Chapter

Museums and the Metaverse: Emerging Technologies to Promote Inclusivity and Engagement

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Abstract

Over the past two decades, museums have increasingly sought to build connections with the community and increase inclusivity of visitors. At the same time, emerging technologies, such as extended reality (XR) and virtual museums (VM) are increasingly adopted to engage with different generational expectations but also for the purposes of supporting inclusivity and neurodiverse populations. First such technologies were adopted to augment exhibitions in the physical museum space for edutainment. Since then, XR has expanded from room-size environments (CAVEs) and augmented exhibitions to the creation of entire virtual museums, such as The Museum of Pure Form and The Virtual Museum of Sculpture. Digital twins of museums are increasingly common, along with UNESCO World Heritage Sites. Such virtual experiences can be leveraged to prepare neurodiverse visitors prior to visiting a museum. This chapter will outline how existing approaches to social stories and sensory maps may be combined with XR experiences to support neurodiverse visitors and their families. While onsite, immersive technologies can be used both for engagement and to provide accommodations for greater inclusivity and diversity.

Keywords: neurodiversity, social stories, sensory maps, museums, ASD

1. Introduction

In times of public health crises when travel becomes restricted, public spaces close, and anxiety over an uncertain future spread, institutions must adopt an agile mindset to continue to engage with their constituents in innovative ways. At the same time, such events as the global spread of COVID-19, which the World Health Organization (WHO) classified a pandemic on March 11, 2020, promote human resilience and spur innovative solutions to emerging problems that find application beyond their immediate intended use cases. Such was the case for cultural heritage institutions who had to quickly pivot to find new ways for the public to engage with their collections. The call to stay home and limit large gatherings of people led museums, galleries, and cultural heritage sites to close around the globe almost overnight. For instance, the Smithsonian announced all 19 of its related institutes, museums, and even the National Zoo would close to the public on March 14, 2020 [1, 2].

At first, front-of-house staff were repurposed in other areas, such as helping to catalog and digitize collections [3]. But as the pandemic wore on, there was increased pressure for furloughs and then layoffs among museum staff and educators [4]. To stave off further loss of human capital and retain public engagement with sites and collections across the globe, many museums turned to emerging technologies. For instance, The Louvre in Paris spent much of the year digitizing and then releasing over 480,000 pieces from its collection in 2021 on their platform, while the work began in 2017 for digitizing UNESCO World Culture Heritage Sites would provide remote access to global locations cut off by border closures and travel bans in 2020 [5, 6].

An unprecedented investment in research and development followed with companies such as Facebook (now Meta) to make extended reality (XR)—including augmented reality (AR), mixed reality (MR), and virtual reality (VR)—commercially available, user-friendly and affordable. The launch of the all-in-one head-mounted display (HMD) Oculus Quest 2 (released October 13, 2022) represents a watershed moment for immersive experiences and the ability to engage the public [7]. At the same time, advancements were made in digital twin technologies. While previous photogrammetric techniques would require thousands of individual photographs painstakingly stitched together manually to create 3D models of objects or spaces, the latest generation of software compiles millions of individual images automatically [8]. The latest handheld scanners, such as Scantech, can also be used to produce high-resolution digital twins of objects, complete with precise colors and textures [9]. Both VR HMD and digital twin systems are now highly portable, user-friendly, and affordable. These technologies are now poised to work in tandem to create high-fidelity recreations of objects and historical sites and view in an immersive environment anywhere in the world.

The advances in technology coupled with the demand for virtual experiences accelerated by the global pandemic have led to an unprecedented effort to digitize museum collections and create digital twins of locations globally. The initial impetus for such projects was to allow for access to locations that were closed to promote social distancing and to incentivize future tourism in general [10]. However, as this chapter will outline, the availability of digital versions of spaces and objects contained within and the hardware to view prior to and during visitation can now be leveraged to support inclusivity and accessibly efforts for neurodiverse populations in cultural heritage institutions. Efforts to support diverse populations with a variety of needs have dominated scholarship on museum studies since the last millennium. With an estimated 10% of the world's population (650 million people) living with a disability, museums have introduced many strategies to promote accessibility. For instance, audio and visual aids have seen widespread adoption, including audio guides, captioning, and sign language interpretation for visitors who are blind, deaf, or hard of hearing. Accessible facilities include wheelchair ramps and elevators, as well as accessible restrooms and parking for those with mobility restrictions. And inclusive programming showcases underrepresented perspectives to celebrate diverse cultures and communities. However, the unique needs of neurodiverse visitors have only recently begun garnering attention [11, 12].

