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Virtualization of Cultural Heritage: Ar/vr Technologies in Museum and Excursion Practice as a Factor in Preserving Memory

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Abstract

The aim of the study was to identify the technological, spatial, and semiotic conditions under which the use of augmented, virtual, and extended reality contributed to the preservation of cultural memory in museum and excursion practice. The study was conducted from May 1 to July 15, 2026, as a structured review of the subject field, supplemented by comparative qualitative content analysis. The final corpus included 42 English-language publications from 2021–2025, of which 31 empirical, project-based, or practice-oriented works were used for coding, while 11 review and conceptual studies were used for theoretical comparison. It was found that technological immersiveness received the highest average score of 1.48 points on a scale from 0 to 2. Spatial-narrative integration received 1.19 points, semiotic integrity 1.13 points, memorial potential 1.03 points, and historical validity 1.00 point. The most balanced formats were excursion and historical-archaeological formats, with an average score of 1.29 points. Museum and hybrid exhibitions received 1.26 points, while remote virtual environments received 0.83 points. Among technological solutions, augmented reality systems had the highest overall score of 1.23 points. Virtual reality provided the most pronounced sense of presence but more often weakened the connection with the material context. It was determined that the preservation of memory depended not on maximum spectacle but on historical authenticity, semiotic integrity, spatial localization, and the alignment of digital content with the curatorial narrative. The proposed criteria can be used for evaluating and designing digital exhibitions.

Keywords: museum space; semiotics of cultural heritage; digital museology; immersive interpretation; visitor experience; cultural communication

1. INTRODUCTION

The digitalization of museum and excursion activities has changed the ways in which cultural heritage is presented. Augmented and virtual reality technologies have made it possible to reconstruct lost objects, combine material exhibits with digital narratives, and expand access to historical and cultural content. As a result, the museum space has become a multi-level communication environment in which the physical object, digital image, sound, and spatial movement of the visitor form a common system of meanings.

Boboc et al. [1] showed that augmented reality has been widely used for monument reconstruction, navigation, and interactive learning. Anastasovitis et al. [2] emphasized the inclusive potential of virtual museology, in particular the ability to adapt cultural content to different audience needs. At the same time, Chen et al. [3] found that the use of AR in museums depended not only on technical quality but also on functional value, social context, and the integration of the digital layer into the museum narrative.

In the field of cultural tourism, AR could support educational goals, accessibility, and the sustainable use of heritage sites, but its effectiveness was determined by its alignment with long-term conservation goals [4]. The further development of XR and metaverse platforms has expanded the possibilities of immersive education, but at the same time has exacerbated the problems of the authenticity of digital reconstructions and the standardization of content [5].

The scientific gap was that most studies focused on immersiveness, usability, and user engagement, while the semiotic impact of AR/VR on cultural memory remained understudied. The aim of the study was to identify the technological, spatial, and semiotic conditions under which AR/VR contributed to the preservation and transmission of the historical and symbolic meanings of cultural heritage.

To achieve this goal, the following tasks were defined: to characterize the main areas of application of AR/VR in museum and excursion practice; to clarify their impact on the transformation of museum space; to analyze the role of immersive technologies in preserving the historical and symbolic meanings of cultural heritage; and to determine the criteria under which digital reconstruction supported authenticity and cultural memory.

2. LITERATURE REVIEW

Scientific research on the virtualization of cultural heritage has generated a significant body of evidence on the technical suitability of augmented, virtual, and extended reality for museum practice. However, the accumulation of technological solutions has not been accompanied by a similar development in the theory of cultural representation. Systematic reviews by Innocente et al. [6], Ramtohul and Khedo [7], and Li et al. [8] showed the diversity of platforms, devices, and usage scenarios for XR, but at the same time revealed the fragmentation of evaluation criteria. In some studies, effectiveness was determined by interface usability, in others by satisfaction, presence, intention to reuse, or learning effects. Due to this heterogeneity, positive findings were not always comparable. Moreover, the technical performance of a system was often interpreted as evidence of its cultural effectiveness, although there is no direct relationship between these characteristics.

Studies of the museum experience have been dominated by the logic of technological optimism. Trunfio et al. [9], Jangra et al. [10], and Wang et al. [11] linked immersiveness to visitor engagement, emotional response, and satisfaction. However, most of the relevant indicators were recorded immediately after the use of the technology. This design was effective at measuring initial impressions, but did little to explain whether they translated into sustained knowledge, historical context, or long-term memory. No less problematic was the novelty effect: high ratings could relate to an unusual way of interacting rather than to the content of the heritage presented. Therefore, visitor satisfaction should not be considered a sufficient indicator of the quality of cultural interpretation.

This methodological problem was of fundamental importance. The museum experience involved at least three distinct outcomes: emotional engagement, information acquisition, and cultural meaning formation. In many works, these were effectively grouped together into a single category of positive experience. This left it unclear whether the immersive environment deepened understanding of the past or merely made the visit more spectacular. Wang et al. [11], for example, identified factors of immersive experience, but the level of immersiveness itself did not answer questions about the historical authenticity or semiotic integrity of the representation.

Augmented reality research has also focused primarily on behavioral and service implications. Panhale et al. [12] considered AR as a tool for the co-creation of experiences, while Tang and Zhou [13] linked its use to a sense of intertemporal connection and satisfaction among visitors to historical museums. These results confirmed the communicative potential of the technology, but did not eliminate the question of the quality of the connection between the past and the present itself. Digital content could support historical contextualization, but it could also construct a simplified version of the past, adapted to the expectations of the audience.

