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360 Virtual Tours at the National Roman Museum. Making Cultural Heritage Participatory, Accessible, and Personalised

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Abstract

As agents of social change, museums should promote inclusivity and accessibility. Despite the challenges of achieving this part of the museum's mission, it is possible to address them on a case-by-case basis. This paper outlines a segment of an ongoing doctoral research project at the National Roman Museum (MNR) in Rome, Italy. First, the concepts of inclusivity and accessibility are discussed. Next, it is explored how Virtual Reality (VR) and Digital Storytelling (DST) can enhance inclusive education. Following this, three 360 virtual tours are introduced, integrated with a DST approach, and created in Delightex. This section outlines how the platform operates, its features, and the technical process of creating the tours. The design principles for making the tours accessible and catering to the diverse interests and needs of various audiences are also addressed. At the current stage of the experimental phase, user experience evaluation involved two main groups: experts in IT and design, and the general public, which comprises individuals with varied demographics and digital skills. This paper presents preliminary results from the experimental stage, outlining the next steps for future development and implementation.

CCS Concepts

•Human-centered computing~Accessibility~Empirical studies in accessibility

Author keywords

inclusivity, accessibility, virtual reality, virtual tour, virtual museum

1. Introduction

The assertion that museums serve as agents of social change has gained significant traction, particularly with the adoption of a new definition by the International Council of Museums (ICOM) in 2022, which characterises museums as nonprofit, permanent institutions dedicated to researching, collecting, preserving, and exhibiting heritage, emphasising public accessibility, inclusivity, diversity, and sustainable development. This comprehensive perspective marks a transformative shift, situating museums not merely as custodians of artifacts but as proactive players in addressing contemporary societal issues and fostering community engagement.

The role of inclusivity and accessibility within museum education is paramount in this context. Museum education, often defined as the acquisition of knowledge and understanding through museum-based learning programs, inherently carries the potential to inspire diverse audiences and foster social cohesion [VDK23]. For museums to effectively function as platforms for social change, they must prioritize inclusivity in their programming, ensuring that traditionally marginalized groups have equitable access to exhibitions and educational initiatives. This commitment enhances the richness of the museum experience and empowers individuals to engage with and influence the narrative regarding their cultural and social identities [VDK23]. Effective museum educational programs can facilitate intercultural education, thus breaking down stereotypes and fostering mutual understanding among diverse visitor groups [TM21].

Despite the promise of social transformation through museums, significant challenges persist in their mission to enact social change. One of the most profound barriers is the influence of historical exclusionary practices, which have shaped institutional frameworks and the narratives of exhibitions. This legacy often manifests in a lack of representation for underrepresented communities, necessitating a conscious and sustained effort to reevaluate and diversify collections and programming [LCD21]. Financial limitations also play a critical role, as many museums contend with restricted budgets that inhibit their capacity to implement innovative outreach initiatives and expand community engagement, which is crucial for building relevance in today's society [LCD21]. Additionally, the challenge of achieving educational equity is compounded by the digital divide, which limits access to resources and knowledge for marginalised populations. Museums often leverage technology for outreach, but disparities in access can exacerbate existing inequalities, underscoring the need for tailored approaches to ensure that all community members can effectively engage with

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museum resources [VDK23]. Consequently, museums must actively work towards reducing educational inequities by diversifying outreach techniques and formats, transforming traditional exhibition models to be more engaging and participatory.

Museums should adopt a case-by-case approach to develop educational programs and outreach initiatives. Each institution must assess its unique context, objectives, and target audiences, using tailored strategies to meet community needs. By setting clear goals and benchmarks, museums can engage diverse populations and foster social change through thoughtful partnerships with local communities and experts [VDK23] [TM21]. This targeted approach helps museums address inclusivity and accessibility while promoting social justice and equity.

2. Contribution to the research or research questions

Enhancing cultural heritage involves nuanced meanings of inclusiveness and accessibility, as they are shaped by international, European, and national regulatory bodies [CP24], as well as advancements in scientific research in the field. Inclusivity refers to ensuring that everyone can actively participate in social and cultural life regardless of circumstances. This involves removing physical and socio-cultural barriers that hinder the whole exercise of individual rights. Accessibility pertains to the ability of environments, services, and content to be used independently and without discrimination by all individuals, including those with disabilities. Both concepts are grounded in the principle of non-discrimination and aim to foster an environment that provides equal opportunities at social, cultural, and professional levels.

