

# **CRAFTING TOMORROW'S MUSEUM EXPERIENCE**

**INTEGRATING EXTENDED REALITY (XR) FOR ACCESSIBILITY,  
ENGAGEMENT, AND EDUCATION.**

Word count: 24,000

**Hanne Mannens**

Student number: 01814228

Supervisor(s): Prof. Dr. Pieter-Jan Maes

A dissertation submitted to Ghent University in partial fulfilment of the requirements for the degree of  
Master of Kunstwetenschappen

Academic year: 2024 – 2025





## Abstract

Extended Reality (XR) technologies, encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), are increasingly reshaping sectors worldwide, including the museum field. This thesis examines the integration of XR in museum settings, focusing on its potential to enhance visitor engagement, accessibility, and educational outcomes while ensuring meaningful, user-centered experiences. As museums evolve from static repositories to dynamic, interactive environments, XR technologies offer a powerful means to transcend physical, geographical, and socioeconomic barriers, fostering deeper connections with diverse audiences.

Through a combination of literature review, field studies, and a case study of the *Actual Day* installation at MSK Ghent, this research investigates how XR can enrich museum experiences. The findings highlight the potential of XR to foster multisensory engagement, deepen emotional connections, and improve inclusivity by addressing physical, geographical, and socioeconomic constraints. However, the study also identifies key challenges, including funding limitations, ethical considerations, and technological obsolescence, which must be navigated to ensure sustainable implementation.

A central focus of this thesis is the importance of user-centered design and co-creation, advocating for active visitor involvement in the development and assessment of XR applications. The study offers actionable strategies and a framework for aligning XR technologies with institutional missions, ensuring their transformative potential is realized in ways that are meaningful and inclusive.

This research contributes to the growing discourse on digital transformation in the cultural sector, offering evidence-based insights and practical frameworks for integrating XR technologies effectively. By blending technological innovation with human-centered practices, museums can redefine the visitor experience, ensuring cultural accessibility and engagement for future generations.

**Keywords — Extended Reality (XR); Museum Innovation; Visitor Engagement; Cultural Accessibility; Edutainment**

## Acknowledgements

This thesis represents a journey through the intersection of Art History at UGent and Visual Design at LUCA School of Arts, exploring how museums navigate their presence in both physical and digital realms. My fascination with how museums establish their identities in virtual spaces has been a central theme in my academic pursuits, reflecting my multidisciplinary journey.

Reflecting on my Visual Design thesis, *This Book Has No Title*, which introduced conceptual art to children aged 7 to 12, I am reminded of my passion for making art accessible and engaging. By incorporating playful mascots and interactive assignments, as well as a TikTok counterpart, the project invited children to reflect on the stories art tells about our world. This passion for accessibility and engagement has guided my exploration of how new media can redefine the museum experience.

This thesis is not just an academic exercise but also a record of a journey—a mapping of intersecting disciplines and an attempt to resolve their interconnections. It touches upon numerous fields, each with immense depth, inviting further exploration beyond the boundaries of this work.

I extend my deepest gratitude to my supervisor, Pieter-Jan Maes, and my former supervisor, Maude Bass-Krueger, for their invaluable guidance and encouragement. My heartfelt thanks go to my teachers at LUCA—Ingwio D'Hespeel, Kilian Longueville, and Thomas De Brabanter—who provided me with the opportunity to create an immersive installation central to this thesis, exhibited at the MSK. Their insights and support were pivotal to its execution. I also thank Jill Andréka and Ellen de Ridder for their collaboration on this project and the MSK for hosting our work. Special thanks to Madeleine Descamps for enabling me to conduct surveys during the exhibition period.

To my father, Erik Mannens, thank you for your meticulous review and thoughtful suggestions, which have greatly enhanced the quality of this thesis. Your dedication to my academic growth has been a cornerstone in this journey.

To my mother, Sarah Vandeputte, my stepparents, Kristof Dierckxsens and Sofie Penel, and my partner, Anton De Smet, your unwavering support and encouragement have been my greatest strength. Your belief in me has propelled me forward, even in the most challenging moments.

To my brothers, Arne and Robbe Mannens, who have hugged me in times of stress and supported me in their own unique ways, your quiet strength and love mean more to me than words can express.

Lastly, I express my gratitude to those close to me for their listening ears, critical feedback, and endless support throughout this process.

As I delve into how museums embrace the digital dimension of art and culture, fostering co-creation and prioritizing visitor research, I am humbled by the collective contributions that have shaped this endeavor. This thesis is a testament to the synergy of academic exploration, mentorship, and the unwavering encouragement of loved ones.

**Hanne Mannens**

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## List of Abbreviations

|      |                                          |
|------|------------------------------------------|
| AI   | Artificial Intelligence                  |
| AR   | Augmented Reality                        |
| CIS  | Collection Information System            |
| DWAN | Digital Women's Archive North            |
| GDPR | General Data Protection Regulation       |
| GUI  | Graphical User Interface                 |
| HMD  | Head-Mounted Display                     |
| HTTP | Hypertext Transfer Protocol              |
| ICOM | International Council of Museums         |
| LOD  | Level-of-detail                          |
| MR   | Mixed Reality                            |
| NEMO | Network of European Museum Organisations |
| POI  | Point of Interest                        |
| sRQ  | Sub-Research Question                    |
| UCH  | Underwater Cultural Heritage             |
| URI  | Uniform Resource Identifier              |
| UUID | Universally Unique Identifier            |
| VA   | Virtual Artifact                         |
| VFX  | Visual Effects                           |
| VR   | Virtual Reality                          |
| WHO  | World Health Organization                |
| XR   | Extended Reality                         |
| 3D   | Three-Dimensional                        |

# 1 Introduction

Technological advancements have consistently reshaped the way humans interact with and interpret the world.<sup>1</sup> Innovations, such as photography in the 19<sup>th</sup> century, revolutionized visual documentation, setting the stage for modern digital photography and the integration of imagery into social media. Similarly, contemporary technological innovations continue to redefine numerous sectors, including the cultural domain, offering museums both opportunities and challenges.

Museums, as custodians of cultural heritage, are at a pivotal moment. The evolving relationship between museums and their audiences has become one of their greatest challenges.<sup>2</sup> Historically, museums functioned primarily as repositories for the preservation and display of artifacts, prioritizing safeguarding over active engagement.<sup>3</sup> While these traditional approaches have been effective for archiving, they often fail to convey the dynamic, lived experiences and broader social contexts that define cultural practices. Today's audiences, diverse and technologically adept, expect more from their cultural experiences. They seek interactive, personalized, and participatory opportunities that transcend passive observation.<sup>4</sup> This shift compels museums to reevaluate their strategies, placing visitor engagement and inclusivity at the core of their mission. Increasingly, museums are tasked with creating environments that not only protect cultural heritage but also foster lifelong learning and meaningful connections, ensuring their relevance in a rapidly changing world.

The digital age has compelled museums to embrace technological integration, fundamentally reshaping their engagement strategies. Tools like artificial intelligence (AI), digital storytelling platforms, and mobile applications have transformed how museums interact with audiences, enhancing accessibility, inclusivity, and participation. Although the International Council of Museums' (ICOM) 2022 redefinition of museums emphasizes accessibility, diversity, and participation, it notably omits direct references to technology.<sup>5</sup> However, technology plays a pivotal role in achieving these objectives, offering innovative ways to connect with audiences and expand cultural outreach.

Governments and organizations worldwide have reinforced this trend, advocating for digital transformation within the cultural sector. Belgium's *Strategische Visienota Cultureel Erfgoed* (2021), for instance, champions digital solutions to address spatial and preservation challenges, enabling broader access to heritage collections.<sup>6</sup> Similarly, initiatives like the 2024 NEMO Museums and AI Conference underscore the critical importance of digital tools in modernizing museum practices and meeting the evolving needs of contemporary audiences.<sup>7</sup>

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<sup>1</sup> Samuel Greengard, *Virtual Reality* (The MIT Press eBooks, 2019), chap. 6, Kobo, <https://doi.org/10.7551/mitpress/11836.001.0001>.

<sup>2</sup> Eilean Hooper-Greenhill, *Museums and the Interpretation of Visual Culture* (Routledge, 2000), chap. 1, Google Books, <https://doi.org/10.4324/9781003124450>.

<sup>3</sup> Olga Van Oost, *Volop inzetten op musea, eerste visienota Overleg Vlaamse Musea, Brussel, FARO.*, 2016, 7, [https://cris.vub.be/ws/portalfiles/portal/36265116/visietekst\\_musea.pdf](https://cris.vub.be/ws/portalfiles/portal/36265116/visietekst_musea.pdf).

<sup>4</sup> Jan Jambon, *Strategische Visienota Cultureel Erfgoed*, Vlaamse Regering, March 31, 2021, 36, [https://www.vlaanderen.be/cjm/sites/default/files/2021-04/strategische\\_visienota\\_cultureel\\_erfgoed.pdf](https://www.vlaanderen.be/cjm/sites/default/files/2021-04/strategische_visienota_cultureel_erfgoed.pdf).

<sup>5</sup> "A museum is a not-for-profit, permanent institution in the service of society that researches, collects, conserves, interprets and exhibits tangible and intangible heritage. Open to the public, accessible and inclusive, museums foster diversity and sustainability. They operate and communicate ethically, professionally and with the participation of communities, offering varied experiences for education, enjoyment, reflection and knowledge sharing;" "Museum Definition," Standards and guidelines, International Council of Museums (ICOM), last modified June 5, 2023, <https://icom.museum/en/resources/standards-guidelines/museum-definition/>.

<sup>6</sup> Jambon, *Strategische Visienota Cultureel Erfgoed*, 9.

<sup>7</sup> "Museums and AI Conference," Our advocacy themes, Network of European Museum Organisations (NEMO), accessed October 30, 2024, <https://www.ne-mo.org/advocacy/our-advocacy-themes/museums-and-ai-conference>.

Despite these advancements, museums face significant challenges in adopting new technologies effectively. Questions persist about how to balance technological integration with the preservation of “authenticity,” a core characteristic that distinguishes museum collections in an age of digital replication.<sup>8</sup> Yet, while museums are integrating emerging technologies at an unprecedented pace, the core question remains: how can these tools be designed and implemented to genuinely enhance the visitor experience?

Among the most promising tools for addressing these challenges is extended reality (XR), which encompasses virtual reality (VR), augmented reality (AR), and mixed reality (MR). XR creates immersive, multisensory environments that allow visitors to engage with museum collections in innovative ways, transcending the limitations of traditional exhibits.<sup>9</sup> During the COVID-19 pandemic, for instance, XR enabled museums to connect with audiences remotely, demonstrating its value in overcoming physical and geographic barriers.<sup>10</sup> Beyond access, XR holds the potential to transform storytelling in museums, offering features like interactive annotations, multilingual content, and expert narrations that deepen engagement and make cultural heritage more accessible to diverse audiences.<sup>11</sup>

However, XR’s adoption is not without challenges. Poorly implemented XR tools risk prioritizing spectacle over substance, potentially distracting visitors rather than enriching their experiences. Furthermore, while XR installations are proliferating globally, there is a noticeable gap in empirical research evaluating their effectiveness. Most existing studies focus on implementation, leaving questions about visitor engagement, learning outcomes, and inclusivity underexplored. For museums to fully realize the potential of XR, it is crucial to develop robust evaluation frameworks that assess how these tools meet audience needs and contribute to meaningful, sustainable experiences.

## 1.1 Literature Review

The integration of XR technologies in museums reflects a broader conversation on the role of digital media in cultural engagement. Despite the potential of XR, its exploration within the field of art history remains limited. This hesitancy can be attributed to the highly technical nature of XR tools and the traditional methodologies of art historical research, which often maintain a significant gap between contemporary technologies and their study. Meanwhile, XR tools evolve rapidly, often outpacing their critical assessment due to issues like technological obsolescence, where both software and hardware risk becoming outdated, as seen with early 2000s digital media.<sup>12</sup> While fields such as communication and computer science boast a more robust body of research on XR, the cultural sector continues to adapt to its possibilities.

One foundational resource is Samuel Greengard’s *Virtual Reality*, which provides a broad overview of XR technologies, detailing their development and cross-sector applications.<sup>13</sup> While not explicitly focused on cultural institutions, Greengard’s discussion of the ethical and technical challenges

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<sup>8</sup> Claartje Bunnik, *Musea voor mensen*, Museumvereniging, 2014, 17-18.

<sup>9</sup> Patricia Buffa and Megan Bates, “Using Augmented Reality to Democratize Access to Museum Collections,” Digital Summit 2024, *MuseumNext*, Virtual Conference, March 25, 2024, <https://museumnext.mn.co/posts/digital-summit-2024-using-augmented-reality-to-democratize-access-to-museum-collections>.

<sup>10</sup> Fredrik Edström, “Memories of Mexico – A Gamified History Lesson,” Museum XR Summit 2024, *MuseumNext*, Virtual Conference, June 26, 2024, <https://museumnext.mn.co/posts/museum-xr-summit-memories-of-mexico-a-gamified-history-lesson>.

<sup>11</sup> Nicola Teffer and Scott Cotterell, “Reality Check: Producing a Scalable and Cost Effective XR Museum Experience,” Museum XR Summit 2024, *MuseumNext*, Virtual Conference, June 26, 2024, <https://museumnext.mn.co/posts/museum-xr-summit-reality-check-producing-a-scalable-and-cost-effective-xr-museum-experience>.

<sup>12</sup> Peter Wegner, “Interoperability,” *ACM Computing Surveys (CSUR)* 28, no. 1 (1996): 285-287, <https://doi.org/10.1145/234313.234424>.

<sup>13</sup> Greengard, *Virtual Reality*.

surrounding XR was instrumental to this thesis, particularly in addressing how museums must navigate similar considerations in their implementations of immersive technologies.

Policy documents such as Belgium's *Strategische Visienota Cultureel Erfgoed* (2021) and Olga Van Oost's *Volop inzetten op musea* (2016) underscore the importance of digital transformation in cultural institutions.<sup>14</sup> These reports emphasize accessibility and preservation but provide limited insights into XR's role in enhancing visitor engagement, a gap this thesis seeks to address. Complementary data from FARO's *Cultureel Erfgoed 2020* (2013) illustrated the needs and potential of digital adoption in the heritage field, highlighting areas for improvement and innovation.<sup>15</sup>

Eilean Hooper-Greenhill's *Museums and the Interpretation of Visual Culture*, despite being published in 2000, remains a seminal work in understanding visitor engagement.<sup>16</sup> Her analysis of the shift from "modernist" authoritative museums to "post-museums" that prioritize visitor interaction provides a framework for exploring XR's potential. Her work highlights the critical yet underexplored area of visitor engagement and interpretation, stressing that museums often overlook how audiences interact with and derive meaning from exhibits. Hooper-Greenhill's assertion that visitors co-create meaning aligns with XR's capacity for personalized, interactive museum experiences.

Cynthia Goodman's chapter "The Future of Museums: The Post-Pandemic Transformation of Experiences and Expectations" underscores how the COVID-19 pandemic accelerated the adoption of digital technologies in museums.<sup>17</sup> Her exploration of innovations such as AI and VR illustrates the potential of these tools to reimagine traditional heritage practices, fostering more dynamic and inclusive cultural experiences. Additional insights from Pieter-Jan Maes' *Technologie en Levend Erfgoed* (UGent) and Pier Luigi Sacco's *The Culture 3.0 Paradigm* (IULM University Milan) further contextualize the digital evolution of cultural practices.<sup>18</sup> These presentations emphasize the shift towards participatory, technology-driven approaches in heritage preservation and engagement, providing critical frameworks for rethinking traditional museum methodologies in the digital era.

Recent journal articles and case studies offer practical insights into XR's application in cultural heritage. Research by Mario Montagud, Pilar Orero, and Anna Matamala explores XR's benefits, while Giuseppe Caggianese et al. analyze how graphical user interfaces influence the sense of presence in virtual exhibitions.<sup>19</sup> Similarly, Sylaiou Styliani's 2009 survey on virtual museums contextualizes the evolution of digital tools in cultural institutions, emphasizing the shift from static presentations to interactive platforms.<sup>20</sup>

Chapters from the book *The Multisensory Museum: Cross-Disciplinary Perspectives on Touch, Sound, Smell, Memory, and Space* complements this analysis by examining the neuroscientific benefits

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<sup>14</sup> Jambon, *Strategische Visienota Cultureel Erfgoed*; Van Oost, *Volop inzetten op musea*.

<sup>15</sup> Jeroen Walterus et al., *Cultureel Erfgoed 2020: Hefbomen voor het Vlaamse cultureel-erfgoedbeleid*, FARO., 2013, [https://faro.be/sites/default/files/bijlagen/e-documenten/hefbomen\\_def.pdf](https://faro.be/sites/default/files/bijlagen/e-documenten/hefbomen_def.pdf).

<sup>16</sup> Hooper-Greenhill, *Museums and the Interpretation of Visual Culture*.

<sup>17</sup> Cynthia Goodman, "The Future of Museums: The Post-Pandemic Transformation of Experiences and Expectations," in *Transitioning Media in a Post COVID World*, ed. Gali Einav (Springer, 2022).

<sup>18</sup> Pieter-Jan Maes, *Technologie en Levend Erfgoed*, PowerPoint presentation, Onderzoeksseminarie I, UGent, September 25, 2024; Pier Luigi Sacco, *The Culture 3.0 paradigm*, PowerPoint presentation, IULM University Milan, October 18, 2016, <https://www.slideshare.net/slideshow/culture-paradigm-university-digital-humanities/68403150>.

<sup>19</sup> Mario Montagud et al., "Culture 4 all: accessibility-enabled cultural experiences through immersive VR360 content," *Personal and Ubiquitous Computing* 24, no. 6 (2020), <https://doi.org/10.1007/s00779-019-01357-3>; Giuseppe Caggianese et al., "Exploring the Feasibility of Diegetic User Interfaces in Immersive Virtual Exhibition with the Cultural Heritage," *2018 14<sup>th</sup> International Conference on Signal-Image Technology & Internet-Based Systems (SITIS)*, IEEE (2018), <https://doi.org/10.1109/SITIS.2018.00101>.

<sup>20</sup> Sylaiou Styliani et al., "Virtual museums, a survey and some issues for consideration," *Journal of Cultural Heritage* 10, no. 4 (2009), <https://doi.org/10.1016/j.culher.2009.03.003>.



of multisensory engagement, highlighting the role of haptic technologies in enriching museum experiences.<sup>21</sup>

Digital platforms such as MuseumNext provide contemporary perspectives through case studies, articles, and events.<sup>22</sup> The 2024 *Museum XR Summit*, held in June 2024, for example, shed light on the transformative potential of immersive technologies in museums.<sup>23</sup> Case studies presented at the summit demonstrated how XR could transcend geographical barriers and enliven collections through interactivity. However, the event also highlighted instances where XR was underutilized, such as VR projects that merely replicated traditional video content, failing to capitalize on XR's immersive potential. In some cases, an interactive screen or more traditional digital tool might achieve the same outcome more effectively without the physical discomfort associated with prolonged VR headset use. Such examples underscore the importance of aligning XR applications with strategic goals to maximize their impact while avoiding pitfalls like audience fatigue or superficiality.

While the literature underscores XR's potential, significant gaps remain in understanding its long-term impact on visitor engagement, education, and inclusivity. Although numerous pilot projects and XR installations have been introduced, few studies rigorously assess their outcomes or provide actionable insights for museums navigating digital transformation. This thesis addresses the need for a user-centered approach to integrating XR technologies in museum settings, guided by the central research question: **How can XR technologies be effectively implemented in museum settings to enhance visitor engagement, accessibility, and educational outcomes, while ensuring meaningful, user-centered experiences?** Through a small-scale study, this research prioritizes the needs and perspectives of museum visitors, providing a framework to incorporate user feedback into the design and application of XR tools. By aligning these technologies with the cultural, educational, and accessibility goals of museums, this study seeks to demonstrate how XR can complement traditional practices to create enriching visitor experiences.

In addition to proposing an evaluation framework, this thesis maps the current XR landscape in museums, analyzing existing installations to identify key trends, challenges, and opportunities. This dual approach—combining practical evaluation with broader contextual analysis—yields actionable strategies for aligning XR technologies with institutional missions and audience expectations. The study highlights the critical role of user-centered design in leveraging XR to foster inclusive, engaging, and impactful museum experiences, contributing to the broader discourse on digital transformation within the cultural sector.

Furthermore, by mapping XR applications in museums, the research provides insights into best practices for future implementations, addressing practical considerations such as funding, technical constraints, and ethical concerns. This comprehensive analysis ensures that museums can navigate these challenges effectively to deliver meaningful, sustainable digital experiences for contemporary audiences. While the study offers conceptual insights into audience engagement, it lays the groundwork for empirical research, advocating for visitor-focused strategies as the foundation of innovative and transformative museum practices. Ultimately, the thesis enriches the ongoing discussion on the role of digital tools in cultural heritage preservation and engagement, emphasizing thoughtful, user-centric design as a cornerstone of successful digital transformation in museums.

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<sup>21</sup> *The Multisensory Museum: Cross-Disciplinary Perspectives on Touch, Sound, Smell, Memory, and Space*, ed. Nina Levent and Alvaro Pascual-Leone (Rowman & Littlefield, 2014).

<sup>22</sup> MuseumNext is an organization dedicated to exploring innovative trends in the museum sector. It hosts conferences and events, fostering discussions among museum professionals on adapting to changing landscapes. The organization's mission is to inspire museums to evolve and succeed in a dynamic world by embracing new ideas and technologies; "MuseumNext – Inspiring Online Learning for Museum Professionals," MuseumNext, accessed December 2, 2024, <https://www.museumnext.com/>.

<sup>23</sup> "Museum XR Summit 2024 – Virtual Conference," Events, MuseumNext, accessed December 2, 2024, <https://www.museumnext.com/events/museum-xr-summit/>.

## 1.2 Methodology

This research adopts a mixed-methods approach to explore the potential of integrating XR technologies into museums, combining qualitative and quantitative methods to ensure a comprehensive analysis. The study utilizes visitor surveys, interviews, literature reviews, and direct observations to construct a robust framework for understanding how XR can improve accessibility, engagement, and educational outcomes in museum contexts. This user-centered methodology blends practical fieldwork with theoretical insights to address the core research questions effectively.

A central focus of the study is the immersive installation *Actual Day*, displayed at the Museum of Fine Arts (MSK) in Ghent, Belgium, from December 7, 2023, to January 8, 2024. Visitor surveys conducted during the exhibition provided essential data on the installation's impact, focusing on its ability to enhance the visitor experience. Feedback was collected on accessibility, ease of use, and its contribution to overall engagement and learning outcomes. This process emphasizes the importance of integrating user perspectives into the development and evaluation of XR technologies, advocating for co-creation and active involvement from the beginning stages.

The research adopted a three-fold information-gathering strategy, covering demographic, experiential, and observational dimensions. The questionnaire design included queries on age, gender, geographic background, museum attendance frequency, and interest in art. Complementing these demographic inquiries, structured interviews explored visitors' experiences with the installation. The interviews, which blended open-ended and yes/no questions, aimed to determine the audience's perception of the installation's value, ease of understanding, and impact on the museum experience. To ensure ethical compliance, the questionnaire was reviewed in alignment with Ghent University's Ethics Approval guidelines.<sup>24</sup>

Visitor interviews were conducted adjacent to the artwork over a one-week period from January 3 to January 8, 2024, targeting a diverse audience that included both tourists and locals with varying levels of interest in the artwork. While the methodology effectively captured a range of perspectives, certain challenges arose, including occasional technical issues with the installation itself necessitating interview interruptions. Each session lasted approximately ten to fifteen minutes, but participant feedback highlighted issues with the questionnaire's length and complexity, which may have contributed to some participants not completing it. Observational data gathered alongside the surveys provided additional insights, particularly regarding visitor interaction with the installation. Positive reactions were observed when visitors engaged with informative labels and when parents interacted with their children in response to the artwork. Despite efforts to maximize the number of interviews conducted, the volume of responses was affected by factors such as the post-holiday period and participant reluctance to interrupt their museum experience for an interview. Personal hesitations in approaching visitors also contributed to fewer interviews being conducted than anticipated. To improve future research, adjustments could include streamlining the questionnaire format to reduce length and complexity, adopting strategies to better approach and engage participants, and incorporating digital data collection methods to facilitate the process and increase participant convenience. These refinements aim to enhance data quality and participant response rates in subsequent studies.

Survey responses were systematically transcribed, coded, and subjected to thematic analysis to identify recurring patterns and themes. Quantitative data, including visitor demographics and engagement metrics, were processed and visualized using statistical tools in RStudio.<sup>25</sup> For qualitative

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<sup>24</sup> "Ethics Approval – Points of Interests and Tips," Ghent University, accessed December 22, 2023, <https://www.ugent.be/lw/en/about-us/organisation/councilsandcommittees/ethicscommittee/ethicsapprovaltips.htm>.

<sup>25</sup> RStudio is an integrated development environment (IDE) for R and Python. It includes a console, syntax-highlighting editor that supports direct code execution, and tools for plotting, history, debugging, and workspace management. RStudio is available in open source and commercial editions; "RStudio IDE," Open Source, Posit, accessed December 3, 2024, <https://posit.co/products/open-source/rstudio/>.

insights, open-ended responses were categorized based on identified themes, with multiple answers carefully evaluated to select those most relevant to the thesis objectives. The analysis was guided by Abigail Housen's *Three Methods for Understanding Museum Audiences* (1987), which provided a structured framework for examining the experiential, demographic, and observational aspects of the data.<sup>26</sup> Cross-tabulation analyses were used to explore correlations between demographic variables (e.g., age, gender, tourist/local status) and visitor responses, revealing trends, insights, and outliers. The findings were organized for clarity and visualized through histograms and other graphical representations in RStudio, facilitating a comprehensive and accessible presentation of the results.

The practical investigation benefited significantly from insights gained at MuseumNext conferences, which provided professional perspectives on XR applications in museums. Relevant case studies were carefully selected for analysis, focusing on themes such as digital learning tools, XR's role in accessibility, audience engagement, and its capacity to connect with contemporary visitors. Discussions and presentations were transcribed, critically assessed, and filtered for depth, analytical relevance, and alignment with the research question. Only discussions offering meaningful insights or unique perspectives were integrated into the analysis.

To contextualize these findings further, insights from the case studies were complemented with information from online articles, user reviews, and additional academic research. This comprehensive approach provided a broader understanding of XR's current applications and its potential to reshape museum experiences. The summarized insights, highlighting the best practices and emerging trends, were incorporated into the thesis, offering a nuanced perspective on XR's transformative role in the museum sector.

To evaluate XR applications in a broader context, field visits to other exhibitions employing XR technologies were conducted, including the *Lam Gods AR Tour* at Sint Bavo's Cathedral Ghent.<sup>27</sup> These visits were structured to systematically assess aspects such as visitor interaction, engagement levels, and the overall effectiveness of the XR implementation. During these visits, I assessed various dimensions of the visitor experience, such as interaction, engagement, queue management, visitor flow, and staff support. This approach facilitated meaningful comparisons between different uses of XR across cultural institutions.

In addition to these field studies, a comprehensive literature review was undertaken to situate the findings within the broader academic discourse. Scholarly works were identified through platforms such as Google Scholar, Litmaps, and the UGent online library.<sup>28</sup> Searches were conducted using carefully selected keywords relevant to the thesis, and results were filtered by date, popularity, and relevance to ensure the inclusion of high-quality sources. Further references were identified by reviewing citations in related theses obtained through promotor recommendations or the UGent library. This iterative process of source discovery provided a nuanced and thorough understanding of current state of knowledge.

This thesis begins by establishing a theoretical framework to explore the need for rethinking traditional museum practices in the context of rapidly advancing technologies. It examines the historical evolution of museum methods, critiques traditional approaches, and highlights how digital tools allow

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<sup>26</sup> Abigail Housen, "Three Methods for Understanding Museum Audiences," *Museum Studies Journal*, Spring-Summer (1987), <https://vtshome.org/wp-content/uploads/2016/08/6-3MethodsforMuseumAudiences.pdf>.

<sup>27</sup> "Lam Gods AR Tour," Sint-Baafs Kathedraal Gent, accessed December 3, 2024, <https://www.sintbaafskathedraal.be/nl/lam-gods-ar-tour/>.

<sup>28</sup> Google Scholar provides a simple way to broadly search for scholarly literature; "Google Scholar," Google, accessed December 3, 2024, <https://scholar.google.com/>; Using the citation network and advanced search features, Litmaps help you find the most important papers on your topic; "Your Literature Review Assistant," Litmaps, accessed December 3, 2024, <https://www.litmaps.com/>; Ghent University Library is a network of faculty libraries and the Book tower, giving access to a broad range of scholarly information; "Ghent University Library," Ghent University, accessed December 3, 2024, <https://lib.ugent.be/>.

museums to overcome physical and logistical limitations. The transformative potential of XR is analyzed through its role in creating inclusive, multisensory, and participatory spaces, illustrating a shift from static exhibitions to dynamic, audience-centered experiences. The spectrum of XR technologies and their cultural roots are discussed, emphasizing their ability to redefine storytelling and interactivity in museum settings.

The practical applications of XR are analyzed in terms of accessibility (chapter 3), visitor engagement (chapter 4), and educational outcomes (chapter 5), supported by case studies that demonstrate the potential of immersive storytelling and multisensory experiences to communicate cultural heritage. The case study of *Actual Day* at MSK Ghent (chapter 6) examines XR's application and impact in enhancing accessibility, fostering engagement, and improving learning outcomes. Audience survey data is analyzed to offer insights into perceptions of digital integration, emotional connections, and visitor preferences, bridging theoretical and practical considerations.

The final chapters address critical factors influencing XR adoption, including funding and ethical considerations (chapter 7), and technical challenges (chapter 8), often overlooked in discussions of digital transformation. These chapters emphasize the importance of strategic planning and aligning XR initiatives with institutional goals. The conclusion evaluates XR's advantages and limitations in museum contexts and offers guidance for leveraging these technologies to create meaningful and accessible cultural experiences for all audiences.

## 2 A New Cultural Frontier

The rapid evolution of information and communication technologies has profoundly impacted society, reshaping daily life and professional practices across sectors.<sup>29</sup> Among these, the cultural and research domains have embraced this shift, leveraging digital advancements to foster wider dissemination and engagement with cultural knowledge.<sup>30</sup> Over the years, perspectives on experiencing art have transformed, particularly with the advent of immersive technologies in the mid-2000s.<sup>31</sup> This shift reflects a broader trend of reimagining how audiences interact with cultural heritage.

Extended reality (XR), an encompassing term for augmented reality (AR), virtual reality (VR), and mixed reality (MR), has emerged as a transformative force across diverse fields, including education, healthcare, and cultural heritage.<sup>32</sup> Powered by advancements in AI and digital processing, XR transcends entertainment, offering cultural institutions groundbreaking tools to present, preserve, and interpret heritage. By enabling immersive and interactive environments, XR bridges the gap between physical and digital experiences, redefines visitor engagement, and transforms traditional museum practices.

This chapter explores how digital tools challenge and reshape museum norms, focusing on its role in cultural heritage. From enhancing educational experiences to reconstructing historical contexts and improving exhibition design, XR unlocks new possibilities for museums to create dynamic, participatory, and inclusive spaces. As cultural institutions navigate this digital frontier, understanding the implications of these tools is crucial for their evolution into more accessible and engaging environments.

### 2.1 The Digital Evolution of Museums

Museums, traditionally seen as static institutions dedicated to the preservation and display of artifacts, have undergone profound changes in recent years.<sup>33</sup> Historically, they relied on conventional exhibition methods: objects displayed behind glass cases with explanatory text, encouraging passive observation.<sup>34</sup> While these approaches evoked awe and curiosity, they often fell short in fostering meaningful engagement, leaving visitors disconnected from the broader cultural and historical contexts surrounding the exhibits.

Rooted in Enlightenment and modernist principles, traditional museum practices emphasized empirical documentation, objectivity, and hierarchical knowledge dissemination.<sup>35</sup> They prioritized static, centralized representations—texts, drawings, photographs, and audiovisual recordings—as the primary means of conveying information. These practices aligned with the intellectual values of systematic observation and standardization, portraying museums as repositories of fixed knowledge. This approach often relegated audiences to passive roles, presenting decontextualized artifacts that lacked interactive or experiential dimensions.

