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An AI-driven framework for sustainable cultural communication: mechanisms, innovations, and synergy

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With the rapid advancement of artificial intelligence (AI) technology, its driving role in sustainable cultural communication has become increasingly prominent. This study systematically explores the intrinsic mechanisms, innovation pathways, and synergistic effects of AI-driven sustainable cultural communication. The findings demonstrate that through technical mechanisms such as data intelligence, cross-modal interaction, and scenario perception, AI profoundly reshapes the production methods, content forms, and reception experiences of sustainable cultural communication. It has developed innovative practices in sustainable cultural communication through pathways that include the digital reconstruction of cultural resources, the innovation of content production paradigms, and the intelligent reconstruction of communication channels. On this basis, AI has further fostered multi-level synergistic effects in the process of sustainable cultural communication, namely internal resource optimization, external network effects, and social value co-creation. Finally, this study examines the ethical challenges and governance pathways of AI-driven sustainable cultural communication, offering a theoretical framework and practical reference for understanding the emerging landscape of sustainable cultural communication in the AI era.

KEYWORDS

artificial intelligence, innovation pathways, mechanistic explanation, sustainable cultural communication, synergistic effects

1 Introduction

Against the backdrop of the digital wave profoundly shaping global social development, AI has evolved beyond a mere technical tool to become a strategic driving force leading the new round of technological revolution and industrial transformation (Hasija and Esper, 2022; Kanitz et al., 2023; Liu and Song, 2022), systematically reshaping the ecological landscape of sustainable cultural communication (de Gil Zúñiga et al., 2024; Kulikov and Shirokova, 2021). The resonance effect formed between technological driving force and cultural innovation not only propels fundamental transformations in the mechanisms of cultural content production and communication paradigms (Zhao and Zhang, 2023) but also expands the boundaries and perceptual dimensions of cultural experiences (Pisoni et al., 2021).

A feasible sustainable development strategy hinges on the consideration of sustainability across various functional systems within society (Li and Guo, 2024), particularly the sustainability of the cultural system. In the era of AI-driven by deep learning and big data, powerful intelligent systems have enhanced the efficiency and quality of sustainable cultural dissemination (Chen et al., 2023; Tang, 2025; Tsatsanashvili, 2024). Against this backdrop,

the sustainability of cultural communication is characterized by the following core features: AI constructs scalable and iterative ecological frameworks through technologies such as digital twins, blockchain, and the metaverse, thereby overcoming the physical and energetic limitations of human creators to enable sustained, large-scale, and automated production of cultural content. Through cross-modal recombination and personalized recommendation, AI meets diverse demands, while also fostering a shift in the agents of dissemination toward an actor-network based on "human-machine symbiosis" (Bahou et al., 2024). This allows multiple actors to efficiently allocate resources through technological collaboration (Danil et al., 2025). Furthermore, by employing deep learning to decode cultural memes, AI builds trans-linguistic channels for cross-cultural dialogue (Wang et al., 2025), ultimately promoting the evolution of cultural communication from superficial symbolic display to a new paradigm of sustainable cultural dissemination characterized by deep value resonance (de Frutos, 2025; Wu and Lin, 2025).

The Dunhuang Academy of China launched the "Digital Library Cave" database platform, which integrates digital resources of cultural relics from the Library Cave of Mogao Grottoes in Dunhuang collected by multiple domestic and foreign institutions. It employs AI technologies for automatic recognition of scroll texts, with human-machine collaborative review, correction, and annotation of the results. This platform not only aggregates catalogs of Dunhuang cultural relics scattered overseas and precious images but also incorporates a vast repository of research outcomes from domestic and foreign Dunhuang studies (Yu et al., 2022). Meanwhile, it serves as an integrated resource management and global sharing platform for Library Cave scrolls and Dunhuang studies materials, featuring multiple functions including image stitching, image concatenation, knowledge graph construction, and full-text retrieval. The "Hangeul Truck" public art project, initiated by Samsung Electronics in collaboration with artists, is another typical case of integrating AI with traditional culture for international communication. AI is emerging as a key element in activating the inherent vitality of culture, and as a new generation of productive forces, it is advancing the cultural industry towards a high-quality and intelligent stage (Fiorucci et al., 2020; Liu, 2023).

However, AI-driven sustainable cultural communication is not a linear process of single-technology embedding, but rather a complex systems engineering endeavor involving the coupling of multiple mechanisms—technological, social, and cultural—the co-evolution of diverse pathways, and the interactive co-construction by multiple actors (Di Vaio et al., 2020). Current academic research on this topic has predominantly focused on case studies at the level of technological application (Chi et al., 2023; Lin et al., 2024) or on descriptive, phenomenon-oriented discussions (Donglin, 2025; Lai, 2021; Mihelj and Jiménez-Martínez, 2021). Other studies, employing quantitative or qualitative methods, have analyzed the subject from singular perspectives such as knowledge transfer, cultural identity, or cultural heritage (Delhi et al., 2020; Koutsi and Stratigea, 2020; Otero, 2022; Sharma, 2025; Rui et al., 2025; Wu and Lin, 2025; Yao, 2025; Pan et al., 2025). Collectively, these studies exhibit a fragmented and unidimensional character, lacking a holistic theoretical explanation of the underlying mechanisms, systematic innovation pathways, and the resultant multidimensional synergistic effects of AI-driven sustainable cultural communication. A universally applicable analytical

framework has yet to be established, which, to some extent, limits the theoretical applicability and inclusiveness of this research domain.

Therefore, this study employs the PRISMA flowchart to screen literature published between 2016 and 2025 in the Web of Science (WOS) and Scopus databases using the keywords "artificial intelligence" and "sustainable cultural communication" (Figure 1, Table 1). This process was undertaken to map existing research findings and theoretical gaps, and, based on this foundation, to formulate research questions. The aim is to construct a theoretical framework capable of integrating multiple dimensions and revealing systemic mechanisms, thereby expanding the current understanding of this issue. The proposed research questions are as follows:

Q1: What are the mechanisms underlying AI-driven sustainable cultural communication?

