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An AI-driven XR Multi-Experience Platform Design by Periods for the Classic Chinese Panoramic Scroll Painting "Along the River during the Qingming Festival"

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Abstract

The integration of extended reality (XR) with digital heritage has considerably broadened the scope of multi-participatory cultural heritage experiences. In digital heritage, three-dimensional (3D) reconstruction of cultural assets is a standard procedure among specialists, with most progress dependent on the 3D documentation, reconstruction, and 3D visualization and representation of cultural assets. However, the scope for the digital application of 2D cultural heritage, such as paintings and documents, is considerably limited, while transforming traditional 2D scroll artwork into an immersive XR experience entails complex technical and interpretive challenges that require interdisciplinary collaboration among art historians, technologists, and designers. To address this gap, this study presents the design of an AI-driven XR multi-experience platform inspired by the classic Chinese panoramic scroll painting "*Along the River during the Qingming Festival*." The painting meticulously illustrates urban life during the Song Dynasty, making it suitable for immersive digital reproduction because of its narrative quality, architectural complexity, and vibrant portrayal of everyday events. The proposed platform integrates AI-driven interpretation and restoration technologies for a digitally and historically realistic environment, allowing multiple users to interact inside the reproduced space. This study aims to design a scalable framework for transforming conventional 2D artifacts into XR multi-participation environments, introducing a novel approach for digital heritage that improves the preservation and accessibility of cultural assets in the digital age. This study offers practical and innovative solutions for the preservation and utilization of cultural heritage in the digital era by enhancing accessibility, educational impact, and innovative interaction with historical artworks.

1. Introduction

1.1 Background and Motivation

Over the past decade, the production of global digital content has significantly increased due to the digitization of traditional materials. Digital heritage, like its traditional counterpart, requires preservation to satisfy national and cultural needs (Mudogo Mutula, 2014). Rapid advances in communication technologies have revolutionized cultural heritage preservation methods (Peters et al., 2017), facilitating precise heritage representations via scanning, 3D modeling, and VR technologies. The growth in digital heritage data has broadened access and enriched preservation strategies, making cultural heritage sites more accessible for immersive experiences (Jinho et al., 2015). Key examples include the immersive 3D reconstruction of the Seokguram Grotto (Park et al., 2014; Tufail et al., 2022), virtual museum development for Takht-i-Bahi heritage (Tufail et al., 2024), AR applications for the Basilica of Saint Catherine (Lin et al., 2025), and virtual restoration of San Geminiano Church, Venice (Balletti et al., 2020). Recent trends highlight a shift toward interactive, multi-participatory experiences, prioritizing co-creation and active engagement (Cade et al., 2022; Paschalis, 2024). Examples include the digital Scroll at the 2010 Shanghai Expo, "Horizon of Khufu," "Tonight with the Impressionists, Paris 1874," and "Wow! Sanxingdui," illustrating how technology revitalizes cultural heritage and public participation (Hyoungki et al., 2025). However, detailed multi-participatory applications of 2D heritage (paintings, documents) remain underexplored.

This study aims to address this gap by developing an AI-driven XR multi-participation platform inspired by the traditional Chinese scroll painting *"Along the River during the Qingming Festival (清明上河圖)."* The painting depicts complex urban life during the Song Dynasty, offering significant potential for immersive experiences due to its narrative complexity (ShiuLan and WeiChao, 2016; Lei, 2023; Yinhao et al., 2019). Transforming a 2D artwork into a 3D XR experience presents challenges such as AI-driven depth modeling, scale optimization, and computing constraints, which may be mitigated by procedural components and dynamic Level of Detail (LOD) adjustment. Ensuring cultural authenticity requires contextualized academic narratives to prevent superficial interpretations. Non-linear XR exploration undermines the scroll's inherent sequential narrative, requiring deliberate design features such as time-toggling pathways to preserve coherence.

The proposed platform employs AI-driven interpretation and restoration, real-time XR rendering, and multi-user synchronization to create a historically accurate, immersive environment. This scalable framework enhances preservation and access, demonstrating a novel integration of traditional heritage with advanced digital technologies for cultural education and engagement (Hwangbyeok, 2018).