Over time, this model has faced growing criticism for its inability to capture the dynamic, socially embedded nature of cultural heritage. As technological advancements and shifting visitor expectations

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<sup>29</sup> Montagud et al., “Culture 4 all,” 887.

<sup>30</sup> Davide Pantile et al., “New Technologies and Tools for Immersive and Engaging Visitor Experiences in Museums: The Evolution of the Visit-Actor in Next-Generation Storytelling, through Augmented and Virtual Reality, and Immersive 3D Projections,” *2016 12<sup>th</sup> International Conference on Signal-Image Technology & Internet-Based Systems (SITIS)*, IEEE (2016): 463-467, <https://doi.org/10.1109/SITIS.2016.78>.

<sup>31</sup> Caggianese et al., “Exploring the Feasibility of Diegetic User Interfaces,” 625.

<sup>32</sup> Greengard, *Virtual Reality*, chap. 1.

<sup>33</sup> Haoran Yang, and Liqun Guo, “Evolution of Exhibition Space Strategies in Smart Museums: A Historical Transition from Traditional to Digital,” *Herança* 7, no. 1 (2024): 1, <https://revistaheranca.com/index.php/heranca/article/view/851/708>.

<sup>34</sup> Maes, *Technologie en Levend Erfgoed*, slide 11.

<sup>35</sup> Maes, *Technologie en Levend Erfgoed*, slide 12.

have reshaped the cultural landscape, museums have embraced innovative methods to redefine their roles.<sup>36</sup> Digital technologies now enable institutions to offer more dynamic and interactive experiences. Visitors can explore artifacts through multimedia presentations, virtual tours, and digital interfaces that provide immersive, context-rich engagement. These innovations not only enhance understanding but also expand accessibility, allowing museums to reach global audiences and foster deeper connections with heritage.

By 2011, the importance of digital transformation in cultural heritage was already widely acknowledged. FARO, a Flemish support center for cultural heritage, underscored the transformative potential of digitization in its field analyses between 2009 and 2011.<sup>37</sup> The report highlighted how digital initiatives could preserve artifacts, enhance public access, and inspire future generations. FARO emphasized that museum collections are invaluable for education, research, and creativity, while also addressing practical challenges like the physical deterioration of artifacts.

ICOM originally defined digital museums as extensions of physical spaces, classifying them into three categories: the *brochure museum*, offering practical visitor information; the *content museum*, providing detailed collection data; and the *learning museum*, which enriches educational opportunities to inspire visitor engagement.<sup>38</sup> Technological advancements have expanded these definitions, enabling museums to create virtual environments that serve as tools for knowledge acquisition, integration, and interactive learning. Through sophisticated interfaces, tracking devices, and multimodal VR/AR technologies, virtual museums can now simulate lifelike exhibitions and redefine user interaction with cultural heritage. Early digital exhibitions were primarily static, relying on text and images, but have since evolved into dynamic, interactive spaces that enhance visitor engagement.

The momentum for digital transformation in museums accelerated with the advent of virtual exhibits, a trend that intensified during the COVID-19 pandemic. To maintain accessibility, cultural institutions rapidly adopted online tours, interactive educational resources, and digital archives. Today, digital engagement is ubiquitous in the art world, paralleling its prevalence in daily life. The COVID-19 crisis made digital strategies imperative, driving an exponential shift toward virtual tours, livestreamed events, and digital collections.<sup>39</sup>

A striking example of the digital transformation in cultural heritage is the extensive use of platforms like Google Arts & Culture.<sup>40</sup> By collaborating with over 3,000 cultural organizations, Google has enabled virtual access to more than 10,000 locations and 100,000 artworks, providing 24/7 access without entry fees. The platform's "Museum Explorer" feature allows users to virtually "visit" museums and cultural sites worldwide, revolutionizing how people engage with art and history from anywhere in the world. For the holiday season, Google introduced creative initiatives such as a "Cultural Advent Calendar" (Fig. 1), collaborating with institutions like the Royal Museum of Fine Arts of Belgium to showcase winter scenes through Bruegel's eyes.<sup>41</sup>

Virtual exhibits now serve as powerful complements to traditional methods, allowing remote audiences to engage with cultural artifacts. This digital evolution supports museums' evolving role as inclusive, participatory spaces, with the pandemic serving as a catalyst for broader acceptance and integration of technology within cultural institutions.

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<sup>36</sup> Yang and Guo, "Evolution of Exhibition Space Strategies," 1.

<sup>37</sup> Walterus et al., *Cultureel Erfgoed 2020*, 11.

<sup>38</sup> Styliani et al., "Virtual museums," 524.

<sup>39</sup> Goodman, "The Future of Museums," 116.

<sup>40</sup> "Google Arts & Culture," Google, accessed December 10, 2024, <https://artsandculture.google.com/>.

<sup>41</sup> "Winter Through Bruegel's Eyes," Cultural advent calendar, Google, accessed December 10, 2024, <https://artsandculture.google.com/story/PwVx23r1GuwWlq>.



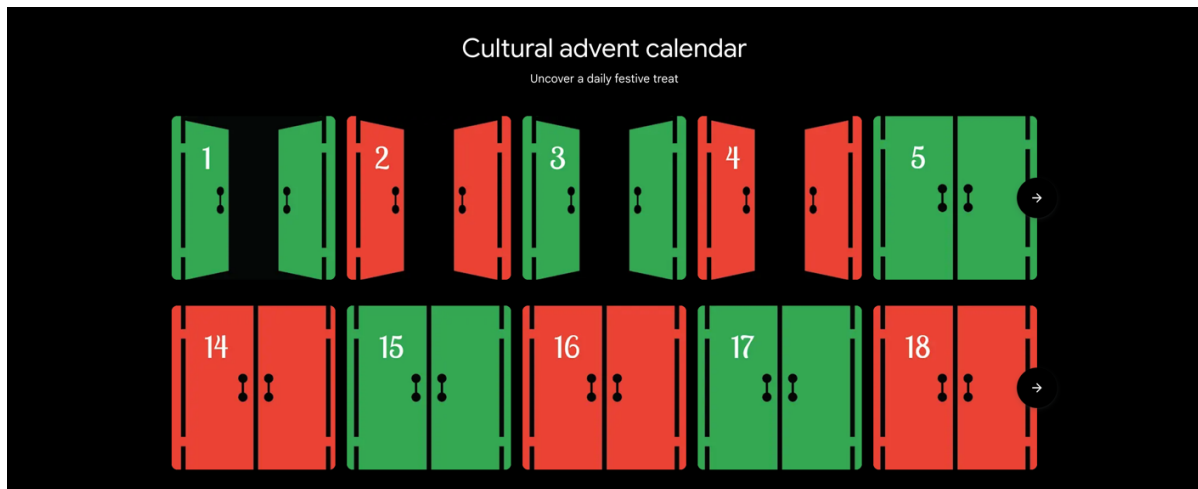


Figure 1. Screenshot of Google Arts & Culture's "Cultural advent calendar".

Pier Luigi Sacco's *Culture 3.0* framework captures the evolution of museums from static repositories to dynamic, participatory spaces, underscoring the transformative role of digital technologies in democratizing cultural engagement.<sup>42</sup> In this paradigm, cultural participation involves active co-creation, shifting audiences from passive consumers to collaborators who shape and produce cultural content.<sup>43</sup> Sacco, a cultural economics expert and head of International Relations at IULM University of Milan, highlights the impact of digital transitions on the production and connectivity of culture. The framework stresses how digital tools enable widespread distribution and foster innovative forms of interaction, where audiences engage directly with cultural material through platforms like smartphones and social media.<sup>44</sup>

A distinctive feature of *Culture 3.0* is the dissolution of boundaries between producers and consumers, as audiences become active participants in cultural creation.<sup>45</sup> Unlike "prosumerism," driven by market dynamics, *Culture 3.0* prioritizes democratized creativity, enabling the public to acquire skills and contribute to cultural narratives.<sup>46</sup> Sacco notes that while earlier cultural eras emphasized passive knowledge absorption, digital technologies empower audiences to shape content and share their voices on platforms such as Instagram, YouTube, and blogs.

This participatory shift is echoed by scholars like Professor Kris Rutten, who identifies dialogue and interaction as key components of digital culture.<sup>47</sup> Rutten observes that technological tools redefine traditional notions of presence by mediating social interactions, reflecting broader trends in museum practices since the mid-20<sup>th</sup> century. Museums, which once focused on static displays, increasingly adopt personalized, visitor-centered approaches.

Co-creation through digital innovation has further redefined museums as facilitators of collaborative cultural experiences.<sup>48</sup> By incorporating technologies such as XR, museums blur the lines

<sup>42</sup> Lore Cambré, "De digitale transitie, een uitdaging voor de Vlaamse museumsector" (Master's thesis, KU Leuven, 2018-2019), 11.

<sup>43</sup> Sacco, *The Culture 3.0 paradigm*, slide 15.

<sup>44</sup> Michelle Tillander, "Creativity, Technology, Art, and Pedagogical Practices," *Art Education* 64, no. 1 (2011): 40, <https://doi.org/10.1080/00043125.2011.11519110>.

<sup>45</sup> Pier Luigi Sacco et al., "From Culture 1.0 to Culture 3.0: Three Socio-Technical Regimes of Social and Economic Value Creation Through Culture, and Their Impact on European Cohesion Policies," *Sustainability* 10, no. 11 (2018): 6, <https://doi.org/10.3390/su10113923>.

<sup>46</sup> The concept of participation in Culture 3.0 differs from the idea of prosumerism. In prosumerism, content creation typically involves market mechanisms, whereas Culture 3.0 emphasizes participation that does not rely on market mediation as a fundamental component.

<sup>47</sup> Kris Rutten, "Participation, Art and Digital Culture," *Critical Arts* 32, no. 2 (2018): 2, <https://doi.org/10.1080/02560046.2018.1493055>.

<sup>48</sup> Marie De Graeve, "'Het museum van de toekomst': een wisselwerking tussen educatie en technologie" (Master's thesis, UGent, 2021-2022), 36.

between creators and audiences, fostering a participatory environment. No longer solely gatekeepers of history, they now serve as platforms for dialogue, engagement, and shared cultural exploration, creating deeper connections between visitors and heritage.

## 2.2 Rethinking Traditional Heritage Practices: A Feminist Critique

Conventional museum practices have faced widespread critique for their Eurocentrism, lack of inclusivity, and the promotion of passive audience roles. Traditional exhibition methods—such as wall-mounted displays or isolated objects highlighted in freestanding cases—often create a psychological divide between the viewer and the artifact.<sup>49</sup> While these methods are designed for ease of organization and spatial clarity, they prioritize reverence over engagement, leaving little room for audience interaction. Rooted in Enlightenment ideals of objectivity and hierarchical knowledge, these approaches fail to accommodate the evolving expectations of modern, diverse audiences. They emphasize preservation and documentation but often neglect the dynamic and experiential aspects of cultural heritage.

Feminist critiques have further exposed how traditional practices marginalize diverse voices by perpetuating Eurocentric, male-dominated narratives.<sup>50</sup> These limitations hinder museums from serving as inclusive spaces that authentically reflect the plurality of human experience.<sup>51</sup> Feminist scholars advocate for methodologies that challenge these norms, such as those exemplified by the Digital Women's Archive North (DWAN) in the UK.<sup>52</sup> DWAN proposes three transformative practices:

- **Intervention:** This approach involves creatively reinterpreting archival materials to generate new meaning and broaden accessibility. By challenging conventional perspectives, intervention encourages dynamic engagement with archives, allowing for a richer and more inclusive understanding of heritage. Alternative access strategies introduced through this method make archives more relevant and open to diverse audiences.
- **Living Archives:** Highlighting the fluid and participatory nature of heritage, this method connects historical records with present-day experiences and socio-political contexts. By prioritizing embodied knowledge, personal engagement, and diverse voices, living archives illustrate that heritage is not static but evolves through contemporary interactions and lived realities.
- **Reimagined Archives:** This methodology focuses on the innovative reuse of archival materials to redefine traditional ideas of preservation and inspire fresh interpretations. By recycling and reimagining how artifacts are presented, reimagined archives challenge conventional preservation practices, fostering creativity and reshaping our understanding of cultural value.

These methodologies address the limitations of static exhibits by recognizing heritage as fluid, dynamic, and inherently participatory.

Modern audiences increasingly seek personalized and interactive experiences, challenging museums to evolve and remain relevant to broader and more diverse demographics. Addressing outdated perceptions of museums as static or unengaging is crucial for these institutions to maintain

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<sup>49</sup> Yang and Guo, "Evolution of Exhibition Space Strategies," 4.

<sup>50</sup> Maes, *Technologie en Levend Erfgoed*, slide 12.

<sup>51</sup> Maes, *Technologie en Levend Erfgoed*, slide 18.

<sup>52</sup> Digital Women's Archive North (DWAN) is a feminist arts and heritage organization, based in the North West (UK). DWAN supports women and girls to identify, collect, disseminate, and celebrate their cultural heritage through creative and digital interventions; "[DWAN] Digital Women's Archive North," [DWAN] Digital Women's Archive North, last modified November 8, 2017, <https://dwarchivenorth.wordpress.com/>.



their appeal. To captivate and expand their visitor base, museums must innovate continuously, exploring new strategies that surprise and resonate with contemporary expectations.<sup>53</sup>

The digital evolution of museums, particularly through virtual and immersive technologies, offers transformative opportunities to make cultural experiences more inclusive. These innovations not only enhance audience engagement but also introduce promising revenue models and expand the cultural sector's potential. As Mario Montagud et al. argue in their article "Culture 4 all: accessibility-enabled cultural experiences through immersive VR360 content," universal access to cultural services is a fundamental right.<sup>54</sup> Yet, the integration of technologies like XR demands thoughtful attention to accessibility, digital literacy, and inclusivity. Despite these challenges, virtual platforms excel at preserving endangered heritage, transcending geographical boundaries, and ensuring cultural participation for individuals of all ages, abilities, and socioeconomic backgrounds.

Museums have embraced digital transformation not just for cataloging and preserving artifacts but also for enriching communication and enhancing visitor enjoyment.<sup>55</sup> This shift prioritizes the audience, reducing the divide between cultural institutions and their visitors. Increasing focus on visitor experiences and the educational aspects of cultural assets fosters deeper engagement. The blend of physical and digital content allows audiences to explore cultural artifacts innovatively, creating entirely new sensory and intellectual experiences.

This digital transition has fostered a more dynamic relationship between museums and individuals, extending far beyond traditional visits. Consequently, digitization has grown significantly across cultural institutions worldwide, from museums and art exhibitions to historical centers and archaeological sites, ensuring these spaces resonate with modern expectations while preserving their essential cultural roles.<sup>56</sup>

XR technologies inherently align with the above-mentioned feminist practices by promoting interactive, inclusive, and personalized engagement with cultural heritage. These technologies allow audiences to immerse themselves in reconstructed historical environments or interact with digital artifacts, transforming static displays into dynamic cultural experiences. By integrating embodied interactivity and contextually relevant storytelling, XR deepens connections between audiences and heritage. Museums adopting these tools become platforms for co-creation, empowering visitors to actively engage with cultural narratives rather than passively observing them.

Digitization through XR technologies transcends traditional barriers such as geography, physical ability, and socioeconomic limitations, creating broader access to cultural experiences. Digitalization allows institutions to scale the dissemination of art and knowledge globally, positioning technology as a crucial tool for engaging diverse audiences. Through tools like virtual tours, online exhibitions, and interactive applications, audiences worldwide can explore museum collections from any location, enabling a truly global cultural exchange.<sup>57</sup> As noted by Fabio Bruno et al. in their article about the sunken "villa con ingress a protiro," these modern technologies enhance the understanding, appreciation, and preservation of both cultural and natural heritage by bridging the gap between audiences and traditional exhibition spaces.<sup>58</sup> The transformative power of XR lies in its ability to transcend physical and spatial limitations, making cultural heritage universally accessible. By overcoming challenges such as travel restrictions, mobility impairments, and financial barriers, XR fosters inclusivity in cultural engagement.<sup>59</sup> These tools allow older adults, individuals with disabilities,

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<sup>53</sup> Pantile et al., "New Technologies and Tools," 463.

<sup>54</sup> Montagud et al., "Culture 4 all," 891.

<sup>55</sup> Caggianese et al., "Exploring the Feasibility of Diegetic User Interfaces," 625.

<sup>56</sup> Fabio Bruno et al., "Virtual tour in the Sunken "villa ingress a protiro" within the underwater archaeological park of Baiae," *ISPRS Journal of Photogrammetry and Remote Sensing* 42, 2/W10 (2019): 45, <https://doi.org/10.5194/isprs-archives-XLII-2-W10-45-2019>.

<sup>57</sup> Yang and Guo, "Evolution of Exhibition Space Strategies," 2.

<sup>58</sup> Bruno et al., "Virtual tour," 45.

<sup>59</sup> Lynn Berger, "Het museum van de toekomst is altijd open (en voor iedereen)," *De Correspondent*, January 5, 2015, <https://decorrespondent.nl/2259/het-museum-van-de-toekomst-is-altijd-open-en-voor-iedereen/6c27a520-d3f0-0768-1a41-6dbc1715bcbc>.

and economically disadvantaged individuals to participate in cultural experiences on par with others. Recognizing this potential, institutions have prioritized providing digital access to cultural artifacts in the 21<sup>st</sup> century. This shift not only extends the reach of museums but also ensures that their collections can be experienced by the broadest possible audience, regardless of physical or logistical constraints.

In addition to accessibility, XR enhances engagement by transforming museums into “smart institutions.”<sup>60</sup> These tools extend beyond merely providing access to cultural activities; they empower users to adapt and personalize their experiences, transcending the limitations of traditional exhibitions. Digital collections and mobile applications enable visitors to curate their experiences, tailoring the depth of information they explore and choosing personalized pathways through exhibits. This blend of physical and virtual interaction creates dynamic, user-centric journeys, allowing audiences to navigate exhibitions at their own pace while enriching their understanding of cultural artifacts.

Immersive technologies, such as XR, offer transformative potential for museums by providing lifelike experiences that enhance the popularization and promotion of cultural heritage while advancing research in the field.<sup>61</sup> Digitalization of locations, artifacts, and events enables hyper-realistic and engaging experiences, accessible anytime and anywhere. Traditional methods of knowledge transfer, reliant on cultural artifacts and annotations, are increasingly being supplemented by immersive approaches that offer richer and more cohesive understandings of historical contexts.

## 2.3 Understanding the Spectrum of XR Technologies

To effectively integrate XR technologies in museum settings, it is crucial to first understand the diverse spectrum of XR experiences, which range from fully immersive environments to subtle digital enhancements of the physical world:

**Virtual Reality (VR)** delivers fully immersive, computer-generated environments that users experience through devices like headsets, haptic gloves, and sensory tools to replicate real-world sensations. In museum contexts, VR can transport users to remote locations, historical periods, or even the heart of artistic processes, offering an engaging and immersive visitor experience. VR provides transformative experiences, enabling visitors to engage deeply with virtual artifacts (VAs)—digital representations of physical objects or conceptual entities, including triggers for specific interactive events.

**Augmented Reality (AR)** overlays digital elements onto the real world, accessible via smartphones and tablets.<sup>62</sup> It enriches museum exhibits by incorporating layers of information, such as three-dimensional (3D) models, dynamic labels, and contextual data. By enhancing physical displays with interactive features, AR deepens the visitor’s understanding of artifacts and their historical or cultural significance.

**Mixed Reality (MR)** merges digital and physical environments, allowing for real-time interaction between VAs and physical environments.<sup>63</sup> In museums, MR creates dynamic exhibits where VAs respond to visitor actions, fostering interactive and engaging experiences.

The **Reality-Virtuality Continuum** (Fig. 2), developed by Paul Milgram and Fumio Kishino in 1994, provides a valuable framework for understanding the range of immersive experiences offered by XR technologies.<sup>64</sup> This continuum ranges from fully real environments, where no digital elements are present, to fully virtual environments, where users are entirely immersed in digitally constructed spaces.

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<sup>60</sup> De Graeve, “Het museum van de toekomst,” 35.

<sup>61</sup> K. Choromański et al., “Development of virtual reality application for cultural heritage visualization from multi-source 3D data,” *ISPRS Journal of Photogrammetry and Remote Sensing* 42, 2/W9 (2019): 261, <https://doi.org/10.5194/isprs-archives-XLII-2-W9-261-2019>.

<sup>62</sup> Greengard, *Virtual Reality*, chap. 1.

<sup>63</sup> Greengard, *Virtual Reality*, chap. 1.

<sup>64</sup> Paul Milgram et al., “Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum,” *Proc. SPIE* 2351 (1994): 282-292, <https://doi.org/10.1117/12.197321>.

AR and MR occupy the middle ground, blending digital and physical elements to create interactive, hybrid experiences. By illustrating XR's flexibility, the continuum showcases its capacity to support a wide variety of interactions, from basic informational overlays to deeply immersive, multi-sensory environments, enhancing how users engage with both the digital and physical realms.

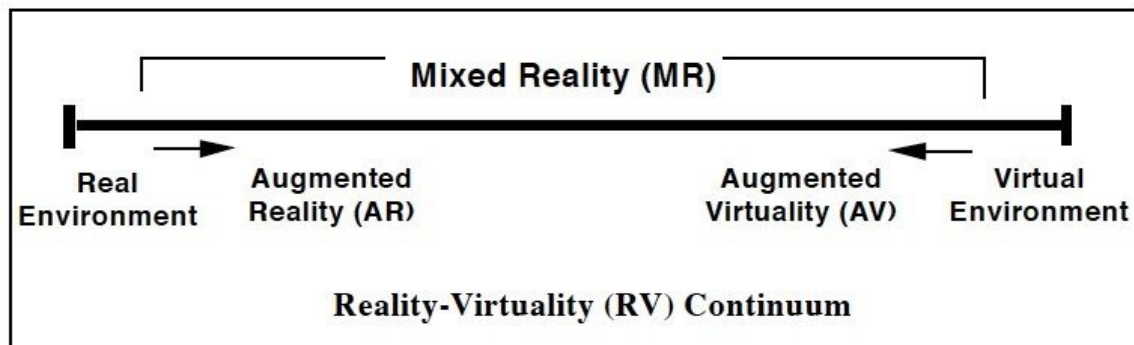


Figure 2. Milgram's Reality-Virtuality Continuum (Milgram and Kishino, 1994).

### Varieties of XR Experiences

XR experiences come in several forms, each offering varying degrees of immersion.<sup>65</sup> For instance:

- **Non-Immersive VR:** Basic displays of digital content (e.g., standard screens).
- **Semi-Immersive VR:** Systems like flight simulators that blend digital content with physical elements for more realistic scenarios.
- **Fully immersive VR:** Advanced setups with head-mounted displays (HMDs) and additional input/output devices such as haptic gloves, fully engaging the senses for lifelike experiences. While these offer unparalleled immersion, they require sophisticated hardware and software to deliver a high-resolution sensory experience.

### The Cultural Roots of XR Technologies

The origins of XR technologies are deeply rooted in cultural and artistic traditions, evolving over centuries. Immersive experiences date back to the 18<sup>th</sup> century, with panoramic paintings like those by Robert Barker, which surrounded viewers with large-scale visuals (Fig. 3).<sup>66</sup> This artistic tradition evolved into 360-degree panoramas and dioramas in the 19<sup>th</sup> century, which used lighting effects to create immersive visual experiences, foreshadowing modern XR applications.<sup>67</sup>

<sup>65</sup> Greengard, *Virtual Reality*, chap. 1.

<sup>66</sup> "Panoramas: 19th-Century Virtual Reality," Shannon Selin, last modified April 16, 2021, <https://shannonselein.com/2016/11/panoramas-19th-century/>.

<sup>67</sup> The diorama, invented by French artists Louis Daguerre and Charles Marie Bouton, utilized screens or backdrops painted on both sides to create different visual effects depending on the direction of illumination. This allowed scenes to change, such as shifting from day to night or showing a train appearing to crash. Today, dioramas are still used in museums to depict natural scenes, creating a 3D illusion that immerses viewers in the environment; R. Derek Wood, "The Diorama in Great Britain in the 1820s," *History of Photography* 17, no. 3 (1993): 284-95, <https://doi.org/10.1080/03087298.1993.10442306>.

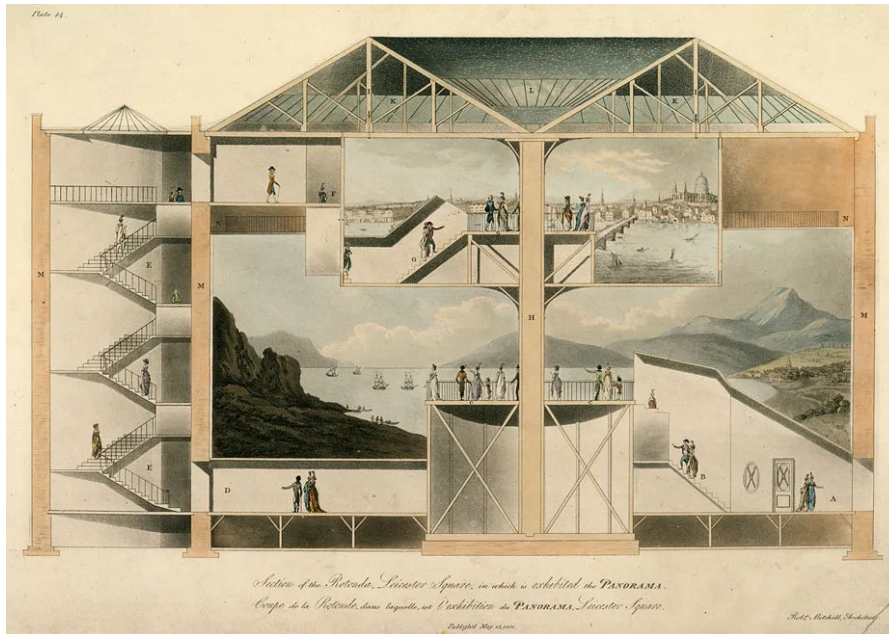


Figure 3. Section of the Rotunda, Leicester Square Panorama, by Robert Barker, 1801.

In the 20<sup>th</sup> century, the idea of virtual reality was explored in literature and film, with works such as Aldous Huxley's *Brave New World* and Stanley G. Weinbaum's *Pygmalion's Spectacles*, imagining devices that could transport users to fully sensory virtual worlds.<sup>68</sup> By the 1950s and 1960s, inventors like Morton Heilig were developing multi-sensory devices like the Sensorama Simulator (Fig. 4) and the Telesphere Mask (Fig. 5), which combined visual, auditory, and tactile elements to create immersive experiences, paving the way for modern VR headsets.<sup>69</sup>

The 1990s saw significant advancements in XR technology, with the introduction of the first head-mounted displays and the coining of the term “augmented reality” by Boeing researcher Tom Caudell to describe systems that blended digital graphics with the physical world.<sup>70</sup> Today, XR technologies are used across diverse fields, including museums, to create interactive, engaging experiences that bring audiences closer to art, history, and culture.

<sup>68</sup> The novel *Brave New World* introduced the concept of movies that could provide sensory experiences to enhance a scene. Similarly, the short story “Pygmalion's Spectacles,” presented the idea of a person wearing goggles that could create a fully immersive virtual experience, including visual, olfactory, gustatory, and tactile sensations; Aldous Huxley, *Brave New World* (Chatto & Windus, 1932); Stanley Grauman Weinbaum, *Pygmalion's Spectacles* (1935), <https://www.gutenberg.org/files/22893/22893-h/22893-h.htm>.

<sup>69</sup> On August 28, 1962, Morton Heilig, a philosopher, filmmaker, and inventor, introduced the Sensorama Simulator, an “experience theater” designed to create a virtual world through mechanical means. Building on his earlier inventions—the Sensorama Motion Picture Projector and 3D Motion Picture Camera—Heilig developed the Telesphere Mask in 1960, a head-mounted display that delivered stereoscopic images, wide vision, and stereophonic sound. The Sensorama further enhanced this experience by incorporating moving air, scents, binaural sound, vibrations, and other sensory stimuli to immerse users in a simulated environment; Morton L. Heilig, “Sensorama Simulator,” United States Patent Office, August 28, 1962, [https://web.opendrive.com/api/v1/download/file.json/MI8xNTA4NjQyOTJf?temp\\_key=I%E9%EC%A2%B6%A6h%F6%ADz%7Biu&inline=1](https://web.opendrive.com/api/v1/download/file.json/MI8xNTA4NjQyOTJf?temp_key=I%E9%EC%A2%B6%A6h%F6%ADz%7Biu&inline=1); Morton L. Heilig, “Stereoscopic-Television Apparatus for Individual Use,” United States Patent Office, patented October 4, 1960, [https://web.opendrive.com/api/v1/download/file.json/MI8xNTA4NjQyNzVf?temp\\_key=M%E9%5E%B2%98%5E%AD%E3%1A%B2J%5D&inline=1](https://web.opendrive.com/api/v1/download/file.json/MI8xNTA4NjQyNzVf?temp_key=M%E9%5E%B2%98%5E%AD%E3%1A%B2J%5D&inline=1).

<sup>70</sup> Greengard, *Virtual Reality*, chap. 1.



## 2.4 The Multisensory Museum Experience

Modern museums have evolved far beyond their traditional role as repositories of historical artifacts. They are now vibrant centers for learning, emotional connection, and community engagement.<sup>71</sup> Multisensory learning is central to this evolution, aiming to stimulate curiosity and emotional responses through a combination of sensory inputs. Neuroscientific research underscores that human perception and learning are inherently multisensory processes.<sup>72</sup> The brain does not merely absorb information passively through the senses but actively interprets, predicts, and seeks to validate or refute expectations about reality. This dynamic process emphasizes the importance of integrating visual, auditory, tactile, spatial, and even olfactory elements into museum experiences.

Museums that incorporate these multisensory elements can profoundly shape visitors' brains, fostering intellectual engagement and emotional resonance.<sup>73</sup> The brain's neuroplasticity—its ability to adapt and reorganize in response to stimuli—means that such experiences can have lasting impacts on visitors' perceptions and knowledge.

Despite efforts to diversify their offerings, many museums still present exhibits in ways that rely predominantly on visual engagement. Artworks are often displayed in strictly controlled environments that create a sense of detachment between the visitor and the object. Research presented at an international design conference in 2018 highlighted that multisensory experiences are particularly effective at engaging diverse audiences, including children, older adults, and individuals with disabilities.<sup>74</sup> These experiences foster deeper connection by making information accessible in ways that cater to different sensory preferences and learning styles.

The significance of multisensory museum experiences extends beyond accessibility for people with disabilities. By engaging multiple senses, museums create opportunities for all visitors to connect more intimately with their collections and the world around them.<sup>75</sup> Each person navigates their sensory and cultural environment uniquely, using a combination of personal tools and preferences. Multisensory exhibits accommodate this diversity, making museum visits more inclusive and meaningful.

Moreover, museums are inherently social spaces. By encouraging visitors to engage with their senses, museums facilitate not only individual connections with artifacts but also shared experiences with others.<sup>76</sup> These collective interactions enrich the museum experience, transforming it into a multifaceted journey of discovery, reflection, and community building.

The concept of virtual museums can be traced back to André Malraux's 1947 idea of the *musée imaginaire*—a “museum without walls” that transcends physical constraints.<sup>77</sup> Today, XR technologies bring this vision to life by integrating sensory and cognitive dimensions to enrich visitor experiences.

Virtual museums, built upon collections of digital media like images, sound files, and 3D models, can recreate physical spaces or invent entirely new environments. This flexibility addresses the limitations of traditional museums, where handling objects is often restricted to protect fragile artifacts.

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<sup>71</sup> Nina Levent and Alvaro Pascual-Leone, “Introduction,” in *The Multisensory Museum: Cross-Disciplinary Perspectives on Touch, Sound, Smell, Memory, and Space*, ed. Nina Levent and Alvaro Pascual-Leone (Rowman & Littlefield, 2014), xiii.

