eXtended Reality (XR) Experiences in Museums for Cultural Heritage: a systematic review

First Author[1[0000-1111-2222-3333]] and Second Author[2[1111-2222-3333-4444]]

[1] Princeton University, Princeton NJ 08544, USA
[2] Springer Heidelberg, Tiergartenstr. 17, 69121 Heidelberg, Germany
lncs@springer.com

Abstract. The incorporation of different types of media promotes a multimodal approach to the dissemination, communication and exploitation of Cultural Heritage in Museums. By utilizing digital technologies allows new forms of interactions with cultural content. Cultural spaces such as museums have been integrating new digital tools, presenting their audiences immersive, interactive, and multisensory experience that is not possible in traditional exhibitions. Withing these approaches a new term of Extended Reality (XR) is emerging and increasing its role in these cultural spaces. XR is the umbrella that englobes all forms of immersion and interaction such as Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR). This article aims to provide a comprehensive state of the art of XR experiences for Cultural Heritage in Museums. To support this goal, a systematic review of the peer-reviewed articles was gathered from the Scopus and Web of Science databases. Results are analyzed and the case studies are presented in this paper.

Keywords: Cultural Heritage, Extended Reality, Museums, Experience.

1 Introduction

According to Fast-Berglund et al. 2018, XR defines a spectrum of new media technologies such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). These technologies provide us with the possibility to create more immersive and meaningful experiences and to reach a bigger range of audiences with different demands and expectations. Such technologies and approaches have a short history in cultural heritage, virtual museums, and tourism.

Cultural Heritage (CH) can be referred to as the selection of physical artefacts and intangible attributes selected by the society that creates a legacy of tangible culture (physical objects) and intangible culture (traditions, languages, knowledge, and folklore) from past generations (Aikawa, 2004). Museums, according to the International Council of Museums (ICOM), a division of UNESCO, have the mission to acquire, conserve, research, communicates and exhibits the tangible and intangible heritage of humanity and its environment for education, study, and enjoyment (ICOM, 2007).

In the last years, cultural environments, such as museums have been merging new and more engaging immersive, interactive, and multi-sensorial approaches, to allow their publics a direct way to exposition space and contents, proving information,

prevailing over the traditional methods. To achieve their mission, museums have been incorporating new technologies to reach, engage and educate their audiences, by preserving the CH and democratize access to culture, and opening a space for dialogue and promotion of the exchange of ideas and knowledge. These approaches will benefit not only elderly or disabled people but all types of publics. It is foreseen that this trend will grow in a post COVID19 scenario (Agostino et al., 2020).
The goal of this paper is to present the state of the art of XR experiences in museums, synthesizing trends in the development of research in the field of XR within the subject area CH, more specifically Museums.
In order to do so, the authors followed guidelines for conducting systematic reviews of research (Okoli & Schabram, 2010) and analyze XR case studies that contain experiences in terms of objectives, results, locations, software, hardware and evaluation, with the aim to answer the following research questions:

RQ1: What is the total distribution and volume by geographic source, location and time of issued studies on XR Technologies in Museums Experiences?

RQ2: What authors, journals, and research articles have had the highest impact on studies focusing on XR Technologies in Museums Experiences?

RQ3: What type of experiences are being developed with XR technologies in Museums Experiences?

2 Reality-Virtuality Continuum

With Augmented Reality (AR), the reality is enhanced by adding extra digital content over the real world. AR is a disruptive technology as it provides a positive result by engaging with the users (Amin & Govilkar, 2015; Khan, Khusro, Rauf, & Mahfooz, 2015). Burkard et. al. (2017) divides AR experiences into four types of AR applications:

1. Area Information: this displays specific information about the user's environment in the camera image like tourist attractions, parks, lagoons, public spaces, etc.
2. Object information: delivers information on a particular object in the immediate environment like sculptures, monuments, buildings, etc.
3. Navigation: provides georeferenced waypoints in the camera image along a navigation route.
4. Games: Lets the user play with game elements on top of the camera image. This permits the real world to become the players playing field like Pokemon Go (Ling, 2017).

While AR overlaps the real world with digital content, VR creates a whole virtual world around the user (Milgram et al. 1994). The user enters these virtual worlds by using headsets to fully immerse in a computer-simulated reality. These headsets generate realistic images and sounds, engaging two senses to create an interactive virtual world.

With Mixed Reality (MR), the real-world and the virtual world blend together, combining interactivity and immersion offering immersive-interactive experience to view the real-virtual world, thus uniting different properties of the continuum into a single immersive reality experience (Milgram et al., 1994, Rahaman et al., 2019).

From a technology point of view, a new term has been introduced, designated by eXtended Reality (XR) (Fraunhofer HHI, 2019). According to Fast-Berglund et al. 2018, XR defines a spectrum of new media technologies such as AR, VR, and MR, as well as all future realities such technologies, might bring. XR covers the full spectrum of real and virtual environments. This new concept can be proposed as a vehicle for promoting enhanced cultural experiences that allow people to virtual travel to other areas and fascinatingly experience local history and lore. (Margetis, Apostolakis, Ntoa, Papagiannakis, & Stephanidis, 2021).

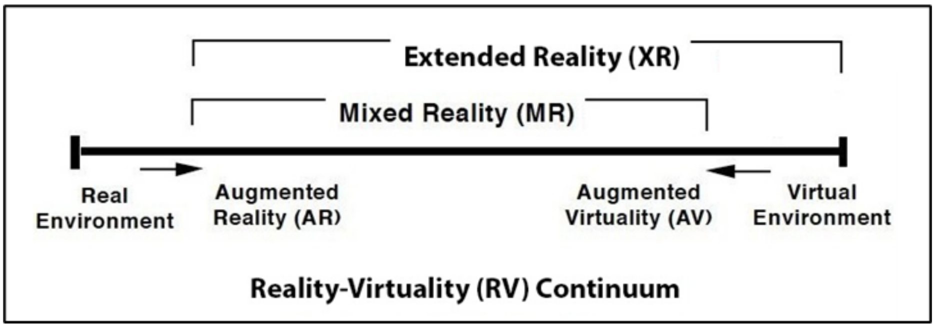

Fig. 1. Extended Reality Continuum (Authors)

In Fig. 1, the Reality-Virtuality Continuum, present by Milgram et al. 1994, is extended by the new umbrella term. As seen in Fig. 1, a less-known term is presented, called Augmented Virtuality. This expression concerns an approach, where the reality, e.g. the user's body, shows in the virtual world that is typically referred to as mixed reality.

XR development requires high-end computer hardware and specialized software. For software, experiences typical use game engines such as Unity3D and UnrealEngine4, integrating SDK's (software development kit) like Vuforia. A game engine is a fully integrated development platform that provides features to create interactive experiences with 3D content, and export experiences to multi-platforms (PC, Web, iOS, Android) (Kim et al., 2017). Regarding hardware, equipment depends on the experience they are intended for. To use AR applications, terminal devices such as smartphones, tablets, or systems like Google Glasses and Hololens are necessary (Amin & Govilkar, 2015). For VR experiences, the development of optimized hardware as HMD (Head Mount Display) systems is becoming the mainstream consumer device, and CAVE displays the most common choice (Bekele et al., 2018). Examples of HMD devices are HTC Vive, Oculus Rift, Google VR and Samsung Gear VR (Gugenheimer et al., 2017).

