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Promotion of Preservation and Inheritance of Shanxi Pu Opera through Participatory Digital Platforms

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Abstract

Background and Aims: Shanxi Pu Opera, one of the oldest forms of traditional Chinese opera, is facing significant challenges in preservation and transmission due to globalization, modernization, and generational cultural gaps. This study aims to explore how participatory digital platforms can be utilized to support the sustainable preservation and cultural transmission of Shanxi Pu Opera. The research investigates user engagement patterns, platform component effectiveness, and technological contributions toward cultural heritage preservation.

Methodology: A quantitative survey was conducted with 200 participants who use or are familiar with digital platforms related to traditional culture. The research instrument was a structured questionnaire, tested for reliability and validity (Cronbach's Alpha = 0.950, KMO = 0.955). Descriptive statistics, Pearson correlation analysis, and a Multi-Layer Perceptron Neural Network (MLPNN) model were used to analyze the data and

assess relationships among platform features and perceived effectiveness in cultural preservation.

Results: The results indicate that key platform components including user interface and experience, content management, and technical architecture are significantly correlated with user engagement and perceived effectiveness. The MLPNN model demonstrated strong predictive performance, with AUC values ranging from 0.603 to 0.915. The most influential factors identified were technical scalability, content auditing, and user-centric design.

Conclusion: Participatory digital platforms show great potential in revitalizing traditional cultural practices such as Shanxi Pu Opera by attracting diverse users and enhancing cultural transmission. To strengthen cultural preservation efforts, future platform development should prioritize interactive features, content accuracy, and inclusive design. This study contributes valuable insights for digital heritage preservation and sets the groundwork for future interdisciplinary research in culture and technology.

Keyword: Shanxi Pu Opera; participatory digital platforms; cultural preservation; user engagement; neural network analysis; intangible cultural heritage

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การส่งเสริมการอนุรักษ์และสืบทอดงิ้วภูโวแห่งมณฑลซานซี ผ่านแพลตฟอร์มดิจิทัลแบบมีส่วนร่วม

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บทคัดย่อ

ภูมิหลังและวัตถุประสงค์: งิ้วภูโว (Shanxi Pu Opera) ถือเป็นหนึ่งในรูปแบบงิ้วจีนดั้งเดิมที่เก่าแก่ที่สุด ซึ่งปัจจุบันกำลังเผชิญกับความท้าทายอย่างมากในการอนุรักษ์และถ่ายทอด เนื่องจากอิทธิพลของ โลกาภิวัตน์ ความทันสมัย และช่องว่างระหว่างรุ่น งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาการใช้ประโยชน์จากแพลตฟอร์มดิจิทัลแบบมีส่วนร่วมในการสนับสนุนการอนุรักษ์และถ่ายทอดวัฒนธรรมของงิ้วภูโวอย่างยั่งยืน โดยมุ่งวิเคราะห์รูปแบบการมีส่วนร่วมของผู้ใช้ ประสิทธิภาพขององค์ประกอบภายในแพลตฟอร์ม และบทบาทของเทคโนโลยีในการส่งเสริมการอนุรักษ์มรดกทางวัฒนธรรม

ระเบียบวิธีการวิจัย: ใช้วิธีการวิจัยเชิงปริมาณ โดยเก็บข้อมูลจากกลุ่มตัวอย่างจำนวน 200 คน ที่ใช้หรือมีความคุ้นเคยกับแพลตฟอร์มดิจิทัลที่เกี่ยวข้องกับวัฒนธรรมดั้งเดิม เครื่องมือวิจัยเป็นแบบสอบถามโครงสร้าง ซึ่งผ่านการทดสอบความเชื่อมั่นและความเที่ยงตรง (ค่าความเชื่อมั่น Cronbach's Alpha = 0.950, ค่าความเหมาะสม KMO = 0.955) วิเคราะห์ข้อมูลโดยใช้สถิติเชิงพรรณนา การวิเคราะห์สหสัมพันธ์แบบเพียร์สัน และแบบจำลองโครงข่ายประสาทเทียมแบบหลายชั้น (MLPNN)

ผลการวิจัย: ผลการวิจัยพบว่า องค์ประกอบหลักของแพลตฟอร์ม ได้แก่ การออกแบบส่วนติดต่อผู้ใช้และประสบการณ์ผู้ใช้ การจัดการเนื้อหา และโครงสร้างเทคนิคของระบบ มีความสัมพันธ์อย่างมีนัยสำคัญกับการมีส่วนร่วมของผู้ใช้และการรับรู้ถึงประสิทธิภาพของแพลตฟอร์มในการอนุรักษ์วัฒนธรรม แบบจำลอง MLPNN แสดงผลการทำนายที่ดี โดยมีค่า AUC อยู่ในช่วง 0.603 ถึง 0.915 โดยตัว

แปรที่มีอิทธิพลสูงสุดคือ ความสามารถในการขยายตัวของระบบ การตรวจสอบและควบคุมเนื้อหา และการออกแบบที่เน้นผู้ใช้เป็นศูนย์กลาง