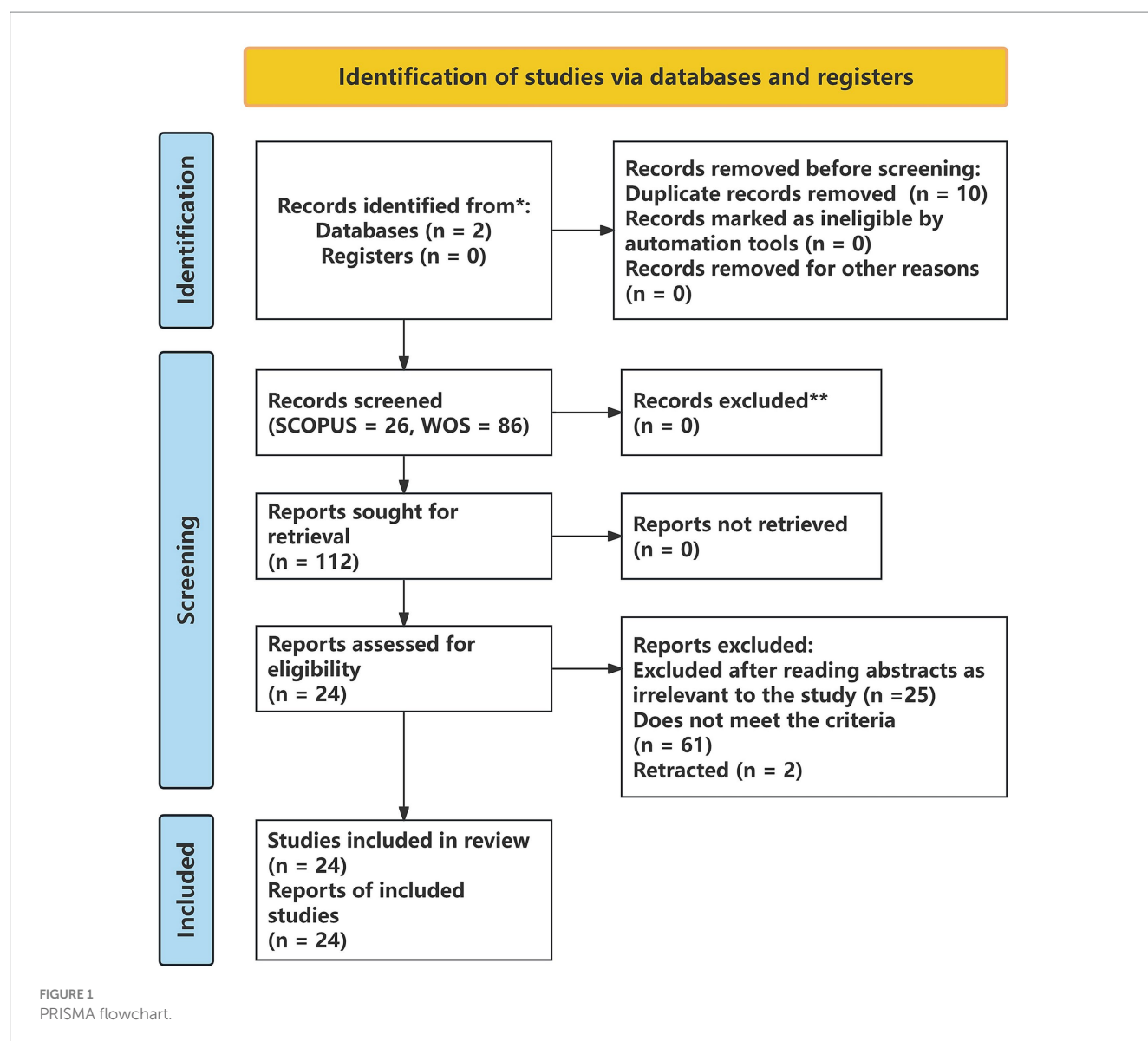Q2: What are the innovative pathways for AI-driven sustainable cultural communication?

Q3: What synergistic effects exist throughout this driving process?

Q4: What are the intrinsic relationships among the three dimensions of mechanisms, pathways, and effects?

Based on this foundation, this paper is anchored in three dimensions: mechanism analysis, pathway construction, and effect assessment (Table 2). It systematically examines the theoretical logic, practical models, and their interrelationships in AI-driven sustainable cultural communication. The aim is to construct an integrated "Mechanism - Pathway - Effect" explanatory framework. This framework is designed to bridge existing theoretical gaps and provide both a scholarly foundation and practical guidance for sustainable cultural communication amidst intelligent transformation.

This research framework, for the first time, conceptualizes AI-driven sustainable cultural communication as a multi-layered, dynamically coupled systemic process. It clearly delineates and interconnects its underlying mechanisms, modes of innovative evolution, and systemic outcomes. The framework not only facilitates moving beyond the limitations of isolated case studies and phenomenological descriptions but is also dedicated to offering a theoretical tool with general explanatory power and scalability. It is capable of accommodating analytical needs across diverse cultural contexts and stages of technological development, thereby enhancing the theoretical integration capacity and interdisciplinary depth of this research field.

The primary theoretical contribution of this study lies in its construction of an interdisciplinary "Mechanisms - Pathways - Effects" integrated analytical framework, which systematically overcomes the explanatory limitations inherent in the long-standing reliance on single-disciplinary perspectives within this field. In contrast to previous fragmented approaches that examined technological efficiency, communication outcomes, or organizational management in isolation, this framework, for the first time, incorporates the technological logic of AI, the practical processes of cultural production, and the co-generation of social value into a coherent and dynamic theoretical system. This represents a pivotal shift in theoretical paradigm, moving from an instrumental application view to a sociotechnical systems perspective. Consequently, the research focus is deepened from a singular lens to an examination of how technological and socio-cultural elements interactively co-constitute sustainability. Furthermore, methodologically, it provides a shared research framework and analytical pathway for interdisciplinary studies bridging the humanities and social sciences with computational science. This integration directly advances the systematization of knowledge production in the field. It not only

Identification of studies via databases and registers

Identification

Records identified from*:
Databases (n = 2)
Registers (n = 0)

→ Records removed before screening:
Duplicate records removed (n = 10)
Records marked as ineligible by automation tools (n = 0)
Records removed for other reasons (n = 0)

Screening

Records screened
(SCOPUS = 26, WOS = 86)

→ Records excluded**
(n = 0)

Reports sought for retrieval
(n = 112)

→ Reports not retrieved
(n = 0)

Reports assessed for eligibility
(n = 24)

→ Reports excluded:
Excluded after reading abstracts as irrelevant to the study (n = 25)
Does not meet the criteria
(n = 61)
Retracted (n = 2)

Included

Studies included in review
(n = 24)
Reports of included studies
(n = 24)

FIGURE 1
PRISMA flowchart.

constructs a more explanatory theoretical model to reveal complex causal chains but also, by establishing a common discourse for cross-domain dialogue, enhances the practical guidance value of the research for cultural institutions, technology developers, and policy formulation. Thereby, it lays a more solid theoretical foundation for the in-depth development of this interdisciplinary domain. In the practical dimension, by analyzing representative cases at home and abroad, it extracts replicable and scalable intelligent sustainable cultural communication models, providing decision-making references for content innovation of cultural institutions, product research and development of technology enterprises, and strategic formulation of government departments, thereby facilitating the effective implementation and iterative optimization of cultural digitalization strategies.

2 Mechanisms

AI-driven sustainable cultural communication is not a breakthrough in a single technical aspect but the outcome of the synergistic interaction of multiple mechanisms (Li, 2025). An in-depth analysis of these intrinsic mechanisms lays the foundation for understanding how AI reshapes the logic of sustainable cultural communication. These mechanisms mainly encompass three dimensions: technical support, process transformation, and motivation generation, which jointly constitute a systematic framework for AI-driven sustainable cultural communication.

2.1 Technical support

At the technical level, AI provides fundamental support for sustainable cultural communication through a triangular architecture comprising data intelligence, algorithmic models, and computational power (Elliott and Soifer, 2022) (Table 3). The data intelligence mechanism enables cultural resources scattered across different times and spaces to be digitized, structured, and tagged, thereby transforming them into computable and analyzable cultural data elements. For instance, cultural big data centers in various regions

TABLE 1 Inclusion and exclusion criteria.

Criteria type	Specific requirements
Inclusion criteria	1. Published between 2016 and 2025 to ensure the timeliness of research data; 2. Focused on the application of artificial intelligence technology in the field of cultural communication, with relevance to the concept of sustainable development; 3. Academic research outputs with rigorous argumentation processes, including journal articles, dissertations, and conference papers.
Exclusion criteria	1. Literature with weak relevance to the research theme, such as studies only exploring the principles of artificial intelligence technology or solely investigating cultural communication theories, without involving the cross-application of the two fields; 2. Non-empirical research outputs, such as review articles and newspaper commentaries; 3. Literature with incomplete data or inaccessible full texts.