By combining these technologies, it is possible to create virtual experiences and even Virtual Museums (VM). VM is a collection of digital objects integrate with a variety of media, providing more ways of interaction and deepening the connection between visitors and objects (Schweibenz, 1998).

3 Research Methodology

This article followed Okoli & Schabram's (2010) systematic review methodology, beginning with the setting of a review protocol: systematic search process, practical screening, literature search, and data synthesis.

3.1 Data sources and search strategies

We performed a systematic literature search for articles published from January 2000 and August 2021 based on Scopus and Web of Science digital libraries. We include articles written in English, related to Extended Reality and Museums and Cultural Heritage, with a transparent methodology and from trusted resources and journals. We exclude those who were not submitted to peer-reviewed process or whose study's full text is not available.

The search strategy was designed to retrieve publications that were evaluated for eligibility and inclusion. The quality of the search strategy is vital as it affects what items may have been missed. The chosen keywords and the relationships between these keywords were the same for searches in each database.

By utilizing the search string: [(TITLE-ABS-KEY (extended AND reality) AND TITLE-ABS-KEY (museum) AND TITLE-ABS-KEY (cultural AND heritage))] we retrieved 14 results from Scopus and 24 from Web of Science.

After applying our selection criteria presented in Table 1 and checking for crossed results we ended up with 27 results.

Table 1. Systematic Review Process

Institute for Scientific information – SCOPUS	
Criteria	**Filters**
Restriction	Topic (Title, Abstract, Keywords)
Documents type	Articles and conference proceedings
Language	English

By not applying any restrictions to the subject area, the first results included papers from other research fields. So, we performed a manual check of the content of the full articles, the abstracts, and the title, then, defined which studies should be included or excluded for our case studies.

By applying these criteria, Esmaeili et al., 2014 and Petriaggi, 2016 were excluded since the authors never relate to or approach XR or XR technologies such as AR / MR / VR in their articles being left with 25 results.

For the analysis of our case studies, we added the keyword "Experience" to our search string which left us with 18 results in total from both databases.

Data extraction results:

From the total of 25 publications, 13 publications were in journals and 12 in conference proceedings (Fig. 2).

Analyzing articles publications, six articles in the first six years (2013-2018) and since 2019, eight articles (this number can increase as the period ends in 1st August 2021).

As for conferences publication, 2018 was an exceptional year, with 5 conferences publications. This is the same number in the period before 2018. After 2018, 4 conferences publications already.

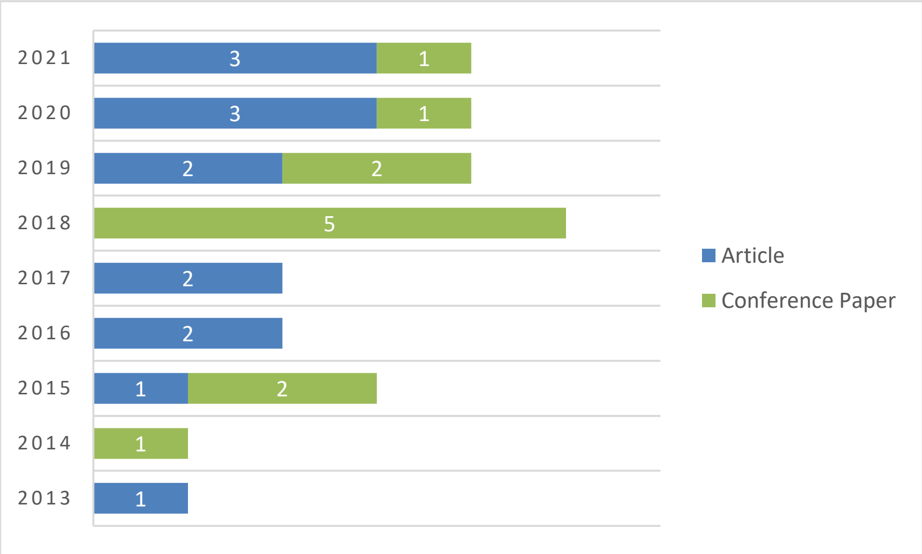

Fig. 2. Number of publication type per year (n=25)

Table 2 presents the contribution of each country to the XR in the museums for the CH area. Of the total of 12 countries, Greece and Italy are on the top of the list with 20% each followed by England and Romania with 12% which make them the top contributors with 64% of the total publications. Then Portugal contributes with 8% and the rest of the countries all contributed with 4% each.

Table 2. Distribution of results by country of contribution (n=25)

Country	Contribution
Greece, Italy	20%
England, Romania	12%
Portugal	8%

Bosnia and Herzegovina, China, Denmark, Malaysia, South Korea, United States of America, Uzbekistan	4%

It is also possible to extract the top 5 authors on the field by citation numbers which are demonstrated in Table 3. The citations to the articles begin in the year 2015, not existing previous citations, which permits to observe the average citation number per year from 2015 to 2021, with a maximum average of 2.29 citations per year from the Madsen & Madsen, authors. For the Publication areas present in the table, show that the authors are publishing their work in different areas such as applied conservation sciences, arts, technologies and engineering.

Table 3. Top 5 authors of the field

Authors	**Publication**	**Cites**	**Cites /year**
(Madsen & Madsen, 2015)	Journal on Computing and Cultural Heritage	16	2.29
(Banfi et al., 2019)	Virtual Archaeology Review	15	2.14
(Katyal, 2017)	California Law Review	8	1.14
(Spiridon & Sandu, 2016)	International Journal Of Conservation Science	7	1
(Anastasovitis, Ververidis, Nikolopoulos, & Kompatsiaris, 2018)	3DTV-Conference	3	0.43

We also explore the distribution of articles per journal, where the MDPI journal has the highest impact of publication with 31% of the publications from the 13 articles Fig. 3. This is a journal that has a mission to foster open scientific exchange in all forms across all disciplines.

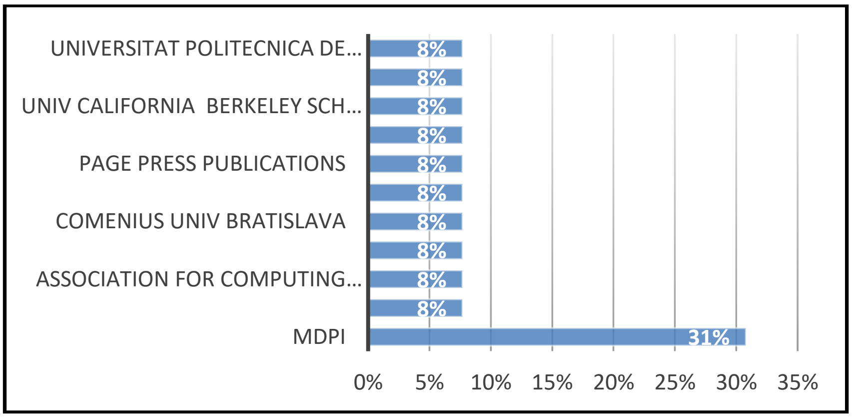

Fig. 3. Articles distribution per journal (n=13)

4 XR Experiences in Museums case studies

Earlier XR experiences have emerged in recent years in several fields of applications. For example, touristic operators working with cultural destinations are constantly investing in new technologies, following the current trend of mobile use. These investments allow companies to stay competitive in the global market since many tourist attractions face a lack of funds to maintain these sites (Fritz, Susperregui, & Linaza, 2015).