<sup>72</sup> Alvaro Pascual-Leone and Roy Hamilton, “The metamodal organization of the brain,” *Progress in Brain Research* 134 (2001): 427-445, [https://doi.org/10.1016/S0079-6123\(01\)34028-1](https://doi.org/10.1016/S0079-6123(01)34028-1).

<sup>73</sup> Alvaro Pascual-Leone et al., “The plastic human brain cortex,” *Annual Review of Neuroscience* 28 (2005): 377-401, <https://doi.org/10.1146/annurev.neuro.27.070203.144216>.

<sup>74</sup> Tazuru Harada et al., “Museum experience design based on multi-sensory transformation approach,” *DS 92: Proceedings of the DESIGN 2018 15<sup>th</sup> International Design Conference* (2018): 2221, <https://doi.org/10.21278/idc.2018.0150>.

<sup>75</sup> Elisabeth Axel and Kaywin Feldman, “Conclusion: Multisensory Art Museums and the Experience of Interconnection,” in *The Multisensory Museum: Cross-Disciplinary Perspectives on Touch, Sound, Smell, Memory, and Space*, ed. Nina Levent and Alvaro Pascual-Leone (Rowman & Littlefield, 2014), 351.

<sup>76</sup> Axel and Feldman, “Conclusion,” 351.

<sup>77</sup> André Malraux, *Le Musée Imaginaire* (Gallimard: 1996).

XR technologies, particularly haptics, offer an alternative by allowing users to experience the tactile qualities of artifacts virtually.<sup>78</sup>

Haptic technologies—providing tactile and motion feedback—are revolutionizing museum engagement by simulating the physical properties of objects.<sup>79</sup> These systems allow users to feel sensations like texture, weight, and friction, fostering deeper, more interactive connections with museum collections. Tools such as haptic gloves, styluses, and touch-sensitive devices enable tactile interactions that bring exhibits to life, enhancing both educational value and emotional resonance.

The development of haptics began in the late 1950s and early 1960s, spearheaded by scientists like Ralph Mosher.<sup>80</sup> Initially applied in teleoperation and robotics, haptics has since expanded to fields like surgical training and 3D modeling for artists and designers. Early human-computer interaction was predominantly visual, relying on screens and input devices like keyboards and mice, with little to no physical response to user actions. Recent advancements have made haptic technology more affordable and practical, providing believable sensory feedback.

In museum contexts, haptics complements traditional, visually focused displays by catering to diverse sensory preferences and learning styles. This approach not only deepens visitor engagement but also broadens accessibility, offering tactile experiences to visually impaired visitors or those seeking more immersive, hands-on interactions. By integrating haptic feedback, museums are redefining the ways audiences connect with cultural and historical artifacts.

Beyond replicating reality, XR enables the creation of entirely “new realities.” As Zhiqiang Zhou argues in his research article “Will the Metaverse Revolutionize the Narrative,” these digital environments immerse users in worlds that extend beyond the physical, transforming how we perceive and engage with reality.<sup>81</sup> This capability “activates the great imagination of human beings,” shifting virtual reality from a mere extension of the physical world to an innovative medium that crafts new sensory and narrative experiences. By transcending the traditional sequence and logic of reality, XR allows desires and interactions to be realized at the touch of a button, fostering novel forms of engagement.

These digital environments engage the imagination, offering immersive storytelling that reshapes how visitors understand history, culture, and art. Such experiences align with the evolving mission of cultural institutions to broaden accessibility and adapt to societal needs. By blending physical and virtual spaces, XR transforms museums into dynamic platforms for cultural exploration.<sup>82</sup>

XR technologies also provide insights into visitor behaviors and preferences, enabling museums to tailor experiences to individual needs.<sup>83</sup> For instance, data collection at the Dallas Museum of Art revealed unexpected visitor patterns, such as a teacher who visited daily for inspiration.<sup>84</sup> Such findings highlight the diverse motivations behind museum visits, from education to reflection, prompting institutions to rethink their gallery designs and programming.

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<sup>78</sup> Samantha Sportun, “The Future Landscape of 3D in Museums,” in *The Multisensory Museum: Cross-Disciplinary Perspectives on Touch, Sound, Smell, Memory, and Space*, ed. Nina Levent and Alvaro Pascual-Leone (Rowman & Littlefield, 2014), 331.

<sup>79</sup> Sportun, “The Future Landscape of 3D,” 335-36.

<sup>80</sup> Sportun, “The Future Landscape of 3D,” 335.

<sup>81</sup> Zhiqiang Zhou, “Will the Metaverse Revolutionize the Narrative,” *Critical Arts* 38, no. 2-3 (2023): 71, <https://doi.org/10.1080/02560046.2023.2282489>.

<sup>82</sup> Tim Deakin, “4 Things You Need to Know Before Embarking on Your Next XR Project,” MuseumNext, last modified August 11, 2022, <https://www.museumnext.com/article/4-things-you-need-to-know-before-embarking-on-your-next-xr-project/>.

<sup>83</sup> “Technology, Senses, and the Future of Museums. A Conversation with Nina Levent, Heather Knight, Sebastian Chan, and Rafael Lozano Hammer,” in *The Multisensory Museum: Cross-Disciplinary Perspectives on Touch, Sound, Smell, Memory, and Space*, ed. Nina Levent and Alvaro Pascual-Leone (Rowman & Littlefield, 2014), 344.

<sup>84</sup> Susan Anderson, “Visitor and audience research in museums,” in *The Routledge Handbook of Museums, Media and Communication*, ed. Kirsten Drotner et al. (Routledge, 2019), 80.

As museums embrace the digital transformation, a humanities-centered approach must steer the integration and application of XR technologies. This perspective ensures that innovation aligns with the fundamental mission of preserving and sharing cultural heritage in meaningful, inclusive, and human-centric ways. While these technologies offer exciting opportunities to expand accessibility and deepen engagement, their integration requires thoughtful planning and a clear understanding of both their possibilities and their constraints.

The adoption of XR technologies must transcend the mere pursuit of technological novelty. Instead, these tools should enhance the cultural experience, enriching visitors' connection to art, history, and heritage. However, managing the digital transformation brings its own set of challenges. Maintaining digital collections demand robust organization, sound policies, and strategic virtual curation.<sup>85</sup> The metaphorical “breaking open of museum walls” enables greater participation but also requires careful adaptation to ensure exhibits are effectively and meaningfully translated into online formats.

The future of museums depends on finding a balance between traditional methods and emerging technologies. By blending established practices with innovative tools, museums can create multisensory, transformative environments that deepen the human connection to culture. New technologies offer immense potential—but also risks—in shaping our approach to heritage and the policies that govern it. The critical challenge lies in how these technologies can be informed by a humanities perspective, ensuring they are applied in ways that honor historical, cultural, and humanistic values.<sup>86</sup> Let us explore these possibilities and challenges in greater depth in the following chapters.

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<sup>85</sup> Eleonora Lupo et al., “Digital for Heritage and Museums: Design-Driven Changes and Challenges,” *International Association of Societies of Design Research Congress* (2023): 10, <https://doi.org/10.21606/iasdr.2023.397>.

<sup>86</sup> Maes, *Technologie en Levend Erfgoed*, slide 8.



### 3 Enhancing Museum Accessibility

The global demographic landscape is shifting significantly, driven by the rise in individuals with disabilities and functional limitations, alongside an aging population. According to the World Health Organization (WHO), over 430 million people globally experience disabling hearing loss, with this number projected to surpass 700 million by 2050.<sup>87</sup> Additionally, approximately 2.2 billion people live with some form of vision impairment.<sup>88</sup> In Europe alone, an estimated 81.5 million adults face hearing loss—approximately one in seven.<sup>89</sup> These demographic changes, coupled with societal shifts like increased migration and evolving family structures, underscore the urgent need for inclusive and accessible solutions, particularly in cultural heritage institutions.

Accessibility is not only a fundamental human right but also a critical societal and economic priority.<sup>90</sup> As demand for accessible services grows, museums and cultural institutions are being called to expand their scope, addressing sensory, cognitive, linguistic, and technological dimensions of inclusivity. Leveraging innovative technologies like XR provides a pathway for museums to meet these demands, transforming their spaces into more inclusive, engaging, and accessible environments for all visitors.

This chapter examines how digital and immersive technologies enhance museum accessibility. It explores the potential of tools like AR, VR, and MR to create user-centered experiences that transcend spatial and temporal boundaries. By integrating these technologies, museums not only enrich visitor engagement but also redefine themselves as participatory spaces for learning and interaction in the digital age.

#### 3.1 Rethinking Museum Accessibility in the Digital Age

The traditional museum model, often limited by physical constraints and static displays, is undergoing a transformative redefinition through digital innovation. XR and digitization technologies empower museums to break down barriers of geography, disability, and socioeconomic status, making collections accessible anytime and anywhere.

The era of storing thousands of artifacts in hidden depots with little public concern is fading. As depots fill up and maintenance costs rise, governments demand greater transparency, and public expectations for on-demand access to cultural heritage have grown.<sup>91</sup> Concepts like the “transparent depot” offer a dual solution, preserving collections while actively engaging the public. For instance, institutions like MSK Ghent incorporate visible restoration workshops (Fig. 6).<sup>92</sup> In 2023, the museum hosted the restoration of seven panels of *The Adoration of the Mystic Lamb* (the Ghent Altarpiece) by the Van Eyck brothers. Visitors could observe the final restoration phase live, with conservators from the Royal Institute for Cultural Heritage (KIK-IRPA) working in a glass-enclosed studio.<sup>93</sup> Similarly, integrating digitization processes into public-facing spaces not only facilitates research but also makes collections accessible online, overcoming temporal and spatial barriers.

While these advancements in accessibility are promising, simply making collections available is not enough. Accessibility must go beyond availability, emphasizing thoughtful curation that provides

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<sup>87</sup> “Deafness and Hearing Loss,” Fact sheets, World Health Organization, last modified February 2, 2024, <https://www.who.int/en/news-room/fact-sheets/detail/deafness-and-hearing-loss/>.

<sup>88</sup> “Blindness and vision impairment,” Fact sheets, World Health Organization, last modified August 10, 2023, <https://www.who.int/en/news-room/fact-sheets/detail/blindness-and-visual-impairment>.

<sup>89</sup> Montagud et al., “Culture 4 all,” 889.

<sup>90</sup> Montagud et al., “Culture 4 all,” 891.

<sup>91</sup> Berger, “Het museum van de toekomst is altijd open.”

<sup>92</sup> “Restoration of the Ghent Altarpiece,” Exhibitions, MSK Ghent, accessed December 13, 2024, <https://www.mskgent.be/en/exhibitions/restoration-ghent-altarpiece>.

<sup>93</sup> The Royal Institute for Cultural Heritage is a federal non-profit institution that takes care of Belgium’s heritage; “About the Royal Institute for Cultural Heritage (KIK-IRPA),” Royal Institute for Cultural Heritage, accessed December 13, 2024, <https://www.kikirpa.be/en/about-us>.

context and narrative. Museums must move beyond basic search functions to deliver enriched, interactive pathways that create meaningful experiences for visitors.

Since the mid-2000s, cultural heritage institutions have embraced immersive technologies like AR, VR, and MR to reimagine exhibition design, storytelling, and education.<sup>94</sup> These tools enable users to interact with cultural artifacts in novel ways, breaking limitations of time and space while introducing innovative methods for learning and preservation.

Immersive technologies support user-centered approaches, offering digital versions of cultural artifacts that remain accessible even when physical access is restricted. This not only democratizes access but also allows museums to cater to a broader and more diverse audience, creating dynamic and inclusive platforms for engagement.

However, these advancements are not without challenges. Effective accessibility solutions must address sensory impairments, cognitive needs, and usability concerns from the earliest stages of technology development. Inclusivity cannot be treated as an afterthought; it must be an integral component of design and implementation.

### 3.2 Storytelling as a Key Accessibility Strategy

Storytelling is emerging as a transformative strategy to enhance accessibility in museums, particularly when using XR technologies. By creating immersive environments, XR brings historical narratives and cultural artifacts to life, dismantling traditional accessibility barriers and offering new avenues for engagement. This approach is particularly impactful for younger audiences who are accustomed to interacting with digital and immersive media.

Research underscores the value of cohesive narratives in fostering meaningful and lasting experiences. By encouraging personal storytelling, museums enable visitors to construct their interpretations, making the experience more engaging and memorable.<sup>95</sup> Scholars such as Eilean Hooper-Greenhill and Elizabeth Vallance emphasize the educational potential of balancing visitor autonomy with guided narratives.<sup>96</sup>

In her seminal work, *Museums and the Interpretation of Visual Culture*, Hooper-Greenhill highlights the multiplicity of interpretations inherent in museum spaces.<sup>97</sup> She argues that visitors derive meaning from exhibits based on their individual contexts, shaped by roles such as parents, scholars, or artists.<sup>98</sup> While curators strive for coherent displays, the diverse backgrounds of visitors often result in varying interpretations, necessitating a balance between structured guidance and open-ended exploration.

Vallance frames museum education as a narrative construction process, advocating for storytelling strategies that align clear objectives with the adaptability to visitor interpretations.<sup>99</sup> Key questions such as “What is the desired outcome?” and “How can engagement be maximized?” are central to designing impactful narratives.<sup>100</sup> Additionally, addressing the often-overlooked question—

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<sup>94</sup> Caggianese et al., “Exploring the Feasibility of Diegetic User Interfaces,” 625.

<sup>95</sup> EunJung Chang, “Interactive Experiences and Contextual Learning in Museums,” *Studies in Art Education* 47, no. 2 (2006): 183, <https://doi.org/10.1080/00393541.2006.11650492>.

<sup>96</sup> Eilean Hooper-Greenhill is a prominent scholar in museum studies, known for her influential works on museums’ educational roles and their interpretation of visual culture, and she served as Director of Research at the University of Leicester’s Department of Museum Studies. Elizabeth Vallance is a museum education scholar whose career spans roles in curriculum theory, art education, and museum studies, including serving as Director of Education at The Saint Louis Art Museum and developing innovative courses like “Artifacts, Museums, and Everyday Life” at Indiana University.

<sup>97</sup> Hooper-Greenhill, *Museums and the Interpretation of Visual Culture*.

<sup>98</sup> Hooper-Greenhill, *Museums and the Interpretation of Visual Culture*, chap 1.

<sup>99</sup> Elizabeth Vallance, “Museum Education as Curriculum: Four Models, Leading to a Fifth,” *Studies in Art Education* 45, no. 4 (2004): 352-353, <https://doi.org/10.1080/00393541.2004.11651780>.

<sup>100</sup> Vallance, “Museum Education as Curriculum,” 353-54.

“What does the visitor want to learn?”—can foster co-creative experiences that resonate deeply with audiences.

Effective storytelling serves as a bridge for conveying complex information to diverse audiences. XR technologies amplify this capability by enabling immersive and multisensory storytelling, allowing visitors to interact with narratives in novel and engaging ways. By integrating visual, auditory, and tactile elements, XR not only enriches the storytelling experience but also ensures greater inclusivity and accessibility for individuals with diverse sensory preferences and learning styles. This dynamic approach to narrative design is further explored in the following case study.

### **Case Study: Ephesus Experience Museum**

The Ephesus Experience Museum in Selçuk, Turkey, exemplifies the transformative power of XR technologies to revolutionize storytelling and accessibility in cultural heritage.<sup>101</sup> Moving beyond traditional methods that often separate narrative from physical engagement, the museum employs an approach known as “subject bodilyization.” This concept places the human body and senses at the center of storytelling, emphasizing active participation and fundamentally altering how stories are experienced and understood.<sup>102</sup>

At the core of the Ephesus Experience is an 18-minute immersive journey that transports visitors through 1,500 years of the city’s history, from the prehistoric Bronze Age to its Roman-era prominence.<sup>103</sup> Designed to complement a visit to the archaeological site, this multisensory experience enriches the exploration of Ephesus by offering perspectives and narratives that go beyond what is physically accessible on-site. Using 360-degree projections, immersive soundscapes, and dynamic light installations, the museum offers a vivid, layered narrative of Ephesus’s cultural and architectural legacy.<sup>104</sup> This integration of XR technologies allows visitors to delve into historical contexts and explore areas of the archaeological site that are otherwise inaccessible, pushing the boundaries of traditional museum displays.

Designed by ATELIER BRÜCKNER, the museum’s creation involved an interdisciplinary collaboration of architects, designers, artists, technologists, historians, and archaeologists.<sup>105</sup> This collective effort ensured historical accuracy while enabling dynamic storytelling. Visitors are transformed from passive spectators to active participants, immersed in a digitally reconstructed past that invited exploration and interaction. To cater to a diverse international audience, the experience features multilingual narrations, ensuring accessibility across cultural and linguistic boundaries. The museum further enhances inclusivity by selecting universal themes that transcend specific cultures and

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<sup>101</sup> “Ephesus Experience Museum,” Museums, DEM Museums, accessed December 13, 2024, <https://www.demmuseums.com/museums/ephesus-experience-museum/>.

<sup>102</sup> Zhou, “Will the Metaverse Revolutionize the Narrative,” 76.

<sup>103</sup> The first room is five-and-a-half minutes long. Here, they learn about the Oracle of Delphi’s prophecies, Androcles’ establishment of the city, the Amazonian women, and the initial cult of Artemis, Ephesus’s protector goddess. The second room, lasting about seven and a half minutes, showcases the city’s peak under Roman rule in the 1<sup>st</sup> and 2<sup>nd</sup> centuries CE. Visitors experience the bustling streets, meet historical figures like Cleopatra and Mark Antony, and witness the rise of Christianity. The final room, approximately two and a half minutes long, is dedicated to Artemis. Visitors are confronted with a life-size statue of the goddess, surrounded by an immersive soundscape and visuals that emphasize her enduring presence and guardianship over the city.

<sup>104</sup> DEM Museums, “Experience the wonders of Artemis at the Ephesus Experience Museum,” Promotional video, posted December 11, 2023, YouTube, 1:33, <https://www.youtube.com/watch?v=hRc52Ah-8UI>.

<sup>105</sup> ATELIER BRÜCKNER is a Germany-based design firm specializing in creating immersive, sustainable, and community-focused environments that integrate content, exhibits, and architecture to deliver engaging and meaningful experiences; “Atelier,” Atelier Brückner, accessed December 13, 2024, <https://www.atelier-brueckner.com/en/atelier>.

eras, fostering connections with visitors from varied backgrounds and making the content both relatable and timeless.

Unlike traditional screen-based displays, XR delivers full immersion and spatial interaction, allowing visitors to navigate a 360-degree digital reconstruction of ancient Ephesus (Fig. 7). This design facilitates both collective engagement and individual interpretation, enabling visitors to become co-creators of their narrative journey. While a shared path ensures narrative coherence, the experience feels uniquely personalized, encouraging participants to engage with the content on their terms. Each visitor assumes the role of protagonist, intertwining their story with those of others, fostering a sense of shared discovery and connection.

This approach, often described as the “naturalization of the story,” creates narratives that feel organic and unforced, as though they emerge naturally from the environment rather than being explicitly designed.<sup>106</sup> XR storytelling fundamentally redefines how narratives are experienced, placing the human body and its interactions with the virtual environment at the center of the process. By challenging the traditional separation of body and mind seen in many narrative forms, XR emphasizes “body precedence,” where stories unfold only through active physical engagement. This contrasts with earlier art forms, which often suppressed physical sensations to focus on spiritual or intellectual engagement.

In XR storytelling, historical events and cultural significance are not merely explained but physically and emotionally felt. Visitors immerse themselves fully, their senses and movements contributing to a profound connection with the narrative. This multisensory engagement ensures that the experience is both intellectually stimulating and deeply resonant, redefining how museums convey history and culture.



*Figure 7. Visitors inside the Ephesus Experience Museum.*

Key elements such as holographic characters, scent design, immersive lighting, and ambient sounds are strategically integrated to enhance each section of the journey. Dynamic visual effects, like dissolving and reassembling particles, symbolically differentiate between historical facts and mythology (Fig. 8). This approach helps visitors seamlessly navigate layered content, offering an engaging visual experience while clearly delineating myth from reality. By blending captivating storytelling with clarity,

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<sup>106</sup> Zhou, “Will the Metaverse Revolutionize the Narrative,” 76.

the design ensures that visitors can appreciate Ephesus's rich history without conflating factual events with mythical narratives.

As Shirin Brückner, Managing Director of ATELIER BRÜCKNER, explains in Rana Rmeily's discussion on the Ephesus Experience Museum, the museum does not aim to fully recreate Ephesus but rather to visualize dimensions of the city that are otherwise inaccessible.<sup>107</sup> This approach enhances appreciation of Ephesus's history while addressing the challenges of physical site preservation and visitor access.

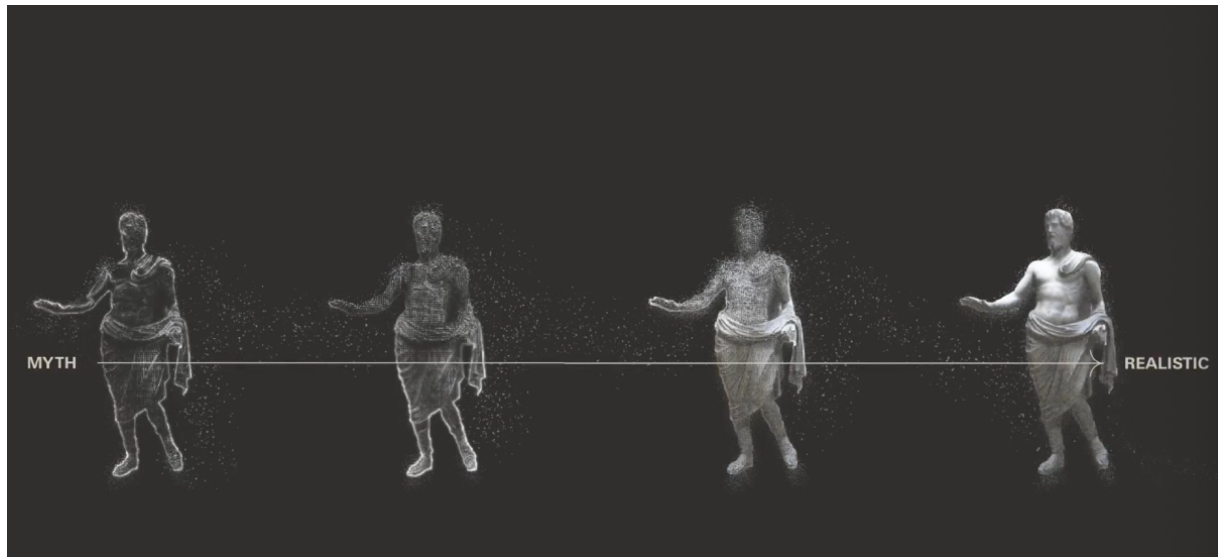


Figure 8. Particle-based transitions illustrate the conceptual spectrum from myth (left) to reality (right).

A defining feature of the Ephesus Experience is its architecture, purposely designed to seamlessly integrate the immersive XR elements. Led by Wassim Meli of ATELIER BRÜCKNER, the architectural approach was minimalist and reversible, ensuring harmony with the archaeological site and its surroundings. This thoughtful design enhances visitors' sense of immersion within the historical narrative.

Collaboration with Marshmallow Laser Feast contributed to the historical accuracy of the experience through meticulous 3D modeling, traditional animation, and visual effects (VFX).<sup>108</sup> Additionally, the VR technologies implemented enable real-time updates, allowing the content to evolve alongside new archaeological discoveries. This adaptability not only preserves historical relevance but also creates opportunities for future innovative enhancements.

The Ephesus Experience Museum, while already excelling in leveraging XR to engage audiences, presents several opportunities to further enrich and personalize the visitor experience.

**Enhancing Interactivity:** Increasing interactivity could significantly deepen visitor engagement. For example, visitors might virtually manipulate and examine ancient artifacts, offering a tactile connection to history. AI-driven avatars could also be introduced, enabling interactions with

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<sup>107</sup> Rana Rmeily, "Ephesus Experience Museum: Immersive Histories for Today's Audiences," Museum XR Summit 2024, *MuseumNext*, Virtual Conference, June 26, 2024, <https://museumnext.mn.co/posts/museum-xr-summit-ephesus-experience-museum-immersive-histories-for-todays-audiences>.

<sup>108</sup> Marshmallow Laser Feast is a UK-based experiential artist collective blending art, immersive technology, and storytelling to create multisensory experiences that explore humanity's relationship with the living world and have been exhibited internationally in galleries, museums, and festivals; "Information," Marshmallow Laser Feast, accessed December 13, 2024, <https://marshmallowlaserfeast.com/information/>.



historical figures such as an Ephesian merchant or an Artemisian priest, providing nuanced insights into daily life and cultural practices in ancient Ephesus.

**Personalized Narratives:** Tailoring experiences to individual interests could amplify visitor engagement. AI systems could customize storylines, allowing mythology enthusiasts to immerse themselves in the lore of Artemis, while those interested in urban development explore architectural advancements. Even without AI, offering diverse narrated content options could encourage repeat visits as audiences explore different facets of Ephesus's history. Interactive decision trees could guide visitors through self-directed paths, fostering unique and personalized journeys through the ancient city.

Advancing XR capabilities could transform the museum from a structured multisensory experience into a fully dynamic and adaptive adventure. Such innovations would not only enhance historical understanding but also foster deeper emotional and intellectual connections to the past.

As XR technologies evolve, they introduce innovative storytelling approaches that blend individual agency with shared experiences. As a digital realm emphasizing active participation, XR offers a framework where visitors shape the narrative landscape themselves, moving beyond passively consuming pre-designed stories. This paradigm shift underscores XR's transformative potential to make storytelling more immersive, participatory, and rooted in both personal and collective realities.

### 3.3 Expanding Audiences with XR Technologies

Museums face the ongoing challenge of integrating audience research into the development of exhibitions, a process that highlights the intricate balance between style and content.<sup>109</sup> Audiences today demand visually compelling narratives that also provide substantive engagement, while the increasing diversity of society—encompassing a broad range of ethnicities, cultural traditions, and historical perspectives—compounds these expectations. Visitors bring unique social and cultural lenses to their interpretation of collections, necessitating a flexible and inclusive approach to curating museum experiences.

In response, museums are redefining cultural heritage as a shared and participatory resource. This shift reflects an evolving societal role, where museums strive to make art, history, and culture universally accessible and relevant. At the same time, the digital age, often referred to as the “internet society,” has expanded access to information and encouraged personal storytelling.<sup>110</sup> These dynamics present museums with a dual challenge: addressing the need for highly individualized visitor experiences while fostering collective, shared engagement. XR technologies offer a powerful means of addressing these demands, enabling museums to design experiences that are both personal and inclusive.

By leveraging XR, museums have demonstrated its ability to broaden their appeal, particularly among demographics that have traditionally shown limited interest in cultural institutions, such as younger audiences.<sup>111</sup> Interactive and immersive elements inherent to XR create dynamic and engaging museum environments, making exhibitions more appealing to a wider audience. These early, memorable experiences foster a foundation for lifelong cultural engagement.

A significant strength of XR technologies lies in their capacity to cater to visitors of all abilities, from children to seniors, non-native speakers, and individuals with disabilities. Universal design principles play a pivotal role in this inclusivity, emphasizing to the broadest range of users, regardless

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<sup>109</sup> Hooper-Greenhill, *Museums and the Interpretation of Visual Culture*, chap 1.

<sup>110</sup> Bunnik, *Musea voor mensen*, 17-18.

<sup>111</sup> Cultural heritage organizations are making concerted efforts to broaden and diversify their audiences, yet they continue to face challenges in engaging beyond their traditional demographic of highly educated, older, middle-class individuals; Jambon, *Strategische Visienota Cultureel Erfgoed*, 37.



of age, ability, or language.<sup>112</sup> XR applications, such as multilingual support, sensory-rich experiences, and adaptable interfaces, enable museums to transcend traditional accessibility barriers, ensuring meaningful engagement for a diverse and global audience.

### **Case Study: Lam Gods AR Tour**

The *Lam Gods AR Tour* at Sint Bavo's Cathedral Ghent, Belgium, highlights the application of AR in enhancing museums experiences (Fig. 9 & 10).<sup>113</sup> Unlike the Ephesus Experience Museum, which utilizes XR as a post-visit reflective tool, the *Lam Gods AR Tour* functions as a preparatory enhancement. Before encountering the physical Ghent Altarpiece, visitors engage with AR-driven content that contextualizes the artwork's history, enriching their appreciation and understanding. This duality in XR application—either as a prelude or as a concluding engagement—demonstrates its flexibility within museum settings.



Figure 9 & 10. Visitors enjoying the *Lam Gods AR Tour*.

The *Lam Gods AR Tour* is thoughtfully designed to accommodate a broad spectrum of visitor preferences and levels of technological familiarity. Visitors can choose between AR glasses or tablets, varying tour lengths, and customizable content depth. These options ensure accessibility for a diverse audience, ranging from casual tourists to dedicated art enthusiasts.<sup>114</sup> AR's ability to support multiple languages and offer localized cultural context enables international visitors to engage deeply with the material in their native tongue, fostering a stronger connection to the artwork.

Upon arrival, visitors are fitted with AR glasses and a portable battery pack to power the device. Using a QR code, they set their language and tour preferences, with museum staff providing assistance to ensure seamless setup. The AR experience then unfolds through eight digital scenes, exploring themes like the cathedral's historical evolution and the intricate symbolism within Van Eyck's masterpiece.<sup>115</sup>

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<sup>112</sup> Daeun Kim and Jeeheon Ryu, "Exploring the Universal XR Design Strategies Considering Interactive Learning Experiences: A Case Study," *Immersive Learning Research* 1, no. 1 (2024): 135-42, <https://doi.org/10.56198/U6C0WP677>.

<sup>113</sup> Sint-Baafs Kathedraal Gent, "Lam Gods AR Tour."

<sup>114</sup> The tour, available in 9 languages (DU, FR, EN, DE, IT, ES, RU, JP, PT), offers options including 'Standard,' 'Master of Detail,' and 'KIDS,' lasting 40 or 60 minutes; the 60-minute tour features additional AR scenes exploring the Mystic Lamb's rich history.

<sup>115</sup> The tour begins with an introduction to the cathedral's history, guided by Bishop Antonius Tries, who explains its evolution over centuries. The second scene depicts Ghent in 1430, featuring a replica of the cathedral and the commissioners of the Ghent Altarpiece, Joos Vijd and Elisabeth Borluut, overseeing work on the Vijd Chapel. The third scene offers a behind-the-scenes look at Jan van Eyck's workshop. The fourth scene explores the iconography of the Ghent Altarpiece, highlighting its 100+ characters and their stories. In the fifth scene, participants zoom in on the altarpiece's panels

The interactive features of the *Lam Gods AR Tour* elevate its immersive quality, offering an engagement level that surpasses traditional guided tours. Visitors are guided by tools like a floating kettle (Fig. 11-13), digital floor arrows, and circles marking key information points. These aids direct participants as they navigate reconstructed digital environments and zoom in on specific details of the artwork (Fig. 14), crating a personalized yet structured experience.

This carefully balanced approach reflects the core methodology of Alfavision, the creators of the AR tour.<sup>116</sup> By integrating flow management into the design process from the outset, Alfavision ensures that visitors maintain an intuitive and cohesive journey through the experience. To achieve this, they developed their own patented software, enabling precise control over the interactive elements and ensuring a seamless user experience.

However, occasional technical issues—such as zone detection errors and timing inconsistencies—highlight the challenges of delivering seamless XR experiences. These technical shortcomings underscore the need for continuous refinement to ensure reliability and user satisfaction.