Regarding possible ways to achieve accessibility and inclusiveness, various technologically advanced tools and methodologies currently exist. Virtual Reality (VR) and Digital Storytelling (DST) were chosen for this project, as they have the potential to foster emotional engagement and cognitive retention. Provided that this is context- and project-dependent, research shows that VR can promote inclusive education by providing immersive and interactive learning experiences for everyone, simulating enjoyable real-world experiences regardless of disabilities or geographical location [AGS23] [CTCT*2023]. VR enables personalised learning experiences [LW20], accommodating diverse learning styles and individual needs. Compared to traditional media, VR is particularly effective in enhancing learners' emotional and cognitive engagement [Xin22], resulting in improved learning outcomes and retention. Furthermore, VR experiences create a strong sense of presence and immersion [BBAL*04] [GCD*11], resulting in users' heightened emotional and cognitive reactions. One notable application of VR is 360 virtual tours, which are increasingly used to enrich archaeological heritage experiences in museums [BBFB22] and on historical sites [AEB20].

Numerous tools exist for developing virtual museums, mostly requiring experts in programming languages. The VIRTUE Platform [GSPG*19] enables curators to create customizable 3D exhibitions with features like teleportation between rooms and web-based artifact management. Lugrin et al. [LKSK*18] present a location-based VR museum where visitors can move within a real 600 m² space while exploring a 7000 m² virtual environment, incorporating interactive displays and intelligent navigation, built with Unity 3D. The Museum of Pure Form [LTFC*04] offers tactile interaction with digitized sculptures in a CAVE-like setting, utilizing 3D scanning and haptic feedback. Meinecke et al. [MHJ22] introduce a virtual museum tour enhanced by machine learning, offering dual-room VR experiences. However, a common point across these studies is the absence of a participatory approach and the lack of integration of Digital Storytelling.

Storytelling has a long history in museums, and in recent decades, it has been increasingly embraced in new forms due to rapid advancements in the digital realm [Bon20]. DST is a method that merges narrative with digital multimedia to create engaging and interactive experiences [Lam12]. It can effectively present a variety of narratives that capture the complex nature of cultural heritage, ensuring that diverse voices are heard and represented. It allows individuals to express their voices and perspectives, fostering deeper engagement in their learning processes. Through DST, people can creatively share their experiences and viewpoints. This approach encourages reflection and active participation, enabling learners to connect with content in a personalised way [LB19].

However, the integration of VR and DST in museum education presents notable challenges, particularly regarding accessibility for diverse audiences. One primary challenge is the technological disparity among visitors, which can limit engagement with VR applications. While advancements in VR technologies have expanded access to some extent, the reality is that not all users possess the necessary technical know-how or equipment, such as VR headsets. This limitation creates a barrier for those who could benefit from enriched educational experiences but lack the means to access them [GSPG*19].

Another significant concern is related to the user interface design of VR experiences. Ensuring that these platforms are intuitive and user-friendly is crucial. Museums must cater to a broad demographic, including individuals with disabilities and those with varying levels of digital literacy [RKI23]. For example, the interfaces of VR applications need to be adaptive, as traditional designs may deter certain groups from engaging fully with digital storytelling and immersive exhibitions. Research indicates that diversifying storytelling methods within digital culture can enhance engagement and accommodate various visitor expectations [RKI23]. Therefore, museums face the challenge of balancing technological sophistication with the need for accessible design to reach diverse audiences in a meaningful way.

Furthermore, while VR and augmented reality (AR) hold promise for enhancing educational experiences, they require significant resources for development and implementation. Many museums, especially smaller institutions, may lack the financial capacity to invest in such technologies [PIL19]. This inequity can perpetuate existing gaps in access, whereby larger institutions can leverage resources to create engaging VR experiences while smaller entities might struggle. Moreover, the rapid pace of technological advancements can render tools obsolete quickly, necessitating continuous updates and staff training on new systems, which can strain resources [MCBF*20].

Overall, while VR and digital storytelling in museums offer substantial educational opportunities, the challenges regarding accessibility underscore the need for careful consideration of user experience design, equitable resource distribution, and inclusive practices. Addressing these challenges is essential to ensure that all

demographics can equally participate in and benefit from innovative museum education strategies.

This pilot study investigates the user experience of groups that differ in demographics, (dis)abilities, and digital skills. Users navigated an experimental version of the 360 virtual tours being developed for the National Roman Museum (MNR), which incorporates a DST approach through a top-down participatory approach. The 360 virtual tours are created using affordable, user-friendly tools that require no design or programming background.

3. Innovation description about how the work extends the state of the art

The MNR is an archaeological museum with special autonomy, featuring four locations that highlight the city's history, three of which are currently open to the public. It collaborates with various organisations to enhance visitor engagement and accessibility, offering services that can be learned about through the museum's official website and tailored to cater to the needs of different audiences. Current multimedia initiatives include YouTube videos showcasing exhibit stories, Facebook posts featuring images from the photography archive, Vimeo videos on glossary entries, a storytelling workshop involving upper secondary school students in narrating the museum through words and images, and a program for the same target aimed at designing virtual paths and communication campaigns. The outputs of the last two initiatives aren't currently available for online exploration.