In this section, we will answer Research Question Q3 regarding what type of experiences are being developed with XR technologies in Museums Experiences. As mentioned in section 3.1 we have obtained 18 results.

Minucciani & Garnero (2013), discuss virtual tourism, presenting two different scenarios: a virtual trip in a virtual world and a real trip augmented with digital content. This discussion is supported by research and implementation of techniques available to transpose their content to the virtual world in a prototypal station installed in the Politecnico di Torino (Fig 4.). The station allows visitors to explore a tour simulation with three basic features. One feature offers the visitor a real and immersive vision of what he would see across the places he's visiting, without turning to city models or synthetic worlds. A second feature brings together the virtual displacement on sites with a physical motion made by the visitor and the final feature is the use of shared databases about historic architecture and cultural heritage.

Fig. 4. Prototypal station. Retrieved from (Minucciani & Garnero, 2013)

The prototype station can be replicable in different contexts and situations of use, allowing the visitor to explore remote sites without using the traditional station in front of a monitor.

In 2015, Madsen & Madsen present an AR system with the objective to facilitate the presentation of information to visitors. This system is divided into two parts. The first installation uses a tablet connected to a large screen TV that allows a single visitor to operate the installation while the other visitors can experience the visualization as over-the-shoulder spectators (Fig. 5.a). The second installation is a handheld experience that allows multiple visitors to operate their viewfinder, enabling them to use it as a window to the past and create their own tour throughout the chapel (Fig. 5.b).

Fig. 5. Left to right – (**a**) Static installation, (**b**) Handheld version. Retrieved from (Madsen & Madsen, 2015)

Partarakis et al. (2015), demonstrate an experience in the Museum Coffee Table that aims to augment the user experience within museum leisure spaces such as cafeterias, targeting family visitors. This system provides an AR physical surface extra information about artists and their creations for the parents while creating an entertainment environment for the children with the integration of popular games. As a result, the entire family can be sitting at the table drinking a coffee and having an extended (completed) visit to the museum.

In 2015 Ahn & Wohn, present what they have learned from four experiences that used a reconstruction of a virtual 3D "Grotto" they have created. The first experience is a VR movie displayed in the VR theater of Gyeongju Expo, the second a special exhibition at the National Museum of Korea, the third one a Stereoscopic film for digital heritage museum, and the last one is and Head Mounted Display (HMD) VR experience. The authors discuss several issues such as performance, physical immersion, interactivity and realism and conclude that exists difficulties to maintain high detail 3D models reality-based in steady frames for virtual interactive applications for CH.

Galdieri & Carrozzino, in 2017 develop the Muse-tools whit the objective to create a system that allows museum curators to be independent while creating reliable virtual spaces reducing the gap between curators and technology. The system is based on an extension of the Unity 3D game engine software to support new features and tools to allow the curator to plan real and virtual exhibitions without relying on expert programmers or artists. A full explorable Virtual Museum (Fig. 6) with four rooms, plus an external open space to demonstrate the possibility of abstracted VR in combination with human heritage exhibition was created using only the features of the author's system showing its capabilities to create virtual and concluding that it is unlikely for this demo to be recreated by a single museum curator.

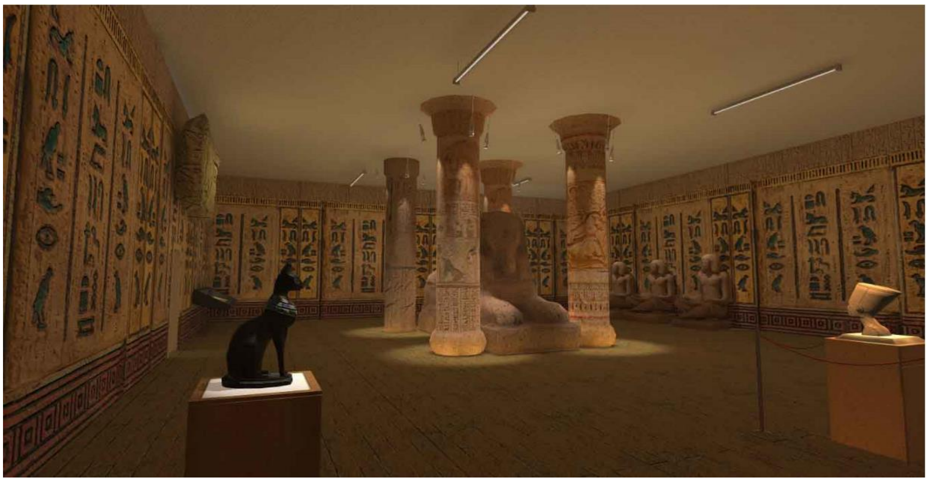

Fig. 6. One of the four rooms from the Virtual Museum: The Egyptian Room. Retrieved from (Galdieri & Carrozzino, 2017)

In 2018, the authors Duguleana & Voinea demonstrate the process of building an AR application that can be used as a digital guide for outdoor museums, monuments or any other type of heritage site. They present three different scenarios of experiences, the visit to the remains of the Etruscan tomb where the application overlaps the real world with a 3D digital reconstruction of the Etruscan tomb (Fig. 7).

Fig. 7. Left to right – (a) Original actual site of the Etruscan tomb (Archaeological Museum of Cecina), (b) Site with the digitally reconstructed tomb overlapping the real world. Retrieved from (Duguleana & Voinea, 2018).

The second experience allows the visitor to observe the famous poet Ovid wandering around the central square in front of the Rome Colosseum reciting one of his poems. The last experience is the 3D reconstruction of a destroyed Romanian Reformed Church monument, allowing the visitor to inspect an intangible monument that does not exist anymore.

Anastasovitis et al., 2018 presents three case studies of serious games created in the context of a European Union-funded project DigiArt (The Internet Of Historical Things And Building New 3D Cultural Worlds. These experiences allow the visitor to observe a simulation of the real world through the application of 3D models that can permit interaction, imagination and triggers immersion of the visitor. Fig 8, displays three examples of the case studies. The first experience is the Open site virtual experience of the Palace of Aigai in Greece where the visitor stands in the past oin 350 BC as an architect assistant (Fig. 8 (a)). The second experience is the virtual cave experience of Scladina Cave in Belgium where the visitor can explore the digital reconstruction of the site base on the scanned model of Scladina cave (Fig. 8 (b). The last shows the Anthropology virtual museum experience of the Liverpool John Moores University skeleton collection, where the visitor can explore the virtual space and observe 3D models of the skeleton collection (Fig. 8 (c)).

