on the physical layer of historical sites and are not anchored to the screen view, users found the POI markers represented by AR icons extremely confusing. Users were unable to determine if they had reached their destination or how to locate their current position. Displaying a notice when the user is near the destination is one solution. Regarding the user's location, an expert evaluator recommended including an icon that would display a map of the user's current location. The AR buttons must be intuitive for the user to ensure the application's usability, and the functional aspects should make it easy for the user to become familiar with using the application.

The usability of the system could be improved with the input of experts. Overall, the prototype received positive reviews from the experts, who appreciated the concept of gathering precise geolocation and historical information effortlessly by directing a camera at a historical site.

4.2 User evaluation

After successfully completing the visit, participants were asked to complete a questionnaire. The FEZAR group had to answer 26 questions, while the GMAP group had to answer 20 questions. The number of questions related to the experiment was limited to 15 for each group, as described in Figure 6. The remaining questions allowed us to gather user feedback and suggestions about the visit for future improvements.

Data analysis (ANOVA). An analysis of variance (ANOVA) test was conducted to assess the significance of the results and the impact of participants' gender and familiarity with the concept of augmented reality on the outcomes.

For each of the two systems, FEZAR and GMAP, we conducted two measures for each participant: visit duration and the number of missed POIs. Comparing the duration of each user's visit between the two systems, we note that there was no significant difference ($F = 1.110$, $P = 0.299$). On the other hand, there was a significant difference in the number of missed POIs between the two experimental protocols ($F = 7.435$, $P = 0.010$).

In the second phase, we tested the influence of participants' gender and familiarity with AR on the findings. For the gender variable, we categorized the participants in each system into two groups: male and female. For FEZAR, there was a significant difference between the two groups in terms of visit duration ($F = 157.920$, $P < 0.001$) and the number of missed POIs ($F = 25.6$, $P < 0.001$). For GMAP, there was a significant difference between the two groups in terms of the duration of the visit ($F = 149.001$, $P < 0.001$). However, there was no significant difference between the groups in terms of the number of missed POIs ($F = 2.295$, $P = 0.138$).

