

Research on the Application of Digital Museum Platforms in the Metaverse Environment within the Context of Cultural Heritage Revitalization

Cun Shang^{1,2}, Anqi Zhang¹, Ying Xue¹, Guoqiang An³, Wenxiang Liu^{4*}

¹ College of Landscape Architecture and Art, Xinyang Agriculture and Forestry University, Xinyang, China

² College of Art and Design, Wuhan University of Technology, Wuhan, China

³ College of Art and Design, Yeungnam University, Gyeongsan Gyeongbuk, Republic of Korea

⁴ College of Forestry, Xinyang Agriculture and Forestry University, Xinyang, China

Email Address

2006230019@xyafu.edu.cn (Cun Shang), anqide622@yahoo.com (Anqi Zhang),

2006230006@xyafu.edu.cn (Ying Xue), agq870527@hotmail.com (Guoqiang An),

2020290002@xyafu.edu.cn (Wenxiang Liu)

*Correspondence: 2020290002@xyafu.edu.cn

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Abstract:

As a transformative technological phenomenon, the Metaverse not only accelerates the integration of Virtual Reality (VR), Augmented Reality (AR), and blockchain technologies but also paves the way for novel application scenarios across diverse industries. Within the Metaverse, digital museums evolve beyond their traditional function as mere exhibition spaces, transforming into multidimensional and highly interactive centers of cultural exchange. This paper endeavors to thoroughly analyze the fundamental components of Metaverse technology, scrutinizing the practical applications of pivotal technologies such as digital collection methods, authentic artifact reconstruction, and intelligent virtual interactions within digital museums. Building on a framework for constructing digital museums, this paper proposes methodologies for designing interactive functionalities and user interfaces by integrating VR with multimedia content, including 3D models, to achieve accessibility features and multi-platform support. The objective is to develop a comprehensive, interactive, and intelligent digital museum system, offering theoretical foundations and practical guidance for the innovative future development of digital museums, thereby driving the transformation of cultural dissemination methods.

Keywords:

Digital Museum, Metaverse, Digital Collection Construction, Cultural Heritage

1. Introduction

As digital technology rapidly advances, the museum industry encounters both a necessity and an opportunity for transformation, especially in the digital preservation and presentation of cultural heritage. Traditional museums, hampered by physical and technological constraints, often face significant challenges in accessibility and engagement [1]. Many museums, owing to their physical locations or exhibit designs, create barriers for specific groups—such as individuals with disabilities, residents in remote areas, and economically disadvantaged communities—to visit. Moreover, traditional display methods are typically static and unidirectional, restricting public interaction and engagement to a certain degree. This limitation not only detracts from the public's learning experience but also hinders the potential of museums as platforms for education and cultural exchange. In this context, innovations in digital technology have endowed museums with new methods of display and interaction, particularly underscoring the significant role of digital museums in the preservation of cultural heritage. The Metaverse, as a convergent technology, presents unique opportunities for the innovation of exhibitions, services, and content in digital museums. This technological amalgamation markedly advances the digitization of cultural heritage and elevates the user experience.

Digital museums, by harnessing advanced information and communication technologies, effectively surmount the limitations of traditional museums. Currently, digital museums utilize Virtual Reality (VR) and Augmented Reality (AR) technologies to enrich and augment the visitor experience. Studies suggest that aesthetic experiences in AR environments can significantly deepen user immersion [2]. By developing mobile AR applications, public engagement and accessibility to cultural artifacts have been significantly enhanced. Research by Khalil demonstrates that AR not only effectively enriches visitor experiences but also plays a pivotal role in the digital transformation of museums, particularly in the post-COVID-19 era [3]. Bachiller's research further confirms that by harnessing VR and AR technologies, museums can not only attract younger audiences but also safeguard artifacts and furnish rich exhibit information [4]. This enables the public to virtually visit from any location, thereby enriching learning experiences and interactivity.

Metaverse technology, distinct from traditional virtual reality, focuses on constructing a shared virtual space, allowing users to interact with digital objects in real-time. The Metaverse, through the integration of augmented reality technology, surpasses traditional virtual reality, creating an immersive environment that emulates real-world scenarios [5]. This environment demonstrates immense potential across various application domains, including culture, education, and training. Metaverse technology uniquely augments the digitization, preservation, and utilization of cultural heritage within digital museums. It significantly enriches visitor experiences by creating a multidimensional interactive environment, enabling users to transcend temporal and spatial boundaries to experience historical events and cultural scenes firsthand. Moreover, blockchain technology within the Metaverse can ensure the digital identity and copyright of cultural assets, thereby enhancing their security and unique value. Research by Du Han and colleagues suggests that the Metaverse holds significant potential in redefining the museum experience [6]. Syahidi and colleagues, through their study on the application of Metaverse technology in virtual exhibition halls, found that immersive environments not only enhance visitor engagement but also enrich their understanding of cultural and historical contexts [7]. Hong Yin Zhu's development of AI technology for digital museums based on the MetaAID framework,

through AI-driven guides and interactive explanations, has enhanced the interactivity and personalization of the museum experience [8]. Federica Rubino's research on blockchain technology for securing, certifying, and managing digital content proposes a reliable method to maintain the integrity and ownership of digital artworks, addressing core issues in creating digital replicas of cultural and historical projects [9].