TABLE 2 Rationale for the selection of framework components.

Dimension	Rationale for selection
Mechanisms	These mechanisms represent the core enabling capabilities of AI in cultural communication, encompassing critical stages from data mining and content generation/integration to contextual adaptation. They constitute the foundational drivers for subsequent innovations.
Innovation pathways	These four pathways correspond to the complete value chain within cultural production and dissemination, spanning from resources to content and finally to channels. They reflect the key transition of AI technology from mere embedding to the active reconfiguration of practices, demonstrating distinct phases and operational feasibility.
Synergistic effects	The identification of these three levels of synergistic effects mirrors a logical progression from internal efficiency gains, to the expansion of external relationships, and ultimately to macro-level value circulation. They encompass outcomes at the organizational, network, and societal levels, aiming to capture the systemic transformative impact brought about by AI.

conduct systematic processing of multimodal cultural resources such as text, images, videos, audio, and 3D models, breaking down the full-chain data barriers from the resource end to the production end and further to the consumption end, and realizing the digital preservation and creative transformation of cultural resources.

The algorithmic model mechanism equips machines with the capability to understand, generate, and optimize cultural content through core AI technologies, including deep learning, natural language processing (NLP), and computer vision (Dubey et al., 2022; Ratten and Jones, 2023). A manifestation of this mechanism in sustainable cultural communication is the breakthrough progress of generative AI technologies in cultural creation. In the artistic creation process, the appropriate application of AI technologies can effectively drive all links, achieving the goals of improving quality and efficiency

TABLE 3 Technical support mechanisms for AI-driven sustainable cultural communication.

Technical mechanisms	Core functions	Application cases in sustainable cultural communication
Data intelligence	Digitization, structuring, and tagging of cultural resources	Construction of cultural big data centers to realize data integration of multimodal cultural resources
Algorithmic models	Understanding, generation, and optimization of cultural content	Generative AI improving quality and efficiency throughout the entire process of artistic creation
Computing power support	Provision of large-scale data processing and model training capabilities	Cloud infrastructure supporting the efficient operation of cultural big data platforms

while reducing costs. This algorithm-driven cultural production capacity is fundamentally transforming the creative ecology of cultural content.

The computing power support mechanism, based on distributed cloud computing and edge computing, provides the necessary technical infrastructure for large-scale cultural data processing and complex model training. Cloud infrastructure distributed across various regions serves as the core foundation supporting the efficient operation of cultural big data platforms, ensuring the reliable implementation of real-time processing, intelligent analysis, and multi-terminal distribution of cultural resources. The importance of such computing power support is particularly prominent in scenarios that require the processing of massive, unstructured cultural data, such as the digital reconstruction of cultural relics and immersive cultural experiences.

2.2 Process transformation

The driving role of AI in sustainable cultural communication not only manifests at the technical level but also profoundly reflects in the systematic reconstruction of the communication process. This reconstruction encompasses the entire process, from content production and distribution to reception and feedback, comprising three core process mechanisms: paradigm innovation in content production, intelligent distribution and precise reach, and immersive experience and interactive transformation.

In the content production phase, AI has brought about a paradigm shift from human-led creativity to human-machine collaboration (Feher and Katona, 2021). Traditional cultural content production highly relies on creators' individual talent and accumulated experience, while the involvement of AI has propelled cultural content production into a new phase characterized by large-scale, personalized, and intelligent development (Yu and Guo, 2023). For instance, in the development of "YinQi Xingzhi"—the world's first intelligent agent for Oracle bone script launched by Tencent—the research team utilized AI technologies to break through the bottlenecks in the research and communication of ancient scripts. It achieved intelligent recognition, analysis, and interpretation of Oracle bone scripts, significantly

lowering the threshold for the public to understand this ancient written culture. This shift not only improves the production efficiency of cultural content but also expands the boundaries and possibilities of cultural expression.

In the content distribution phase, the intelligent distribution mechanism based on user portraits and recommendation algorithms is reshaping the communication pathways of cultural content. By analyzing users' cultural preferences, consumption habits, and contextual characteristics, this mechanism achieves precise matching and personalized delivery of cultural content (Al Naqbi et al., 2024), effectively addressing the terminal obstruction of sustainable cultural communication in the era of information overload.

In the experience and interaction phase, AI has transformed the mode and depth of cultural reception through immersive technologies and natural interaction interfaces. Relying on multimodal immersive technologies and natural interaction systems such as Virtual Reality, Augmented Reality, digital twins, speech recognition, and affective computing (Baccour et al., 2022), it not only breaks through temporal, spatial, and physical constraints, transforming the reception model from passive to active and upgrading it from one-way reception to two-way collaboration. Furthermore, through symbol visualization, emotional resonance construction, and autonomous value construction, it facilitates the progression of cultural reception from superficial information retention to in-depth logical understanding and ultimately to value identification. This aligns with the core tenets of embodied cognition, media situation, and cultural identity theories, providing a new theoretical perspective and practical paradigm for interdisciplinary research on sustainable cultural communication.

2.3 Motivation generation

Beyond the mechanisms at the technical and process levels, AI-driven sustainable cultural communication is also supported by a series of mechanisms that generate motivation, which constitute the intrinsic driving forces for the innovative development of sustainable cultural communication. These mainly include three types of motivations: demand pull, technology push, and ecological synergy.

The demand-pull mechanism is embodied in growing user expectations for personalized, interactive, and high-quality cultural content, which serves as a key driving force for the development of AI-enabled sustainable cultural communication products. Supported by multilingual intelligent systems, sustainable cultural communication no longer merely focuses on the accuracy of translation but places greater emphasis on the expression of cultural connotations. This requires technical systems to possess emotional recognition capabilities, semantic reasoning capabilities, and cultural transfer capabilities (Spinzi, 2025). Such demand for continuous upgrading drives the in-depth application of AI technologies in the field of sustainable cultural communication.

The technology push mechanism manifests as the continuous expansion of the boundary of possibilities for sustainable cultural communication innovation brought about by technological breakthroughs in the AI field itself (Prados-Peña et al., 2025). From early content retrieval and tag recognition to today's content generation and scenario understanding, every leap in AI technical capabilities has opened up new imaginative spaces for sustainable cultural communication. The maturity of multimodal large models

enables AI to simultaneously understand and generate cultural content in various forms, such as text, images, audio, and video (Guha et al., 2023), greatly enriching the expression methods of sustainable cultural communication.

The ecological synergy mechanism emphasizes that multiple actors form innovative synergy through collaborative interaction within the AI-enabled sustainable cultural communication system. In-depth collaboration among governments, local media, technology enterprises, and cultural institutions can form an open ecosystem characterized by resource integration, capability complementarity, and value sharing. This ecological synergy not only reduces the innovation costs and risks for individual actors but also accelerates the emergence and diffusion of AI-enabled sustainable cultural communication innovations through knowledge spillover, network effects, and value linkage.

