Augmented Reality in Heritage Apps:Current Trends in Europe

Ursula Luna [1], Pilar Rivero [2],* and Naiara Vicent [1]

[1]   University of the Basque Country UPV/EHU, 8940 Leioa, Spain
[2]   Grupo ARGOS; Facultad de Educación, Instituto de Investigación en Ciencias Ambientales (IUCA)
     University of Zaragoza, c/ Pedro Cerbuna 12, 50009 Zaragoza, Spain
*   Correspondence: privero@unizar.es; Tel.: +34-976-76-1000

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Abstract: Although augmented reality (AR) has come to play an increasingly important role in a wide range of areas, its use remains rather limited in the realm of heritage education. This paper sets out to analyze which heritage-related apps can be found in Europe that partly or wholly use AR as a tool to help users learn about different types of heritage. Our study only identified a limited number of such apps and we used this sample both to paint a portrait of the current state of the question and also to highlight certain observable trends. The results showed that most such apps used AR to reconstruct spaces and buildings, and to a lesser extent, objects. Many of these apps used an academic mode of communication to provide a temporal perspective of monumental and (mainly) historical heritage. The paper also outlines future lines of research dedicated to finding more apps that could be used to increase the current sample size. This would allow for a more comprehensive assessment of such apps from an educational point of view. Several case studies are proffered in order to highlight the keys to successful use of AR in heritage apps.

Keywords: augmented reality; heritage; mobile learning; mobile applications

1. Introduction

At the turn of the century, when information and communication technologies (ICT) had already acquired great importance in most sectors of society, the first proposals for their use in educational and heritage contexts began to appear. The spread of access to the Internet and mobile devices, such as tablets and smartphones, resulted in these new technologies being democratized. Indeed, this led to the development of tools that provided the general public with previously unprecedented access to information, with mobile applications (henceforth simply "apps") being the most widespread manifestation of this trend. Today, the educational potential of these types of devices and programs is no longer debatable [1], since their use in both formal and non-formal educational settings has become an undeniable fact. Mobile learning and e-learning have made it possible to adapt content to every type of user, by improving pedagogical processes and allowing for a type of learning which is social and collaborative and in which communication is multilateral and horizontal [2].

Expanding beyond their original use in industry during the nineteen-nineties [3], more complex elements, such as virtual reality (VR), augmented reality (AR), and variations on these have been taken up more widely for a variety of uses over the past decade. The spread of these tools in recent decades has led to an abundance of research and publications on the potential of AR [4]. Nonetheless, as other authors have pointed out [5], there have been relatively few studies addressing the use of AR in education; there is not only a widespread lack of theoretical reflection on the issue [6], but also a belated application of this new technology in education when compared to its use in other fields [7].

In fact, only a 2016 study from Spain has really begun to delve into the issue by showing that only 12.6% of analyzed apps with heritage content made use of AR [8].

Accordingly, this is an important fledgling field of study in which work must continue to be done, especially given the advantages that various virtual tools can offer in the area of education and heritage [9]. So, the main purpose of this exploratory study is to address the current state of European heritage education apps that make use of AR. As far as we are aware, this is the first Europe-wide study on this topic and it will include a brief examination of applications for mobile devices that are currently available, with a description of their main features and the use that they make of AR for heritage purposes. The specific objectives of this study were:

1. To find and inventory heritage-related open-access apps of European origin that use AR.
2. To carry out a statistical–descriptive analysis of these apps in order to outline their main characteristics.
3. To identify predominant trends in how the identified heritage apps make use of AR.

2. Heritage Education, APPs and Augmented Reality

The spread of mobile devices, such as tablets and smartphones, and improvements to access to the Internet have prompted changes in not only how we research and conserve heritage but also how we share and teach it [8]. Indeed, museums have led the way in experimenting with ways that these new technologies can be used as educational tools, while also touting these innovations as part of their strategy to the democratize culture [10,11]. Accordingly, we can see the shift from the use of the traditional audio guides to PDAs (Personal Digital Assistant) [12], and then finally to apps that are developed for mobile devices. The fruitfulness of all these devices for education has been widely documented over recent decades [13,14], and so has their unsurpassed usefulness in heritage teaching–learning processes.

The growing use of mobile devices for all sorts of tasks has led to a boom in the app-development industry. This type of software allows people to not only access important information but also to communicate in new ways with other social agents [15]. However, the dearth of research and critical evaluation on the use of heritage-related apps in education—including important questions like whether or not they incorporate any kind of virtuality—must be stressed [8,16]. Moreover, the studies that have been conducted tend to focus excessively on technical aspects [12] or are aimed at tourism [9,17]. There are few proposals for the integration of these heritage resources into the sphere of formal educational apart from some trials [18]. This strongly contrasts with what has occurred in other types of technology, which have been applied in school contexts [19,20], both at basic educational levels and in the training of future teachers [21,22].