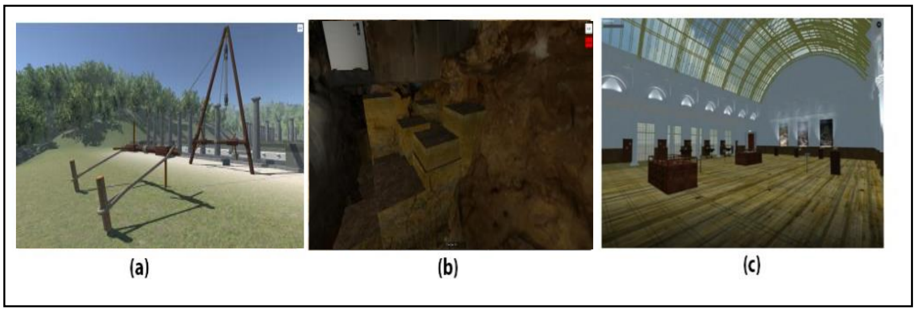

Fig. 8. Left to right – (**a**) Open site virtual experience (Palace of Aigai), (**b**) Virtual cave experience (Scladina Cave), and (**c**) Anthropology virtual museum experience (LJMU skeleton collection). Retrieved from (Anastasovitis et al., 2018).

The authors Adao et al., 2019 introduced the MixAR, a full-stack system with the capability to provide the visualization of virtual reconstructions seamlessly overlapping the real world with digital content (e.g. upon ruins). The system allows the visitor to freely explore the digital content and the archaeological site. To evaluate MixAR, a set of immersive and non-immersive experiences of the digitally reconstructed buildings that took place in the Vila Velha's Museum were implemented. In these experiences, the user could visualize the Chapel 3D digital reconstruction overlaying the real world, allowing to explore the interior of the 3D model. The overall user satisfaction, on a 1-100 scale, was 77.53 for the immersive experience and 71.34 for the non-immersive experience.

In 2019, Banfi et al. present a holistic approach to the Basilica of Sant'Ambrogio in Milan that starts from data collection such as 3D survey and historical records, followed by the creation of 3D models and ending with an XR experience (Fig. 9). These experiences offer an increased level of information and create an increased awareness of the intangible value and historic richness that would be possible by the traditional ways. With their research, they discuss the potential and challenges to the utilization of these technologies in the CH field. One of the potential uses is the already consider increased availability of information to the visitors, providing multiply outcomes with different levels of information. But at the same time, these outcomes create challenges themselves, like the problems faced for the parametrization of historical building shapes, difficulty to represent historical hypotheses and the communication of intangible values. For this, the authors propose that the creation process must be carried with communication between the creator's experts, restorers and art historians.

Fig. 9. Extended Reality and informative models for multiple devices. Retrieved from (Banfi et al., 2019).

In 2019 Cisternino et al., present the possibility to extended their previous work, an AR indoor experience, into MR outdoor experience, creating a set of virtual portals, accessible through a smartphone or a mobile device, generating in the visitor the sensation of time travel, between the real world (the present) and the virtual world (the past).

Duguleană et al., in 2020, present a thorough investigation that reveals significant progress from the technologies used to digitize CH and report the creation of a Virtual Assistant with artificial intelligence for CH in museums of Romania (Fig. 10). 3D VR avatars were considered innovative by young audiences. The introduction of virtual elements increased the levels of interaction of the visitors with the museum content and lead to an increase in visitor's numbers. The enhancement of the engagement and the attractiveness of cultural institutions are two crucial objectives, such as social and psychological points of view and economically.

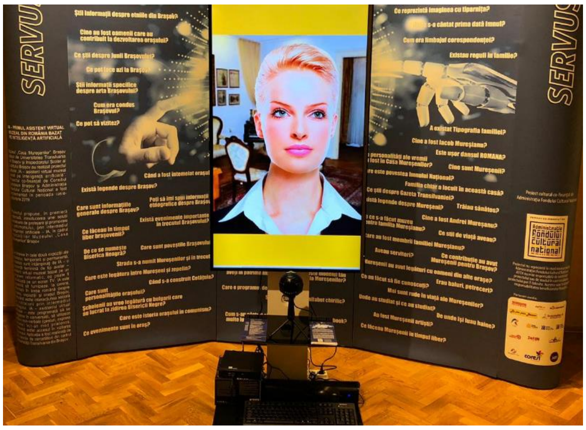

Fig. 10. Virtual Assistant physical stand. Retrieved from: (Duguleană et al., 2020)

In 2020, Silva & Teixeira present a PhD project for the creation of an XR platform for immersive and interactive experiences for CH, designed for Serralves Museum and Coa Archeological Park, based on the study of the state of the art of XR applications/experiences from CH in museums and archaeological parks. The main objectives of the project are, the understanding of the potential of XR within CH and the development of an XR platform that could create multiple experiences for CH, contributing with new approaches to process and deliver immersive and interactive content for CH environments. The platform will provide and enhance the augmented experience for visitors to these sites. The system is based on new multilayered and narrative modalities.

Tennent et al., in 2020, show Thresholds, a VR experience that recreates the world's first photographic exhibition and toured multiple museums. The experience allows having multiple visitors at the same time in the real and virtual space, being replaced by ghostly avatars into the virtual world. The visitors can walk and explore the virtual world and experience the digital content such as high-quality scans from the original photographs (Fig. 11). Visitors were observed how they experienced the work to extract information for the design of VR user experiences for museums.

Fig. 11. Virtual wood and glass vitrine that hold several photographs. Retrieved from (Tennent et al., 2020)

In 2021, Rizvić et al. display four XR applications to bring visitors back in time, into the history of Bosnia and Herzegovina, by recreating digital objects, events and characters from the past. In the first experience, “Nine Dissidents”, the authors record VR videos and create a VR movie to represent the conflicting opinions that existed on the character of the socialist regime in Yugoslavia. The second one, “Old Crafts Virtual Museum”, uses VR technology to exhibit and preserve the crafts presented in Old Town Sarajevo Bašcaršija since the 15th century. Actors dress as craftsmen who appear in a virtual world, telling stories about their crafts. The third one “Battle on Neretva VR” places the visitor in the middle of one of the most important battles in Yugoslavia during WWII. The visitor is giving the mission to destroy a bridge and save his wounded comrades. “Sarajevo 5D”, the last experience, combines AR technology with the recreation of cultural monuments and objects that have disappeared from their original locations. Thus, allowing the visitor to learn about their historical significance and original appearance. All the applications are display in Fig. 12.

