Advanced technologies for auditory inclusion: designing accessible virtual exhibits

di Elena Loreto Olmedo-Pagés, Rosario Arquero-Avilés, Gonzalo Marco-Cuenca

1. Introduction

In recent years, there has been growing interest in scientific output concerning the use of Information and communication technologies (ICT) as a tool for the social inclusion of people with disabilities[1]. The continual development of digital technologies and the increasing concern for building an equitable and just society have contributed to the proliferation of studies aimed at creating inclusive technologies and educational programmes that enable people with disabilities to participate actively in society[2].

However, much of this output focuses either on advocating for Universal design in the creation of digital content[3], or on the application of specific guidelines tai-

ELENA LORETO OLMEDO-PAGÉS, Santander-UCM pre-doctoral contract, IDEA Lab Research Group, Faculty of Documentation Sciences, Complutense University of Madrid, Spain, e-mail: elolmedo@ucm.es
ROSARIO ARQUERO-AVILÉS, Senior Lecturer, IDEA Lab Research Group, Faculty of Documentation Sciences, Complutense University of Madrid, Spain, e-mail: carquero@ucm.es
GONZALO MARCO-CUENCA, Senior Lecturer, IDEA Lab Research Group, Faculty of Medicine (Department of Documentation Sciences and History of Science), University of Zaragoz, Spain, e-mail: gmarco@unizar.es
Last website consultation: May 28th 2025.

1 Matilde Bolaño; Nixon Duarte; Keguin González, *Scientific production on the use of ICT as a tool for social inclusion for deaf people: a bibliometric analysis*, «Salud, ciencia y tecnología», 3 (2022), n. 318, DOI: 10.56294/saludcyt2023318.

2 *Ivi, passim*; Hanna Alieksieieva, *Formation of readiness for the use of digital technologies in future qualified computer workers with hearing impairments*, «Forum for education studies», 1 (2023), n. 1, p. 280, DOI: 10.59400/fes.v1i1.280.

3 Achraf Othman [*et al.*], *A theoretical framework for accessibility and inclusion in the metaverse*, «Multimodal technologies and interaction», 8 (2024), n. 3, p. 21, DOI: 10.3390/mti8030021; Umaporn Ployjiw; Pasapitch Chujai Michel, *Development of augmented reality learning materials for the hearing impaired students in primary I*, «International journal of information and education technology», 13 (2023), n. 11, p. 1696-1703; Petar Radanliev [*et al*], *Accessibility and inclusiveness of new information and communication technologies for disabled users and content creators in the Metaverse*, «Disability and rehabilitation: assistive technology», 19 (2024), n. 5, p. 1849-1863, DOI: 10.1080/17483107.2023.2241882.

AIB studi, vol. 65 n. 1 (gennaio/aprile 2025), p. 115-128. DOI 10.2426/aibstudi-14158
ISSN: 2280-9112, E-ISSN: 2239-6152 - Copyright © 2025 Elena Loreto Olmedo-Pagés, Rosario Arquero-Avilés, Gonzalo Marco-Cuenca

lored to certain disabilities, which can inadvertently exclude others from the planning process[4]. Thus, although scientific output is increasing, there remains very limited information on the application of digital technologies to overcome communication barriers for people with hearing impairments in particular. Moreover, the existing information tends to focus exclusively on Sign language as the primary means of communication[5,6,7]. Similarly, there are specific projects on the creation of inclusive applications, but no specific methodology that can be applied to the design of spaces[8].

Hearing impairment can significantly affect an individual's ability to communicate by altering the way they acquire language and speech from an early age. This, in turn, impacts their cognitive development and education, hinders their integration into the workforce, harms their mental health and increases their social isolation[9]. Therefore, implementing measures that promote communication with this group and enable their full participate in cultural activities without barriers is essential to achieving genuine inclusion.

GLAM institutions can provide advanced digital content to enhance the accessibility of their services and heritage[10]. In doing so, individuals with hearing impairment - who have traditionally been excluded from many physical cultural spaces - can discover new opportunities through digital technologies to access content, visit exhibitions, engage with artworks, and participate in cultural experiences[11].

1.1 Disability and inclusion in the Metaverse

The advanced technologies we hear about daily are not entirely new; however, recent advancements in both hardware and software have made them more attainable and

4 Branislav Sobota; Štefan Korečko; Miriama Mattová, *Web-based 3D virtual environments utilization in primary and secondary education of children with multiple impairments*, «Electronics», 12 (2023), n. 2792, DOI: 10.3390/electronics12132792; John Dudley [*et al.*], *Inclusive immersion: a review of efforts to improve accessibility in virtual reality, augmented reality and the metaverse*, «Virtual reality», 27 (2023), p. 2989–3020, DOI: 10.1007/s10055-023-00850-8.