There are, however, some hotbeds of activity in Spain [8,15,18,23] and the United Kingdom [11,24,25], where interesting in-depth studies have been conducted on the evaluation of heritage apps. These show that for the main part, apps are developed by organizations such as museums and archeological sites, where the advantages that mobile devices offer visitors can easily be exploited [25,26]. In the case of Spain, the government has been the main driver in this type of app development, followed by public museums and then foundations and associations [8]. A growing number of educational partnerships have flourished between private companies, public administrations, and formal educational establishments, among others [27]. These applications vary considerably: some offer a route to follow in a museum or heritage space, outdoor routes, quizzes, and even more complex gamification approaches, whereas others simply provide information about heritage assets, whether in the form of texts, videos or other resources [15]. Data collected in Spain show the prominence of apps that suggest a planned visit, while those that give information about specific heritage features come in at a distant second place [8]. Another study of museum apps from around the globe shows that they are mainly used to provide guided tours for exhibitions and furnish practical information about visits [11].

Of all the uses and tools that apps offer, various types of virtualization have had the greatest impact, and of those, AR stands out most of all. Devices' greatly enhanced abilities, 3D sensor equipment, and graphics technologies enable AR to be used easily and comfortably, thereby facilitating them to reach a wider market [28].

If we turn to the use of this tool in educational contexts, previous studies have demonstrated how AR has enabled students to better understand reality, observe elements from a variety of points of view, and create scenarios that facilitate simulation or the contextualization of information, to name just a few benefits [6,27]; however, it is also true that the most recent studies often find notable contradictions in the advantages that AR has to offer education [5].

With respect to the use of AR in heritage contexts, useful studies have hailed from Spain [29], Italy [17,30], Greece [31,32], the Czech Republic [33], Taiwan [26,34], Korea [35,36], and Malaysia [37]. It should not be forgotten that many of these initiatives resulted from the first AR and VR projects funded by the European Union at the beginning of the 2000s, such as Lifeplus [38], Archeoguide [39], Itacitus [17], and Ancient Pompeii [37,38].

Recent research shows that these tools can lead to visitors better understanding cultural heritage [35]. When used as a guide, they can offer content customization [8], which enables substantially more engagement and interaction with heritage than other tools can provide [25,29]. Similarly, visitors tend to find these tools to be more interesting, fun, and immersive [26]. There is no doubt that this is appealing, as is clearly demonstrated by previous research [40].

But AR has much more to offer: it can enable spaces, buildings, and monuments that no longer exist to be recreated [6,9,41]; it can allow for an object to be viewed in its entirety or in part without the possibility of an object suffering any damage [26,31,42]; it can provide a touristic route enhanced with superimposed information that elucidates places of interest [31,43]; it can provide visitors with a virtual tour guide [31]; and it can even contain games in which AR superimposes actions on reality [25,31]. Given these possibilities, one of the fields that can benefit the most from the use of mobile technology is archeology. Those working in this field have already anticipated that VR and AR would play a prominent role in public outreach and education [3]. The possibility of recreating objects or spaces that no longer exist for visitors at sites or heritage presentation areas was the driving motivation for taking up digital devices imbued with this type of technology.

Technology has progressively changed and advanced so as to enable access to AR, which can be activated in some apps by scanning QR codes or other user markers [7,22,33] (see Figure 1), while in others, this is done through activating GPS [22,31]. Other devices such as Google Glasses [11] and other types of goggles have also been used for this purpose—though these run into greater limitations since they constitute yet another costly gadget that users must obtain.

