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Virtual and augmented reality as tools for cultural reconstruction

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Abstract. The aim of the study was to explore the possibilities of virtual and augmented reality technologies for the reconstruction of cultural heritage and their integration into educational practices. The study employed a comparative and cognitive-cultural approach to analyse digital projects in three areas: reconstruction of lost monuments, museum practices, and educational applications. The methodology focused on examining sources of three-dimensional modelling, methods of integration into virtual environments, and the functional use of digital platforms across different national contexts. The results of the study demonstrated that virtual and augmented reality technologies provided new opportunities for the preservation and transmission of cultural heritage. They enabled the creation of highly detailed digital copies of architectural and cultural monuments, ensuring their long-term archiving and scientific interpretation. The Palmyra reconstruction project and the Virtual Museum of the Kyiv-Mohyla Academy confirmed the effectiveness of these tools in documenting war damage and safeguarding heritage. At the same time, the "Reborn Rome" initiative revealed the potential of reconstructing entire historical environments, highlighting their value for educational purposes. The analysis of museum practices at the Louvre and the British Museum showed transformations in the ways of presenting and experiencing works of art, while case studies from the United States, Japan, and Ukraine demonstrated that immersion in virtual environments improved learning outcomes and contributed to the development of innovative educational models. The results can be applied by museums, cultural institutions, and educational organisations to preserve heritage digitally and enhance learning through immersive technologies

Keywords: digital replicas; immersive technologies; museum practices; interactive engagement; educational programmes

INTRODUCTION

The relevance of the study was determined by the growing importance of digital technologies in the preservation and actualisation of cultural heritage, as well as by the urgent need to integrate these tools into the humanities. In the modern world, cultural monuments face numerous threats caused by armed conflicts, rapid urbanisation, and natural or technogenic disasters, which have already led to the irretrievable loss of significant architectural and artistic heritage. Under such conditions, the creation of digital models and immersive environments has become not only a means of visualisation, but also an effective strategy for preserving memory about cultural objects and ensuring their accessibility to researchers and society. The research problem lay in the contradiction between the rapid development of virtual reality (VR) and augmented reality (AR) technologies, on the one hand, and the insufficient level of their theoretical conceptualisation and practical integration into the processes of cultural memory reconstruction, formation of historical narratives, and educational practices, on the other.

A number of authors have already outlined scientific guidelines in this area. For example, B. Patychuk (2023) demonstrated that the use of the metaverse not only contributed to the preservation of architectural heritage but also created space for the cultural reuse of lost objects, confirming the potential of digital platforms for restoring collective memory. S. Ivanysko *et al.* (2024) showed that cultural heritage in the context of the Russian-Ukrainian war has become a vulnerable target, and the destruction of monuments has reached the scale of a cultural crime,

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bringing the issue to the level of international humanitarian discussions. K. Pletsan *et al.* (2023) proved that digital transformation in the field of heritage protection has made it possible to create effective mechanisms for restoring monuments using 3D modelling and interactive technologies, which has significantly increased the possibilities for their documentation and popularisation. At the same time, Y. Trach (2020) showed that the experience of Ukrainian VR reconstructions of historical and cultural objects demonstrated the practical applicability of these solutions for scientific and educational purposes, in particular through the creation of virtual copies of lost buildings.

In a broader context, B. Rodriguez-Garcia *et al.* (2024) found that systematic reviews of VR reconstructions of cultural heritage demonstrated the high effectiveness of immersive technologies in ensuring an authentic perception of historical artefacts, confirming their importance in shaping new formats of interaction with culture. Research by P.M. May *et al.* (2020) showed that the use of AR in museum education contributed to an increase in visitors' cognitive activity and created a multidimensional learning environment. In turn, A.A. Kennedy *et al.* (2021) found that AR in museum spaces fostered positive emotions, increased interest, and improved knowledge, proving the psychological effect of immersive practices.

In the field of art education, J. Hutson & T. Olsen (2022) demonstrated that VR, combined with digital humanities methods, created new formats for studying art history that went beyond traditional didactics. An analysis by H. Musiol (2021) found that the integration of VR into digital and environmental humanities projects contributed to the formation of innovative prototypes, where artistic practice was combined with scientific knowledge. S. Muenster (2022) showed that the use of 3D technologies in humanities research and education opened up broad opportunities for reproducing complex cultural phenomena and expanded the range of interdisciplinary approaches.

A review of the literature revealed several important gaps that determined the need for further research. Despite noticeable progress in the development of immersive technologies, the integration of VR and AR into the reconstruction of war-damaged cultural objects remained insufficiently studied, with most existing works focusing primarily on technical rather than conceptual aspects. Moreover, there was no unified or generally accepted methodology for assessing the impact of immersive technologies on the processes of cultural memory reconstruction and the shaping of historical narratives, which limited the ability to compare results across different projects and contexts. In addition, the prospects for applying VR and AR in the humanities education system had been explored only fragmentarily, and most studies provided general observations without a detailed analysis of specific national contexts.

