Sounds of History: A Digital Twin Approach to Musical Heritage Preservation in Virtual Museums

ChangMan Zou , Sang-Yong Rhee , Lin He , DaYang Chen * , Xiaofei Yang *

Posted Date: 15 April 2024

doi: 10.20944/preprints202404.0912.v1

Keywords: music cultural heritage; Digital collection; digital twin; virtual museum

 doi:10.20944/preprints202404.0912.v1

Article

Sounds of History: A Digital Twin Approach to Musical Heritage Preservation in Virtual Museums

ChangMan Zou [1,2], Sang-Yong Rhee [2], Lin He [4], DaYang Chen [3,*] and XiaoFei Yang [4,*]

[1] College of computer science and technology, Beihua University, Jilin, 132013, China; zouchangman@beihua.edu.cn
[2] Computer Engineering, Kyungnam University, Changwon-si, 51767 Gyeongsangnam-do, Korea
[3] Academy of music, Beihua University, Jilin, 132013, China; syrhee@kyungnam.ac.kr
[4] Shanghai Institute of Advanced Studies, Chinese Academy of Sciences, Shanghai, 201210, China; hel@sari.ac.cn
* Correspondence: chendayang@beihua.edu.cn (D.C.); yxf@sari.ac.cn (X.Y.)

Abstract: Music cultural heritage, as an important component of cultural heritage, possesses significant cultural value and inheritance significance. With the development of society and the passage of time, these precious traditional music cultural heritages inevitably face the dilemma of gradual depletion or even disappearance. In the digital age, effectively protecting and inheriting these music cultural heritages has become an urgent problem to be addressed. Therefore, this paper proposes an application method based on digital twin technology, exploring how to protect and inherit music cultural heritages through digital twin technology. By leveraging digital twin technology, a virtual museum dedicated to showcasing the richness and historical connotations of music cultures is created, preserving and simulating the soundscapes of historical music eras. Through the integration of audio archives, 3D modeling, and interactive displays, users can immerse themselves in the experience of historical music in the digital space. This paper evaluates the feasibility and cultural preservation value of this digital music history museum through the creation of music digital twin technology instances and user survey feedback, and discusses the prospects of digital twins in the field of music cultural heritage.

Keywords: music cultural heritage; Digital collection; digital twin; virtual museum

1. Introduction

Music, as an art form that transcends eras and cultures, carries profound historical and cultural value. Musical cultural heritage embodies the significant manifestation of human history and cultural diversity. It represents not merely an exhibition of art but also a crucial component of social and cultural identity. Musical cultural heritage encompasses, but is not limited to, traditional music, folk songs, ceremonial music, and related cultural expressions. As witnesses to history, these heritages record the evolution of human civilization and serve as vital channels for the transmission of cultural and societal values [1]. However, the preservation of musical cultural heritage faces numerous challenges. With the acceleration of globalization in politics, economy, culture, and changes in modern lifestyles, many traditional forms of music and expressions are gradually disappearing [2]. For instance, specific ethnic instruments and performing arts face the threat of extinction due to a lack of successors or audience. Additionally, the ongoing development of science and technology poses challenges to the preservation of musical cultural heritage, as the authenticity of music forms and traditional performance methods are impacted by modern media [3].

 doi:10.20944/preprints202404.0912.v1

In this context, the protection and transmission of musical cultural heritage become increasingly critical. Due to its multifaceted information and diverse presentation methods, existing preservation approaches—such as manual recording, documentary collection, digital capture, and information documentation—often face limitations due to resources and technology, affecting their effectiveness. Therefore, in the digital age, finding effective ways to protect and transmit this heritage to ensure its comprehensive, in-depth understanding and appreciation by a broader audience is an urgent issue to address [4].

Digital twin technology, as an emerging digitalization technique and exhibition concept, offers a new perspective and potential for the preservation of musical cultural heritage. By creating a virtual world as a novel platform for cultural dissemination, it presents musical cultural heritage in digital form to the public. The construction of digital twins for musical cultural heritage not only allows for more comprehensive recording and preservation of musical works, instruments, and methods of performance but also provides researchers and the public with an interactive and immersive experience. This approach not only enhances public awareness and interest in musical cultural heritage, allowing for interaction and experience in digital spaces but also offers new perspectives and tools for its preservation [5]. This has significant implications for the protection and dissemination of musical cultural heritage.

This paper proposes a new method for preserving and transmitting musical cultural heritage in virtual museums using digital twin technology. It focuses on exploring and evaluating the application of digital twin technology in the protection of musical cultural heritage within virtual museums. The paper will delve into how digital twin technology can replicate and reproduce musical cultural heritage in virtual museums, including specific applications, challenges faced, and potential solutions. To demonstrate the effectiveness of this method, the paper uses Kunqu Opera from China as a case study to construct a virtual music community and interactive platform. Through an analysis of user experience and transmission effects, this method not only effectively preserves musical cultural heritage but also provides the public with a new, highly interactive way to deepen their understanding and appreciation of musical cultural heritage, thereby promoting its protection and sustainable transmission.