สรุปผล: แพลตฟอร์มดิจิทัลแบบมีส่วนร่วมมีศักยภาพสูงในการฟื้นฟูและส่งเสริมการอนุรักษ์มรดกทางวัฒนธรรมดั้งเดิม เช่น งิ้วภูโว โดยสามารถดึงดูดผู้ใช้จากหลากหลายกลุ่ม และเสริมสร้างการมีส่วนร่วมในการถ่ายทอดวัฒนธรรมอย่างมีประสิทธิภาพ การพัฒนาแพลตฟอร์มในอนาคตควรให้ความสำคัญกับฟีเจอร์แบบโต้ตอบ ความถูกต้องของเนื้อหา และการออกแบบที่ครอบคลุมทุกกลุ่มผู้ใช้ งานวิจัยนี้ให้ข้อมูลเชิงลึกที่มีคุณค่าในด้านการอนุรักษ์วัฒนธรรมผ่านสื่อดิจิทัล และเป็นแนวทางสำหรับการวิจัยสหวิทยาการในอนาคตระหว่างวัฒนธรรมและเทคโนโลยี

คำสำคัญ : งิ้วพู่ซานซี, แพลตฟอร์มดิจิทัลแบบมีส่วนร่วม, การอนุรักษ์วัฒนธรรม, การมีส่วนร่วมของผู้ใช้, การวิเคราะห์โครงข่ายประสาทเทียม, มรดกทางวัฒนธรรมที่จับต้องไม่ได้

Introduction

Traditional Chinese opera, an intricate synthesis of music, literature, performance, and visual art, stands as one of the most culturally rich and symbolically complex elements of China's intangible heritage. Among its many regional forms, Shanxi Pu Opera holds a distinct position as the earliest of the four major Bangzi operas. Originating during the late Ming to early Qing dynasty in Yuncheng, it has endured for over four centuries. It is characterized by sharp tonal transitions, historically grounded storylines, and unique vocal and movement techniques. However, like many traditional art forms globally, Shanxi Pu Opera faces significant threats in the modern era. The decline in live audience numbers, the aging performer base, and the fragmentation of cultural transmission due to generational shifts reflect the broader crisis confronting intangible heritage in the 21st century (Bai & Jimenez, 2023; Pang et al., 2024).

Modernization and globalization have accelerated the erosion of traditional cultural expressions. The dominance of digital entertainment, the urban-rural divide in cultural accessibility, and the fast pace of contemporary life have all contributed to the diminishing prominence of Pu Opera. In addition, the lack of institutional infrastructure and educational initiatives to promote heritage awareness among youth further compounds the issue. The urgency to preserve this endangered art form calls for innovative strategies that are not merely archival but participatory, engaging, and

adaptive to the lifestyles and expectations of contemporary audiences particularly the younger generations (Zhang & Sornyai, 2025).

In response, participatory digital platforms have emerged as a powerful and inclusive avenue for cultural preservation. These platforms are not passive repositories of information, but dynamic environments where users can interact, co-create, and contribute to the circulation of cultural knowledge. Building upon the theoretical foundations of Participatory Culture Theory (Jenkins, 2006), User Engagement Theory (O'Brien & Toms, 2008), and Digital Commons Theory (Ostrom, 1990; Benkler, 2006), participatory digital platforms facilitate storytelling, education, and collaborative curation. Their affordances such as user-generated content, feedback loops, and real-time interaction have the potential to transform heritage from static tradition into a living digital ecosystem (Lan, 2021; Li, 2024; Yang, 2025). These platforms are particularly promising in culturally rich yet at-risk domains like traditional opera, where emotional resonance, visual immersion, and narrative depth are central to user engagement.

Despite their potential, there remains a substantial research gap at the intersection of participatory digital platform design, machine learning-based predictive analytics, and the specific context of intangible cultural heritage (ICH) preservation, especially in non-Western settings (Giaccardi, 2012; Smith & Akagawa, 2009). While previous research has explored digital museum interfaces, online archives, and virtual performance environments (Parry, 2007; Bruton, 2011; Todorova-Ekmekci, 2021), few studies have examined how core components of digital platforms UI/UX, technical scalability, content governance, and community management directly influence cultural transmission outcomes (Holdgaard & Klastrup, 2014). Moreover, the application of neural network modeling to assess these interactions remains underutilized in heritage contexts (Huang & Song, 2022). This lack of empirical investigation limits our ability to formulate design principles and engagement strategies that are both data-informed and culturally sensitive.

Therefore, this study seeks to fill that gap by systematically analyzing how participatory digital platforms can support the sustainable preservation and dissemination of Shanxi Pu Opera. It incorporates both traditional statistical methods and Multi-Layer Perceptron Neural Network (MLPNN) modeling to uncover both linear

and nonlinear relationships between platform components and perceived effectiveness. Drawing from diverse theories and supported by robust empirical data, this research contributes to the growing body of knowledge in digital heritage studies, platform management, and cultural technology design. Ultimately, it provides actionable insights for developers, cultural institutions, and policymakers striving to revitalize heritage in the digital age.

Objectives

1. To investigate the key challenges hindering the preservation and cultural transmission of Shanxi Pu Opera in the context of globalization, digital transformation, and generational disconnect.

2. To identify and analyze the core components of participatory digital platforms including user interface and experience (UI/UX), content management and auditing, technical scalability, and community governance and assess their roles in fostering user engagement and cultural retention.