The aim of the study was to determine the potential of VR and AR technologies for the preservation and interpretation of cultural heritage. Accordingly, the tasks included: analysing the current state of digital reconstructions in Ukraine and worldwide; identifying how immersive environments influence the perception of history and art; revealing the educational value of such technologies in the humanities.

MATERIALS AND METHODS

The study applied an analytical method to VR/AR projects in cultural heritage and education. The cases included virtual museums in Syria and Ukraine (Kyiv), large-scale urban reconstructions in Italy (Rome), museum exhibitions in France (Paris), the United Kingdom (London), and Ukraine (Lviv, Kyiv), as well as educational platforms in the United States (Stanford, MIT), Japan (Tsukuba), and Ukraine (Lviv) (Virtual Museum of Syria, n.d.; National University of "Kyiv-Mohyla Academy" Virtual Museum, n.d.; British Museum, n.d.; Virtual tourism, n.d.; Virtual Human Interactional Lab, n.d.; Reinventing Education, n.d.; Artificial Intelligence Laboratory, n.d.; Lviv's Heritage in 3D, n.d.; Mona Lisa Beyond the Glass…, 2019; Rome Reborn: The Pantheon, 2024).

The selection of materials was based on three criteria: the availability of official digital platforms or programmes, the accessibility of descriptions of the technologies used, and representativeness for three areas: the reconstruction of cultural monuments, museum communication, and educational practices. This allowed to include cases that reflected both the conservation of destroyed objects and the restoration of intact historical spaces and their integration into the educational process. The research methodology included a descriptive and comparative approach. For each case, the data sources on which the reconstruction was based were recorded. These included text and visual sources, as well as modern 3D visualisation technologies. Technical means of integration into VR and AR environments, methods of creating virtual tours, and demonstration formats (online platforms, museum exhibitions, educational lectures) were noted. Particular attention was paid to the cross-country comparison of practices. The Syrian and Ukrainian cases were analysed as examples of recording war damage and its digital preservation. The Italian experience of Rome Reborn represented the reconstruction of a historic city in its heyday. French and British museum initiatives were evaluated through the prism of interpretive potential and impact on the perception of art objects. Educational projects in the United States, Japan, and Ukraine were compared in terms of ways to integrate VR and AR into educational programmes at various levels.

The analytical framework was based on a cognitive-cultural approach. For each example, the cognitive possibilities of virtual reality (VR) and augmented reality (AR) were identified, including the presence effect, multi-channel interaction, and interactive perception, as well as the ways in which cultural and historical contexts were reflected in the virtual environment. This ensured a comprehensive comparison of digital practices across different national and disciplinary settings.

RESULTS

Reconstruction of cultural monuments using VR and AR technologies

Virtual and augmented reality have become effective tools for recreating destroyed or lost architectural and historical-cultural objects. The use of three-dimensional modelling, photogrammetry and geospatial data has made it possible to create digital replicas of monuments that are under threat of destruction or have already lost their authentic appearance. Such solutions not only ensured the archiving of information about cultural objects, but also provided interactive access for a wide audience through virtual tours, educational programmes and museum exhibitions. The use of VR and AR in this context was interdisciplinary in nature, combining methods from archaeology, architecture, computer science and cultural studies.

One notable example was the reconstruction of the ancient city of Palmyra in Syria, which suffered extensive damage in 2015. The destruction of architectural complexes affected key cultural heritage sites – the Temple of Bel, columned streets and other monumental structures that had previously been included in the UNESCO World Heritage List (Site of Palmyra…, 2017). In response to the losses, international research and technical teams launched the large-scale Palmyra VR Project (Virtual Museum of Syria, n.d.), which involved the creation of comprehensive three-dimensional models of architectural monuments. The main goal of the project was to preserve information about objects that could not be physically restored in digital format and to provide access to them for the scientific and educational community (Fig. 1).

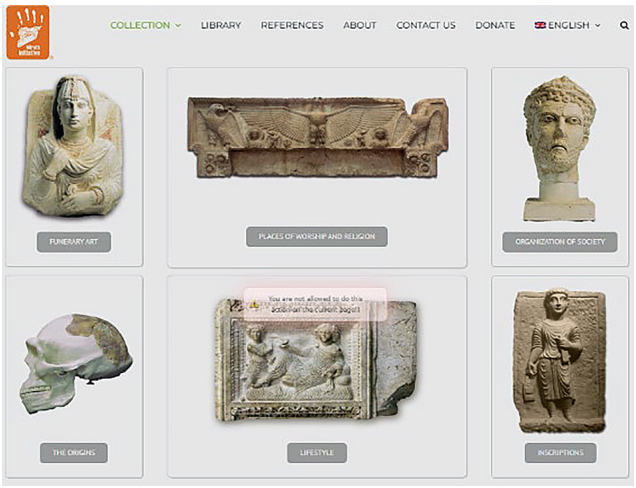

Figure 1. Palmyra VR Project interface

Source: Virtual Museum of Syria (n.d.)