5 M. Bolaño; N. Duarte; K. González, *Scientific production on the use of ICT* cit.

6 U. Ployjiw; P. Michel, *Development of augmented reality learning materials* cit.

7 Christian Ovalle; Isaac Leonardo Vallejos García; Franco Rafael Zapata Berrios, *Real-Time transcriptionist based on artificial intelligence to facilitate learning for people with hearing disabilities in virtual classes*, «International journal of online and biomedical engineering (iJOE)», 20 (2024), n. 3, p. 75–88, DOI: 10.3991/ijoe.v20i03.46811.

8 Luis Roberto Ramos Aguiar; Francisco Javier Álvarez Rodríguez, *Digital content for libraries considering extended reality, physical interaction disabilities, Universal design for learning and user-centered design: a systematic review*, «Investigación bibliotecológica: archivonomía, bibliotecología e información», 38 (2024), p. 109-127, DOI: 10.22201/iibi.24488321xe.2024.99.58872.

9 C. Ovalle; I. L. Vallejos García; F. R. Zapata Berrios, *Real-Time transcriptionist based on artificial intelligence* cit.

10 L. R. Ramos Aguiar; F. J. Álvarez Rodríguez, *Digital content for libraries* cit.

11 Clark Chad, *Extended reality in informal learning environments. in beyond reality: augmented, virtual, and mixed reality in the library*, edited by Kenneth Varnum. Chicago: American library association editions, 2019, p. 17-30.

beneficial across various domains[12]. These innovations are transforming how people experience physical and virtual environments, shifting them from passive observers to active participants in immersive experiences[13].

Immersive virtual environment technologies fall under the umbrella term 'extended reality' (XR), which includes three main categories: virtual reality (VR), augmented reality (AR), and mixed reality (MR). VR creates a fully digital environment in which users can interact by simulating their physical presence in realistic or imaginary worlds, using various devices that enhance immersion to varying degrees. AR, by contrast, does not replace the real world but enhances it by overlaying digital elements, visible through devices such as smartphones or smart glasses. MR represents a further evolution of AR, as it not only overlays digital data onto the physical environment but also enables real-time interaction between the two, integrating the virtual and the real in a more sophisticated manner[14].

The interconnection between physical and virtual environments enabled by these technologies gives rise to the Metaverse—an integrated ecosystem of virtual worlds offering immersive experiences and limitless possibilities for communication and collaboration. This emerging environment presents significant opportunities for both entertainment and education, as it has become a novel way of engaging with media content, offering considerable inclusive and accessible potential[15].

As these advanced technologies become more widely available, there is growing concern about their effectiveness in removing barriers for people with disabilities. The mere availability of these tools to a broader audience does not guarantee their accessibility. Barriers related to access to technology and internet connectivity persist; therefore, it is essential to prioritise technologies that are easy to access, simple to use, and intuitive to navigate, while also designing spaces that incorporate accessibility requirements from the outset[16,17].

A high-quality Metaverse is characterised by accessibility and openness; honesty and rationality; safety and security for all; a foundation built on principles of equity and social inclusion; sustainability; a strong emphasis on privacy, ethical behaviour, and integrity; protective mechanisms to safeguard personal data; the freedom for individuals to express themselves; a commitment to responsible innovation; and complementarity with the physical world[18].

Inclusive immersion is supported by four fundamental factors: first, an ethical commitment to ensuring that technological developments are accessible to everyone; second, recognition of the potential of virtual reality (VR) and augmented real-

12 L. R. Ramos Aguiar; F. J. Álvarez Rodríguez, *Digital content for libraries* cit.

13 Stephanie Hui-Wen Chuah, *Why and who will adopt extended reality technology? Literature review, synthesis, and future research agenda*, «SSRN», (2019), DOI: 10.2139/ssrn.3300469.

14 Khalil Omar [*et al.*], *Usability heuristics for Metaverse*, «Computers», 13 (2024), n. 222, DOI: 10.3390/computers13090222.

15 A. Othman [*et al.*], *A theoretical framework for accessibility* cit.

16 P. Radanliev [*et al*], *Accessibility and inclusiveness* cit.

17 B. Sobota; Štefan Korečko; M. Mattová, *Web-Based 3D Virtual Environments* cit.

18 Matteo Zallio; P. John Clarkson, *Designing the Metaverse: a study on inclusion, diversity, equity, accessibility and safety for digital immersive environments*, «Telematics and informatics», 75 (2022), n. 101909, DOI: 10.1016/j.tele.2022.101909.

ity (AR) as effective tools in care and rehabilitation contexts; third, the commercial benefit of designing experiences that can be used by the broadest possible audience; and fourth, clear evidence that accessibility-focused design enhances the user experience for all individuals[19].

One of the key advantages of virtual environments is their ability to adapt to specific needs, allowing users to customise the input and output of information to avoid overstimulation. These environments are user-friendly, easy to understand and manage. They are flexible and effective in providing near-instant feedback—and they are visually engaging. By adapting to users' needs, individuals can perform actions that may not be possible in the real world, thereby increasing their engagement. Moreover, actions can be repeated and modified, enabling users to explore and enjoy themselves in a safe space where time is not a limiting factor[20,21]. These experiences have been shown to enhance user motivation and engagement in learning[22,23].