2. Related Research Work

2.1. Analysis on the Current Situation of Music Cultural Heritage Protection

Musical cultural heritage, broadly defined, encompasses all cultural and historical information conveyed through music. This includes not only various musical compositions, such as traditional songs, ethnic music, and religious music, but also related practices of performance, musical instruments, music production techniques, and the role of music in social and cultural activities. As a form of cultural expression, music is an integral part of human history and social structure, reflecting the diversity, creativity, and understanding of the world across human societies [6].

The importance of musical cultural heritage lies in its unique cultural and educational value. Firstly, music serves as a powerful medium for conveying and preserving history, culture, and traditions. Through music, individuals can learn about and experience the historical narratives, lifestyles, and values of different cultural backgrounds [7]. Moreover, musical cultural heritage is a significant marker of ethnic and regional cultural identities, fostering connections between individuals and communities and promoting an understanding and respect for cultural diversity [8]. However, many traditional musical forms have been neglected or forgotten, especially those transmitted orally. Thus, the protection of musical cultural heritage is not only about preserving the past but also about maintaining cultural diversity and promoting the sustainable development of future cultures [9].

 doi:10.20944/preprints202404.0912.v1

The preservation of musical cultural heritage currently faces multifaceted challenges and limitations, stemming from changes in the external environment as well as the inherent limitations of preservation methods. In the process of globalization and modernization, traditional musical cultural heritage is at risk of marginalization and neglect. The rise of mainstream culture and commercial entertainment forms in modern society makes it difficult for traditional music to compete, reducing opportunities for its dissemination and performance and impacting the younger generation's interest and transmission of traditional music [10]. The rapid development of technology has, to some extent, altered the ways in which music is produced and disseminated. Although modern technology has facilitated the recording and preservation of music, it may also affect the authenticity of musical expression. For example, music recorded through digital means might not fully capture the nuances and emotional expressions of live performances [11]. Many traditional musical forms rely on oral transmission, which, despite its personalization and flexibility, is extremely vulnerable. Once the number of transmitters decreases or breaks, the related musical cultural heritage may be lost permanently [12]. The protection and transmission of musical cultural heritage require corresponding resources and financial support, including training transmitters, organizing musical events, and recording and preserving music. However, in many cases, these activities have not received sufficient attention and financial support, especially in economically disadvantaged regions [13]. Currently, methods used for the preservation of musical cultural heritage are often limited to the physical recording of music and the collection of documentary materials. Although these methods have played a role in preserving musical compositions, they are insufficient in transmitting the skills and expressive methods of musical performance [14]. Given these challenges and limitations, exploring new preservation methods and technological applications for the protection of musical cultural heritage is particularly important and urgent.

2.2. Application Analysis of Digital Twin Technology

Digital twin technology, as an innovative information technology, has begun to be widely applied across various industries. The concept of digital twins was first introduced by the United States Air Force in 2002. Digital twin technology involves creating a high-fidelity virtual replica of a physical entity to simulate, monitor, and optimize the entity, providing support for decision-making, performance optimization, future trend prediction, and necessary interventions [15].

Over time, with technological advancements, the diversity and flexibility of digital twin technology have led to its broad application across different fields. Particularly under the influence of Industry 4.0 and the Internet of Things (IoT), digital twins have become a key technology in manufacturing, urban planning, healthcare, and more [16]. In the manufacturing sector, digital twins are utilized to create virtual copies of products to optimize design, test performance, and predict maintenance needs [17]. In urban planning, the application of digital twins aids city administrators in more effectively monitoring and managing urban infrastructure [18]. In the medical field, digital twin technology is employed to simulate human organs or entire physiological systems, optimizing treatment plans and pre-operative procedures [19]. The energy industry uses digital twins to monitor and optimize the production and distribution of energy [20]. In recent years, with improvements in computing power and advancements in data analysis techniques, digital twin technology has become more efficient and precise in simulating complex systems and processes.

In the field of cultural heritage preservation, digital twin technology offers a novel perspective. By constructing accurate digital models of historical buildings, artworks, or even entire historical scenes, it not only provides rich resources for research and education but also scientific foundations and methods for the preservation and restoration of cultural heritage. Notably, digital twin technology can capture and reproduce the intricate features and historical contexts of cultural heritage, which is particularly important for protecting heritage that is vulnerable to environmental and temporal degradation. Furthermore, the application of digital twins in cultural heritage preservation extends beyond the replication and archiving of physical characteristics. By integrating virtual reality (VR), augmented reality (AR), and other interactive technologies, digital twins can offer the public immersive cultural experiences, allowing people to transcend the boundaries of time and

 doi:10.20944/preprints202404.0912.v1

space to directly experience and learn about different cultures. In this process, public participation and experience become active parts of cultural transmission, which is significant for enhancing societal recognition and awareness of the value of cultural heritage. Therefore, this paper aims to explore the potential and application of digital twin technology in the preservation of musical cultural heritage, particularly in the context of virtual museums. Through this research, we seek to reveal how digital twin technology can help us better understand, preserve, and transmit precious musical cultural heritage.