The digital models were created by combining various data sources: high-resolution photogrammetry, archival drawings and photographs, and satellite images. The use of these materials made it possible to create multi-level virtual reconstructions that took into account both the general proportions of architectural complexes and small decorative elements. The accuracy of the modelling made it possible to reproduce the texture of the stone, the structural organisation of the buildings, and the spatial interaction between different architectural components. The result was digital replicas that not only served as visualisations but also as a scientific source for further architectural analysis. The developed models were integrated into a VR environment, which opened up opportunities for their practical use. Researchers obtained a tool for remote analysis of architectural solutions, comparative studies, and reconstruction of historical contexts that would otherwise have been lost. VR tours were created for a wide audience, allowing them to virtually visit the territory of Palmyra, familiarise themselves with architectural ensembles and obtain multi-level information about their historical function and development. This combination of scientific and educational components contributed to the formation of a new type of interaction with cultural heritage, in which the user was not only a passive observer but also an active participant in the process of cognition. The Palmyra VR Project demonstrated that digital technologies can serve as a compensatory mechanism in the event of the loss of the physical cultural environment. Virtual reconstructions ensured the long-term preservation of material culture in digital form, while making it accessible to researchers, educators and the general public. This example confirmed the effectiveness of VR in the field of cultural heritage, where digital representation can become not only a means of archiving, but also a tool for restoring cultural memory and supporting intercultural dialogue.

The Ukrainian context has seen significant development in the use of VR technologies for the reconstruction and preservation of cultural heritage. One example is the Virtual Museum of Kyiv-Mohyla Academy (National University of "Kyiv-Mohyla Academy" Virtual Museum, n.d.), which was created as a comprehensive

digital platform for representing architectural objects and monuments that are at risk of being lost or have been destroyed as a result of contemporary social and military challenges. The main objective of the project was not only to document cultural artefacts, but also to create an interactive environment in which digital copies could be used in educational, scientific and museum contexts. Three-dimensional models were created based on photogrammetry, archival drawings, historical images and modern visualisation technologies (Fig. 2, 3).

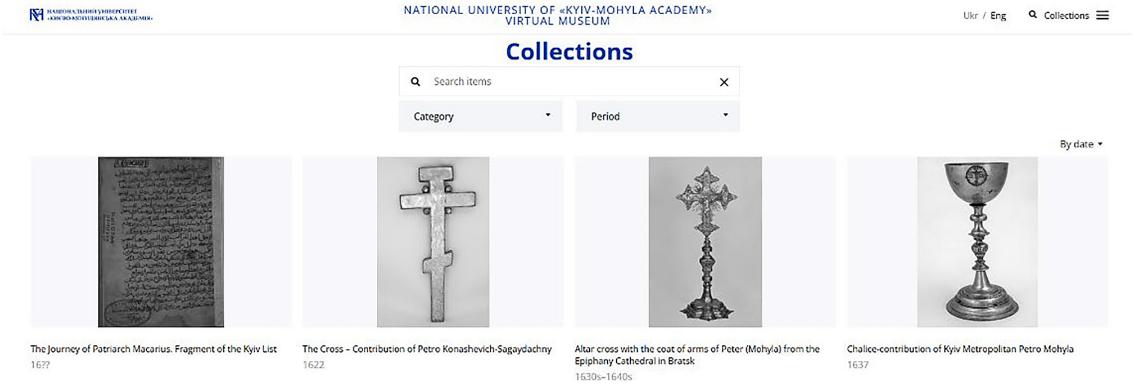

Figure 2. Interface of the Virtual Museum of Kyiv-Mohyla Academy
Source: National University of "Kyiv-Mohyla Academy" Virtual Museum (n.d.)

