XR technologies fostering museum visits for people with impairments

Dimitrios Koukopoulos[1], Konstantinos Koukoulis[1], Stella Sylaiou[2] and Christos Fidas[1]

[1] *University of Patras, University Campus, 26504, Rion, Greece*
[2] *International Hellenic University, Address, Serres, Index, Greece*

Abstract
XR technologies are a trend nowadays for enhancing museum visits. Although museum visits are a way to enhance well-being in modern cities, there is a question concerning how inclusive they can be, especially for people with impairments. In this work, we are interested in people with impairments like low vision or hearing problems. In such a context, we investigate the issue of how XR technologies can benefit museum visits for impaired people. Based on the literature, we make an attempt to specify user needs and associate them with XR technology functionalities taking into account how those functionalities have been implemented in current systems for museum visits. To the best of our knowledge, there is no system for museum visits that can personalize its features to the special needs of impaired persons independently of the type of impairment they are facing. Another challenge is the engagement of impaired persons in the design and development of such systems. Our results suggest that this scientific domain is in its infancy and a lot of work remains to be done, especially for the human-computer interaction community.

Keywords
Impairments, XR systems, museum visits

1. Introduction

Nowadays, the world is increasingly trying to exploit the advantages of XR technologies in everyday life. People have started to become familiar with XR technologies and companies, institutions and even governments are trying to exploit this popularity to provide personalized services to their audience. In the case of museums, incorporating XR technologies may lead to better engagement with their audience by providing distance access to their collections or facilitating a better experience in the museum. The potential of those technologies has been exploited within museum environments for preservation purposes, facilitation of everyday functions like ticketing, or even promotion of the democratization concerning accessibility. The focus of this work is how museum visits can be inclusive using XR technologies to promote well-being in modern cities.

A lot of work is targeting the use of technology in the everyday life of a museum [1–3]. There is also much work for online users who need a virtual tour for exhibitions [4–7]. However, there is a limited amount of research that focuses on people with impairments and in most cases, applications are focused on only one impairment type. In [8] they state that most mobile AR apps for museum visitors do not support hearing-impaired visitors even though this community accounts for over 5% of the world's populace. Furthermore, in [9] they state that only 20 of the 90 low-vision studies recruited participants with low vision. Most of the research in the field is based on simulation of low vision. Also, in [10] they state that according to the US Center for

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dkoukopoulos@upatras.gr (D. Koukopoulos); kkoukoulis@upatras.gr (K. Koukoulis); sylaiou@ihu.gr (S. Sylaiou), cfidas@upatras.gr (C. Fidas)
0000-0001-7019-4224 (D. Koukopoulos); 0000-0002-6017-8690 (K. Koukoulis); 0000-0001-5879-5908 (S. Sylaiou); 0000-0001-6111-0244 (C. Fidas)

Disease Control and Prevention, 25% of US adults have a disability that "impacts major life activities".

In this work, we are dealing with the user needs of people with impairments concerning museum visits and how those needs can be facilitated by XR technology functionalities to enhance the visiting experience in the museum or provide distance access to their collections. In this context, there are many questions to be answered: What are the XR technological tools that museums use to facilitate their visitors (distanced or in situ)? Is this technology equally helpful for all their visitors? What about people with impairments?

2. XR Technology for museum visits

Milgram and Kishino defined a lot of concepts related to computer-generated realities [11, 12]. Augmented Reality (AR) is about providing a digital layer of information to the vision [13] or even to other senses [13, 14]. Virtual reality (VR) "produces a digital environment in which visual perception, sense of hearing, and sense of touch are highly similar to those of actual environment within a certain range" [15]. Also, VR is there to engage several human senses [16]. Mixed reality (MR) is not a clearly defined term [17, 18]. In MR, the digitally displayed information tends to be an integral part of the real world. The user has the option to treat that object like it is real. For a common understanding, we use the following definitions [19]: VR enhances our presence and interaction with a computer-generated environment hiding from the user the real world, and AR enhances our perception and understanding of the real world by superimposing virtual information on our view of the real world, and MR is when real and virtual environments blend. Extended Reality (XR) is used to describe all these realities. However, in [20] they state that X should stand for any reality format. Going beyond the XR technologies is the metaverse [21–24]. We will adapt the definition from [21], where the metaverse can be seen as a virtual environment blending physical and digital, facilitated by the convergence between the Internet and Web technologies and XR. XR offers all the technological tools that are necessary for someone to build new worlds. It also offers devices for entering those worlds.