3. To evaluate the effectiveness of participatory digital platforms in enhancing user engagement and cultural sustainability, with special attention to the influence of digital co-creation, feedback loops, and interaction mechanisms across different user demographics.

4. To apply machine learning techniques (Multi-Layer Perceptron Neural Network) to predict the contribution of platform features to perceived cultural preservation outcomes and to identify the most influential digital attributes.

Hypotheses

1. There is a statistically significant positive relationship between user interface and user experience (UI/UX) design and user engagement in participatory digital platforms related to Shanxi Pu Opera preservation.

This hypothesis is based on Human-Computer Interaction theory (Norman, 2013), which emphasizes the role of interface clarity, usability, and emotional design in shaping user participation.

2. Content management and community governance features are positively correlated with the effectiveness of cultural transmission via participatory digital platforms.

This draws on Digital Commons Theory (Ostrom, 1990; Benkler, 2006), which argues that collectively managed knowledge systems enhance content authenticity and engagement.

3. Technical architecture and platform scalability significantly influence user satisfaction and perceived effectiveness in digital heritage preservation.

Grounded in Platform Theory (Gawer, 2014), this hypothesis posits that flexible and scalable infrastructure supports sustained participation and performance across diverse user bases.

Literature Review

1. Participatory Culture and Digital Platforms

Participatory culture, as theorized by Jenkins (2006), redefines cultural consumption into an interactive and collaborative process. Instead of being passive recipients, users become active contributors creating, remixing, and circulating content. This framework has been applied widely in digital heritage contexts, where communities co-create narratives and perform collective memory (Carpentier, 2011). Participatory digital platforms are thus seen as enablers of cultural democratization, fostering inclusion and continuous engagement.

In the context of cultural heritage, these platforms allow for storytelling, documentation, and feedback loops that empower users as both learners and co-curators (Palfrey & Gasser, 2011). They support dynamic knowledge flows, aligning with emerging paradigms in cultural co-creation and digital citizenship.

2. Cultural Heritage and the Digital Turn

The digitalization of heritage has become a global movement, supported by UNESCO and cultural institutions worldwide. Digital heritage platforms enable preservation beyond physical boundaries through archiving, 3D reconstruction, and interactive environments (Giaccardi, 2012). However, scholars caution that digital

preservation must go beyond mere documentation it must foster engagement, interpretation, and transmission (Smith, 2006).

Recent research shows that participatory features like community voting, live annotation, or immersive interaction enhance public interest in traditional arts (Koukopoulos & Koukopoulos, 2018; Lan, 2021). However, challenges remain in ensuring content accuracy, long-term access, and equitable participation.

3. User Engagement in Digital Cultural Contexts

User engagement refers to the emotional, cognitive, and behavioral involvement of users with digital platforms. O'Brien and Toms (2008) propose a multi-dimensional model that emphasizes aesthetic appeal, usability, and affective response as critical to sustained digital interaction. In heritage contexts, interface design, personalization, and narrative clarity are crucial for capturing diverse audiences especially younger users unfamiliar with traditional content (Zhou et al., 2025).

Furthermore, digital storytelling methods have been shown to enhance learning and retention by embedding culture into relatable and interactive formats. Tools like recommendation engines, gamified features, and feedback loops encourage revisits and participation (Dragoni et al., 2017).

4. Governance, Community, and the Digital Commons

Community governance is a vital component of participatory platforms. Drawing from Digital Commons Theory (Ostrom, 1990; Benkler, 2006), platforms must balance openness with rules that maintain content quality and authenticity. Successful cultural platforms rely on moderation systems, user rating mechanisms, and transparent content policies to prevent misinformation and promote trust.

These governance strategies are essential in heritage contexts where the authenticity of cultural expression is critical. Without thoughtful moderation, digital heritage risks distortion, misrepresentation, or trivialization.

5. Platform Architecture and Scalability

Scalability refers to a platform's ability to grow and accommodate increasing user activity without performance degradation. According to Platform Theory (Gawer, 2014), robust technical architecture including modularity, cloud support, and responsive

design is foundational to sustaining long-term engagement. In cultural platforms, infrastructure must support multimedia storage, user uploads, and real-time interaction.

Studies show that technical breakdowns, lags, or interface bugs significantly reduce user trust and retention making reliable technical design a core factor in cultural preservation through digital means (Tiwana, 2013; Tsipi et al., 2023).

6. Gaps in the Existing Literature

While previous studies have explored aspects of participatory culture, heritage digitalization, and platform design, few have investigated how specific platform components contribute to the preservation of traditional operatic forms like Shanxi Pu Opera. Even fewer studies use machine learning approaches, such as neural networks, to identify predictive relationships among these variables.

There is also a lack of research situated in non-Western contexts, particularly within localized Chinese cultural ecosystems. This study addresses these gaps by combining quantitative analysis with MLPNN modeling to examine how UI/UX, content governance, scalability, and user behavior contribute to sustainable cultural transmission.