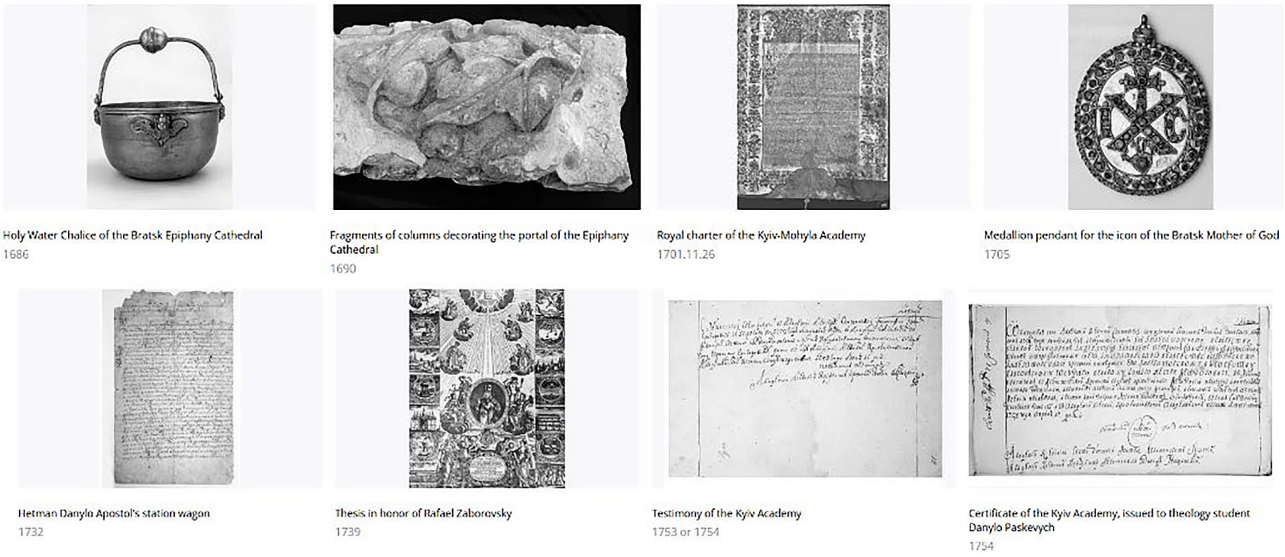

Figure 3. Exhibition collections of the Virtual Museum of Kyiv-Mohyla Academy
Source: National University of "Kyiv-Mohyla Academy" Virtual Museum (n.d.)

The combination of these sources ensured the accurate reproduction of architectural structures and museum artefacts, including their details, scale and spatial organisation. The result was the creation of 3D copies that were integrated into a VR environment, allowing not only the archiving of cultural heritage, but also providing users with the opportunity to interact with the reproduced objects in the form of lectures, scientific research or virtual exhibition spaces. A significant result of the project was the formation of a concept of digital preservation of cultural heritage, within which the VR platform performed a dual function: on the one hand, an archive with a high level of scientific reliability, and on the other, an educational resource for a wide audience. This made it possible to integrate digital models into courses on cultural history, architecture and art, as well as to use them in interdisciplinary research. The importance of the project went beyond the local level. The Virtual Museum of Kyiv-Mohyla Academy gained international significance as it became a tool for promoting Ukrainian cultural heritage in the global academic and museum environment. This provided new opportunities for cultural diplomacy, expanded the accessibility of Ukrainian heritage to foreign researchers, and at the same time integrated Ukrainian experience into global discussions on digital humanities and cultural memory preservation practices (Marukhovska-Kartunova *et al.*, 2024).

In the European context, a key example was the Rome Reborn: The Pantheon (2019) project, aimed at large-scale

recreation of a virtual image of Ancient Rome in the 4th century AD. The main goal of the initiative was to create a comprehensive three-dimensional model of the city that reflected not only architectural ensembles but also the spatial logic of the urban environment. The project reconstructed the main public buildings, including the Colosseum, the Roman Forum, thermal baths, temples and basilicas, as well as residential quarters with the recreation of their internal structure. A distinctive feature of the project was the combination of historical and archaeological data with high-resolution computer graphics (Fig. 4).

Figure 4. Rome Reborn interface
Source: Rome Reborn: The Pantheon (2024)

Archaeological drawings, excavation data, textual sources from the ancient period, and the results of modern research on the history of Roman architecture were used to create the models. This ensured a high level of scientific reliability and accuracy of the reconstructions. At the same time, the use of VR tools made the results accessible to a wide audience, who could interact with the digital space in the form of interactive walks. The project allowed users to move through the virtual streets of the city, view architectural objects from different angles, and perceive the recreated space on a scale as close to reality as possible. This created conditions for a new type of immersion in the study of urbanism and architecture, where traditional textual or graphic representations were replaced by a multi-channel and dynamic experience. The significance of Rome Reborn went beyond purely scientific interest. Its results were actively implemented in the educational process of universities, where VR reconstructions were used as a tool for teaching the history of architecture, archaeology, and cultural studies. In addition, digital models became part of museum exhibitions and specialised online platforms, providing broad access to both the academic community and visitors interested in the history of Rome. In this way, the project demonstrated the potential of VR reconstructions for interdisciplinary education, museum practice, and cultural promotion, establishing them as an effective tool in the field of digital humanities (Frischer & Massey, 2022).

A comparison of the above examples revealed several key trends. In the case of Syria, the reconstruction aimed to preserve cultural heritage destroyed by conflict while making it accessible to the international community. Ukrainian initiatives demonstrated a similar approach, but in the more dynamic context of modern warfare, where digital documentation was combined with the task of creating an evidence base for destruction. The Italian project Rome Reborn developed another dimension – it was based not on the conservation of losses, but on the reconstruction of the historic city in its heyday, providing a tool for educational immersion and scientific analysis. Thus, each of the above cases represented different models of VR and AR application: from documenting losses to reconstructing the past in its entirety (Table 1).