1.2 *"Along the River during the Qingming Festival"* Painting

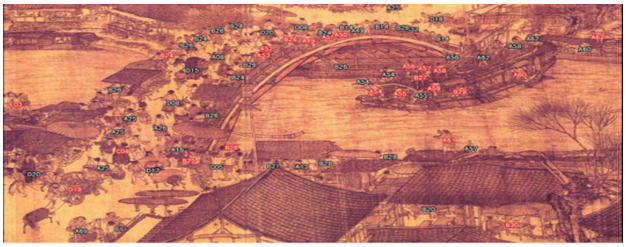
"Along the River during the Qingming Festival" painting is a significant Chinese cultural artifact noted for historical and artistic value (Feifei, 2024). It was painted by Zhang Zeduan (1085–1145) during the Northern-Southern Song Dynasty transition. Zhang is renowned for genre painting, particularly urban scenes with detailed bridges, ships, streets, and markets. This era saw economic growth in agriculture, commerce, and handicrafts, relatively free from religious or political constraints. The painting vividly portrays busy urban life during the Northern Song period. Later, the Ming Dynasty enhanced the painting with new elements and vibrant colors, creating a dynamic composition. In 1736, five Qing Dynasty court artists produced a version presented to Emperor Qianlong. Table 1 summarizes artists, exhibitions, and locations for the Song, Ming, and Qing dynasty versions.

Dynasty	Artist	Exhibition	Location
Song	Zhang Zeduan	Imperial Palace	Kaifeng
Ming	Qiu Ying	Liaoning Museum	Suzhou
Qing	Chen Me	Taipei	

Table 1. Song, Ming, and Qing dynasties artists, exhibition and locations

The painting serves as a significant record of Song Dynasty urban planning, architecture, attire, and transportation (Foong, 2020). Some interpretations suggest it implicitly critiques government misconduct or societal indifference (Zhang, 2017). Various replicas, such as the Ming Dynasty version (National Palace Museum, Taipei) and the Qing Dynasty reproduction (Palace Museum, Beijing), exist (Figure 1). China, under Xi Jinping's third term, has highlighted historical legacy through socialist narratives. The Millennium City Park in Kaifeng, inspired by the painting, was established by Qingyuan Co., Ltd. in 1998, opened in 2001, designated a 5A national travel site, and serves as a filming location.

The painting inspired modern adaptations, including a digital animated version for the 2010 Shanghai Expo (Figure 2), exemplifying ancient Chinese artistic achievements. China's 14.5 Regulations (2012-2025) promote advanced cultural industries. COVID-19 accelerated digital media growth, enhancing platforms like TikTok and Xiaohongshu through AI-driven personalized content (Ming et al., 2024). Additionally, China Manufacturing 2035 emphasizes AI and autonomous technology, underscoring the government's initiative to combine cultural heritage with digital innovation. Scholars argue that AI can effectively transform museum exhibitions (Meng et al., 2024).



(a) The bridge scene from Song Dynasty (1120)

(b) The bridge scene from Ming Dynasty (1502 - 1552)

(c) The bridge scene from Ming Dynasty (1736)

Figure 1. The Bridge scene transition from Song and Ming dynasties by period.

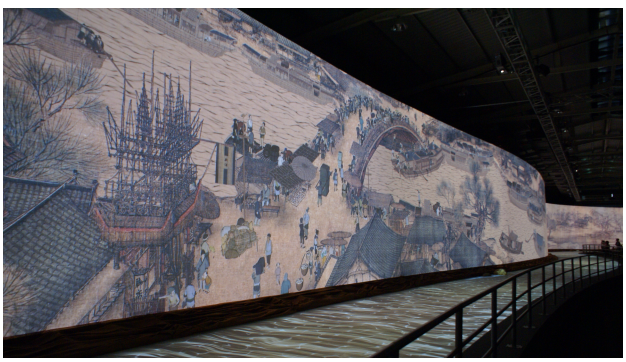


Figure 2. The digital version of the painting exhibited in Shanghai Expo 2010.

The digital version of the painting vividly reflects the detailed descriptions of the original work from the Song and Ming dynasties, enabling viewers to directly experience the urban life and characters depicted in it; as a result, this has garnered attention for its attempt to reinterpret traditional heritage using modern digital technology. In the present study, the AI-based Qingming River Painting, recreated with a modern interpretation, was created using the latest generative AI technology to reconstruct traditional heritage from a modern perspective. This approach aims to reflect both classical artistry and modern social aspects by integrating modern cityscapes with the traditional painting heritage. We broadly divided the process of creating this painting using generative AI into three stages. The following sections present each stage.