2. Neurodiversity and museums

The American Alliance of Museum (AAM) commissioned a study to review how inclusivity efforts were being implemented across institutions, as well as perceptions of such programming by both regular museum attendees and the public in general during the pandemic [13]. The results of the study were used to develop resources and strategies for museums, including primers for professionals to support efforts to promote diversity, equity, accessibility, and inclusion (DEAI). Support for such efforts have gained momentum with museum administrators and researchers, especially in addressing physical disabilities, however, the same call to action for supporting neurodiversity has yet to be headed. The lack of attention paid to this marginalized community becomes clear when reviewing AAM primers, which do not even mention neurodiversity [13]. Therefore, while advances in inclusivity efforts have been made with regards to ethnicity, culture, physical disability, race, religion, and gender, there remains a significant percentage of the population not considered [14–16]. With an estimated 15–20% of the global population considered to be neurodiverse, greater attention needs be paid to the specific needs of this group [17]. The population is also estimated to be growing. In 2022, the Centers for Disease Control and Prevention (CDC) reported that 1 in 44 children were diagnosed with autism spectrum disorders (ASD). The rate of diagnosis makes this population one of the largest among those with disabilities [18].

Individuals with ASD are classified as having neurodevelopmental difficulties, which may include autism, ADHD, ADD and dyslexia as the most common co-occurring diagnoses [18]. The different types and levels of social and intellectual abilities of the group require the diagnosis to use the term "spectrum disabilities" due to the way in which they can manifest. Despite such diversity in experiences and abilities, there are certain physiological considerations for museum professionals to consider when designing experiences that are inclusive. For example, those with ASD can find navigating museum spaces challenging given crowds, unexpected audio modulation, and/or lighting intensities [19]. Furthermore, museum challenges can include unforeseen vestibular sensory input from interactive exhibitions, close proximity of large crowds, and an overactive visual field.

The average museum going public may not experience stressors with sensory stimuli common in museums, such as noise, waiting in lines, crowds, or exhibition lighting, but those with sensory sensitivity may. Moreover, the 2001 Council for Museums, Archives, and Libraries identified that a fully accessible program should include many considerations associated with access, such as social, financial, emotional, attitudinal, cultural, and/or educational [20]. Notably absent were sensory considerations of access. Therefore, Schwartz and Knowles recently recommend readjusting the list to expand considerations of sensory needs of visitors. Sensory sensitivities not only dissuade those with ASD from visiting certain locations, but also their families due to the potential negative social behaviors that might arise [21].

Addressing the needs of the neurodiverse population of visitors to museums has only recently entered the accessibility conversation. The broadest adoptions regarding accommodations in institutions remain confined to physical accessibility with considerations for those with ASD emerging in the United Kingdom (UK) in large and established museums with resources [22]. Those programs that do exist that support accessibility for neurodiverse populations commonly use the following strategies:

1. *Providing sensory-friendly experiences*: Many museums are offering sensory-friendly experiences or "quiet hours" for visitors who may be sensitive to loud noises or bright lights.

2. *Providing sensory maps*: Some museums provide a guide that highlights sensory-friendly areas and features of a museum, such as quiet spaces, low lighting, and

tactile exhibits, as well as identifying potentially problematic areas with larger crowds or loud noises.

3. *Offering audio guides and other accessibility technology*: Some museums are offering audio guides and other forms of accessibility technology, such as apps, to help mitigate sensory input and modulate information to navigate the museum and access the exhibits.

4. *Providing social stories and visual schedules*: Some museums are providing social stories and visual schedules to help visitors with autism prepare for their visit and understand what to expect.

5. *Training staff on neurodiversity*: Many museums are training their staff on neurodiversity and how to best support visitors with a range of neurological conditions.

6. *Providing alternative format materials*: Many museums are providing alternative format materials such as large print, audio descriptions, and other multimedia experiences to make their exhibits and events more accessible to visitors with sensory processing.