Table 1. Key results of VR and AR reconstructions of cultural heritage

Result of VR and AR reconstructions	Content of the result	Examples of application
New form of archiving	Preservation of architectural and cultural data in the form of digital copies with a high level of detail	3D scanning of heritage sites, creation of digital replicas of destroyed monuments
Interactive interaction	Ability to move within virtual spaces, view objects from different angles, and access supplementary information	Virtual museum tours, VR excursions to historical sites
Educational dimension	Use in university programs, museum pedagogy, and cultural diplomacy; overcoming physical and geographical limitations	VR lectures, AR textbooks, international cultural projects

Source: compiled by the author based on N.J. Shih *et al.* (2020), R. Spallone *et al.* (2022), R.G. Boboc *et al.* (2022)

The use of VR and AR in the reconstruction of monuments has proven effective in three areas. First, these technologies have contributed to the preservation of material objects in digital form and minimised losses in the event of destruction. Secondly, they have provided greater access to cultural heritage, enabling researchers and visitors from around the world to interact with restored monuments. Thirdly, VR and AR have become tools for integrating cultural heritage into the educational process, combining academic authenticity and audience engagement. Thus, the review of international and national examples has confirmed the universality and promise of VR and AR reconstructions in the field of cultural heritage preservation. Despite different contexts – from war damage to

archaeological reconstructions of ancient cities – all projects demonstrated the high potential of digital technologies to ensure the accessibility and longevity of cultural memory. Given these results, VR and AR can be considered integral tools of modern cultural policy aimed at preserving and actualising historical and cultural heritage.

The impact of virtual and augmented reality on the perception of history and art

Immersive technologies have opened up new opportunities for interpreting historical events and art objects. The use of VR and AR in museum practices has changed the way visitors interact with cultural heritage, expanded the boundaries of perception, and shaped new educational formats. Traditional familiarisation with exhibitions in physical space has been supplemented with interactive tools that provide a sense of presence and expand the cognitive capabilities of the audience. This has made it possible to combine aesthetic perception with analytical consideration, creating a multi-level system of access to cultural content (Trunfio *et al.*, 2022).

The French experience demonstrated the integration of VR in leading museum institutions. The Louvre introduced VR exhibitions that provided visitors with the opportunity to interact directly with individual works of art. In particular, when using the Mona Lisa Beyond the Glass… (2019) app, visitors could view the painting in virtual space, enlarging individual fragments and exploring artistic details that were inaccessible in the physical hall. This form of presentation did not replace the original, but provided an additional tool for its study. The VR exhibition combined visual material with multimedia explanations, which helped to form a holistic view of the art object. Such practices allowed for a combination of emotional and scientific perception, expanding the range of interpretative possibilities (Fig. 5).

Figure 5. VR exhibition "Mona Lisa Beyond the Glass"
Source: Mona Lisa Beyond the Glass… (2019)

British museums have also been actively using virtual technologies. The British Museum (n.d.) has provided users with the opportunity to take VR tours of the halls containing collections from ancient Egypt and Mesopotamia. The virtual routes were integrated with the museum's databases, allowing users to obtain structured scientific information about the artefacts during their virtual journey. The effect of presence was enhanced by the ability to move freely around the exhibition space and interact with digital copies of the objects. This format created new educational narratives in which history and archaeology were presented through a multidimensional experience that included visual, spatial, and intellectual levels. The use of VR at the British Museum confirmed that technology can combine academic authenticity with accessibility for visitors of all levels of preparation (Fig. 6, 7, 8).

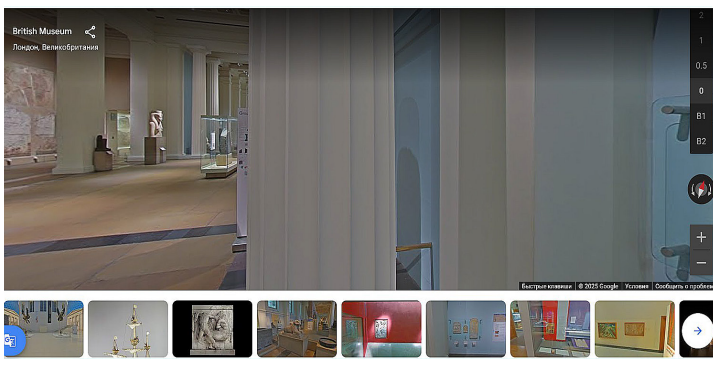

Figure 6. Gallery of British Museum in VR tour interface
Source: Google Arts & Culture (n.d.)

Figure 7. Gallery of British Museum in VR tour interface

Source: Google Arts & Culture (n.d.)

Figure 8. Icon of Triumph of Orthodoxy

Source: Google Arts & Culture (n.d.)

Ukrainian museums were in the process of testing augmented reality in their activities. Experimental AR applications were implemented in Lviv and Kyiv, allowing reconstructions of the original appearance of exhibits to be superimposed on their current state. Such solutions made it possible to visualise fragmented or damaged objects in their restored form, giving visitors an idea of their original shape and function. In practical terms, AR applications were used for interactive lectures and museum demonstrations, where users could compare the real exhibit with its digital reconstruction. This created a new level of perception, in which the authentic object was combined with its virtual reconstruction, forming a comprehensive view of the cultural artefact (Fig. 9).