3 Innovation pathways

Having clarified the intrinsic mechanisms of AI-driven sustainable cultural communication, it is necessary to further explore the specific pathways for its innovative development. These pathways not only include the digital reconstruction and activation of traditional cultural resources but also the systematic innovation of content production paradigms, as well as the intelligent reconstruction of communication channels and the integration of cross-border ecosystems, collectively forming an innovation matrix for AI-driven sustainable cultural communication.

3.1 From digitalization to intelligence

In the theoretical and practical system of AI-driven sustainable cultural communication, the digitalization of cultural resources serves as a fundamental preliminary pathway. Its connotation has evolved from traditional shallow digital translation to systematic reconstruction and in-depth innovation centered on the core logic of "dataization—intelligence—valorization." For instance, relying on multimodal technologies such as 3D scanning, spectral imaging, and NLP, full-dimensional and high-precision digital capture is conducted on material and intangible cultural heritage, as well as spiritual cultural resources. Through knowledge graph construction, semantic modeling, and standardized processing, a computable, correlatable, mineable, and iterable cultural data ecosystem is formed (Cotella, 2023). This not only breaks the physical constraints and fragmentation dilemmas of traditional cultural resources but also lays the groundwork for data and technical foundations for AI-driven value mining, content innovation, and precise communication.

The intelligence of cultural resources encompasses dual demands: rescue and protection, as well as creative transformation. On one hand, technologies such as computer vision, NLP, and generative adversarial networks are utilized for digital archiving, virtual restoration, and simulated reconstruction of endangered intangible cultural heritage, damaged ancient books, and minority languages, alleviating their survival crisis. On the other hand, it involves extracting cultural symbols, deconstructing core connotations, adapting to modern scenarios to achieve integrated innovation, and endowing endangered cultures with digital vitality (Mishra et al., 2024).

The intelligent transformation of cultural institutions is a key carrier, with standardization and openness as the core principles. At the standardization level, unified norms for data collection, storage, and sharing must be established to address the issue of data silos. At the openness level, classified and hierarchical data sharing platforms should be constructed, opening resources to multiple actors through compliant authorization, balancing data openness and copyright protection, and promoting the ecological transformation of sustainable cultural communication towards multi-actor collaboration.

3.2 From standardization to personalization

AI is driving a paradigm shift in cultural content production, shifting from standardized, large-scale production to personalized, customized creation (Mazzanti et al., 2025), which reshapes the production methods, creative subjects, and value logic of cultural content. Breakthroughs in generative AI technologies, especially the maturity of multimodal large models, have significantly lowered the technical threshold and cost constraints of cultural creation, enabling more individuals and micro-teams to participate in the creation of high-quality cultural content.

At the practical level of personalized customization, AI achieves precise matching and adaptive adjustment of cultural content through a closed-loop system of user portrait analysis, intelligent content generation, and dynamic feedback optimization. Taking streaming platforms such as Netflix and Spotify as examples, by analyzing users' viewing and listening histories combined with real-time behavioral data, they not only realize precise content recommendation but also influence content topic selection and style positioning at the creation stage (Lotz et al., 2022). For instance, Netflix optimizes drama plots and character settings based on user preference data. Similarly, in the fields of news communication and knowledge services, platforms such as Apple News rely on algorithms to conduct multidimensional modeling of user interests, realizing personalized content curation and dynamic adjustment of expression methods.

AI-based personalized content strategies can dynamically adjust the presentation forms and narrative perspectives of content according to the cultural backgrounds, cognitive characteristics, and preference habits of different audiences (Kumar et al., 2024), thereby effectively enhancing the penetration and emotional resonance of sustainable cultural communication. Furthermore, some international communication platforms have attempted to utilize AI technologies to automatically generate promotional materials that conform to local cultural contexts and aesthetic preferences for audiences in different regions, thereby significantly improving the accuracy and acceptance of cross-cultural sustainable communication.

However, it is important to note that AI-driven personalized content strategies do not inherently lead to the diversification of cultural dissemination. The latent "Filter Bubble" effect underlying such strategies constitutes a core tension between personalization and cultural diversity, prompting deeper inquiries into the value of algorithms. From the perspective of filter bubble theory, algorithmic personalization not only fails to effectively broaden users' cultural horizons but is highly likely to become a key constraint that limits cultural exposure (Lunardi et al., 2020). This constraint arises from the core logic of algorithmic personalization: algorithms construct accurate user profiles through deep mining of historical behavioral data and continuously recommend cultural content that aligns with users' existing cognitions and interests based on the principle of "preference matching." This creates a closed-loop cycle of "user preference reinforcement - algorithm-driven precise recommendations - further solidification of user preferences" (Ludwig et al., 2025).

Within the framework of this study, the potential of artificial intelligence to induce cultural homogenization can also be explained. At the mechanism level, platforms aiming to enhance user retention and interaction naturally incline algorithms to recommend standardized, high-click, high-engagement popular content. Niche and differentiated cultural content, lacking sufficient traffic support, are excluded from mainstream recommendations, forming the root of homogenization. At the pathway level, core traffic continuously concentrates toward content aligned with mass preferences, further compressing channels for diverse cultural dissemination and promoting convergence in cultural diffusion. At the effect level, the interplay of the above mechanisms and pathways gives rise to a homogenization effect. Niche and marginal cultures gradually weaken due to insufficient dissemination channels, cultural diversity is eroded, and cultural innovation may even be inhibited.

The "Mechanisms - Pathways - Effects" framework proposed in this study not only explains the logic of AI-induced cultural homogenization but also enables the development of a systematic and optimized solution to address this dilemma and promote diversified cultural dissemination. The core rationale involves applying reverse interventions—"mechanism reconstruction, pathway optimization, and effect guidance"—targeting the chain of "mechanism root causes, pathway obstruction and effect solidification" that drive homogenization, thereby facilitating a transition from homogenization to diversification (Figure 2). At the mechanism level, it is essential to break away from the singular attention-economy-driven preference matching mechanism and establish a dual-driven mechanism that balances preference matching with diversity safeguards. Algorithms should shift from prioritizing traffic to balancing traffic with cultural value. While preserving the advantages of personalization, cultural diversity weight constraints and niche culture activation rules should be introduced. Incorporating multicultural indicators into the algorithmic system and implementing traffic support for niche and differentiated cultural content can curb homogenization at its source. At the pathway level, a diversified interaction network should be constructed, establishing multiple pathways for cultural dissemination. Simultaneously, a "cultural exploration mode" can be developed through user initiative and algorithmic guidance, recommending heterogeneous content and lowering barriers to acceptance, thereby fostering a pluralistic and symbiotic dissemination landscape. At the effect level, a closed-loop guidance effect integrating dynamic assessment and feedback optimization should be implemented. A cultural dissemination diversity evaluation system can be introduced to monitor key multicultural indicators. When these indicators fall below thresholds, mechanisms and pathways can be automatically adjusted. Additionally, a user feedback and interaction mechanism can be established to further refine the design.