2. The Proposed Design Framework and Implementation Process

2.1 AI-based Data Collection and Pre-processing

We systematically gathered high-resolution imagery that closely resembled the compositional structure and visual characteristics of the original painting during the initial data collection stage. These images primarily consisted of digitized versions of the original painting as well as its historically significant variants from the Ming and Qing dynasties. To systematically address uncertainty inherent in historical interpretation and modern representation, particularly regarding the fidelity of digitized paintings, stylistic variations across dynasties, and the selection criteria for contemporary relevance, we adopted a critical reconstruction paradigm from Apollonio et al. (2021). This involved iterative expert consultation, provenance and confidence tagging, and transparent assumption logging. We engaged with art historians from the Beijing Palace Museum, Liaoning Provincial Museum, and Taipei Palace Museum early in the data selection process to identify and document ambiguities in the source material, such as debated elements in original/variant paintings, uncertain color fidelity in digitized scans, and interpretation of brushstroke techniques. The process involved tagging the metadata of collected images with provenance information, such as the museum's source, scan date, and catalog ID, and assigning confidence levels regarding historical accuracy based on the documentation from the museums and scholarly consensus.

We explicitly documented the assumptions we made during the selection of modern images, such as defining 'contemporary relevance' as structures constructed after 2000 and prioritizing diversity in architectural styles, as well as the preprocessing decisions we made, such as justifying specific augmentation techniques for brushstroke patterns and setting thresholds for color palette extraction. In parallel, extensive photographic datasets representing contemporary urban scenes were meticulously collected. This data was specifically sourced from major Chinese metropolitan areas, including Beijing, Shanghai, Shenzhen, and Kaifeng, focusing on capturing diverse modern architectural elements such as high-rise buildings, complex urban bridges, wide riverside parks, and contemporary transportation systems. We curated approximately 30,000 modern cityscape images to ensure sufficient variability for training purposes. Additionally, pre-processing involved sophisticated digital augmentation methods. The traditional painting's handwritten brushstroke patterns, ink textures, and distinct color palettes were digitally extracted and converted into standardized image patches. These patterns were used as style references in the AI model's later training, allowing for a smooth combination of traditional styles and modern city images. The primary objective at this stage was to ensure that the synthesized images maintained both historical authenticity and contemporary relevance, effectively blending traditional aesthetics with modern visual coherence, while transparently allowing the interpretive choices made within the critical reconstruction framework.

2.2 Learning Generative AI-Models

We initiated the core generative learning phase using advanced deep-learning architectures after completing the data pre-processing. To create the best images, we used a mix of generative adversarial networks (GANs) and neural style transfer algorithms. The GAN architecture employed was a StyleGAN2 variant, renowned for its exceptional ability to generate high-resolution and visually coherent imagery, particularly in artistic contexts. The following subsections present the process in detail.

2.2.1 Style Transfer Model: The neural style transfer part used the VGG-19 convolutional neural network, which has 19 layers and was trained on ImageNet, to extract features. We specifically utilized the Gatys et al. (2016) style transfer approach. Traditional brush strokes, subtle ink gradations, and historically accurate color schemes extracted from original paintings served as the style reference set. Modern urban photographic imagery provided the content reference (See Figure 3). The optimization process reduced a combined loss function that included content loss (the average squared difference on important features from layers like conv4_2) and style loss (the average squared difference on Gram matrices of features from layers like conv1_1, conv2_1, conv3_1, conv4_1, and conv5_1), with weights (like style weight α=1e3 and content weight β=1e0) chosen based on experience for the best visual blend. This process allows the trained network to consistently translate traditional painting aesthetics onto modern city images while preserving visual harmony.