3. Music Cultural Heritage Protection Method Based on Digital Twin Technology

3.1. Analysis on the Application of Digital Twin Technology in the Protection of Musical Cultural Heritage

Digital twin technology, with its capacity to transcend geographical and physical barriers, offers a novel avenue for the enhanced access and engagement with musical cultural heritage. This innovative approach, by creating virtual spaces, renders musical heritage that was once inaccessible, readily available, and provides platforms for public participation and interaction. Through the employment of Virtual Reality (VR) and Augmented Reality (AR) within the framework of digital twin technology, it is possible to present musical cultural heritage in an environment that is not only more immersive but also highly interactive. Such an experiential paradigm shift not only augments the vividness and engagement of musical heritage but also substantially enriches the understanding of its cultural and historical context.

Digital twin technology introduces an avant-garde method for the education and exhibition of musical heritage. Within these virtual confines, it is feasible to reconstruct musical scenes from diverse historical epochs, thereby enabling users to engage with and comprehend the history and culture of music in an interactive milieu. Furthermore, digital twin spaces facilitate the digital restoration and preservation of musical heritage, offering a lifeline to musical forms that are either endangered or on the brink of extinction. This capability not only serves the purpose of safeguarding cultural heritage but also equips music scholars and researchers with innovative analytical tools.

Moreover, digital twin technology fosters a shared space for individuals from various cultural backgrounds, promoting the exchange and comprehension amongst different musical heritages. This cross-cultural dialogue and exchange are paramount for the advocacy of global cultural heritage protection and understanding. In light of the significant contributions of digital twin technology to the preservation of cultural heritage, the exploration of effective strategies for integrating musical cultural heritage within digital twin technology emerges as a compelling research topic. This inquiry not only promises to enrich the field of cultural preservation but also to enhance the global appreciation and understanding of musical heritage.

3.2. Design of Virtual Music Museum Based on Digital Twin Technology

The construction of a virtual music museum based on digital twin technology presents a viable means for the effective preservation and transmission of the world's intangible musical cultural heritage, exemplified by China's Peking Opera, Kunqu Opera, and the art of the Guqin. This virtual museum aims to seamlessly integrate technologies such as Virtual Reality (VR), Augmented Reality (AR), blockchain, and Artificial Intelligence (AI) with the characteristics of musical cultural heritage preservation and exhibition. The goal is to create a digital space that not only serves educational purposes but also offers entertainment value, as illustrated in Figure 1.

 doi:10.20944/preprints202404.0912.v1

Figure 1. Virtual diagram of virtual museum design architecture.

The implementation of such a museum requires the careful consideration of how to effectively blend these advanced technologies with the nuances of music heritage to foster a digital environment that honors the depth and diversity of cultural expressions. The integration of VR and AR technologies enables immersive experiences that bring visitors closer to the subtleties of musical performances and traditions, while AI and blockchain provide innovative solutions for the cataloging, analysis, and secure sharing of cultural data. This multidisciplinary approach aims to construct a virtual space where education and entertainment converge, offering users a rich, interactive learning environment alongside engaging cultural explorations.

By adopting this technologically integrated framework, the virtual music museum not only safeguards intangible musical heritage but also enhances its accessibility and understanding among global audiences. This initiative underscores the potential of digital twin technology as a transformative tool for cultural preservation, offering new pathways for the appreciation and continuation of the world's musical legacies.

The development of a virtual museum primarily encompasses key technologies such as 3D modeling, audio archive integration, and user interface design. In June 2023, the Ministry of Culture and Tourism of the People's Republic of China published the " Digital safeguarding of the intangible cultural heritage—Digital resources collection and description(WH/T 99.3-2023)," with Part 3 specifying clear standards for the digital resource collection and cataloging of traditional music within intangible cultural heritage [21]. This paper will fulfill the design for the collection and cataloging of digital resources for cultural heritage, based on the requirements set forth by these standards.

3D Modeling Technology: Utilizes laser scanning among other techniques for the digital scanning of physical artifacts, capturing precise three-dimensional model data. Computer graphics technology is then employed to model and render the scanned data, creating lifelike virtual exhibits and spaces. Animation and interactive features are added to exhibits and scenes to enhance user experience and engagement, akin to the process for a classical guitar. For instance, Artec Studio could be used for laser scanning a real classical guitar to obtain high-precision 3D model data. This data is then imported into Blender for further modeling and editing to repair any potential defects or damages and to add more details and textures. Realistic exhibition scenes are created in virtual showrooms using Unity3D or Unreal Engine, placing the classical guitar appropriately. Finally, interactive features are added using Unity3D or Adobe Animate, such as enabling users to click on

 doi:10.20944/preprints202404.0912.v1

the guitar to access more information or play audio samples, thereby enhancing engagement and experience.