In this context, GLAM institutions are committed to using digital tools to create immersive experiences accessible across a range of devices. Accessible virtual exhibitions represent an emerging strategy with significant potential to democratise access to culture. These initiatives combine technological resources with cognitive, sensory, and communicative accessibility criteria, enabling diverse audiences to engage with cultural content in an autonomous and meaningful way.

1.2 Virtual exhibitions and hearing impairment

People with disabilities have varying needs depending on their individual abilities. Moreover, many individuals experience multiple forms of disability, which may require highly specific adaptations. Combined with the principle that good design should ensure high usability for all users—regardless of whether they have a disability—this has led several scholars to advocate for the application of Universal design in their research[24,25,26].

The principles of Universal design, originally formulated in 1997 to promote environments, products, and communications accessible to all[27], were revised by Dombrowski et al. (2019) in light of advances in virtual reality (VR) and the experiences

19 J. Dudley [*et al.*], *Inclusive immersion: a review* cit.

20 Abir Osman Elfakki; Souhir Sghaier; Abdullah Alhumaidi Alotaibi, *An efficient system based on experimental laboratory in 3d virtual environment for students with learning disabilities*, «Electronics», 12 (2023), n. 4, p. 989, DOI: 10.3390/electronics12040989.

21 James Hutson, *Social virtual reality: neurodivergence and inclusivity in the Metaverse*, «Societies», 12 (2022), n. 4, p. 102, DOI: 10.3390/soc12040102.

22 *Ivi, passim.*

23 Recep Cakir; Ozgen Korkmaz, *The effectiveness of augmented reality environments on individuals with special education needs*, «Education and information technologies», 24 (2019), p. 1631-1659, DOI: 10.1007/s10639-018-9848-6.

24 J. Dudley [*et al.*], *Inclusive immersion: a review* cit.

25 L. R. Ramos Aguiar; F. J. Álvarez Rodríguez, *Digital content for libraries* cit.

26 Don Douglas McMahon; Zachary Walker, *Leveraging emerging technology to design an inclusive future with universal design for learning*, «Center for educational policy studies journal», 9 (2019), n. 3, p. 75-93, DOI: 10.26529/cepsj.639.

27 Wolfgang F. E. Preiser; Korydon H. Smith, *Universal design handbook*. McGraw-Hill: Maidenhead, 2011.

of users with diverse disabilities[28]. In this context, seven principles adapted to VR are particularly noteworthy: equitable use (accessibility for people with varying abilities); flexibility in use (accommodating different preferences and abilities); simple and intuitive use; perceptible information (clear and effective communication); tolerance for error (minimising the impact of accidental actions); low physical effort; and appropriate size and space for comfortable and effective interaction.

Existing mobile accessibility guidelines can be effectively applied to enhance the accessibility of virtual reality for users with disabilities, according to Teófilo et al. (2018)[29]. In their study, features such as zooming and captioning were found to be beneficial in VR environments. Closed captioning improved participants' understanding of the content, while a voice assistant supported navigation and comprehension.

Despite the expanding body of research in the field of virtual reality, there remains a notable lack of standardised accessibility guidelines that developers can systematically adopt, along with limited availability of specialised tools to address common accessibility challenges[30,31,32]. However, this situation is beginning to improve, with initiatives such as Meta's publication of dedicated accessibility design guidelines for the Meta Quest VR platform. Likewise, Apple has released an initial set of design guidelines for its VisionPro devices, covering key aspects such as user experience and interface (UX/UI), interaction modalities, kinematics, visual representation, audio processing, ergonomics, and accessibility standards[33]. There are also tools developed as guides for the creation of Extended Reality (XR) applications, providing a foundation for designing successful and inclusive experiences[34].

However, although this approach may be regarded as fully inclusive, it often proves too general, failing to address many users' specific needs. For Universal design to truly fulfil its principles, the particular requirements of all users must first be identified.

While developers define accessibility criteria for the construction of various platforms, it is important to emphasise that this responsibility does not rest solely with them. The development of a new tool does not automatically make it accessible;

28 Matt Dombrowski [*et al.*], *Designing inclusive virtual reality experiences*. In: *Virtual, augmented and mixed reality multimodal interaction*, edited by Jessie Y. Chen, Gino Fragomeni, vol. 11574. Cham: Springer international publishing, 2019, p. 33-43.

29 Mauro Teófilo [*et al.*], *Evaluating accessibility features designed for virtual reality context*. In: 2018 IEEE International conference on consumer electronics (ICCE). Piscataway: IEEE, 2018, p. 1-6, DOI: 10.1109/ICCE.2018.8326167.

30 A. Othman [*et al.*], *A theoretical framework for accessibility* cit.

31 J. Dudley [*et al.*], *Inclusive immersion: a review* cit.

32 Fiona Heilemann; Gottfried Zimmermann; Patrick Münster, *Accessibility guidelines for VR games. A comparison and synthesis of a comprehensive set*, «Frontiers in virtual reality», 2 (2021), DOI: 10.3389/frvir.2021.697504.