This study aims to enhance MNR's educational offerings by creating three inclusive, accessible, personalised, and technologically advanced museum paths, one for each venue currently open to the public. The Delightex web-based platform was selected for designing and implementing museum paths due to its features that cater to the needs of individuals with Specific Learning Disorders, Special Educational Needs, certain types of intellectual disabilities, and vision impairments, as well as non-native speakers. Additionally, its user-friendly interface enables non-experts to easily create virtual tours. DST is integrated into the 360 virtual tours through a top-down participatory approach. The combination of these elements establishes this project as an innovative contribution to museum education.

4. Methods

4.1. Functioning and features of Delightex

Teachers and students can use the Delightex platform, formerly known as CoSpaces Edu, to develop their own virtual and augmented reality experiences. Creators can create experiences on Delightex by dragging and dropping various creation features, including 3D objects, building blocks, multimedia elements, block-based scripting, and more. Choosing a scene type is the first step in creating an experience. Five categories of experiences are available for use:

1. A comprehensive 3D virtual space is used to develop VR and AR projects.
2. 360 images are used to develop virtual reality projects.
3. MERGE Cube: used for MERGE Cube augmented reality experiences.
4. Quiz: a tool for making interactive quizzes
5. Tour: used to develop more straightforward virtual tours, using 360 images.

To develop more complex virtual tours, creators can combine 360 scenes and 3D environments in a single project. Depending on the type of scene, 360 or 3D, creators can build their experiences using a set of pre-created elements. The platform offers a collection of elements that can be used to create unique experiences. This library is divided into eight categories: characters, animals, housing, nature, transport, items, buildings, and special, each containing a vast range of elements, such as 3D avatars that can be animated, buildings, plants, and a number of special items to aid in the development process. Nearly every digital element in the library can be styled in a unique way and animated using the pre-created animations. Another feature provided by the platform is the "Upload" section. Teachers and students can create experiences by uploading their own personalised photos, videos, 3D models, and sounds. In the 360 and 3D scenes, creators can utilize the "Environment" section to upload a 360 photo or select a 3D world as the environment, apply a visual filter, and add background sound to enhance the experience.

Delightex uses a visual coding language called CoBlocks to program the project, allowing the creator to drag and drop code blocks. Each block of code, or statement, instructs Delightex to initiate a specific action in a scene. CoBlocks are classified into two types: expression blocks and statement blocks. The statement CoBlocks frequently perform a specific action, while the expression CoBlocks include values (colours, numbers, strings, and other items) that are always inserted into other CoBlocks. In addition to CoBlocks, Delightex Pro enables creators to utilize TypeScript and Python, which are more advanced programming languages.

Delightex Pro features a physics engine, enabling creators to integrate real-world mechanics and develop more complex experiences.

4.2. Technical process of building the 360 virtual tours in Delightex

A high-quality 360 image is the foundation of any virtual tour. These images can be captured using a 360 camera. On the Delightex platform, after selecting the 360 image as the project type, the project's first scene editing area is displayed, containing a single item, a camera object, representing the user’s point of view. The next step in creating a virtual tour is to add a 360 image (3 Degrees of Freedom, hereafter 3DoF) to the “Environment” section. This 360 image will provide an immersive environment for users to see and explore.

The next stage in the development process of the virtual tour is to fill the environment with interactive elements from the Delightex library, such as information panels and quiz panels, or custom elements like images, icons, and videos. These elements can be strategically positioned across the environment, providing users with contextual information or triggering specific actions when selected. To simulate movement between locations, multiple scenes must be implemented in the project, along with additional 360-degree image uploads. These additional scenes can represent different rooms in a building or entirely distinct locations. Creators can link scenes together using the "Go to scene" block of code, which ensures the transition between scenes. To enrich the user experience, creators can integrate various custom multimedia elements, such as audio clips that narrate key concepts, background music, images, and videos. These interactive elements can be dragged and dropped into a scene and positioned at specific locations. Another approach to increase interactivity is to use CoBlocks or another scripting language supported by the platform. Using these code blocks, creators can add various pop-ups with information, integrate quizzes, and build choice routes as they progress through the tour. This functionality transforms the platform into a highly adaptable system on a wide range of themes.

Another essential feature of the Delightex platform is the ability to pre-visualize the tour before sharing it publicly. This feature enables creators to test navigation, interactivity, and all project features. After testing all the functionalities, the virtual reality experience can be shared with the public via a QR code, a link, or a unique access code.

The MNR's 360 tours offer an immersive and interactive exploration of the museum's environment, designed to ensure cognitive and cultural accessibility and navigation while lowering geographical and physical barriers. The virtual tours simulate the real experience of exploring the museum, augmenting it with multimedia elements and interactive functionalities.

The 360 images captured three of the museum's venues and, with the help of the navigation system, recreated the museum's actual layout. This technique enables users to freely explore each museum venue, creating a sense of real presence in this virtual world.

The navigation system is represented by arrow-shaped icons that, in addition to assisting users with navigation, enable users to transition from one 360 image to another. A dynamic map of the museum has also been integrated, which displays the user's current location based on their position in the virtual world (Figure 1).