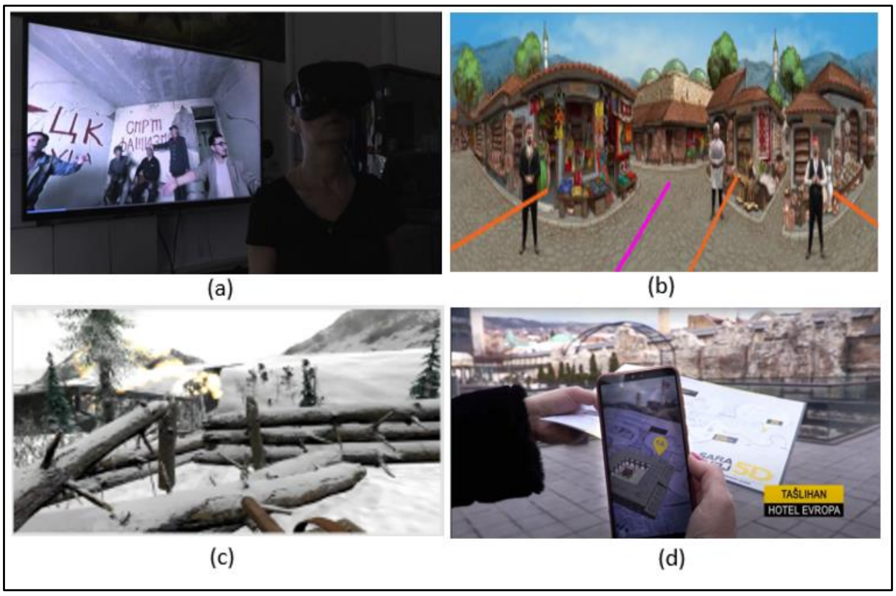

Fig. 12. From left to right **(a)** First application “Nine Dissidents”, **(b)** Second application “Old Crafts Virtual Museum”, **(c)** Third application “Battle of Neretva VR”, **(d)** Forth application “Sarajevo 5D”. Retrieved from (Rizvić et al., 2021).

Harun & Mahadzir, in 2021, developed a 360º Virtual tour of the traditional Malay house, after having performed a literature review on VR photography and analyzing examples of other 360º systems that already exist mainly in the Asia area. They aim to preserve the architectural heritage for the future generation by providing local and digital visitors heritage information with effectiveness, simplicity, and a low-cost system. The system works with a simple but effective interface as shown in Fig. 13 and delivers detailed information of the building displayed around the 360º world as anchor points. Results show that the development of their Virtual Tour can indirectly attract the people's interest in the uniqueness of traditional Malay houses.

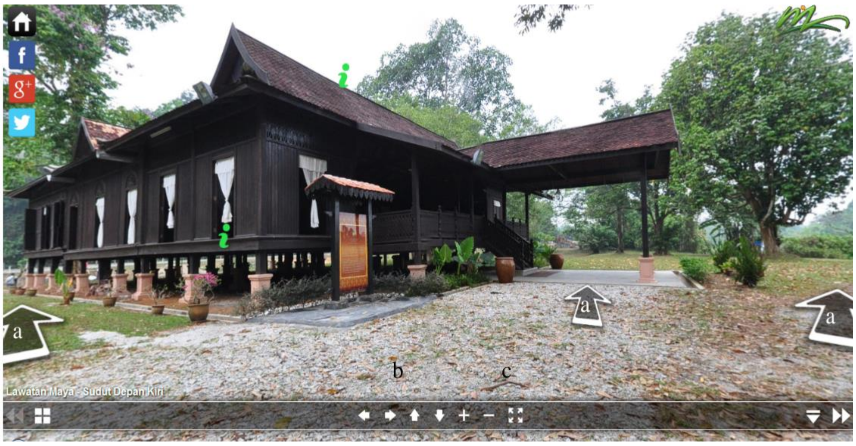

Fig. 13. 360º Virtual Tour Main Interface. Retrieved from (Harun & Mahadzir, 2021)

Banfi & Previtali, in 2021 propose a method to improve human-computer interaction between Heritage Building Information Modelling (HBIM) and advanced XR projects. This digital process allows the transmission and shares the tangible and intangible values of built heritage between different software, devices and formats to create a more sustainable way from a technological point of view. At the same time, it is possible to keep the high levels of parametricity, interoperability, orientation and virtual interactivity of digital models. Supported by these results, the authors developed an XR experience for the Church of San Valentino in Italy that allows the visitor to explore the virtual space of the 3D modelling from the Church implemented in a virtual world using VR and see the 3D model imposed into the real world by the use of AR.

Margetis et al., in 2021 propose a synthesis of AR, VR and MR technologies to provide unified X-Reality experiences for "real" and virtual visits to the museum. Three XR definitions are proposed: a superset, an extrapolation, and a subset of MR. XR aims to fuse layered objects into the real world through immersive digital worlds. Two new concepts to XR are introduced: Diminished Reality, to denote the fading of real parts of the environment that are substituted by digital counterparts, and True Mediated Reality, to define the need for delivering realistic virtual characters. The first results show that XR allows museum visitors to interact with the physical environment while immersed in an XR application.

5 XR case studies tables analysis

In this chapter, to answer RQ1 and RQ2, we organize the information into two tables: the first table (**Table 4)** displays the case studies in terms of locations, objectives, evaluations, and results, and the second table (**Table 5)** contains data regarding technology, software and hardware used in the experiences. For this analysis, the case studies (Silva & Teixeira, 2020) and (Margetis et al., 2021) are not included because of being conceptual articles and not having an implementation of an experience, thus being not present most of the information required to the table.

In Table 4, Location is referred to the place where the experience was tested: Museum, University Lab or Other (standing for city spaces, conferences, etc.). The Objective is the main goal of the experience, and Evaluation reports if any type of assessment was performed and if it occurs, how it was evaluated. For Results, we consider three possibilities: R1 – for Prototype; R2 – for Pilot and R3 for Product.

Table 4. Locations, objectives, evaluations and results of the XR case studies.

Authors	Location	Objective	Evaluation	Result
(Minucciani & Garnero, 2013)	University Lab.	Prototypal Station: allows the visitor to visit remote sites without turning to the traditional station in front of a monitor	n/a	R1
(Partarakis et al., 2015)	University Lab.	Museum Coffee Table: allows the visitors to extend (complete) their visits within leisure spaces of the museum such as cafeterias.	Questionnaire, twelve participants, recording the use of the system to be analyzed offline	R2
(Madsen & Madsen, 2015)	Museum	Two installations for the visualization of a 3D reconstruction of a castle chapel, running autonomously, at interactive framerates on modern tablets, during open hours	Anonymously logged data from the visitors, number of times the application was used.	R2
(Ahn & Wohn, 2015)	Museum / Other	Virtual 3D reconstruction of the Seokguram Grotto (four projects)	n/a	R2
(Galdieri & Carrozzino, 2017)	University Lab.	Create a toolbox system to support the development of digital experience by curators, diminishing the gap between curators and technology	Questionnaires to evaluate the technology acceptance sent to over 350 museum curators, 63 answers received.	R3
(Anastasovitis et al., 2018)	University Lab.	Design and development of three desktop serious games for promoting European CH.	n/a	R1
(Duguleana & Voinea, 2018)	Museum / Other	Demonstrate the use of AR applications with three different experiences.	Questionnaire, 92 participants distributed by the 3 experiences, 8 in the first, 63 in the second and 12 in the third	R2
(Adao et al., 2019)	Other	Implement the MixAR system to allow visitors access of *in situ* experiences of reconstructed buildings that no longer exist.	Questionnaire, 18 participants where 56% were students of technological areas.	R1
(Banfi et al., 2019)	University Lab.	3D survey and gather data of historical records of the church, to create an XR experience	n/a	R1