33 Callum Parker [*et al.*], *Building a Metaverse for all: opportunities and challenges for future inclusive and accessible virtual environments*. In: *Extended abstracts of the Chi conference on human factors in computing systems (CHI EA '24)*. New York: Association for computing machinery, 2024, p. 1-5, DOI: 10.1145/3613905.3636307.

34 Arlindo Gomes [*et al.*], *Extended by design: a toolkit for creation of xr experiences*. In: *2020 IEEE International symposium on mixed and augmented reality adjunct (ISMAR-Adjunct)*. Recife: IEEE, 2020, p. 57-62, DOI: 10.1109/ISMAR-Adjunct51615.2020.00029.

rather, it is the responsibility of all users who create public spaces within it to ensure accessibility. Crucially, people with disabilities must be actively involved before, during, and after the process of creating the experience[35].

When designing immersive experiences for individuals with hearing impairments, one of the main challenges identified in educational contexts is the use of devices that induce full immersion and, consequently, result in the loss of visual contact with the real environment[36].

Particularly for individuals with hearing impairments, one of the most significant challenges lies not only in providing alternative means of transmitting sound, but also in adapting language. In this regard, easy reading emerges as a key tool, offering texts that are clear, structured, and easy to understand, thereby facilitating access to information and promoting reading comprehension. Presenting information in text using large, simple fonts, standardised pictograms, and high-contrast design ensures greater accessibility to the content provided[37].

When selecting the most suitable tools for creating accessible virtual exhibitions, many researchers choose platforms such as Spatial. Its scripting engine, Unity, enables the creation of spaces with complete freedom, allowing developers to implement the necessary accessibility measures for smooth navigation[38,39,40,41]. The platform allows for the creation of spaces where sound can be adjusted and other users muted within the same environment, where contrasting colours can be applied, and where text can be displayed in various fonts and sizes. A wide range of media content can be integrated, facilitating the inclusion of audio and video with subtitles, static images with alternative text, and the ability to expand these elements as users navigate the space. It also provides accessible communication channels, such as written chat and voice interaction, ensuring multiple communication options. The tool is user-friendly and intuitive, enabling anyone to contribute to content creation regardless of their skill level or experience.

As part of the R&D&I project entitled Cultural and bibliographic heritage in the GLAM (Libraries, archives, and museums) context (reference: PID2020-113405RB-I00), funded by the State research agency of the Spanish Ministry of science and innovation and carried out in collaboration with the IDEALab research group[42], we have designed

35 Reza Hadi Mogavi [*et al.*], *Envisioning an inclusive metaverse: student perspectives on accessible and empowering Metaverse-enabled learning*. In: Proceedings of the tenth ACM conference on learning @ scale (L@S '23). New York: Association for computing machinery, 2023, p. 346-353, DOI: 10.1145/3573051.3596185.

36 B. Sobota; Štefan Korečko; M. Mattová, *Web-Based 3D Virtual Environments* cit.

37 *Ivi*, *passim*.

38 Janos Simon, *Augmented reality application development using unity and Vuforia*, «Interdisciplinary description of complex systems», 21 (2023), n. 1, p. 69-77, DOI: 10.7906/indecs.21.1.6.

39 Xinqi Liu; Young-Ho Sohn; Dong-Won Park, *Application development with augmented reality technique using unity 3d and Vuforia*, «International journal of applied engineering research», 13 (2018), n. 21, p. 15068-15071, DOI: 10.7906/indecs.21.1.6.

40 M. Sarosa [*et al.*], *Developing augmented reality based application for character education using unity with Vuforia SDK*, «Journal of Physics: Conference Series», 1375 (2019), n. 1, DOI: 10.1088/1742-6596/1375/1/012035.

41 Topi Nieminen, *Unity game engine in visualization, simulation and modelling*, [bachelor's thesis]. Tampereen: Tampereen yliopisto, Faculty of Information technology and communication sciences, 2021.

42 IDEALab Research Group, <https://www.ucm.es/idealab_researchgroup>.

and developed virtual exhibitions using Spatial that meet the necessary criteria to ensure accessibility to cultural heritage for individuals with hearing impairments. This article presents the outcomes of this initiative, which serve as the basis for establishing a design guide for virtual environments accessible to hearing-impaired users.

2. Methodology

This initiative employs open-source software and low-code/no-code platforms, encouraging the use of resources under Creative Commons licences and the reuse of 3D models made publicly available by initiatives such as Europeana and Sketchfab. These tools support the creation of educational and engaging experiences that make cultural heritage accessible to individuals with hearing impairments.

For this reason, Spatial was selected as the platform for developing the digital content of the virtual exhibition space. The 2D and 3D models forming the narrative structure were incorporated and reused to support the information presented in Easy Reading format, following a process of adapting texts specifically created for this purpose.

The creation of this virtual exhibition was structured in two main phases. The first, corresponding to the pre-production phase, focused on defining the general concept of the exhibition, selecting and organising the content, designing the virtual space, and identifying the principles of inclusivity and the levels of interaction envisaged for users. The second phase, corresponding to production, involved the technical development of the exhibition, including the three-dimensional modelling of the exhibition space, the generation of accessible multimedia content, and the incorporation of previously digitised heritage objects.