The Metaverse can construct an all-encompassing immersive environment, making visitors feel as though they are part of the exhibit rather than mere observers. This immersion intensifies visitor engagement and perception, thereby amplifying the effectiveness of learning and experience [10]. The Metaverse broadens accessibility, enabling users from any location to access museum exhibitions, significantly enhancing the museum's accessibility and audience reach [11]. Through the Metaverse platform, anyone with internet access can virtually visit digital museums, regardless of their geographical location, shattering traditional geographic constraints on museum visits [12]. The platform amalgamates various information technologies, including artificial intelligence, big data, and cloud computing, bestowing digital museums with augmented capabilities not only in display but also in intelligent services, management, and decision-making [13].

Despite the numerous innovations the Metaverse introduces to digital museums, its application has also unveiled some notable issues. Firstly, the intricacy of technological implementation and the high costs pose significant barriers. Additionally, rapid technological iterations may render existing systems quickly obsolete, escalating maintenance and upgrade costs. Another challenge is user acceptance. Although digital museums offer innovative visiting methods, visitors of different ages and backgrounds may significantly differ in their acceptance of new technologies. Some studies suggest that factors such as users' technical proficiency, attitudes towards new technologies, and initial experiences with technology can influence their willingness to engage with digital museums. Therefore, designing user-friendly digital museum systems that can attract a broad spectrum of visitors presents a formidable challenge.

2. Literature Review

As information technology rapidly evolves, particularly with advancements in domains such as Virtual Reality (VR) and Augmented Reality (AR), digital museums are increasingly heralded as crucial platforms for the digital preservation and revitalization of cultural heritage. In developing digital museums, the digital capture of artifacts, the reconstruction of their authenticity, and the integration of intelligent interactive technologies are paramount.

2.1. Artifact Digital Capture

The digital capture of artifacts is a fundamental step in constructing digital museums, ensuring the long-term preservation and effective management of cultural items while continually broadening the scope of research and display. This process involves transforming physical artifacts into virtual counterparts, not only aiding in their preservation but also facilitating subsequent research, display, and educational endeavors. Typically, the digital capture process of artifacts encompasses the following four steps: Firstly, developing a capture plan tailored to the physical characteristics and preservation state of the artifact. Secondly, detailed measurement and high-resolution imaging using various devices. Thirdly, data processing to

enhance the quality and usability of the captured image and video data. Fourthly, 3D modeling, wherein digital models of artifacts are reconstructed using 3D modeling techniques based on the processed data. These steps lay a robust foundation for the digitization of artifacts, not only revitalizing cultural heritage but also establishing a basis for future preservation and research. In recent years, artifact digitization has extensively employed technologies such as 3D scanning, high-resolution photography, and spectral imaging. These technologies not only meticulously record the form, color, and surface textures of artifacts but also unveil their microstructures, providing high-quality data for research and display.

2.1.1. Artifact Digital Capture Technologies

3D scanning technology is currently one of the most extensively utilized in artifact digitization. This technology captures the shape and intricate details of artifacts with high precision, thereby constructing highly realistic 3D models. Researchers can document the shape and minute surface textures of an artifact without physical contact using laser scanners and structured light scanning technology, which is particularly crucial for fragile or precious artifacts [14]. High Dynamic Range Imaging amplifies image detail by combining multiple images at different exposure levels, particularly in environments with complex lighting. This technology is indispensable when documenting artifacts with intricate surface textures and colors, as it captures details with greater accuracy and presents a more authentic visual effect [15]. Multispectral and hyperspectral imaging technologies capture images at varying wavelengths, unveiling the material composition beneath the surface of the artifact and traces of past restorations. Hyperspectral imaging provides a broader spectrum of information, essential for understanding the material science and fabrication techniques of artifacts [16].