Finally, we must stress that currently it is quite difficult to make scientifically supported judgments about the use of apps and AR in heritage education. On the one hand, the rapid pace at which digital technology continues to develop leads to constant changes and novelties. This makes it rather difficult to carry out a long-term study on the topic; when such studies are conducted, they cannot be totally uptodate [40]. In education, therefore, we find a series of major ongoing projects that are somewhat idiosyncratic and specific, because they are developed by private or local entities and do not form part of a broader action plan [18]. On the other hand, developing new software tools requires funding that in many cases is hard to come by, since such projects are very costly for many heritage institutions [16]. In other words, economic resources are a sine qua non for the development of a quality tool which isbased on clear educational goals and which can be changed and improved following theanalysis of results [18]. Furthermore, apps and AR also need to overcome technical difficulties, which is no small feat given that there are currently a wide variety of mobile devices with a range of screen sizes and processing powers. Such details often make it impossible to design apps that run on all devices and operating systems [30].
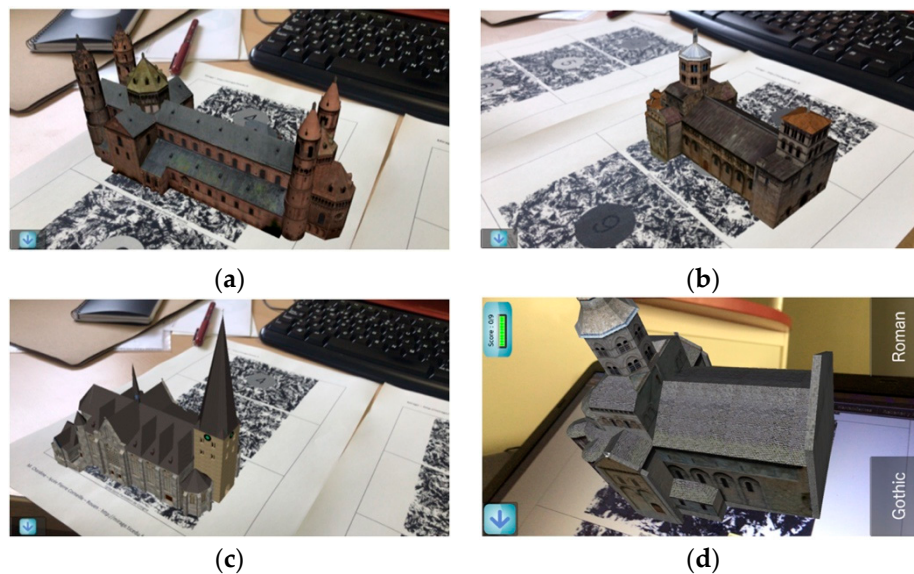
Figure 1. The app Arquitecture gotique/romane in action, which is accessed by scanning downloadable codes.

3. Method

In the quest to paint the landscape of open-access European heritage apps that use AR, we have conducted an exploratory study that has determined the main features of relevant apps. In so doing, we have performed a frequency analysis of the data collected for each of the apps based on statistical–descriptive research.

The research process was based on the SHEO (Spanish Heritage Education Observatory) method [44], which was created to analyze heritage education programs and will be explained momentarily. The process of adapting this method to the present study parallels that which was found in the work of Gillate et al. [45]. More specifically, in this study we only carried out the first three phases proposed by the SHEO method, that is the phases devoted to the inventorying, selection, and analysis of AR apps. We have compiled a specific factsheet for the last of these phases, which was adapted to better suit the study and analysis of the sample.

3.1. Phase 1:Finding and Inventorying Relevant Apps

The first phase was based around the search for European apps with heritage content that wholly or partially use AR. We only examined apps that could be downloaded, and we discarded any apps that either could only be used on a specific device provided by an institution or required some sort of accessory (whether bought or freely available). This phase of the project closely followed the methodology employed by Economou and Meintani [11] and Ibáñez–Etxeberria and Kortabitarte [8], which combines a bibliographic search on both specialized websites as well as the main mobile app distribution platforms.

The bibliographic search relied on the usual databases mentioned in research journals—ProQuest, Education Resources Information Center (ERIC), SSCI, and Dialnet—and additionally other reports on apps and mobile learning. A careful search was conducted in Google Play and the Apple Store in English, Spanish, French, Italian, and German using combinations of "AR" and the words "heritage", "museum", "archeology", "architecture", and "art." Searches were also conducted using the specific names of spaces or heritage assets mentioned in the bibliographic search and on specialized websites. It should also be mentioned that searching app platforms itself simultaneously led to the discovery of new apps that could be included in this study, thanks to the recommendations made by the platform based on the desired subject matter and also due to the finding other products offered by certain developers.

This phase was fully carried out during February 2019 and during which the preliminary sample used in this study was produced. All in all, 61 apps were found.

3.2. Phase 2:Selection and Final Sample

Phase 2 of this investigation involved identifying apps that should be weeded out from the sample. To do so, we employed a set of inclusion and exclusion criteria adapted from the abovementioned SHEO method (Table 1).

Table 1. Inclusion and exclusion criteria for the final sample.