3. Results

The different steps followed for the creation of accessible virtual exhibitions are those advocated by Arquero et al. (2023)[43]. These can be summarised in Figure 1.

Phase	Description	Key components
Design	Initial phase in which the conceptual approach, the content, the design of the space, and the criteria for accessibility and user interaction are defined	General concept of the exhibition, selection and organisation of content, design of the virtual space, principles of inclusivity, levels of user interaction
Creation	Technical phase of development of the virtual exhibition	Modelling of the exhibition space, creation of accessible multimedia content, reuse of digitised heritage objects

Figure 1 - Phases in the design and creation of accessible virtual exhibitions

43 Rosario Arquero; Gonzalo Marco; Silvia Cobo, *Exposiciones virtuales del patrimonio cultural en instituciones GLAM. Propuesta metodológica y estudio de caso de promoción y divulgación del patrimonio bibliográfico y documental*. In: *patrimonio e instituciones GLAM, galerías, bibliotecas, archivos y museos. innovación, gestión y difusión*. Gijón: TREA, 2023, p. 347-365.

3.1 Design of an accessible virtual exhibition

The starting point of the process was the definition of the exhibition concept, understood as the pivotal pillar of the museographic discourse. This was formulated based on the analysis of three key components: the heritage content available, the expressive possibilities of the virtual space, and the communicative needs of the target public, especially the hearing impaired. Based on these elements, a coherent narrative was structured to enable the clear, ordered, and visually effective transmission of knowledge, thus favouring an accessible and attractive cognitive experience.

Content curation was geared towards creating a user-centred experience. In this regard, quality was prioritised over quantity of information, selecting cultural objects of greater relevance and educational value for the narrative. These were presented through high-resolution digital resources (2D and 3D), complemented with hypermedia elements such as explanatory videos and animations. In particular, adapted subtitles and easy reading texts were included to ensure the communicative accessibility of the materials. This selection was carried out avoiding information overload and promoting meaningful interaction with the content.

The design of the virtual environment was based on the spatial layout of physical museums, with the aim of generating a sense of familiarity that would foster the visitor's immersion. Although the digital space allows for wide creative freedom, we opted for an intuitive and usability-oriented layout, with visual and navigational elements that would facilitate an autonomous visit. The structure of the environment was configured to maintain the user's interest, allow constant orientation, and evoke positive emotional responses.

Accessibility was considered a cross-cutting criterion in all phases of the design. Functions were implemented to personalise the experience according to the user's needs, such as the choice between different ways of accessing information. The environment was developed in such a way that all users, regardless of their hearing abilities, could interact with the content without barriers. In terms of textual content, clear, precise, and easy-to-understand language was used, ensuring that the core message of the exhibition was accessible to a diverse audience.

Overall, this holistic approach enabled the design of a virtual exhibition that was not only technically innovative but also consistent with the principles of equity, participation, and cultural inclusion. This experience demonstrates that virtuality, when conceived from an accessible perspective, can broaden the scope and effectiveness of museum practices in the digital age.

3.2 Creating an accessible virtual exhibition: IDEA Lab's exhibitions

3.2.1 ExpoIDEALab

The IDEA Lab Research Group creates exhibitions aimed at disseminating the cultural and bibliographic heritage of GLAM institutions. Within the context of the aforementioned project, funded by the State Research Agency of the Ministry of Science and Innovation (R&D&I Project PID2020-113405RB-I00/AEI/10.13039/501100011033), the group works with the National archaeological museum and its Library, selecting one of its pieces and making an exhaustive bibliographic selection from the collections of this institution, creating a link between archaeological pieces and the reference bibliography. These virtual exhibitions are open to all users on the Internet.

An example of this is the Library of the Dama de Elche[44].

44 IDEALab Research Group, *La Biblioteca de la Dama de Elche*, ExpoIDEALab, <https://expoidealab.es/s/biblioteca-dama-de-elche/page/portada>

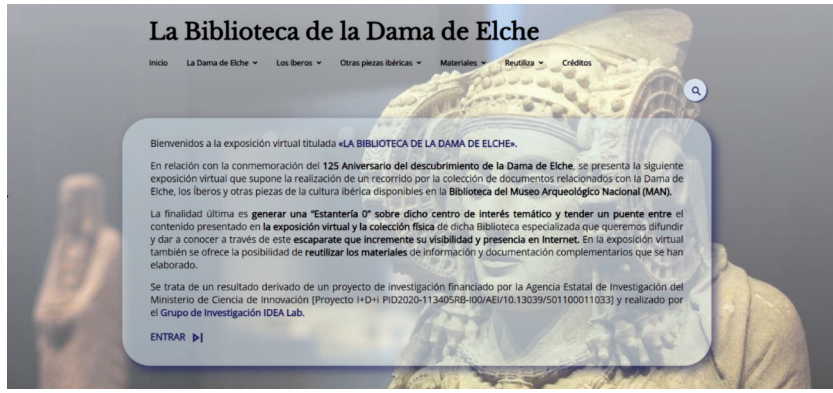

Figure 2 - Cover of the virtual exhibition of the Library of the Dama de Elche. Via ExpoIDEALab. (<https://expoidealab.es/s/biblioteca-dama-de-elche/page/portada>)

In this case, we present a digital initiative developed by the IDEA Lab Research Group. This exhibition commemorates the 125th anniversary of the discovery of the Dama de Elche, one of the most emblematic pieces of Iberian art.