Technologies related to XR [14, 16, 19, 25–27] are constantly evolving [28]. We may have some categories related to the ability to use these technologies in an indoor or outdoor setting: AR/MR can be indoor or outdoor while VR is mainly set to be indoor. Mobile AR can be categorized depending on the technology used to trigger the superimposing [26]. Another category is related to the level of immersion which depends on the type of device and the type of reality. For example, we cannot expect a fully immersive experience with the use of a desktop device or with the use of an AR app. The devices used for XR are mobile devices, desktop displays [16], HMDs (like Google cardboard [29] and Meta Quest Pro [30], CAVE [31], holographic, or smart glasses. Also, new types of devices that could offer a deeper sense of impressiveness have started to become common (like Haptic Feedback). AR devices like HMDs or smartphones [25] are used because they are portable and can facilitate the display of information in the real environment. Caves or desktop computers can be used for VR, while HMDs can be used for all XR systems. The most common devices for MR are see-through HMDs [32]. XR applications are created using dedicated development kits (commercial or not). There are many developments in software for VR (like [33–37]). For AR we have software like [38–42]. For MR we cannot identify any exclusive list of toolkits or devices, but the abovementioned software can be used in some cases [43].

3. Museums and impaired persons

According to [44], "in the context of health experience, an impairment is any loss or abnormality of psychological, physiological or anatomical structure or function". This definition also includes losses that occurred during the person's lifetime. In [45], it is stated that disability "is any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being" and a handicap is a "disadvantage for a given individual resulting from an impairment or a disability, that limits or prevents the fulfilment of a role that is normal (depending on age, sex, and social and cultural factors) for that individual". A brief list of impairments includes (according to [45]): 1. Intellectual 2. Other psychological 3. Language 4. Aural 5. Ocular 6. Visceral 7. Skeletal 8. Disfiguring 9. Generalized, sensory, and other impairments. In [46], they state that impairments can be related to vision, hearing, mobility, cognitive, or speech. In all cases, the impairment might be temporary, situational, or permanent.