Conceptual Framework

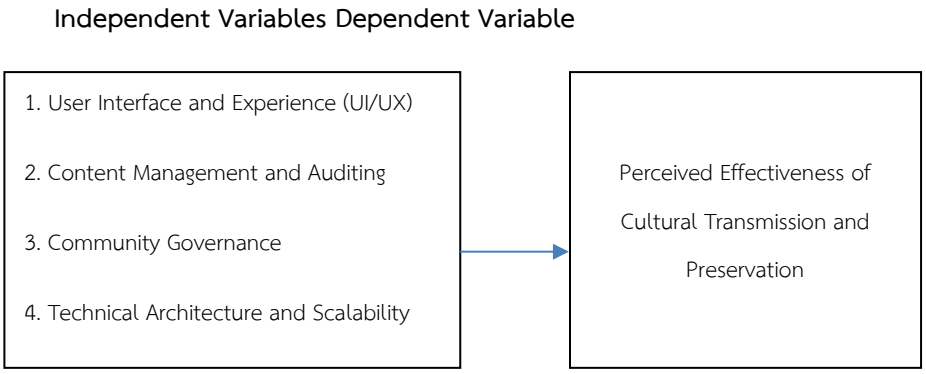


Figure 1. Conceptual Framework

This study is guided by a conceptual framework that integrates theoretical insights from Participatory Culture Theory (Jenkins, 2006), User Engagement Theory (O'Brien & Toms, 2008), Platform Theory (Gawer, 2014), and Digital Commons Theory (Ostrom, 1990). It hypothesizes that the effectiveness of cultural preservation through participatory digital platforms is shaped by both the structural design of the platform and the interactive experiences it enables.

The framework identifies six core components of digital platforms as independent variables: User Interface and Experience (UI/UX), Content Management and Auditing, Community Governance, Technical Architecture and Scalability, Data Analytics and Intelligent Recommendation, Compliance and Social Responsibility

These components collectively influence the platform's ability to foster User Engagement, a mediating variable that reflects users' cognitive, emotional, and behavioral involvement. User engagement, in turn, is posited to have a direct impact on the dependent variable the Perceived Effectiveness of Cultural Transmission and Preservation of Shanxi Pu Opera.

The framework also supports the analytical strategy employed in this study, which uses both traditional statistical tools (e.g., Pearson correlation) and a Multi-Layer Perceptron Neural Network (MLPNN) to explore both linear and nonlinear interactions between variables. This approach allows for a nuanced understanding of how specific platform features contribute to cultural outcomes.

Research Methodology

Research Design

This study adopted a quantitative research design using a structured questionnaire-based survey to examine user perceptions, engagement patterns, and the effectiveness of participatory digital platforms in preserving Shanxi Pu Opera. Quantitative methods were selected due to their capacity to systematically capture measurable relationships among platform components, user engagement factors, and cultural outcomes. Prior research on participatory systems (Kaplan & Haenlein, 2010) supports the use of structured quantitative instruments to analyze user interaction and satisfaction within digital platforms.

To complement traditional statistical analysis, this study also implemented a Multi-Layer Perceptron Neural Network (MLPNN) model to identify nonlinear relationships and uncover hidden patterns in the data, thereby enhancing predictive accuracy and offering practical insights for platform design optimization.

Population and Sample

The target population consisted of digital platform users in China with varying degrees of familiarity with traditional Chinese culture and opera. A purposive sampling technique was used to select participants who met the following criteria:

(1) Aged 18 and above

(2) Had prior experience using at least one participatory digital platform (e.g., WeChat, Douyin, Bilibili, or digital museum apps)

(3) Expressed interest in Chinese opera or cultural heritage topics

(4) Represented diverse demographic backgrounds (age, gender, education, location)

A total of 200 valid responses were collected. This sample was statistically adequate for neural network modeling and factor analysis. The dataset was randomly divided into two subsets: 72.1% for model training (n = 142) and 27.9% for testing (n = 55).

Ethical Considerations

Participation in the study was voluntary and anonymous. Informed consent was obtained from all respondents prior to participation. No personally identifiable information was collected. The study design and ethical procedures were reviewed and approved by the research committee of Mahasarakham University's Faculty of Informatics.

Research Instruments

The primary research instrument employed in this study was a structured questionnaire, developed based on an extensive review of the literature and refined with expert feedback from specialists in digital media and cultural studies. The questionnaire was designed to measure user demographics, digital platform usage behaviors, perceptions of platform components, and the perceived effectiveness of

digital tools in the preservation of Shanxi Pu Opera. The instrument consisted of four main sections:

1. Demographic Information including age, gender, and the level of familiarity with Shanxi Pu Opera.

2. Platform Usage Patterns capturing information about the types of participatory digital platforms used by respondents (e.g., WeChat, Douyin, Bilibili, digital museums), their frequency of use, and perceived functions in supporting cultural preservation.

3. Evaluation of Platform Components measuring key elements such as: User Interface and User Experience, User Engagement, Content Management and Auditing, Data Analytics and Intelligent Recommendation, Community Management and Governance, Technical Architecture and Scalability, Compliance and Social Responsibility

Each item was rated using a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree).

4. Perceived Effectiveness of the Platform evaluating respondents' perceptions regarding the platform's role and success in facilitating the preservation and intergenerational transmission of Shanxi Pu Opera.