2.1.2. Display application of digital cultural relics

The interactive display of digitized artifacts, enabled by touch screens and multimedia systems, allows the public to directly engage with digital information—for instance, by magnifying details through touch, rotating views, or exploring their historical contexts. This approach renders learning about artifacts more intuitive, making it particularly suited for educational and public outreach purposes [17]. Augmented Reality (AR) and Virtual Reality (VR) technologies offer a novel platform for artifact presentation, allowing the public to virtually experience historical scenes and the original environments of artifacts. These technologies not only augment the allure of exhibitions but also enhance educational interactivity and immersion [18]. Online digital museums and archives incorporate digitized artifacts into online databases and virtual exhibitions, making these invaluable resources accessible to global researchers and the public. This not only facilitates international research collaboration but also amplifies the influence of cultural heritage. With the aforementioned technologies, digitized artifacts serve not only scientific research purposes but are also exhibited to the public through digital museum platforms. Digital models enable researchers to conduct thorough analyses and studies without risking damage to the original artifacts. Simultaneously, the public can enjoy immersive cultural heritage experiences through Virtual Reality (VR) or Augmented Reality (AR) technologies, transcending the limitations of time and space.

2.2. Artifact Authenticity Reconstruction

The literature suggests that based on digital capture, authenticity reconstruction technologies further enhance the quality and realism of digital artifact presentations. This involves employing advanced graphic rendering technologies and computer vision algorithms to restore the original appearance of artifacts and even recreate their historical usage scenarios. For instance, laser scanning and photogrammetric techniques can precisely capture and collect 3D data of artifacts, thereby creating realistic digital models. These models not only preserve the information of the artifacts but also serve virtual displays and educational purposes [19]. Furthermore, research on virtual heritage indicates that virtual reconstructions entail more than merely creating digital replicas; they imbue digital models with deeper value through interaction and semantics. For instance, in the conservation project of the Mogao Caves, laser scanning and multi-baseline rotational photogrammetry were employed to digitize statues and murals for future research and virtual exhibitions [20]. Overall, the application of advanced graphic rendering and computer vision algorithms renders digital presentations of artifacts more realistic and detailed, thus providing novel methods and tools for the preservation and study of cultural heritage [20]. The literature demonstrates that virtual reconstruction technology can simulate the structure and decorations of ancient buildings, allowing audiences to virtually walk through historical sites via digital museum platforms. Zhu's research created immersive experiences utilizing virtual reality technology, allowing users to navigate and interact within a virtual environment, experiencing the allure of ancient architecture and cultural heritage. This digital museum encompasses virtual venue design, 3D model construction, and virtual tours, offering audiences a rich interactive experience and historical insights [20]. The application of artifact authenticity reconstruction technology not only augments the visual impact of the exhibits but also deepens the public's comprehension of cultural heritage.

2.3. Combination of Virtual and Real Cultural Relics with Intelligent Interactive Technology

With the progression of artificial intelligence and machine learning, intelligent interactive technologies have emerged as a prominent research focus in the realm of digital museums. These technologies empower digital museums to deliver more personalized and interactive visitor experiences. Virtual reconstruction techniques, integrated with Natural Language Processing (NLP), markedly enhance the capabilities of intelligent guided services in museums. NLP enables museums to intelligently recommend exhibits and provide pertinent information based on the interests and behavioral patterns of visitors. Such systems analyze users' browsing histories and preferences, thereby tailoring bespoke visiting experiences for each individual. For instance, the integration of deep learning and recommendation systems enables these guided services to deliver more personalized and dynamic recommendations [21].

Specifically, NLP technology facilitates the following functionalities: personalized recommendations, where the system suggests exhibits and content pertinent to users' interests based on their browsing history and search records; real-time interaction, where visitors can obtain needed information during their visits through voice assistants and chatbots; behavior analysis, where the system tracks and analyzes user behavior patterns within the museum to continually refine recommendation algorithms and content presentation [22]. These intelligent guided services integrated with NLP technology not only augment the interactivity and user experience of

museums but also effectively manage and showcase the rich cultural heritage resources.

2.4. Digital Museums and Immersive Platform Construction

Research indicates that immersive technologies markedly increase visitor engagement and satisfaction. Studies by Lee and colleagues have demonstrated that VR enhances users' sense of immersion and interactivity, which is often associated with higher educational outcomes and deeper emotional connections [23]. Research emphasizes that VR's capabilities markedly enhance cognitive, behavioral, and emotional engagement in educational environments. Zheng and colleagues have highlighted the advantages of digital museums, particularly through virtual tours and three-dimensional exhibit displays [24]. These technologies allow users to explore artifacts from multiple angles and in detail, a capability that traditional museums cannot offer. Such immersive and interactive experiences enhance user engagement and provide deeper understanding and appreciation opportunities for cultural heritage.