Audio Archive Integration Technology: Digital processing of actual musical artifacts' audio materials includes recording, editing, and format conversion. An audio database is established for the integration, management, and retrieval of audio archives, facilitating their display and playback in the virtual museum. Audio playback engines or media player technologies are applied for smooth audio playback and control, using software like Adobe Audition, Soundminer, Pro Tools, VLC Media Player, and HTML5 Audio Player.

User Interface Design Technology: Designs an intuitive and user-friendly interface, including navigation menus, exhibit browsing, and information viewing functions, enabling easy operation and navigation by users. Integrates 3D models, audio, video, and other multimedia content within the user interface to provide rich display effects and interactive experiences. Responsive interface designs adapt to different devices and screen sizes, including PCs, tablets, and smartphones, meeting the access needs of users across various platforms. Application software includes Adobe XD, Sketch, Unity3D, HTML/CSS/JavaScript, Bootstrap, and Media Queries.

Designing a virtual museum based on digital twin technology also requires adherence to a generalized methodology to ensure the museum's design can adapt to diverse needs and scenarios. This includes establishing clear goals and audiences, designing for interactive experiences, and continuously improving and optimizing based on user feedback and technological advancements, as demonstrated in Figure 2. This approach ensures the museum's design remains competitive and appealing while fulfilling its core objectives of education and entertainment.

Figure 2. Interactive experience and virtual scene design.

3.3. Construction and Implementation of Digital Music History Museum

The Digital Music History Museum, utilizing digital twin technology, aims to preserve and exhibit a range of significant musical cultural heritages. Initially, selected musical works undergo standard digitalization processes, including high-quality audio recording and the restoration and digital conversion of existing recordings. Moreover, detailed documentation and simulation of these musical works' historical background, performance methods, and instruments used are conducted.

 doi:10.20944/preprints202404.0912.v1

Based on these foundations, the application of the Digital Music History Museum is realized through the development of virtual spaces and interactive experiences.

(1) Development of Virtual Spaces for the Digital Music History Museum

The development of virtual spaces primarily involves using 3D modeling technology to construct a virtual environment for the museum, including recreations of historical performance venues, such as classical concert halls or traditional music venues. These environments not only visually reconstruct historical scenes but also simulate the acoustic characteristics of different venues through 3D sound technology. This article employs Unity or Unreal Engine for the development of virtual environments, leveraging their robust 3D rendering and physics simulation capabilities, suitable for creating high-quality virtual exhibition halls. Furthermore, applications compatible with mainstream VR devices (e.g., Oculus Rift, HTC Vive) and mobile AR platforms (e.g., ARKit, ARCore) are developed to ensure broad user access.

In terms of 3D models and animations, 3D scanning technology is utilized to capture detailed information of real-world objects such as instruments and costumes, converting them into high-precision 3D models. 3D animation technology is employed to demonstrate instrument performance methods and dramatic actions, enhancing the interactivity of learning and experience.

For content management, a backend content management system is developed to facilitate museum staff in updating exhibition content, adding new educational resources, and event information. It supports multimedia content such as text, images, videos, and 3D models.

Regarding network technology and cloud services, cloud computing services (e.g., AWS, Google Cloud Platform) are used to deploy virtual exhibition hall applications to support high concurrent access and smooth experiences for global users. High-speed network technology and CDN are employed to optimize content loading speed, reducing latency.

The virtual exhibition hall, through the above design and technical implementation strategies, not only showcases the artistic beauty and cultural depth of musical cultural heritage but also provides an interactive and educationally rich virtual experience, attracting more domestic and international visitors to delve into and appreciate traditional musical arts.

(2) Development of User Interactive Experiences

User interactive experience development includes simulated experiences, gamified learning, interactive lectures, and workshops. Simulated experiences utilize VR/AR technology to allow visitors to personally experience traditional music performance, opera acting, etc., such as simulating playing the Guqin or dressing up as a character from Peking Opera. Gamified learning designs interactive games related to music projects, such as dubbing Peking Opera or memorizing Guqin pieces, to add fun and deepen memory. Virtual lectures and workshops are set up to allow visitors to participate in real-time interactive teaching, communicating directly with artists or experts.

For virtual reality and augmented reality technology, applications compatible with various VR headsets (e.g., Oculus Rift, HTC Vive) and AR platforms (e.g., ARKit for iOS, ARCore for Android) are developed, ensuring users can access interactive experiences through their devices. High-quality virtual environments and interactive objects, such as accurately restored instruments and costumes, are created using 3D modeling and animation.

AI technology, such as machine learning and natural language processing, provides intelligent interactive teaching support, adjusting teaching difficulty and content based on user performance and feedback. AI-assisted music composition and performance tools are developed, allowing visitors without professional knowledge to create music works in traditional styles.