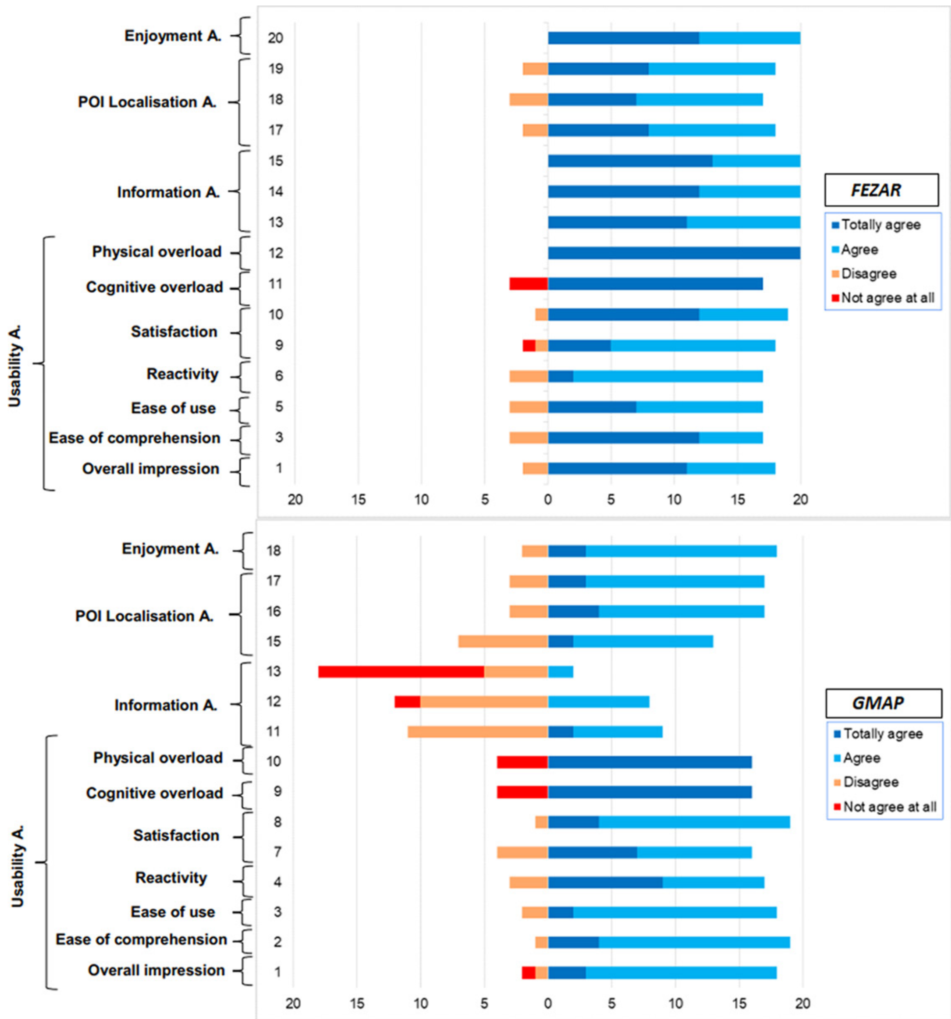

Fig. 6. Questionnaire results for both FEZAR (above) and GMAP (below) conditions

For user familiarity with the concept of AR, we divided the participants into three groups: those who have already used an augmented reality application, those who have never used an augmented reality application, and those who do not know what augmented reality means. For FEZAR, there was a significant difference between the groups in terms of the duration of the visit ($F = 137.672$, $P < 0.001$), as well as the number of missed POIs ($F = 41.376$, $P < 0.001$). For GMAP, the results were similar. However, there was a significant difference in both the duration of the visit ($F = 252.134$, $P < 0.001$) and the number of missed POIs ($F = 35.369$, $P < 0.001$). This can only be attributed to the fact that the three groups do not have an equal number of participants. As it turns out, 55% of the participants had never used an AR application before the test.

Questionnaire descriptive data. The findings of the user-based evaluation, as illustrated in Figure 6, clearly demonstrate user satisfaction with FEZAR. To further investigate the results, a comparison between the FEZAR application and GMAP is conducted based on the six dependent variables.

Time: Figure 7 indicates that the average time spent during the visit using FEZAR was 22 miniutes and 36 seconds ± 1 minute and 16 seconds, with a 95% confidence interval (CI). In the case of GMAP, the time did not exceed 20 minutes and 30 seconds ± 1 minute and 32 seconds, with a confidence interval of 95%. It can be deduced that the FEZAR user spends more time navigating around the monuments in order to reach the final destination.

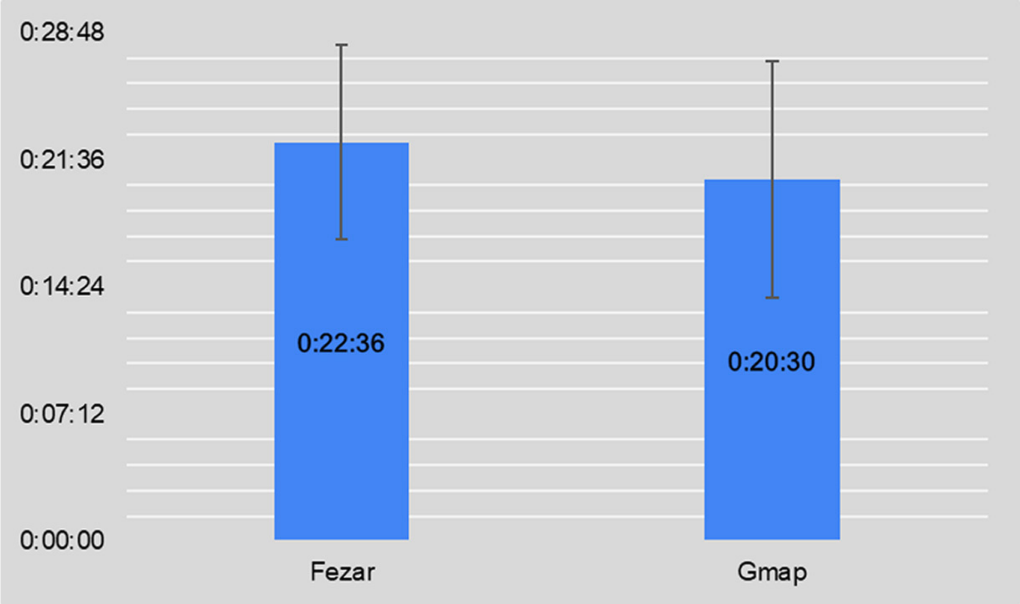

Fig. 7. The average time spent during the visit for both devices (95% CI)

Accuracy: According to Figure 8, only 35% of FEZAR users were able to visit all POIs, while 65% of users missed one to three monuments during their visit. Additionally, only 10% of GMAP users were able to locate all five POIs, while 70% and 20% missed one to three and three to five monuments, respectively. Thus, we can say that during the tour, FEZAR users were able to explore more monuments than GMAP users.