In order to provide information in a more immersive manner, the virtual tour also incorporates a number of interactive elements, such as information panels (Figure 2) that can be activated by selecting an intuitive icon and contain detailed descriptions of the exhibits and works of art, as well as 3D scans of the statues, which allow users to see and manipulate the selected artefacts. Each 3D model is accompanied by two interactive buttons represented by icons, one for rotating and the other for resizing, allowing users to inspect details from various perspectives and sizes.

Background music has been integrated throughout the virtual tour to improve its ambiance. Usually, the Delightex platform allows for the implementation of background music, but it must be done independently for each scene; thus, even if the same music is chosen, it will restart as users transition from one scene to another. To ensure that the music does not restart or interrupt when transitioning between scenes, an additional script written in TypeScript was integrated into this virtual tour. This script ensures that the background music plays continuously throughout the tour.

Accessibility was an essential factor in the design of this virtual tour. As a result, all information panels used the reading aloud and immersive reading features, as well as the ability to use the Picture Dictionary and translate texts into other languages. All of the virtual tour's texts were originally written in Italian (Figure 3). All of these resources can be translated and listened to in a variety of languages (Figure 4) by using the text-to-speech and translation feature. By assisting non-native speakers in understanding the information, the translation feature supports accessibility and balanced opportunities for learning. The Delightex platform offers options for customizing the text displayed, in addition to its translation function. These options include font size, color, spacing, line focus, hyphenation, and options for highlighting verbs, adjectives, nouns, and adverbs.

The app can be used with a Google Cardboard headset or even a Meta VR headset, but it is not mandatory. The 360 virtual tours can be navigated through personal computers and phones.

Figure 1: *This is a scene from one of the three 360° virtual tours developed for the MNR. Users can navigate between scenes by using the different arrows available. In the upper right corner, there is an icon to turn the music on or off. The lower right corner features a map of the museum, which highlights the hall where the user is currently located. The book icon provides access to stories on the Ideas narrative dimension, along with object labels. Additionally, icons located beneath the 3D model allow users to interact with it.*

Figure 2: *Part of a story accessed by clicking on the book icon. From the book and speaker icon below in the text panel, users can access the reading aloud and immersive reading features.*

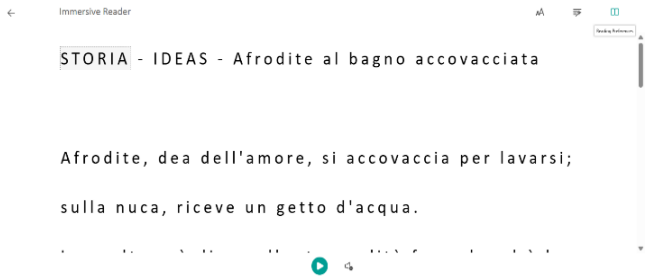

Figure 3: *An example of the available immersive reading features. The original language has been set. Users can pause the reading or adjust the voice settings. From the top right corner, users can select various immersive reading features.*

Figure 4: *Some available immersive reading features. The English language has been selected for translating the document, and a British accent voice is reading it aloud. Users can pause the reading or adjust the voice settings.*

4.3. Participatory and accessible design of the 360 virtual tours integrated with a DST approach

Integrating Universal Design for Learning (UDL) principles into the development of 360 virtual museum tours is crucial for making these digital experiences inclusive, engaging, and accessible to a diverse audience. By applying UDL, designers can incorporate multiple forms of representation (such as text, audio, and visual cues) and interactive features that cater to diverse learning styles and abilities, including those with disabilities [Zak23]. This not only helps meet accessibility standards [KS20] but also enhances the user experience through adaptable interfaces and interactive elements that cater to individual preferences and needs [WN23]. Additionally, UDL in virtual tours creates an environment where visitors can explore museum collections at their own pace, engaging with content that reflects differentiated instruction strategies commonly used in museum learning settings [Zak23]. Therefore, leveraging UDL supports a transformative learning experience that bridges traditional museum exhibits and modern digital engagement, ultimately strengthening museums' cultural and educational missions.

Recreating the space and atmosphere of a museum as a physical structure is crucial for providing users with a deep understanding of the museum setting, as the museum's cultural complexity is due not only to how its collections were created, but also to the story of its container [Nar11]. Furthermore, preparation is crucial for visitors with Autism Spectrum Disorders (ASD), intellectual disabilities, and young children before attending a museum. Understanding the layout, available services, and relaxation areas can significantly reduce anxiety and enhance comfort during the visit [FWWG21]. This is particularly beneficial for individuals with ASD, who may often find unfamiliar environments overwhelming; knowing what to expect helps them navigate the museum effectively and engage more meaningfully with exhibits [FWWG21]. 360 virtual museums serve as an excellent tool for pre-visit orientation. They provide immersive experiences that allow potential visitors to explore museum spaces in advance, familiarizing themselves with the environment, which can alleviate apprehensions about sensory overload and unfamiliar surroundings [KCWT*22]. The ability to visualize interactive elements and services offered enables these individuals and their caregivers to plan effectively for their visit, ensuring a supportive experience that accommodates their needs [KCWT*22]. This accessibility ultimately fosters inclusion and engagement with cultural institutions.