Reliability and Validity

Internal consistency reliability was assessed using Cronbach's Alpha, which produced a coefficient of 0.950, indicating excellent reliability across the instrument. These results meet the threshold standards outlined by Murtagh & Heck (2012) and reflect high instrument robustness. The theoretical framework for item development was informed by the Technology Acceptance Model (TAM) and UTAUT, both widely used to model user perceptions and behavior in digital system adoption contexts.

Data Analysis

The data collected in this study were analyzed using both descriptive and inferential statistics to address the research objectives and test the proposed hypotheses. The following statistical techniques were employed:

1. Descriptive statistics were used to summarize demographic data and user perceptions.

2. Pearson correlation analysis examined the relationships among platform features and perceived effectiveness.

3. A Multi-Layer Perceptron Neural Network (MLPNN) was developed to predict perceived platform performance. The network employed a hyperbolic tangent activation function in the hidden layer and SoftMax in the output layer.

4. Model performance was evaluated using Receiver Operating Characteristic (ROC) analysis. An important plot was also generated to assess the relative weight of each input feature in predicting outcomes.

Results

This section presents the findings from the quantitative analysis of 200 valid responses. The results are organized in alignment with the study's objectives, encompassing user demographics, platform engagement, correlation analysis, and predictive modeling using a Multi-Layer Perceptron Neural Network (MLPNN).

1. User Demographics and Platform Engagement

Age Distribution

The majority of respondents fell into the 19–30 age group (39%), followed by the 31–45 group (31%). This indicates a predominantly young to middle-aged user base, reflecting digital fluency and potential for cultural transmission among these cohorts.

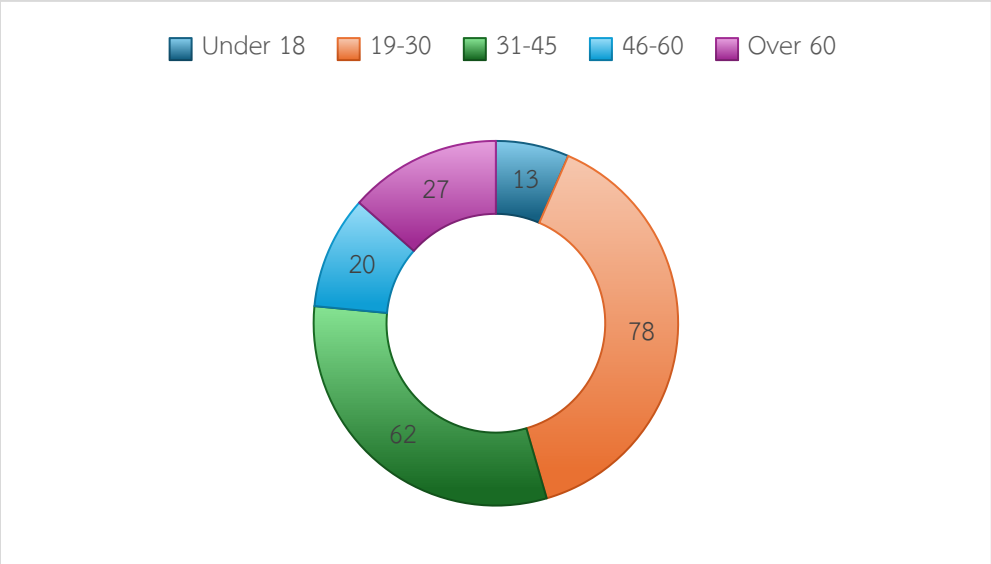


Figure 2. Age Distribution Chart

2. Gender Distribution

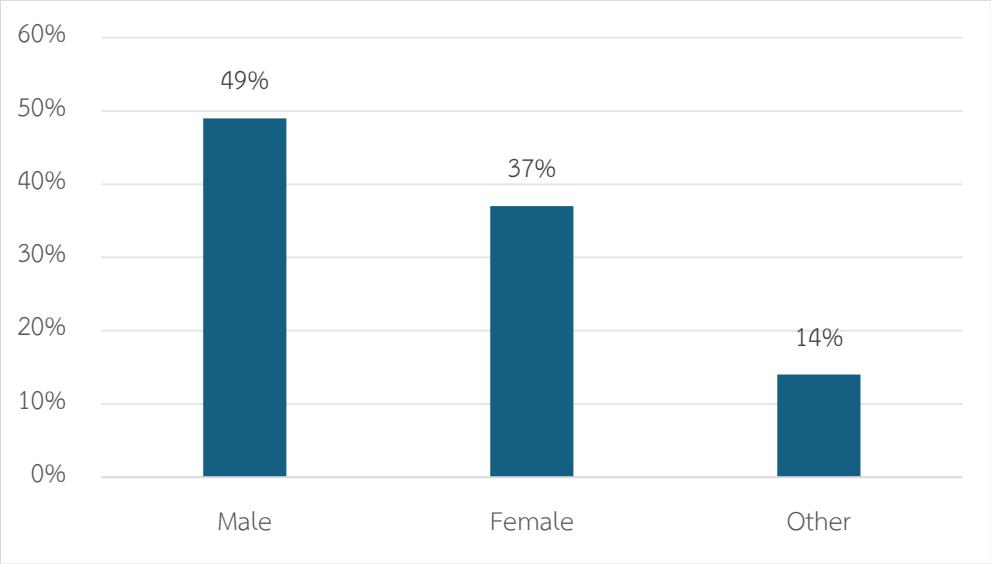


Figure 3. Gender Distribution

Figure 3 presents the gender distribution of the respondents. Respondents identified as male (49%), female (37%), and other gender identities (14%). This diversity

suggests that participatory digital platforms are inclusive tools capable of engaging a broad spectrum of users across identity groups.