Constructing immersive platforms is a key component in achieving the goals of digital museums. These platforms employ Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) technologies to create a multisensory environment that immerses users in a real three-dimensional space. Research by Garcia and colleagues indicates that immersive technologies markedly enhance museum visitors' engagement and satisfaction. By employing tools such as Virtual Reality (VR) and Augmented Reality (AR), museums can effectively convey complex historical and cultural information. These technologies offer interactive and immersive experiences that enable visitors to explore exhibits in ways that traditional methods cannot achieve. This approach not only augments educational value but also deepens users' emotional connections to the content, making the museum experience more profound and memorable. Additionally, digital museums utilize immersive technologies to create virtual spaces that enable users to browse exhibits as if they were on-site. These virtual tours often employ 360-degree panoramic photography and interactive elements, providing an immersive educational experience that makes cultural content more accessible and comprehensible. Through ongoing technological research and application, digital museums are poised to achieve broader cultural exchange and educational dissemination worldwide.

3. Implementation Method of Digital Museum Construction Under the Metaverse

As digital technologies swiftly advance, the concept of the Metaverse presents a novel pathway and innovative platform for the realization of digital museums. The specific methodologies for constructing digital museums within the Metaverse environment entail the use of diverse tools and technologies, as well as the development process of the Metaverse platform.

3.1. Tools and Technologies Used

The construction of digital museums in the Metaverse entails a range of tools and technologies that support everything from basic 3D modeling to complex user interactions and data management. 3D modeling is pivotal in constructing digital museums, allowing artifacts and exhibition spaces to be precisely recreated and presented in a virtual environment. Commonly used 3D modeling software

encompasses Autodesk Maya, 3ds Max, and Blender. These tools are utilized to create accurate three-dimensional replicas of museum exhibits, facilitating digital displays and interactive experiences. For instance, virtual museums might employ Blender to create 3D models of exhibition halls and integrate interactive elements in Unity, enabling virtual users to experience realistic museum environments [27].

Virtual Reality (VR) and Augmented Reality (AR) technologies offer users immersive experiences, allowing them to explore virtual museums in all dimensions. Through head-mounted devices like Oculus Rift or HTC Vive, users can navigate and interact freely in virtual spaces. These high-end VR devices support Six Degrees of Freedom (6DoF) tracking, enabling users to navigate and manipulate objects in the virtual environment, thereby providing an immersive experience [26]. Furthermore, AR technology overlays virtual information onto the real world, offering users enriched information and interactive experiences. Network and server technologies, encompassing efficient networking technologies and robust server support, are fundamental for constructing online virtual museums. Utilizing cloud computing services like Amazon AWS and Google Cloud Platform offers a variety of storage options. For instance, AWS's Amazon S3 and Google Cloud's Cloud Storage provide data storage solutions tailored to different access frequencies, including standard storage, infrequent access storage, and cold storage, to meet the diverse data storage needs of museums [27]. The scalability of cloud computing enables museums to dynamically adjust resources based on demand, avoiding over-provisioning and thereby saving costs.

Metaverse interaction platforms like Roblox, Decentraland, and Microsoft's Mesh offer tools and community support for building and sharing virtual environments. Roblox is a virtual platform where users can create and engage in games and experiences. It offers robust development tools, enabling users to design their own games and virtual worlds using the Lua programming language. Roblox is not merely a gaming platform but also a social platform, where users can interact with friends and participate in various community activities [28]. Decentraland, leveraging blockchain technology, is a virtual world where users can buy land, build structures, and create content. Decentraland provides a decentralized environment, allowing users to freely create and share their virtual experiences [28]. Microsoft's Mesh is a platform designed to augment collaboration and communication through mixed reality technology. Users can participate in meetings and interactions through customized virtual avatars, augmenting the effects of remote work and collaboration. Mesh for Teams enables users to create and enter immersive virtual spaces, supporting a variety of devices, from smartphones to mixed reality headsets, making virtual communication more personalized and vivid [30]. These platforms not only offer a wealth of tools and technical support but also cultivate strong community networks, encouraging users to create and share virtual content, further advancing the development of the Metaverse.

3.2. Metaverse Reality Platform Development Process

Developing a Metaverse reality platform is a multifaceted, multi-stage project encompassing the following steps: Requirement

Analysis and Planning, the initial phase of developing a Metaverse platform necessitates detailed requirement analysis to identify target user groups, main

functionalities, and basic requirements for the user interface. The objective of this stage is to clearly define the project goals and end-user expectations.

System Design building on the requirement analysis results, system architecture design is undertaken, encompassing the selection of suitable software and hardware environments, database design, and determination of data interaction protocols. Concurrently, 3D designers commence the construction of the museum's virtual environment and exhibit models. This stage also involves designing the user interface and user experience.

Development and Implementation, the development team initiates the coding process, implementing various system modules according to the design documents. This encompasses developing the front-end user interface, implementing back-end logic, and integrating the database. This stage also necessitates the integration of various APIs and services, such as payment systems, user management systems, and network services.