The decision to use 3DoF instead of 6DoF was primarily due to the lack of informatics engineers among the MNR staff capable of developing and editing complex 360 virtual tours. Keeping the tours technically simple and developing them with an easy-to-use tool, such as Delightex, allows museum professionals at the MNR, even without programming skills, to modify the tours as needed. Secondly, this choice presents an opportunity to teach participants in the project the basics of developing 360 virtual tours.

Incorporating music into museum pathways can enhance emotional engagement [MS21] and sense of presence by creating an immersive auditory environment that complements the visual experience. Auditory stimuli, such as background music or soundscapes, can evoke emotional responses and foster a deeper engagement with the exhibited artifacts [CTNT*17]. Additionally, music tailored to specific exhibits can provide context and meaning, enhancing visitors' understanding and enjoyment of the artwork [CTNT*17]. Research indicates that auditory environments can significantly influence navigation and user experience within virtual spaces, with music serving both functional and aesthetic roles during tours [CTNT*17]. For example, carefully selected music can guide users through narratives and themes, which are critical in effectively engaging users while exploring the virtual museum [RMAJ*22]. Moreover, physiological measurements suggest that music can affect the emotional state of individuals, leading to increased enjoyment and sustained attention during the tour [WJL23]. Therefore, integrating music into a 360 virtual museum tour can significantly improve the user's overall sense of presence and satisfaction.

Including maps in a virtual museum tour can improve the user experience by enhancing a sense of presence, spatial awareness, and navigation efficiency. Maps are essential tools that help users orient themselves within the virtual environment, reducing feelings of disorientation and facilitating easier exploration. Scholars [ZZJP24] highlight the effectiveness of mini-maps as navigational aids, noting their success in improving spatial cognition and navigation efficiency in virtual museum contexts.

The decision was made to make the 360 virtual tours accessible via computers and smartphones eliminating the need for virtual reality visors. This approach enhances accessibility, as not

everyone owns visors, and virtual experiences using them can cause dizziness or nausea, particularly for individuals who are susceptible. Additionally, relying on visors contributes to the digital divide. However, users who enjoy the tours on their phones are informed that they can rotate their devices horizontally to access the VR viewing mode, which can be used with a Google Cardboard headset.

The DST component has been integrated into the 360 virtual tours through a top-down participatory approach, actively involving high school and university students, including those with physical and intellectual disabilities, in creating stories. A top-down participatory approach to museum education emphasizes structured engagement facilitated by museum professionals while incorporating visitor input in content creation and programming. This model enables institutions to transition from traditional pedagogical roles to dynamic platforms where visitors actively engage in their learning experiences. Nina Simon articulates this notion in her definition of a participatory museum as a space where visitors can create, share, and learn from one another, thus fostering individual creativity and collective knowledge [Sim10]. Additionally, this approach acknowledges the diverse needs of museum audiences, including accessibility considerations, which are crucial in contemporary exhibit design [Wan24]. By utilizing technology such as voice-driven interactive guides, museums can enhance visitor engagement and inclusivity, ensuring that all voices, especially those of marginalized groups, are heard. This process not only enhances learning but also democratizes knowledge creation, aligning with current educational paradigms that prioritize visitor interaction and active participation [CK16]. Ultimately, a top-down participatory approach cultivates a collaborative learning environment where museum professionals lead the way in providing opportunities for meaningful visitor contributions, thus reshaping the role of museums in society.

The archaeologist involved in this project selected artifacts representative of various aspects of ancient Romans' lives, which the former Director of the MNR approved. Participants were then engaged in focus groups on accessibility and inclusivity in museum settings to understand their perceived needs and their ideas on how to make museum narratives more compelling.

Based on these discussions, the four narrative dimensions named Ideas, People, Objects, and Physical (IPOP) [PSHR*14] seemed the most appropriate to meet the objectives of this project. Research conducted at the Smithsonian Institution reveals that these are the narrative dimensions that most interest museum visitors. The Ideas narrative dimension is related to an attraction to concepts, abstractions, linear thinking, facts, and rational reasoning. The People dimension encompasses an attraction to human connection, emotional experiences, stories, and social interactions. The Objects dimension is focused on things, aesthetics, craftsmanship, ownership, and visual language. Finally, the Physical dimension is about somatic sensations, including movement, touch, sound, taste, light, and smell.