3. Knowledge Level of Shanxi Pu Opera

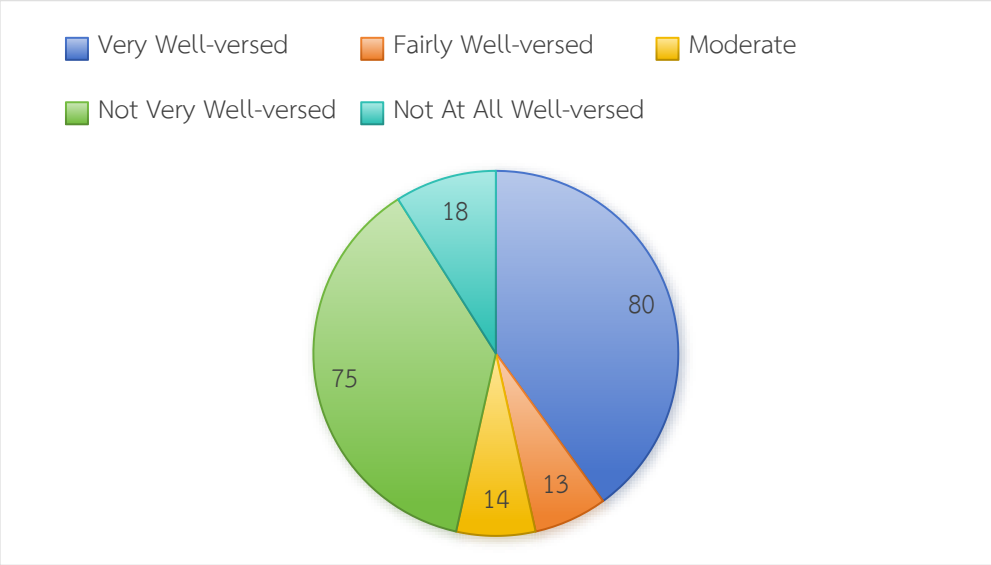


Figure 4. Knowledge Level of Shanxi Pu Opera

Figure 4 depicts the level of knowledge and familiarity that respondents have with Shanxi Pu Opera. While 40% of respondents reported being “very familiar” with Shanxi Pu Opera, 37.5% had limited knowledge, and 6.5% were relatively familiar. This indicates a mixed awareness level, highlighting the opportunity for digital platforms to serve as educational and engagement tools for broader public audiences.

2. Reliability and Validity Analysis

To ensure the quality and consistency of the data collection instrument, reliability and validity testing was conducted on the questionnaire used in this study.

Table 1. Reliability Statistics

Cronbach’s Alpha	Number of items
.950	20

Table 1 shows a Cronbach's Alpha of 0.950 for the instrument, confirming excellent internal consistency. Kaiser-Meyer-Olkin (KMO) = 0.955, and Bartlett's Test of Sphericity ($p < 0.001$) further validate the data's suitability for multivariate analysis.

Table 2. KMO and Bartlett's Test of Sphericity

Measure	Value
KMO Sampling Adequacy	.955
Approximate Chi-Square (Bartlett's)	3083.872
Degrees of Freedom	406
Significance (p-value)	< 0.001

Table 2 presents the results of the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity. The KMO value of 0.955 indicates that the sampling is highly adequate for factor analysis. Additionally, the significant p-value (< 0.001) from Bartlett's test confirms that the correlation matrix is not an identity matrix, indicating that the variables are sufficiently interrelated to proceed with further multivariate analysis.

Together, these results confirm the questionnaire's strong validity and reliability, supporting the robustness of subsequent statistical analyses.

3. Correlation Analysis

The Pearson correlation analysis examined relationships between platform components and perceived cultural preservation effectiveness.

Table 3. Pearson Correlation Between Platform Components and Perceived Effectiveness.

Platform Component	Pearson Correlation (r)	Significance (p-value)
User Interface and User Experience	0.261**	0.000

User Engagement	0.265**	0.000
Content Management and Auditing	0.305**	0.000
Data Analytics and Intelligent Recommendation	0.262**	0.000
Community Management and Governance	0.296**	0.000
Technical Architecture and Scalability	0.290**	0.000
Compliance and Social Responsibility	0.204**	0.004

$p < 0.01$ indicates statistical significance

The results in Table 3 demonstrate that all examined components of participatory digital platforms are positively and significantly correlated with the perceived effectiveness of the platform in preserving and transmitting Shanxi Pu Opera. Among them, Content Management and Auditing showed the highest correlation ($r = 0.305$), followed by Community Management and Governance ($r = 0.296$) and Technical Architecture and Scalability ($r = 0.290$). While Compliance and Social Responsibility exhibited a relatively lower correlation ($r = 0.204$), it still reached statistical significance ($p < 0.01$), suggesting that even legal and ethical dimensions play a role in influencing user perceptions of the platform's effectiveness. These findings suggest that improvements across these platform components can significantly enhance user engagement and support the effective transmission of Shanxi Pu Opera.