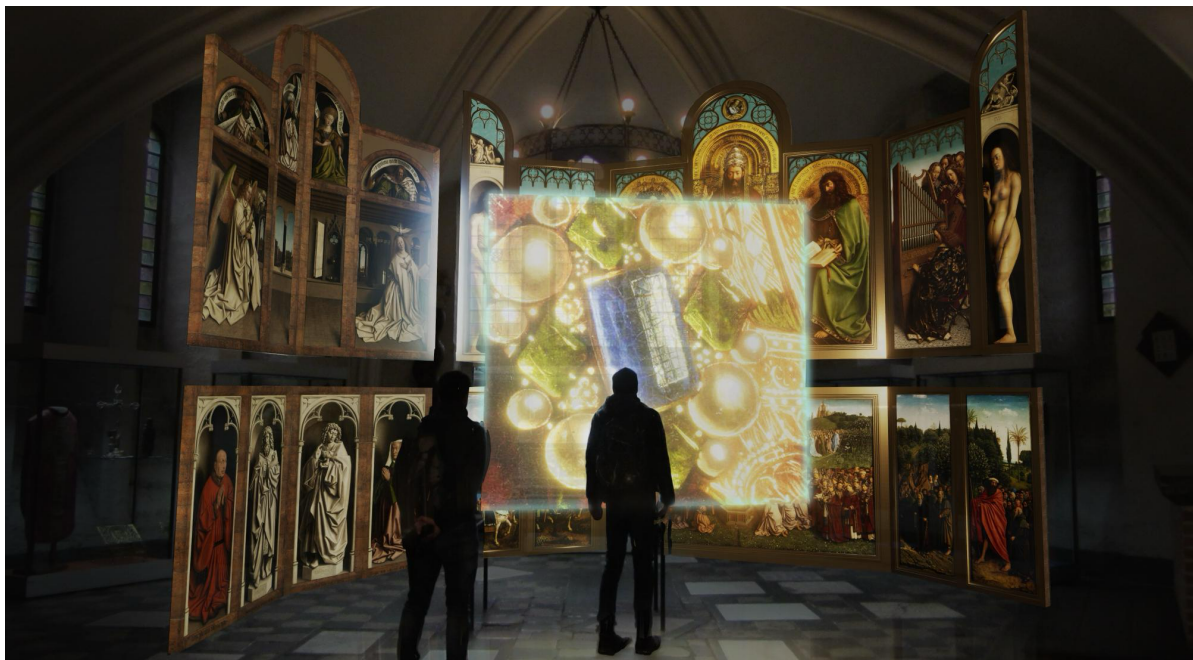


Figure 14. AR experience enabling participants to zoom in on the altarpiece's panels.

While the *Lam Gods AR Tour* offers an impressive AR experience, opportunities remain for greater inclusivity. Features like adjustable text sizes, audio descriptions, and haptic feedback could enhance accessibility with visual, auditory, or mobility impairments. By integrating these features, the tour could better align with universal design principles, ensuring that all visitors can engage fully with the content.

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to uncover Van Eyck's genius, though time limits prevent exploring all panels, concluding the 40-minute tour. Additional scenes in the extended tour cover the altarpiece's tumultuous history, from its concealment during iconoclasm and its disassembly and relocation to Germany, to its WWII rescue by the Monuments Men and its modern restoration.

<sup>116</sup> Alfavision is an innovative museum design and solutions company known for creating inclusive, memorable visitor experiences through expert scenography, strong storytelling, patented technology, and seamless operational planning, with hands-on experience in managing museum operations like The Historium in Bruges, Belgium; "About," Alfavision, accessed December 24, 2024, <https://www.alfavision.be/about>.

### 3.4 Addressing Accessibility Barriers

XR technologies present transformative solutions to overcome accessibility barriers in museums, enabling both remote and on-site engagement for global audiences. These technologies transcend traditional physical and temporal constraints, offering virtual tours that connect individuals—whether remote visitors or those with mobility impairments—to cultural heritage in ways that were previously unattainable.<sup>117</sup> Beyond extending access, XR supports the preservation and digital display of museum collections, ensuring that artifacts remain available for future generations while reducing wear and tear on physical items.

The potential of XR is demonstrated across industries, including sports. For example, the NBA's partnership with Oculus to provide virtual courtside seats showcases how immersive experiences can simulate real-life events.<sup>118</sup> This capability translates seamlessly into museum contexts, where XR allows users to experience heritage from anywhere in the world, offering intimate engagement without physical attendance.

Museums like Roald Amundsen's house, Uranienborg, in Norway highlight XR's capacity to overcome preservation-related accessibility limitations.<sup>119</sup> Due to the fragile condition of the site's interiors, only a small number of visitors are allowed on-site annually.<sup>120</sup> Through a VR replica created by Glitch Studios and distributed globally on Steam, nearly 28,000 digital visitors explore the house each year—far surpassing the 3,000 physical visitors permitted.<sup>121</sup> This innovation ensures that Amundsen's legacy is shared broadly, unrestricted by conservation concerns.

Beyond physical constraints, XR facilitates access to unreachable sites, including those in war zones or submerged underwater. For example, the Underwater Cultural Heritage (UCH), encompassing artifacts and archaeological sites beneath the ocean, remains inaccessible to most individuals due to environmental challenges.<sup>122</sup> XR democratizes access by creating digital replicas of such sites, allowing exploration without the need for specialized skills or equipment.

#### **Case Study: The Sunken “Villa a Protiro”**

The Marine Protected Area of Baiae, near Naples, Italy, is home to submerged Roman ruins, including the “Villa a Protiro” (Fig. 15), which sank due to seismic activity during the 4<sup>th</sup> and 5<sup>th</sup> centuries AD.<sup>123</sup> XR technology breathes new life into this inaccessible site through a VR experience that allows

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<sup>117</sup> Sunanda Rani et al., “Exploring the Potential of Artificial Intelligence and Computing Technologies in Art Museums,” *ITM Web of Conferences* 53, 01004 (2023): 4, <https://doi.org/10.1051/itmconf/20235301004>.

<sup>118</sup> Meta Quest, “Adam Levine and Jonah Hill Sit Courtside | Oculus Go,” Promotional video, posted November 12, 2018, YouTube, 0:30, [https://www.youtube.com/watch?v=SUdJt\\_3i0Us](https://www.youtube.com/watch?v=SUdJt_3i0Us).

<sup>119</sup> Roald Amundsen, a Norwegian Polar explorer who disappeared in 1928, left behind his home, Uranienborg, which later became a museum showcasing his belongings and is now managed by Museums in Akershus (MiA) as a state property; “Uranienborg,” Roald Amundsen's House, MiA, accessed December 28, 2024, <https://amundsen.mia.no/en/uranienborg-2/>.

<sup>120</sup> Anders Bache and Sami Hamid, “Digitising Hard to Exhibit Historical Spaces,” Museum XR Summit 2024, *MuseumNext*, Virtual Conference, June 26, 2024, <https://museumnext.mn.co/posts/museum-xr-summit-digitising-hard-to-exhibit-historical-spaces>.

<sup>121</sup> Glitch Studios is an award-winning digital experience design studio with offices in Oslo, London, and Istanbul, specializing in bold, innovative storytelling and reimagining audience experiences through cutting-edge design and technology; “Glitch Studios,” Glitch Studios, accessed December 28, 2024, <https://www.glitchstudios.co/>; Steam is the world's biggest distribution platform for games and digital experiences; “Roald Amundsen's House,” Education, Steam, accessed December 28, 2024, [https://store.steampowered.com/app/1435700/Roald\\_Amundsens\\_House/?beta=0](https://store.steampowered.com/app/1435700/Roald_Amundsens_House/?beta=0).

<sup>122</sup> “Threats to the Underwater Cultural Heritage,” Underwater Cultural Heritage 2001 Convention, UNESCO, last modified November 20, 2024, <https://www.unesco.org/en/underwater-heritage/threats>.

<sup>123</sup> “Villa a Protiro,” Visite Guidate, Parco Sommerso di Baia, accessed December 28, 2024, <https://parcoarcheologicodibaia.it/index.php/en/visite-guidate/villa-protiro>.

users to virtually explore a 3D reconstruction of the villa while uncovering its historical and archaeological significance.<sup>124</sup>

The VR application employs HMD technology, delivering an immersive experience with high-resolution visuals, spatial audio, and intuitive handheld controllers.<sup>125</sup> These controllers, equipped with buttons, joysticks, and touchpads, enable users to interact naturally within the 3D space, with their position and orientation tracked in real time. The journey begins above water, offering a reconstructed view of the coastline before guiding users to the submerged ruins (Fig. 16). Visitors can choose between two modes: free exploration or a guided tour led by a virtual dive buddy, accommodating varied preferences and learning styles.<sup>126</sup> The guided mode provides a coherent narrative structure, while the free exploration mode encourages self-paced engagement, fostering a more personalized connection to the site.

Interactive Points of Interest (POIs), marked with color-coded icons, enrich the experience by delivering layered multimedia content (Fig. 17).<sup>127</sup> These include 3D reconstructions, 360-degree videos, and detailed audio narratives that provide historical, archaeological, and even biological insights. To enhance realism, advanced graphical effects such as underwater light rays, refractions, bubbles, and caustics replicate the conditions of the submerged environment. Users navigate the space by moving their heads and directing the wireless handheld controllers. To “swim,” users pull the trigger button while pointing in their desired direction, seamlessly exploring the underwater landscape. Upon reaching a POI, users activate it by pointing and clicking, unlocking its multimedia content displayed within a 3D frame.

One of the standout features of the VR experience is the ability to toggle between the villa’s current submerged state and its hypothetical reconstructed grandeur (Fig. 18), allowing users to visualize its original architecture, furnishings, and surroundings.<sup>128</sup> This dual perspective deepens understanding, providing context for both the villa’s historical significance and its current preservation status. The integration of exploration, storytelling, and interaction creates a rich and engaging experience that rivals physical diving. Advanced technologies and thoughtful design allow users to immerse themselves fully in the site’s history, fostering a deeper appreciation for its cultural and archaeological value.

### 3.5 Toward Inclusive Museum Design

The integration of XR technologies marks a significant milestone in making museums more inclusive and accessible. Projects like the Villa a Protiro demonstrate how XR can bridge accessibility gaps, offering diverse audiences an opportunity to engage with heritage in innovative ways. By blending historical accuracy with advanced technology, XR allows institutions to preserve cultural artifacts while creating meaningful and enriching experiences.

Structured pathways, as seen in the Ephesus Experience and *Lam Gods AR Tour*, further enhance accessibility by providing clear navigation and cohesive narratives. These XR-enhanced experiences ensure visitors follow intended routes, preventing key aspects of the narrative from being overlooked. Interactive tools, such as virtual guides and digital markers, help maintain the flow and improve engagement, fostering a more immersive experience.

Looking forward, the success of these projects underscores the importance of incorporating XR into future museum design. By offering multilingual content, personalized storytelling, and interactive

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<sup>124</sup> “Dry Visit – Virtual Underwater Visit – iMARECulture,” Education, Steam, accessed December 28, 2024,

[https://store.steampowered.com/app/1242830/Dry\\_Visit\\_Virtual\\_Underwater\\_Visit\\_iMARECulture/](https://store.steampowered.com/app/1242830/Dry_Visit_Virtual_Underwater_Visit_iMARECulture/).

<sup>125</sup> Bruno et al., “Virtual tour,” 47.

<sup>126</sup> Bruno et al., “Virtual tour,” 49.

<sup>127</sup> Bruno et al., “Virtual tour,” 48.

<sup>128</sup> “Dry Visit Baiae,” iMARE Culture, accessed December 28, 2024, <https://imareculture.eu/downloads/project-tools/dry-visit-baiae/>.



exploration, XR enables museums to cater to diverse audiences, including children, seniors, non-native speakers, and individuals with disabilities.

Museums can amplify their role as inclusive, participatory spaces by leveraging XR's potential to merge storytelling, accessibility, and innovative design. These technologies promise to redefine the visitor experience, ensuring that cultural heritage remains relevant, engaging, and universally accessible in the digital age.

## 4 Beyond the Frame: Transforming Viewer-Art Interaction

Museums, as vital cultural institutions, dedicate substantial resources to crafting exhibitions that make their collections and knowledge accessible to the public.<sup>129</sup> These exhibitions are multifaceted, integrating a diverse array of media such as artifacts, still and moving images, written and spoken text, architectural elements, gestures, movement, and increasingly, virtual and augmented reality. Despite this variety, the core interaction in most exhibitions remains the same: a visitor observing a displayed object, often supported by written or spoken text designed to enhance understanding. While this traditional approach has its merits, it can limit the depth and scope of audience engagement, as it predominantly confines the viewer's role to passive observation.

The restrictions inherent in traditional museum settings stem largely from the need to preserve delicate artifacts, manage physical barriers, and adhere to the static nature of conventional displays.<sup>130</sup> Policies like “Do Not Touch” often prevent audiences from experiencing art in the interactive ways it was originally intended—whether ceremonial objects, tactile garments, or dynamic installations.

Art, in its many forms—painting, sculpture, theater, film, music, and dance, among others—has always been a dynamic and interactive medium. It conveys ideas, experiences, and cultural values in ways that transcend language, acting as a powerful communication system between artist and viewer.<sup>131</sup> Art holds a fundamental role in human culture, enabling individuals to connect with narratives, identities, and shared histories. Even within the confines of traditional museums, art often provokes profound emotional and psychological responses.<sup>132</sup> However, the emergence of XR technologies is revolutionizing this dynamic, offering audiences immersive and interactive ways to engage with collections.

This chapter explores the transformative potential of XR in reshaping viewer-art interaction, fostering emotional connections, and revitalizing the cultural significance of art in society. Through innovative technologies like AR and VR, museums can preserve the integrity of their collections while providing enriched, multisensory experiences that democratize access and expand the reach of art to diverse audiences.

### 4.1 Rethinking the Museum Experience

Throughout history, many forms of art were inherently interactive, designed to invite direct participation and engagement. Musical instruments were meant to be played, haute couture garments worn, ceremonial objects handled during rituals, and architectural spaces inhabited. However, as museums became custodians of cultural heritage, these interactive elements were frequently constrained. Preservation concerns, physical barriers, and institutional policies transformed once-dynamic experiences into primarily visual encounters, limiting the depth of engagement visitors could have with art.

In today's cultural landscape, visitors increasingly seek participatory and inclusive experiences. Advances in digital media and evolving cultural consumption patterns have driven this demand,

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<sup>129</sup> Jennifer Blunden, “Adding ‘something more’ to looking: the interaction of artefact, verbiage and visitor in museum exhibitions,” *Visual Communication* 19, no. 1 (2020): 45-46, <https://doi.org/10.1177/1470357217741938>.

<sup>130</sup> Francesca Bacci and Francesco Pavani, “‘First Hand,’ not ‘First Eye’ Knowledge: Bodily Experience in Museums,” in *The Multisensory Museum: Cross-Disciplinary Perspectives on Touch, Sound, Smell, Memory, and Space*, ed. Nina Levent and Alvaro Pascual-Leone (Rowman & Littlefield, 2014), 17.

<sup>131</sup> Dahlia W. Zaidel, “Art and brain: insights from neuropsychology, biology and evolution,” *Journal of Anatomy* 216, no. 2 (2010): 177, <https://doi.org/10.1111/j.1469-7580.2009.01099.x>.

<sup>132</sup> Marcus T. Pearce et al., “Neuroaesthetics: The Cognitive Neuroscience of Aesthetic Experience,” *Perspectives on psychological science* 11, no. 2 (2016): 265-279, <https://doi.org/10.1177/1745691615621274>.



compelling museums to rethink their traditional roles.<sup>133</sup> Economic pressures, shifting societal values, and the globalized exchange of ideas have further accelerated the need for innovation. Museums are transitioning from static repositories of artifacts to dynamic, interactive spaces that host diverse events, often resembling large-scale international happenings or performances.

This shift began in the mid-20<sup>th</sup> century, as museums started moving beyond their traditional focus on conservation.<sup>134</sup> In *Experience or Interpretation*, Nicholas Serota highlights how contemporary museums now prioritize stimulating emotional and sensory connections through performative and immersive elements.<sup>135</sup> In this new paradigm, the interaction between visitors and artifacts takes precedence. Museums are no longer passive spaces for observation; instead, they are becoming environments where visitors actively participate, engaging directly with art and performances in ways that create meaningful and lasting impressions.

The advent of XR technologies has propelled this evolution to new heights, enabling museums to bridge the gap between traditional practices and contemporary expectations. XR allows audiences to experience art in ways that transcend physical limitations—offering multiple perspectives, close-ups of intricate details, and interactive engagement with artworks that would otherwise be out of reach.<sup>136</sup>

By merging the physical and digital realms, XR creates hybrid experiences that democratize access to art, making it more inclusive and accessible to diverse audiences. These technologies enrich appreciation and understanding, empowering museums to reimagine the visitor experience as dynamic, participatory, and deeply immersive.

## 4.2 Interacting with Haute Couture: Breaking the “Do Not Touch” Rule

Museums are increasingly adopting strategies to make exhibitions more immersive and engaging by expanding beyond traditional visual interactions. They are now incorporating auditory, tactile, olfactory, and other sensory dimensions to create multidimensional experiences with artifacts.<sup>137</sup> This evolution reflects a broader “sensory turn” in museum studies, emphasizing the significance of sensory and embodied interactions in enhancing visitor engagement.<sup>138</sup>

Research in sensory studies has underscored the significance of integrating multi-sensory and immersive elements into exhibition design. As scholars like David Howes and Constance Classen argue, sensory experiences are deeply intertwined with cultural and social values, offering visitors a richer and more personal connection to the exhibits.<sup>139</sup> By leveraging XR technologies, museums can

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<sup>133</sup> Frederica Dal Falco and Stavros Vassos, “Museums Experience Design: A Modern Storytelling Methodology,” *The Design Journal* 20, no. sup1 (2017): S3977, <https://doi.org/10.1080/14606925.2017.1352900>.

<sup>134</sup> Dal Falco and Vassos, “Museums Experience Design,” S3977.

<sup>135</sup> Nicholas Serota, *Experience or Interpretation: The Dilemma of Museums of Modern Art* (Thames and Hudson, 1997).

<sup>136</sup> Rani et al., “Exploring the Potential of Artificial Intelligence,” 4.

<sup>137</sup> Maholo Uchida and Jingyu Peng, “Feeling the exhibition: Design for an immersive and sensory exhibition experience,” in *The Routledge Handbook of Museums, Media and Communication*, ed. Kirsten Drotner et al. (Routledge, 2019), 306.

<sup>138</sup> The “sensory turn” refers to a scholarly shift in the humanities and social sciences over the past few decades, focusing on the body and senses as integral to human experience, shaped by biological, social, and cultural factors. This interdisciplinary approach has influenced fields like history, anthropology, and museum studies, emphasizing sensory engagement in understanding, communicating, and enhancing experiences, including innovative practices in museums to explore touch, sound, smell, and other sensory dimensions; Uchida and Peng, “Feeling the exhibition,” 307-308.

<sup>139</sup> David Howes is a Canadian anthropologist, legal scholar, and pioneer in the anthropology of the senses, with influential contributions to sensory studies, legal pluralism, and cross-cultural aesthetics; David Howes, *Empire of the Senses: The Sensual Culture Reader* (Berg Publishers, 2005); Constance Classen is a cultural historian specializing in the history of the senses, known for her influential works on sensory studies; Constance Classen, *The Book of Touch* (Berg Publishers, 2005).

now craft environments that stimulate multiple senses, revolutionizing traditional visitor experiences. XR allows for virtual handling of delicate objects, delivering simulated sensory feedback and immersive engagement while ensuring the preservation of artifacts.

The following case study illustrates how AR technology helps museums transcend preservation constraints. By breaking the “Do Not Touch” barrier, AR offers visitors the ability to virtually interact with haute couture garments, providing a uniquely personalized and sensory-rich experience.

### **Case Study: Fashioning San Francisco**

The 2024 exhibition *Fashioning San Francisco: A Century of Style* at the Fine Art Museum of San Francisco offers a compelling example of how AR technology can transform visitor-art interaction.<sup>140</sup> Running from January 20 to August 11, 2024, the exhibition showcases a century of historical costumes and haute couture, but conservation concerns prevent direct physical interaction with the garments. To address this challenge, the museum collaborated with Snap Inc. to implement AR technology, enabling visitors to virtually “wear” these iconic outfits through AR mirrors.<sup>141</sup>

This approach democratizes access to haute couture, a domain often associated with exclusivity and tailored designs for specific body types.<sup>142</sup> Museum director Thomas P. Campbell explains, “Our digital team had the idea of democratizing the exhibition by letting visitors try on the clothes. It allows people to visualize themselves in these garments and helps them understand these dresses in a different way.”<sup>143</sup>

The AR mirrors superimpose digital versions of the garments onto visitors’ reflections in real time, creating an interactive and immersive experience.<sup>144</sup> This innovative feature relies on three key components:

1. **High-Fidelity 3D Reproductions:** Digital replicas of the garments capture intricate details like fabric texture, color, and movement, ensuring an authentic visual experience.
2. **Motion Tracking:** Advanced tracking technology allows the digital garments to respond naturally to visitors’ movements, enabling fluid and realistic interactions.
3. **Seamless Interaction:** The experience is intuitive and requires no additional downloads or apps. Cameras and screens automatically activate the AR interface when visitors step into position.

Visitors virtually “wear” three iconic dresses (Fig. 19), selected for their floor-length, full-sleeve designs, which ensure seamless digital overlays.<sup>145</sup>

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<sup>140</sup> This is the first major presentation of the Fine Arts Museum of San Francisco’s costume collection in over 35 years, featuring designs from iconic fashion figures such as Christian Dior, Alexander McQueen, Christopher John Rogers, Comme des Garçons, and Rodarte; many of which have never been displayed before, celebrating San Francisco’s tradition of self-expression through fashion; “Fashioning San Francisco: A Century of Style,” Exhibitions, FAMSF, accessed December 29, 2024, <https://www.famsf.org/exhibitions/fashioning-san-francisco#about>.

<sup>141</sup> Snap Inc. is a technology company known for its app Snapchat, which focuses on empowering self-expression and visual communication through its innovative camera technology, blending real-world and digital experiences; “Snap Inc.,” Snap Inc., accessed December 29, 2024, <https://www.snap.com/>.

<sup>142</sup> Buffa and Bates, “Using Augmented Reality.”

<sup>143</sup> Min Chen, “De Young Museum’s New Fashion Exhibition Lets Visitors Don Historic Designs With Snap’s A.R.,” *Artnet News*, January 23, 2024, <https://news.artnet.com/art-world/fashioning-san-francisco-de-young-snap-ar-2422348>.

<sup>144</sup> Snap Inc., “Snapchat AR Experience at ‘Fashioning SF’ at de Young Museum,” Promotional video, posted January 24, 2024, YouTube, 1:26, <https://www.youtube.com/watch?v=G5cTgKx1wUs&t=1s>.

<sup>145</sup> Chen, “De Young Museum’s New Fashion Exhibition.”

- Yves Saint Laurent's 1955 "Soirée de Paris" dress for Maison Dior,
- A 1985 lamé evening ensemble by San Francisco designer Kasik Wong,
- A vibrant 1987 Valentino gown.

Curator Laura L. Camerlengo highlights that these garments are chosen to work within AR's current limitations in rendering skin tones and reconstructing body shapes.<sup>146</sup> The designs accommodate all visitors, creating a consistent and inclusive visual experience.



Figure 19. The Snap AR try-on activation at "Fashioning San Francisco: A Century of Style," featuring models in designs [from left] by Kasik Wong, Valentino, and Yves Saint Laurent.

The development process begins with extensive photography of the dresses, which Snap's lens team uses to create photorealistic 2D reproductions. Collaboration with the museum's curatorial team ensures the AR animations preserve the integrity of the designs while incorporating subtle enhancements to deliver an engaging and magical experience.<sup>147</sup>

Inclusivity is central to the project. Snap tested the AR lenses with a diverse group of individuals to ensure the digital garments adapt seamlessly to varying heights and body types. Advanced tracking technology recognizes visitors' silhouettes based on their attire, enabling responsive interactions without compromising privacy. No personal data or tracking information is stored or shared.<sup>148</sup>

The AR mirrors are housed in private nooks styled after luxury dressing rooms (Fig. 20), designed by lead exhibition designer Julia Pike.<sup>149</sup> Located in the Piazzoni Mural Room, these intimate spaces provide an elegant setting for visitors to interact with the technology. Visitors step in front of the mirrors, where digital garments gradually appear over their reflections. A camera button allows them to capture photos, which they can save by scanning a QR code. Museum docents assist less tech-savvy visitors, ensuring the experience is accessible to everyone.<sup>150</sup>

<sup>146</sup> Kendra Smith, "De Young Museum exhibit lets you pose in Valentino, courtesy of Snap," *SFGATE*, January 24, 2024, <https://www.sfgate.com/sf-culture/article/snap-exhibit-fashioning-sf-de-young-18613554.php>.

<sup>147</sup> The curatorial team comprises Camerlengo, Talia Spielholz, and lead conservator Beth Szubay.

<sup>148</sup> Smith, "De Young Museum."

<sup>149</sup> Buffa and Bates, "Using Augmented Reality."

<sup>150</sup> Smith, "De Young Museum."

This immersive interaction lets visitors twirl and see the garments move naturally with their bodies, adding a dynamic and personalized dimension to the exhibition. Visitors praise the lifelike flow of the Yves Saint Laurent dress and the sense of weight conveyed by the Valentino gown.<sup>151</sup> Rajni Jacques, Snap's global head of fashion and beauty, remarks that the AR mirrors transcend passive observation, encouraging active engagement and enhancing the exhibition's storytelling and emotional resonance.<sup>152</sup>



Figure 20. Installation view of “Fashioning San Francisco: A Century of Style.”

The AR mirrors inspire considerable social media engagement, with visitors often selecting their outfits carefully to capture eye-catching photos.<sup>153</sup> Fitted, low-cut attire tends to yield the best results, while darker clothing enhances contrast, allowing the AR technology to detect silhouettes more accurately. Many guests share their images online, creating a viral feedback loop that attracts new audiences. This fusion of physical and digital experiences underscores the evolving role of screens in museums and the rising trend of museum selfies. To further capitalize on this momentum, the museum hosted a pre-opening event for local creators and influencers, sparking online engagement with a potential reach exceeding one million users.<sup>154</sup>

The AR installation attracted an average of 500 visitors daily, with 30% attending specifically for the AR experience.<sup>155</sup> Feedback remains overwhelmingly positive, with many praising the unique and enjoyable interaction. An unexpected outcome of the AR installation is its ability to connect diverse, cross-generational audiences. Younger visitors, adept with digital tools, frequently assist older attendees in navigating the AR experience, fostering meaningful intergenerational interaction. This demonstrates the potential of XR technologies—often seen as catering to specific age groups—to unite people of different generations in a shared, tangible experience.

<sup>151</sup> Chen, “De Young Museum’s New Fashion Exhibition.”

<sup>152</sup> Chen, “De Young Museum’s New Fashion Exhibition.”

<sup>153</sup> Smith, “De Young Museum.”

<sup>154</sup> Buffa and Bates, “Using Augmented Reality.”

<sup>155</sup> Buffa and Bates, “Using Augmented Reality.”



### 4.3 Enhancing Emotional Connection Through VR

Through XR technologies, museums are redefining visitor engagement by allowing individuals to step into historical contexts and artistic processes. This approach goes beyond traditional passive observation, offering personalized experiences that resonate on emotional, intellectual, and physical levels. Digital storytelling—leveraging tools such as avatars, virtual tours, and interactive narratives—helps visitors feel a sense of ownership over their journey, facilitating memorable and impactful connections with the exhibits.<sup>156</sup>

When visitors shift from being mere spectators to active participants, they transition from passive value judgment to active value generation. This intrinsic value, derived primarily from immersive activities, provides pleasure and a sense of escape from everyday life.<sup>157</sup> By unlocking new possibilities in digital storytelling, XR opens access to unique cultural experiences and spaces that were once beyond reach. Additionally, immersive technologies enable interactions and functions unavailable in everyday life, offering extraordinary avenues for exploration and engagement.<sup>158</sup>

The following case study exemplifies the potential of VR to craft these transformative experiences. At the Musée d'Orsay, the *Van Gogh's Palette* VR installation revolutionizes the exploration of Van Gogh's art through an immersive, story-driven approach. By integrating interactive storytelling with cutting-edge VR technology, *Van Gogh's Palette* creates a dynamic environment where visitors can directly engage with the artist's creative process.

#### **Case Study: Van Gogh's Palette**

VR technologies provide an innovative platform for creating immersive art experiences, exemplified by *Van Gogh's Palette*, a VR installation developed for the Musée d'Orsay to complement the "Van Gogh at Auvers-sur-Oise" exhibition.<sup>159</sup> This installation merges education with immersive entertainment—or "edutainment"—to offer visitors an engaging and dynamic exploration of Van Gogh's works and creative process.<sup>160</sup>

To accommodate diverse visitor preferences, the museum provides two tailored VR formats: a concise 10-minute experience focused on Van Gogh's final months and an extended 20-minute version covering his entire life.<sup>161</sup> This adaptability allows the museum to manage high visitor volumes effectively while offering a deeply customizable interaction with the artist's work.

The VR journey begins as visitors put on headsets and are transported into a meticulously recreated version of Dr. Gachet's living room, constructed from archival resources.<sup>162</sup> This location

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<sup>156</sup> James Hutson and Piper Hutson, "Museums and the Metaverse: Emerging Technologies to Promote Inclusivity and Engagement," in *Application of Modern Trends in Museums*, ed. Ladislav Župčán (IntechOpen, 2023), 37, <http://dx.doi.org/10.5772/intechopen.104681>.

<sup>157</sup> Zeya He et al., "When art meets tech: The role of augmented reality in enhancing museum experiences and purchase intentions," *Tourism Management* 68 (2018): 128, <https://doi.org/10.1016/j.tourman.2018.03.003>.

<sup>158</sup> Montagud et al., "Culture 4 all," 892.

<sup>159</sup> The exhibition, held from October 3, 2023, to February 4, 2024, was the first to focus on the artist's prolific final two months, showcasing over 40 paintings and 20 drawings created during a period of profound artistic renewal and personal struggle; "Exposition Van Gogh à Auvers-sur-Oise Les derniers mois," Expositions, Musée d'Orsay, accessed December 29, 2024, <https://www.musee-orsay.fr/fr/agenda/expositions/van-gogh-auvers-sur-oise>.

<sup>160</sup> "Exposition Réalité virtuelle – La Palette de Van Gogh," Expositions, Musée d'Orsay, accessed December 29, 2024, <https://www.musee-orsay.fr/fr/agenda/expositions/realite-virtuelle-la-palette-de-van-gogh>.

<sup>161</sup> Agnès Abastado et al., "How to Bring VR into a Major Cultural Institution," Museum XR Summit 2024, *MuseumNext*, Virtual Conference, June 26, 2024, <https://museumnext.mn.co/posts/museum-xr-summit-how-to-bring-vr-into-a-major-cultural-institution>.

<sup>162</sup> VIVE Arts, "Behind the Scenes – La Palette de Van Gogh," video, posted December 1, 2023, YouTube, 5:37, <https://www.youtube.com/watch?v=eW31oVQ5erM>.

holds particular significance, as it is where Van Gogh used his final palette to complete the portrait of Marguerite Gachet, Dr. Gachet's daughter. Marguerite's voice serves as the narrator, offering an intimate perspective on Van Gogh's creative state.<sup>163</sup> Her narration provides a poignant touch, as she was one of the last individuals to truly know the artist.

Participants are invited to pick up Van Gogh's final palette from the table (Fig. 21), a symbolic gateway into his "pigment landscape," which represents his inner world.<sup>164</sup> In this immersive VR environment, the palette transforms into an expansive, walkable landscape that participants can explore.<sup>165</sup>

Within this vivid setting, visitors interact with five iconic works from Van Gogh's time in Auvers-sur-Oise: *Marguerite at the Piano* (Fig. 22), *The Church at Auvers* (Fig. 23), *Portrait of Dr. Gachet* (Fig. 24), *Wheatfield with Crows* (Fig. 25), and *Roots* (Fig. 26). Guiding them through this journey is *The Kingfisher* (Fig. 27), an element drawn from Van Gogh's work held at the Van Gogh Museum in Amsterdam. This virtual guide leads visitors to different areas of the palette and highlights interactive features embedded within the experience.<sup>166</sup>

By blending narrative storytelling with interactive engagement, the VR installation invites participants into Van Gogh's studio to experience his artistic process in ways that are impossible in traditional museum settings, offering a uniquely immersive and transformative encounter with his art.