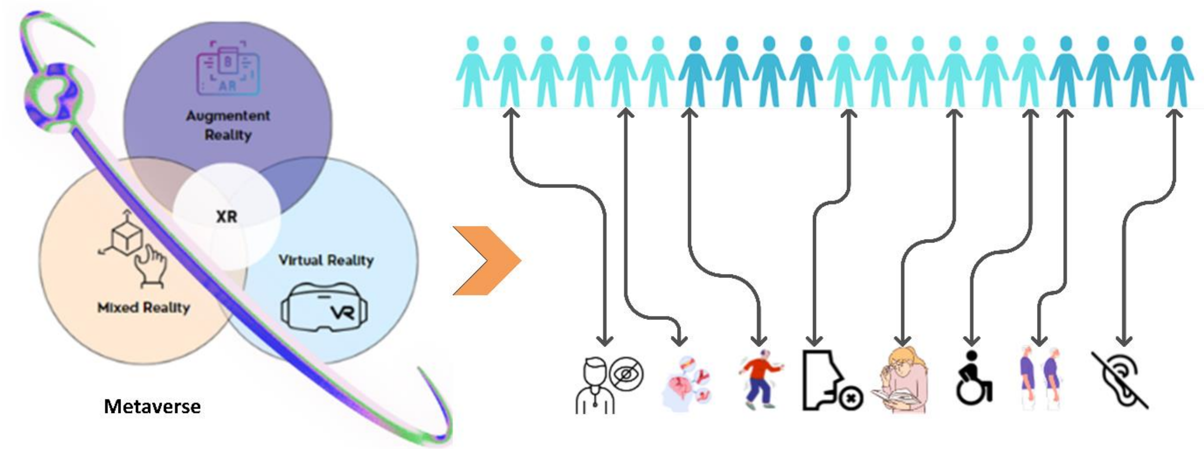

Figure 1: Extended reality for everyone

In a study [47], participants highlighted that "the biggest issues in XR technology are overuse of motion tracking, lack of flexibility with other hardware, lack of customization ability, lack of compatibility with assistive technology, lack of visual, and audio, and haptic cues and an overall lack of consideration for most kinds of disability needs". In this work, we mainly focus on the requirements that are required to assist impaired people. To understand the challenges that should be confronted when an XR system is designed, [47] determines some directions to be aware of:

- Understanding of specific diverse user needs and how they relate to XR.
- Identifying modality needs that are not obvious but required.
- Suitable authoring tools for supporting accessibility requirements in XR.
- Using languages, platforms, and engines that support accessibility semantics.
- Providing accessible alternatives for content and interaction.
- Providing specific commands within the VR environment, which assist with navigation to support different modalities.
- Using virtual assistive technologies to provide non-visual feedback.

It is obvious that each impairment type needs to be treated in a special way. In [48] they also list needs together with requirements that are needed to be served to create a system that is accessible for people without excluding a type of impairment. In Table 1, we list these needs along with the proposed system requirements that provide help for impaired persons. Research that is currently available does not deal with all the types of impairment together. In [8], they deal with hearing-impaired persons, and they conclude that major elements of engagement for a mobile AR application are Aesthetics, Curiosity, Usability, Interaction, Motivation, Satisfaction, Self-Efficacy, Perceived Control, Enjoyment, Focused Attention, and Interest.

Table 1
User needs and requirements. A revised version of the data that is presented in [48]

N	Need	Requirements	XR type
1	Assistive technology users: to navigate, identify locations, objects	Navigation / alternative mapping, position rearrangement, sensitivity, and resizing /	VR/MR

	and interact	important objects in suitable modality/filtering and sorting	
2	Physical disability users: to interact with items with no bodily movement to perform any given action.	Device-independent actions - not physically / same input for all the UI methods, multiple input methods at the same time.	VR/MR
3	Cognitive and learning disabilities users: to personalize the immersive experience in various ways.	Symbol sets used to communicate and layered over objects / turn off or 'mute' non-critical environmental content	VR/MR
4	Limited mobility, or tunnel or peripheral vision users: may need a larger 'Target size' for a button or other controls.	Hit targets are large with spacing, multiple actions or gestures are not required at the same time / 'Sticky Keys' requirements for various inputs	VR/MR
5	Limited mobility users: use voice commands to navigate, interact and communicate.	Navigation and interaction by Voice Activation / Voice activation should use native screen readers or voice assistants rather than external devices.	XR
6	Colour-blind users: to be able to customise the colours used.	Customized high-contrast skins for the environment.	XR
7	Screen magnification users: to check the context of their view	Check the context of view and track/reset focus/interface elements - enlarged, menu reflow.	VR/MR
8	Screen magnification users: to be made aware of critical messaging and alerts often without losing focus.	Critical messaging or alerts have priority roles that can be understood and flagged to AT, without moving the focus	VR/MR
9	Blind users: to interact with a gestural interface, such as a virtual menu system.	Touch screen accessibility gestures / self-voicing option - menus / re-mapping of gestures.	VR/MR
10	Deaf or hard-of-hearing users (with the written language not to be their first): signing of video for text, objects, or item descriptions.	Text, objects, or item descriptions via a signing avatar/restriction for signing videos.	VR/MR
11	Cognitive Impairments users: easily overwhelmed.	Allow the user to set a 'safe place' - quick key, shortcut, or macro.	VR/MR
12	All Users: too much time or experience to lose track of time.	Tools that support digital well-being, / set alarms for time limits during an immersive session	XR
13	Screen magnification, cognitive and learning disability, spatial orientation impairment users: to maintain focus and understand their position they are.	Reset and calibrate their orientation/view in a device-independent way / Field of view can be personalized - / clear visual or audio landmarks.	VR/MR
14	Users of assistive technology such as blind, or deaf-blind users communicating via specialized apps, may have sophisticated 'routing' requirements for inputs and outputs.	Text output, alerts, environment sounds, or audio to a braille or second screen device/flow of critical messaging or content on a second screen/touch screen accessibility gestures.	XR
15	Physical or cognitive and learning disabilities users: may find some interactions too fast to keep up with or maintain.	Change the speed/timing for interactions or critical inputs can be modified / clear start and stop mechanisms.	VR/MR