The main aim of this exhibition is to offer a virtual tour through a collection of documents that make reference to the Dama de Elche as a centre of interest, also related to the Iberians and other pieces of Iberian culture available in the library of the National archaeological museum (MAN). Through this platform, the aim is to generate a 'Shelf o' that serves as a bridge between the digital content presented and the physical collection of the library, enhancing its visibility and presence on the Internet.

The exhibition includes various thematic sections, such as *La Dama de Elche*, *The Iberians* and *other Iberian pieces*, each of which offers detailed information and visual resources on the respective themes. In addition, access is provided to complementary materials and documentation that can be downloaded and reused by educational or cultural institutions interested in mounting their own exhibitions on La Dama de Elche.

3.2.2 IDEA Lab's accessible virtual exhibitions

In addition to creating virtual exhibitions that include the full content of each project, the team also develops parallel exhibitions in the Metaverse. These feature a curated selection of materials from the original exhibition and offer an immersive experience designed to support the original content and serve as a key factor in attracting and retaining a wider audience.

Adapting an existing virtual exhibition to make it accessible to people with hearing impairments requires a rigorous methodological approach, based on the principles of Universal design and communicative accessibility. This process involves not only the incorporation of technical elements but also a significant transformation in the way the exhibition experience is conceived, taking into account the linguistic and communicative diversity of the deaf community.

First, a comprehensive evaluation of the existing virtual exhibition is carried out to identify communication barriers that hinder access to information for deaf users. This assessment covers both verbal content (texts, audio, and voice-overs) and the navigation structure, the organisation of information, and the visual layout of exhibition elements. The complexity of the language used and the absence of visual or signed alternatives are also considered.

Following this initial assessment, an intervention plan is developed that includes the integration of specific accessibility resources. These include the transcription of audiovisual content, the addition of appropriate subtitles, and the simplification of texts using easy reading techniques. These techniques prioritise simple syntactic structures, everyday vocabulary, and visual aids, which improve reading comprehension for users with varying levels of literacy.

The new accessible resources are integrated into the virtual environment created specifically for each project, ensuring they are fully functional and available to all users without the need for additional configurations.

Continuing with the example of the Library of the Dama de Elche, one can visit the virtual exhibition created in Spatial[45], which seeks to transfer the contents of the exhibition of the same name developed in ExpoIDEALab to the Metaverse environment. The aim is to offer an immersive and accessible experience to a broader and more diverse audience.

This is an interactive three-dimensional environment that realistically simulates a museum room, allowing users to explore different stages in the history of the Dama de Elche through the chronological and interconnected arrangement of multimedia elements and 3D reproductions.

In line with the principles of Universal design and communicative accessibility, elements have been incorporated to facilitate navigation and comprehension of the content for people with different abilities. This includes the adaptation of texts into easy reading formats and the integration of visual resources. Visitors can interact with the exhibits, access detailed information, and participate in activities that enrich the educational and cultural experience.

In addition, the exhibition establishes links with other platforms and digital repositories, such as Europeana and the library of the National archaeological museum, thereby facilitating access to complementary materials and encouraging the reuse of content.

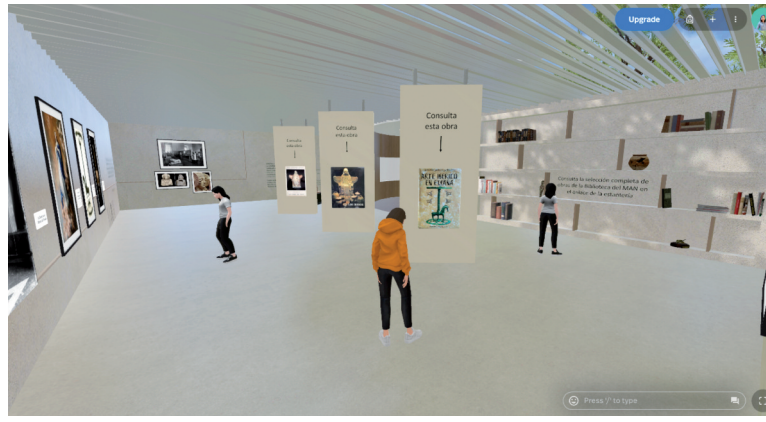

Figure 3 - Accessible room of the Library of the Dama de Elche. Via Spatial.io[46]

45 IDEALab Research Group, *La Biblioteca de la Dama de Elche accesible*, Spatial.io, <https://www.spatial.io/s/La-Biblioteca-de-la-Dama-de-Elche-accesible-6646457ef7b6e118bbeodc6c?share=5744842105782556526>

46 <https://www.spatial.io/s/La-Biblioteca-de-la-Dama-de-Elche-accesible-6646457ef7b6e118bbeodc6c?share=5744842105782556526>

Access to this exhibition is possible via a web browser or through VR-compatible devices, meaning that a smartphone is sufficient to enter. The environment loads quickly and allows users to select a customisable avatar with which to explore this open-architecture space with modern museum aesthetics.