		that reaches a new level of interactivity for different types of devices (desktop, mobile, VR headset) and users (experts, non-experts).		
(Cisternino et al., 2019)	University Lab. / Other	Evaluate the feasibility to extend an existing AR indoor experience, to a MR experience with the creation of outdoor points of interest (Virtual Portals).	n/a	R1
(Duguleană et al., 2020)	Museum	To develop an intelligent conversational agent (Virtual Assistant) to improve the accessibility to information inside a history museum.	User Acceptance Evaluation questionnaire, 2 minutes duration, over 250 students.	R3
(Tennent et al., 2020)	Museum	To recreate into a VR experience the world's first photographic exhibition.	Evaluate the top 15 items of the experience using the time spent by each visitor for each item	R3
(Banfi & Previtali, 2021)	University Lab.	Improve human-computer interaction between HBIM and advance XR projects, by design a new digital process and implementing it on XR experience	n/a	R1
(Harun & Mahadzir, 2021)	Other	Development of a 360° virtual tour of the traditional Malay house to preserve Malay architectural heritage for future generations	n/a	R3
(Rizvić et al., 2021)	Museum / Other	To present four projects that bring back visitors to the history of Bosnia and Herzegovina and recreated objects, events, and characters from its past.	Two different UX evaluation methods: (1) qualitative studies for exploring new modalities of expression and pilot solutions (2) quantitative studies to obtain a reliable measure of the success of VR/AR applications.	R2

From Table 4 we can observe that near 47% of the experiences was tested/presented in a University Lab were 86% from the 47% were only on University Lab. And the remaining 14% were tested/presented in University Lab and Other. Then 40% were tested/presented in Museums in which half of the 40% were tested/presented only in Museums and the other half was tested in Museums and Other locations. As for Other locations only was 13% since some of the experiences were tested in both Museums and Other or University Lab. and Other in a total of 33%.

In terms of evaluation, 53% of the experiences were evaluated, using mostly qualitative methods, typically questionnaires, with the number of participants ranged from 12 to over 250 answers. 47% did not report any kind of evaluation of the experience.

Regarding results, 40% are prototypes, 33% pilots and 27% already products. Although almost all prototypes were present in a University Lab, only one in seven experiences were evaluated, while on the other hand, 80% of the pilots, located mostly in Museums, were evaluated.

Table 5 presents information regarding the technology used to implement the experiences: XR modality (AR/VR/MR/360º/XR), software platforms and hardware devices.

Table 5. Software and Hardware used on XR case studies.

Authors	XR modality	Software	Hardware
(Minucciani & Garnero, 2013)	VR	GraphDB, Google Maps	n/a
(Partarakis et al., 2015)	AR	Microsoft Byte Tag / Microsoft Surface SDK / Protégé / SPARQL	Mobile device
(Madsen & Madsen, 2015)	AR	Arduino / Unity 3D / 123D Catch / Maya	Arduino / iPad / TV Screen / iPhone
(Ahn & Wohn, 2015)	VR	Unreal Engine 4	Desktop / Head Mount Display
(Galdieri & Carrozzino, 2017)	VR	Unity 3D	Desktop
(Anastasovitis et al., 2018)	VR	Unity 3D	Desktop / Head Mount Display
(Duguleana & Voinea, 2018)	AR	n/a	Mobile device
(Banfi et al., 2019)	XR	Autodesk A360 / Unreal Engine 4	Desktop / Oculus Rift / Mobile device
(Adao et al., 2019)	AR / MR	Unity 3D / Metaio SDK /Blender	Mobile device
(Cisternino et al., 2019)	MR	Unity 3D / ARcore / ARKit	Mobile device
(Duguleană et al., 2020)	VR	Google Cloud Speech to Text / Proprietary using NLU programming language and RASA platform	Desktop / Large TV Screen
(Tennent et al., 2020)	VR	Orion SDK / Unity 3D / Autodesk 3D Studio Max	Laptop / HTC Vive / Leap Motion sensor
(Banfi & Previtali, 2021)	AR / VR	Unreal Engine / Twinmotion	Desktop / Head Mount Display / Mobile device
(Harun & Mahadzir, 2021)	VR / 360º	n/a	n/a
(Rizvić et al., 2021)	XR	Unity 3D	Desktop / Head Mount Display / Mobile Device

According to Table 5, 53.3% of the experiences use only VR, 33.3% use only AR, 13.3% use MR or XR. If we consider the use of each of the XR modalities, AR, MR or VR, then 66% uses VR, 46% uses AR and 26% use MR.

Analyzing the software and hardware components, two publications (Duguleana & Voinea, 2018 & Duguleana & Voinea, 2018) do not mention which software was used and two publications (Minucciani & Garnero, 2013 & Harun & Yanti Mahadzir, 2021) do not mentions which hardware was used.

Regarding the 13 publications that have refer software or hardware, 54% use Unity 3D and 23% use Unreal Engine as software platforms, and 31% use mobile devices only (such as cellphones, tablets), while the remaining 69% use desktop mixing with other types of hardware such as Head Mounted Display, Large TV Screens, Leap Motion Sensors and Mobile Devices. With this we can observe that 77% of the authors are using Game Engines to develop their experiences and utilizing more common approaches in terms of hardware with Mobile Devices and Desktops, indicating a path to standardization in Software and Hardware for the creation of XR experiences.

6 Discussion and future directions

In this paper, we explore and analyze a literature review of research made in the Scopus and Web of Science digital libraries from the string Extended Reality in Museums for Cultural Heritage and Extended Reality in Museums for Cultural Heritage Experiences for the analysis of case studies. The relatively small number of publications indicates that the use of XR technology is still in its early phases in the CH area in Museums. With these results, we answered our three research questions for the XR in the Museums Experiences. The first question, "What is the total distribution and volume by geographic source, location and time of issued studies on XR Technologies in Museums Experiences?" showed us that after the year 2018 we start to see a growing number of publications and the countries Greece and Italy are the ones contributing the most for these publications; The second question, "What authors, journals, and research articles have had the highest impact on studies focusing on XR Technologies in Museums Experiences?" present us that the authors (Anastasovitis et al., 2018; F. Banfi et al., 2019; Katyal, 2017; Madsen & Madsen, 2015; Spiridon & Sandu, 2016) are the top 5 authors with more impact in the studies of XR technologies in Museums and as for the journals demonstrated us that MDPI has more impact with 31% publications from 13. The last question, "What type of experiences are being developed with XR technologies in Museums Experiences?" presented us that the majority of the authors are developing VR experiences, resorting to game engine software to develop their experiences. From our results, it is present that the XR will be adopted by even more institutions XR since it has clear benefits for attracting visitors and encouraging revisits, where the visitors can experience more engaging, immersive, and meaningful CH content (Banfi et al., 2019; Margetis et al., 2021). Also was present that these technologies can help to preserve and reviving CH lost content (Harun & Mahadzir, 2021; Madsen & Madsen, 2015; Rizvić et al., 2021). Nevertheless, the XR technologies have a positive influence on the CH giving several different tools to this area to develop better and enhanced experiences for its visitors, but there is still present a gap between museum curators and these new technologies which can't be filled without the help of new categories of professionals that can understand museums and new technologies at the same time (Galdieri & Carrozzino, 2017).