It is worth noting that the participants in the experimental phase addressed in this paper navigated the 360 virtual tours, which featured only the Ideas narrative dimension. This is for a twofold reason. This dimension is related to the most complex content to create for non-experts, as it involves scientific data, concepts, abstractions, and linear thought, and is therefore developed by one of the Authors with a background in archaeology. Furthermore, inserting the Ideas narrative dimension at this stage enabled the implementation of virtual tours for all components, albeit on a smaller scale, thereby providing an opportunity to evaluate the user experience. Consequently, participants are currently collaborating to develop stories focused on the remaining three narrative dimensions. Once these stories receive approval from the archaeologist involved in this research project and the Educational Department of the MNR, they will be included in the 360 virtual tours, which will be freely accessible to anyone on the official museum website.

Another critical aspect of the virtual experience is its personalisation. This is achieved not only by incorporating various forms of representation and interactive features that address the needs of diverse audiences, as stated above, but also by inserting different narratives related to the abovementioned IPOP narrative dimensions that cater to the varying interests of users, further enhancing the personalised experience. As a matter of fact, before starting the 360 virtual tours, end users will be profiled using the 8-item version of the IPOP questionnaire [PSHR*14], which is a self-administered questionnaire that investigates narrative preference(s) through indirect questions. Then, they will be suggested the preferential narrative dimension(s) accordingly and will be free to select related stories or explore other narrative dimensions as they wish.

5. Preliminary results

User experience evaluation involved two main categories: the general public, which differed in demographics, (dis)abilities, and digital skills, and ICT and online education experts. For the former, a user experience questionnaire was utilised, while for the latter, the interview method [Mer10] was used.

In the general public category, a group of 14 Master's degree students from the University Politehnica Timişoara, specialising in Multimedia Technologies with a focus on Web Technologies 2.0, was involved, which is hereafter referred to as sub-group 1 (SG1). SG1 possesses high levels of digital skills. There was also a group of 20 Italian high school art students with low digital skills, hereafter referred to as sub-group 2 (SG2). In SG2, there are: one person with reduced mobility, three people on the autism spectrum, one person with Down syndrome, a first-generation migrant who does not yet have a strong command of the language of the host country, three people with Special Educational Needs, and three people with Specific Learning Disorders.

The questionnaire that both sub-groups filled in consists of six sections, namely navigation through scenes, background music, 3D models of museum artefacts, text and object labels of museum artefacts, a map of the museum, and an overall rating.

In terms of navigation through scenes, SG1 found the initial navigation instructions to be pleasant (n = 7; 50%), simple (n = 6; 42,9%), and useful (n = 5; 35,7%). Only one participant out of 14 reported finding them boring. On the other hand, SG2 also found the instructions to be useful (n = 12; 60%), simple (n = 10; 50%), and pleasant (n = 11; 55%). Out of 20 respondents in SG2, only

one found the instructions to be useless, one found them boring, and one found them irritating. For SG1, navigating back and forth between scenes using the colored arrows was rated as very easy (n = 4; 28.6%), easy (n = 8; 57.1%), and neither easy nor difficult (n = 2; 14.3%). In contrast, for SG2, it was very easy (n = 5; 25%), easy (n = 11; 55%), or neither easy nor difficult (n = 4; 20%). Consequently, most members of SG1 did not encounter any difficulties in understanding which arrows to use to move in the direction they wanted (n = 11; 78,6%); a similar value resulted for SG2, where 17 (85%) members reported no difficulties. In discussing the potential implementation of navigation in Delightex, two members of SG1 proposed distinguishing the arrows for moving forward and backward more clearly. Additionally, two other members suggested incorporating the museum map as an extra navigation tool for moving between rooms. One member recommended adding the WASD keys to simplify movement controls. A member of SG2 also raised this point last. No other suggestions were put forward by the remaining members of both groups, who found the current navigation smooth.

Regarding the background music, SG1 found it neutral (n = 7; 50%), pleasant but not engaging (n = 5; 35,7%), and, at the extreme opposites, one found it engrossing while another one irritating, while SG2 perceived it as neutral (n = 8; 40%), pleasant but not engaging (n = 6; 30%), engrossing (n = 5; 25%), and just in one case irritating. The audio quality of the music was adequate according to all members of SG1, whereas only half of SG2 rated it equally, considering it insufficient in two cases (10%) and great in 8 (40%). The soundtrack was generally well-received; however, only six members of SG1 (42,9%) and 10 members of SG2 (50%) kept the music playing at all times. Those who chose to turn off the music, either consistently or occasionally, provided a few reasons. Specifically, two members from SG1 and four members from SG2 (20%) found it too loud for comfortable conversation with others. Additionally, one member from SG1 and one member from SG2 found the music unnecessary, while three members from SG2 (15%) perceived it as distracting while reading.

Regarding 3D models of artefacts, SG1 found the possibility to zooming in and out and rotate clockwise museum's objects quite interesting (n = 8; 57,1%) or very interesting (n = 6; 42,9%), while SG2 found it quite interesting (n = 11; 55%), very interesting (n = 6; 30%) and neither interesting nor boring (n = 3; 15%). Their manipulation was deemed easy by all respondents of SG1 and 17 (85%) respondents of SG2. In the discussion about possible implementations of the 3D models, one member from SG1 suggested allowing users to move the objects in more directions. Additionally, two members expressed a desire for more 3D models to be included in this experimental version. Two respondents provided feedback from SG2, each wanting improved colors and greater detail, thus referring to the size format of the 3D objects that Delightex can support.