In educational AR systems, this contradiction was particularly pronounced. Kleftodimos et al. [14] combined geolocation, gamification, and educational content to interpret an archaeological site. This format increased user engagement, but gamification risked shifting attention from historical material to task mechanics. Thus, interactivity was not a pedagogical

advantage in itself. Its value depended on whether it guided the user to analyze the site or merely maintained the pace of interaction.

The semiotic aspect of digital heritage also remained underdeveloped. Galani and Vosinakis [15] showed that digital characters and scale models could make architectural and intangible heritage more accessible for interpretation. However, the digital character was not a neutral mediator. Its appearance, voice, manner of speaking, and programmed stance determined which version of the past the visitor perceived. Thus, the reconstruction not only conveyed information but also selectively shaped meaning. Similarly, Wang and Meng [16] linked the digitization of museums to cultural symbolism, cognitive identity, and public participation, but their model did not sufficiently account for conflicting interpretations of heritage. A cultural symbol did not always have the same meaning for different social groups, so increasing engagement did not necessarily mean achieving interpretive agreement.

In this context, there was a risk of semiotic substitution. The digital model could gradually cease to be perceived as an interpretation and begin to function as a supposedly accurate reproduction of the past. The visitor received a holistic visual image, although some of the details could be based on assumptions, design decisions, or incomplete historical data. If the level of reconstructive uncertainty was not indicated, technological persuasiveness enhanced not knowledge, but the illusion of authenticity. That is why photorealism could not automatically be considered a sign of authenticity.

Research on virtual museum spaces further demonstrated that XR was changing not only the way exhibits were viewed but also the institutional self-representation of the museum. Hellwig [17] found that digital flights and animated itineraries were used to construct museum identity and relationships with the audience. However, the visual freedom of such formats could contribute to the transformation of the museum into a branded media product. In this case, the space was subject not to the logic of the collection, but to the dramaturgy of the digital spectacle.

Song and Evans [18] interpreted augmented reality as a factor in rethinking museum practices, while Iacono et al. [19] proposed a specific VR configuration for a museum institution. However, the case-study nature of such works limited the possibility of generalization. The result depended on the museum's subject matter, the characteristics of the exhibits, the digital literacy of visitors, the technical equipment, and the resources of the institution. Therefore, the success of a single project does not prove the universal effectiveness of VR for all types of cultural heritage.

Comparative user experience studies further demonstrated that XR performance depended not only on the content of the exhibition but also on the way it was technically presented. Leopardi et al. [20] found differences between X-reality solutions in terms of the level of presence and the nature of visitor interaction. This confirmed that the same cultural material could be perceived differently depending on the device, interface, and degree of sensory engagement. At the same time, such dependence made it difficult to separate the cultural effect from the reaction to technological novelty.

A similar problem was identified by Wang et al. [21], who linked the method of displaying VR content to intentions to use the technology in museum tourism. However, behavioral intention characterized the acceptance of the interface, not the depth of heritage interpretation. In a virtual museum of traditional clothing, the user experience was largely determined by the quality of cultural interaction and the structure of the digital environment [22]. However, the digital representation of the clothing could convey the form, ornamentation, and viewing method, but it only partially reproduced the social functions, symbolic differences, and context of use of the objects. In contrast, a virtual tour of a submarine museum demonstrated the advantages of a spatially concretized reconstruction in which navigation was directly related to the architecture of the historical site [23]. This case showed that immersiveness was most culturally productive when it supported the logic of real space rather than replacing it with arbitrary digital dramaturgy.

The study of intangible digital heritage required separate critical consideration. Dobrovolska et al. [24] demonstrated the potential of web analytics for the systematization of online resources and digital collections. However, the discovery and cataloguing of digital material were not the same as its preservation. Intangible heritage existed through practice, knowledge transfer, and community participation. A video recording, a three-dimensional model, or a digital description could capture individual manifestations, but did not fully reproduce the social context in which they acquired meaning. Thus, digital preservation sometimes preserved form while at the same time weakening the connection to living cultural practice.

The analysis showed that the existing literature convincingly substantiated the ability of AR/VR to increase the accessibility, interactivity, and emotional richness of the museum experience. At the same time, the evidence base remained limited by short-term measurements, case studies, heterogeneous indicators, and insufficient distinction between technological effects and cultural outcomes. Long-term memory retention, transparency of reconstructive assumptions, multiplicity of interpretations, and the risk of replacing the material object with a digital image remained insufficiently studied.

The scientific gap, then, was not a lack of evidence for the utility of AR/VR, but rather the lack of an integrated model that could distinguish technologically appealing representations from culturally grounded ones. Such a model would have to take into account immersiveness, historical authenticity, semiotic integrity, the spatial logic of the museum environment, the participation of heritage bearers, and the ability of the digital narrative to sustain memory after the end of direct

interaction.

3. MATERIALS AND METHODS

The study was conducted from May 1 to July 15, 2026, as a structured review of the subject field, supplemented by comparative qualitative content analysis. The search was completed on July 15, 2026. Sources were selected from *Scopus*, the *Web of Science Core Collection*, and *Google Scholar*. Search queries were applied to the titles, abstracts, and keywords of publications. They were formed using the *AND* and *OR* operators with the terms *cultural heritage*, *museum space*, *museum digitalization*, *augmented reality*, *virtual reality*, *extended reality*, *immersive museum*, *heritage interpretation*, *semiotics of cultural heritage*, *visitor experience*, and *cultural memory*. On *Google Scholar*, the first 200 results, ordered by relevance, were checked.