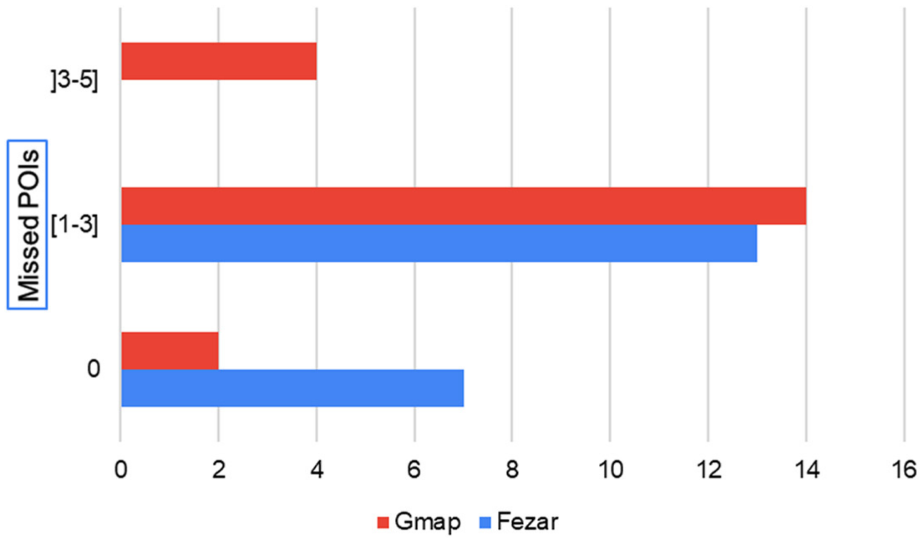

Fig. 8. The intervals of missed POIs per each system

Usability: The usability of each system is evaluated in terms of satisfaction, responsiveness, mental and physical workload, simplicity of use and understanding, and overall impression. Figure 6, which summarizes these usability criteria, clearly indicates that FEZAR is considered highly usable and user-friendly, with minimal cognitive or physical burden.

Localization of POIs: Users of FEZAR were slightly more likely than users of GMAP to find navigating and guiding around landmarks during the tour to be quite simple (87.5% for FEZAR vs. 85% for GMAP). On the other hand, a significantly higher percentage of FEZAR users (90%) compared to GMAP users (65%) were able to easily find their final destination.

Information: The objective here was to compare the potential of each system in terms of providing the user with information while they visit historical sites. This includes evaluating the ease of access to tourist information and the quality of descriptions for the monuments they are visiting. Figure 6 shows that FEZAR is considered more informative than GMAP. 100% of FEZAR users responded that the device allows direct and quick access to tourist information and that the virtual layer provides sufficient descriptions about each visited place. For GMAP, only 10% of the users were able to access tourist information directly from the POI, and 40% received sufficient information about the monuments through the system interface.

Enjoyment: 100% of users who tested FEZAR found the tour enjoyable, with 60% finding it very enjoyable. For GMAP, the responses varied. 10% of the users found their visit quite boring, 75% found it amusing, and 15% found it very amusing.

5 DISCUSSION

The objective measurements indicate that FEZAR users spend more time than GMAP users searching for monuments of interest. This can be attributed to the fact that FEZAR encourages visitors to approach the monuments closely or to take the time to compare the images in the description with the actual view of the sites. Furthermore, the results show that FEZAR users were able to locate and explore more monuments than GMAP users. This finding may help to explain why the

AR group spent more time during the visit. The following is an argument for the validity of the hypotheses we outlined before conducting the user evaluation, based on the objective and subjective results of our study.

Hypothesis H1: The questionnaire results revealed that the participants found the visit to be significantly more enjoyable when using FEZAR. Therefore, hypothesis H1 related to the aspect of enjoyment can be validated. This may be because the majority of FEZAR users are just getting started with augmented reality software. They were thrilled with the opportunity to receive guidance, instructions, and information about monuments, including images, simply by pointing the camera in a particular direction. 90% of FEZAR users indicated that they would like to download the latest version of the application and use it on their upcoming trip to Fez.