Users can move freely through the space using keyboard controls (WASD keys), mouse clicks, or, in VR environments, gestures and controllers. Navigation is fluid and allows smooth movement between different rooms, as the environment is designed to avoid unnecessary obstacles, facilitating movement even for users unfamiliar with virtual environments. Similarly, visual elements such as signs, arrows, or markers serve as guides to aid orientation. Users can also zoom in on objects to observe them in detail and access additional information via pop-up icons.

Furthermore, the Spatial platform allows the simultaneous presence of multiple users, who appear as avatars within the same space. Real-time interaction with other users is possible, fostering the creation of virtual communities centred around cultural heritage.

Overall, navigating this virtual room offers an immersive, intuitive, and educational experience, combining the technical possibilities of the Metaverse with museographic and accessibility-focused criteria.

3.2.3 A complementary approach

This project aims to explore new forms of dissemination and access to cultural heritage, harnessing the possibilities offered by emerging technologies and the Metaverse environment. Both environments respond to a common objective—the dissemination of cultural and bibliographic heritage—but employ different and complementary strategies. While ExpoIDEALab offers organised and documentary access, ideal for informative and academic consultation, the Spatial environment enables a sensorial and experiential approach, designed for a broader public and with a significant recreational and social component.

Criterion	ExpoIDEALab	Spatial
Nature of the environment	Web browser-based virtual exhibition (2D)	Immersive three-dimensional environment within the Metaverse
Platform	ExpoIDEALab (specialised CMS for digital exhibitions)	Spatial.io (collaborative virtual and augmented reality platform)
Technical accessibility	Highly accessible from any device with a browser	Requires greater technical skills; computer or virtual reality device recommended
Navigation model	Structured in thematic pages, sequential and linear navigation	Free movement in 3D space, with the possibility of spatial interaction with objects and other users
Interactivity	Limited to browsing content and links	High interactivity: real-time movement, interaction with objects, avatar presence
Accessibility and inclusion	Adapted content (e.g. easy reading), responsive design, high usability	Visually accessible interface, customisability, pending deaf-specific improvements

Criterion	ExpoIDEALab	Spatial
Educational objectives	Digital dissemination of the bibliographic heritage linked to the Dama de Elche and the Iberians	Immersive experience of heritage content, museum recreation in 3D
User experience	Focused on reading and organised consultation of documents and images	Focused on the sensory, immersive and multisensory exploration of heritage
Re-use possibilities	Registration: access to downloadable materials for educational institutions	Limited: not intended for direct download, but for online experience of the environment
Social/collaborative aspect	Solo or individual	Possibility of group visits in real time, interaction with other users via voice or chat
Complementary function	Repository and digital catalogue for consultation purposes	Recreation and enhancement of this catalogue in a more attractive and contemporary environment

Figure 4 - Differences between ExpoIDEALab and Spatial virtual exhibits

In short, ExpoIDEALab is structured as a virtual exhibition within an easily accessible web environment, designed for linear navigation and based on the reading and consultation of textual and graphic content. Its nature is fundamentally informative and educational, with a design focused on clarity and content organisation. It can be accessed from any device and allows individualised consultation of the documentary heritage linked to the Dama de Elche and the Iberian world.

Spatial's complementary virtual exhibition represents an evolution towards an immersive museum experience, built in a three-dimensional environment where users move freely and interact with digitised objects, exhibition panels, and other users in real time. This environment prioritises multisensory interaction, free exploration, and the social dimension of knowledge. It is specifically designed to generate meaningful experiences through technology, while reproducing the dynamics of a physical museum space in a digital context. Although it requires more advanced technical access, it also enables innovative forms of interaction and collective learning.

When combined, both platforms offer a holistic approach to heritage, merging documentary rigour with sensorial experimentation and responding to contemporary demands for accessibility, dissemination, and education. This duality represents a replicable model for the GLAM field, uniting the informative and the experiential, the textual and the immersive, in favour of an inclusive and enriching experience for all audiences.

4. Conclusion

The joint analysis of the ExpoIDEALab and Spatial environments highlights the potential of combined digital strategies for the dissemination of cultural heritage from an inclusive, participatory, and educational perspective. Although based on different logics, such as the sequential organisation of web content and the immersive exploration of three-dimensional environments, both spaces form a complementary digital ecosystem that enables the diversification of access, understanding, and participation.

The integrated use of both models exemplifies a multiplatform heritage communication strategy, where documentary rigour and technological innovation converge to broaden access to, and engagement with, cultural heritage. Overall, this process of adaptation not only promotes equitable access to digital bibliographic and documentary resources but also contributes to the consolidation of inclusive practices capable of addressing the communication needs of audiences traditionally excluded from the cultural sphere.