Inclusion criteria	Exclusion criteria
The app is for mobile devices	Technical error
Integrates AR use	Not available in the main stores or has disappeared
Addresses European heritage	Is a duplicate app

The first criterion for excluding an app was the presence of a technical error or failure that prohibited the use of the app during the period of analysis. The second exclusion criterion, non-availability, meant that it was not possible to download the app at the time that we were searching for and inventorying applications, either because it was no longer available in the stores or because it had been a pilot project and was no longer available on any app sales platform. In other words, the search of bibliographic databases or other sources often showed that some apps existed, but they were not available for use during the dates the study was conducted. As for the third exclusion criterion, an app was labeled a duplicate under two circumstances: first when it was produced by a developer that also offered a similar product with the only change being the use of a different heritage object. Second, an app was considered a duplicate when the provider also offered different apps with the same content, but in different languages, for example, a museum app in English, German, and Spanish.

As a result, first the inclusion criteria were applied in this phase to establish the initial or pre-sample, and subsequently the exclusion criteria were applied (Table 2).

This process (Table 2) produced the final sample of 35 apps from the 61 inventoried in Phase 1. This was the total number of applications obtained and then used during the analysis phase, on which the present exploratory study was based.

3.3. Phase 3: Analysis

We then devised an app analysis tool for Phase 3, which was based on the factsheet created by the GIPyPAC group (Grupo de Investigación en Patrimonio y Paisajes Culturales–Heritage and Cultural Landscape Research Group), a research team that has for years studied and analyzed apps related to heritage education in Spain. This phase began with a comprehensive study of the categories and dimensions proposed by other authors [15]. We then added new categories and dimensions that were specifically useful for analyzing heritage apps. In this case, those relating to the use of AR were added, with the original factsheet adapted to better meet the specific needs of this research project.

We settled on three different dimensions and 15 variables in the factsheet for the descriptive study of the apps (Table 3) in order to identify current trends and future lines of research. We recorded observations in a template created using a spreadsheet, while the data were processed using the SPSS statistical analysis program.

The description–metadata dimension, which consisted of seven variables, and the heritage dimension (variables 8 through 11) were taken from the ARSMULEP project factsheet [15], which belongs to the previously mentioned research group GIPyPAC. The apps' descriptive data were collected within the first dimension. The V1 indicates the type of entity promoting the app. This can be a private company, public administration, museum/heritage presentation site, a university/other training center, a collective, a citizen association/privately-led project, or, finally, an entity resulting from collaboration among different public administrations. This same dimension indicates the country in which the app was developed (V2), the year that it was launched (V3), and the year that it was last updated (V4) according to the information provided in the stores. Next, we included the operating

systems with which the app was compatible (V5). As for the type of app (V6), apps were distinguished between those that suggested a route or a self-guided route through a heritage area or museum, those that showed a heritage object or objects, and finally, apps that offered a game. Within this final category, we introduced further distinctions between games, such as contests/quizzes, serious games, role-playing games, simulation games, and action/adventure games. Lastly, the audience at which apps were targeted was recorded in V7, which distinguished between those that were aimed at the general public and those that were meant for a specific type of user.

Table 2. Initial sample and reasons for exclusion used to determine the main sample.

No.	App Name	Reason for Exclusion	No.	App Name	Reason for Exclusion
1	3D Çatal Höyük	3	32	L'Ara com'era AR cube	
2	3D NEOLITICKÁ NÁDOBA	3	33	Liguria Heritage AR	
3	3D NEOLITICKÝ HROB	3	34	Llegendes en familia	2
4	3D NEOLITICKÝ RONDEL	3	35	London History AR	
5	AGINCOURT 600 AR	2	36	Lorca Renace	2
6	Antonine Wall		37	Lunt Meadows AR Explorer	
7	Apptaula		38	MACH 3D Museo Arqueológico Chelva	
8	ARmuseum	2	39	Musei di Viggiano AR	
9	Architecture gotique-romane		40	Museo Carlos V	
10	Asturica Emerge		41	Museu FTPJ	
11	Barcelona Modernisme		42	Museu Guarda	
12	Caistor roman town AR		43	Neolit v Bylanech	2
13	Casa Batlló	2	44	OTE Museum AR	
14	Casa Grotta VR AR		45	Porthkerry Country Park AR app	2
15	Castellones de Ceal RA		46	PUGLIAREALITY+	2
16	Cástulo Virtual		47	Roma in tabula	
17	Chevré 3D		48	Sorolla Museum AR	
18	Città Ideale AR	2	49	Stonehenge Experience	2
19	Ciutadella Ibèrica Calafell		50	StreetMuseum	2
20	Conoce Irún		51	Suton Hoo	2
21	Der sprechende Kelte		52	Svijanský zámek AR	3
22	ENTER Mölndal Tulebosjön		53	Talking Ravenna	1
23	Fuendetodos		54	Temple Newsam AR	
24	Geogaming Barcelona	2	55	Terrassa Augmentada	2
25	Glamorgan Heritage Coast AR		56	Timetraveler The Berlin Wall Augmented Lite	
26	Guideo	2	57	UAR Urban Augmented Reality	2
27	HMS Caroline AR Experience	2	58	Urdaibai oka app	
28	Imageen Tarraco		59	William Lindley AR	
29	Inmersion1418	2	60	Window on The World Augmented Reality	
30	Italicaap	2	61	Zálezlice	
31	La ruta del galeón	2			