A holistic approach to accessibility is being considered that addresses pre-visit planning and resources to familiarize visitors with sensory information and routes through unfamiliar locations [23, 24]. Support onsite can include accessibility maps, museum social stories, sunglasses, headphones, and even therapy putty [25]. Engaging a sensory sensitive audience now includes integrating kinesthetic or tactile exhibits and including "cool down" spaces with sensory modalities that allow individuals who are overstimulated to regulate their cognitive flexibility and extended the duration of the stay. Such areas are often equipped with therapy balls, mats, mood lighting, and sound modulation [26]. In certain programs, trained occupational therapy students run special sensory activities, and act as personal tour guides to support visitors and foster exhibit interactions [12]. Given that parents with children with autism report 70% higher rates of anxiety, isolation, and depression, the sense of well-being and belonging in the museum experience is significant and impactful [27].

One way a positive experience can be facilitated is to ensure preparedness for a visit. Research gathered indicates that families that feel prepared for the visit and prepare all involved greatly affects the quality of the experience that follows [28]. One of the most common ways individuals and families prepare is gathering information via the internet. An institutions website, social media pages, and advocacy organizations all provide information to learn about an organization and neurodiverse programming available there. The channels for disseminating information and social sharing are evident in that 35% of museums offer a mobile application (app). Therefore, the dialogical relationship between visitors and the museum is one that unfolds through storytelling—information is passed from the institution to visitors and, in turn, visitors provide feedback via social media. The development of this dialog is ongoing and helps create a personal story through the interactions prior to a visit and then shared thereafter [29]. But overcoming the anxiety of visiting an unknown location and potential sensory processing issues once onsite is just the first step towards accessibility.

Studies have revealed that 44–52% of those diagnosed with ASD have additional learning disorders or difficulties. That being the case, once the population overcomes the physical barriers to entry, comprehending the educational material presented represents another obstacle [30–32]. Fortuitously, museums were prepared for the needs of diverse learners and already have a range of resources to assist. Through online resources and digital access, collections, exhibitions, and educational resources are available remotely and, once onsite, virtual tours, digital audio guides and other interactive digital experiences further understanding of curated content [33]. On the other hand, the digitizing of collections and digital twin mapping of museum spaces carried out during the pandemic was not carried out with the directive of creating inclusive experiences. As such, the content was created for the neurotypical population at large [5, 6]. But these digital resources can be reconfigured and combined in a novel way with other strategies for inclusivity to assist individuals better understand the site they will visit and the societal expectations through the use of expanded digital storytelling [34].

3. Digital storytelling and museums

The use of storytelling as a method to convey information is an inherently human strategy and is counted among the oldest of social practices for communication and learning [35, 36]. With the expansion of digital technology, the way in which stories are delivered and received has been transformed and conceptualized into digital storytelling through various digital communication tools [37]. Instead of one medium used to tell a story, such as a speech, text, or video, digital storytelling often combines video, text, audio narration, and more into a multimodal experience. With the latest generation of emerging technologies in XR supported by artificial intelligence (AI), multimedia digital communication tools and hypermedia-supported tools can expand the limits of storytelling for museum goers and support neurodiverse populations [37–41]. This approach does not require investment in infrastructure or a radical reworking of current educational content to be effective.

Most institutions already provide accessible resources through a variety of mechanisms including their websites, social media accounts, digital applications, or traditional printed handouts of maps or museums guides. These resources are being coupled with mobility-enhancing systems using interactive digital storytelling, personalization and adaptability, and mixed media [42]. The new, enhanced experiences have the potential to improve the attractiveness of not only cultural heritage sites and museums, but also act as a new conduit for interpretation, analysis, and cultural knowledge for diverse communities. Additionally, the innovative use of new digital technologies will provide new forms of cultural interactive experiences that are comfortable, sensory-friendly, and comprehensible to neurodiverse audiences.