This project constitutes a replicable and scalable model for future initiatives in the GLAM field, demonstrating that technology, when guided by pedagogical, collaborative, and socially committed intentions, can transform the way we access, interpret, and share cultural heritage.

Acknowledgements
Initiative within the framework of the R+D+i Project entitled *Cultural and bibliographic heritage in the context of GLAM (Libraries, Archives, and Museums)* (reference: PID2020-113405RB-I00), funded by the Spanish Ministry of Science and Innovation, State Research Agency, in collaboration with IDEALab research group (https://www. ucm.es/idealab_researchgroup). Elena Loreto Olmedo-Pagés' participation in this research was made possible by the funding she received as a pre-doctoral contract from the Complutense university of Madrid in collaboration with Banco Santander.

Articolo proposto il 28 maggio 2025 e accettato il 22 giugno 2025.

ABSTRACT
AIB studi, 65 n. 1 (gennaio/aaprile 2025), p. 115-128. DOI 10.2426/aibstudi-14158
ISSN: 2280-9112, E-ISSN: 2239-6152 - Copyright © 2025 Elena Loreto Olmedo-Pagés, Rosario Arquero-Avilés, Gonzalo Marco-Cuenca

ELENA LORETO OLMEDO-PAGÉS, Santander-UCM pre-doctoral contract, IDEA Lab Research Group, Faculty of Documentation Sciences, Complutense University of Madrid, Spain, e-mail: elolmedo@ucm.es
ROSARIO ARQUERO-AVILÉS, Senior Lecturer, IDEA Lab Research Group, Faculty of Documentation Sciences, Complutense University of Madrid, Spain, e-mail: carquero@ucm.es
GONZALO MARCO-CUENCA, Senior Lecturer, IDEA Lab Research Group, Faculty of Medicine (Department of Documentation Sciences and History of Science), University of Zaragoz, Spain, e-mail: gmarco@unizar.es

Tecnologie avanzate per l'inclusione uditiva: progettare mostre virtuali accessibili
Le istituzioni GLAM (gallerie, biblioteche, archivi e musei) stanno convertendo le loro collezioni in dati digitali con l'obiettivo di creare attività coinvolgenti e inclusive che raggiungano un pubblico eterogeneo. In questo contesto, il Metaverso offre un ambiente virtuale immersivo e dinamico, sostenuto da tecnologie come la realtà virtuale e aumentata, che trasforma il modo tradizionale di interagire con il patrimonio. Questo ambiente non promuove solo l'intrattenimento, ma anche l'apprendimento, la collaborazione e l'esplorazione, soprattutto per le persone con problemi di udito. Da una prospettiva inclusiva, l'obiettivo è eliminare le barriere sociali e ambientali in modo che gli utenti possano accedere al patrimonio culturale e trarne beneficio attraverso questi spazi digitali. Nell'ambito del progetto di R&S&I intitolato *Cultural and bibliographic heritage in the GLAM context (Libraries, Archives and Museums)* (riferimento: PID2020-113405RB-I00), finanziato dall'Agenzia di Ricerca Statale del Ministero spagnolo della Scienza e dell'Innovazione, in collaborazione con il gruppo di ricerca IDEALab, vengono sviluppate mostre virtuali accessibili, che integrano collezioni di varie istituzioni attraverso la collaborazione e l'uso della

narrazione. Queste mostre cercano di offrire un'esperienza comprensibile, sicura e arricchente, utilizzando strumenti come l'easy reading e promuovendo una connessione emotiva con il passato. L'ambiente virtuale diventa così uno spazio inclusivo dove il divertimento, l'espressione di sé e l'interazione libera da limitazioni sociali sono facilitati.

Advanced technologies for auditory inclusion: designing accessible virtual exhibits

GLAM institutions (galleries, libraries, archives, and museums) are converting their collections into digital data to create engaging and inclusive activities that appeal to a diverse audience. In this context, the Metaverse provides an immersive and dynamic virtual environment, underpinned by technologies such as virtual and augmented reality, which is transforming the traditional way of interacting with heritage. This environment promotes not only entertainment but also learning, collaboration, and exploration—particularly for people with hearing impairments.

From an inclusive perspective, the Metaverse aims to eliminate social and environmental barriers, enabling users to access and benefit from cultural heritage through these digital spaces. As part of the R&D&I project *Cultural and Bibliographic Heritage in the GLAM Context (Libraries, Archives, and Museums)* (reference PID2020-113405RB-I00), funded by the State Research Agency of the Spanish Ministry of Science and Innovation in collaboration with the IDEALab Research Group, accessible virtual exhibitions are being developed. These exhibitions integrate collections from various institutions through collaboration and storytelling.

They aim to provide a comprehensible, safe, and enriching experience by using tools such as easy reading and fostering an emotional connection with the past. The virtual environment thus becomes an inclusive space where enjoyment, self-expression, and interaction, free from social limitations, are facilitated.