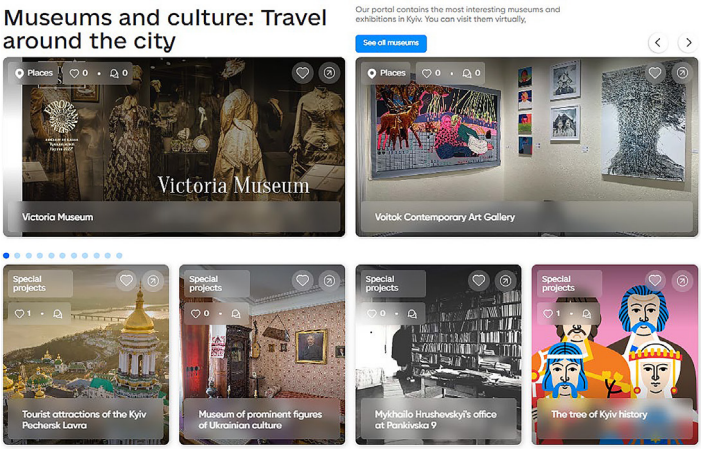

Figure 9. Exhibitions of Kyiv Tourism Hub

Source: Virtual tourism (n.d.)

A comparative review of these examples demonstrated the diversity of approaches to the application of VR and AR in the field of art and history. French VR exhibitions focused on detailing works of art and expanding the possibilities for their study. The British Museum used VR as a tool for interactive access to large-scale collections,

creating new forms of popular science presentation of history. Ukrainian practices focused on reconstructing the original appearance of exhibits, which allowed them to restore their integrity in the perception of the modern audience. Despite the differences, all examples had one thing in common: the use of immersive technologies made it possible to overcome the limitations of traditional museum space and form new approaches to the presentation of cultural heritage. The use of VR and AR in museum practices has proven its effectiveness in combining several aspects. The technologies expanded the cognitive potential of perceiving history and art through interactive engagement and multi-channel experiences, while also contributing to the creation of innovative educational models that combined academic content with immersion in a virtual environment. In addition, VR and AR have increased the accessibility of cultural heritage for those groups of visitors who were unable to physically visit museums. Taken together, these characteristics have shown that immersive technologies have become an integral part of contemporary museum and educational practices, transforming the ways in which society interacts with cultural heritage.

Educational applications of virtual and augmented reality technologies

The use of virtual and augmented reality in education has demonstrated the potential to transform the learning process in the humanities. Immersive technologies have made it possible to combine academic content with visualisation and interactive engagement, which has helped to expand cognitive abilities and increase the engagement of students and pupils. An important feature of VR and AR was the creation of a multi-level learning environment where traditional forms of information presentation were complemented by practical tools for immersion in virtual spaces and reconstructed objects. This shaped a new format of educational activity that combined theoretical knowledge and empirical experience (Valli & Carlomagno, 2024).

The experience of introducing immersive technologies into education demonstrated different models of their application depending on the level of education and national context. Universities in the United States have become one of the leading centres for the integration of VR into educational programmes, particularly in courses on art history and cultural studies. Stanford University offered courses that gave students the opportunity to virtually visit reconstructed ancient monuments and medieval cathedrals (Virtual Human Interactional Lab, n.d.). This allowed them to analyse architectural details, the spatial organisation of objects and the cultural context of their functioning. The use of VR went beyond traditional text materials and illustrations, creating an immersive experience in a restored historical space. Such classes provided a deeper understanding of cultural phenomena and contributed to the development of analytical skills. At the Massachusetts Institute of Technology, VR was actively integrated into interdisciplinary courses, where digital reconstructions were used not only to analyse works of art, but also to study sociocultural processes (Reinventing Education, n.d.). This demonstrated a gradual transition from the narrow professional use of technologies to their application as a universal learning tool capable of combining humanities and technical knowledge. The American experience as a whole showed that VR courses became the basis for the formation of new educational models, where technological innovations were integrated into the academic process.

A similar approach to integrating immersive technologies into the educational process was implemented in Japan, where the main focus was on school education. Unlike in the United States, where VR was used primarily in university courses and combined academic and research practices, Japanese initiatives were aimed at adapting historical material for primary and secondary school students. As part of the collaboration between the Artificial Intelligence Laboratory (n.d) and the University of Tsukuba, a new generation of AR textbooks was developed, allowing historical scenes to be reproduced directly on the pages of printed publications. The use of tablets or smartphones made it possible to activate three-dimensional models of architectural complexes, objects of material culture, or reconstructions of events, creating the effect of immediate presence. This practice provided students with a new format for acquiring knowledge, in which the textual material of the textbook was combined with visual elements and interactive tasks. The educational effect was that schoolchildren could not only familiarise themselves with the facts, but also visualise historical phenomena in their cultural and spatial context. This contributed to the development of spatial thinking, the formation of a comprehensive understanding of historical processes, and increased motivation to learn. In addition, the involvement of university researchers in the development of school materials made it possible to combine academic reliability with modern methods of presenting information, which made AR textbooks both scientifically sound and pedagogically effective tools (Kleftodimos & Evagelou, 2025).

The Ukrainian experience logically complemented the examples given, as it demonstrated the use of VR in higher education in the context of contemporary challenges, in particular the destruction of cultural heritage during the war. Lviv Ivan Franko National University held VR lectures on cultural heritage, during which students worked with three-dimensional models of destroyed architectural objects. This allowed them to familiarise themselves with monuments that could not be visited physically and to form a holistic understanding of their historical and cultural value. Unlike American university practices focused on the reconstruction of world monuments, Ukrainian VR lectures also served to preserve national cultural memory. At the same time, this approach echoed the Japanese one, as both models demonstrated a desire to make cultural heritage accessible to those who were unable to interact with it in physical space (Fig. 10).