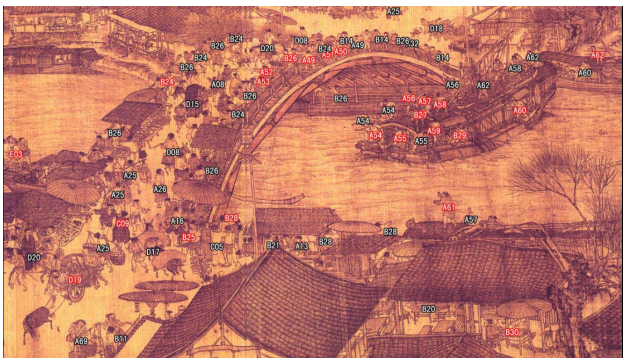


Figure 3. The original painting with reference content.

2.2.2 Deep Learning-based Object Recognition Model: To ensure accurate compositional integration, a state-of-the-art object detection algorithm, YOLOv7 (Wang et al., 2022), was employed. Specifically, we utilized the YOLOv7-W6 architecture. This model was trained on labeled datasets containing diverse modern urban elements such as skyscrapers, contemporary bridges, electric vehicles, and pedestrian figures. Training involved standard YOLOv7 procedures: input resolution of 1280x1280, mosaic augmentation, SGD optimizer with momentum (0.937), weight decay (5e-4), and a learning rate schedule (initial lr=0.01, cosine annealing). Model performance was validated using standard metrics (mAP@0.5). Precise identification and segmentation of these modern elements enabled their seamless merging with the traditional painting context, enhancing the historical-modern fusion. During the training process, hyperparameters were meticulously tuned. The StyleGAN2 model was trained for about 500 cycles on an NVIDIA A100 GPU, starting with adaptive learning rates of 0.0025 that were slowly lowered using an exponential decay method. The combined loss function included adversarial loss, perceptual loss (using pre-trained VGG-19 feature extractors), and style consistency loss to ensure that the generated images looked realistic and consistent.

2.3 Model Creation and Post-processing

Following the initial generation phase, synthesized images underwent rigorous post-processing to refine visual quality and

ensure consistency with traditional aesthetics. The post-processing stage incorporated multiple digital editing tools, including Adobe Photoshop and specialized Python libraries such as OpenCV and PIL, to systematically enhance the final images. The post-processing is presented below in detail.

2.3.1 Color Adjustment: Traditional color tones, particularly the characteristic blue-green (qing-lü) and yellow-ochre hues prevalent in Song dynasty paintings, were accurately reproduced and harmoniously blended with modern architectural elements through digital color grading techniques (See Figure 4 below). Histogram matching and color balance algorithms were systematically applied to maintain historical authenticity and modern relevance.

Figure 4. The reproduced painting elements and characters ©Crystal CG

2.3.2 Securing Structural Consistency: Advanced image blending algorithms, such as Poisson blending and alpha compositing, were applied to ensure structural and spatial coherence. We adjusted the scale and perspective alignment of modern bridges and riverside scenes to naturally integrate them with the traditional spatial composition of the Qingming painting. Additionally, deep-learning-based super-resolution methods (e.g., ESRGAN) were employed to enhance image clarity, particularly around intricate architectural details and human figures.

2.3.3 Detail Enhancement and Validation: Traditional brushstroke textures were selectively reapplied to modern urban components using texture synthesis techniques to minimize visual discrepancies between old and new elements. Additionally, a comprehensive evaluation strategy was implemented. Structured sessions with domain experts (art historians specializing in Song-Ming-Qing dynasties, digital heritage scholars) were conducted. Experts assessed architectural accuracy, clothing authenticity, social context harmony, and overall historical plausibility using standardized evaluation forms and qualitative feedback. The above activities directly addressed uncertainties flagged during critical reconstruction. Structural Similarity Index (SSIM) was used to measure structural fidelity between generated elements and target traditional styles. Besides, Fréchet Inception Distance (FID) was used to assess the realism and quality of the overall generated imagery compared to a reference set of authentic historical paintings and high-quality modern images (See Figure 5).

Figure 5. Synthesized image with new elements added based on the original painting’s elements.

As shown in Figure 6 below, the rigorous and iterative process successfully generated an AI image of the painting that captures the dynamism and vibrancy of contemporary cityscapes while meticulously preserving traditional artistic sensibilities. The methodology transcends mere replication, proposing a novel framework that significantly advances the integration of traditional cultural heritage with modern digital techniques. This process represents a critical contribution toward redefining the scope and potential of digital heritage, demonstrating how generative AI can facilitate innovative, culturally meaningful, and visually compelling reinterpretations of traditional artworks.