In terms of network technology and data management, cloud service platforms (e.g., AWS or Google Cloud) host applications and data, ensuring high performance and stable access experience while facilitating cross-platform data synchronization. A database is established to store user behavior data and interactive results, supporting users in saving and sharing their experiences and works.

 doi:10.20944/preprints202404.0912.v1

Device compatibility and access ensure that interactive experiences support various terminal devices, including PCs, smartphones, tablets, and VR/AR devices, covering a wider user group. User interfaces are designed for ease of use, ensuring even tech novices can quickly engage in interactive experiences.

In content presentation, high-definition screens and projection technology display related cultural backgrounds, art technique analyses, historical stories, etc., enriching visitors' learning content in various forms such as video and text, and providing in-depth information about exhibits through interactive touch screens or smart devices.

In this virtual museum, visitors can freely explore different exhibition areas, interact with exhibits, and even participate in virtual concerts. For example, users can choose different music works to listen to, obtaining detailed explanations and background information about the works. Additionally, they can experience the audience perspective in real concerts through virtual reality devices. This museum is not only a protector of musical cultural heritage but also a tool for inheritance and education. By offering educational resources and interactive activities, such as music history courses and virtual performance experiences, the museum plays a significant role in promoting music knowledge and cultural understanding. This case of the Digital Music History Museum showcases the tremendous potential of digital twin technology in the preservation and dissemination of musical cultural heritage, offering new perspectives on the modern protection of traditional cultural heritage.

Immersive experiences, multisensory interactions, personalized tours and explorations, interactive learning tools, social functions, and shared experiences. Through these interactive methods, the Digital Music History Museum provides users with a rich, educationally potent cultural experience platform. These experiences not only enhance user engagement and satisfaction but also help deepen their understanding and appreciation of music history.

4. Example Verification and Effect Evaluation

4.1. Construction of Chinese Kunqu Opera Virtual Music Community and Interactive Platform

The Chinese Kunqu Opera virtual music community and interactive platform integrate and apply digital twin technologies such as virtual reality (VR), augmented reality (AR), blockchain and artificial intelligence (AI), aiming to provide users with an immersive Kun opera experience and communication platform . The platform uses virtual reality (VR)/augmented reality (AR) technology, blockchain technology, artificial intelligence (AI) technology, and cloud service platforms (such as AWS, Google Cloud) and other services. Through these design and technical solutions, we were able to create a virtual music community and interactive platform that not only retains the cultural essence of Kunqu Opera, but also incorporates modern technology. This platform provides users with a brand new cultural experience and learning space. The platform will also provide an intuitive, easy-to-use and colorful virtual environment, allowing users to enjoy a personalized and interactive experience while exploring the art of Kunqu Opera.

 doi:10.20944/preprints202404.0912.v1

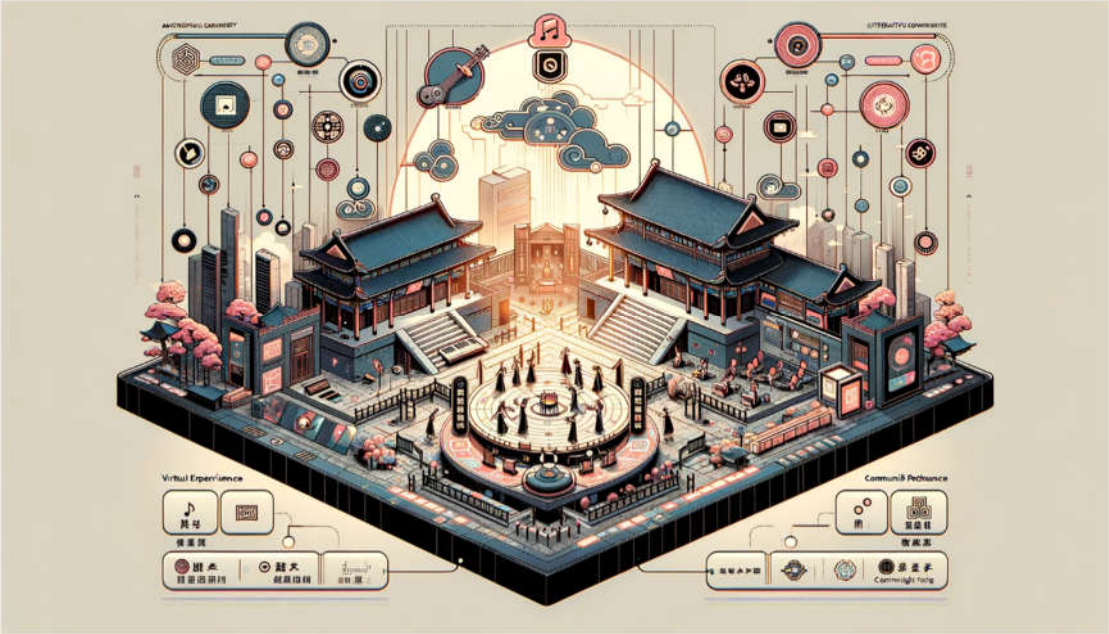

Figure 3. Virtual map of Chinese Kunqu Opera virtual music platform.