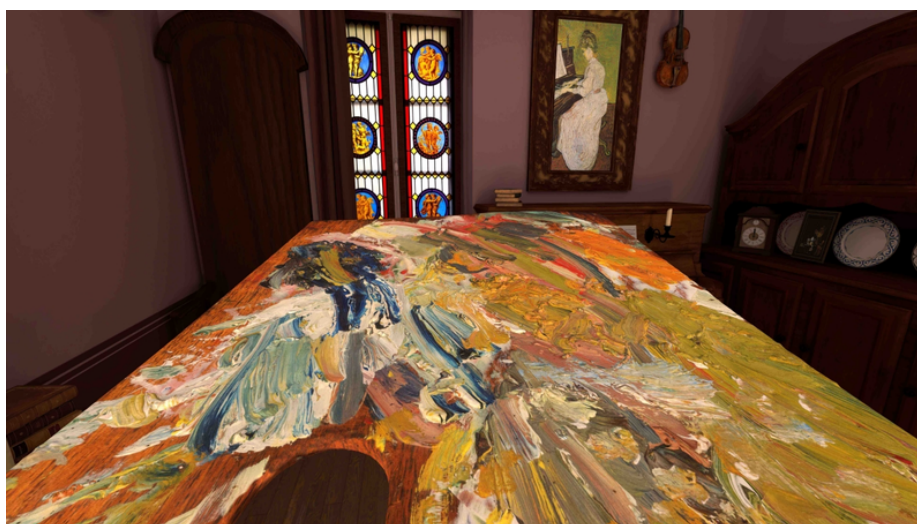


Figure 21. Van Gogh's palette in the VR recreation of Dr. Gachet's living room.

The VR experience enables visitors to interact directly with Van Gogh's artistry through three key journeys:<sup>167</sup>

1. **Perspective Alternation:** Visitors can explore altered viewpoints within paintings such as *The Church at Auvers*.
2. **Color Experimentation:** A virtual palette allows participants to mix colors, offering insights into Van Gogh's chromatic choices.
3. **Brushstroke Simulation:** Visitors simulate Van Gogh's brush techniques, engaging their whole body in the creative process.

<sup>163</sup> VIVE POST-WAVE Team, "Van Gogh's Palette: Blending Paintings, Letters, and VR at the Musée d'Orsay," VIVE, December 21, 2023, <https://blog.vive.com/us/van-gogh-exhibition-at-musee-dorsay-exploring-his-last-days-and-letters/>.

<sup>164</sup> VIVE Arts, "Behind the Scenes."

<sup>165</sup> Lucid Realities, "Van Gogh's Palette," Teaser video, posted November 9, 2023, Vimeo, 00:37, <https://vimeo.com/882907431>.

<sup>166</sup> Musée d'Orsay, "Exposition Réalité virtuelle."

<sup>167</sup> Musée d'Orsay, "Version 360° de la Palette de Van Gogh," video adaption of the VR experience, posted January 29, 2024, YouTube, 8:10, <https://www.youtube.com/watch?v=CESTuX2nlqM&t=10s>.



These interactions provide a deeper, intuitive understanding of Van Gogh's methods, making the art accessible to casual viewers and enthusiasts alike.<sup>168</sup> Marguerite's voice guides visitors through the emotional and technical layers of each piece, fostering intellectual and emotional connections with Van Gogh's work.

The musical accompaniment features Liszt's transcriptions of Wagner operas, reflecting Vincent Van Gogh's admiration for the composer.<sup>169</sup> These melodies are reworked—either slowed down or sped up—to evoke the sense of disorientation and suspended time that characterized Van Gogh's creative process. This auditory layer enhances the immersive atmosphere, deepening the emotional resonance of the experience.

Unlike many VR installations that invite visitors to "step into" a painting, *Van Gogh's Palette* takes a distinctive approach by immersing the audience in the artist's palette rather than his canvases. Chloé Jarry, a project developer from Lucid Realities, explains, "The palette is not the artwork; it's a tool. We can play with this tool and let the audience enter the palette, while art is something that needs to be learned how to observe."<sup>170</sup> This perspective preserves the integrity of Van Gogh's two-dimensional works while offering a fresh way to explore his techniques and creative vision.

An additional advantage of focusing on the palette instead of the paintings is the freedom it provides to experiment without the ethical concerns of altering or "touching" his original works. This choice allows the creators to innovate while remaining respectful of Van Gogh's artistic legacy.<sup>171</sup>

To bring the palette to life, photogrammetry software was employed to recreate its texture and materiality in 3D.<sup>172</sup> This advanced technology captures minute variations in brushstrokes and color, adding authenticity and sensory depth to the VR experience (Fig. 28).

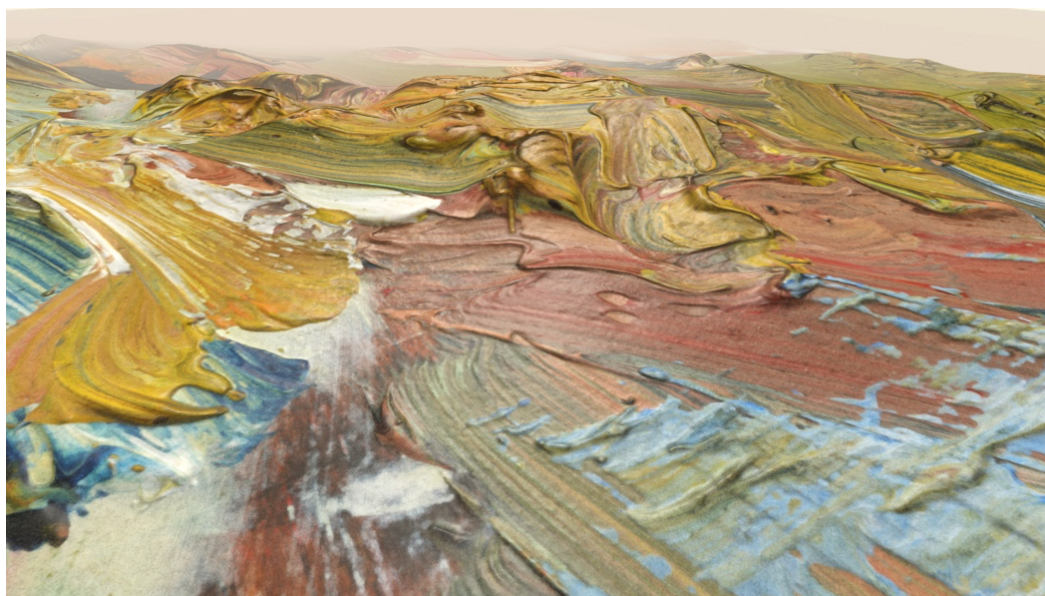


Figure 28. Van Gogh's palette transformed into a walkable 'pigment landscape' in VR.

The success of *Van Gogh's Palette* is a testament to a well-coordinated public-private partnership.<sup>173</sup> The Musée d'Orsay collaborated with Lucid Realities, Unframed Collection, TSVP, and

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<sup>168</sup> Musée d'Orsay, "Exposition Réalité virtuelle."

<sup>169</sup> Musée d'Orsay, "Exposition Réalité virtuelle."

<sup>170</sup> VIVE, "Van Gogh's Palette."

<sup>171</sup> VIVE Arts, "Behind the Scenes."

<sup>172</sup> Musée d'Orsay, "Exposition Réalité virtuelle."

<sup>173</sup> Jim Richardson, "Virtual Reality at the Musée d'Orsay: Van Gogh's Palette," *MuseumNext*, July 13, 2024, <https://www.museumnext.com/article/virtual-reality-at-the-musee-dorsay-van-goghs-palette/>.

ViveArts to bring the project to life.<sup>174</sup> Responsibilities ranged from scripting and securing funding to production and visitor integration.

The Unframed Collection team managed the VR installation's design and logistics, ensuring seamless integration into the museum's visitor flow. Positioned near the main exhibition entrance, the VR setup included 12 headsets running continuous sessions, accommodating up to 400 visitors daily. The experience was supported by user-friendly furnishings, trained facilitators, and custom management systems, minimizing wait times and enhancing accessibility.

Two mediators assisted visitors with the VR equipment, providing a welcoming and smooth experience.<sup>175</sup> Accessibility considerations included wheelchair accommodations, through the experience was restricted for children under eight and not recommended for individuals with certain medical conditions.<sup>176</sup>

Van Gogh's Palette attracted over 40,000 participants, achieving a 98% satisfaction rate.<sup>177</sup> Surveys revealed that 64% of visitors were influenced to attend the museum because of the VR experience, while 9% stated they would not have visited otherwise. The exhibition broke attendance records for the Musée d'Orsay, marking its highest visitor engagement in 40 years.

The VR installation allowed visitors to connect with Van Gogh's art on a deeply personal level. By stepping into the immersive pigment landscape, participants gained unique insights into his emotional depth and artistic techniques. This interactive, sensory-rich approach makes complex artistic concepts more accessible and demonstrates the potential of XR as an educational and engagement tool.

#### 4.4 The Future of Viewer-Art Interaction

The integration of XR technologies in exhibitions like *Fashioning San Francisco* and *Van Gogh's Palette* underscores the transformative potential of these tools in redefining the relationship between viewers and art. These technologies deepen insights into artworks, foster emotional connections, and create memorable, interactive encounters that transform museums into dynamic hubs for learning and exploration.

As XR technologies continue to advance, their capacity to drive innovation, foster cross-generational connections, and enhance social interaction in museum settings will only grow. By embracing XR, museums can redefine their role in the digital age, leveraging technology to engage audiences in new ways while ensuring that art remains a vital, inclusive, and accessible part of human culture. This forward-thinking approach positions XR as a cornerstone in the evolution of museum experiences, bridging the gap between tradition and innovation.

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<sup>174</sup> Lucid Realities, part of the CLPB Media Group and based in Paris, is an immersive production and distribution company, known for pioneering XR experiences that blend innovation, storytelling, and edutainment; "Lucid Realities Studio," Lucid Realities, accessed December 29, 2024, <https://lucidrealities.studio/>; Unframed Collection is the first VOD platform dedicated to distributing VR experiences to cultural venues; "About," Unframed Collection, accessed December 29, 2024, <https://unframed-collection.com/en/about>; Tournez S'il Vous Plaît (TSVP) is a French production company specializing in acclaimed documentaries and award-winning feature films; "All About Us," TSVP, accessed December 29, 2024, <https://tsvp-prod.com/all-about-us/>; VIVE Arts is a platform dedicated to integrating art with cutting-edge technologies like XR, enabling innovative artistic experiences, preserving cultural heritage, and expanding global access to art through digital innovation; "Home VIVE," VIVE Arts, accessed December 29, 2024, <https://www.vivearts.com/>.

<sup>175</sup> Richardson, "Virtual Reality at the Musée d'Orsay."

<sup>176</sup> VR experiences are not recommended for pregnant individuals, or those prone to epileptic seizures, migraines, or with balance or vision disorders; Musée d'Orsay, "Exposition Réalité virtuelle."

<sup>177</sup> Richardson, "Virtual Reality at the Musée d'Orsay."

## 5 Transforming Learning Experiences

Museums have long been celebrated as guardians of knowledge, yet their educational role has undergone significant transformation.<sup>178</sup> Education today transcends traditional frameworks, seeking innovative ways to engage individuals of all ages and backgrounds. Once reliant on a didactic model that positioned collections as authoritative and unchanging, museums now prioritize dialogue, interactivity, and participatory engagement.<sup>179</sup> This evolution aligns with lifelong learning trends that emphasize experiential, self-directed exploration over rigid, formal structures.

By addressing themes such as diversity, ecology, and visual literacy, museums have become dynamic spaces for critical thinking and personal development.<sup>180</sup> Their role has shifted from being mere conveyors of information to serving as guides that empower visitors to critically evaluate and interpret knowledge. Art museums now encourage reflection on evolving definitions of art and cultural value, while science museums invite visitors to engage directly with scientific concepts. These experiences cultivate a deeper understanding of history, culture, and the world, shaping informed and reflective citizens.<sup>181</sup>

As visitors increasingly seek personalized and meaningful learning opportunities, museums must balance their role as custodians of knowledge with their commitment to fostering exploration and dialogue. XR technologies present exciting opportunities to enhance this balance. VR can immerse audiences in reconstructed historical settings, while AR overlays add rich contextual depth to physical artifacts. Research underscores the educational benefits of these technologies; for example, a University of Maryland study found an 8.8% improvement in information retention through VR experiences.<sup>182</sup> These insights highlight XR's potential to make learning not only more effective but also more engaging and memorable.

This chapter delves into the evolving relationship between museums and education in the digital age, exploring the “educational turn” in the art world, the complexities of balancing truth and fiction in XR storytelling, and the transformative role of interactivity. By exploring how XR can redefine learning in museum settings, this chapter underscores the potential of these technologies to create accessible, engaging, and deeply impactful experiences for diverse audiences.

### 5.1 Museums and the Educational Framework

The role of museums as educational institutions has long been acknowledged, evolving significantly since the advent of public museums.<sup>183</sup> In the 18<sup>th</sup> century, museums primarily catered to the entertainment of the privileged and educated elite. With the emergence of nation-states in the 19<sup>th</sup> century, museums began to adopt broader educational missions. Early public museums, though often with limited access, served as symbols of governmental power and wealth, showcasing art, science, and industry to highlight national achievements. By the mid-19<sup>th</sup> century, industrialization and urbanization brought new societal challenges, prompting governments to view museums as instruments of public education and social betterment. They became part of a network of institutions aimed at equipping citizens to navigate and appreciate modern life.

By the late 19<sup>th</sup> century, museums were firmly established as educational institutions with significant social responsibilities.<sup>184</sup> However, their pedagogical approach relied heavily on didactic

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<sup>178</sup> Van Oost, *Volop inzetten op musea*, 13.

<sup>179</sup> Hooper-Greenhill, *Museums and the Interpretation of Visual Culture*, chap 1.

<sup>180</sup> Van Oost, *Volop inzetten op musea*, 13.

<sup>181</sup> Jambon, *Strategische Visienota Cultureel Erfgoed*, 38.

<sup>182</sup> Eric Krokos et al., “Virtual memory palaces: immersion aids recall,” *Virtual Reality* 23, no. 1 (2019): 12, <https://doi.org/10.1007/s10055-018-0346-3>.

<sup>183</sup> George E. Hein, *Learning in the Museum* (Routledge, 1998), Introduction, Kobo, <https://doi.org/10.4324/9780203028322>.

<sup>184</sup> Hooper-Greenhill, *Museums and the Interpretation of Visual Culture*, chap 1.

methods, with the assumption that presenting objects in an authoritative manner would inherently lead to learning. Exhibits often reflected universalist ideals, addressing homogeneous audiences with limited consideration for individual or cultural differences.

In contrast, modern educational perspectives prioritize the diverse needs and experiences of visitors. Contemporary approaches emphasize participatory and relational strategies, recognizing that visitors bring unique interpretations and cultural contexts to their museum encounters. This shift aligns with broader trends in lifelong and informal learning, where knowledge acquisition is seen as an ongoing, experiential process rather than confined to formal educational settings.<sup>185</sup>

Today, cultural education in museums serves dual purposes: imparting discipline-specific knowledge and using art and culture as tools to develop critical thinking, empathy, and other broad skills.<sup>186</sup> These objectives are deeply entwined with societal contexts, reflecting and challenging cultural norms. Museums increasingly embrace the idea of art as a participatory experience, fostering collaborative meaning-making and redefining how audiences interact with collections.

The notion of an “educational turn” in the art world, as theorized by Irit Rogoff in 2008, encapsulates this evolving dynamic.<sup>187</sup> It marks a shift in how art, curators, audiences, and institutions interact.<sup>188</sup> Art is no longer seen merely as an object for aesthetic appreciation but as a medium for critical dialogue, creativity, and social engagement. Rogoff emphasizes that this turn reflects broader societal changes, using art institutions to respond to new political, social, and institutional contexts.<sup>189</sup>

This perspective resonates with John Dewey’s philosophy of art as “an experience.”<sup>190</sup> Dewey views art as a deeply interactive process, where exploration and engagement foster intellectual growth and reflection.<sup>191</sup> For Dewey, true learning arises in environments where individuals connect with knowledge in personally meaningful ways, transforming information into something they can question, reinterpret, and integrate into their own understanding. In this framework, art becomes a tool not only for aesthetic appreciation but also for raising awareness, stimulating critical thought, and fostering creativity within society.

Dewey’s ideas challenge traditional, hierarchical models of knowledge transmission, where information flows unidirectionally from expert to audience.<sup>192</sup> Instead, he envisions knowledge as a collaborative and multidirectional process. In this model, artists, curators, and audiences contribute equally to the interpretive experience. Art educates not by dictating meaning but by empowering individuals to question, analyze, and explore.

The educational turn has redefined the roles of curators and visitors alike. As Paul O’Neill and Mick Wilson note in *Curating and the Educational Turn*, curators are no longer mere custodians of knowledge.<sup>193</sup> Instead, they act as facilitators of meaning-making, fostering open-ended inquiry and

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<sup>185</sup> Hooper-Greenhill, *Museums and the Interpretation of Visual Culture*, chap 1.

<sup>186</sup> Joke Schauvliege and Pascal Smet, *Groeien in cultuur: conceptnota cultuureducatie*, ACCE and CANON Cultuurcel, 2012, 13, [https://www.vlaanderen.be/cjm/sites/default/files/2020-01/Cultuureducatie\\_conceptnota-groeien-in-cultuur\\_2012.pdf](https://www.vlaanderen.be/cjm/sites/default/files/2020-01/Cultuureducatie_conceptnota-groeien-in-cultuur_2012.pdf).

<sup>187</sup> Irit Rogoff is a pioneering scholar in the field of Visual Culture and a prominent voice in transdisciplinary approaches to knowledge production, with influential work spanning visual culture, curatorial practices, and critical geography; Irit Rogoff, “Turning,” *e-flux Journal*, no. #0 (2008), <https://www.e-flux.com/journal/00/>.

<sup>188</sup> Dragana Stojanović, “Educational Turn in Art: Turning art into the production of a new knowledge,” *Zbornik radova Akademije umetnosti*, no. 5 (2017): 57, <https://doi.org/10.5937/ZbAkUm1705056S>.

<sup>189</sup> Irit Rogoff, “Turning,” 48.

<sup>190</sup> John Dewey (1859-1952) was an American psychologist, and educational reformer, a leading figure in pragmatism and functional psychology, whose influential works on democracy, education, and progressive pedagogy reshaped modern thought on society and learning; John Dewey, *Art as Experience* (Perigee Books, 1980).

<sup>191</sup> Stojanović, “Educational Turn in Art,” 58.

<sup>192</sup> Stojanović, “Educational Turn in Art,” 58.

<sup>193</sup> Paul O’Neill is a Bristol-based curator, artist, and writer known for his extensive work on curatorial practice; Mick Wilson is an artist, writer, educator, and Dean of the Graduate School of Creative Arts and Media in Dublin, known for his exhibitions and publications on curatorial practice, cultural



encouraging diverse interpretations. Visitors, in turn, are no longer passive recipients of information but active participants who shape their own interpretations of artworks.

From Rogoff's perspective, the educational turn in art introduced the idea of "opening," a collaborative process of generating new knowledge through engagement.<sup>194</sup> Rogoff emphasizes that the educational value of art lies in its accessibility and its potential to inspire fresh insights and understanding. This shift dismantles traditional hierarchies, transforming art into a shared, participatory experience. The artist is no longer viewed as a solitary genius, nor is the critic the sole arbiter of value. Similarly, visitors are no longer a passive audience awaiting explanation; they become co-creators of meaning. In this framework, museums evolve into dynamic spaces for dialogue and discovery, where the act of interacting with art holds as much significance as the art itself.

Eilean Hooper-Greenhill underscores the importance of deeply engaging with audiences to create meaningful educational experiences.<sup>195</sup> This requires understanding visitors' perspectives and incorporating them into the interpretive process. By recognizing the diverse ways in which people make sense of their museum experiences, institutions can design programs that resonate intellectually and emotionally.<sup>196</sup>

Achieving this balance involves blending traditional cultural practices with innovative pedagogical methods. Hands-on and "minds-on" activities are integral to fostering active participation and intellectual stimulation.<sup>197</sup> The goal is to create structured experiences that are engaging and thought-provoking, ensuring that entertainment enhances rather than overshadows the museum's educational mission.

This paradigm shift extends to the integration of digital tools, including XR technologies, within museum education. XR holds the promise of creating immersive and interactive learning experiences, but its implementation must enhance rather than overshadow the educational content. Jane Alexander, Chief Information Officer at the Cleveland Museum of Art, aptly states, "The best use of digital is to not make you aware of the technology, but to make you aware of the art."<sup>198</sup> Thoughtfully crafted XR experiences should enrich visitors' understanding, fostering critical inquiry and engagement while staying aligned with the museum's core mission.

## 5.2 Balancing Truth and Fiction in XR Experiences

Designing XR-based museum experiences involves navigating the delicate balance between historical accuracy and creative storytelling. Museums are tasked with preserving historical truths while also engaging diverse audiences through compelling narratives. XR technologies amplify this challenge, as gamified elements and immersive storytelling can blur the line between factual and fictional embellishments. To maintain this balance, educators and curators must carefully distinguish between authentic historical data and interpretative elements, ensuring clarity for the audience.

Cultural heritage institutions are increasingly adopting polyphonic approaches, presenting multiple perspectives to connect past narratives with contemporary audiences.<sup>199</sup> This methodology acknowledges that heritage holds varied meanings, shaped by individual experiences, biases, and cultural assumptions. By linking visitors' personal "backpacks" of knowledge to the interpretative process, museums create opportunities for diverse viewpoints to flourish. However, this inclusivity must

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discourse, and free expression; Paul O'Neill and Mick Wilson, "Introduction," in *Curating and the Educational Turn*, ed. Paul O'Neill and Mick Wilson (Open Editions, 2010), 14.

<sup>194</sup> Stojanović, "Educational Turn in Art," 61.

<sup>195</sup> Hooper-Greenhill, *Museums and the Interpretation of Visual Culture*, chap 1.

<sup>196</sup> Hein, *Learning in the Museum*, Introduction.

<sup>197</sup> Hein, *Learning in the Museum*, Introduction.

<sup>198</sup> Kelly Song, "Virtual reality and Van Gogh collide – technology is turning museums into a booming industry," *CNBC*, September 24, 2017, <https://www.cnn.com/2017/09/22/how-technology-is-turning-museums-into-a-booming-industry.html>.

<sup>199</sup> Jambon, *Strategische Visienota Cultureel Erfgoed*, 35-36.



not come at the expense of historical integrity. Well-designed XR experiences can foster interactive storytelling that engages visitors without compromising factual accuracy.

### **Case Study: The Secret Excavation**

An exemplary model of balancing historical accuracy with storytelling is the interactive game *The Secret Excavation*, developed by NUMENA for the Franziskanermuseum in Villingen-Schwenningen, Germany.<sup>200</sup> The game delivers historical content through a captivating fictional narrative, ensuring that factual information remains transparent and accessible.<sup>201</sup> The developers prioritized fidelity to historical truths, aiming to faithfully reflect the information provided in museum displays and labels. However, to enhance interactivity and immersion, they introduced fictional elements, enriching the narrative without compromising accuracy. In this context, a museum visit becomes as much about storytelling as it is about history. Importantly, the game avoids portraying characters or reconstructions as absolute truths, instead emphasizing the fluidity and multiple perspectives that history often encompasses.

To achieve this balance between authenticity and creativity, the developers adhered to four foundational principles:

1. **Distinguishing Fact from Fiction:** The game design maintains a clear separation between historical accuracy and fictional storytelling, enabling players to discern what is grounded in fact. This distinction is achieved either intrinsically, integrated into the narrative itself, or extrinsically, presented alongside the story. For example, in *The Secret Excavation*, players engage with Dr. Wagner, a character representing factual perspectives by articulating information sourced directly from museum labels. Her role contrasts with a fictional AI-generated Celtic prince, creating a dialogue that prompts players to evaluate differing viewpoints.<sup>202</sup> Similarly, in *The Lost Pathway*, another game for the same museum, this separation is extrinsically reinforced through color-coded text that visually distinguishes between the fictional story and historical evidence.<sup>203</sup>
2. **Consistent Narrative Arc:** The overarching story remains entirely fictional, deliberately avoiding any potential confusion between the narrative and historical facts.
3. **Historical Facts as Decision Points:** Key gameplay moments are anchored in accurate historical details, requiring players to engage deeply with authentic content. In *The Secret Excavation*, players are tasked with locating and scanning objects within the museum, integrating the virtual experience with the physical artifacts. This design ensures players remain connected to the historical material as they examine objects, solve puzzles, and make decisions grounded in factual information.
4. **A Play Space for Interpretation:** The fictional elements are crafted to invite diverse interpretations, providing a conceptual “play space” where players can explore multiple

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<sup>200</sup> NUMENA is an award-winning creative studio specializing in VR and AR applications, driven by a fascination with the intersection of 3D space, technology, and human experience; “NUMENA,” NUMENA, accessed December 31, 2024, <https://www.numena.de/>; NUMENA, “The Secret Excavation TEASER: An Augmented Reality Game at the Franziskaner Museumnum,” Teaser video, posted September 16, 2022, YouTube, 00:53, <https://www.youtube.com/watch?v=3WfXlxO2dXo>.

<sup>201</sup> Andreea Ion Cojocaru, “Truth vs Fiction in Narrative XR for Museums,” Museum XR Summit 2024, MuseumNext, Virtual Conference, June 26, 2024, <https://museumnext.mn.co/posts/museum-xr-summit-truth-vs-fiction-in-narrative-xr-for-museums>.

<sup>202</sup> NUMENA, “The Secret Excavation: An AR Game about the German Celts at the Franziskaner Museum,” video, posted October 17, 2023, YouTube, 6:49, [https://www.youtube.com/watch?v=y1hBPXIA\\_do&t=13s](https://www.youtube.com/watch?v=y1hBPXIA_do&t=13s).

<sup>203</sup> NUMENA, “Der verlorene Pfad (The Lost Pathway),” Teaser video, posted October 23, 2023, YouTube, 00:55, <https://www.youtube.com/watch?v=Ih1khN8wmnM>.

perspectives and meanings. This approach encourages personal reflection while broadening the scope of engagement.

Visitors engage in activities like scanning artifacts, solving puzzles, and making choices based on historical facts, bridging the gap between interactive gameplay and museum education. The experience not only strengthens connections between digital and physical artifacts but also fosters reflection on the complexities of historical interpretation.

A standout feature of *The Secret Excavation* is its exploration of the boundaries between historical truth, interpretation, and imagination. The inclusion of the AI-generated character encourages players to consider how speculative reconstructions intersect with historical fact.

Unlike traditional exhibits where additional information is accessed through static features such as panels or buttons, XR experiences embed content directly within the narrative. This integration enhances immersion, keeping audiences engaged while grounding the storytelling in factual contexts.<sup>204</sup>

### 5.3 Learning as an Active Process

Modern museum education emphasizes the shift from passive observation to active engagement, with XR technologies driving this transformation. These tools allow visitors to explore, problem-solve, and connect deeply with educational content, fostering curiosity, enhancing comprehension, and improving knowledge retention in ways that traditional methods often cannot achieve.<sup>205</sup>

George E. Hein's constructivist approach highlights the active nature of learning, where individuals integrate new knowledge with their prior experiences and understanding.<sup>206</sup> Rather than prescribing fixed learning outcomes, constructivism emphasizes the value of environments that encourage visitors to reconstruct meaning through interactions with objects, spaces, and social contexts. Hein asserts that every element of a museum—its architecture, exhibitions, and atmosphere—elicits emotions, memories, and reflections, all of which shape the learning experience. Constructivist learning thrives both the mind and body are engaged, prioritizing experimentation and exploration over rigid, predetermined outcomes. Museums, therefore, should foster intellectually stimulating environments that inspire critical thinking while respecting the diverse and subjective interpretations of their visitors.

John H. Falk and Lynn D. Dierking's **Contextual Model of Learning** (Fig. 29) complements Hein's framework, identifying three overlapping contexts that shape museum learning: personal, socio-cultural, and physical.<sup>207</sup> The personal context includes motivations, prior knowledge, and the sense of control that enables visitors to navigate free-choice environments.<sup>208</sup> The socio-cultural context emphasizes group interactions and social mediation, which can enhance or hinder learning experiences.<sup>209</sup> The physical context involves the museum's design, orientation aids, and external reinforcement, creating secure and engaging spaces that support exploration.<sup>210</sup> Learning, according

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<sup>204</sup> Cojocaru, "Truth vs Fiction."

<sup>205</sup> Edström, "Memories of Mexico."

<sup>206</sup> George E. Hein is a prominent figure in museum education and evaluation, known for founding the Program Evaluation and Research Group (PERG) and for his influential work on qualitative evaluations and visitor research in museums; Hein, *Learning in the Museum*, chap 8.

<sup>207</sup> John Howard Falk is renowned for his expertise in free-choice learning and research on the community impacts of museums, libraries, zoos, and aquariums; Lynn Diane Dierking is a leading researcher in free-choice and lifelong learning, known for her contributions to museum education; John H. Falk and Lynn D. Dierking, *The Museum Experience Revisited* (Routledge, 2013), 26-34, <https://doi.org/10.4324/9781315417851>.

<sup>208</sup> Falk and Dierking, *The Museum Experience Revisited*, 27.

<sup>209</sup> Falk and Dierking, *The Museum Experience Revisited*, 27-28.

<sup>210</sup> Falk and Dierking, *The Museum Experience Revisited*, 28-29.

to this model, unfolds over time as visitors integrate new information with their ongoing experiences in a cumulative process of meaning-making.<sup>211</sup>

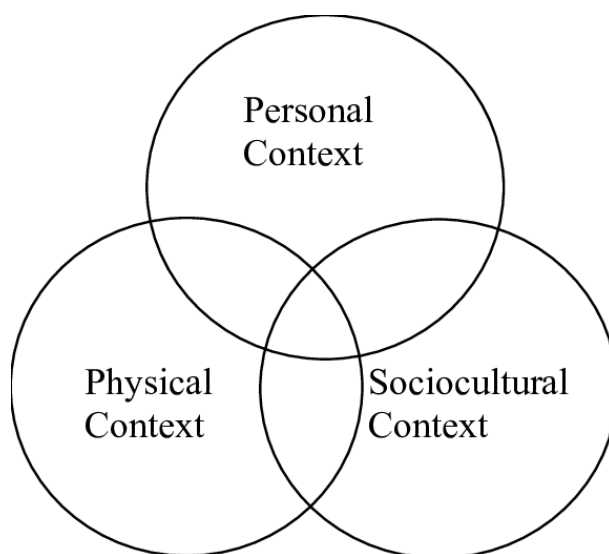


Figure 29. *The Contextual Model of Learning* (Falk and Dierking, 2000).

XR technologies align seamlessly with these frameworks by offering tools for personal expression, such as leaving digital imprints or interacting creatively with artifacts. These applications personalize the museum experience, making it more engaging and memorable. However, museums must carefully balance visitor autonomy with their educational mission, ensuring that XR experiences provide coherent narratives and meaningful context while encouraging self-directed exploration.

## 5.4 Innovating the Museum Learning Landscape

A key challenge for museums is understanding their diverse audiences and delivering meaningful, inclusive educational experiences.<sup>212</sup> XR technologies present an opportunity to engage a broad spectrum of visitors, from tech-savvy digital natives to those less familiar with technology. To ensure accessibility and effectiveness, museums must conduct extensive user testing and audience research. Starting with an assessment of visitors' technological comfort and gaming familiarity, these efforts can refine XR designs to meet the needs of various demographics while avoiding misinterpretations stemming from differing technological proficiencies.

Hein's constructivist philosophy also emphasizes the value of systematic visitor studies to evaluate and improve museum practices.<sup>213</sup> Engaging museum staff in observing and analyzing visitor experiences provides invaluable insights into learning outcomes and visitor behavior. Such studies enable museums to critically examine exhibitions and programs, fostering a culture of continuous improvement. As Hein suggests, museums that embrace this reflective approach become more effective interpreters of culture, capable of creating enriching, even transformative, visitor experiences.

The next chapter will explore a small-scale case study exemplifying how museums can incorporate visitor studies into their educational strategies, offering practical insights into aligning institutional goals with audience engagement.

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<sup>211</sup> Falk and Dierking, *The Museum Experience Revisited*, 29-30.