Figure 6. AI-generated image of the 21-century reproduced from the original painting ©AIMZ

3. XR multi-participation platform reflecting layers of each period

3.1 XR-Based Multi-User Participation Platform Design

This study explores innovative approaches in digital heritage by developing an AI-driven XR multi-participation platform focused on the traditional panoramic scroll painting, "Along the River during the Qingming Festival." While existing XR applications largely concentrate on architectural monuments and archaeological sites, this study uniquely transforms a significant 2D cultural artifact into an interactive 3D digital environment, significantly enhancing both historical authenticity and contemporary usability. See Figure 7 as an example for this transformation.

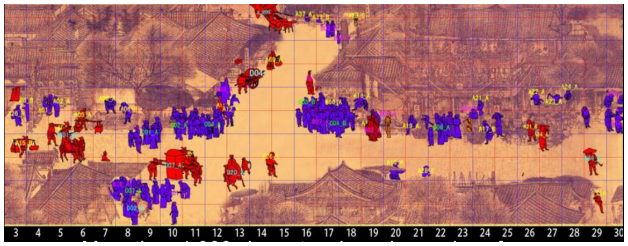


Figure 7. 2D painting transformation into 3D immersive environment

The platform meticulously designs itself to visualize and facilitate interaction with the painting's temporal transformations, representing distinct historical periods (selected and reconstructed using the critical reconstruction paradigm outlined in section 2.1) through layered immersive experiences. The proposed platform incorporates three primary methodological phases to achieve comprehensive digital restoration and effective user interaction. The proposed design of the AI-based XR multi-participation platform facilitates multi-user interaction within a shared virtual environment through the integration of VR, AR, and MR technologies. The platform consists of temporal transition functionality, an AI-powered docent, interactive engagement, avatar-based multi-user access, and real-time scene rendering, creating a unified, immersive experience where users can experience the painting and engage in a dynamic, shared virtual environment. Firstly, we executed extensive digital restoration and layered temporal representation. High-resolution image analysis and advanced 3D modeling techniques were applied to accurately reconstruct versions of the original Northern Song Dynasty painting, its adaptations from the Ming and Qing Dynasties, and a contemporary reinterpretation generated through advanced AI techniques. Architectural features, historical attire, transportation modes, and other intricate cultural elements were rigorously verified and digitally reconstructed to ensure historical accuracy and fidelity. Secondly, the platform's XR-based multi-participation capabilities were developed, supported by cutting-edge technological components detailed below.

3.1.1 Real-time Scene Rendering: Leveraging the high-performance capabilities of Unity 3D and Unreal Engine, the platform delivers seamless and immersive user experiences through virtual reality (VR) head-mounted displays (HMD). Users can freely navigate and interact within high-resolution 3D environments. A study by Fan et al. (2022) on real-time scene rendering in a digital museum context demonstrated that such museums with real-time scene transition can facilitate automatic roaming and independent navigation, with the impact of switching scenery at every time layer offering comprehensive descriptions or multimedia content, delivering an enriched interactive experience for users. They further showed that the museum guide map can facilitate rapid transitions between navigation scenes while an audio guide is provided for each scene. When paired with gyroscope-equipped 3D glasses, it delivers an immersive viewing experience.

3.1.2 Temporal Transition Functionality: Temporal Transition and time-layered environments have been utilized in online virtual museum contexts. Champion et al. (2021) demonstrated that virtual spaces featuring time-based layers can facilitate education and enable users to explore and analyze artistic contexts. They can offer access to art as purchasable commodities, pre-visit experiences, or information regarding the background or evolution of artworks and artifacts. They can additionally superimpose the virtual collection with visualizations of remote visitors and their motivations. A benefit of virtual museums compared to physical counterparts is the ability to rearrange digital artifacts with time-related layers in engaging and informative manners. Nathania and Wahid (2022) examined the narrative environment's context, wherein stories are integrated into space to improve audience engagement. Time in a narrative is conveyed through the narrated time and the actual time perceived by the audience. The two types of time can overlap, regardless of the audience's conscious awareness. A distinctive feature allows users to transition effortlessly between historical layers (Northern Song, Ming, Qing, and contemporary periods) at any given location. This functionality facilitates immediate visual comparisons of historical evolution, significantly enhancing educational value and user understanding.