The initial search array covered 126 records: 48 were found in *Scopus*, 42 in the *Web of Science Core Collection*, and 36 were selected after viewing the *Google Scholar* results. After removing 31 duplicates, 95 unique papers remained. During the title and abstract screening, 37 entries were excluded: 15 were mainly related to technical modeling, 9 to digital archiving, 7 to tourism technologies without a clear connection to cultural heritage, and 6 to digital tools not related to *AR*, *VR*, or *XR*.

The full-text evaluation covered 58 papers. Of these, 16 were excluded: 7 did not contain an analysis of museum or cultural communication, 4 did not provide a sufficient description of the technological solution, 3 repeated cultural cases that had already been presented, and 2 did not meet the established time limits. The final corpus consisted of 42 English-language publications from 2021–2025: 41 journal articles and 1 international conference paper. By year, the corpus included 2 papers from 2021, 6 from 2022, 7 from 2023, 21 from 2024, and 6 from 2025.

The corpus included papers that examined the use of *AR*, *VR*, or *XR* in museums, virtual exhibitions, historical sites, archaeological routes, or digital cultural heritage environments. Mandatory criteria included the characterization of cultural content and the presence of results in terms of interpretation, learning, accessibility, authenticity, visitor interaction, or memory formation. Papers that were dedicated only to 3D scanning, photogrammetry, or software testing were not included.

The analysis was conducted at two levels. The unit of analysis at the first level was a single scientific publication. For all 42 works, the year, type of research, format of cultural space, type of heritage, applied technology, evaluation method, and stated result were recorded. The unit of analysis at the second level was a specific museum, excursion, or virtual case described in 31 empirical, project-based, or practice-oriented publications. Eleven systematic, bibliometric, meta-analytic, and conceptual works were used for theoretical comparison but were not rated on the project scale of 0–2.

The coding matrix was generated in *Microsoft Excel 365*. It contained 13 variables: heritage type, spatial format, technology, access device, level of interactivity, digital content function, narrative structure, user role, historical base, designation of reconstruction uncertainty, spatial relationship, stated outcome, and duration of assessment.

Table 1. *Coding criteria for AR/VR/XR cultural heritage projects*

Criterion	0 points	1 point	2 points
Technological Immersiveness	Static presentation without active user participation	Limited navigation or selection of digital elements	Spatial, sensory, or personalized interaction
Historical validity	The sources of the reconstruction were not specified	Sources were partially cited, while the boundaries of assumptions remained unclear	Verified sources were used, and hypothetical elements were clearly identified
Semiotic integrity	Digital images were not associated with cultural meanings	Individual symbols or images received explanations	Visual, textual, and auditory signs formed a coherent system of meanings
Spatial-narrative integration	The technology acted as an autonomous attraction	Digital content was partially consistent with the exhibition	Technology supported a consistent itinerary and a coherent museum narrative
Memorial potential	The entertainment or demonstration function prevailed	Specific educational or emotional components were present	Knowledge, emotional understanding, and cultural identification were combined

Source: developed by the authors.

The initial coding was carried out by a single researcher. After 14 days, 20% of the empirical and case materials were re-checked. Conflicting assessments were reviewed based on the full text of the publication and the operational definitions provided in the table. After coding, descriptive frequencies were determined, and a qualitative comparison of museum, excursion, and remote formats was carried out. Statistical tests were not used, as the study did not involve testing causal relationships.

4. RESULTS

4.1. STRUCTURE AND CONTENT CHARACTERISTICS OF THE CORPUS OF PUBLICATIONS

The consistent application of the selection criteria enabled us to form a final corpus of 42 English-language publications. Its temporal structure showed a clear concentration of scientific interest in 2024. This year accounted for half of all included works. At the same time, only 2 publications were published in 2021, indicating a rapid expansion of the research field following the spread of affordable mobile AR solutions, autonomous VR headsets, and remote museum formats.

By publication type, the corpus consisted almost entirely of journal articles. The materials of the international conference were represented by one paper devoted to digital collections of intangible cultural heritage. By research design, empirical, project-based, and practice-oriented works prevailed. The theoretical part of the corpus included systematic and thematic reviews, bibliometric studies, meta-analyses, and conceptual and strategic works. The quantitative structure of the corpus is presented in Table 2.

Table 2. *Distribution of included publications by year, type, and design*

Characteristic	Category	Number, n	Share, %
Year of publication	2021	2	4.8
	2022	6	14.3
	2023	7	16.7
	2024	21	50.0
	2025	6	14.3
Publication type	Journal article	41	97.6
	Paper from the international conference	1	2.4
Research unit	Empirical, project-based, and practice-oriented works	31	73.8
	Systematic, substantive, and framework reviews	5	11.9
	Bibliometric research	2	4.8
	Meta-analytic study	1	2.4
	Conceptual and strategic works	3	7.1
Total		42	100.0

Note: percentages are calculated from the total number of included publications, n = 42. Eleven review, bibliometric, meta-analytic, and conceptual papers were not rated on the 0–2 design scale.

Source: compiled by the authors based on the results of a structured review.