Testing and Optimization, continuous testing is conducted throughout the development process, including functional, performance, and user experience tests, to ensure the platform's stability and smoothness. The purpose of this phase is to ensure software quality and to identify and rectify potential defects. Launch and Iteration ,

Upon completion of software development, the system is deployed on servers for testing in actual operational environments and for performance optimization. Based on user feedback and market changes, the development team must continuously update and optimize the platform, incorporating new features and content to maintain user engagement and satisfaction. Through these methodologies and steps, a digital museum can be effectively implemented and operated within the Metaverse environment, offering users a novel cultural experience and communication platform.

4. The Metaverse, the Construction Strategy for Digital Museums

4.1. Framework system for digital museum construction under the metaverse

Within the context of the Metaverse, the construction strategy for digital museums necessitates a comprehensive framework system. Platforms like Roblox, Decentraland, and Microsoft's Mesh enhance the display capabilities and intelligent services, management, and decision-making of digital museums through the integration of Artificial Intelligence (AI), big data, and cloud computing technologies. AI processes and analyzes vast amounts of data, assisting museums in better understanding visitors' needs and behaviors to optimize exhibitions and services. Personalized guided services powered by AI technology can recommend specific exhibitions and activities based on visitors' interests and past interactions [31]. Big data technology enables the collection, storage, and analysis of massive datasets from various channels, including visitor traffic, social media interactions, and online feedback. This data can be utilized for real-time monitoring and predicting visitor activity patterns, optimizing resource allocation and security management [32]. Efficient data storage and processing, supported by cloud computing, provide robust storage and computing capabilities essential for the seamless operation of virtual environments and digital museums. Cloud platforms enable museums to easily expand their storage capacity and computational power, ensuring stability and efficiency under high traffic conditions. The integration of these technologies not only augments the display capabilities of digital museums but also enhances efficiency and accuracy in intelligent services,

management, and decision-making. Building on this foundation to provide a rich and dynamic visiting environment for global users, architectural design for the Metaverse should encompass all aspects from infrastructure construction to user experience.

(1) Full-Platform Access Support

Full-platform access support is a crucial component of digital museums, ensuring that users can seamlessly access museum content through various devices, including smartphones, tablets, PCs, and VR headsets. This multi-device compatibility not only enhances user convenience and access rates but also broadens the museum's visitor range, allowing more individuals to experience the rich content of digital museums anytime, anywhere.

(2) Social Media and Web Integration

Social media and web integration are vital for promoting digital museums and attracting visitors. Utilizing the expansive reach of social media platforms, museums can attract more visitors by posting virtual exhibitions, live guided tours, and audience interactions. Moreover, web integration allows for the synchronization of content updates across multiple platforms, ensuring a consistent experience for users on different devices. Additionally, leveraging social media's interactive features, museums can collect audience feedback to enhance the quality of exhibitions and services.

(3) Infrastructure and Technical Support System

The infrastructure and technical support system constitute the cornerstone of digital museum construction. Ultra-high-speed network connections, deployed using 5G technology, ensure high data throughput and low latency to support the virtual reality experiences of numerous simultaneous users. High-performance servers, leveraging cloud computing technology, utilize scalable server architectures to support complex data processing and large-scale concurrent user sessions. Ultra-high-speed connections, high-performance servers, and advanced security protocols collectively create a stable, efficient, and secure technical environment. This infrastructure ensures that digital museum content can be rapidly loaded and smoothly operated while safeguarding user data privacy and security. Additionally, Software Development Kits (SDKs) and Application Programming Interfaces (APIs) are crucial modern software development tools. They support third-party developers in creating and integrating customized content and functionalities, enabling the development of powerful and feature-rich applications. For example, Facebook's developer platform offers several APIs and a comprehensive SDK, enabling developers to easily integrate Facebook features into their applications, facilitating user login, content sharing, and ad management [2,1]. By leveraging Software Development Kits (SDKs) and Application Programming Interfaces (APIs), a unified data management platform can be created. This platform supports the real-time collection, processing, and analysis of data, thereby optimizing exhibition content and visitor interactions. Additionally, a sustainable operation and maintenance system, implemented via cloud computing, supports all technical needs of museum operations, including content updates, system monitoring, and troubleshooting. This integration ensures that digital museums operate efficiently, continually adapting to technological advancements and visitor feedback.