Legend: 1 = Technical error; 2 = Not available; 3 = Duplicate.

Table 3. Study object: dimensions and variables.

Dimension			Variables
D1	Descriptive	V1	Type of entity promoting the app
		V2	Country
		V3	Year app was launched
		V4	Year of latest update
		V5	Operating system
		V6	Type of app
		V7	Target audience
D2	Heritage	V8	Heritage chronology
		V9	Typology of heritage referred to
		V10	Heritage perspective
		V11	Purpose of the heritage communication process
D3	AR usability	V12	Type of AR use
		V13	Method of AR activation
		V14	Technical requirements
		V15	Prominence given to AR in the app

The second dimension was related to heritage and analyzed heritage typology (V9), the perspective (V10), and the purpose of communication (V11), for which we adopted the indicators proposed by the EDIPATRI (Education and Interpretation of Heritage) Research Group at the University of Huelva, Spain [46]. This research team works on heritage education and has established a set of criteria for analyzing educational programs dealing with heritage. The third dimension, which refers to the use and prominence given to AR in the app, was composed of four variables that were previously set out in research on virtuality, heritage, and education. The types of use that can be made of AR (V12) were for reconstructing heritage objects or items, reconstructing buildings and monuments, recreating actions from the past such as crafts or customs, recreating spaces, and finally, recreating important people or fantasy objects which could be observed in AR and could provide specific explanations or act as guides during a tour as well as furnish additional information about a heritage space or element [9,25,41,42]. With respect to activating AR, this can be done by scanning a QR or other type of code, by geolocation or by using accessories such as AR headsets [6,7]. The V14 addressed the technical requirements for AR use in the app. The applications that had to be used in situ were differentiated from those that could be used through downloaded codes or other methods of activating AR. Lastly, V15 indicated how much prominence was given to AR in the app. Augmented reality could be the sole or main tool, feature strongly or fairly strongly, or be a simple accessory in the application to which barely any prominence was given at all.

4. Results

The statistical–descriptive analysis produced the following results based on the analyzed dimensions of the total sample.

4.1. Descriptive Dimension

In the results for the descriptive dimension, we found that the most common type of entity (V1) for app development was museums, which were responsible for the creation of 42.9% of the sample ($n = 15$). Museums were followed by private companies ($n = 7$; 20.0%), and public administrations ($n = 5$; 14.3%). Next, came the apps arising out of collaborations among different agents, such as between a university and a museum or public administration and a museum ($n = 4$; 11.4%), those created by a university or research group ($n = 3$; 8.6%), and finally, those developed by individuals ($n = 1$; 2.9%).

With respect to the country in which the apps were developed (V2), a high percentage were found to hail from Spain with 37.1% ($n = 13$), followed by the United Kingdom ($n = 7$; 20.0%) and Italy ($n = 4$; 11.4%). Other countries produced less apps in the sample: France ($n = 3$; 8.6%), Germany ($n = 2$; 5.7%),

Portugal (*n* = 2; 5.7%), Austria (*n* = 1; 2.9%), the Czech Republic (*n* = 1; 2.9%), Greece (*n* = 1; 2.9%), and Sweden (*n* = 1; 2.9%).

When it comes to the year that the inventoried apps were created (V3), the same percentages were found for 2018 (*n* = 10; 28.6%) and 2015 (*n* = 10; 28.6%), which were the highest values. The lowest values were for 2014 (*n* = 3; 8.6%) and 2013 (*n* = 1; 2.9%). If we observe the years when the apps were last updated (V4), the highest frequency can be found in 2018 (*n* = 10; 28.6%), and this value progressively falls as you look further back in time. Thus, in 2017 there were eight apps updated (22.9%); in 2016, seven (20.0%); in 2015, four (11.4%), and then, in 2014, two (5.7%). Lastly, we found four apps that were updated in the current year, 2019 (11.4%).