The resulting distribution showed that the evidence base was mainly formed not through the generalization from long-term museum programs, but through individual technological implementations, experimental prototypes, and user experience studies. Theoretical works provided a classification of technologies and an identification of general trends, but did not always contain sufficient information to assess the historical validity, semiotic integrity, or memorial potential of a particular solution. A similar unevenness was noticeable in systematic and bibliometric works, in which technological architecture, immersiveness, and user experience were described in more detail than mechanisms for preserving cultural memory [1, 6, 7, 25–27].

4.2. TECHNOLOGICAL AND SPATIAL-MUSEUM STRUCTURE OF THE CASE ARRAY

At the second level, 31 main museum, excursion, or virtual case studies were analyzed. This part of the analysis did not include 11 works that were of a review, bibliometric, meta-analytic, or purely conceptual nature.

The largest group was made up of projects integrated into the physical museum exhibition or built as a hybrid combination of a material object and a digital layer. A smaller but equally significant share was made up of digital solutions for archaeological and historical routes and fully remote virtual environments. This ratio showed that the museum remained the main institutional platform for AR/VR, although almost half of the cases already extended beyond the traditional exhibition hall.

By dominant technology, AR and VR were represented almost equally. AR was more often used for overlaying explanatory content on physical objects, geolocation navigation, and activation of digital characters. VR was mainly used for spatial reconstruction, remote visiting, and simulation of the effect of presence. The third group included mixed solutions that combined AR, VR, MR, 360-degree video, material interfaces, or several types of devices. The main characteristics of the 31 cases are summarized in Table 3.

Table 3. *Characteristics of museum, excursion, and virtual AR/VR/XR cases*

Variable	Category	Number, n	Share, %
Format of cultural space	Physical or hybrid museum exhibition	17	54.8
	Historical, archaeological, or excursion location	7	22.6
	Remote virtual environment	7	22.6
Dominant technology	Augmented reality	12	38.7
	Virtual reality	11	35.5
	Augmented, mixed, or hybrid reality	8	25.8
Heritage type	Material	19	61.3
	Intangible	4	12.9
	Mixed	8	25.8
Primary access device	Smartphone or tablet	10	32.3
	VR head-mounted display	9	29.0
	Desktop or web interface	6	19.4
	Material, haptic, or multi-device interface	6	19.4
User role	Mostly passive or guided perception	6	19.4
	Navigation and selection of digital elements	11	35.5
	Active manipulation, co-creation, or social interaction	14	45.2
Total		31	100.0

Note: Each case was assigned to one dominant category within the respective variable. Hybrid solutions were considered to be solutions in which no single technology defined the entire interaction scenario.

Source: compiled by the authors based on a coding matrix of 31 cases.

The dominance of tangible heritage was due to the technological convenience of its visual reproduction. Architectural objects, archaeological sites, museum artifacts, and historical interiors could be represented as three-dimensional models, spatial reconstructions, or digital overlays. Intangible heritage required a more complex structure of representation, since the transmission of practice, oral knowledge, or cultural action could not be limited to a visual model. Such projects used digital characters, voice narrations, multimedia collections, and reconstructed scenarios of cultural practices [15, 24]. An example of the combination of a physical scale model, a mobile device, and augmented digital content is presented in Figure 1.

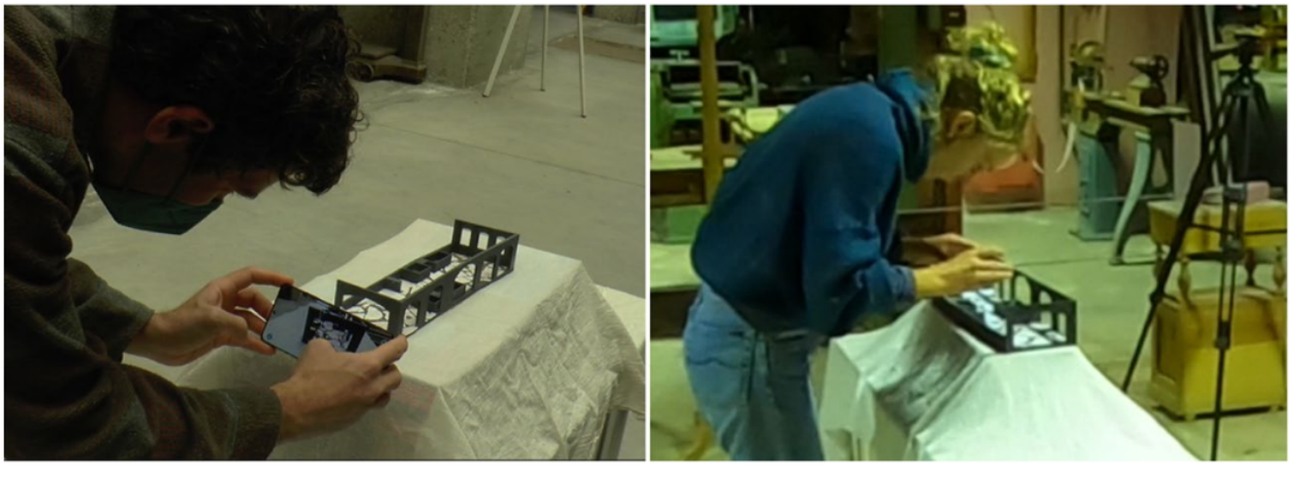

Figure 1. *User interaction with a mobile AR installation of cultural heritage*

Source: Reproduced from Galani and Vosinakis [15, Figure 5].