4. Predictive Modeling with MLPNN

To uncover deeper, non-linear relationships among variables, a Multi-Layer Perceptron Neural Network (MLPNN) model was implemented. Model Configuration Training Sample: 72.1% (n = 142), Testing Sample: 27.9% (n = 55) and Activation Functions: Hyperbolic tangent (hidden layer), Softmax (output layer).

Table 4. Case Processing Summary

	N	Percent

Sample	Training	142	72.1%
	Testing	55	27.9%
Valid		197	100.0%
Excluded		3	
Total		200	

As shown in the network summary, the dataset included a total of 200 valid cases, with 142 cases (72.1%) used for training and 55 cases (27.9%) used for testing.

The network structure includes an input layer with 7 nodes representing user interface, user engagement, content management, data analytics, community management, technical architecture, compliance, and social responsibility. The hidden layer consists of one unit and uses the hyperbolic tangent activation function, and an output layer with 5 nodes for platform performance classification using the SoftMax activation function and cross-entropy function as error metric.

5. Model Performance (ROC Analysis)

To evaluate the effectiveness of the model, Receiver Operating Characteristic (ROC) curve analysis was performed. The Area Under the Curve (AUC) values for the five output categories range from 0.603 to 0.915, indicating acceptable to excellent predictive accuracy across the different levels of perceived platform performance.

Table 5. AUC Scores for Predicted Outcomes

Output Category	AUC Value
Category 1	0.603
Category 2	0.707
Category 3	0.704
Category 4	0.915
Category 5	0.700

The highest AUC score of 0.915 demonstrates excellent model performance in predicting user-perceived platform effectiveness, especially for highly engaged user categories.

6. Variable Importance Plot

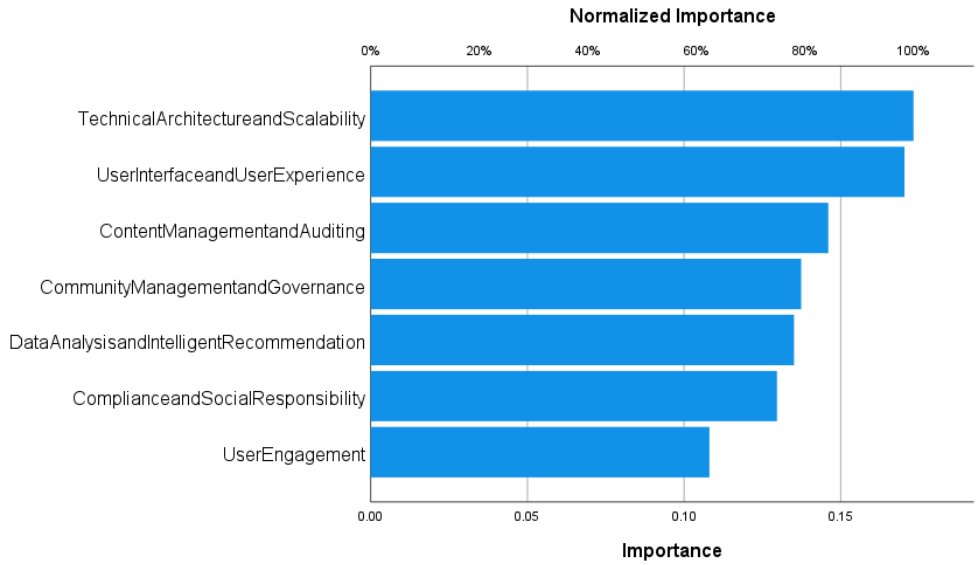


Figure 5. Importance Plot of Independent Variables

The model identified Technical Architecture and Scalability, UI/UX, and Content Management as the most influential predictors of platform success. These findings confirm that both technical infrastructure and user-centric design are essential for the effective digital preservation of cultural heritage like Shanxi Pu Opera.

Discussion

This section interprets the empirical findings in light of the study's objectives, theoretical underpinnings, and the broader literature on digital heritage, platform design, and participatory culture.

1. Addressing the Challenges of Preserving Shanxi Pu Opera

The first objective of this study was to examine the critical challenges facing the preservation and cultural transmission of Shanxi Pu Opera. The demographic analysis showed that young to middle-aged adults (aged 19–45) are the primary users of

participatory platforms. This is a promising indicator, as these age groups are often more technologically engaged and socially networked, suggesting they can play a central role in heritage revitalization.

However, the finding that over one-third of respondents have limited familiarity with Shanxi Pu Opera reinforces concerns raised by earlier studies (e.g., Han, 2024; Wu, 2021) about declining cultural literacy and the marginalization of traditional arts in the digital era. This highlights the dual challenge of not only preserving content but also making it relevant and accessible to a new generation.

Drawing on Cultural Capital Theory (Bourdieu, 2018), we can interpret this knowledge gap as a reflection of uneven exposure to cultural education and resources. Participatory platforms thus hold potential as decentralized learning environments, where users engage in informal education and experiential learning about traditional forms such as Pu Opera.