As far as the operating systems for which these apps were available (V5) are concerned, most apps were available for Android and iOS (*n* = 19; 54.3%), while nine apps were only available for iOS devices (*n* = 9; 25.7%) and seven exclusively for Android systems (*n* = 7; 20.0%).

As for the types of apps inventoried (V6), a high percentage was tools for recommending a visit, either indoors or outdoors (*n* = 27; 77.1%). To a lesser extent, there were apps that focused on a specific heritage object or element (*n* = 6; 17.1%) and the rest were mainly aimed at providing specific information about a fact or event (*n* = 2; 5.7%). To conclude the descriptive dimension, we found that all the apps (*n* = 35; 100%) were targeted at the general public, with different levels of adaptation depending on the user (V7).

4.2. Heritage Dimension

Moving on to the second dimension, heritage, we collected an extremely wide range of data about the historical periods treated in these heritage apps (V8). The highest percentage of apps offered information about heritage in Antiquity (*n* = 10; 28.6), followed by those that combined the heritage of different chronological stages (*n* = 9; 25.7%). Third place was shared by Prehistory (*n* = 5; 14.3%) and Contemporary Era apps (*n* = 5; 14.3%), while in last place we found apps dealing with the Middle Ages (*n* = 3; 8.6%) and the Early Modern Period (*n* = 3; 8.6%).

An analysis of heritage typology (V9) showed that most applications were geared towards history (*n* = 18; 51.4%), followed by heritage more broadly (*n* = 7, 20%) and artistic heritage (*n* = 7, 20.0%). To a lesser extent, we found ethnological heritage (*n* = 4; 11.4%), and in last place, natural heritage (*n* = 1; 2.9%).

The aim of the heritage perspective variable (V10) was to determine the perspective that these apps take towards the heritage that they elucidate. The most common perspectives were temporal–historical (*n* = 13; 37.1%) and monumental (*n* = 8; 22.9%). To a lesser extent, we found a perspective geared towards diverse points of view (whether cultural or natural; *n* = 5; 14.3%) and an aesthetic perspective (*n* = 5; 14.3%) (Figure 2). Lastly, there was a single case of a fetishist–exceptionalist perspective (*n* = 1; 2.9%), which means that something was valued for being rare or unique.

Figure 2. The Sorolla Museum's use of AR. Source: Google Play.

With respect to the type of communication (V11), nearly all apps were academic ($n = 33$; 94.3%), i.e., they focused on conveying cultural facts and information. The purpose of conservation—which is, precisely, what drives ideas on the need to conserve the cultural artifacts of everyday life—takes a very distant second place ($n = 2$; 5.7%).

4.3. AR Usability Dimension

With respect to the final dimension, which addresses the usability of AR in heritage apps, V12 (Table 4) showed that 65.7% of the apps wholly or partially included some type of reconstruction of heritage spaces, monuments or other places of interest ($n = 23$; 65.7%), followed by apps that used AR to view objects ($n = 14$; 40.0%) or to add written information about a physical object that the visitor can see on-site ($n = 10$; 28.6%).

Table 4. Uses of AR in the app (V12).

Use of AR	Frequency			Percentage		
	Yes	No	Total	Yes	No	Total
Object	14	21	35	40.0%	60.0%	100%
Building/monument	23	12	35	65.7%	34.3%	100%
Actions	7	28	35	20.0%	80.0%	100%
Fantasy	1	34	35	2.9%	97.1%	100%
Guide	7	28	35	20.0%	80.0%	100%
Additional person	4	31	35	11.4%	88.6%	100%
Written information	10	25	35	28.6%	71.4%	100%

The V13 relates to how apps activate AR. In most cases, users activated AR by scanning a code ($n = 19$; 54.3%). This was followed by apps in which AR could be used in conjunction with GPS ($n = 14$; 40.0%). There was only a minimal use of QR codes ($n = 1$; 2.9%); this was also the case with apps that only needed to be downloaded and the device's camera activated to view the heritage item ($n = 1$; 2.9%).

The requirements for using the AR tool (V14) were, in most cases, in situ ($n = 29$; 82.9%) compared to 17.1% ($n = 6$) of apps for which this was not a requirement. A small percentage of apps allowed the tool to be used anywhere ($n = 5$; 14.3%) by using codes provided by the developer, while only one of the apps (2.9%) allowed for AR to be used by simply activating the mobile device's camera.