3.3 From one-way reception to interactive participation

AI is reshaping the fundamental paradigm of sustainable cultural communication, transforming it from the traditional one-way
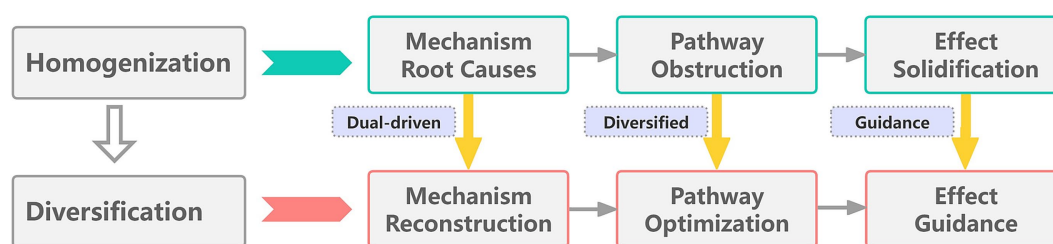
FIGURE 2
From homogenization to diversification.

indoctrination model to a new model of two-way interaction and multi-stakeholder participation. This transformation is reflected not only in the diversification of communication channels but also more profoundly in the decentralization of communication power, the reconstruction of communication relationships, and the optimization of communication effects (Poulopoulos and Wallace, 2022).

At the power structure level, AI further advances the decentralization and popularization of sustainable cultural communication power. By significantly lowering the threshold for content creation and dissemination, AI transforms ordinary people from passive cultural recipients into active cultural participants and communicators, stimulating the vitality of grassroots cultural innovation. This power structure reform helps break the elite monopoly in sustainable cultural communication, forming a more diverse, inclusive, and resilient cultural ecosystem.

At the channel innovation level, AI-driven intelligent media platforms are emerging as new hubs for sustainable cultural communication. By integrating multiple communication mechanisms, such as social recommendations, algorithmic distribution, and search engines, these platforms have constructed a more three-dimensional, sustainable cultural communication network. Furthermore, the communication model relying solely on algorithmic distribution may carry the risk of "information cocoons." In response, some platforms have adopted a hybrid model combining social recommendation with algorithmic cocoon-breaking—while respecting user interests, they consciously broaden users' cultural horizons and expose them to diverse cultural content. This balance reflects the complexity and dialectics of channel design for sustainable cultural communication in the era of AI.

At the experience construction level, immersive interaction and contextualized communication have become key features of AI-driven sustainable cultural communication (Casillo et al., 2022; Eljattari et al., 2025). AI not only changes the channels and carriers of sustainable cultural communication but also profoundly redefines the way cultural reception is experienced—from one-way viewing and interpretation to full-body immersive experiences—thereby enhancing the appeal and memorability of sustainable cultural communication (Li et al., 2025). For instance, in the cultural and museum sectors, immersive exhibitions utilize AI-driven Virtual Reality and Augmented Reality technologies to enable audiences to experience historical scenarios in an immersive manner. In the cultural tourism sector, some scenic spots utilize AI and spatial perception technologies to provide tourists with real-time, location-based narrative-guided tours and contextualized content delivery, overlaying in-depth cultural information layers onto physical spaces

to form dynamic and personalized meaning-exchange arenas. Such practices not only demonstrate the expansion of perceptual dimensions through technology but also reflect the profound transformation of sustainable cultural communication models from single information transmission to multidimensional context construction.

3.4 From boundary rigidity to cross-border integration

Among the various innovative dimensions of AI-driven sustainable cultural communication, a particularly critical pathway manifests in the systematic dissolution and structural reconstruction of traditional communication boundaries, thereby promoting the formation of a cross-border integration ecosystem characterized by high openness and dynamic adaptability. This pathway not only breaks down the inherent divisions between links such as creation, distribution, and reception within sustainable cultural communication but also significantly weakens the institutional and technical barriers between sustainable cultural communication and related fields such as science and technology, education, and tourism, fostering the emergence of a more liquid, connected, and innovative cultural ecosystem.

At the industrial level, AI has facilitated in-depth integration within the cultural industry and between culture and other industries, constructing a new type of value network featuring data-driven and intelligent interaction (Glikson and Woolley, 2020). For instance, supported by AI technologies, the film and television industries, as well as the gaming industry, have realized the sharing and transformation of narratives and visual expressions, forming cross-media story worlds.

At the regional level, AI has significantly accelerated the cross-regional integration and global flow of cultural resources. Taking digital exhibitions co-organized by platforms such as Google Arts and Culture, the Palace Museum, and international partners as examples, these platforms utilize AI technologies for high-definition digitalization, multilingual interpretation, and personalized recommendation of collections. This enables cultural resources that were previously restricted by geography to achieve global accessibility and sharing, promoting mutual learning among civilizations and the expression of cultural diversity.

At the organizational level, AI drives the transformation of the actor structure of sustainable cultural communication toward networked and flexible directions. The traditional centralized, institution-led

communication model is being gradually supplemented or even replaced by distributed, collaborative creation networks that rely on AI platforms. For example, numerous independent creators participate in content co-creation through open-source models such as Stable Diffusion and GPT, forming decentralized prosumer integration communities. This reflects the profound evolution of power structures and collaboration logic in cultural production relations.

4 Synergistic effects

AI's drive for sustainable cultural communication goes beyond instrumental efficiency innovation. Its essence lies in creating systemic advantages through multiple synergies of internal resources, external networks, and social values (Table 4), thereby achieving value leap and sustainable development.

4.1 Internal resource synergy

Within cultural institutions or enterprises, AI enables the in-depth integration of key elements such as data, technology, and creativity, generating multiple synergistic effects, including optimal resource allocation, improved operational efficiency, and release of innovation potential.

Data-technology synergy is reflected in AI systems' ability to break down originally isolated data silos and technical modules, forming a unified and efficient digital infrastructure. This synergy not only reduces data processing costs but, more importantly, creates new value from data interconnection. Through correlative analysis and mining insights of diverse cultural data, it uncovers cultural patterns and user needs that cannot be presented by a single data type.

Human-AI creative synergy is another crucial form of internal synergy in the AI-driven sustainable cultural communication system (Zhu et al., 2025). In this synergy, human creative thinking complements AI's computing capabilities, jointly enhancing the quality and efficiency of cultural innovation. On one hand, AI can assist creators in completing repetitive and basic tasks such as material collection, preliminary screening, and simple editing, allowing human creators to focus more on core creative conception. On the other hand, AI can expand human creative boundaries and enhance decision-making quality by generating diverse schemes, providing data-driven feedback, and predicting outcomes (Dogru et al., 2025).

Organization-technology synergy emphasizes the adaptation and promotion of organizational structures, processes, and cultures to the application of AI technologies. Tencent's practice has found that effectively integrating the value concept of "Technology for Good" into product design and algorithmic rules enables technical applications to better serve the positive values of sustainable cultural communication. For instance, by establishing an identification system for AI-generated synthetic content to prevent fraud risks, adhering to publishing high-quality information, and resisting false and low-quality content. This is not only a reasonable constraint on technical capabilities but also a concrete manifestation of organizational values at the technical level. Such synergy between organizational culture and technical capabilities ensures that AI applications remain aligned with the original intention of promoting cultural prosperity and development.

TABLE 4 Levels of synergistic effects in AI-driven sustainable cultural communication.

Levels of synergy	Core mechanisms	Value outputs
Internal resource synergy	In-depth integration of elements such as data, technology, and creativity	Optimal resource allocation, improved operational efficiency, and release of innovation potential
External network synergy	Network effects formed by multi-actor participation	Ecological value multiplication, innovative knowledge spillover, and cross-border capability complementarity
Social value synergy	Positive interaction between economic value and cultural value	Dual gains of commercial and social benefits, and mutual promotion of cultural confidence and industrial development

4.2 External network synergy

Outside the system, AI forms a collaborative ecosystem based on network effects by connecting multiple actors and integrating complementary resources (Anthony et al., 2023). This external network synergy not only expands the coverage of sustainable cultural communication but also enhances the overall system's innovation capacity and adaptability through inter-actor capability complementarity and knowledge spillover (Hemmer et al., 2025).