While existing accessibility resources seek greater inclusivity in visitor experience, new considerations delivered via digital storytelling can serve to address obstacles for neurodiverse individuals. In general, inclusivity seeks to provide equal access to opportunities and resources for potentially marginalized populations. In order to be truly inclusive, these individuals must not only feel welcomed on location through accommodations, but also prior to the visit. An understanding of the travel logistics, parking, desired paths mapped by curatorial staff, sensory-friendly areas, and more can reduce anxiety of the unknown for those with ASD and assist with sensory processing hinderances before even entering the physical space of a museum itself. Providing such information through existing technology and digital assets facilitated with expanded digital experiences leads to a better experience and retention of educational material presented onsite during regular operating hours [43]. While "Sensory Days" seek to offer experiences tailored to those with ASD, they inadvertently segregate the population from the general public and imply that "normal" visiting hours are not for them [44]. Through expanded digital experiences, a sense of belonging can be created where regular visiting hours are welcoming. In addition, the ability afforded through virtual walkthroughs and digital recreations of the location provides an opportunity to revisit the site, review educational materials provided, and encourages post-visit interactions through sharing experiences on the institutions social media platforms. All of this instils conceptual anchors of memory and subsequent reinforcement of institutional messaging [25]. Other ways digital storytelling can support accessibility for neurodiverse visitors include:

1. *Providing multiple ways to access information*: Digital storytelling can provide different ways to access the same information, such as through text, audio, and video, to accommodate different learning styles and abilities.

2. *Enhancing engagement*: Interactive digital stories can engage visitors in a more immersive and personalized way, allowing them to explore and learn at their own pace.

3. *Creating a safe and inclusive environment*: Digital storytelling can create a safe and inclusive environment for visitors with neurodiverse needs, by providing accessible and inclusive design, and allowing visitors to control their own pace and level of engagement with the museum's content.

4. *Accessibility features*: Digital storytelling can be enhanced with accessibility features such as closed captioning, Audio Description, and sign language interpretation which can support visitors with different abilities.

Digital storytelling can thus allow visitors to personalize their experiences by providing a wide range of options, tailored to their specific needs, interests, and preferences, making the experience more engaging and inclusive. In a technology-driven age, museums are seeking a variety of these tools using XR to stay current with the ways their visitors are engaging with the world in their daily lives.

The ways in which museums are seeking to tell stories with technology include digital tour guides, AR and Bluetooth technologies, and smart museums. The integration of digital tour guides is becoming more commonplace, and companies are looking to support this adoption. Examples such as Mobile Tour App and Digital Guide System are digital solutions that allow museums to embed their own images, videos, and audio of their collections for visitors to experience [45]. The multimedia component allows for greater memory retention than traditional storytelling by addressing different learning styles [46]. This new form of content delivery combines participation commonly seen with computer or video games complete with automatic story generation and narration. For example, the British Museum uses AR in their mobile game A Gift for Athena (2014) for the Parthenon gallery using tablets that can be checked out. The game tasks visitors with finding specific statues based on an outline and rewards them with more information about the works prior to assigning another task to explore [47]. Furthermore, these digital tours need not be solely in person. Virtual experiences can also represent inclusive alternatives to traditional museum visits through the digital embodiment of historical characters and their stories that may also blend physical artifacts with the immersive experience [29]. In such a way, visitors can experience the rich tapestry of stories in museum collections prior to visiting (if at all) and have a greater understanding onsite.

Along the same lines as digital tour guides, smart museums are also eliminating physical barriers to their collections by allowing technological advancements to remove sensory barriers, as well. Smart museums, such as the Smart Museum of Art (Chicago) bring together traditional exhibitions with emerging technologies where the use of immersive technology seek to enhance how material on complex cultural heritage is delivered to visitors [48]. The use of technology to enhance visitor experience can include interactive exhibits, virtual reality experiences, and mobile apps that provide additional information and resources. Smart museums may also use technology to collect data on visitor behavior and preferences, and to improve the overall management and operation of the museum. Overall, the goal of a smart museum is to make the museum visit more engaging, interactive, and personalized for visitors. The transition to becoming "smart" refers to the heterogeneous technologies allowing museum environment to become more interactive, innovative, and accessible [49].

Therefore, the infrastructure and ability to move past the elimination of mere physical barriers for museum accessibility exists. The developments support the call for greater attention to neurodiverse accessibility as only addressing physical disabilities and accessibility will no longer suffice. The new multisensory approach afforded by digital storytelling and smart museums is essential to remove barriers to learning as part of the museum experience [50]. Once sensory obstacles have been removed and/or minimized, personalized learning experiences can be tailored to each individual and material and spaces delivered by way of storytelling. At the same time, engaging visitors through multisensory approaches and considerations can bolster learning for stories are not limited to oral communication and are critical for the creation of an atmosphere through the senses.