Temporal transition and real-time scene rendering allow users to traverse historical epochs from the Song Dynasty to the Ming Dynasty and into the modern day through gesture-based scrolling (Brumana et al., 2018; Casanova-Salas et al., 2024). The platform utilizes temporal Transition to enable users to experience and engage with historical, cultural, or evolving virtual spaces across various temporal dimensions, exemplified by the recreation of Kaifeng, transitioning from the Song Dynasty to the Ming Dynasty and ultimately to modern-day reconstructions. Consequently, multiple users may inhabit different time layers while simultaneously observing or interacting within a shared virtual environment (Jung et al., 2022). Hung and Lee (2024) argued that most of the prior research on XR museums has predominantly examined the potential of XR interactions from entertaining and engaging viewpoints, focusing on the effects of XR interactions on visitors' engagement and their social interaction abilities during their visits. Some studies have suggested innovative features to engage visitors, including the ability to enter the paintings or offering multi-modal tactile experiences to enhance user engagement and immersion. They further articulated that this emphasis on entertainment may generate engaging yet less informative environments, which undermines the primary objective of museums. Hung and Lee (2024) looked into how to design XR docents and spatial computing interactions to provide museum visitors with knowledge that is informative, engaging, and empathetic, based on their research findings.

3.1.3 AI-Powered Docent System: We integrated an advanced docent system based on natural language processing (NLP), utilizing state-of-the-art language models like BERT and GPT. This system offers dynamic and contextually relevant explanations of historical backgrounds, individual figures, and architectural specifics, significantly enriching user interaction and educational outcomes. In our proposed platform, the AI-powered docent and interactive features of the platform allow users to explore various scenarios within the paintings, where each user participates through the platform's interactivity (Park et al., 2024). The AI serves as a bridge between time layers, and the AI docent functions as a living guide (Wen and Ma, 2024). Spallone et al. (2023) conducted a study aimed at improving the cultural assets of the Museo d'Arte Orientale (MAO) in Turin via digitization, 3D modeling, and virtual and augmented reality experiences. The objective was to create avatars for museum heritage storytelling that convey the evolutionary process of Buddha iconography in the Mathura region through three statues from the MAO's permanent collection. Utilizing their prototype design, they developed an avatar guide and detailed the tour path in augmented reality (AR). They developed digital storytelling associated with the avatar that can enhance the experience by offering insights into the context, history, and characters pertinent to the works. The proposed multi-participation platform design allocates each user a customizable AI-generated avatar that exhibits realistic gestures and expressions. This avatar simultaneously navigates the historical context and evolution of the painting by period, utilizing its paintings as a collaborative object while offering visual indicators of user focus and interaction within the platform.

3.1.4 Interactive Spatial Exploration: Users navigate historical environments through customized avatars, actively engaging with and obtaining additional information on objects, figures, and architectural structures. The system provides personalized interaction and multimedia information (text, audio, images), enhancing learning effectiveness and user immersion. To preserve and reinterpret the distinctive temporal-spatial narrative technique inherent to traditional handscroll paintings, the XR platform incorporates gesture-based interactive scrolling. This innovative approach enables users to gradually reveal narrative scenes, closely mirroring the original experience of unrolling a scroll. The platform dynamically integrates continuous visual narratives across time, maintaining spatial continuity while allowing temporal exploration.

3.1.5 Multi-User Participation System: The platform supports simultaneous interactions among multiple users via robust Photon-based synchronization technology. The process allows real-time communication, collaborative exploration, and discussion among users, facilitating group education, research, and interactive seminar sessions. User interaction data is systematically gathered for future platform assessment and research development. The platform includes an innovative generative AI content expansion and user-driven creative system. External content creators can easily upload and exhibit AI-generated artworks, using advanced generative models such as StyleGAN2 and Stable Diffusion, directly within the XR environment. These contributions significantly expand the creative and interpretative scope of the platform, encouraging user engagement and content diversity. Additionally, users can independently create and share their personalized interpretations of the painting. This user-generated content feature promotes active participation, fostering a vibrant community of creativity and enhancing cultural heritage through contemporary digital expression.