Government-industry-university-research synergy is a crucial network form in the AI-driven sustainable cultural communication ecosystem. Cross-sectoral dialogue and collaboration among government representatives, academic experts, enterprise leaders, and research institutions not only help form a shared understanding of the development trends of AI-driven sustainable cultural communication but also provide institutional guarantees for the effective alignment of policy formulation, technological research and development, and market application.

Platform-user synergy emphasizes the interactive symbiotic relationship between platform enterprises and end-users. In the AI era, users are no longer merely consumers of cultural content but also content co-creators, communicators, and feedback providers. During the operation process, an increasing number of online platforms rely not only on their own creative capabilities but also actively engage users in content creation, forming a complementary content ecosystem that combines professional production with user-generated content. This in-depth platform-user synergy not only enriches the diversity of cultural content supply but also enhances users' sense of participation and belonging, thereby improving the stickiness and sustainability of sustainable cultural communication.

Domestic-international synergy focuses on the balance and interaction between localization and globalization of sustainable cultural communication. While AI technology promotes international cultural communication, it also faces challenges related to cultural adaptability and local acceptance. This requires AI technology to maintain the consistency of core cultural connotations while conducting appropriate localized adaptation for different cultural scenarios, achieving a localization balance.

4.3 Social value synergy

The highest-level synergy of AI-driven sustainable cultural communication is reflected in the positive mutual construction and dynamic balance formed between economic value and cultural value, as well as between short-term gains and long-term impacts. This synergy mechanism at the social value level not only ensures the commercial sustainability of AI-enabled sustainable cultural communication projects but also guarantees their continuous release of positive socio-cultural externalities, thereby achieving the organic unity and resonant enhancement of industrial benefits and cultural effects (Xia et al., 2024).

This synergy logic has been fully demonstrated in several representative international cases. For instance, relying on its advanced content recommendation algorithms and user behavior analysis systems, Netflix has actively promoted the production and dissemination of non-English original series (e.g., South Korea's Squid Game, Germany's Dark) while accurately expanding global markets and increasing subscription revenue. It has not only achieved commercial success but also fostered cross-cultural understanding and the globalization of regional aesthetics. Google Arts and Culture, through AI-supported high-definition digitalization, image recognition, and content tagging, has opened the collection resources of over 2,000 cultural and museum institutions worldwide to the public free of charge. This not only strengthens the social value and public trust of its brand but also invisibly builds an open and accessible digital cultural community, enabling a leap from technology-driven to culturally inclusive practices. Similarly, as a public service broadcaster, the BBC has introduced generative AI tools into its digital archiving and content reproduction processes. While reducing production costs and expanding content forms, it adheres to the accuracy and educational nature of sustainable cultural communication, embodying effective synergy between commercial logic and public mission.

In these cases, AI has transcended its instrumental attribute to become a structural medium, connecting commercial operations and cultural narratives, and promoting the formation of a new communication ecosystem that combines industrial competitiveness with cultural appeal.

5 Research framework

This paper constructs an integrated "Mechanisms-Pathways-Effects" framework, designed to systematically parse the dynamic process of AI-driven sustainable cultural dissemination. The framework constitutes an organic system with intrinsic logical connections, rather than a mere listing of discrete elements. It entails a coherent progression from underlying mechanisms, through operational pathways, to resultant effects, as illustrated in Figure 3.

5.1 Intrinsic connections

The triad of "Mechanisms-Pathways-Effects" constitutes a complete causal chain that progresses from foundational potential, through practical action, to systemic outcomes. This framework

encapsulates the full logic of AI-empowered cultural dissemination, addressing the questions of "why it works," "how it is implemented," and "what effects are produced."

Specifically, the mechanisms serve as the foundation and driving force for the pathways and effects. Technological underpinnings provide the technical feasibility for all innovative pathways. Process transformation mechanisms directly define the specific stages and models of pathway implementation. Furthermore, momentum generation supplies both intrinsic and extrinsic incentives for the selection and advancement of these pathways. For instance, the technical mechanism of algorithmic models is the core prerequisite for realizing the shift from standardized to personalized pathways, while the process transformation mechanism of immersive experience directly drives the practical implementation of pathways moving from one-way transmission to interactive engagement.

Furthermore, the pathways function as the practical vehicle and the translation process for the mechanisms. The four innovative pathways are the critical bridges that translate static mechanisms into dynamic practice. They concretely specify how to reorganize and optimize the processes, models, and boundaries of cultural dissemination based on the foundations provided by the mechanisms.

Concurrently, the synergistic effects are the systemic outcomes generated through the operation of the mechanisms via specific pathways, representing results that surpass the mere sum of individual components. Internal resource synergy is a direct result of pathways optimizing internal processes. External network synergy is an inevitable product of cross-boundary integration pathways. Social value synergy constitutes the ultimate objective and a manifestation of sustainability, achieved through the combined action of all mechanisms and pathways.

The mechanisms, pathways, and effects are interlocked, forming a closed feedback loop. Critically, the synergistic effects feedback to generate new social demands. These demands are subsequently translated into renewed momentum, which in turn drives the iterative refinement of the mechanisms and the continuous optimization of the pathways.

5.2 External influencing factors

The strength and specific manifestations of the internal relationships within the "Mechanisms - Pathways - Effects" framework constructed in this study are not fixed. Instead, they are significantly moderated by a series of external contextual variables. These variables constitute the external boundary conditions and adaptive environment for the framework's operation, profoundly influencing the entire process from mechanism activation to the emergence of final effects. Neglecting these moderating factors would lead to an oversimplified and potentially erroneous understanding of the AI-driven sustainable cultural dissemination process.