Regarding the labels of texts and objects in 3D models, the fact that the museum introduced itself to users using the first-person singular and a colloquial tone was largely appreciated by SG1 (n = 10; 71.42%) and considered fun and original, helping to lower the barrier between the institution and individuals. Four respondents from SG1 did not comment on this aspect. A similar trend was observed in SG2, where 14 respondents (70%) shared the same positive sentiment. Additionally, while one respondent acknowledged the interesting nature of this stylist choice, they preferred a traditional introduction in the third person singular. Only one respondent disliked the colloquial tone, while the remaining individuals did not provide feedback. Similarly, the positioning of the Ideas stories before the objects' labels - thus allowing respondents to grasp the significance of the artefact first and then learn about technical details such as inventory numbers, materials, collection information, and dating - was largely appreciated by 13 respondents (92, 85%) in SG1. Only one person felt indifferent to it. This trend slightly decreased in SG2, as 15 respondents (75%) gave the same positive answer, while four did not express themselves on the topic, and one felt neutral about it. Overall, according to SG1 the Ideas stories and objects' labels were quite useful (n = 7; 50%), very useful (n = 5; 35,7%) or neither useful nor useless (n = 2; 14,3%), whereas they were quite useful (n = 9; 45%), very useful (n = 8; 40%), neither useful nor useless (n = 2; 10%) according to SG2. Only one SG2 respondent deemed them of little use. Read-aloud, immersive reading, and translation features were used by only 4 (28,6%) respondents in SG1 but by 18 (90%) respondents in SG2. Those in SG1 who rated them highly. More nuanced feedback came from SG2. Thirteen (65%) people viewed all immersive reading features positively. However, while appreciating the reading-aloud voice feature, two respondents noted that it felt somewhat robotic and lacking in expression. Two individuals (10%) mentioned that translations would be especially useful for foreign tourists. One person highlighted that the reading-aloud voice could be particularly beneficial for blind users, while another suggested that it would allow users to listen while multitasking.

According to the feedback from SG1, the museum map was perceived as very useful by 8 participants (57.1%), quite useful by 4 participants (28.6%), and neither useful nor useless by 2 participants (14.3%). In SG2, the map was deemed quite useful by 9 participants (45%) and very useful by 8 participants (40%), while 2 participants found it of little use and 1 participant rated it as neither useful nor useless. Additionally, 13 out of 14 respondents in SG1 (92.9%) and 18 out of 20 respondents in SG2 (90%) found the yellow highlighting on the map, indicating the current user's location, easy to understand.

In terms of the overall rating of the virtual experience, respondents in SG1 reported that they enjoyed the virtual tour (VT), with 9 participants (64.3%) expressing this sentiment, while 5 (35.7%) found it quite enjoyable. Consequently, nine respondents (64.3%) would recommend VT to friends, 4 (28.6%) might, and only one would not. Additionally, 5 participants (35.7%) felt inspired to visit the museum in person, 6 (42.9%) were unsure, and 3 (21.4%) expressed a negative interest in a physical visit. In SG2, out of 20 participants, 8 (40%) enjoyed the virtual tour (VT), while 11 (55%) found it quite likable. Only 1 participant did not like it very much. Additionally, nine respondents (45%) would recommend VT to friends, 10 (50%) might recommend it, and just one would not. Furthermore, 10 respondents (50%) felt inspired to visit the museum in person, 9 (45%) felt unsure, and only 1 responded negatively.

In summary, to enhance the user experience, five individuals (four from SG1 and one from SG2) recommended implementing interactivity for navigating between scenes and manipulating the

3D models. Two participants (one in SG1 and one in SG2) desired additional 3D models and more information about the selected artifacts. One person in SG1 mentioned that they would prefer a shorter VT. No other suggestions were provided, as the remaining respondents either felt uncertain about what to recommend for improvement or stated that they appreciated the virtual experience as it is. Therefore, it is possible to state that, overall, the VT experience was positive for both SG1 and SG2, regardless of individuals' digital skills and disabilities.

The interview with an ICT and online education expert consisted of six interconnected sections: general impressions, navigation and orientation, information delivery and accessibility, interactivity and immersive reading features, platform-specific and technical aspects, and future improvements. It provided critical validation and constructive recommendations regarding the accessibility and inclusivity of the MNR's virtual tours. The expert's feedback underscored the project's success in creating a user-friendly and accessible experience while highlighting areas for future enhancement.