<sup>212</sup> Hooper-Greenhill, *Museums and the Interpretation of Visual Culture*, chap 1.

<sup>213</sup> Hein, *Learning in the Museum*, chap 8.

## 6 Case Study: Actual Day

The integration of XR technologies into museum settings represents a burgeoning field, with audience experiences remaining relatively underexplored. As XR continues to expand its presence in cultural institutions, understanding how visitors interact with these technologies is essential for realizing their transformative potential. XR's ability to dissolve traditional boundaries between creators and audiences introduces opportunities for participatory and immersive cultural experiences, but to fully leverage this innovation, museums must develop a nuanced understanding of their audiences' preferences and expectations.

Traditional visitor studies, often reliant on demographic data, tend to oversimplify the complexities of museum interactions.<sup>214</sup> A more refined approach, focusing on audience behaviors, motivations, and needs, is critical for creating engaging and meaningful museum experiences. By moving beyond surface-level metrics, museums can foster interactions that resonate on a personal level, fostering deeper connections between visitors and cultural content.

This chapter examines *Actual Day* (Fig. 30), an immersive installation displayed at the Museum of Fine Arts (MSK) in Ghent from December 7, 2023, to January 8, 2024. Developed collaboratively by Jill Andréka, Ellen de Ridder, and myself as part of LUCA School of Arts' Visual Design program, *Actual Day* reimagined classical art through an AI-driven, weather-responsive digital augmentation.<sup>215</sup>



Figure 30. Visitors watching *Actual Day* during Museumnacht at MSK Gent. © Martin Corlazzoli

<sup>214</sup> Chang, "Interactive Experiences and Contextual Learning in Museums," 171.

<sup>215</sup> Visual Design, "mskxlucadigitalestudio," video, Posted October 20, 2024, YouTube, 3:07, <https://www.youtube.com/watch?v=w4R4cQ-nshA>.

Designed for Museum Night (Museumnacht) at MSK Ghent, *Actual Day* bridges the gap between classical art and contemporary digital innovation.<sup>216</sup> The installation reinterprets Emile Claus' *Sunny Day* (Fig. 31), creating a sensory and emotional engagement through real-time weather-responsive animations. Despite the constraints of a limited three-week development period, the project showcased the potential of emerging technologies to reimagine traditional art forms and enable dynamic visitor interactions.

Although the project faced technical and budgetary limitations, it effectively demonstrates the feasibility of integrating XR principles such as multisensory engagement and real-time augmentation, even without relying on fully immersive tools like VR headsets or AR interfaces. While not strictly XR, the installation embraced its foundational concepts, providing insights to broader XR applications in museum contexts.

By exploring the design, execution, and audience reception of *Actual Day*, this chapter highlights how XR technologies can transform museum practices. It underscores the importance of audience feedback in refining digital experiences and offers valuable perspectives on the challenges and opportunities presented by XR within cultural heritage spaces.

## 6.1 Artistic Vision and Technical Design

The installation *Actual Day* reinterprets Emile Claus' *Sunny Day*, which portrays two women doing laundry beneath a luminous interplay of sunlight and shadow. Claus' luminist style, characterized by its poetic use of light, color, and atmosphere, serves as the foundation for the installation.<sup>217</sup> The painting's photographic composition and its harmonious balance of light and shade provide a framework for exploring its evocative qualities.

Building on these artistic attributes, the installation extends the painting's realism by envisioning how the scene might appear under varying weather conditions. This approach blends art and the natural world, emphasizing realism and atmospheric transitions to immerse viewers in Claus' masterful depiction of light and shadow.

The realization of *Actual Day* involves several innovative processes that integrate AI and real-time technology to bring Claus' artwork into a contemporary, dynamic medium:

1. **Animation Creation:** The team used RunwayML to generate animations depicting the painting under various weather conditions.<sup>218</sup> Given the nascent stage of video-generation AI, the process required iterative experimentation, resulting in four base animations reflecting five wind scenarios (no wind, calm, light, moderate, and strong). These animations are further enhanced in Adobe After Effects to include weather-specific visual elements such as rustling leaves and rainfall.<sup>219</sup> This process produced 32 unique video

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<sup>216</sup> During Museumnacht in Ghent, ten museums, including MSK, remain open from 18:00 to 01:00 on the night of December 7 to December 8, 2023, allowing visitors to explore without tickets or reservations; "Muzikale Museumnacht lokt meer dan 30.000 bezoekers," *Stad Gent Persruimte*, December 8, 2023, <https://persruimte.stad.gent/232829-muzikale-museumnacht-lokt-meer-dan-30-000-bezoekers>.

<sup>217</sup> "Sunny Day," Search the collection, MSK Ghent, accessed January 2, 2025, <https://www.mskgent.be/en/collection/1904-X>.

<sup>218</sup> RunwayML is a platform that leverages AI to revolutionize content creation and editing, including text-to-video generation, advanced editing, and machine learning models for various audiovisual applications; "Advancing creativity with artificial intelligence," RunwayML, accessed January 2, 2025, <https://runwayml.com/>.

<sup>219</sup> Adobe After Effects is a professional digital visual effects, motion graphics, and compositing software; "After Effects," Products, Adobe, accessed January 2, 2025, [https://www.adobe.com/be\\_en/products/aftereffects.html](https://www.adobe.com/be_en/products/aftereffects.html).



sequences, each paired with corresponding soundscapes that heighten the sensory experience.<sup>220</sup>

2. **Real-Time Weather Integration:** A custom-coded system developed using Processing and the OpenWeather API dynamically links real-time weather data from Ghent to the displayed animations.<sup>221</sup> This iterative parameterization process ensures accuracy while maintaining the poetic essence of the original artwork.<sup>222</sup>
3. **Sound and Multisensory Components:** Soundscapes are incorporated to deepen the multisensory engagement. Sounds like rustling leaves or the patter of rain complement the visual elements, immersing visitors in a cohesive environment that bridges the sensory gap between art and nature.

The digital projection was displayed adjacent to the original painting in Room S of the MSK Ghent (Fig. 32). Sound effects are delivered through boxes placed near the beamer, creating an immersive experience. While curatorial constraints prevent the projection from matching the scale of the original artwork, the deliberate juxtaposition invites visitors to reflect on the evolving relationship between classical art and contemporary technology. This side-by-side presentation encourages a dialogue between tradition and innovation, prompting deeper engagement with both the original painting and its digital reinterpretation.

## 6.2 Objectives

This study investigates how XR technologies are experienced by audiences in museum settings, addressing the central research question: *“How can XR technologies be effectively implemented in museum settings while ensuring user-centered experiences?”* To approach this broad topic comprehensively, the research is divided into four sub-research questions (sRQ), each grounded in themes explored in the preceding chapters: accessibility, viewer-art interaction, learning experiences, and perceptions of digital futures in museums. By integrating insights from these sub-questions, the study aims to offer a holistic understanding of audience experiences and provide actionable recommendations for museums.

**sRQ1: Does digital integration enhance accessibility and align with audience expectations in the digital age?**

**Hypothesis:** Frequent museumgoers (weekly or monthly) are anticipated to be more cautious or ambivalent about integrating digital technology, as they may already find satisfaction in traditional museum experiences. Conversely, less frequent visitors may see digital enhancements as a draw, potentially encouraging more frequent attendance. Younger visitors (under 35), who are more accustomed to digital technologies in daily life, are expected to show greater enthusiasm and desire for digital integration compared to older age groups.

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<sup>220</sup> Multiple animated versions were created to depict various weather conditions, from breezes to storms and drizzle to snowfall and fog, with additional night-time versions included for the installation’s premiere during Ghent Museumnacht.

<sup>221</sup> Processing is a flexible software sketchbook and a language for learning how to code. Processing has promoted software literacy within the visual arts and visual literacy within technology; “Welcome to Processing!,” Processing, accessed October 30, 2024, <https://processing.org/>; With an OpenWeather API you can obtain real-time weather data for any location. OpenWeather provides hyperlocal minutely forecast, historical data, current state, and from short-term to annual forecasted weather data. All data is available via industry standard APIs; “Weather API,” OpenWeather, accessed October 30, 2024, <https://openweathermap.org/api>.

<sup>222</sup> Parameters were established for each weather scenario, with wind categorized into four levels by speed: calm (< 0.3 m/s), light (0.3-5.4 m/s), moderate (5.4-24,5 m/s), and strong (> 24,5 m/s).

Audiences, especially younger generations, increasingly expect interactive and digital experiences in museums. XR technologies, with their sensory and interactive capacities, address these expectations, bridging the gap between passive observation and immersive engagement. Frequent visitors might not crave these innovations as strongly, while younger audiences may be more drawn to XR installations due to their familiarity with digital mediums.

**sRQ2: How does XR influence visitor perception and interaction with art while enhancing the viewer-art relationship in museums?**

**Hypothesis:** The use of XR technologies will likely attract audiences and encourage them to spend more time engaging with the artwork. Multisensory elements, such as movement and sound, are expected to heighten visitor attention and interaction with the installation.

By adding a dynamic layer to traditional displays, XR can transform how visitors perceive and interact with art. This study hypothesizes that the immersive qualities of XR, such as real-time changes and multisensory features, will deepen contemplation and create more meaningful connection between the audience and the artwork.

**sRQ3: Does the use of digital technology enhance educational outcomes?**

**Hypothesis:** The digital element is expected to enhance understanding and appreciation of the painting by offering additional insights into the artwork and the artist. XR's interactive nature may help visitors notice details they might otherwise overlook.

Museums serve as educational institutions, and XR has the potential to amplify this mission by making learning immersive and engaging. By extending the time visitors spend with the artwork and enriching the sensory experience, XR can facilitate a deeper connection with the material, enhancing comprehension and retention.

**sRQ4: What is the public perception of the future of digital tools in museums?**

**Hypothesis:** While XR is anticipated to become an integral aspect of museums, its adoption will depend on its meaningful application. Public unfamiliarity with XR could act as a barrier, with concerns about overuse or lack of understanding about its potential benefits.

This theme explores public attitudes toward XR's long-term role in museums. While XR's popularity continues to grow, skepticism or uncertainty about its relevance and implementation could hinder widespread acceptance. Audiences may need clear examples of how XR complements traditional displays to fully embrace its integration.

## 6.3 Survey Analysis

To evaluate the impact of the *Actual Day* installation, visitor surveys were conducted during the exhibition.<sup>223</sup> The findings are categorized into five themes: demographics, accessibility, engagement, education, and general interest in digitization.

### **Demographic Profile**

Survey participants were primarily young adults (ages 20-30) and middle-aged visitors (ages 40-50) (Fig. 33). Gender representation was balanced, with 52% identifying as male and 48% as female. The audience included a mix of locals (57%) and tourists (43%).

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<sup>223</sup> Hanne Mannens, "Visitor Feedback Questionnaire," MSK Ghent, January 3-8, 2024.

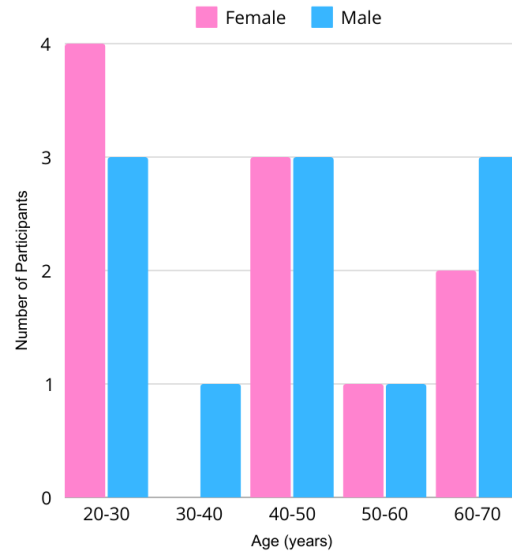


Figure 33. Distribution of survey participants' ages.

Regarding museum attendance (Table 1), the majority were casual visitors, attending museums a few times per year. None indicated frequent attendance, such as weekly visits. All respondents expressed some level of interest in art, though intensity varied. Notably, no participants reported a lack of interest in art, which is unsurprising given the museum setting that naturally attracts individuals with an affinity for art.

Table 1

*Museum Attendance Profile*

| Frequency       | Count | Percentage |
|-----------------|-------|------------|
| Very Frequent   | 0     | 0.00       |
| Regular         | 5     | 23.81      |
| Few Times       | 13    | 61.90      |
| Once a Year     | 3     | 14.29      |
| Interest        | Count | Percentage |
| Very Interested | 4     | 19.05      |
| Interested      | 12    | 57.14      |
| Regular         | 5     | 23.81      |
| Not Interested  | 0     | 0.00       |

**Accessibility**

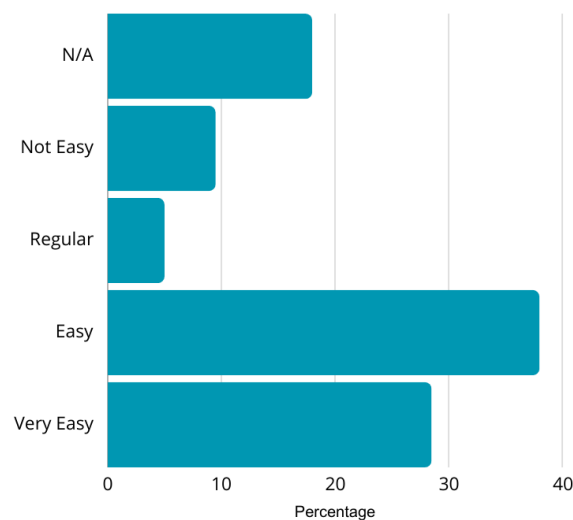
All survey respondents expressed interest in the *Actual Day* installation; however, this result may reflect selection bias, as those uninterested were less likely to participate. Many visitors found the technological aspect particularly appealing, with one participant noting that it stood out as one of the few technology-driven features in the museum (participant 13). Table 2 outlines the key factors that captured visitor attention.

**Table 2***Attraction Profile*

| Attraction                     | Count | Percentage |
|--------------------------------|-------|------------|
| Interaction Technology and Art | 5     | 23.81      |
| Movement and Dynamics          | 6     | 28.57      |
| Sound                          | 1     | 4.76       |
| Light and Color                | 4     | 19.05      |
| Coincidence and Context        | 2     | 9.52       |
| Concept                        | 3     | 14.29      |

Participants shared their perspectives on the ease of interacting with the AI features (Fig. 34), emphasizing the importance of intuitive and user-friendly interfaces. One visitor remarked on her “bad luck” with the pleasant weather during her visit, expressing a wish to see the installation under snowy conditions (participant 15). Another participant stated that the curiosity to see the display in rain or snow encouraged the idea of a repeat visit (participant 20).

Some visitors required additional explanation—either through labels or interactions with others—to fully grasp the installation’s concept. This was especially true on clear weather days when the depicted gentle breeze felt less immediately connected to the painting’s context. By contrast, during rain or snow, the atmospheric connection was more intuitive for visitors, enhancing their engagement.



*Figure 34. Feedback on the ease of understanding and interacting with AI features.*

The survey assessed participants’ overall museum experiences (Fig. 35) and the installation’s contribution to their enjoyment (Fig. 36). While most respondents valued the installation, only 5% felt it added insufficient value. One participant described the museum experience as generally “too passive” (participant 10), emphasizing the potential of digital tools to make it more engaging. Another appreciated the installation as a refreshing break, especially when the museum experience became monotonous (participant 8).

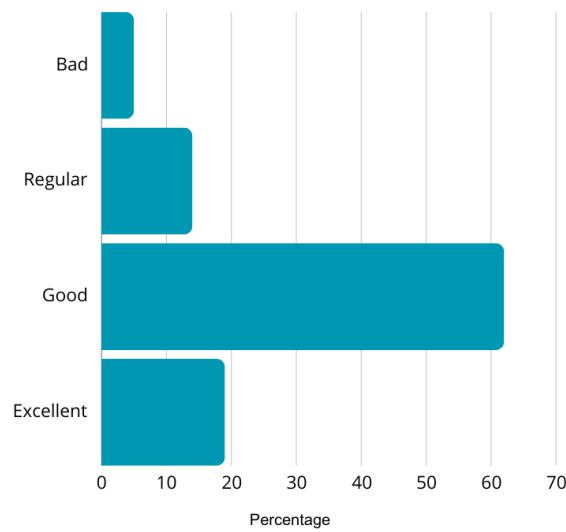


Figure 35. Participants' overall museum experience ratings.

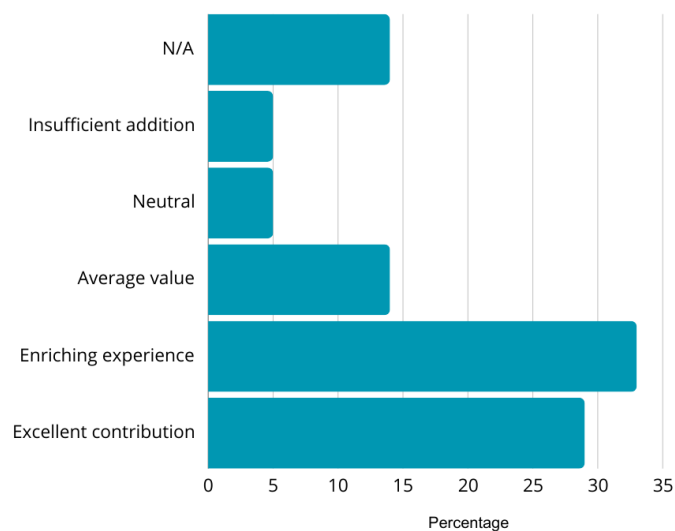


Figure 36. Participants' perception of the installation's contribution to their overall enjoyment.

A Spearman correlation analysis revealed a moderate negative relationship between age and the perceived contribution of AI to the experience (Fig. 37).<sup>224</sup> The Spearman's correlation coefficient ( $R$ ) was -0.38, indicating that as participants' age increased, their enthusiasm for AI contribution tended to decrease. However, the result was not statistically significant ( $p = 0.089$ ), suggesting a weak trend rather than conclusive evidence. Younger participants generally found the AI element more enjoyable,

<sup>224</sup> Spearman's rank correlation coefficient ( $\rho$ , or  $\rho$ ) is a statistical measure that assesses the strength and direction of a monotonic relationship between two variables. Unlike numerical values, it relies on ranking the variables, making it suitable for both continuous and discrete ordinal data. A perfect positive ( $\rho = 1$ ) occurs when higher ranks in one variable exactly match higher ranks in the other, while a perfect negative correlation ( $\rho = -1$ ) occurs when higher ranks in one variable correspond to lower ranks in the other. A correlation near zero indicates a monotonic relationship. Spearman's correlation is particularly useful for analyzing relationships in non-linear data.



while older participants rated it less positively. A larger sample size could provide more definitive insights into this trend.

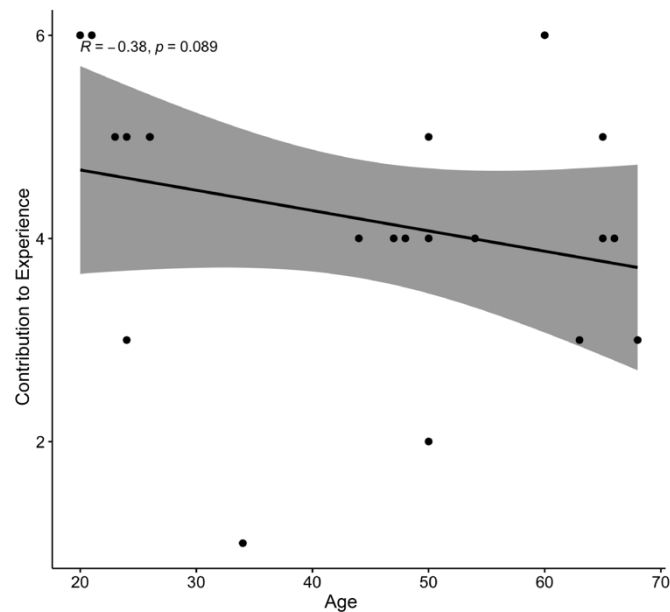


Figure 37. Correlation between age and perceived AI contribution to the experience.

A second correlation examined the relationship between museum attendance frequency and AI contribution ratings (Fig. 38). The correlation coefficient ( $R$ ) of 0.27 suggested a weak positive relationship, indicating that more frequent museumgoers tended to rate the AI component slightly more favorably. However, the result was not statistically significant ( $p = 0.23$ ), underscoring the need for further investigation with a larger sample size. While the data hinted a trend, it lacked sufficient evidence to draw firm conclusions.

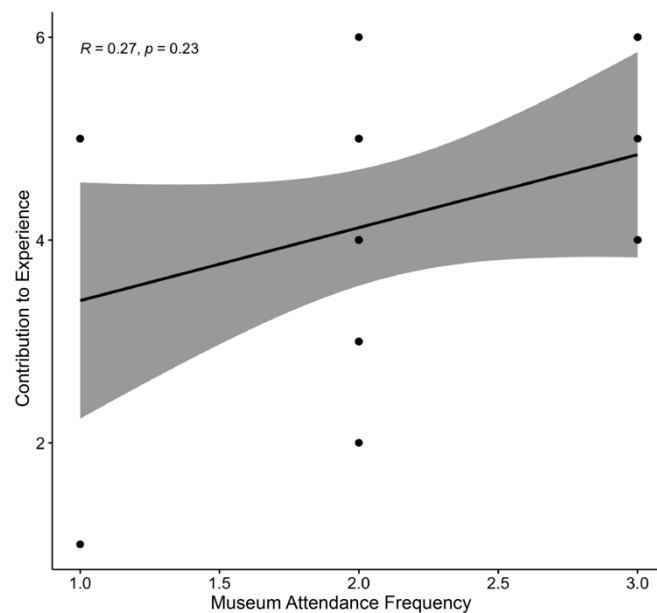


Figure 38. Correlation between museum attendance frequency and perceived AI contribution to the experience.

Suggestions for improving the installation focused primarily on aesthetic and technical refinements. Visitors proposed adding a frame around the projection (participant 4), addressing the screensaver issue (participant 17), and refining the AI-generated imagery, particularly to make arm movements more realistic (participant 21). Additionally, one participant suggested relocating the installation to a more secluded area, such as a corner, to minimize disruption to the flow of the exhibit (participant 5).

### **Engagement**

Nearly all survey respondents (95%) indicated that the AI component enhanced their engagement with the installation. Visitors highlighted various elements contributing to this experience (Table 3), with sound and audiosphere and new perspectives being the most frequently mentioned factors. Many appreciated the activation of multiple senses, which created a deeper connection to the artwork. For some, the digital experience enhanced their engagement with the painting, creating a sense of immersion, with one participant describing it as feeling like they were “inside the scene” (participant 6). Another visitor noted that the installation captured her attention in a way that encouraged her to spend more time observing the artwork than she otherwise might have (participant 8). One participant remarked that while the painting itself was already captivating, the installation amplified its emotional resonance and level of involvement (participant 16). She observed that the animation brought the painting to life, making her look longer and enjoy it more.

**Table 3**

#### *Attraction Elements*

| <b>Enhancing Experience</b> | <b>Count</b> | <b>Percentage</b> |
|-----------------------------|--------------|-------------------|
| No Response                 | 2            | 9.52              |
| Motion                      | 3            | 14.29             |
| Sound and Audiosphere       | 5            | 23.81             |
| Light and Visual Effects    | 3            | 14.29             |
| New Perspectives            | 5            | 23.81             |
| Emotional Depth             | 2            | 9.52              |
| Digitization                | 1            | 4.76              |

The survey also explored the balance between visual and physical interactivity. When asked if they missed any physical interactive elements, 81% of respondents said no, while 14% felt the installation lacked physical engagement, and 5% did not respond. Regarding preferences (Fig. 39), half of visitors expressed a preference for visual installations.

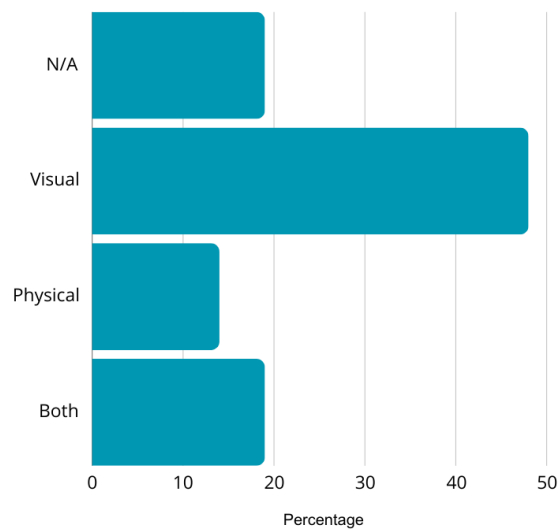


Figure 39. Visitor preferences for physical or visual elements.

### **Education**

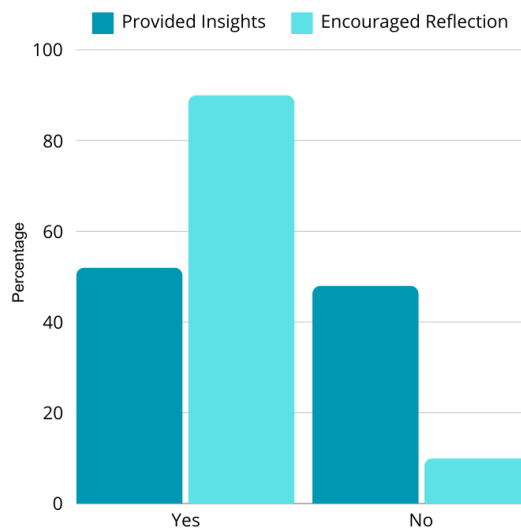
The survey explored how XR technology influenced visitors' educational experiences, particularly their understanding and appreciation of the painting. Overall, the AI component was reported to enhance engagement, with no respondents indicating a lack of improvement in their understanding or appreciation of the artwork (Table 4). One visitor confessed that she initially struggled to understand the action depicted in the painting but found the digital element illuminated the dynamics of the scene (participant 4). Another participant remarked that the installation encouraged viewers to observe the painting from different perspectives, offering a fresh lens through which to appreciate its details (participant 3).

**Table 4**

#### *Contribution to Understanding*

| Level of Appreciation           | Count | Percentage |
|---------------------------------|-------|------------|
| No Response                     | 3     | 14.29      |
| Greatly Increased Appreciation  | 4     | 19.05      |
| Positive Experience             | 7     | 33.33      |
| Significant Added Value         | 6     | 28.57      |
| Slightly Increased Appreciation | 1     | 4.76       |
| No Increase in Appreciation     | 0     | 0.00       |

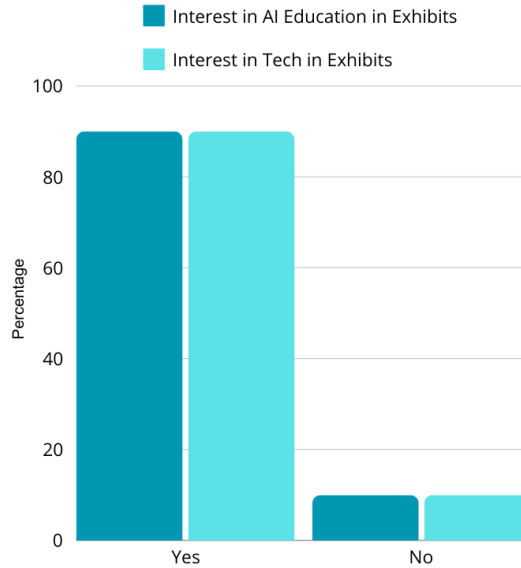
When asked whether the installation encouraged them to spend more time contemplating the painting, the majority responded affirmatively. However, opinions were more divided on whether the AI element provided additional insights into the painting or its artist (Fig. 40).



*Figure 40. Participant responses on whether the installation encourages reflection and provided insights.*

### **General interest in Digitization**

The survey revealed strong visitor support for incorporating digital tools into museum settings. A significant majority expressed interest in technology-based exhibits. Additionally, 90% showed enthusiasm for educational content delivered through AI (Fig. 41).



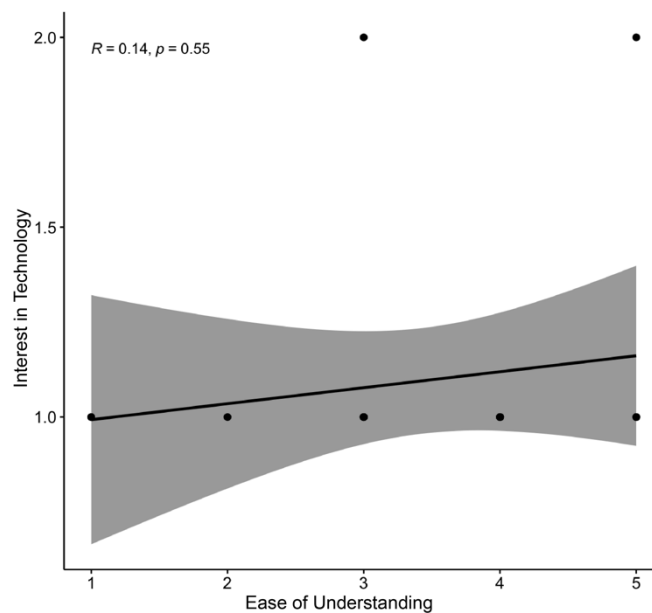
*Figure 41. Visitor interest in technology-based exhibits and AI-driven educational content.*

When asked about the broader use of AI in museums (Table 5), none of the respondents expressed doubt or negativity towards its implementation. Instead, responses varied in enthusiasm, with 38% being highly enthusiastic and others showing cautious optimism.

**Table 5***Thoughts on Use of AI*

| Level of Enthusiasm            | Count | Percentage |
|--------------------------------|-------|------------|
| No Response                    | 3     | 14.29      |
| Highly enthusiastic            | 8     | 38.10      |
| Positive (Specific Conditions) | 5     | 23.81      |
| Interesting Addition           | 3     | 14.29      |
| Cautiously Positive            | 2     | 9.52       |
| Doubtful or negative           | 0     | 0.00       |

A statistical analysis examining the relationship between ease of understanding the AI-based artwork and interest in technology in museums (Fig. 42) revealed a very weak positive correlation (Spearman's correlation coefficient  $R = 0.14$ ). This suggests a slight tendency for visitors who express a greater interest in museum technology to understand the AI-based artwork easier. However, the correlation was not statistically significant ( $p = 0.55$ ), indicating that this observed relationship may be coincidental. The lack of significance highlights the need for further research with larger sample sizes or additional variables, such as prior exposure to technology or AI familiarity, to uncover more meaningful patterns.



*Figure 42. Correlation between ease of understanding the artwork and interest in museum technology.*

While enthusiasm for AI was evident, several participants voiced concerns about its implementation. One visitor noted that fine artistic details, such as brushstrokes, became less distinct in the digital version (participant 4). Another stressed the need for digital tools to complement, rather than overshadow, original artworks (participant 13). A third cautioned against an overreliance on digital features, urging museums to stay true to the artist's vision and avoid losing touch with traditional art forms (participant 2).

Participants also shared suggestions for how museums could utilize AI to enhance visitor experiences. Ideas included allowing visitors to ask open-ended questions about artwork or artists, offering additional context based on specific queries (participants 4 and 17), and creating personalized



tours based on previous visits (participant 21). Notably, the MSK already allows visitors to engage with paintings by asking questions, demonstrating a step toward these aspirations.<sup>225</sup>

Interactive features were also highlighted as desirable, with one participant citing an example from a historical museum in Amsterdam where visitors could edit photos to reflect historical time periods (participant 2).<sup>226</sup> Another respondent emphasized the need for innovation to attract younger audiences, noting that variety is crucial to cater to diverse visitor preferences (participant 20).

Overall, these responses underscore robust support for integrating AI and XR technologies into museums, not only to enrich engagement but also to deepen educational experiences. As one participant succinctly put it, “Variety is key.”

## 6.4 Discussion

The purpose of this study is to investigate how museum audiences experience XR technologies, focusing on their influence on accessibility, engagement, viewer-art relationships, educational outcomes, and perceptions of digital tools. While the survey questions were originally centered on AI—reflecting the thesis’s initial scope before expanding to XR—the insights gathered remain broadly applicable to the digitization of museum settings, including XR technologies.