(1) User Interface Design Proposal

This design proposal aims to ensure an intuitive and user-friendly interface while integrating visual elements of Kunqu Opera to enhance the cultural experience. The homepage employs a visual design that fuses traditional Kunqu elements, such as costumes, masks, and stages, with a modern, minimalist interface. The primary color palette consists of tranquil blue-green hues, creating an atmosphere that melds classical and contemporary influences. The homepage is designed to feature modules such as performance previews, selected videos, and latest news, showcased through scrolling banners and dynamic modules.

The virtual experience zone leverages VR/AR technology to provide users with an immersive experience in viewing Kunqu performances. Users can experience performances in a 3D virtual space via virtual reality headsets or smartphones. Interactive elements, including virtual interactive seat selection and role-playing game elements, are incorporated to enhance engagement.

The learning area offers tiered tutorials ranging from basic knowledge to advanced techniques, including lessons on singing styles and body movement training, presented in various formats such as videos, images, and audio. Utilizing AI technology, the system provides personalized recommendations and feedback based on the user's learning progress and preferences, including the generation of customized practice content and evaluation of user performances, thereby facilitating AI-assisted learning.

An interactive discussion area features a dedicated forum where users can initiate discussions, share experiences, and upload original content. This area supports live teaching and performance by artists and enthusiasts, with capabilities for real-time comments and tipping by the audience.

This proposal integrates traditional cultural elements with cutting-edge technology to create a user interface that not only enhances the accessibility and enjoyment of Kunqu Opera but also promotes interactive learning and community engagement within a modern digital framework.

(2) User Experience Design Proposal

This proposal presents a streamlined user journey with an easy-to-navigate interface to ensure rapid access to content and features of interest. Introduction of beginner tutorials via guided instruction aids new users in familiarizing themselves with the platform's functionalities.

Personalized Experience: Utilizing user behavior data analysis, the platform recommends content, performances, and learning resources that align with user interests. It allows for

 doi:10.20944/preprints202404.0912.v1

customization of personal profile pages, including selection of favored Kunqu Opera roles, plays, and artists.

Interaction and Community Building: The enhancement of community interaction features, such as forums, user-generated content (UGC), live commentary, and interactive Q&A, encourages user sharing and communication. A points and rewards mechanism is designed to recognize active users and quality content creators, fostering community participation.

Accessibility Design: The platform ensures inclusivity for all users, including those with visual, auditory, or other disabilities. Features such as text-to-speech, speech-to-text conversion, high contrast modes, and magnification tools are implemented to guarantee content accessibility.

(3) Technical Design Proposal

Virtual Reality (VR)/Augmented Reality (AR) Technology: VR/AR content is developed using Unity or Unreal Engine to ensure high-quality visual effects and smooth interaction. Coupled with 3D modeling and animation, these technologies reproduce the nuances of Kunqu performances, enhancing realism through:

Content Creation: High-quality 3D scanning and motion capture technologies record the performances of Kunqu artists, ensuring accurate representation of movements and expressions. Virtual environments, characters, and interactive elements are built using Unity or Unreal Engine development platforms.

Platform Compatibility: Applications compatible with mainstream VR headsets (e.g., Oculus Rift, HTC Vive) and AR platforms (e.g., ARKit for iOS, ARCore for Android) are developed. For users without VR/AR devices, a web-based 3D experience is provided, accessible via mouse and keyboard interactions.

User Interaction: Interactive tutorials and gamified learning elements, such as role-playing and performance guidance, are designed to increase user engagement. Multi-user virtual environments support online user interaction and collaboration.

Blockchain Technology: A secure and transparent transaction system built on blockchain technology is utilized for ticketing and art sales. Smart contracts automate transactions, ensuring fairness and security through:

Smart Contracts: Automated transaction processing and contract term enforcement, such as ticket sales, copyright management, and art trading, are facilitated by smart contracts. All transaction records are transparent and traceable, increasing user trust.

Token System: The issuance of platform-specific tokens for internal transactions, rewarding contributors, and purchasing virtual goods. A token economic model is designed to regulate supply and demand, maintaining token value.

Digital Collectibles (NFTs): Unique digital art pieces and collectibles, such as limited edition Kunqu videos, audios, or virtual items, are offered through NFT technology. An NFT marketplace enables users to buy, sell, and exchange these digital collectibles.

Artificial Intelligence (AI): Machine learning analyzes user data to provide personalized learning content and recommendations. Voice and image recognition technologies are developed for the learning area's automatic evaluation functions, such as assessing singing accuracy and body posture, including:

Recommendation System: A machine learning-based recommendation algorithm analyzes user behavior and preferences, offering personalized content recommendations, such as performances, tutorials, and articles. The recommendation strategy is adjusted in real-time to match changing user interests.

Content Generation: Deep learning models, such as Variational Autoencoders (VAE) or Generative Adversarial Networks (GAN), automatically generate Kunqu music and performance scripts for user exploration and learning. AI-assisted creation tools help users produce Kunqu-related music and textual content.