Firstly, macro-level contextual variables establish the foundational constraints and opportunities for the framework's operation. The cultural policy and regulatory environment plays a pivotal role. For instance, stringent data governance and privacy protection regulations may constrain the in-depth development of data-intelligent mechanisms, thereby limiting the scope and precision of personalized dissemination pathways. Conversely, national strategies that encourage digital cultural heritage innovation
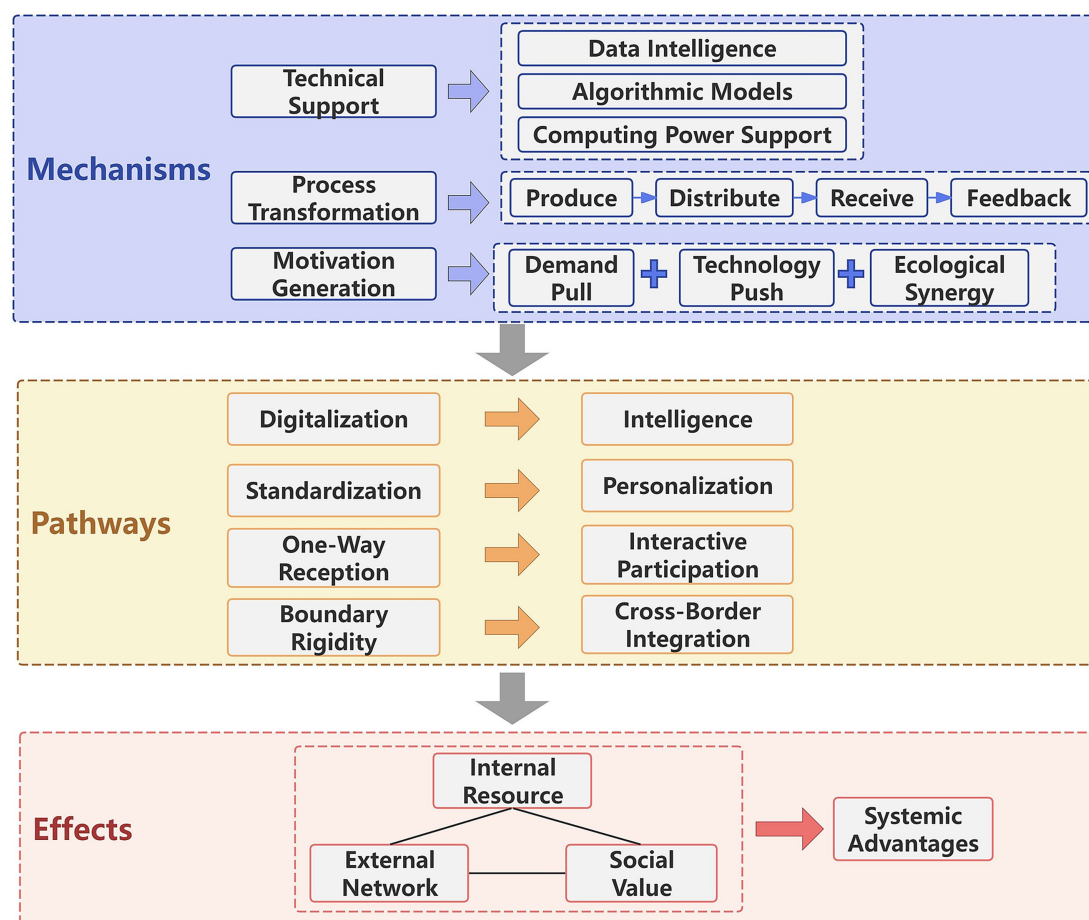
FIGURE 3
Research framework.

and application can significantly amplify technological impetus and ecosystem synergy, providing institutional legitimacy for pathways such as cross-boundary integration. The socio-cultural context, encompassing public trust in technology, aesthetic conventions, and cultural values, moderates the acceptance and efficacy of process transformation mechanisms. In societies with higher technological trust, innovative pathways like immersive interaction are more readily accepted by audiences, thus translating more smoothly into positive social value synergy. In regions with uneven digital infrastructure, weaknesses in computational support mechanisms directly constrain the evolution speed and penetration of pathways from digitalization to intelligence.

Secondly, meso-level organizational variables determine the implementation capacity and strategic orientation of the framework at the level of specific actors. The resource endowment, strategic positioning, and organizational culture of cultural dissemination entities are critical mediators in translating mechanisms into pathways. Large, resource-rich institutions with digital technology integration capabilities can more fully mobilize technological support mechanisms, proactively lead content production paradigm innovation, and potentially implement multiple innovative pathways simultaneously to achieve scalable synergistic effects. In contrast, resource-constrained small cultural organizations rely more heavily on ecosystem synergy for momentum. Their pathway choices often

manifest as leveraging external platforms and tools for targeted breakthroughs, with effect generation more concentrated on external network synergy. Furthermore, an organization's agility and innovative culture determine its adaptation speed to process transformation mechanisms. Hierarchically rigid, risk-averse organizations may create a disconnect between advanced mechanism design and actual pathway execution.

Finally, the inherent uncertainty and rapid iteration of technological variables continuously reconfigure the dynamic equilibrium within the framework. The maturity, accessibility, and integration complexity of AI technologies directly redefine the connotations and boundaries of technological mechanisms. For example, the rapid proliferation of generative AI tools has substantially lowered the barrier to high-quality content creation. This not only strengthens technological impetus but also renders the process transformation mechanism of "content production paradigm innovation" more universal, thereby altering the starting line for organizations of different scales in pursuing innovative pathways. Simultaneously, technology integration complexity—the seamless coordination between data, algorithms, and computing power—functions as a key technological variable moderating the conversion efficiency from mechanisms to pathways. While high-complexity integration can potentially elicit stronger synergistic effects, it also imposes greater demands on organizational capabilities and contextual

adaptation, potentially amplifying the moderating effects of organizational and contextual variables.

In summary, the three categories of external variables—contextual, organizational, and technological—do not exist in isolation. They are interwoven, collectively forming a multi-layered moderating system for the proposed framework. Rigorous research and practical application must involve the thorough identification and dynamic analysis of these moderating effects. This is essential for understanding the framework's specific manifestations and efficacy boundaries across different contexts, thereby avoiding the mechanical application of theoretical models and enhancing both the explanatory authenticity of the framework and the pertinence of derived strategies.

5.3 Case analysis

5.3.1 AI + digital palace museum

The "AI + Digital Palace Museum" initiative serves as a concrete and comprehensive exemplar for the "Mechanisms - Pathways - Effects" framework proposed in this study. This case systematically demonstrates the dynamic process of AI-driven sustainable cultural dissemination.

At the mechanisms level, the Palace Museum has constructed a robust technological underpinning based on high-precision 3D modeling and cultural relic knowledge graphs. This foundation has catalyzed an internal process transformation, evolving from the digital acquisition of artifacts to intelligent management. For the public, it has enabled the intelligent distribution of exhibition content and immersive AR/VR interactive experiences. The momentum generation stems from sustained public demand for innovative cultural experiences, the maturation of digital technologies, and an open collaborative ecosystem established with technology firms and academic institutions. Collectively, these mechanisms have given rise to distinct innovative pathways: The practice has not only achieved a leap from the digital preservation to the intelligent activation of cultural heritage resources but has also shifted the dissemination model from one-way display to two-way interactive engagement through personalized recommendations and interactive applications. Furthermore, leveraging IP licensing and collaborations with industries such as gaming and fashion, it has successfully implemented cross-boundary integration.

The synergistic operation of the aforementioned mechanisms and pathways has ultimately yielded multi-layered synergistic effects. Internally, it has achieved the integration and optimization of data, research, and creative resources. Externally, it has formed a culture-technology collaboration network centered on itself. At the societal level, it has significantly enhanced cultural awareness and identity while creating new economic and educational value. Of particular importance, this case clearly reveals the dynamic closed-loop among the framework's components: The emergence of social value synergy, such as increased engagement from younger demographics, feeds back to reinforce the social demand and policy support for continuous innovation. This, in turn, provides renewed momentum for the next cycle of technological iteration and pathway expansion. This complete cycle not only validates the explanatory power of the proposed framework but also vividly illustrates that AI-driven sustainable cultural dissemination constitutes a self-reinforcing and continuously evolving systemic endeavor.

5.3.2 Dunhuang digital library cave

The practice of the "Dunhuang Digital Library Cave" database platform by the Dunhuang Academy provides a concrete and comprehensive case study that exemplifies the framework proposed in this research. This case systematically illustrates the dynamic process of artificial intelligence-driven sustainable dissemination and revitalization of endangered cultural heritage.