The elicitation of emotions such as empathy enriches stories, maintaining the attention of the audience while also creating memorable experience one can become invested in [51]. Storytelling supports other cognitive factors that improve learning, including improving attention and time on task by keeping the listener engaged, and empathy through emotional identification with the subject providing a cognitive framework to help understand and retain new information [52]. Drawing upon previous research, the following proposes leveraging the engaging nature of storytelling and delivered through the new immersive and interactive digital experiences to mitigate various ASD symptoms that would prohibit access to and appreciation of cultural heritage in museums. The educational resources of social stories and sensory maps that have been created to support neurodiverse visitors with various sensory processing disorders (SPD) should be digitized. The proposed "storymap" combination can then be transformed into a digital expression and experience through digital storytelling strategies. Taken together, this digital storymap can provide support prior to the visit, onsite, and engage diverse audiences with personalized, story-driven narratives of museum collections, while supporting multisensory experiences.

4. Sensory maps and museums

Visual stories, or sensory maps, may be used prior to visitation to prepare visitors for what to expect onsite. Such sensory maps provide "descriptions of a particular situation, event or activity, which include specific information about what to expect in that situation and why" ([53], p. 168). A sensory map is a guide that highlights sensory-friendly areas and features of a museum, such as quiet spaces, low lighting, and tactile exhibits. The resource can be a helpful tool for visitors with autism or sensory processing disorders (SPD). Research has noted that families with ASD children also have accompanying sensor processing and participation challenges 40–90% greater than other populations [54]. Additionally, studies also confirm that even adults who are overresponsive to stimuli in the environment describe their museum visits as disorganized, overwhelming, irritating, and distracting. The situation may result in the need to cope by spending extensive periods of time alone in order to regulate their emotional state, and result in feelings of isolation and exhaustion [55].

Regardless of demographic considerations such as age, visitors with SPD are often grouped into two separate categories by museum and occupational therapy researchers as either sensory avoiders or sensory seekers [25]. Sensory avoiders are individuals with SPD who have a heightened sensitivity to certain stimuli, such as loud noises or certain textures. This population may avoid or have an aversion to certain types of sensory input, as it can be overwhelming or uncomfortable for them. Sensory seekers, on the other hand, are individuals with SPD who have a lower sensitivity to certain stimuli and may seek out more intense or varied sensory experiences. Individuals who seek stimuli may have a greater need for movement and touch, which often results in easily becoming board in environments. Both groups face challenges that might manifest as either unwanted behavior that elicit sensory input, such as a compulsion to move, bump into other visitors, maintaining an understanding of their presence in space, or, alternatively, actions that seek to avoid stimuli by covering ears due to noises, and/or difficulties retaining attention with multiple sensory inputs. In both cases, the individuals may have difficulty interpreting and processing sensory information appropriately. Addressing the concern, sensory maps plot routes considering which galleries are most congested, loud noise areas, and potential tactile exhibitions in order to address the needs of both populations [21].

Understanding the different sensory processing subcategories and groups affected will assist museum administration in better serving these populations. For instance, the categories of sensory processing include: auditory (hearing), gustatory (or taste), tactile (touch), proprioception (body awareness), vestibular (balance), visual (sight), and olfactory (smell) referencing [56]. Furthermore, within SPD there are generally three subtypes of sensory processing—*hypersensitivity, hyposensitivity,* and *general sensory overload*.

1. *Hypersensitivity*, also known as over-responsivity, is a condition where an individual is overly sensitive to certain sensory inputs. They may have an aversion to certain types of stimuli, such as loud noises or certain textures, and may avoid or have a strong negative reaction to them.

2. *Hyposensitivity*, also known as under-responsivity, is a condition where an individual is less sensitive to certain sensory inputs. They may seek out more intense or varied sensory experiences and may have a greater need for movement and touch.

3. *General sensory overload* refers to an individual's overall difficulty processing and interpreting sensory information correctly. They may have difficulty with tasks

such as paying attention, staying organized, or completing activities of daily living. They may have symptoms of both hypersensitivity and hyposensitivity.