Hypothesis H2: The results also indicate that FEZAR is considered highly usable among the samples that tested the application. We believe that the usability test conducted before the user evaluation was successful in providing a usable application for the users. As stated by Tan et al. in [41], heuristic analysis should be implemented at early stages before user testing. This is because heuristic evaluation identifies more problems and addresses different levels of severity compared to user evaluation. Nevertheless, we could not find clear evidence that the AR application is more usable than other means used for guidance. Additionally, the number of missed monuments is not significant, which can be attributed to the high usability of the system. We can conclude that the results do not support hypothesis H2.

Hypothesis H3: Regarding POI localization, the results confirm that FEZAR facilitates navigation and guidance during the visit. Nevertheless, we could not find enough evidence to suggest that users found navigating to monuments less difficult when using the AR application. Hence, hypothesis H3 is not confirmed. This lack of restrictions on user navigation routes could be a possible reason for this issue with the FEZAR application. Several participants suggested augmented reality by adding the itinerary to each point of interest.

Hypothesis H4: In terms of information, the results obtained from the questionnaire revealed that FEZAR is considered significantly more informative than GMAP. This strengthens our assumption that FEZAR users take more time to browse the descriptions in front of heritage sites. Therefore, hypothesis H4 can be validated. Interaction methods, such as location-based filtering, distance-based filtering, the use of commonly known icons, and the use of type-based AR markers, are a few examples of how we remove information "noise" and support users in directly accessing information related to visited tourist attractions.

Our findings are consistent with earlier studies. The audio AR model "SARIM" by Kaghat et al. [39] enhances visitors' museum experiences by making them more informative, enjoyable, and user-friendly compared to the official audio guide used by the Arts and Craft museum in Paris. Kourouthanassis et al. [20] conducted a field experiment on the AR mobile application CorfuAR, which stimulates feelings of happiness and excitement among visitors during their visits. The results of a usability test conducted by Phithak and Kamollimsakul with users in the field [22] showed that their augmented reality application, KORAT, had a higher usability score of 4.45 out of 5.

6 CONCLUSION AND FUTURE WORKS

This paper presents an examination of user task performance within a geography-based AR mobile application called FEZAR. The aim is to understand how AR technology can impact the user experience in the context of tourism. To achieve this goal, five experts conducted a heuristic evaluation prior to the user evaluation. The experts' feedback allowed us to identify and resolve usability issues related to our geography-based AR application. The experts also expressed general enthusiasm for the application, and all agreed that our FEZAR application has potential, although it needs time to mature. Forty representative users conducted a posterior user evaluation in the narrow alleys of the ancient medina of Fez. The experiment aimed to study user performance while visiting five monuments using two experimental protocols: an AR mobile application and a 2D geolocation map mobile application. For both systems, we measured task completion time and missed location intervals. Additionally, the evaluation aimed to assess the usability of the tool, POI localization, informativeness, and enjoyment. According to the results, FEZAR is a highly usable platform that facilitates the discovery of monuments of interest while also enhancing the visitor's engagement with them. Findings also show that FEZAR makes the visit much more pleasant and facilitates access to abundant tourist information compared to other mediums used.

We can infer from the user evaluation results that the augmented reality application helped the user perform better during their visit. Therefore, we believe that there is compelling evidence that augmented reality technology has a positive impact on the user experience in the field of tourism. To enhance the visitor's experience with AR tools, tourism marketers and product developers should consider that AR solutions must effectively integrate real and virtual environments. The virtual elements of AR must strike a balance between visual appeal and not obstructing the user's view of the actual monuments. To achieve this goal, it is essential to periodically update of the system's usability and conduct user evaluations.

As with any empirical study, there are some limitations to our findings. The data is self-reported using questionnaires, which means the results are primarily based on a subjective approach. To obtain more detailed feedback on the visit as a whole or on specific components of our AR application, qualitative methods such as interviews would be beneficial. Secondly, there are two key metrics for evaluating user performance: time and accuracy. We had to employ logging techniques to measure users' accuracy and time due to the multiple design issues that emerged during the program's development. To enhance data reliability, we believe that the quantitative variables in the study should be calculated automatically. Finally, instead of the expected 100 actual tourists, we had to select 40 representative users due to limited research time and funding. The generalizability of the findings will be significantly enhanced by recruiting a substantial number of actual tourists who are visiting Fez for the first time.

Future directions for this research include proposing a semantic layer to generate adaptive recommendations of historical information based on the user's circumstances and interests. We explore the use of web content mining to adaptively update tourist content by leveraging social networks and/or web platforms for the informational component. In order to emphasize the level of interest within the research community regarding the evaluation of augmented reality interfaces, we also plan to publish a review of the research literature on the topic.

7 CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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