The presented example demonstrates a spatial-interpretive model of virtualization, within which digital content does not replace the material object but expands the ways of perceiving it. The use of a mobile device makes it possible to combine a physical scale model with additional visual and informational elements, while maintaining the user's direct connection with the museum environment. However, active interaction alone does not guarantee a deep understanding of the cultural meaning of the object if the digital layer is not aligned with the curatorial narrative and does not explain the symbolic context of the heritage.

A comparison of user roles showed that 14 out of 31 projects involved active manipulation of digital objects, collaborative interaction, or selection of the sequence of a cultural narrative. Examples of such approaches were tangible AR interfaces, social collaborative viewing of digital artifacts, haptic exploration, and gamified spatial navigation. At the same time, user activity did not always imply in-depth interpretation. In some solutions, it focused on technical action, while the

explanation of cultural meaning remained an additional element [14, 28, 29]. Ch'ng et al.'s social AR project involved multi-user discussion of cultural objects, while CubeMuseum AR combined a physical cube, digital artifacts, and several stages of user evaluation.

4.3. CODING RESULTS ACCORDING TO FIVE CRITERIA

The overall distribution of scores demonstrated a gap between the technological sophistication of the projects and the completeness of their cultural-memorial argumentation. The highest average score was recorded for technological immersiveness. In 18 cases, this criterion received 2 points, which meant the presence of spatial, sensory, personalized, or multi-channel interaction.

The remaining four criteria mostly received a score of 1. This meant that historical justification, semiotic structure, spatial-narrative connection, and memorial function were present, but did not constitute systematically developed components of the project. The evaluation results are presented in Table 4.

Table 4. *Distribution of AR/VR/XR case scores by coding criteria*

Criterion	0 points, n (%)	1 point, n (%)	2 points, n (%)	Average score	Median
Technological Immersiveness	3 (9.7)	10 (32.3)	18 (58.1)	1.48	2
Historical validity	8 (25.8)	15 (48.4)	8 (25.8)	1.00	1
Semiotic integrity	5 (16.1)	17 (54.8)	9 (29.0)	1.13	1
Spatial-narrative integration	6 (19.4)	13 (41.9)	12 (38.7)	1.19	1
Memorial potential	7 (22.6)	16 (51.6)	8 (25.8)	1.03	1

Note: Mean values were used as descriptive characteristics of the corpus, not as results of statistical testing. A score of 0 indicated the absence of the criterion, 1 indicated partial representation, and 2 indicated systemic integration.

Source: compiled by the authors based on the results of qualitative coding of 31 cases.

Technological immersiveness was the only criterion for which the median was 2. It was most pronounced in VR projects with head-mounted displays, spatial navigation, six degrees of freedom, interactive artifacts, or haptic feedback. In such cases, the user not only observed the digital space but also moved within it, changed perspective, and interacted with reconstructed objects. In particular, projects at the Balzi Rossi Museum and Le Corbusier Museum were aimed at spatially reproducing the museum environment, while haptic solutions complemented the visual presence with a sense of material contact [10, 19, 30]. Descriptions of the Balzi Rossi and Le Corbusier Museum projects confirmed the orientation of these solutions toward interactive visits and the effect of presence. The virtual reconstruction of the historical landscape of Balzi Rossi, created as an element of an immersive museum environment, is presented in Figure 2.

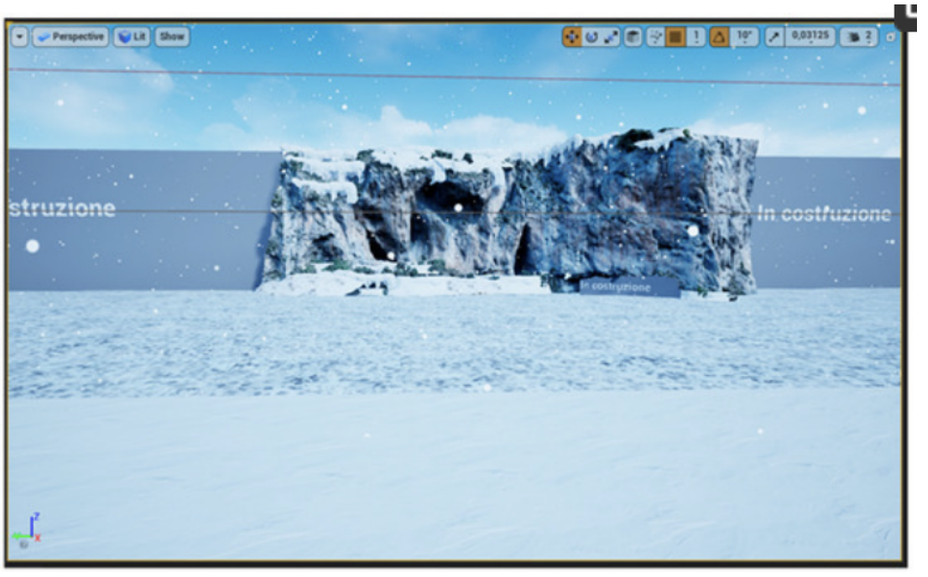

Figure 2. *Virtual reconstruction of the historical landscape of Balzi Rossi*

Source: Reproduced from Iacono et al. [19, Figure 4].

The virtual reconstruction of Balzi Rossi illustrates the ability of VR to recreate historical landscapes and spaces that are inaccessible to direct observation. The high level of detail in the digital environment supports the effect of presence and facilitates spatial understanding of the monument, but at the same time increases the risk of perceiving the reconstructed elements as absolutely authentic. Therefore, the cultural and educational value of such a solution depends on a clear distinction between documented data, reconstructive assumptions, and design components of the digital model.