Although the research is small-scale and lacks statistical rigor, it offers meaningful insights into XR’s transformative potential in museums. Beyond its immediate findings, the study demonstrates the value of systematically measuring visitor experiences—a practice not commonly employed in museum settings. By integrating data collection and interpretation, this approach provides a valuable framework for understanding audience interactions with digital tools.

The knowledge gained from this study is intended to guide museum organizers and developers in enhancing the visitor experience within the rapidly evolving digital landscape. The findings underscore the importance of continued exploration into XR’s applications in museums, encouraging further research to deepen understanding and optimize these emerging technologies.

### Accessibility

**SRQ1: Does digital integration enhance accessibility and align with audience expectations in the digital age?**

The results confirm that digital technologies like XR can significantly enhance accessibility and inclusivity in museum settings. The *Actual Day* installation demonstrated a strong audience interest in digital elements, with all respondents expressing enthusiasm. Key features such as the interplay between technology and art, dynamic visuals, and sensory-rich design were particularly appreciated. These findings reinforce the hypothesis that digital integration can attract a wider audience, including demographics traditionally less engaged with cultural institutions, such as younger visitors. For example, during the exhibition, one visitor was observed connecting with her child through the movement and sound of the installation, demonstrating how technology can create shared, meaningful interactions with art.

The data also revealed that XR technologies encourage repeat visits by offering dynamic experiences. Visitors expressed interest in returning to see the installation under different weather conditions, illustrating how XR’s customizable features can sustain long-term audience engagement.

However, the study also identified barriers to accessibility. Some visitors required additional context or explanatory materials to fully grasp the installation, particularly during less intuitive weather

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<sup>225</sup> Helke Smet, “AI pilot project in the MSK: start a conversation with a painting,” *MSK Ghent*, November 29, 2023, <https://www.mskgent.be/en/in-depth/ai-at-the-msk>.

<sup>226</sup> “AI-portrait photo souvenir,” Things to Do in Amsterdam, Tripadvisor, accessed January 3, 2025, [https://www.tripadvisor.com/AttractionProductReview-g188590-d27800999-AI\\_portrait\\_photo\\_souvenir-Amsterdam\\_North\\_Holland\\_Province.html](https://www.tripadvisor.com/AttractionProductReview-g188590-d27800999-AI_portrait_photo_souvenir-Amsterdam_North_Holland_Province.html).

scenarios. These findings underscore the importance of user-friendly interfaces and thoughtful design to ensure XR installations are accessible to all visitors, regardless of their familiarity with digital technologies.

While correlations between age, attendance frequency, and AI contribution ratings were not statistically significant, trends suggest that younger visitors, who are more familiar with digital technologies, are more enthusiastic about XR integration. Contrary to initial hypotheses, frequent museumgoers also appeared open to digital enhancements, potentially valuing them as a means of deepening their engagement with exhibits.

## **Engagement**

### **sRQ2: How does XR influence visitor perception and interaction with art while enhancing the viewer-art relationship in museums?**

The data strongly support the hypothesis that XR technologies significantly enhance visitor engagement with art. Respondents emphasized the importance of multisensory features such as sound and motion, which were frequently cited as elements that deepened their connection to the artwork. The ability to activate multiple senses created a more immersive experience, with participants describing sensations of being “inside the scene” and spending more time observing the painting than they normally would.

The findings demonstrate that XR technologies reshape the traditional viewer-art relationship by adding a dynamic, interactive layer to static displays. Features like real-time animations and emotional resonance amplified intellectual and emotional engagement, encouraging audiences to approach the artwork from fresh perspectives.

While the majority of participants were satisfied with visual and auditory interactivity, the absence of a strong desire for physical interaction suggests that XR installations can succeed without tactile elements. This underscores the importance of focusing on sensory-rich visual and auditory components when designing XR experiences for cultural spaces.

## **Education**

### **sRQ3: Does the use of digital technology enhance educational outcomes?**

The survey data confirm that digital technologies, such as XR, can enhance educational outcomes by improving visitors’ understanding and appreciation of artwork. A significant majority reported that the installation provided a positive experience, added value, or greatly increased their appreciation of the painting.

Participants highlighted how the digital element illuminated previously overlooked details and clarified the narrative of the artwork, supporting the hypothesis that XR fosters deeper engagement with (complex) scenes. Prolonged contemplation of the artwork, prompted by the immersive qualities of XR, further underscores its potential to enhance learning and retention.

However, some division was observed regarding the AI’s ability to provide additional insights into the artist or painting. This suggests that while XR excels at creating engaging and immersive experiences, its educational content should be more explicitly integrated to ensure that visitors gain a comprehensive understanding of the artwork’s historical and artistic significance.

## **General interest in Digitization**

### **sRQ4: What is the public perception of the future of digital tools in museums?**

Survey responses reveal strong public support for the integration of digital tools in museums. A significant majority of respondents expressed interest in technology-based exhibits, AI-driven features,

and educational content delivered through digital means. This enthusiasm highlights the growing expectation for museums to embrace technological innovation as part of their visitor experiences.

However, concerns about over-reliance on digital features emphasize the need for a balanced approach. Visitors stressed that digital tools should complement, rather than overshadow, traditional exhibits. Maintaining the integrity of original artworks and aligning digital innovations with the artist's vision will be critical to gaining widespread acceptance of XR technologies.

Suggestions for personalization and interactivity, such as open-ended questions about artworks, personalized tours, and interactive features, underscore the importance of tailoring XR experiences to individual preferences. These features resonate strongly with younger audiences, making them essential for attracting new demographics to museums.

As this chapter concludes its exploration of how XR technologies influence museum accessibility, engagement, viewer-art relationships, educational outcomes, and public perceptions, it paves the way for critical discussions on broader implementation considerations. While the findings highlight XR's potential to transform museum experiences, they also underscore the importance of thoughtful execution to ensure inclusivity, accessibility, and meaningful engagement.

The next chapters will delve into two pivotal aspects of integrating XR into museum settings: funding and ethical considerations, and technical challenges. By bridging these practical and conceptual discussions, the subsequent chapters aim to provide a comprehensive framework for the responsible and effective adoption of XR in cultural institutions. This transition marks a step toward understanding not only how XR impacts visitors but also what it takes to sustain and scale these innovative technologies in museum contexts.

## 7 Funding and Ethical Considerations

As XR technologies increasingly find their place in cultural institutions like museums and galleries, they offer transformative possibilities for engaging with historical artifacts, art, and cultural narratives. However, their implementation involves significant financial, ethical, and social considerations. Addressing these challenges is essential to making XR a sustainable and valuable addition to cultural institutions.

### 7.1 Funding XR Projects: Balancing Costs and Value

Integrating XR technologies into museums is often perceived as a high-risk, high-reward venture.<sup>227</sup> The upfront investment includes expenses for VR headsets, sensors, specialized spaces, high-quality rendering, custom software, ongoing maintenance, and staff training. For institutions already constrained by tight budgets, funding these initiatives presents a significant challenge. However, when thoughtfully scoped and strategically budgeted, the potential rewards—enhanced visitor engagement, educational impact, increased attendance, critical acclaim, and publicity—can far outweigh these costs. Successful XR exhibitions often leave lasting impressions, becoming touchstones in cultural discourse long after their initial runs.

A critical strategy for mitigating financial risks in XR projects involves fostering public-private partnerships, as exemplified by the *Van Gogh's Palette* project discussed earlier in this thesis. In this initiative, the museum provided exhibition space and historical content, while private partners managed VR production and distribution.<sup>228</sup> Notably, VIVE Arts introduced its *VIVE XR Elite* standalone VR glasses for the first time in a museum environment, adding both innovation and convenience.<sup>229</sup> This collaborative approach demonstrates how combining resources and expertise can overcome logistical and financial barriers, enabling museums to introduce cutting-edge XR experiences without carrying the full financial burden.

The partnership also succeeded in aligning the VR experience with the museum's educational mission. By involving the museum as a co-producer and integrating curatorial insights into the creative process, the project ensured that the narrative integrity and educational objectives of the experience were maintained.

Despite its achievements, the implementation of such a large-scale VR experience presented significant challenges.<sup>230</sup> Securing funding required a combination of public funds, sponsorships, and contributions from partners like VIVE Arts, which provided VR headsets. Technical hurdles, such as maintaining VR hardware and software, necessitated a dedicated support system. The expertise of Lucid Realities and Unframes Collection in immersive storytelling and operational management proved essential in navigating these issues.

The *Van Gogh's Palette* initiative offers several valuable lessons for the museum sector.<sup>231</sup> Adopting a phased approach was particularly effective; the project began with a focused 10-minute VR experience, which was expanded based on visitor feedback. This strategy enabled the museum to test and refine the concept incrementally, minimizing risks and offering a scalable model for other institutions.

Additionally, the project underscored the importance of sustainable business models.<sup>232</sup> By charging a modest fee (€6 per ticket, available both online and on-site), the museum balanced cost

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<sup>227</sup> Deakin, "4 Things You Need to Know."

<sup>228</sup> Abastado et al., "How to Bring VR into a Major Cultural Institution."

<sup>229</sup> "VIVE XR Elite," Products, VIVE, accessed January 4, 2025, <https://www.vive.com/us/product/vive-xr-elite/overview/>.

<sup>230</sup> Richardson, "Virtual Reality at the Musée d'Orsay."

<sup>231</sup> Richardson, "Virtual Reality at the Musée d'Orsay."

<sup>232</sup> Richardson, "Virtual Reality at the Musée d'Orsay."

recovery with accessibility. This pricing model helped manage visitor flow while ensuring affordability for a broad audience. Looking ahead, the Musée d'Orsay plans to extend the project's reach by touring it internationally, offering a roadmap for monetizing VR initiatives through licensing and distribution. This approach not only extends the lifespan of the project but also ensures ongoing returns on investment, providing a replicable blueprint for future XR endeavors.

For smaller museums or those new to XR, mobile-based AR or VR applications offer a cost-effective entry point.<sup>233</sup> Starting with short-term exhibitions or pilot programs allows institutions to evaluate audience reception and technical feasibility before scaling up. Multidisciplinary collaboration with technologists, designers, curators, and educators is essential to ensure projects are both technologically advanced and culturally meaningful.<sup>234</sup> By starting small, incorporating visitor feedback, and leveraging strategic partnerships, museums can embrace XR as a transformative tool.<sup>235</sup> With careful planning and a commitment to long-term sustainability, XR can redefine the museum experience, combining innovation with cultural preservation to reach diverse audiences while creating memorable, impactful exhibits.

## 7.2 Ethical Considerations: From Privacy to Sustainability

The integration of XR technologies in museums introduces significant ethical challenges that require careful attention to ensure these innovations enhance visitor experiences without compromising individual rights or institutional integrity. Key concerns revolve around privacy, copyright, safety, and sustainability.

### **Privacy Concerns**

XR technologies frequently collect extensive data, including personal and biometric information, to deliver immersive and interactive experiences.<sup>236</sup> This reliance on sensitive data raises significant privacy and security concerns. Improper handling or misuse of this data could lead to identity theft, unauthorized surveillance, or manipulation. Additionally, behavioral data collected in virtual environments may be used to create psychological profiles, which can be exploited for targeted advertising or shared with third parties, often without explicit consent.

To mitigate these risks, museums must adhere to stringent data protection regulations, such as the General Data Protection Regulation (GDPR) in Europe.<sup>237</sup> Transparency is essential: institutions should clearly communicate what data is being collected, its intended use, and who has access to it. Securing explicit visitor consent ensures ethical handling of sensitive information while fostering trust in the use of XR technologies.

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<sup>233</sup> Richardson, "Virtual Reality at the Musée d'Orsay."

<sup>234</sup> Teffer and Cotterell, "Reality Check."

<sup>235</sup> Richardson, "Virtual Reality at the Musée d'Orsay."

<sup>236</sup> Panagiotis Kourtesis, "A Comprehensive Review of Multimodal XR Applications, Risks, and Ethical Challenges in the Metaverse," *Multimodal Technologies and Interaction* 8, no. 11 (2024): 27, <https://doi.org/10.3390/mti8110098>.

<sup>237</sup> The GDPR, effective since May 2018, is a landmark EU privacy law that applies to organizations worldwide that collect or process the personal data of EU citizens; Jambon, *Strategische Visienota Cultureel Erfgoed*, 32.

## **Copyright and Intellectual Property**

Creating digital replicas of museum artifacts using techniques like photogrammetry and 3D modeling introduces copyright and intellectual property challenges.<sup>238</sup> Museums must secure the necessary permissions before digitizing and uploading artifacts to platforms, particularly cloud-based systems, where ownership rights could inadvertently shift to third parties.

Understanding and complying with intellectual property laws, alongside diligent contract management, are essential to safeguarding the rights of both museums and creators. This ensures that the integrity of cultural assets is maintained in digital formats.

## **Safety in XR Environments**

The immersive nature of XR experiences introduces unique safety considerations, especially when VR headsets isolate users from their physical surroundings.<sup>239</sup> Museums must design XR experiences that prioritize both physical and psychological safety. This involves several critical considerations:

- **Understanding User Interaction:** XR environments should align with natural sensory processing and offer intuitive navigation.<sup>240</sup> Developers need to carefully balance the level of realism and interaction offered, ensuring that experiences are engaging without overwhelming. Effective systems provide intuitive cues and feedback, often using real-world metaphors that make navigation and manipulation within the virtual space more natural and accessible.
- **Minimizing Physical Risks:** To prevent adverse reactions such as motion sickness, disorientation, or panic, museums should avoid overly intense simulations. Clear, manageable cues should guide users, ensuring that the pace and intensity of the experience remain comfortable and accommodating for a diverse audience.
- **Feedback and Presence:** A seamless feedback loop is essential to maintain users' sense of immersion and control. Real-time, responsive feedback reinforces the user's actions and ensures a coherent virtual experience. Conversely, poor design or technical glitches that disrupt this loop can degrade the user experience and increase risks, highlighting the importance of robust system design and testing.<sup>241</sup>

Museums should also follow manufacturer guidelines, including recommendations for frequent breaks (ideally every 30 minutes) to prevent eyestrain or fatigue.<sup>242</sup> Additionally, users should be cautioned against engaging in potentially hazardous activities, such as driving, immediately after XR sessions due to lingering disorientation.

## **Sustainability: Ecological and Technological Challenges**

Sustainability is a foundational principle in cultural heritage preservation and extends naturally to the implementation of XR technologies. However, the ecological demands of XR systems, including their reliance on energy-intensive hardware and frequent updates, present significant challenges. Museums can address these issues by prioritizing energy-efficient technologies and establishing

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<sup>238</sup> Vincent Rossi and Jamie Cope, "Q&A with Vincent and Jamie," interview by Jim Richardson, Museum XR Summit 2024, *MuseumNext*, Virtual Conference, June 26, 2024, Video, 11:44, <https://museumnext.mn.co/posts/museum-xr-summit-qa-with-vincent-and-jamie>.

<sup>239</sup> Teffer and Cotterell, "Reality Check."

<sup>240</sup> Greengard, *Virtual Reality*, chap. 4.

<sup>241</sup> Teffer and Cotterell, "Reality Check."

<sup>242</sup> "Health and safety warnings," Quest Legal, Meta, effective January 7, 2025, <https://www.meta.com/be/en/legal/quest/health-and-safety-warnings/>.



recycling programs to manage outdated hardware responsibly.<sup>243</sup> These measures help mitigate the environmental impact associated with XR use.

On the technological front, the rapid pace of advancements can quickly render XR systems obsolete, leading to waste and additional costs. To counter this, museums should invest in adaptable and modular solutions, which allow for upgrades and expansions as technology evolves. This approach not only ensures that installations remain functional and relevant but also optimizes the long-term value of these investments. These topics will be further examined in the next chapter, which delves into the technical considerations necessary for creating seamless and sustainable XR experiences.

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<sup>243</sup> Jambon, *Strategische Visienota Cultureel Erfgoed*, 20.

## 8 Technical Considerations: Ensuring Seamless Experiences

The integration of XR technologies in museums demands meticulous attention to detail, ensuring that users are fully immersed without disruption. The delicate balance of combining hardware, software, and user interface components define the success of these systems. Missteps—such as visual glitches, audio delays, or interaction mismatches—can break immersion, diminishing user satisfaction and even causing physical discomfort.<sup>244</sup>

### 8.1 3D Models and Technology Integration

The digitization of museum collections through 3D modeling has revolutionized access and engagement, offering possibilities both within physical galleries and in virtual environments.<sup>245</sup> These 3D interventions allow cultural institutions to reimagine how audiences interact with artifacts, creating immersive and accessible experiences. However, the implementation of 3D modeling comes with significant technical challenges and strategic considerations.<sup>246</sup>

The use of 3D models in museums raises critical questions about their presentation. Effective applications must engage multiple senses, accommodate diverse abilities, and provide varying levels of interpretation while preserving the narrative and physical integrity of artifacts.<sup>247</sup> For example, digitized models can offer new forms of access to fragile or inaccessible objects, bridging gaps in traditional museum experiences.

In 2018, the M+ Museum exemplified this potential with the digitization of Marcel Duchamp's *Box in a Valise*.<sup>248</sup> Recognizing that the artifact would enter a decade-long storage period, the museum created a detailed 3D digital twin using photogrammetry (Fig. 43).<sup>249</sup> This ensured continued public access to every intricate detail of the work, even when the original piece was unavailable.

Unlike 2D digitization, which is relatively straightforward, 3D modeling is a labor-intensive and time-consuming process.<sup>250</sup> It involves capturing objects from multiple angles and lighting conditions to ensure fidelity. The complexity increases with objects that feature irregular shapes, reflective surfaces, or changing forms, such as live plants or certain artworks. Time constraints and limited access to objects further complicate this process.

High-quality 3D models are typically produced using laser scanning or structured light, which offer precise, non-contact methods ideal for fragile or oversized artifacts.<sup>251</sup> Photogrammetry—a method that stitches together photographs taken from various angles—is another widely used technique, particularly for creating visually accurate and scalable digital replicas.<sup>252</sup> However, the

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<sup>244</sup> Greengard, *Virtual Reality*, chap. 4.

<sup>245</sup> Sportun, "The Future Landscape of 3D," 331.

<sup>246</sup> Vincent Rossi, "A Vision for an XR Future," Museum XR Summit 2024, *MuseumNext*, Virtual Conference, June 26, 2024, <https://museumnext.mn.co/posts/museum-xr-summit-a-vision-for-an-xr-future>.

<sup>247</sup> Teffer and Cotterell, "Reality Check."

<sup>248</sup> "Marcel Duchamp: Lessons for a Creative Life from Box in a Valise," M+ Online Exhibition, accessed January 4, 2025, <https://duchamp.mplus.org.hk/en>.

<sup>249</sup> Hester Chan and Markus Lanxinger, "Unboxing Marcel Duchamp's Boite-en-Valise in 3D," Digital Summit 2024, *MuseumNext*, Virtual Conference, March 25, 2024, <https://museumnext.mn.co/posts/digital-summit-2024-unboxing-marcel-duchamps-boite-en-valise-in-3d>.

<sup>250</sup> Teffer and Cotterell, "Reality Check."

<sup>251</sup> Sportun, "The Future Landscape of 3D," 332.

<sup>252</sup> The 3D model of Duchamp's *Box in a Valise* was created using the RealityCapture, a photogrammetry software designed to generate high-quality 3D models from photographs and scans, known for its speed, precision, and user-friendly approach to revolutionizing 3D imaging; "About Us," RealityCapture, accessed January 4, 2025, <https://www.capturingreality.com/About-Us>.

process involves multiple stages, including modeling, texturing, retopology, rigging, and rendering. For Duchamp's *Box in a Valise*, this workflow spanned approximately three weeks, with rendering alone accounting for much of the time.<sup>253</sup>

Beyond the creation process, 3D models require significant storage and processing power due to their data intensity.<sup>254</sup> Ensuring these models are accessible to the public demands intuitive, robust databases capable of integrating with existing museum systems. Currently, many museum databases are not designed to host large volumes of 3D data, presenting an additional layer of organizational and logistical challenges.

Despite the complexities, the benefits of 3D modeling extend far beyond virtual exhibitions. In conservation, 3D scans serve as invaluable tools for monitoring the condition of artifacts, providing precise records that can detect changes over time due to environmental factors, neglect, or vandalism.<sup>255</sup> This information can guide restoration efforts and support preventive care.

Moreover, 3D models facilitate exhibition planning by enabling curators to visualize and arrange displays virtually, reducing risks to fragile artifacts during preparation.<sup>256</sup> They also enhance educational outreach, providing tactile replicas or interactive digital experiences for audiences who might not otherwise have access to these artifacts.

The integration of 3D scans into accessible digital platforms holds immense promise for expanding museum engagement. However, museums must address challenges such as high costs, data protection, staff training, and object safety during scanning.<sup>257</sup> Moving forward, the development of user-friendly, searchable databases tailored for 3D content will be critical. These systems must seamlessly integrate with existing collections management tools to maximize their utility and impact.

## 8.2 Balancing Realism with User Comfort

Balancing realism, user comfort, and technological limitations is crucial to creating immersive and effective XR experiences. While high-resolution graphics enhance visual fidelity, they also demand significant processing power. If the system cannot maintain real-time rendering, the resulting delays disrupt immersion, breaking the sense of presence and causing user discomfort. Effective synchronization of sensory inputs—visual, auditory, and haptic—is essential to maintaining a cohesive virtual environment. Research shows that even minor delays, as short as 50 milliseconds, can compromise the experience, leading to discomfort.<sup>258</sup> Similarly, in AR applications, precise alignment of virtual elements with the physical world is critical; inaccuracies in scaling or anchoring can undermine realism and engagement.

Graphical user interfaces (GUIs) further influence the sense of presence, particularly in cultural heritage settings.<sup>259</sup> Borrowing principles from the gaming industry, XR designers can leverage diegetic interfaces, which integrate seamlessly into the virtual environment, or non-diegetic overlays, that remain external to the narrative. In museum contexts, GUIs should enhance the user's connection to artifacts and narratives without detracting from the content. This approach ensures that the focus remains on the cultural material while fostering a natural and immersive user experience.

Overly realistic simulations risk overwhelming users, potentially causing motion sickness, anxiety, or physical discomfort.<sup>260</sup> Effective XR design emphasizes achieving a balance: creating

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<sup>253</sup> Chan and Lanxinger, "Unboxing Marcel Duchamp's Boite-en-Valise."

<sup>254</sup> Sportun, "The Future Landscape of 3D," 334.

<sup>255</sup> Sportun, "The Future Landscape of 3D," 334.

<sup>256</sup> Chan and Lanxinger, "Unboxing Marcel Duchamp's Boite-en-Valise."

<sup>257</sup> Sportun, "The Future Landscape of 3D," 334.

<sup>258</sup> Greengard, *Virtual Reality*, chap. 4.

<sup>259</sup> Caggianese et al., "Exploring the Feasibility of Diegetic User Interfaces," 625.

<sup>260</sup> Greengard, *Virtual Reality*, chap. 4.

environments that feel “real enough” to evoke desired responses without replicating the physical world in exact detail. Subtle illusions, such as perceived movement or tactile sensations, can suffice to maintain engagement. Similar to how audiences accept the suspension of disbelief in film, users can find virtual spaces engaging without demanding complete accuracy. Designers must carefully manage elements like lighting, textures, and motion, avoiding exaggerated manipulations that could lead to disorientation or diminish the overall experience.

A deep understanding of user behavior in XR environments is fundamental for designing intuitive interfaces. By analyzing interaction patterns, systems can be optimized to align with human sensory and cognitive capabilities.<sup>261</sup> XR platforms employ a range of interaction methods, including physical controllers, hand gestures, voice commands, and virtual menus, all reliant on precise sensors and responsive feedback mechanisms. Misalignment between user actions and system responses detracts from immersion, emphasizing the importance of seamless integration in XR design.

### 8.3 Building Durable and Adaptable XR Systems

As XR technologies evolve, the ability to process and manage datasets efficiently is critical. While technological advances will continue to redefine how data is handled, the importance of clean, well-structured data remains constant.<sup>262</sup> Control over the software development process is vital for museums adopting XR technologies, as it ensures the flexibility to add and refine features in response to user feedback and technological advancements.<sup>263</sup>

The Smithsonian Institution’s 3D Program serves as an exemplary model of how institutions can build durable and adaptable XR systems that stay relevant over time.<sup>264</sup> This initiative employs an open-source pipeline to create, manage, preserve, and publish interactive 3D and XR content. Integrated with the Smithsonian’s IT infrastructure, this system ensures that its digital assets remain accessible and relevant as technology progresses.

The program is designed for enterprise-level management of 3D and XR data, automating workflows for content capture, processing, authoring, and delivery via platforms such as WebGL and WebXR.<sup>265</sup> The Smithsonian 3D API underpins these processes, supporting the delivery of high-quality, adaptable experiences. A core objective of the initiative is to develop a custom 3D viewer capable of hosting enduring narratives and content, which can migrate to future platforms as WebXR standards and internet bandwidth improve, delivering richer, higher-fidelity experiences.

The program emphasizes the use of photogrammetry over laser scanning, due to its reliance on non-proprietary, preservation-friendly formats. This approach mitigates the risk of proprietary file types becoming obsolete, ensuring long-term usability of digital assets. Additionally, the inclusion of comprehensive provenance metadata further ensures the durability of these assets.<sup>266</sup> By assigning persistent Uniform Resource Identifiers (URIs) to evolving pieces of information and publishing

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<sup>261</sup> Greengard, *Virtual Reality*, chap. 4.

<sup>262</sup> Teffer and Cotterell, “Reality Check.”

<sup>263</sup> Rossi, “A Vision for an XR Future.”

<sup>264</sup> “About,” 3D Digitization, Smithsonian, accessed January 5, 2024, <https://3d.si.edu/about>.

<sup>265</sup> WebGL (Web Graphics Library) is a JavaScript API for rendering interactive 2D and 3D graphics in web browsers, leveraging GPU acceleration and integrating seamlessly with web standards; “WebGL,” The Khronos Group, accessed January 5, 2025, <https://www.khronos.org/webgl/>; The WebXR Device API is a W3C standard that enables web browsers to access AR and VR devices, providing a unified platform for immersive experiences across devices like the Oculus Rift, HTC Vive, and HoloLens; “WebXR,” Immersive Web, accessed January 5, 2025, <https://immersiveweb.dev/>.

<sup>266</sup> Data provenance, a type of metadata, documents the origin, creation process, and context of data, including details about who collected it, when, where, and why, alongside information about its content, quality, and administration; Erik Mannens et al., “On the Origin of Metadata,” *Information* 3, no. 4 (2012): 803-804, <https://doi.org/10.3390/info3040790>.

versioned metadata linked to a temporal dimension, it allows for automated trust estimation and robust data preservation.<sup>267</sup>

Through the Memento paradigm and Hypertext Transfer Protocol (HTTP) provenance headers, this system links provenance information to specific versions of information resources, enabling “smart” search engines and users to assess and trust data based on calculable proofs.<sup>268</sup> The integration of this detailed provenance metadata also ensures data is timelessly hereditary, enriching and securing its use for future applications. By leveraging these advanced frameworks, museums can confidently adapt to evolving digital landscapes while maintaining the integrity and accessibility of their XR systems.

At the core of the Smithsonian’s 3D Program is Packrat, a dual-purpose tool that functions as both a preservation environment and a workflow management system.<sup>269</sup> Packrat assigns universally unique identifiers (UUIDs) to 3D assets, linking them to museum records through the Smithsonian’s Enterprise Data Asset Network.<sup>270</sup> This network consolidates information from various Collection Information Systems (CISs), creating a unified framework for managing digital content.

To enhance efficiency, Cook, an orchestration tool within the system, automates tasks that would otherwise require extensive manual input.<sup>271</sup> Cook integrates software tools like MeshLab, Blender, and other photogrammetry programs, streamlining the production of 3D content.<sup>272</sup> Once high-resolution 3D models are created, Cook can automatically generate level-of-detail (LOD) assets, optimizing the content for various platforms without sacrificing accuracy.

Processed 3D assets are then incorporated into Voyager Story, a platform designed to ensure the integrity and quality of the models.<sup>273</sup> Voyager Story supports interactive features such as annotations and guided tours, with all changes tracked across LOD assets to maintain consistency with the high-resolution source. The assets are WebXR-compatible, facilitating seamless integration with online platforms.

Public interaction with these 3D models is facilitated through Voyage Viewer, a WebXR-enabled interface compatible with multiple devices. Voyage Viewer is equipped with accessibility features such

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<sup>267</sup> A Uniform Resource Identifier (URI) is a unique sequence of characters used to identify abstract or physical resources, such as web pages, people, or concepts, with URLs as a subset of URIs that provide location and retrieval information.

<sup>268</sup> The Memento paradigm is a framework that introduces a temporal dimension to the web, enabling users to access archived versions of web resources through time-based content negotiation, linking live content with its past states using HTTP protocols and tools like TimeGates and TimeMaps; Herbert Van de Sompel et al., “Memento: Time Travel for the Web,” *arXiv:0911.1112* (2009), <https://doi.org/10.48550/arXiv.0911.1112>; Hypertext Transfer Protocol (HTTP) is an application-layer protocol designed for transmitting hypermedia documents like HTML, enabling communication between web browsers and servers as well as machine-to-machine interactions and API access.

<sup>269</sup> “Packrat,” RStudio, GitHub, accessed January 5, 2025, <https://rstudio.github.io/packrat/>.

<sup>270</sup> “Smithsonian Digital Asset Management System (DAMS),” Smithsonian, accessed January 5, 2025, <https://www.si.edu/dams>.

<sup>271</sup> Smithsonian Cook is a Node.js-based tool that streamlines 3D model processing by integrating multiple tasks like mesh decimation, UV coordinate creation, and file conversion into customizable workflows controlled via a web API, interface, or command line; “Smithsonian Cook,” Smithsonian, GitHub, accessed January 5, 2025, <https://smithsonian.github.io/dpo-cook/>.

<sup>272</sup> MeshLab is an open-source software for processing and editing 3D triangular meshes, offering tools for cleaning, inspecting, rendering, texturing, and converting models, as well as preparing them for 3D printing; “MeshLab,” MeshLab, accessed January 5, 2025, <https://www.meshlab.net/>; Blender is a free and open-source 3D creation suite licensed under the GNU General Public License, supporting the entire 3D pipeline—including modeling, animation, rendering, and video editing—while allowing customization through Python scripting; “The Freedom to Create,” About, Blender, accessed January 5, 2025, <https://www.blender.org/about/>.

<sup>273</sup> “Smithsonian Voyager,” Smithsonian, GitHub, accessed January 5, 2025, <https://smithsonian.github.io/dpo-voyager/>.

as keyboard controls, screen reader integration, and audio narration, ensuring inclusive engagement.<sup>274</sup> The platform is versatile, supporting quality control, content creation, and interactive exploration.

Packrat, Cook, and Voyager are interconnected components but can also function independently, allowing institutions to adapt them to their specific needs. Although originally designed for the Smithsonian's IT infrastructure, these tools offer a scalable and adaptable framework for other museums and cultural institutions seeking to implement XR technologies. With modifications, they could serve as a comprehensive system for managing 2D and XR data across various cultural settings.

By making these tools open-source, the Smithsonian encourages collaboration within the museum and tech communities. This open-source approach fosters innovation and invites institutions worldwide to contribute to and benefit from the development of sustainable XR solutions. Through this initiative, the Smithsonian sets a benchmark for building durable, adaptable, and accessible XR systems while advancing the field of digital heritage preservation.

## 8.4 Rigorous Testing and Quality Control

Investing in XR is not solely a financial decision—it is also a commitment to the technological robustness and longevity of the systems in use. The mantra “try before you buy” is particularly apt in this context; a single technical failure can compromise months of planning and preparation.<sup>275</sup> The success of XR relies on its ability to provide seamless, uninterrupted immersion. Even minor glitches or delays can disrupt the illusion, diminishing user trust and engagement.

A poignant example of this comes from the Auckland War Memorial Museum, which faced severe setbacks during its adoption of VR technology.<sup>276</sup> Within two weeks, 15 newly acquired VR headsets malfunctioned under regular visitor use, rendering an entire exhibition unusable. This experience underscores the critical importance of thorough pre-deployment testing and the establishment of robust maintenance protocols to prevent similar failures.