(4) Content Innovation and Display

Content innovation and display are essential to attracting and retaining visitors in digital museums. In the Metaverse, three-dimensional digital artifact displays epitomize a core innovation. High-precision 3D scanning technology transforms artifacts and exhibits into three-dimensional models, enabling visitors to explore these exhibits from multiple angles and different levels of detail in a virtual environment. This not only enhances the authenticity and interactivity of the displays but also allows visitors to see details that are difficult to observe in reality, such as the backsides or internal structures of artifacts. This type of three-dimensional display can be augmented with Virtual Reality (VR) and Augmented Reality (AR) technologies to provide an immersive viewing experience. Additionally, three-dimensional digital artifact displays possess significant conservation and educational value. By digitally preserving artifacts, museums can effectively reduce physical wear and tear while enabling more individuals to remotely appreciate precious cultural heritage. Especially when it is not possible to visit the museum in person, three-dimensional digital artifact displays provide an alternative that ensures the broad and continuous dissemination of culture.

Interactive educational programs are essential tools for enhancing user engagement and learning outcomes in digital museums. By designing educational applications that are both entertaining and educational, museums can gamify the knowledge transmission process, rendering learning more engaging and appealing. For instance, puzzle games based on exhibit stories, virtual archaeological explorations, or cultural knowledge competitions can be developed. These interactive applications not only enhance users' motivation to learn but also augment knowledge retention and depth of understanding. Furthermore, interactive educational programs can be customized according to users' interests and learning progress.

Establishing a flexible exhibition system that supports real-time content updates and dynamic adjustments is another substantial innovation in digital museums within the Metaverse. This system allows museums to promptly reflect the latest research findings and archaeological discoveries, maintaining the freshness and academic cutting edge of exhibit content. For example, when new archaeological findings or artifact restoration results emerge, they can be swiftly incorporated into relevant exhibits, enabling visitors to learn about them firsthand. Moreover, the dynamic exhibition system can adjust and update exhibit content based on seasons, holidays, or specific themes, augmenting the diversity and interest of viewing experiences. Real-time content updates also support the application of multimedia display methods, including videos, animations, and audio explanations, further enriching the exhibition's presentation and interactive experience.

Through innovations such as three-dimensional digital artifact displays, interactive educational programs, and real-time content updates and dynamic exhibitions, digital museums within the Metaverse not only enhance the visitor experience and learning outcomes but also promote the preservation and dissemination of cultural heritage. These innovative measures not only bring new development opportunities to museums but also offer global visitors a richer and more diverse cultural experience.

(5) User Interaction Platform

The user interaction platform encompasses Virtual Reality (VR), Augmented Reality (AR), and multi-user interaction systems. These platforms, by providing immersive experiences and extensive interactive features, enable users to engage more deeply and explore museum content comprehensively. VR and AR technologies offer

users immersive viewing experiences, while multi-user interaction systems facilitate communication and interaction among users, enhancing the museum's social attributes and appeal.

Based on the analysis above, the construction architecture of digital museums within the Metaverse can be summarized as a set of infrastructure, a technical support system, three user interaction platforms, and three access platforms. The framework system diagram, as illustrated in Figure 1, encompasses the following main components:

Access Platform comprises:
Support for Access Across All Platforms: Ensures access via devices such as smartphones, tablets, PCs, and VR headsets.
Social Media Integration: Leverages social media platforms to promote virtual exhibitions and interactive content.

Network Integration: Facilitates multi-platform content synchronization updates and a unified experience.
Technical Support System comprises:
Infrastructure: Consisting of ultra-high-speed network connections, high-performance servers, and advanced security protocols to ensure content loads quickly, runs smoothly, and remains secure.
Content Innovation and Display: Encompasses three-dimensional digital artifact displays, interactive educational programs, real-time content updates, and dynamic exhibitions.
User Interaction Platform comprises:
Virtual Reality (VR): Offers immersive exhibition experiences.
Augmented Reality (AR): Provides interactive experiences that merge the real environment with virtual content.
Multi-user Interaction System: Facilitates communication and interaction among users, enhancing social attributes.
This structured approach to digital museum architecture within the Metaverse not only fosters a comprehensive and engaging visitor experience but also supports the effective dissemination of cultural heritage through innovative and interactive platforms.