2. Platform Components That Drive Preservation Effectiveness

The second objective focused on identifying the platform features most valued by users in the context of cultural preservation. Both correlation and MLPNN analyses highlighted content management, UI/UX, and technical scalability as the most influential factors. This aligns closely with research by Dragoni et al. (2017) and Koukopoulos & Koukopoulos (2018), who emphasized that intuitive interfaces and reliable infrastructures significantly enhance user satisfaction and retention.

Importantly, the high correlation between content management and perceived effectiveness suggests that users prioritize authentic, curated, and regularly updated content. In participatory platforms, this is particularly critical to prevent the dilution or distortion of intangible heritage. Theoretical support for this can be found in Digital Commons Theory (Ostrom, 1990; Benkler, 2006), which emphasizes the role of governance and shared rules in managing cultural resources.

The significance of community governance also reinforces this point. Platforms that include moderation tools, comment regulation, and user-rating systems help foster trust and cultural authenticity, two critical pillars of sustainable heritage platforms.

3. The Role of User Engagement as a Mediator

The third objective of the study was to assess how digital platform components affect user engagement and, in turn, cultural transmission outcomes. The User Engagement Theory (O'Brien & Toms, 2008) served as the theoretical foundation for understanding these dynamics. The findings show that user engagement plays a critical mediating role, influencing whether users remain active participants in cultural exchange or become passive observers.

Engagement in this context goes beyond time spent on the platform. It includes emotional connection, identity alignment, and participatory behaviors such as commenting, sharing, and co-creating content. This supports Jenkins's (2006) notion of participatory culture, in which platforms act as arenas of cultural co-creation rather than mere dissemination.

Moreover, findings from the MLPNN importance plot confirm that UI/UX and interactive features are not just aesthetic concerns but core drivers of sustained user behavior. This highlights the importance of designing for emotion and usability concepts central to Human-Computer Interaction theory (Norman, 2013).

4. Interpreting MLPNN Model Insights

The MLPNN analysis added a deeper, more predictive layer to this research. The model's high AUC scores, particularly 0.915 for one of the user segments, suggest excellent performance in forecasting users' perceived platform effectiveness. This indicates that machine learning models can uncover non-linear, multivariate relationships not easily captured by traditional statistics.

For example, the combination of technical scalability + UI/UX + content auditing emerged as a synergistic triad. This finding implies that platform developers should not view features in isolation; instead, the interaction among features is what ultimately drives cultural impact. This supports findings in platform studies (Tiwana, 2013; Lasorella et al., 2024) that call for holistic system design in digital engagement environments.

The MLPNN model also provides practical value by helping platform managers prioritize resource allocation. By identifying which features most heavily influence user

engagement and perception, developers can strategically invest in improvements that maximize cultural impact and retention.

5. Alignment and Contribution to Existing Literature

Overall, this study extends prior work on digital heritage in several keyways:

5.1 While many previous studies focused on documentation and digital archiving, this research emphasizes participatory engagement, user co-creation, and adaptive platform design.

5.2 The integration of machine learning into cultural heritage research is still novel. This study shows how predictive models like MLPNN can offer new insights for design decision-making.

5.3 The conceptual framework developed here synthesizes theories from cultural studies, platform theory, and digital interaction offering a more interdisciplinary and data-driven lens.

This aligns with the emerging body of work that treats digital heritage platforms as ecosystems not only of preservation but also of cultural negotiation, reinvention, and identity expression. (Smith, 2006; Jenkins, 2009; Nieborg & Poell, 2018).

6. Unexpected Findings and Critical Reflections

One of the more unexpected findings was the relatively low correlation between Compliance and Social Responsibility and user engagement. This may suggest that users assume ethical standards are “baked into” digital platforms and do not actively assess or value them unless breaches occur. Alternatively, this could reflect a lack of transparency around data practices or governance policies areas that future design research might explore more closely.

Another critical reflection concerns the inherent limitation of using self-reported data, which can be influenced by social desirability bias or recall errors. Although neural network modeling mitigated this by modeling patterns beyond conscious awareness, qualitative follow-up studies (e.g., interviews or focus groups) could enrich understanding of emotional drivers and cultural motivations.

Recommendations

Recommendations for Future Research

1. Future research should engage a broader and more heterogeneous sample that includes users from diverse geographic locations, socio-economic backgrounds, and levels of cultural literacy. This will enhance the generalizability of the findings and provide insights into how different populations interact with heritage platforms.

2. To understand how user engagement and cultural awareness evolve over time, researchers should consider longitudinal studies that track user behavior and perceptions across months or years. This would provide more robust evidence on the long-term impact of participatory platforms on cultural transmission.

3. There is significant value in conducting cross-platform or cross-cultural comparative studies that analyze how different types of intangible heritage (e.g., opera, crafts, rituals) are preserved through digital means.

4. While this study relied on self-reported survey data, future studies should incorporate real-time behavioral metrics such as clickstream data, session duration, content interactions, and platform pathways.

5. A mixed-methods approach, incorporating both statistical analysis and qualitative insights from interviews or focus groups, would offer a more holistic understanding of user motivations, emotional engagement, and cultural meanings.

6. Future research should investigate how specific participatory features (e.g., live comments, user-submitted stories, collaborative archiving) influence cultural co-creation, knowledge exchange, and user retention.

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