Learning Assistance: Natural language processing (NLP) and voice recognition technologies develop intelligent tutoring robots for voice-interactive learning and feedback. Computer vision

 doi:10.20944/preprints202404.0912.v1

analyzes user performance videos to provide movement correction and performance improvement suggestions.

Other Technologies: Cloud service platforms (e.g., AWS, Google Cloud) deploy applications, ensuring stability and scalability. NoSQL databases (e.g., MongoDB) support extensive user interaction data and personalized content. The latest network security protocols and encryption technologies protect user data from unauthorized access and leaks. Transparent privacy policies allow users to control their data and preferences. Responsive design frameworks (e.g., Bootstrap) ensure good platform performance across various devices and screen sizes. JavaScript frameworks (e.g., React or Vue) create dynamic user interfaces and single-page applications (SPAs), enhancing the responsiveness and smoothness of user interactions. Server-side technologies like Node.js or Python develop APIs for user requests and data exchanges. A microservices architecture ensures platform scalability and modularity, facilitating future feature additions and maintenance.

4.2. Effectiveness Evaluation and Feedback Analysis of the Chinese Kunqu Virtual Music Community and Interaction Platform

The assessment of effectiveness and analysis of user feedback are crucial for the Chinese Kunqu Virtual Music Community and Interaction Platform. Various methods were employed to gather user feedback, aiming to comprehensively understand the platform's performance and user experience.

Initially, user surveys and feedback analyses were conducted. Through online questionnaires and real-time feedback devices, data on user satisfaction with the museum experience were collected, encompassing evaluations of exhibits, interactive elements, and educational content. For users with educational purposes, a specific assessment of learning outcomes was conducted, collecting data on users' mastery of Kunqu Opera history before and after visiting, through tests and interviews. Special feedback was also gathered on interactive experiences, such as virtual reality performances and music games. Furthermore, user behaviors within the museum were tracked and analyzed using data analysis tools, including visit duration, interaction frequency, and browsing paths, to identify interest points and behavior patterns. These surveys and analyses enabled the platform to better understand user needs, continuously optimize experiences, and enhance its effectiveness in preserving and disseminating Kunqu cultural heritage.

Additionally, evaluations and suggestions from cultural heritage experts were solicited, including music historians, cultural heritage preservationists, and digital technology experts. Most acknowledged the platform's effectiveness in preserving musical cultural heritage, particularly through high-quality digitalization, facilitating the preservation and dissemination of valuable musical works and cultural information. Experts also provided suggestions on balancing technology and content, and enhancing diversity and inclusivity.

Combining these evaluation methods and expert recommendations, it is concluded that the Chinese Kunqu Virtual Music Community and Interaction Platform plays a significant role in the preservation, education, and cultural exchange of musical cultural heritage. As a new form of protection and dissemination for musical cultural heritage like Kunqu, its value in cultural preservation is demonstrated in multiple aspects. Through digital technology, ancient and rare musical works are preserved for the long term, traditional music is revitalized and popularized, and the virtual music community and interaction platform offers a new platform for music education and cultural heritage. By breaking geographical and physical barriers, it enables people worldwide to access and experience musical cultural heritage. User feedback and expert evaluations have provided valuable insights and directions for improving the platform. Efforts will continue to optimize the platform, enhance user experience, and act as protectors and promoters of musical cultural heritage.

5. Further Discussion

The future development of digital twin technology in the field of musical cultural heritage is trending towards diversification and intensification. Its potential lies in providing richer, more interactive, and personalized cultural experiences, while offering new possibilities for the preservation and research of musical cultural heritage. With the ongoing advancement of technology,

 doi:10.20944/preprints202404.0912.v1

the potential impact of digital twin technology on the preservation of musical cultural heritage is becoming increasingly significant. The following analysis highlights key areas of impact: enhancing preservation accuracy and quality, expanding dissemination and education pathways, fostering international cooperation, supporting complex data analysis, and the coexistence of challenges and opportunities. The impact of technological progress on the preservation of musical cultural heritage is profound and complex, necessitating a cautious approach to addressing accompanying challenges while fully leveraging technological advantages.

As the application of digital twin technology in the musical cultural heritage field deepens, future research directions and the challenges faced become more evident. These include the study of multimodal data fusion, research on optimizing user experience, ethical issues in digitalizing cultural heritage, sustainability and accessibility of technology, and the promotion of cross-cultural understanding and communication. Through these research directions and addressing challenges, the future may see further expansion of digital twin technology applications in the musical cultural heritage field, providing increased support for the protection and dissemination of global cultural heritage.