3.2 Generative AI Content Expansion and Participatory System

Generative artificial intelligence (AI) possesses transformative potential for the preservation and revitalization of cultural heritage assets and employs sophisticated algorithms, including neural networks and diffusion models, to replicate, restore, and enhance cultural artifacts, texts, and historical paintings (Menotti, 2025). Generative AI can digitally restore damaged artifacts, recreate lost elements, and facilitate immersive experiences for education and tourism by synthesizing data from various sources, including photographs, manuscripts, audio recordings, and 3D scans that can be called generative AI content (See Figure 8). The uses of generative AI content include rebuilding ancient sites online, fixing old manuscripts, and making lifelike images of cultural heritage in its historical setting. Furthermore, AI-driven tools promote the democratization of cultural heritage by rendering it accessible to worldwide audiences via virtual and augmented reality platforms (Magdalena, 2023).

Figure 8. A video transformed into 3D using Generative AI based on the original paintings.

The proposed platform design employs a multi-layered content delivery mechanism for generative AI to enhance interactivity, user engagement, and participation. The platform integrating VR, AR, and MR facilitates immersive, interactive, and collaborative experiences for cultural heritage artifacts, while generative AI can enhance these environments with dynamic, adaptive, and user-driven content provided in real time (Pinto et al., 2024). In the content delivery mechanism, AI creates persistent 3D environments that adapt according to user interactions, which encompass real-time AI-generated text, 3D models, voice recognition, virtual environments, multi-user synchronization through shared persistent virtual worlds, context-aware personalization reflecting user behavior and environment, and interoperability between VR headsets and AR glasses (Petrović, 2018; Soliman et al., 2024). Furthermore, AI produces dynamic 3D environments informed by user input or narrative guidelines; it generates avatars, objects, textures, and sounds instantaneously, allowing users to collaboratively produce and modify AI-generated content (Chamola et al, 2024). The platform converts the static paintings into a collaborative time machine, utilizing generative AI as both a preservation tool and a creative catalyst, while XR technologies facilitate an immersive exploration of *"Along the River during the Qingming Festival"* through its paintings and historical evolution.

4. Conclusions and Future Prospects

This study explored innovative possibilities in digital heritage by developing an AI-driven XR platform based on the

traditional painting. Using advanced generative AI and XR technologies, the platform transforms the historically significant 2D artwork into an interactive, immersive 3D experience, combining historical authenticity and contemporary engagement. The platform incorporates multiple temporal layers, meticulously reconstructing periods from the Northern Song, Ming, and Qing dynasties and integrating a modern reinterpretation via AI models. Each period maintains rigorous historical accuracy through detailed architectural, social, and cultural representations. Real-time XR rendering, smooth temporal transitions, and AI-powered docent systems enrich user interactions, offering relevant historical context. The platform is designed for multi-user collaboration; it supports simultaneous exploration, discussion, and educational activities through synchronization technologies. External creators and users can contribute original content via generative AI, enhancing creative and educational value. This participatory approach fosters an ongoing dynamic and collaborative community.

The study demonstrates how the integration of traditional heritage with cutting-edge technologies can expand access and engagement, offering practical solutions for cultural heritage conservation and appreciation. The platform uses GANs, natural language processing, and interactive chatbots to enhance user interaction and historical understanding, enabling users to inquire directly with historical characters depicted in the artwork. In addition, machine learning and crowdsourcing clarify ambiguous details, revealing new academic insights. AI-assisted pattern recognition identifies recurring motifs, aiding comparative analyses. Generative AI reconstructs missing artwork sections using historical data, and VR allows users to explore historically accurate scenes of Song Dynasty Kaifeng populated by AI-generated characters. Cultural authenticity and historical accuracy will be validated through expert reviews and user testing to ensure digital experiences align with historical contexts. Integrating digital humans, such as AI-driven interactive avatars, enables real-time dialogues with historical characters, enhancing cultural immersion and cognitive engagement. For example, a merchant avatar dynamically answers historical queries, creating an active cultural dialogue (See Figure 9).

Figure 9. Example of a new digital cultural artefacts experience

AI-driven multi-user participatory experiences revolutionize static artworks, transforming them into dynamic, collaborative environments. Despite accuracy and ethical challenges, this approach democratizes cultural participation. Future research will focus on technological refinement, evaluate user experience comprehensively, and assess the platform's practical application across educational and cultural institutions, ensuring ongoing relevance and effectiveness.

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