For future works, there is the option to do a literature review of XR with AR / VR / MR terms to see how much influences the number of results. Also, the design and evaluation process can be thoroughly explored and compared between articles to understand the existing difficulties when creating XR experiences for CH in Museums.

References

1. Adao, T., Padua, L., Narciso, D., Sousa, J. J., Agrellos, L., Peres, E., & Magalhaes, L. (2019). MixAR: A Multi-Tracking Mixed Reality System to Visualize Virtual Ancient Buildings Aligned Upon Ruins. JOURNAL OF INFORMATION TECHNOLOGY RESEARCH, 12(4), 1–33. https://doi.org/10.4018/JITR.2019100101
2. Agostino, D., Arnaboldi, M., & Lampis, A. (2020). Italian state museums during the COVID-19 crisis: from onsite closure to online openness. Museum Management and Curatorship, 1–11. https://doi.org/10.1080/09647775.2020.1790029
3. Ahn, J., & Wohn, K. (2015). Lessons Learned from Reconstruction of a Virtual Grotto - From Point Cloud to Immersive Virtual Environment. In Guidi, G and Torres, JC and Scopigno, R and Graf, H and Remondino, F and Brunet, P and Barcelo, J and Duranti, L and Hazan, S (Ed.), 2015 DIGITAL HERITAGE INTERNATIONAL CONGRESS, VOL 2: ANALYSIS \& INTERPRETATION THEORY, METHODOLOGIES, PRESERVATION \& STANDARDS DIGITAL HERITAGE PROJECTS \& APPLICATIONS (pp. 651–654). IEEE.
4. Aikawa, N. (2004). An Historical Overview of the Preparation of the UNESCO International Convention for the Safeguarding of the Intangible Cultural Heritage. Museum International, 56(1–2), 137–149. https://doi.org/10.1111/j.1350-0775.2004.00468.x
5. Amin, D., & Govilkar, S. (2015). Comparative Study of Augmented Reality Sdk's. International Journal on Computational Science & Applications, 5(1), 11–26. https://doi.org/10.5121/ijcsa.2015.5102
6. Anastasovitis, E., Ververidis, D., Nikolopoulos, S., & Kompatsiaris, I. (2018). Digiart: Building new 3D cultural heritage worlds. 3DTV-Conference, 2017-June, 1–4. https://doi.org/10.1109/3DTV.2017.8280406
7. Banfi, F., Brumana, R., & Stanga, C. (2019). Extended reality and informative models for the architectural heritage: From scan-to-bim process to virtual and augmented reality. Virtual Archaeology Review, 10(21), 14–30. https://doi.org/10.4995/var.2019.11923
8. Banfi, F., & Previtali, M. (2021). Human-Computer Interaction Based on Scan-to-BIM Models, Digital Photogrammetry, Visual Programming Language and eXtended Reality (XR). APPLIED SCIENCES-BASEL, 11(13). https://doi.org/10.3390/app11136109
9. Bekele, M. K., Town, C., Pierdicca, R., Frontoni, E., & Malinverni, E. V. A. S. (2018). A Survey of Augmented , Virtual , and Mixed Reality. ACM Journal on Computing and Cultural Heritage, 11(2), 36. https://doi.org/10.1145/3145534
10. Burkard, S., Fuchs-Kittowski, F., Himberger, S., Fischer, F., & Pfennigschmidt, S. (2017). Mobile location-based augmented reality framework. IFIP Advances in Information and Communication Technology, 507, 470–483. https://doi.org/10.1007/978-3-319-89935-0_39
11. Cisternino, D., Gatto, C., D'Errico, G., De Luca, V., Barba, M. C., Paladini, G. I., & De Paolis, L. T. (2019). Virtual Portals for a Smart Fruition of Historical and Archaeological Contexts. In DePaolis, LT and Bourdot, P (Ed.), AUGMENTED REALITY, VIRTUAL REALITY, AND COMPUTER GRAPHICS (AVR 2019), PT II (Vol. 11614, pp. 264–273). SPRINGER INTERNATIONAL PUBLISHING AG. https://doi.org/10.1007/978-3-030-25999-0_23

12. Duguleană, M., Briciu, V.-A., Duduman, I.-A., & Machidon, O. M. (2020). A virtual assistant for natural interactions in museums. Sustainability (Switzerland), 12(17). https://doi.org/10.3390/SU12176958
13. Duguleana, M., & Voinea, G. D. (2018). Enhancing the Experience of Visiting Outdoor Heritage Sites Using Handheld AR. In Stephanidis, C (Ed.), HCI INTERNATIONAL 2018 - POSTERS' EXTENDED ABSTRACTS, PT III (Vol. 852, pp. 184–191). SPRINGER INTERNATIONAL PUBLISHING AG. https://doi.org/10.1007/978-3-319-92285-0_26
14. Esmaeili, H., Woods, P. C., & Thwaites, H. (2014). Realisation of virtualised architectural heritage. Proceedings of the 2014 International Conference on Virtual Systems and Multimedia, VSMM 2014, 94–101. https://doi.org/10.1109/VSMM.2014.7136676
15. Fast-Berglund, Å., Gong, L., & Li, D. (2018). Testing and validating Extended Reality (xR) technologies in manufacturing. Procedia Manufacturing, 25, 31–38. https://doi.org/10.1016/j.promfg.2018.06.054
16. Fraunhofer HHI. (2019). XR4ALL Moving The European XR Tech Industry Forward. 95.
17. Galdieri, R., & Carrozzino, M. (2017). TOWARDS DEDICATED SOFTWARE TOOLS TO ASSIST THE CREATION OF VIRTUAL EXHIBITS. SCIRES-IT-SCIENTIFIC RESEARCH AND INFORMATION TECHNOLOGY, 7(1), 17–28. https://doi.org/10.2423/i22394303v7n1p17
18. Gugenheimer, J., Stemasov, E., Frommel, J., & Rukzio, E. (2017). ShareVR: Enabling co-located experiences for virtual reality between HMD and Non-HMD users. Conference on Human Factors in Computing Systems - Proceedings, 2017-May, 4021–4033. https://doi.org/10.1145/3025453.3025683
19. Harun, N. Z., & Mahadzir, S. Y. (2021). 360° Virtual Tour of the Traditional Malay House as an Effort for Cultural Heritage Preservation. IOP Conference Series: Earth and Environmental Science, 764(1). https://doi.org/10.1088/1755-1315/764/1/012010
20. Haynes, R. (2018). Eye of the Veholder: AR Extending and Blending of Museum Objects and Virtual Collections. In Jung, T and Dieck, MCT (Ed.), AUGMENTED REALITY AND VIRTUAL REALITY: EMPOWERING HUMAN, PLACE AND BUSINESS (pp. 79–91). SPRINGER-VERLAG BERLIN. https://doi.org/10.1007/978-3-319-64027-3_6
21. Hsiao, P.-W. (2019). The LOHAS Digital and Interactive Vitalization Community for Heritage and Sustainability of The Ruins of St. Paul. In Meen, TH (Ed.), PROCEEDINGS OF 2019 IEEE EURASIA CONFERENCE ON BIOMEDICAL ENGINEERING, HEALTHCARE AND SUSTAINABILITY (IEEE ECBIOS 2019) (pp. 79–82). IEEE.
22. ICOM. (2007). Museum Definition. https://icom.museum/en/resources/standards-guidelines/museum-definition/
23. Kakarountas, A., Dragoumanos, S., & Kakarountas, K. (2014). Extending Visitor's Reality at Museums. 5TH INTERNATIONAL CONFERENCE ON INFORMATION, INTELLIGENCE, SYSTEMS AND APPLICATIONS, IISA 2014, 196+.
24. Katyal, S. K. (2017). Technoheritage. CALIFORNIA LAW REVIEW, 105(4), 1111–1172. https://doi.org/10.15779/Z38PN8XF0T
25. Khan, A., Khusro, S., Rauf, A., & Mahfooz, S. (2015). Rebirth of Augmented Reality -- Enhancing Reality via Smartphones. Bahria University Journal of Information & Communication Technologies, 8(1), 110–121.
26. Kim, S. K., Kang, S. J., Choi, Y. J., Choi, M. H., & Hong, M. (2017). Augmented-reality survey: From concept to application. KSII Transactions on Internet and Information Systems, 11(2), 982–1004. https://doi.org/10.3837/tiis.2017.02.019
27. Koterwas, T., Suess, J., Billings, S., Haith, A., & Lamb, A. (2018). Augmenting Reality in Museums with Interactive Virtual Models. In Jung, T and Dieck, MCT (Ed.), AUGMENTED REALITY AND VIRTUAL REALITY: EMPOWERING HUMAN,