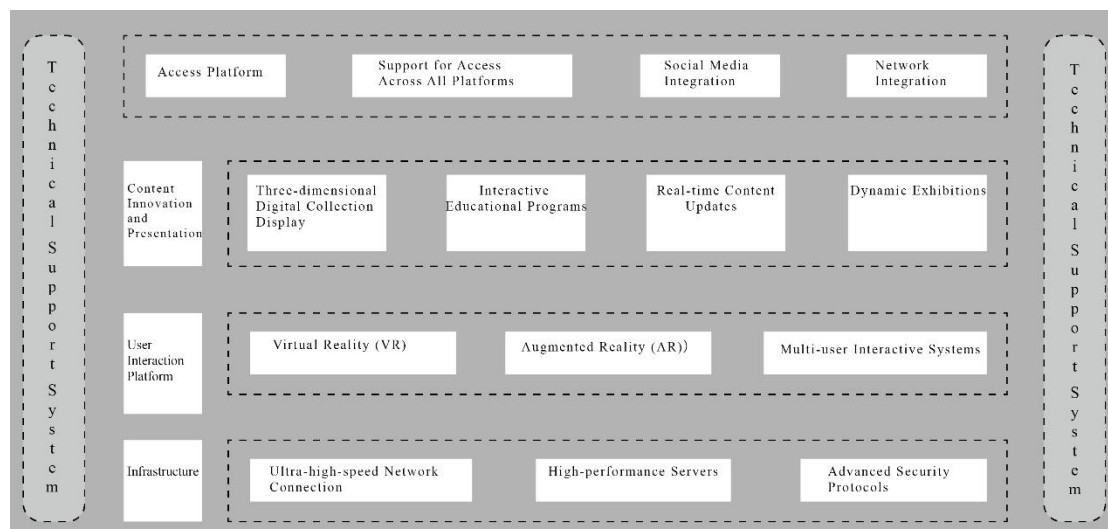


Figure 1. The framework diagram of digital museum construction

4.2. Digital museum construction architecture design under the metaverse

Constructing a successful digital museum in the Metaverse necessitates a comprehensive consideration of multiple design aspects to ensure the platform is both efficient and interactive. The architectural design for constructing a digital museum in the Metaverse primarily encompasses:

(1) Tools and Technologies Used

During the construction of a digital museum, key tools and technologies encompass Virtual Reality (VR) and Augmented Reality (AR) platforms, with Unity3D and Unreal Engine being the most commonly used tools for creating interactive 3D environments and virtual exhibitions. These platforms support high-quality rendering, complex physical effects, and rich interactive functionalities, making the exhibit content more vivid and appealing [34]. Big data analytics tools, such as Hadoop and Spark, analyze user behavior and exhibit data to optimize exhibition content and enhance user experiences. For instance, analyzing users' navigation paths and dwell times can reveal which exhibits are most popular and permit adjustments in exhibit layout and presentation methods [35]. Cloud computing platforms, such as Amazon Web Services and Microsoft Azure, support high-load access demands and large-scale data storage, ensuring high availability and scalability of the exhibitions. Through cloud computing, digital museums can scale resources on-demand to meet peak access demands while ensuring data security and backups [36].

(2) Interactive Features and User Interface Design

Emphasizing user experience, User Interface (UI) and User Experience (UX) design are crucial for ensuring the usability and engagement of digital museums within the Metaverse. Multimodal interactions, such as voice, touch, and gesture recognition, can enhance users' immersion, rendering the user experience more natural and enriched. For example, using voice commands to access information about exhibits or using gestures to rotate 3D models [37].

(3) Integration of Virtual Reality with Multimedia Content

A successful digital museum in the Metaverse should seamlessly integrate Virtual Reality technology with rich multimedia content. This entails using precise 3D scanning technology to replicate artifacts and enabling users to view these artifacts in 360 degrees through virtual reality. This necessitates the platform not only support high-quality 3D rendering but also manage large volumes of multimedia data while maintaining a smooth user experience.

(4) Integration of Virtual Reality with Multimedia Content

A successful digital museum in the Metaverse should seamlessly integrate Virtual Reality technology with a diverse array of multimedia content. This involves utilizing precise 3D scanning techniques to replicate artifacts, enabling users to view these pieces in a full 360-degree panorama via virtual reality. Such platforms must not only support high-quality 3D rendering but also manage extensive multimedia data while ensuring a seamless user experience [38]. Additionally, multimedia content, including videos, audio narrations, and interactive animations, can enrich the exhibit content and enhance user engagement. For instance, by embedding historical films or expert commentaries, visitors can gain a more comprehensive understanding of the narratives behind the exhibits [39].

(5) Accessibility Features and Multi-platform Support

To ensure that all potential users can access the digital museum in the Metaverse, the platform needs to support a variety of devices, including PCs, smartphones, tablets, and various types of virtual reality headsets, thus ensuring accessibility for all potential visitors. Design considerations should also accommodate users of varying abilities, including those with visual and hearing impairments. Support such as screen

readers, subtitles, and sign language videos should be implemented to ensure that all users can access and enjoy museum content [40].

By integrating Virtual Reality and Augmented Reality technologies, digital museums in the Metaverse not only provide a novel, immersive museum experience but also enhance their educational and cultural dissemination capabilities through intelligent management and services. The digital museums of the future will function as comprehensive, multifunctional platforms for cultural exchange, continually evolving through technological innovations to better serve the public.