With respect to the prominence or importance given to AR in the app (V15), the highest percentage corresponded to apps in which AR was the main and only tool ($n = 15$; 45.7%), followed by a high prominence in proportion to other elements offered in the app ($n = 10$; 28.6%). The percentage of apps that afforded medium prominence to AR ($n = 4$, 11.4%) was the same as for apps in which AR was barely given any prominence at all and was not much more than a mere add-on ($n = 4$, 11.4%).

5. Discussion of Results

We are well aware that this study only provides a first and approximate picture that will need to be complemented and expanded upon as more apps are planned and developed. That said, it is equally true that given the dearth of other studies, the present article has used the sample of currently available apps to offer relevant information about the main characteristics of open-access and free heritage apps from Europe that make use of AR. Accordingly, the descriptive portion of the present study reveals that museums, the institutions entrusted with protecting and interpreting patrimony, are the entities that most frequently develop this type of application. As Economou and Meintani [11] have highlighted, these are precisely the institutions that first championed the exploitation of digital technologies as tools for display, research, and learning. In this case, museums and heritage presentation spaces have found AR to be an ideal tool for meeting the public's demand for better ways to understand heritage. Augmented reality is also dynamic and attractive, a fact that leads to more people visiting such spaces to learn about what new tools and technologies have to offer. Furthermore, this ties in with tourism

and marketing considerations [9,17]. The importance of collaboration between different entities must also be highlighted: this type of cooperation stands out as a fruitful option for the future and can even be seen as an attractive strategy, thanks to the opportunity for multiple sectors to work together as well as for obtaining necessary funding from a variety of sources.

In relation to this idea, it has been noted that the countries that have developed most applications are precisely those where major studies have been carried out in the field of apps—though this could be put a bit differently: the places where this field has been most pursued are also those where the greatest amount of literature has been produced on the topic. This in turn could enable the apps that have been created to be more easily identified. In contrast, it is more difficult to find products of this type in places where research has not yet been published. Furthermore, it must be remembered that the present study has solely focused on the five majority languages in Europe, which might also influence the fact that Spain and the United Kingdom are the countries that were most widely represented. The fact that we were only been able to study applications that were currently available has limited the opportunity to learn about other previously developed applications that have disappeared, either because they have not been updated or because they have not been considered to be sustainable. In fact, the data confirm what some authors have previously stated [8,40]: the pace at which technology is advancing and the lack of applications that are sustainable over time mean that many have reached their expiration dates. At the most technical level, we must stress that almost half of the apps cannot currently be used on both of the main operating systems, a fact that makes it difficult for a large number of users to access them.

It should also be highlighted that one of these apps' objectives should be adaptability to different users [2,8,13], and hence, to exploit the opportunities offered by mobile learning and mobile devices. However, none of those that have been analyzed offers adaptation levels, even though some started out by highlighting that they are targeted at specific audiences, such as children or teenagers. So, the pattern of traditional analogical products can be said to be repeating itself and that the opportunity to exploit the potential that this type of technology has to offer is being squandered. This analogical aspect becomes all the more visible when other aspects of these apps are highlighted. Coinciding with other results obtained from the assessment of apps more generally [8,11], the majority of apps employing AR features only offer itineraries. This result is not totally unexpected, given that AR enables the reconstruction of scenarios that enhance the understanding of heritage; this is especially enriching in the case of itineraries. However, the opportunity may have also been lost to showcase heritage, to be able to interact with heritage and with the community that exists around it by means of hybrid proposals that complement any given planned visit. In contrast, an academic tone still predominates in these apps: this makes the user little more than a receiver of information and means that the level of interactivity is low [46]. While these apps can be labeled as educational, they do not fully meet the standards of what it means to be truly educational, since they omit aspects that are central to the learning process, such as engagement, self-learning (based on reflection, investigation as well as spaces for experimentation and simulation), and the other elements that have been shown to stimulate the learning of students and other users alike. Perhaps the use of AR as a business lure has played an outsized role on the development of this technology in heritage contexts: as a result, much attention has been dedicated to technical aspects and functionality of these apps, while educational and informative-planning concerns have often taken a back seat.

The content that these apps deal with is mainly historical heritage, which is presented from a temporal, monumental heritage perspective. As Vicent et al. [9] have stated, this is due to the archeological sites being the main users of this tool, since it allows for now-lost objects and elements from them to be reconstructed. This issue is related to the fact that a very high percentage of applications recommend routes for visitors and can only be used in situ, either by scanning codes or by activating GPS. Apps of this type are created to interpret heritage at a specific point in time that coincides with visiting a particular heritage space. The use of AR allows for guided visits to become journeys to the past. All of this prevents access to heritage from geographical locations other than the site itself.