Author Contributions: Conceptualization, X.F.Y. and C.M.Z.; methodology, S.Y.R., C.M.Z. and L.H.; software,C.M.Z. and L.H.; validation, D.Y.C., and L.H.; investigation, D.Y.C. and C.M.Z.; resources, X.F.Y. andS.Y.R.; writing—original draft preparation, C.M.Z., D.Y.C. and L.H.; writing—review and editing, X.F.Y.and C.M.Z.; visualization, L.H.and D.Y.C.; supervision, S.Y.R., D.Y.C.and X.F.Y.; project administration,D.Y.C.; All authors have read and agreed to the published version of the manuscript.

Acknowledgments: This work was supported by the phased achievement of the social science research key project of Jilin Provincial Department of education, "Research on the forms and ways of music education resources serving cultural endowment under the new situation" (Project No.: jjkh20210081sk); The research project of education and teaching reform of Beihua University "research and practice of vocal music teaching based on mixed teaching mode" (Project No.: xjzd2021035) is a phased research result；Phased research results of the general self-selected topic of the Jilin Provincial Social Science Fund Project "Research on the Development Strategy of Digital Empowerment of Cultural Tourism Integration of Ethnic Music in Jilin Province"; the doctoral and youth project of the Jilin Provincial Social Science Fund Project "Cultural Tourism Development and Cultural Heritage Inheritance and Protection in Jilin Province" "Digital Empowerment Research" phased research results.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zhang, X.; Yang, D.; Yow, C.H.; Huang, L.; Wu, X.; Huang, X.; Guo, J.; Zhou, S.; Cai, Y. Metaverse for Cultural Heritages. *Electronics* 2022,*11*, 3730. https://doi.org/10.3390/electronics11223730
2. Guo W. The beginning of the metaverse: the value transformation of music education in the post-digital era [J]. Journal of East China Normal University (Education Science Edition), 2023, 41(11): 52-66. https://doi.org/10.16382/j.cnki. 1000-5560.2023.11.005.
3. Sang, Y.; Zhao, L.; Sun, K.; Wang, X.; Meng, X.Y. Research on digital twin technology framework and application of Great Wall Cultural Heritage. Technol. Innov. Appl.2021,11, 19–23:27. [Google Scholar]
4. Grieves, Michael, and John Vickers. "Origins of the digital twin concept." Florida Institute of Technology 8 (2016): 3-20.
5. Schippers H. Applied ethnomusicology and intangible cultural heritage[J]. The Oxford handbook of applied ethnomusicology, 2015: 134-156.
6. Grant C. Endangered musical heritage as a wicked problem[J]. International Journal of Heritage Studies, 2015, 21(7): 629-641.
7. Howard K. Musical instruments as tangible cultural heritage and as/for intangible cultural heritage[J]. International Journal of Cultural Property, 2022, 29(1): 23-44.
8. Music as intangible cultural heritage: Policy, ideology, and practice in the preservation of East Asian traditions[M]. Routledge, 2016.
9. Boyu Z, Hui Y, Schippers H. Report: The rise and implementation of intangible cultural heritage protection for music in China[J]. the world of music, 2015: 45-59.
10. Bremer-Laamanen M, Stenvall J. Selection for digital preservation: dilemmas and issues[M]//Managing preservation for libraries and archives. Routledge, 2018: 53-65.

 doi:10.20944/preprints202404.0912.v1

11. Boyu Z, Hui Y, Schippers H. Report: The rise and implementation of intangible cultural heritage protection for music in China[J]. the world of music, 2015: 45-59.
12. Lv L. Research on the Digital Dissemination of Non-heritage Traditional Culture in the Context of the Meta-universe[J]. Transactions on Social Science, Education and Humanities Research, 2023, 2: 102-107.
13. Nguyen T A, Trinh A H, Pham T A. Enhancing the digitization of cultural heritage: State-of-Practice[J].
14. Wang Z. Digital twin technology[M]//Industry 4.0 - Impact on intelligent logistics and manufacturing. IntechOpen, 2020.
15. Gabellone F. Digital Twin: a new perspective for cultural heritage management and fruition[J]. Acta Imeko, 2022, 11(1): 7 pp.-7 pp.
16. Besoain F, Jego L, Gallardo I. Developing a virtual museum: Experience from the design and creation process[J]. Information, 2021, 12(6): 244.
17. Oliveira M, Martinho C T. Virtual museums, new media arts and sound archives[J]. 2021.
18. Wang Q, Li L, Hu S. Computer network information security protection faced by digital art museums based on the internet of things[J]. Wireless Communications and Mobile Computing, 2021, 2021: 1-10.
19. El Debuch H, Iovino S, Parenti G, et al. The Virtual Museum: How Technology and Virtual Reality May Help Protect and Promote Cultural Heritage[M]//Heritage in War and Peace: Legal and Political Perspectives for Future Protection. Cham: Springer International Publishing, 2024: 149-164.
20. Argyriou L, Economou D, Bouki V. Design methodology for 360 immersive video applications: the case study of a cultural heritage virtual tour[J]. Personal and Ubiquitous Computing, 2020, 24(6): 843-859.
21. https://zwgk.mct.gov.cn/zfxxgkml/kjjy/202308/t20230804_946421.html（WH/T 99.3-2023）