16	Vestibular disorders, epilepsy, and photosensitivity users: some interactions may trigger motion sickness and other effects.	Alternatives for interactions that may trigger epilepsy or motion sickness and/or flickering images at maximum	VR/MR
17	Hard-of-hearing users may need accommodations to perceive audio.	Spatialized audio content, and text descriptions of important audio content.	XR
18	Spatial orientation, cognitive impairments, or hearing loss users in just one ear: may miss information in a stereo or binaural soundscape.	Allow mono audio sound.	XR
19	Users: customize captions, subtitles, and other text.	Captioning, subtitling of multimedia content, customizable context, sensitive reflow of captions, subtitles, and text content.	XR

4. Survey of apps assisting people with impairments based on XR functionalities.

In Table 2, we present a list of indicative research related to applications facilitating impaired persons during museum visits, along with app features that exploit XR functionalities. In all cases, these applications try to invent ways to transmit the information that cannot be perceived due to the impairment, using another channel. For example, they provide more acoustic information to low-vision persons.

Table 2
Systems and applications that assist impaired persons in a museum visit.

System Name	Features for people with impairment	Technology
Anagnostakis et al. 2017 [49]	Navigation in exhibition halls and the tactual exploration of exhibit replicas using touch-sensitive audio descriptions and touch gestures on a mobile device.	3D printed exhibits, touch sensors, Arduino boards, mobile app
Sulaimani et al. 2023 [50]	Navigate autonomously around a museum combining current traditional non-technical accessibility methods with the use of 3D sound technology.	mobile application, AR
Ahmetovic et al. 2021 [51]	Supporting sighted and low vision visitors in accessing 2D visual artworks through interactive artwork descriptions: the user can quickly find descriptions; navigate the description; augment descriptions with visual information;	mobile app, AR
Soares et al. 2020. [52]	It contains a screen reader, and the user can listen to all the extra information. This inclusive feature is essential for people with disabilities, such as visually impaired or intellectually disabled people.	mobile app, AR
Zaal et al. 2020 [53]	Use narrations and spatialized ‘reference’ audio combined with haptic feedback.	modified narratives, enhanced audio, haptics, VR
Trichopoulos et al. 2022. [54]	AR-based digital storytelling system without the use of images, to improve the experience of visually impaired visitors in the heritage site.	AR, tangible interface, binaural audio, smart glass.

5. Conclusions and Discussion

In this work, we dealt with systems or applications that are specially created for impaired persons. Most of the apps target only one impairment, providing ways to help these people have a better experience when visiting a museum. Furthermore, we listed several users' needs and requirements for any XR application focusing on impaired people. These requirements should be followed by application designers to promote inclusion. However, this does not happen today. We could hardly see an implementation of one or two of these requirements in applications that are for the general population.
We believe that the research on the use of technology that assists people with impairments should be done with the impaired people and not using simulations. In [47] they mention that “For AR and VR to become truly accessible to persons with disabilities, then those who are experiencing disabilities must be included in the development. In the words of disability activist James Charlton, “Nothing about us without us.”. In the future, the systems that are created for enhancing the museum experience should adapt to the personalized needs of the persons, impaired or not.

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