Unlike VR, which can create immersive environments, AR requires the use of real spaces. Consequently, we could be tempted to conclude that the very nature AR encourages that it is used in situ. Even if this is the case, there is another possibility that allows AR to interact with real spaces through the use of videos, photos (as in the case of the app Imageen Tarraco) or even without the need to interact with determined elements. That said, if developers do not provide tags for download or access on a website, it becomes all the more difficult for these tools to be integrated into educational spaces such as the classroom. There is an extremely limited number of apps that enhance a visit by exploiting the potential of play or simulation, even though their effectiveness in cognitive processes has been clearly demonstrated [27]. One exception that can be highlighted is the "Architecture Gothique/Roman" app [18], a game-based AR app designed to be used in the classroom.

6. Conclusions

We can conclude that today, there are very few heritage apps which have met the inclusion criteria laid out in this study. This small sample size precludes a truly exhaustive study of heritage apps using AR. Nevertheless, we have been able to paint a general picture in broad brush strokes through the study of the sample. Though this group is limited, it has nevertheless generated some important data that ought to be further studied. As mentioned in the previous section of this paper, the use of AR in apps has an incredible potential to provide new ways of seeing and understanding heritage, even if at present we have detected a general lack of educationally sophisticated design.

Having completed the first Europe-wide study of open-access apps with heritage content, we can now outline the common characteristics and features of apps that use AR and provide a snapshot of the current trends in Europe:

1. The main entities developing these apps are museums and other heritage presentation sites (V1).
2. They have mainly been developed in Spain, the United Kingdom, and Italy, in 2015 and 2018 (V2, V3, V4), although the majority of apps become outdated over time.
3. They are not fully adapted to multiplatform systems (V5).
4. They can be used during both indoor and outdoor visits (V6).
5. They cannot be adjusted to meet various levels of user knowledge (V7).
6. They largely focus on heritage from Antiquity (V8).
7. Historical heritage is the main focus, which is treated from a temporal, monumental perspective (V9, V10).
8. The tone and type of communication is almost exclusively academic (V11).
9. AR is used for the reconstruction of spaces and monuments. It is also often used to view heritage objects or items (V12).
10. Apps are activated by scanning codes, and to a lesser extent, by activating GPS. A large percentage of apps require users to be in situ (V13, V14).
11. AR is usually the only or at least principal use of the app; if not, it usually features very prominently in the application (V15).

The developed apps have also been identified as being targeted at tourists or occasional visitors. Hardly any apps are available that can be used in the classroom. Lastly, this is an exploratory study framed in a very specific and limited geographical (Europe) and temporal (2019) context, and so we must be aware of any resulting research limitations. For example, the fact that the analyzed apps had to be available in the app stores at the time that we carried out our research limited and considerably reduced the sample size. Digital technologies always run into the same issue, namely, their shelf life: since apps have a short lifespan and are often linked to very specific projects that render them unsustainable [4], the speed at which these technologies are developed is faster than the speed of research and the publication process. If the results of user experiences are not published, then it becomes very difficult for apps contributions to be included in any future research. In this case, apps that did not work or were not available in app stores were discarded, which means that the oldest apps

have not been taken into account. The non-existence of studies on these apps, and even more so, of any evaluation of their uses in the area of heritage education, prevents any comprehensive comparison including older digital applications. Another additional limitation has been the search languages. Had the number of languages included in the search been higher, the sample would probably have also been larger. This means that a more comprehensive search needs to be undertaken in more languages, an undertaking that would require a European project with participants from a variety of countries where searches can be carried out in other EU languages.

To conclude, we think that the educational opportunities for heritage learning and teaching that both AR and mobile devices provide deserve further research and scholarly attention. Proposed future lines of research include continuing the analysis of these apps to identify those that are successful and so establish the key features that enable AR apps to be created and used that are suitable for the learning and teaching of heritage. The search for and inventorying of more applications should also continue in a broader geographical and temporal framework so as to keep the inventory up to date. Work will be done to integrate these types of tools into formal and informal educational contexts. This ought to be coupled with various forms of app assessment that examines aspects such as uses, educational functions, and perceived user satisfaction of the learning processes (as has already been done in some cases [18]). Lastly, we would like to highlight the importance of evaluating this type of tool, since this leads to improvements in AR apps' development and usage in education. We agree with Economou and Meintani [11] that it is not only a question of incorporating new technologies into heritage but also that their use should have some well-defined objectives and meet specific educational needs that go beyond the purely informative and contemplative.

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