PLACE AND BUSINESS (pp. 365–370). SPRINGER-VERLAG BERLIN. https://doi.org/10.1007/978-3-319-64027-3_25
28. Ling, H. (2017). Augmented Reality in Reality. IEEE Multimedia, 24(3), 10–15. https://doi.org/10.1109/MMUL.2017.3051517
29. Madsen, J. B., & Madsen, C. B. (2015). Handheld visual representation of a castle chapel ruin. Journal on Computing and Cultural Heritage, 9(1). https://doi.org/10.1145/2822899
30. Margetis, G., Apostolakis, K. C., Ntoa, S., Papagiannakis, G., & Stephanidis, C. (2021). X-reality museums: Unifying the virtual and realworld towards realistic virtual museums. Applied Sciences (Switzerland), 11(1), 1–16. https://doi.org/10.3390/app11010338
31. Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented reality: A class of displays on the reality-virtuality continuum. Telemanipulator and Telepresence Technologies, 2351(December 2013), 282–292. https://doi.org/10.1117/12.197321
32. Minucciani, V., & Garnero, G. (2013). Geomatics and virtual tourism. Journal of Agricultural Engineering, 44(2s). https://doi.org/10.4081/jae.2013.s2.e100
33. Okoli, C., & Schabram, K. (2010). Working Papers on Information Systems A Guide to Conducting a Systematic Literature Review of Information Systems Research. Working Papers on Information Systems, 10(2010). https://doi.org/10.2139/ssrn.1954824
34. Partarakis, N., Kontaki, E., Zidianakis, E., Drossis, G., Birliraki, C., Metaxakis, G., Barka, A., Poutouris, V., Mathioudakis, G., Zidianaki, I., Chatziantoniou, A., Koutlemanis, P., Zabulis, X., Margetis, G., Grammenos, D., Apostolakis, E., Stamatakis, E., Paparoulis, G., Antona, M., & Stephanidis, C. (2018). Digital Heritage Technology at the Archaeological Museum of Heraklion. In Stephanidis, C (Ed.), HCI INTERNATIONAL 2018 - POSTERS' EXTENDED ABSTRACTS, PT III (Vol. 852, pp. 196–203). SPRINGER INTERNATIONAL PUBLISHING AG. https://doi.org/10.1007/978-3-319-92285-0_28
35. Partarakis, N., Zidianakis, E., Antona, M., & Stephanidis, C. (2015). Art and Coffee in the Museum. In Streitz, N and Markopoulos, P (Ed.), DISTRIBUTED, AMBIENT, AND PERVASIVE INTERACTIONS (Vol. 9189, pp. 370–381). SPRINGER-VERLAG BERLIN. https://doi.org/10.1007/978-3-319-20804-6_34
36. Petriaggi, R. (2016). MANAGEMENT STRATEGIES FOR CONSERVATION RESTORATION AND FRUITION OF UNDERWATER ARCHAEOLOGICAL PARKS. ARCHAEOLOGIA MARITIMA MEDITERRANEA-AN INTERNATIONAL JOURNAL ON UNDERWATER ARCHAEOLOGY, 13, 55–72.
37. Rahaman, H., Champion, E., & Bekele, M. (2019). From photo to 3D to mixed reality: A complete workflow for cultural heritage visualisation and experience. *Digital Applications in Archaeology and Cultural Heritage*, *13*(January). https://doi.org/10.1016/j.daach.2019.e00102
38. Rizvić, S., Bošković, D., Okanović, V., Kihić, I. I., Prazina, I., & Mijatović, B. (2021). Time travel to the past of bosnia and herzegovina through virtual and augmented reality. Applied Sciences (Switzerland), 11(8). https://doi.org/10.3390/app11083711
39. Schweibenz, W. (1998). The '"Virtual Museum"': New Perspectives For Museums to Present Objects and Information Using the Internet as a Knowledge Base and Communication System. Internationalen Symposiums Für Informationswissenschaft, November, 185–200. http://www.informationswissenschaft.org/wp-content/uploads/isi/isi1998/14_isi-98-dv-schweibenz-saarbruecken.pdf
40. Silva, M., & Teixeira, L. (2020). Developing an eXtended Reality platform for Immersive and Interactive Experiences for Cultural Heritage: Serralves Museum and Coa Archeologic Park. Adjunct Proceedings of the 2020 IEEE International Symposium on Mixed and Augmented Reality, ISMAR-Adjunct 2020, 300–302. https://doi.org/10.1109/ISMAR-Adjunct51615.2020.00084

41. Spiridon, P., & Sandu, I. (2016). MUSEUMS IN THE LIFE OF THE PUBLIC. INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE, 7(1), 87–92.
42. Tennent, P., Martindale, S., Benford, S., Darzentas, D., Brundell, P., & Collishaw, M. (2020). Thresholds: Embedding Virtual Reality in the Museum. ACM JOURNAL ON COMPUTING AND CULTURAL HERITAGE, 13(2). https://doi.org/10.1145/3369394
43. Zyla, K., Montusiewicz, J., Skulimowski, S., & Kayumov, R. (2020). VR technologies as an extension to the museum exhibition: A case study of the Silk Road museums in Samarkand. MUZEOLOGIA A KULTURNE DEDICSTVO-MUSEOLOGY AND CULTURAL HERITAGE, 8(4), 73–93. https://doi.org/10.46284/mkd.2020.8.4.6