A significant portion of the expert's feedback centered on the tour's navigational design and its impact on user accessibility. The expert's overall first impression was that the navigation was "straightforward" and the tour's elements were "easy to understand," which is crucial for accommodating users with varying levels of digital literacy. The initial instructions, which combine text and icons to explain how to navigate the virtual space, were deemed particularly "effective," "clear and complete". Additionally, the background music was considered "appropriate" for the museum setting and of "satisfactory quality". This approach is fundamental to inclusivity, as it lowers the initial barriers for engagement.

The expert also provided specific recommendations for improving orientation and navigation. A key suggestion was to enhance the museum map's interactivity, allowing users to click on a specific room and be "teleported" directly to it. This would supplement the existing arrow-based navigation and cater to different user preferences, thereby improving navigation efficiency —a known challenge in virtual environments.

Regarding the delivery of information and specific accessibility features, the expert's analysis was highly positive. The design of the information panels was praised for enabling the "optimal exploitation of the reading-aloud, immersive-reading and translation features". This is a critical point for inclusivity, as these features were intentionally integrated to support individuals with Specific Learning Disorders, vision impairments, and non-native speakers. The expert's comment serves as an external validation that the implementation successfully meets these accessibility goals.

While the interactivity with 3D models of artifacts was considered "adequate," the expert recommended enhancing the ability to zoom in on these models as much as possible. This suggestion directly addresses accessibility, as greater zoom capability would allow users, including those with visual impairments, to inspect the artifacts' details more closely.

The expert also identified a technical limitation within the Delightex platform concerning the display of text panels associated with images and recommended a proactive accessibility solution. To avoid user confusion, the expert suggested that the initial navigation tutorial should inform users in advance about the number of pop-ups they will encounter. This minor adjustment enhances the predictability of the interface, which is a key principle of accessible design, particularly for users who may find unexpected actions disorienting.

To conclude, the expert's feedback confirms that the virtual tour's design successfully incorporates key accessibility and inclusivity principles. The straightforward navigation, effective use of icons, and robust implementation of reading and translation tools were highlighted as major strengths. The recommendations for an interactive map and enhanced zoom capabilities offer a clear path for making an already accessible experience even more inclusive for a broader audience in future iterations.

6. Conclusions

This study has demonstrated the potential of 360 virtual tours, enriched through digital storytelling, to transform the museum experience by making cultural heritage more inclusive, accessible, and personalised. However, several limitations have emerged that warrant further attention. The experimental phase was constrained by a limited number of participants and, in some cases, by external factors such as unstable network conditions, which may have inadvertently influenced user experiences. Technical challenges were also encountered, notably the limitations of medium format 3D models for smooth web navigation. These challenges underscore the complexity of integrating immersive technologies within existing museum frameworks.

The next step involves expanding the user base to include a broader demographic spectrum. Future studies should involve larger, more diverse participant groups, including those with different age, socioeconomic backgrounds, and accessibility needs, to better understand how different audiences engage with 360 virtual tours. Longitudinal research could track whether virtual experiences translate into increased physical museum visits or sustained engagement with cultural heritage over time.

Another step consists of refining interactivity based on expert recommendations (such as enhanced navigational cues and deeper 3D model manipulations). Although the study demonstrated the promising use of immersive elements, further research should focus on optimizing the technical aspects—for example, refining navigation systems with enhanced interactive maps, minimizing disruptions in background music continuity, and improving the handling of 3D models. Investigations into integrating advanced coding methods for adaptive user interfaces could further tailor the experience for various digital skill levels.

Furthermore, it will be necessary to incorporate additional narrative dimensions beyond the preliminary Ideas component. The current study primarily addressed the "Ideas" narrative dimension. Future research can systematically investigate how the remaining IPOP dimensions (People, Objects, and Physical) influence user experience and learning outcomes and whether

personalised narrative strategies can further enrich user engagement and cultural understanding.

Future research could assess the educational outcomes associated with the use of digital storytelling combined with VR. Researchers might explore how these virtual tours can function as effective inclusive educational tools, especially in diverse or marginalised communities, and measure their impact on intercultural dialogue and social inclusion. Analysing how the methodology applies in different cultural heritage environments will be valuable. Comparative research might involve replicating the study in other museums or heritage sites, both domestically and internationally, to examine the scalability and adaptability of virtual tours and highlight cultural nuances in user interaction and storytelling. Future directions could also explore the development and integration of more advanced accessibility features, including intuitive voice-based navigation, customizable text-to-speech outputs, and enhanced translation services, to ensure that virtual tours cater seamlessly to users with diverse needs. Further research in this direction will help bridge the digital divide, offering a truly participatory experience to all visitors.

This iterative process is expected to enhance the technical robustness and educational value of the virtual tours, holding significant implications for the evolution of research in digital cultural heritage. The insights gained from this pilot study pave the way for future research opportunities that can further democratize access to cultural heritage while pushing the boundaries of virtual technology in educational settings. Exploring such questions elevates the state of the art in museum studies and inspires cross-disciplinary collaborations that could lead to revolutionary approaches in digital cultural engagement.

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