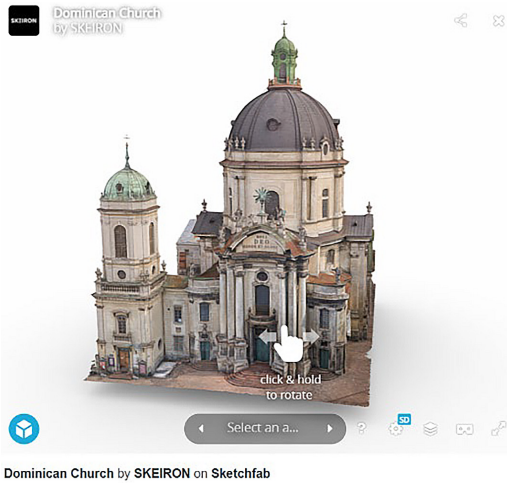

Figure 10. 3D visualisation of Dominican Church
Source: Lviv's Heritage in 3D (n.d.)

A comparison of practices in the United States, Japan, and Ukraine revealed different approaches to the implementation of VR and AR in education. University programmes in the United States focused on the use of VR for immersion in reconstructed cultural spaces, which contributed to the development of analytical skills and the combination of humanities and technological aspects. Japan demonstrated a focus on school education, where AR textbooks helped to visualise material and shape perceptions of historical events through interactive engagement. Ukrainian universities used VR to restore access to destroyed cultural monuments and create learning environments that combined local and global cultural contexts. All these examples showed that VR and AR not only increased student and pupil engagement, but also shaped new educational models that combined academic rigour with innovative approaches to presenting material. A summary of the results gave reason to conclude that VR and AR have become an important factor in the modernisation of the educational process in the humanities. Immersive technologies opened up access to cultural heritage in conditions of limited resources and destruction, created a multidimensional learning experience, and promoted the development of critical thinking. They ensured versatility of application, as they were effective in school, university, and interdisciplinary education. This confirmed that VR and AR shaped new approaches to teaching cultural heritage, combining traditional academic structure with innovative means of knowledge transfer, which met the modern needs of humanities education.

DISCUSSION

The results of the reconstruction of cultural monuments using VR and AR in this study were consistent with the conclusions of G. Neglia *et al.* (2024), who emphasised the role of digital tools in preserving heritage during military conflicts. Examples from Palmyra and Ukrainian initiatives demonstrated the universality of this approach. At the same time, the cited works placed greater emphasis on the risks of losing objects and the need for urgent response, while this study also highlighted the long-term function of digital conservation. Thus, the results of this study expanded on the conclusions of its predecessors, as they emphasised not only the defensive but also the educational function of digital replicas.

The recreation of Palmyra in Syria in the Palmyra VR Project echoed the approaches of Y.J. Alkhatib *et al.* (2023), who viewed 3D reconstructions as a way to bring lost heritage back to life. This study showed that such reconstructions not only restored the architectural appearance but also shaped the educational environment. Unlike the authors mentioned above, who focused primarily on technical and visualisation aspects, the results of this work demonstrated the cultural and social dimensions of digital copies. This made it possible to combine scientific reconstruction with the formation of new models of interaction with the past, which complemented the experience of previous studies. An analysis of the use of interactive 360° media in heritage preservation, conducted by R. Dieb *et al.* (2024), confirmed the importance of visual accessibility for an international audience. In this study, a similar emphasis was placed on virtual tours of Palmyra and other sites, which created a sense of presence for users. However, unlike the study by the aforementioned authors, where technology served primarily as a means of popularisation, the results of this work revealed its potential for scientific analysis and the educational process. Thus, the approach of this study complemented existing practices by integrating entertainment, educational and research aspects into a single immersive format.

The study by S. Pouryousefzadeh *et al.* (2021) revealed the potential of innovative technologies for restoring cultural heritage within "smart cities" The results of this study were consistent with their conclusions, as they also showed the possibilities of VR and AR for integrating heritage into modern urban spaces. At the same time, the role of these technologies in preserving cultural memory under conditions of destruction was emphasised, which had not been a central aspect in the work of the aforementioned authors. Thanks to this, the results of this study broadened the context, demonstrating the versatility of VR and AR in combining urban and cultural dimensions. The large-scale virtualisation of Rome in the Rome Reborn project, described by M. Fasolo (2024), emphasised the educational potential of VR reconstructions. These conclusions were confirmed in this study, which also traced the integration of digital models into the educational process. A particular emphasis was placed on distinguishing between the reconstruction of lost objects and the virtualisation of cities in their period of prosperity. Thus, the results of this study expanded on M. Fasolo's conclusions by revealing different strategies for using VR: as a compensatory mechanism and as a tool for educational immersion. This allowed for a more comprehensive outline of the range of possibilities offered by immersive technologies.