Stimuli, or lack thereof, is of critical importance for supporting accessibility for these three populations. The heightened input from those with hypersensitivity requires sensitivity to and avoidance of highly stimulating areas of a museum, whereas those with hyposensitivity seek out tactile, auditory and other stimuli, and, finally, general sensory overload may have symptoms of both [57, 58]. The threshold for the number and amount of stimuli the nervous system can process is different for diverse populations and requires the ability to modulate said stimuli before, during, and after museum visits [59]. Given that the processing of stimuli and information is environmental, there has also been a call to reframe the concept of disability as relating to the environment instead of something inherently within the person experiencing them [60].

In supporting such visitors, sensory maps can be made available in multiple formats, such as printed, digital, or an app, and can be provided to visitors upon arrival or made available online in advance. The removal of future unknowns of a new location, visitors can pre-plan excursions and reduce anxiety. The resource can reduce stress for both the neurodiverse individual and their entire family potentially visiting with them. Such maps can be downloaded onto mobile devices, such as smartphones or tablets, or printed before a planned visit. Examples include the Sensory Friendly Map of the Metropolitan Museum of Art (https://www.metmuseum.org/-/media/files/events/programs/progs-for-visitors-with-disabilities/sensory-friendly-map.pdf). Potential crowded areas are highlighted in sensory maps, as well as identifying more high-traffic times of day and instances where there may be dramatic shifts in lighting. International institutions, such as the British Museum, have gone even further and included information on areas that might be potentially offensive to those with olfactory sensitivities, uniforms commonly worn by staff, identifying entrances and exits, and special events that might balloon attendance (https://www.britishmuseum.org/sites/default/files/2019-11/British-Museum-Sensory-Map-PDF-Download.pdf).

5. Social stories and museums

Like sensory maps, and often mistaken for them, social stories provide a social narrative about programming in a museum or cultural heritage institution. The term "social stories," a term trademarked by Carol Gray in 1991, are short, simple descriptions of a specific situation or activity, such as visiting a museum. These stories can be helpful for visitors with autism or other developmental disorders by providing a clear and predictable explanation of what to expect during a museum visit [61]. The goal is to not change the behavior of visitors, but to improve the individuals understanding of the events and the expectations. Originally devised with no visual stimuli as the subject or object of the resource, the inclusion of visual imagery was later revised based on an increased understanding and available research for those using the tool in 2006 [62]. Examples include Social Stories: Spectrum Project (2017) at the San Diego Natural History Museum (https://www.sdnhm.org/visit/accessibility/social-stories/) and the Social Story at the Brandywine Museum of Art (https://www.brandywine.org/museum/accessibility/social-story). Unlike sensory maps that provide sensory information about the environment, the narrative approach of social stories includes all information about the environment, the adjustments that have been considered for the comfort of the visitor and a breakdown of each individual step that might limit access intellectually or socially for a visitor [63].

These social stories, otherwise known as social narratives, describe a situation that may be challenging for those with ASD where social behavior and cues are clearly identified. These narratives are used to inform those with socialization challenges of potentially difficult situations [64]. Museums and educational institutions like the Eugene Science Center Chicago Children's Museum, Boston Children's Museum and The Metropolitan Museum of Art in New York have social narratives embedded on their websites that can be downloaded and printed as PDFs (e.g. https://bostonchildrensmuseum.org/visit/accessibility/; https://www.twentyonesenses.org/places/united-states/il/chicago-1/chicago-childrens-museum/). These examples exhibit a storytelling strategy using therapeutic and educational mediations for the population in question. The brief narrative is presented using visual aids and text to reassure those of what to expect in a given social event, exchange, or activity. The resources are used as materials to learn how to promote the development of autonomy and learn social skills, including routines, understanding rules, and expectations.