A high technological assessment, however, did not automatically mean high historical validity. Only in 8 cases were the sources of the reconstruction clearly indicated, and the confirmed and hypothetical elements were distinguished. In 15 projects, archival materials, museum collections, expert consultations, or a photogrammetric base were mentioned, but the boundaries of the reconstructive assumptions remained insufficiently transparent. In the remaining 8 cases, the historical basis of the digital representation was practically not explained.

This result was particularly important for realistic VR reconstructions. The high visual detail created an effect of authenticity, although the scientific basis of individual colors, textures, character actions, or spatial details might not be revealed. Thus, the technical persuasiveness of the digital image turned out to be more developed than the mechanisms for communicating to the user the degree of historical certainty.

Semiotic integrity reached a systemic level in 9 cases. In these projects, textual, visual, aural, and spatial signs were unified around a clear cultural meaning. In the other 17 cases, individual symbolic elements were explained but did not form a coherent system. For example, a digital character might convey a distinct historical narrative, but its voice, appearance, and position in the narrative were not always culturally justified. Similarly, a three-dimensional artifact might be accompanied by a factual reference but remain loosely connected to broader social practices, memory conflicts, or collective identity.

Spatial-narrative integration received a slightly higher score than historical validity and memorial potential. In 12 cases, digital content was consistently linked to a museum route, archaeological location, or virtual exhibition structure. At the same time, in 6 projects, the technology functioned as a relatively autonomous demonstration. In such cases, the visitor could obtain a vivid digital experience, but their connection with the previous and subsequent elements of the exhibition remained limited.

Most often, systemic integration was recorded in geolocation AR routes. Digital material was activated directly near the historical object, so the space became part of the interpretive structure. At the same time, gamification could shift the focus toward finding digital points and completing tasks. Thus, route integration improved the connection between content and place, but did not guarantee sufficient depth of historical explanation [4, 14, 31].

The memorial potential received an average score of 1.03. In 8 cases, a systematic combination of cognitive, emotional, and identification components was established. In 16 projects, memory was partially actualized, mainly through learning, emotional involvement, or visual reproduction of the past. Another 7 cases were focused primarily on demonstrating technology, entertaining interaction, or overall visitor satisfaction.

Thus, digital representation more often provided access to an image of the past than formed a comprehensive mechanism for its understanding. The memorial aspect was most consistently presented in works where digitalization was directly linked to cultural symbolism, identity, and the creation of memory [16, 32]. At the same time, the review by Yap emphasized that digitalization increased the accessibility and educational function of the museum, but also created organizational and interpretative difficulties.

4.4. DIFFERENCES BETWEEN MUSEUM, EXCURSION AND DISTANCE FORMATS

A comparison of the three formats showed that none of them had an advantage across all criteria. Remote virtual environments achieved the highest technological immersiveness, but had the lowest scores on spatial-narrative integration and historical validity. This was explained by the fact that the digital space could be technically coherent, but could lose its direct connection to the material place, scale, texture, and spatial logic of the original monument.

Museum and excursion formats exhibited a more balanced structure. Excursion and archaeological routes received the highest score for historical validity, as digital reconstructions were more often tied to a specific location. Physical and hybrid museum exhibits had the highest score for semiotic integrity, as digital content interacted with original objects, museum labels, and curatorial structure.

Table 5. *Average scores of criteria by cultural space format*

Criterion	Museum or hybrid exhibition, n = 17	Excursion or historical location, n = 7	Remote virtual environment, n = 7
Technological Immersiveness	1.47	1.43	1.57
Historical validity	1.06	1.29	0.57
Semiotic integrity	1.24	1.14	0.86
Spatial-narrative integration	1.41	1.43	0.43
Memorial potential	1.12	1.14	0.71
Average of five criteria	1.26	1.29	0.83

Note: Scores ranged from 0 to 2. Due to the descriptive nature of the study, differences between formats were not tested statistically.

Source: compiled by the authors based on the results of comparative qualitative content analysis.

Excursion formats received the highest integral descriptive index of 1.29. Their advantage was the direct connection of digital content with the place. However, they were dependent on mobile equipment, lighting, geolocation, weather conditions, and the user's ability to simultaneously control the screen and the physical environment.

Museum exhibits had a nearly similar score of 1.26. Their strength was the combination of digital reconstruction with the original object and curatorial explanation. The risk arose when the digital interface attracted more attention than the exhibit itself.

Remote environments received an average score of 0.83. They expanded geographic access, enabled repeat visits, and allowed the presentation of inaccessible or lost objects. At the same time, the remote format often lost physical context and transformed the museum space into a navigational interface. Studies of virtual visits also found both positive and negative elements of authenticity, convenience, and emotional engagement. In particular, the analysis of Generation Z included 107 virtual museum visits, which showed heterogeneity in the experience depending on the structure of the web environment [33].

4.5. DIFFERENCES BETWEEN AR, VR AND HYBRID TECHNOLOGIES

A comparison of technology groups confirmed that VR provided the highest level of immersion, but was inferior to AR in spatial integration. AR was more likely to maintain a connection to a physical exhibit or historical location. XR/MR and hybrid solutions had the highest scores for semiotic integrity and memorial potential, although their technological structure was more complex and required the coordination of multiple communication channels.

These differences are presented in Table 6.