The use of AR for the restoration of cultural objects, highlighted by A.O. Sachenko & I.R. Kit (2024), was consistent with the Ukrainian examples considered in this study. The similarity lay in the use of augmented reality to reconstruct fragmented or damaged artefacts. At the same time, the results of this work showed that AR not only visualised the original appearance of objects but also created a new level of museum communication. This differed from the more technical focus in the study by A.O. Sachenko & I.R. Kit and made it possible to highlight the pedagogical and educational potential of AR, which still requires further development. The study by H. Li & I. Hiromu (2021) examined projection mapping technologies as a means of bringing cultural objects to life. The results of this work confirmed the importance of visual immersion in engaging the audience. At the same time, VR and AR were considered more broadly as tools providing not only aesthetic but also cognitive impact. Thus, the results obtained made it possible to specify the conclusions of H. Li & I. Hiromu by demonstrating the integration of visual perception effects with educational and scientific potential. This made it possible to outline the multi-level impact of immersive technologies on society.

The phenomenological approach to museum experience developed by C. Palmer (2023) was found to be relevant for comparison with the obtained results. The author emphasised the interaction of visitors with digital space as a way of understanding cultural content. In this study, a similar idea was implemented through the analysis of VR exhibitions at the Louvre and the British Museum. However, unlike C. Palmer's work, which focused on individual experience, the results of this study also considered the collective dimension – educational programmes, university courses, museum lectures. This made it possible to refine the conclusions of the predecessor, expanding them towards the social integration of VR. The digital replicas of museum artefacts described by G. Patrucco *et al.* (2023) confirmed the importance of three-dimensional models as a scientific source. In this study, a similar emphasis was placed on the analysis of Ukrainian and international projects. At the same time, the results of this work also highlighted the educational and diplomatic potential of digital models, which went beyond purely scientific use. Thanks to this, they refined the conclusions of the aforementioned authors, proving that digital replicas can serve as a means of cultural diplomacy and popularisation of national heritage in the global space.

The combination of 3D imaging with mixed reality, as discussed by V. Barrile *et al.* (2022), highlighted the potential of new technologies in museum activities. In this study, these conclusions were confirmed by the example of Ukrainian AR applications that restored the original appearance of exhibits. However, attention was focused on the integration of such practices into the educational process, which differed from the more technological approach of V. Barrile *et al*. This led to the conclusion that VR and AR are becoming not only tools for museum presentation but also platforms for comprehensive humanities education. The creation of 3D objects for VR and AR applications, described by S. Van Nguyen *et al.* (2022), demonstrated the technical aspects of digital model formation. These findings were further developed in the direction of integrating 3D models into educational courses and museum exhibitions. While the work of the aforementioned authors emphasised technological innovations, the results of this work demonstrated their cultural and educational potential. This made it possible not only to confirm the importance of digital technologies but also to outline new perspectives for their use in humanities practices.

A comparative analysis outlined the common and distinctive features in approaches to the use of virtual and augmented reality in the reconstruction of cultural heritage, museum practices, and educational models. It was shown that, regardless of national contexts and research traditions, VR and AR are universal tools for preserving cultural memory and forming new formats of interaction with the past. A comparison of the results with scientific developments made it possible to not only confirm but also refine previously formulated conclusions, broadening the understanding of the possibilities of immersive technologies in the humanities. Such complexity provides a basis for generalising key trends and formulating the final conclusions of the study.

CONCLUSIONS

The study showed that VR and AR enable the reconstruction of cultural objects and their integration into education and museum practice. Projects such as Palmyra VR, the Virtual Museum of Kyiv-Mohyla Academy, and Rome Reborn demonstrated the creation of authentic 3D replicas for archiving, research, and public access. Immersive environments reproduced spatial and morphological features of monuments, supporting remote analysis and interpretation. The results confirmed three main outcomes: digital preservation, interactive engagement, and educational integration. Examples from the Louvre, the British Museum, and cases from the United States, Japan, and Ukraine highlighted the cognitive and pedagogical value of these technologies. Altogether, VR and AR proved to be effective tools for preserving heritage and modernising the humanities.

The comparative analysis revealed distinct functional objectives: in contexts of war damage, priority was given to documenting losses and ensuring digital preservation; in historical urbanism projects, emphasis was placed on reconstructing entire urban ensembles for research and education; in museum practice, the focus lay on enhancing accessibility and explanatory value. Effective scaling of such initiatives required cooperation among museums, universities, archives, technology partners, and heritage protection bodies. The study confirmed that VR and AR serve as efficient tools for cultural reconstruction and education, highlighting the need for international standards and collaboration to secure validity, sustainability, and accessibility of digital heritage solutions.

A limitation of the study was that the analysis was based mainly on individual cases and available public

sources, which did not allow for a comprehensive overview of existing VR/AR projects and their technical characteristics. Promising areas for further research were identified as the development of unified standards for digital conservation, the evaluation of the pedagogical effectiveness of VR/AR in different educational contexts, and the integration of artificial intelligence for the automation of cultural object reconstruction processes.

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