5. Conclusion and Discussion

5.1. Conclusion

Digital museums in the Metaverse and Metaverse-based applications, by delivering immersive and interactive experiences, markedly enhance user engagement and learning outcomes. Research indicates that technologies such as Virtual Reality (VR) and Augmented Reality (AR) enable visitors to gain deeper insights into exhibit backgrounds, enhancing both the learning experience and the enjoyment of the visit [41]. Furthermore, by integrating big data and cloud computing technologies, digital museums can conduct precise visitor behavior analyses, thereby better meeting user needs and optimizing exhibition strategies. This paper not only deepens our understanding of how digital museums can leverage modern technology to enhance visitor experiences but also explores the potential applications of Metaverse technology in cultural dissemination and education. Through analyzing the integration of various technologies and innovative practices, this paper provides theoretical and practical guidance for the future development of digital museums. Additionally, this paper emphasizes the importance of considering inclusivity and accessibility in the design and implementation of digital museum projects, enabling a broader audience to benefit from new technologies.

5.2. Enhancement of User Experience

Compared to traditional museums, digital museums in the Metaverse primarily offer more immersive experiences through technologies such as Virtual Reality (VR) and Augmented Reality (AR). Virtual reality technology significantly enhances the museum visiting experience, particularly by offering immersive and interactive exhibition methods, which greatly increase user engagement and satisfaction. Immersive technologies, particularly Augmented Reality (AR) and Extended Reality (XR), markedly enhance the overall experience of museum users. This new mode of exhibition enables them to gain a deeper understanding of the background and details of exhibits. Furthermore, through customized educational pathways and multimedia content, digital museum platforms increasingly meet the learning needs of visitors of various ages and backgrounds.

5.3. Enhancement of Educational Outcomes

Virtual reality museum platforms have exhibited significant potential in the field of education. These platforms effectively enhance user motivation and knowledge absorption through dynamic visual displays and interactive learning modes. Particularly with VR museum platforms offering dynamic learning materials and interactive experiences, users gain a deeper understanding of the exhibition content. This innovative method of learning is particularly effective in improving information

retention rates among younger visitors [43]. Additionally, the platform's multimedia content and customized educational pathways support visitors of diverse backgrounds and learning needs, showcasing the potential of technology to meet varied educational requirements.

5.4. Cultural Heritage and Technology Integration

With the evolution of technology and the advent of new media, research in digital museums and the Metaverse has ushered in revolutionary changes to the presentation and education of cultural heritage. Virtual reality museum platforms transcend physical and geographical limitations, enabling global visitors to access and learn about cultural heritage worldwide without barriers. This not only helps protect fragile or hard-to-access cultural assets but also opens new avenues for global cultural exchange and understanding. The Metaverse, as an emerging technological trend, enhances the accessibility, interactivity, and engagement of digital museums through digital technologies such as VR, AR, and blockchain. As technology advances, virtual museums are expected to increasingly focus on providing cross-cultural and multilingual educational resources, fostering dialogue and resonance among different cultures. These technologies not only enhance methods for preserving cultural heritage but also provide visitors with new ways to interact with and deeply understand cultures.

6. Future Trends and Prospects for Digital Museums

Within the context of the Metaverse, the rapid development of digital museums has ushered in unprecedented opportunities for the presentation and education of cultural heritage. The application of technologies such as Virtual Reality (VR), Augmented Reality (AR), and Artificial Intelligence (AI) has markedly enhanced user experiences and engagement [43]. For example, AR technology plays a crucial role in the management and preservation of cultural heritage by augmenting the real world with computer-generated information, offering users richer interactive experiences. Meanwhile, virtual reality and Metaverse technologies are extensively employed in virtual museums and the digital re-creation of cultural heritage. These technologies not only enable users to explore historical sites immersively but also deliver personalized educational and entertainment content through AI-driven virtual guides and interactions.

Although VR technology offers innovative exhibition methods for museums, its implementation also faces several challenges. For instance, producing high-quality 3D content is not only costly but also requires specialized technical support. To address these challenges, it is recommended that museums establish partnerships with tech companies to jointly explore cost-effective solutions and utilize open-source technologies and community resources to reduce development and maintenance costs. Additionally, the rapid iteration of technology necessitates that museums continuously invest in updating hardware and software to maintain the modernity and appeal of exhibitions. Developers are advised to use big data analytics tools to monitor and analyze visitor behavior, optimizing exhibition content and user interface design based on data feedback to enhance data-driven decision-making.

Through these measures, digital and virtual technologies can be better leveraged to provide the public with rich and educational cultural experiences, while also supporting research institutions. Future digital museums will continue to evolve,

becoming significant platforms for cultural exchange and education, providing users with limitless possibilities for exploration.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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