Unfortunately, these social stories are generally found in the form of print media, which are outdated and do not fulfill their potential of full accessibility and inclusion that other digital and virtual interventions and experiences now afford [64, 65]. Accessible interventions need to align with daily use cases of individuals outside of the museum context. As such, new AR and VR options are being created to meet users where they are. For instance, Wearable Immersive Virtual Reality (WIVR) technology has been leveraged to produce an innovative social story aptly named the Wearable Immersive Social Story (WISS) [66]. By integrating immersive social stories using AR and VR one is able to take advantage of 360° videos with embedded elements that are interactive. Visual cues that include audio, images, and geometric shapes make the experience more engaging and entertaining in order to gain a greater understanding of the social expectations of visiting a specific institution. While digital media expands in museums to embed more multimedia experiences with images, video, and audio, VR can now be used more widely to assist those with ASD. However, these examples of immersive and wearable social stories remain confined to therapeutic and educational interventions for those with autism and include common use cases such as teaching students how to safely cross a road [67].

6. Sensory maps, social stories and adaptive extended reality

The future of accessibility will combine the resources and technology listed above. Sensory maps represent an educational tool to prepare those with ASD to engage with new situations and/or in new environments. The multisensory approach used to create sensory maps ensures that whether over- or under-stimulated, visitors will be prepared for the visit and to benefit from the educational materials provided. The currently exist in the form of handouts provided by an institution that takes into consideration how people perceive interacting with a space. Social stories, on the other hand, use a narrative approach to both deliver content and to address situational awareness for those with ASD. Taken together, the proposed combined "storymap" can now be transformed into a digital expression and experience. Digital storytelling strategies can be used and experienced with various XR wearable devices. This immersive storymap can provide support prior to the visit, onsite, and engage diverse audiences with personalized, story-driven narratives of museum collections, while supporting adaptive, multisensory experiences.

Using the benefits of both sensory maps and social stories with VR, especially, enables those with sensory processing disorders, and other cognitive difficulties, to feel more comfortable in the museum space. Social stories can capitalize on existing avatar creators that are cross-platform and interoperable, such as Ready Player Me (https://readyplayer.me/) for a more immersive, enjoyable, and personalized experience. The use of avatars selected and created by a neurodiverse individual improve inclusivity through their use in virtual environments to better understand social contacts that may/ will occur onsite, familiarizing them with the facilities prior to visiting, and the rewarding recognition of accomplishment by completing a visit. As noted, the benefits of using head-mounted displays (HMD) and VR include improved focus and attention span as these remove the distractions of the outside world, which can be overwhelming for those with stimuli sensitivity [68].

There are several use cases already available that demonstrate the efficacy of integrating emerging immersive technologies into cultural heritage institutions. One such example is A Dip in the Blue (2022), an application (app) developed for museum visitors with ASD to provide a clear visual agenda along with additional accessibility resources [69]. The app uses a social story that is inspired by the experience of an archeologist discovering a tomb in Naples. After the experience, a survey gathers data on the emotional reaction and sensory feedback experienced as part of the tour. Additional, services and functional features within the app include a dashboard management panel, a live virtual tour scheduling system, a media library dedicated to storing documents, textual and multimedia contact like audio and video tours. There is additional socializing functionality built in with the ability to broadcast live streams of virtual tours.

Another example that uses interactive technologies, including mixed-reality, provides an interactive cultural visit of the church of Roncesvalles at the beginning of the popular tourist destination of Camino de Santiago [70]. The inclusion of avatars provides the ability for natural social interactions to further enhance the visit. The church is experienced onsite through the use of a three-dimensional projection mapping, while an agent generating conversation acts as a storyteller for visitors. The avatar of the storyteller uses the techniques of storytelling while exhibiting emotional reactions during their narration of local stories of the objects in the room. Therefore, the storytelling experience is supported by the engagement with actual objects in the environment and the emotional conversation avatar thus bridging the real and virtual. But what makes this experience unique is the considerations of mapping the senses.

Moving beyond merely the visual, future cultural experiences will include multisensory interactions. The importance of all of the senses for a truly immersive experience has been well-documented [71, 72]. As such, a 2016 report of the Workshop in Cologne sought to understand how to map the senses and listed three steps [73]. The first step includes a researcher mapping a specific urban space to be recreated. The second includes the subjective experiences of visitors by capturing the emotions and feelings of the citizens connected to the location. And, finally, the third is the connection of the researcher to the local community. These steps shed light on the soundscape and smellscape that compliment a visual imagery of a place. Smells often provide a memory which helps identify a place and the effects of climate should be considered. For instance, cold weather reduces the expansion of smells whereas warm weather expands them [74]. Creating an adaptive experience that can not only change based upon the environment represented, but also react to the physical and emotional states of visitors will become ever more important in crafting compelling virtual experiences.