Table 6. *Average scores of criteria by dominant technology*

Criterion	AR, n = 12	VR, n = 11	XR/MR and hybrid solutions, n = 8
Technological Immersiveness	1.33	1.73	1.38
Historical validity	1.17	0.91	0.88
Semiotic integrity	1.17	1.00	1.25
Spatial-narrative integration	1.42	0.91	1.25
Memorial potential	1.08	0.91	1.13
Average of five criteria	1.23	1.09	1.18

Note: AR – augmented reality; VR – virtual reality; XR – extended reality; MR – mixed reality. Each case was classified according to the dominant technological logic.

Source: compiled by the authors based on the coding results.

AR had the highest overall score of 1.23. Its advantage was not in maximum immersion, but in preserving the real object within the field of perception. The digital layer could complement, rather than completely replace, the material monument. This created better conditions for spatial and historical contextualization.

VR received the highest value of technological immersiveness, 1.73. However, its overall score was lower due to the separation of the digital environment from the physical object and the uneven explanation of reconstructive assumptions. In a number of studies, the main outcome was presence, comfort, reduction of cybersickness, convenience, or intention to reuse. Cultural authenticity was assessed less frequently.

Hybrid technologies proved to be the strongest in terms of semiotic integrity. The combination of a material interface, digital object, sound, text, and social interaction made it possible to present heritage as a system of related signs. However, increasing the number of channels did not always improve intelligibility. In the absence of a clear hierarchy, the user received an excess of stimuli, and the museum narrative became fragmented.

4.6. OUTCOME ORIENTATION AND DURATION OF ASSESSMENT

Analysis of the reported results showed the dominance of the indicators of immersiveness, engagement, and overall user experience. Only 5 out of 31 cases directly addressed cultural memory, authenticity, or identity. Another 7 studies assessed learning or interpretation, which might indirectly support memory but was not identical to its long-term preservation.

A predominance of short-term evaluation was also established. In 18 cases, results were recorded during a single session or immediately after the interaction. Only 2 projects contained delayed or longer evaluations, which extended beyond one month. The corresponding results are presented in Table 7.

The prevalence of immediate posttesting limited the ability to distinguish between technological novelty effects and enduring cultural outcomes. A high score after the first VR session could reflect the unfamiliarity of the device, spatial presence, or enjoyment of the interactivity. It did not confirm that the user had retained historical information, reinterpreted a cultural symbol, or formed a lasting connection to the represented community.

Studies focused on learning have used interface comparisons, surveys, expert interviews, and task performance assessments. For example, the CubeMuseum AR study included an AR interface comparison, expert interviews, an online survey, and separate testing of an optimized design. This provided a multi-level validation of usability, but the main findings were still about motivation, engagement, and learning performance, not delayed retention of cultural memory.

The results allowed us to identify three main models of cultural heritage virtualization. The first model was technological

and demonstrative in nature. It prioritized immersiveness, interface novelty, and overall impression. Such projects received high marks according to the technological criterion, but lower marks according to historical validity and memorial potential.

Table 7. *Main outcome and duration of case evaluation*

Variable	Category	Number, n	Share, %
Main declared result	Immersiveness and engagement	10	32.3
	Learning and interpretation	7	22.6
	Satisfaction and behavioral intentions	6	19.4
	Memory, authenticity or cultural identity	5	16.1
	Accessibility and inclusion	3	9.7
Duration of assessment	Single session or immediate posttest	18	58.1
	Repeated short-term assessment up to 4 weeks	5	16.1
	Deferred evaluation for more than 1 month	2	6.5
	Not specified or not applicable	6	19.4
Total		31	100.0

Note: The primary outcome was defined by the main dependent variable or central finding of each publication. The duration category described the period between interaction with the technology and the final assessment.

Source: compiled by the authors based on coding results.

The second model was spatial-interpretive. It prevailed in AR itineraries and hybrid museum exhibitions. Digital content was tied to a specific object or location, supported the sequence of visitor viewing and complemented the material environment. It was this model that provided the best balance between technological interaction and cultural contextualization.

The third model was semiotic-memorial in its nature. It was the least common, but most relevant to the issue of memory preservation. In such projects, digital images, voices, texts, spatial elements, and user participation were combined around a historically grounded narrative. The technology served as a mediator between the material object, cultural meaning, and the modern visitor, rather than a standalone spectacular product.

Thus, the coding did not confirm that a high level of immersiveness alone determined the ability of AR/VR to preserve cultural memory. The most balanced projects were those in which the digital content was spatially connected to the monument, relied on verified historical materials, explained symbolic meanings, and engaged the user in meaningful, rather than just technically active, interaction. Virtualization supported memory when it did not replace the heritage object, but restored the connections between its material form, cultural context, and contemporary interpretation.

5. DISCUSSION

The results showed that the technological immersiveness of AR/VR projects was better developed than their historical, semiotic and memorial components. The average score of technological immersiveness was 1.48 points , while historical validity – 1.00, semiotic integrity – 1.13, spatial- narrative integration – 1.19, memorial potential – 1.03. Thus, the sense of presence and interactivity were not always accompanied by a sufficient explanation of cultural meanings.

This conclusion was consistent with Wang and al. [34], who linked the development of immersive cultural heritage to technological realism, accessibility and user interaction. However, the coding carried out showed that technical persuasiveness could even increase the risk of uncritical perception of the reconstruction. If the boundaries between documented and hypothetical details were not marked, the digital image was perceived as an accurate reproduction of the past.