The successful integration of XR technologies in museums requires a meticulous balance of technical precision, user-centered design, and sustainability. Each stage—from the creation of immersive 3D models to the synchronization of sensory inputs and the deployment of adaptable systems—plays a critical role in delivering meaningful, engaging, and accessible experiences for diverse audiences.

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<sup>274</sup> “How to Use the 3D Viewer,” 3D Digitization, Smithsonian, accessed January 5, 2025, <https://3d.si.edu/how-use-3d-viewer>.

<sup>275</sup> Deakin, “4 Things You Need to Know.”

<sup>276</sup> Nils Pokel, “VR – hype, hope or just hard?,” moderated by Sarah Tutton, MuseumNext Australia panel, February, 2017, posted April 11, 2017, by MuseumNext, Vimeo, 1:00:15, <https://vimeo.com/212692208>.



## 9 Conclusion: Guiding Museums Forward

This thesis investigates the transformative impact of XR technologies—spanning VR, AR, and MR—on museum practices, emphasizing their potential to enhance accessibility, visitor engagement, and educational outcomes. By bridging physical and digital realms, XR empowers museums to transcend their traditional roles as static repositories, transforming them into participatory spaces that offer personalized, interactive, and multisensory experiences. These tools respond to the evolving expectations of a diverse and technologically adept audience, fostering deeper emotional and intellectual connections with cultural heritage.

Examples such as the AR installation *Fashioning San Francisco* and the VR-driven *Van Gogh's Palette* demonstrate XR's effectiveness in attracting and engaging new audiences, breaking attendance records, and boosting visitor satisfaction. The participatory nature of these experiences often inspires visitors to share their interactions online, creating a viral cycle that draws even more attention. Additionally, younger tech-savvy visitors frequently assist older attendees in navigating XR technologies, fostering valuable intergenerational engagement and enriching the museum experience for all.

However, the implementation of XR comes with challenges that demand thoughtful consideration. Poorly executed XR risks prioritizing spectacle over substance, detracting from meaningful engagement. There are also gaps in research regarding the long-term impact of XR on learning, inclusivity, and sustained engagement. Systematic studies are needed to evaluate how these technologies influence visitor satisfaction, knowledge retention, and behavioral changes such as return visits and advocacy for cultural heritage.

This study highlights the importance of user-centered design in ensuring that XR tools genuinely enhance museum objectives. By exploring the *Actual Day* installation at MSK Ghent, this thesis illustrates how even modest applications of XR principles can improve accessibility and engagement. While limited in scope, this research underscores the value of systematic visitor feedback and provides a foundation for integrating audience insights into the design and application of digital tools in museums.

Critical challenges to the adoption of XR in museums—including funding constraints, ethical considerations, and technological limitations—require careful navigation. This thesis advocates for a balanced approach that harmonizes innovation with sustainability and inclusivity. Museums must establish robust evaluation frameworks to measure the effectiveness of XR tools in achieving their institutional goals and fostering long-term engagement. Open-source platforms and scalable solutions, such as those pioneered by the Smithsonian, offer pathways for smaller institutions to adopt XR affordably and effectively.

To ensure the successful integration of XR technologies, this thesis recommends prioritizing investments in reliable XR infrastructure while focusing on inclusive and intentional design. Crafting compelling and accurate narratives should remain central to XR projects to foster deeper audience engagement. Initiating with short-term exhibitions or pilot programs can provide valuable insights into audience response and technical feasibility, serving as a foundation for scaling up successful initiatives. Interdisciplinary collaboration—engaging technologists, designers, curators, and educators—is vital to creating projects that are both technologically innovative and culturally relevant. By starting small, gathering audience feedback, and leveraging strategic partnerships, museums can effectively harness XR as a transformative tool for redefining cultural engagement.

This study serves as a foundation for future empirical research, encouraging continued exploration into the integration of XR in museum settings to deepen understanding and optimize emerging technologies. Future research should delve into several critical aspects of XR integration in museums. First, understanding long-term engagement is essential—studies should assess whether XR fosters lasting emotional and intellectual connections or if its appeal diminishes as the novelty fades. Additionally, examining audience segmentation is crucial to uncover how different demographic groups

interact with XR and to design experiences tailored to their diverse needs. Cultural authenticity is another key area of exploration; research must evaluate how XR applications preserve the integrity of cultural heritage while avoiding oversimplification of stereotyping. Finally, there is a need to investigate how XR can be seamlessly incorporated into museum operations and curatorial workflows, ensuring it complements traditional practices without causing disruptions.

A mixed-methods approach, combining quantitative metrics (e.g., time spent, satisfaction scores) and qualitative insights (e.g., interviews, focus groups), can provide a comprehensive understanding of XR's impact. Non-intrusive tracking tools could further illuminate how visitors interact with XR exhibits, offering data to refine exhibit designs and optimize visitor pathways.

Ultimately, XR technologies offer museums a unique opportunity to engage, educate, and inspire, making cultural heritage more relevant and accessible to diverse audiences. This study contributes to the growing discourse on XR's role in cultural institutions, emphasizing the need for thoughtful application grounded in both technological innovation and human-centered design. By fostering inclusivity and creativity, museums can harness XR to create transformative experiences that bridge the past and the future, ensuring their enduring impact in a rapidly changing world.

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## Appendix



**Enquete Masterproef Kunstwetenschappen Hanne Mannens  
MA | 2022-23 | promotor: Prof. dr. Maude Bass-Krueger**

### **Demographic Information**

Age:

Gender:

Location (local resident, tourist, etc):

### **How frequently do you visit art museums?**

Very frequent (weekly) / regular (monthly) / a few times a year / once a year

### **How would you describe your level of interest in art?**

Very interested / interested / regular / not interested

### **Were you attracted to this installation?**

Yes / no

### **What attracted you to this installation?**

### **Do you think the use of AI enhanced your experience with the artwork? Did it influence your engagement with the painting?**

Yes / no

### **If yes; what elements of the artwork enhanced your experience?**

### **Did the AI element contribute to your understanding or appreciation of the painting? How?**

### **Did it encourage you to spend more time contemplating the artwork?**

Yes / no

### **Did you miss any physical interactive elements in the artwork?**

Yes / no

### **Do you general have preference for things physical or visual?**

### **If physical; how did you experience this?**

**Did the AI element provide additional insights into the painting or the artist (Emile Claus)?**  
Yes / no

**How easy was it for you to understand and interact with the AI features?**

**Were there any challenges or suggestions for improvement?**

**Are you generally interested in the use of technology, such as AI, in museum exhibits?**  
Yes / no

**Would you like to see more AI-driven elements in museum displays?**  
Yes / no

**Would you be interested in more educational content delivered through AI in museums?**  
Yes / no

**Can you envision other ways museums could utilize AI to enhance visitor experiences?**

**What are your thoughts on the broader use of AI in museums?**

**How would you rate your overall experience at the museum?**

**To what extent did the AI artwork contribute to your overall enjoyment of the visit?**

**Please share any additional thoughts, comments, or suggestions regarding the AI artwork or the use of AI in museums.**

**I give permission for the information stated in this interview to be used anonymously for an unpublished Master's thesis. Additionally, I grant permission for the data to be used in subsequent publications, articles, or research outputs related to this study, ensuring anonymity and confidentiality are maintained. This includes, but is not limited to, conference presentations, academic journals, and other scholarly endeavors. The data will be used solely for academic and research purposes.**

**Signature:**

## Images



Fig 4. Morton L. Heilig, *Sensorama Simulator*, 1962, Picture from Volkskrant, "Virtual reality jarenvijftigstijl," Op reis door een virtuele werkelijkheid, accessed December 10, 2024. <https://www.volkskrant.nl/wetenschap/op-reis-door-een-virtuele-werkelijkheid~b0000698/>.

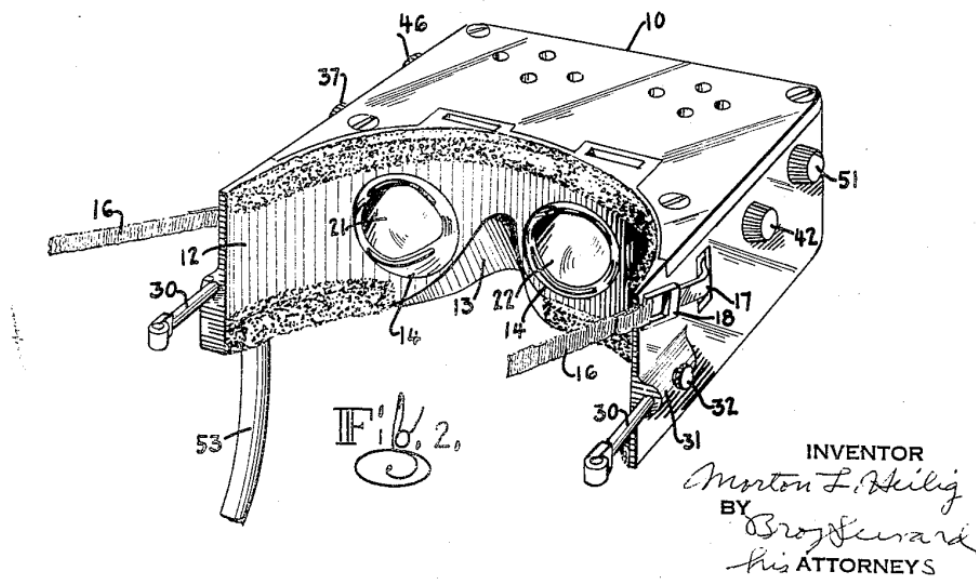


Fig 5. Morton L. Heilig, *Telesphere Mask*, 1960, from United States Patent Office, "Stereoscopic-Television Apparatus for Individual Use," Screenshot taken by Hanne Mannens on December 10, 2024.

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Fig 6. Restoration of the Ghent Altarpiece, Picture from MSK Ghent, "Restoration of the Ghent Altarpiece," Exhibitions, accessed December 13, 2024.

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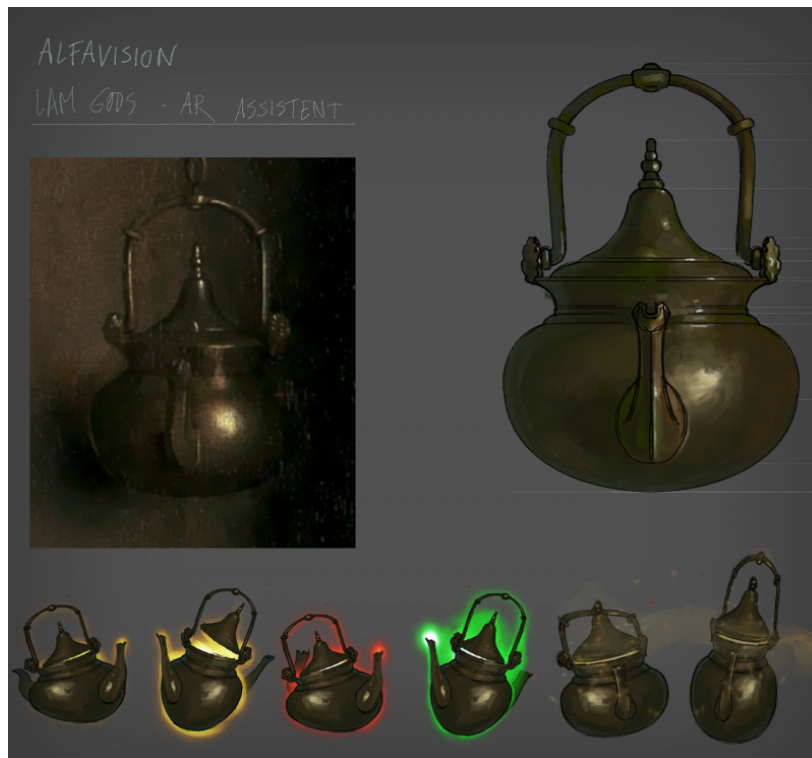


Fig 11. Preparatory drawings of the digital assistant, Picture from Alfavision, "The Ghent Altarpiece AR," Projects, accessed December 24, 2024. <https://www.alfavision.be/project/ghent-altarpiece-ar>.

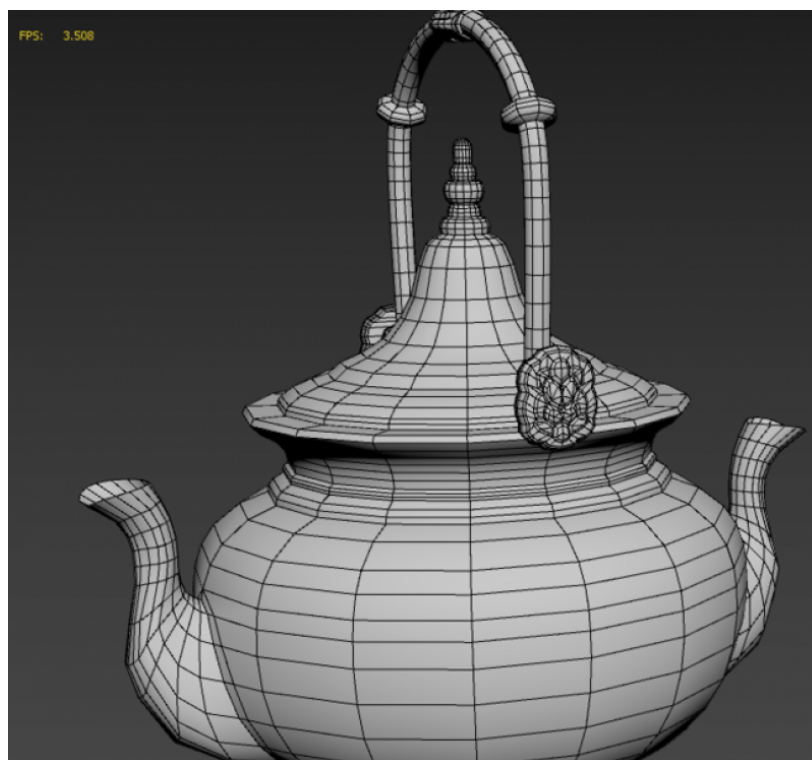


Fig 12. Intermediate step in the realization of the digital assistant, Picture from Alfavision, "The Ghent Altarpiece AR," Projects, accessed December 24, 2024. <https://www.alfavision.be/project/ghent-altarpiece-ar>.





Fig 13. Final result of the digital assistant, Picture from Alfavision, "The Ghent Altarpiece AR," Projects, accessed December 24, 2024. <https://www.alfavision.be/project/ghent-altarpiece-ar>.



Fig 15. Mosaic floor from the Villa a Protiro, featuring black and white tesserae with hexagonal motifs, dating to the 2<sup>nd</sup> century AD, Picture from Parco Sommerso di Baia, "Villa a Protiro," Visite Guidate, accessed December 28, 2024. <https://parcoarcheologicodibaia.it/en/visite-guidate/villa-protiro>.



Fig 16. The beginning of the VR experience showcasing a reconstructed coastline view above water before transitioning to the submerged ruins of the Villa a Protiro, Screenshot via Steam, “Dry Visit – Virtual Underwater Visit – iMARECulture,” Screenshot taken by Hanne Mannens on December 28, 2024.

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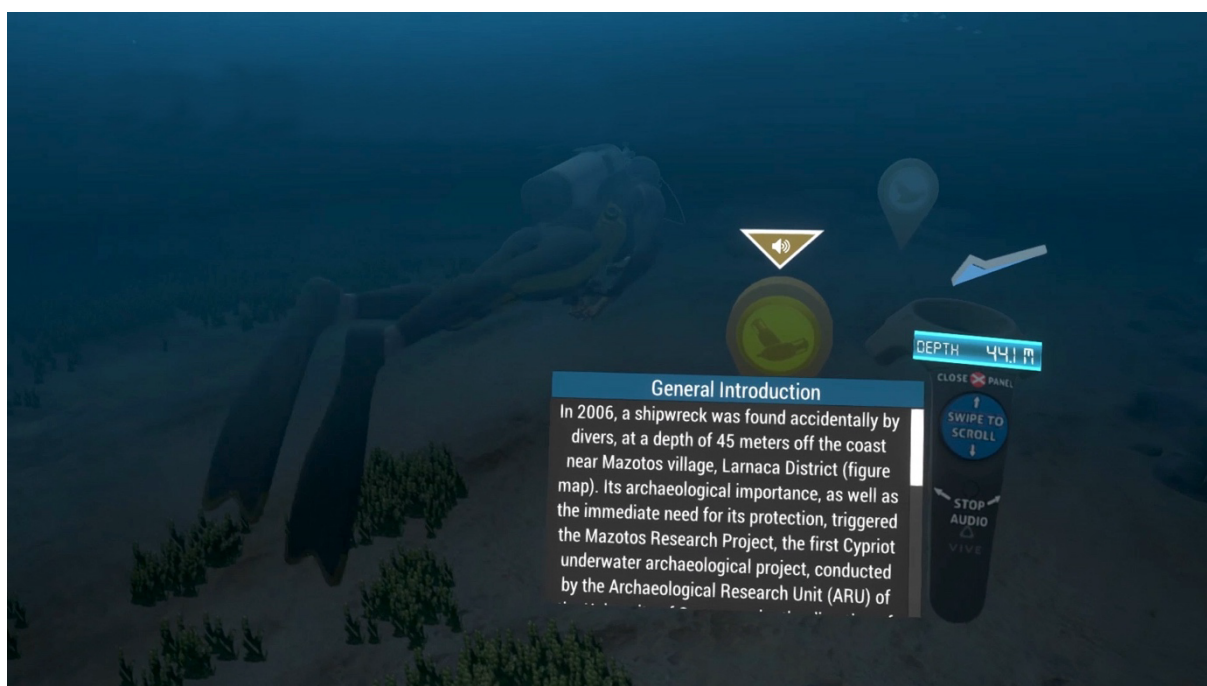


Fig 17. Interactive Points of Interest (POIs) with color-coded icons offer multimedia content, Screenshot via Steam, “Dry Visit – Virtual Underwater Visit – iMARECulture,” accessed December 28, 2024.

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Fig 18. The VR experience allows users to toggle between the villa's current submerged state and its hypothetical reconstructed grandeur, showcasing its original architecture and furnishings, Screenshot via Steam, "Dry Visit – Virtual Underwater Visit – iMARECulture," accessed December 28, 2024. [https://store.steampowered.com/app/1242830/Dry\\_Visit\\_Virtual\\_Underwater\\_Visit\\_iMARECulture/](https://store.steampowered.com/app/1242830/Dry_Visit_Virtual_Underwater_Visit_iMARECulture/).





Fig 22. Vincent van Gogh, *Marguerite Gachet au piano*, 1890, Oil paint on canvas, 102,5 x 50 cm, Kunstmuseum Bâle, inv. 1635, Picture from Wikipedia, "Marguerite Gachet au piano," accessed December 29, 2024. [https://fr.wikipedia.org/wiki/Marguerite\\_Gachet\\_au\\_piano](https://fr.wikipedia.org/wiki/Marguerite_Gachet_au_piano).



Fig 23. Picture of a participant engaging with one of Van Gogh's iconic works at Musée d'Orsay, Vincent Van Gogh, *L'église d'Auvers-sur-Oise, vue du chevet*, 1980, Oil paint on canvas, 74 x 94 cm, Musée d'Orsay, Paris, inv. RF 1951 42, Picture from Musée d'Orsay, "Réalité virtuelle – La Palette de Van Gogh," Expositions, accessed December 29, 2024. <https://www.musee-orsay.fr/fr/agenda/expositions/realite-virtuelle-la-palette-de-van-gogh>.



Fig 24. Still from the VR experience at the Musée D'Orsay showing the portrait of Dr. Gachet, Vincent Van Gogh, *Le Docteur Paul Gachet*, 1890, Oil paint on canvas, 68,2 x 57 cm, Musée d'Orsay, Paris, inv. RF 1949 16, Picture from Hyperallergic, © Lucid Realities, TSVP, Musée d'Orsay, and VIVE Arts, "A Topsy-Turvy Van Gogh VR Experience," accessed December 29, 2024. <https://hyperallergic.com/860326/a-topsy-turvy-van-gogh-vr-experience-musee-d-orsay/>.





Fig 25. Vincent Van Gogh, *Korenveld met kraaien*, 1890, Oil paint on canvas, 50,5 x 103 cm, Van Gogh Museum, Amsterdam, inv. s0149V1962, Picture from Van Gogh Museum Amsterdam, © Van Gogh Museum, Amsterdam (Vincent van Gogh Stichting), "Korenveld met kraaien," Collectie, accessed December 29, 2024. <https://www.vangoghmuseum.nl/nl/collectie/s0149v1962>.

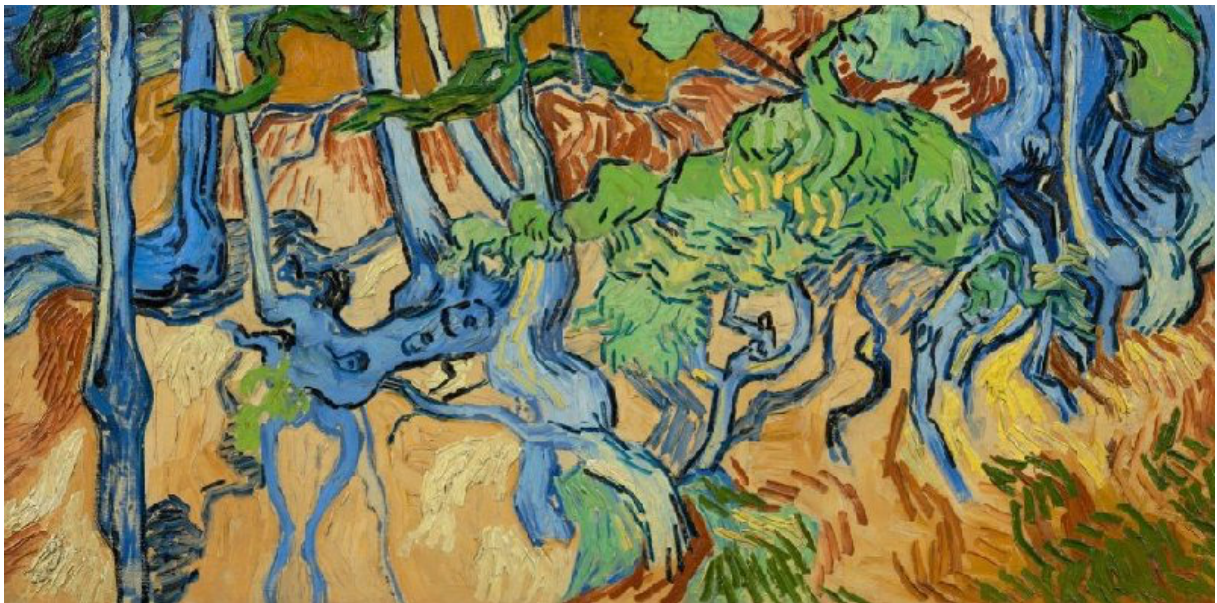


Fig 26. Vincent Van Gogh, *Boomwortels*, 1890, Oil paint on canvas, 50,3 x 100,1 cm, Van Gogh Museum, Amsterdam, inv. s0195V1962, Picture from Van Gogh Museum Amsterdam, © Van Gogh Museum, Amsterdam (Vincent van Gogh Stichting), "Boomwortels," Collectie, accessed December 29, 2024. <https://www.vangoghmuseum.nl/nl/collectie/s0195v1962>.





Fig 27. Vincent Van Gogh, *Ijsvogel aan de waterkant*, 1887, Oil paint on canvas, 26,6 x 19,1 cm, Van Gogh Museum, Amsterdam, inv. s0100V1962, Picture from Van Gogh Museum Amsterdam, © Van Gogh Museum, Amsterdam (Vincent van Gogh Stichting), "Ijsvogel aan de waterkant," Collectie, accessed December 29, 2024. <https://www.vangoghmuseum.nl/nl/collectie/s0100v1962>.



Fig 31. Emile Claus, *Sunny Day*, 1899, Oil paint on canvas, 92,7 x 73,5 cm, Museum of Fine Arts Ghent, inv. 1904-X, Picture from MSK Gent, "Sunny Day," Search the collection, accessed October 30, 2024. <https://www.mskgent.be/en/collection/1904-X>.





Fig 32. Setup of the *Actual Day* installation in Room S of the MSK Ghent, featuring a digital projection from a beamer, Picture taken by Hanne Mannens on January 4, 2024.



Fig 43. 3D Digital twin of Marcel Duchamp's *Box in a Valise*, 1935-1941/1963-1966, M+, Hong Kong, © Association Marcel Duchamp / ADAGP, Paris — SACK, Seoul, 2022, images provided by HATO, interactive design by HATO, 3D model developed by Plinth, Picture from ZTYLEZ Magazine, "The father of 20<sup>th</sup>-century conceptual art was once criticized as "vulgar and intolerable"! M+ latest online exhibition reviews Duchamp's groundbreaking masterpiece!" Accessed January 4, 2025. <https://zstylez.com/art-en/exhibition-en/2022/10/18/216643/?lang=en>.

## Illustration Credit

Fig 1. Screenshot of Google Arts & Culture's "Cultural advent calendar," Screenshot taken by Hanne Mannens on December 4, 2024. <https://artsandculture.google.com/>.

Fig 2. Reality-Virtuality Continuum by Paul Milgram and Fumio Kishino, "A Taxonomy of Mixed Reality Visual Displays," 1994, from ResearchGate, uploaded by Thammathip Piumsomboon, accessed December 10, 2024. [https://www.researchgate.net/publication/321405854\\_Exploring\\_enhancements\\_for\\_remote\\_mixed\\_reality\\_collaboration/figures?lo=1](https://www.researchgate.net/publication/321405854_Exploring_enhancements_for_remote_mixed_reality_collaboration/figures?lo=1).

Fig 3. *Section of the Rotunda, Leicester Square Panorama*, by Robert Barker, 1801 (building from 1792), Etching, colored aquatint, Published by Robert Mitchell, London, British Library, 56.i.12 [Plate 14], Picture from MET Museum, "When Thomas Cole Caught "Panoramania", " Perspectives, accessed December 10, 2024. <https://www.metmuseum.org/perspectives/thomas-cole-panorama>.

Fig 7. Visitors inside the Ephesus Museum Experience, Picture from ATELIER BRÜCKNER, "Ephesus – Experience Museum," accessed December 13, 2024. <https://www.atelier-brueckner.com/en/projects/ephesus-experience-museum>.

Fig 8. Particle-based transitions illustrate the conceptual spectrum from myth (left) to reality (right), Screenshot from Museum XR Summit, "Ephesus Experience Museum: Immersive Histories for Today's Audiences," MuseumNext Conference, June 26, 2024, Screenshot taken by Hanne Mannens on July 3, 2024. <https://museumnext.mn.co/posts/museum-xr-summit-ephesus-experience-museum-immersive-histories-for-todays-audiences>.

Fig 9. Visitors enjoying the AR tour, Picture from Alfavision, "The Ghent Altarpiece AR," Projects, accessed December 24, 2024. <https://www.alfavision.be/project/ghent-altarpiece-ar>.

Fig 10. Visitors enjoying AR tablet tour, Picture from Alfavision, "The Ghent Altarpiece AR," Projects, accessed December 24, 2024. <https://www.alfavision.be/project/ghent-altarpiece-ar>.

Fig 14. AR experience enabling participants to zoom in on the altarpiece's panels, Picture from Alfavision, "The Ghent Altarpiece AR," Projects, accessed December 24, 2024. <https://www.alfavision.be/project/ghent-altarpiece-ar>.

Fig 19. The Snap AR try-on activation at "Fashioning San Francisco: A Century of Style," featuring models in designs [from left] by Kasik Wong, Valentino, and Yves Saint Laurent, Photos courtesy of Snap Inc., Picture from Artnet, "De Young Museum's New Fashion Exhibition Lets Visitors Don Historic Designs With Snap's A.R.," Art & Exhibitions, accessed December 29, 2024. <https://news.artnet.com/art-world/fashioning-san-francisco-de-young-snap-ar-2422348>.

Fig 20. Installation view of "Fashioning San Francisco: A Century of Style," de Young, San Francisco, 2024, Photograph by Gary Sexton, Courtesy of FAMSF, Picture from FAMSF, "Fashioning San Francisco: A Century of Style," Exhibitions, accessed December 29, 2024. <https://www.famsf.org/exhibitions/fashioning-san-francisco#about>.

Fig 21. Van Gogh's palette in the VR recreation of Dr. Gachet's living room, Picture from Lucid Realities, "La Palette de Van Gogh," Portfolio, accessed December 29, 2024. <https://lucidrealities.studio/index.php/portfolio/la-palette-de-van-gogh-2/>.



Fig 28. Van Gogh's palette transformed into a walkable 'pigment landscape' in VR, recreated using photogrammetry to capture intricate brushstrokes and color, Picture from Musée d'Orsay, "Video 360° - Plongez dans la palette de Vincent van Gogh," Articles, accessed December 29, 2024. <https://www.musee-orsay.fr/fr/articles/video-360deg-plongez-dans-la-palette-de-vincent-van-gogh-277248>.

Fig 29. The Contextual Model of Learning by John H. Falk and Lynn D. Dierking, "Contextual model of learning," 2000, from ResearchGate, uploaded by Christine M. Van Winkle, accessed January 2, 2025. [https://www.researchgate.net/publication/314277190\\_MEANINGFUL\\_LEARNING\\_AT\\_A\\_NATIONAL\\_HISTORIC\\_SITE\\_HOW\\_INTERPRETIVE\\_TOUR\\_MESSAGE\\_CONTENT\\_AFFECTS\\_VISITOR\\_LEARNING\\_TRANSFER/figures](https://www.researchgate.net/publication/314277190_MEANINGFUL_LEARNING_AT_A_NATIONAL_HISTORIC_SITE_HOW_INTERPRETIVE_TOUR_MESSAGE_CONTENT_AFFECTS_VISITOR_LEARNING_TRANSFER/figures).

Fig 30. Visitors watching *Actual Day* during Museumnacht at MSK Gent, December 7, 2023, Jill Andréka, Ellen de Ridder, and Hanne Mannens, *Actual Day*, 2023, Projected video installation, MSK Ghent, Photograph by © Martin Corlazzoli, Posted on Instagram by MSK Ghent, December 8, 2023, Accessed October 30, 2024. [https://www.instagram.com/p/C0mgvwyMFFI/?img\\_index=5](https://www.instagram.com/p/C0mgvwyMFFI/?img_index=5).

Fig 33. Distribution of survey participants' ages, Created by Hanne Mannens using RStudio and Canva Histogram Maker. <https://www.canva.com/graphs/histograms/>.

Fig 34. Feedback on the ease of understanding and interacting with AI features, Created by Hanne Mannens using RStudio and Canva Histogram Maker. <https://www.canva.com/graphs/histograms/>.

Fig 35. Participants' overall museum experience ratings, Created by Hanne Mannens using RStudio and Canva Histogram Maker. <https://www.canva.com/graphs/histograms/>.

Fig 36. Participants' perceptions of the installation's contribution to their overall enjoyment, Created by Hanne Mannens using RStudio and Canva Histogram Maker. <https://www.canva.com/graphs/histograms/>.

Fig 37. Correlation between age and perceived AI contribution to the experience, Created by Hanne Mannens using RStudio.

Fig 38. Correlation between museum attendance frequency and perceived AI contribution to the experience, Created by Hanne Mannens using RStudio.

Fig 39. Visitor preferences for physical or visual elements, Created by Hanne Mannens using RStudio and Canva Histogram Maker. <https://www.canva.com/graphs/histograms/>.

Fig 40. Participant responses on whether the installation encouraged reflection and provided insights, Created by Hanne Mannens using RStudio and Canva Histogram Maker. <https://www.canva.com/graphs/histograms/>.

Fig 41. Visitor interest in technology-based exhibits and AI-driven educational content, Created by Hanne Mannens using RStudio and Canva Histogram Maker. <https://www.canva.com/graphs/histograms/>.

Fig 37. Correlation between ease of understanding the artwork and interest in museum technology, Created by Hanne Mannens using RStudio.