Adaptive content and interactive storytelling will revolutionize museum experiences. In order to make such experiences possible, the collection of biometrics of visitors will be required. Furthermore, adaptive content that adjusts to the needs of diverse audiences through new paradigms of interaction will provide accessible digital content to a wide range of visitors [75]. Researchers will need to use the following strategies to collect data to personalize avatars to craft custom-made experiences associated with museum visits.

1. *Biometric data collection*: This can include collecting data such as facial features, body measurements, and voice samples from visitors. This data can be used to create a 3D avatar of the visitor, which can be used in virtual reality and augmented reality experiences.

2. *Surveys and questionnaires*: Museums can gather information about visitors' preferences, interests, and background through surveys and questionnaires. This information can be used to tailor the content and activities of the museum visit to the individual visitor.

3. *Tracking and monitoring*: Museums can use technology such as RFID tags and cameras to track visitors' movements and interactions within the museum. This data can be used to understand the visitor's behavior, interests, and preferences and personalize the experience accordingly.

4. *Social media integration*: Museums can collect data from visitors' social media profiles and use it to personalize the museum experience. For example, if a visitor has a history of visiting similar museums or expressing interest in a certain topic, the museum could suggest exhibits or activities that align with those interests.

5. *Personalized recommendations*: Museums can use the data collected from the above methods to provide personalized recommendations for exhibits, activities, and other experiences within the museum. This can include suggesting exhibits that align with the visitor's interests, providing personalized tours, or offering augmented reality experiences that bring the exhibits to life in a more interactive way.

6. *Feedback*: Museums can also gather feedback from visitors about their personalized experiences and use that feedback to improve and refine the personalized experience in the future.

Examples of this in practice can already be seen in research projects like CHESS (Cultural Heritage Experiences through Socio-personal interactions and Storytelling). CHESS (https://chess.diginext.fr/) applies constant adaptable and personalized content to enhance the experience of the Acropolis Museum, Athens [76]. The onsite engagement with objects in the museum personalizes interactive stories for each visitor. The project was created to further enhance a visit by personalizing an engaging and interactive storytelling experience by adapting information about cultural artifacts for each individual visitor. Thus, the latest generation of state-of-the-art museum programming seeks to create cultural adventures that are driven by stories and narratives. Such experiences involve users in many roles of a scenario through multimodal interfaces and extends over time and space. This user-centered approach personalizes the educational experience with real-time adaptive capabilities using localization systems. The collapsing of space and time made possible through virtual connectivity means that one will also be able to engage in such experiences at home through various devices.

7. Conclusion

Museums will continue to adopt the latest emerging technology to engage with the all of their constituencies. As the goal of museums is to ensure accessibility for all, the needs of neurodiverse populations will continue to drive innovation and technological adoption. Digital storytelling strategies can now be used and experienced with various immersive and wearable devices. New immersive storymaps can provide support prior to the visit, onsite, and engage diverse audiences with personalized, story-driven narratives of museum collections, while supporting adaptive, multisensory experiences. The integration of narrative and storytelling in virtual environments encompasses both the needs to understand a given space physically and intellectually. Furthermore, these new digital tools are effective in visualizing and presenting historical and cultural heritage, and support staffing restrictions. The presentation through digital storytelling continues to evolve in use and methodology and is inherently multimedia. Through the medium storytelling, digitized objects and virtual reconstructions of environments allow visitors to engage with the culture and history of a location or subject like never before. The pedagogical device generates a narrative through the experience of interactive events and affords visitors the ability to direct their own story and visit, creating meaning and context [77]. Systems will continue to evolve that create emotional connections with visitors, allowing for the preferences to be known and storytelling activities to adapt and evolve [70]. For example, detecting children in a room, a system could modify the age level of content and appearance of the avatar presenting said content; mini games may encourage interaction with objects in a given exhibition or gallery, while an avatar employs storytelling to invest the visitor in their history or significance. Finally, as the multiverse of metaverses evolves, portals will be created that link museum collections of like content that can be easily traversed for an even more expanded and immersive experience with art and culture.

Conflict of interest

The authors declare no conflict of interest.

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