The found advantage of immersiveness was consistent with Trunfio's results et al. [35], according to which the functional characteristics of devices influenced the presence and behavior of visitors. At the same time, in the analyzed corpus, only 5 out of 31 cases directly assessed memory, authenticity, or cultural identity. This showed that satisfaction and intention to reuse the technology could not be considered sufficient indicators of memory retention.

Meta-analysis Zhou et al. [36] confirmed the positive impact of AR and VR on museum learning. However, the results showed that the assimilation of information was not always accompanied by semiotic integrity. In most cases, cultural symbols were only partially explained. A similar problem was important for the digital representation of crafts , since a technological model could convey the form of an object, but not fully reproduce the social practices, skills, and symbolic meanings associated with its creation [37].

A comparison of spatial formats showed the advantage of excursion and historical locations, the average score of which was 1.29 points . Museum and hybrid exhibitions received 1.26, remote environments – 0.83 points. This was consistent with Chung et al. [38], who established the dependence of the museum experience on the organization of virtual space. The remote format expanded access, but weakened the connection with the materiality, scale and spatial context of the monument.

Kamariotou and al. [39] emphasized the need for strategic planning for virtual exhibitions. The analysis concretized

this requirement: planning should encompass not only navigation and user comfort, but also historical argumentation, narrative consistency , and transparent labeling of reconstructive assumptions. Xu's Conclusions et al. [40] regarding the position of museum professionals also confirmed that digital solutions should be consistent with curatorial logic, and not function as an isolated attraction.

Practical cases have shown that the best results were achieved in hybrid formats. The v- Corfu project combined AR and VR to expand access to cultural heritage [41], while gamified VR storytelling used three-dimensional reconstructions, digital characters, and 360-degree video [42]. Such solutions increased engagement, but their cultural effectiveness depended on whether gamification was subordinated to historical content.

Thus, the results confirmed that the memorial potential of AR/VR was determined not by maximum immersiveness , but by a combination of historical authenticity, semiotic integrity, and spatial integration. The most effective projects were those in which digital content complemented the material object, explained cultural meanings, and formed a coherent connection between the past and the present visitor.

6. CONCLUSIONS

The study identified the technological, spatial, and semiotic conditions under which the use of AR, VR, and XR in museum and excursion practice contributed to the preservation of cultural memory. The structured review covered 42 English-language publications from 2021–2025, of which 31 empirical, project-based , or practice-oriented works were used for in-depth coding, and 11 systematic, bibliometric , meta-analytic , and conceptual studies were used for theoretical comparison.

It was found that the technological development of immersive solutions outpaced the quality of their cultural justification. The highest average score was given to technological immersiveness – 1.48 points on a scale from 0 to 2. Spatial- narrative integration was 1.19 points , semiotic integrity – 1.13, memorial potential – 1.03, historical justification – 1.00 points . Thus, most projects provided interactivity and a sense of presence better than explaining the origin of reconstructed elements, the cultural function of digital signs and mechanisms of long-term memory preservation.

Among the formats, the most balanced were excursion and historical and archaeological locations, the average score of which was 1.29 points . Museum and hybrid expositions received 1.26 points , remote virtual environments - 0.83 points . The advantage of spatially localized formats was explained by the preservation of the connection between digital content, physical place and material object. By technological type, AR solutions received the highest overall score - 1.23 points . VR provided maximum immersion , but more often weakened the connection with the material context. Hybrid technologies better supported semiotic integrity, but required clear coordination of several communication channels.

The practical significance of the results was to identify five criteria for evaluating AR/VR/XR projects : technological immersiveness , historical validity, semiotic integrity, spatial- narrative integration, and memorial potential. Museum institutions should identify the boundaries of reconstructive authenticity, align digital elements with curatorial logic, maintain a visible connection to the material object, and subordinate gamification to cultural content.

Limitations of the study were related to the English-language corpus, the time frame of 2021–2025, the predominance of short-term user assessments, and coding by a single researcher. Future studies should include double independent coding, a broader linguistic and geographical corpus, delayed memory measurement, and comparison of digital reconstructions with traditional museum formats.

AUTHORSHIP AND CONTRIBUTIONS

Hanna Marynchenko contributed to the conceptualization and methodological development of the study, conducted the literature search and investigation, performed the formal analysis, and participated in writing the original draft as well as reviewing and editing the manuscript. Dmytro Nefodov contributed to the conceptualization and methodology, carried out the historical analysis, interpreted the results, participated in reviewing and editing the manuscript, and provided supervision. Raddamila Kosarevska contributed to the investigation, spatial and architectural analysis, interpretation of the results, preparation of the original draft, and review and editing of the manuscript. Mariia Silich contributed to the investigation, analysis of augmented reality and extended reality (AR/XR) technologies, interpretation of the technological aspects of the study, preparation of the original draft, and review and editing of the manuscript. Ivan Kostashchuk contributed to the methodology and investigation, conducted the spatial analysis, participated in the interpretation of the results and review and editing of the manuscript, and provided supervision. All authors made substantial contributions to the conception and design of the study, critically reviewed the manuscript, approved the final version for publication, and agreed to be accountable for all aspects of the work.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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DATA AVAILABILITY

Data are available from the corresponding author upon reasonable request. The data consist of information extracted and coded from the publications included in the structured review.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

In the course of preparing this manuscript, the authors employed ChatGPT to improve the linguistic quality and readability of the content. After utilizing this AI tool, the authors conducted comprehensive review and necessary revisions to ensure the accuracy, integrity, and scientific rigor of the manuscript. All authors bear full responsibility for the final content of the published work, including any errors or inconsistencies that may arise.

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