At the mechanism level, the Dunhuang Academy established a robust technological foundation through high-precision digital acquisition techniques such as ultra-high-definition photography and multispectral imaging, combined with AI-based text recognition and multi-level knowledge graph construction. Building upon this foundation, it facilitated internal procedural transformations — from the digital restoration of dispersed cultural relics and accurate interpretation of variant characters to the intelligent management of documentary resources. Simultaneously, it enabled global public access through intelligent manuscript retrieval, multilingual translation, and immersive online interactive experiences. The driving forces behind these developments stem from the persistent public demand for in-depth understanding of Dunhuang culture, the iterative maturation of digital technologies, and an open collaborative ecosystem involving technology enterprises and international collection institutions.

These mechanisms collectively gave rise to a clearly defined innovation pathway: the practice not only achieved a breakthrough in transitioning the Dunhuang Digital Library Cave artifacts from fragmented preservation to digital aggregation and reintegration but also accomplished a leap from digital display to intelligent interpretation. Furthermore, by integrating with higher education scenarios and collaborating with international museums on exhibitions, it successfully realized cross-disciplinary integration.

The synergistic operation of the aforementioned mechanisms and pathways ultimately generated multi-level collaborative effects. Internally, it optimized the integration of cultural relic data, research outcomes, and digital creative resources, significantly enhancing the accessibility and depth of Dunhuang studies. Externally, it formed a transnational cultural-technology cooperation network centered on the Dunhuang Academy, promoting the digital "repatriation" of dispersed cultural relics. At the societal level, it notably increased the international recognition and acceptance of Dunhuang culture, creating distinctive educational and cultural dissemination value.

Particularly important is that this case clearly reveals a dynamic closed-loop among the framework elements: the emergence of synergistic social value effects, such as increased public engagement and heightened academic research interest, in turn reinforces the social demand and policy support for sustained innovation, thereby providing new impetus for further technological iteration and pathway expansion. This complete cycle not only validates the explanatory power of the proposed framework but also vividly illustrates that AI-driven sustainable dissemination of endangered cultural heritage constitutes a self-reinforcing and continuously evolving systemic endeavor.

6 Ethical challenges and governance pathways

While driving sustainable cultural communication, AI also poses a series of ethical challenges and governance dilemmas (Galaz et al.,

2021; Jovanovic and Campbell, 2022; Li et al., 2024). Only by establishing a sound system of ethical norms and governance can we ensure the healthy development of AI-driven sustainable cultural communication and realize the sustainability of positive interaction between technology and culture (Pansoni et al., 2023a).

6.1 Ethical challenges

The primary ethical challenge facing the AI-enabled sustainable cultural communication system is algorithmic bias and the resulting cultural discrimination (Hermann, 2022). Since the training data of AI models often reflects existing cultural biases and power structures in the real world, these biases may be amplified by algorithms and entrenched in cultural recommendations, content generation, and user interaction (Pavlik, 2023; Van Dis et al., 2023). For instance, mainstream cultures may receive more exposure and promotion opportunities, while minority cultures and marginalized cultures may be further neglected, thereby exacerbating cultural inequality. Such algorithmic bias not only undermines the protection of cultural diversity but may also weaken the cultural identity of minority groups (Tan et al., 2025).

Second, AI may intensify the risk of cultural homogenization and diminish the diversity of cultural expressions. AI models trained on global data may tend to generate cultural content that conforms to mainstream standards, leading to the erosion of local characteristics and cultural uniqueness (Xavier and Korunka, 2025). Protecting cultural diversity and uniqueness while leveraging AI to enhance the efficiency of sustainable cultural communication has become an urgent ethical issue to address.

Furthermore, over-reliance on AI may trigger a subjectivity crisis and authenticity dilemma in sustainable cultural communication (Divon and Ebbrecht-Hartmann, 2025). As AI-generated content accounts for an increasingly large proportion of sustainable cultural communication, the authenticity and originality of culture may be called into question. On the one hand, AI-generated content may blur the boundaries of cultural innovation, triggering disputes over copyright and attribution. On the other hand, excessive technical intermediation may weaken interpersonal interaction and emotional connections in sustainable cultural communication, rendering cultural experiences superficial and fragmented.

6.2 Governance pathways

Faced with the aforementioned ethical challenges, it is necessary to construct a multi-level and multi-dimensional governance system to ensure the healthy development of AI-driven sustainable cultural communication. This governance system should include three core elements: ethical frameworks, pluralistic co-governance, and technology-driven governance (De Almeida et al., 2021; Pansoni et al., 2023b).

6.2.1 Construction of ethical norms

Based on the iterative nature of AI technology and the value attributes of sustainable cultural communication, it is essential to establish an ethical value system and practical principles that are both guiding and operational (Morley et al., 2020). This system should go beyond generalized ethical initiatives, focusing on the core demands of sustainable cultural communication and clarifying key requirements, such as the protection of cultural diversity, adherence to value rationality, guarantee of communication fairness, and protection of user rights and interests (Alsaleh, 2024). It should also incorporate ethical principles, including algorithmic fairness, content compliance, data privacy protection, and respect for cultural sovereignty. Meanwhile, efforts should be made to promote the in-depth integration of ethical norms with industry practices and technological RandD, embedding ethical considerations into the entire process of design, application, and evaluation of AI-enabled sustainable cultural communication tools, thereby avoiding the decoupling between technological development and ethical norms.

6.2.2 Pluralistic collaborative governance

Based on collaborative governance theory, a governance network featuring co-construction, co-governance, and shared benefits among multiple stakeholders should be built to break the limitations of single-actor governance (Birkstedt et al., 2023). This network covers core stakeholders such as government departments, technology enterprises, cultural institutions, academic circles, and user groups, with each actor assuming differentiated governance roles based on their respective powers and responsibilities:

- Governments undertake regulatory and guiding responsibilities, defining governance boundaries and development orientations through formulating laws, regulations, industry standards, and policy incentives.
- Technology enterprises fulfill their primary responsibilities by embedding ethical norms into product RandD and operational processes, and by establishing internal compliance reviews and risk prevention mechanisms.
- Cultural institutions play a gatekeeping role in upholding cultural cores and value boundaries in content creation and communication.
- Academic circles provide theoretical support and technical consulting, promoting theoretical innovation and practical transformation of ethical governance.
- User groups form social supervision forces through supervision, feedback, and participation in governance.

Through multiple interactive mechanisms, including rule co-construction, standard coordination, supervision and evaluation, and interest coordination, all actors converge on governance synergy to achieve a transformation from fragmented governance to systematic governance (Wirtz et al., 2022).

6.2.3 Technology-driven governance

Leveraging the development achievements of Governance Technology, embedded governance and adaptive optimization of ethical principles are realized to provide technical support for the governance system. Specifically, governance effectiveness can be enhanced through three technical pathways:

- Establish an identification and traceability system for AI-generated content. Endow AI-generated cultural content with unique identifiers based on technologies such as digital watermarking and blockchain (Clough and Wu, 2022), clarifying

content sources and creators to protect users' right to know and right to traceability.

- Develop tools for algorithmic transparency and interpretability. Through algorithm log recording, visual presentation, and natural language explanation, reduce governance difficulties caused by algorithmic black boxes, and improve the traceability, auditability, and accountability of sustainable cultural communication processes.

- Build a digital rights confirmation and copyright protection mechanism for cultural resources. Utilize the decentralized and tamper-proof characteristics of blockchain (Cao, 2022) to realize property rights registration, circulation traceability, and infringement monitoring of cultural IPs and digital cultural and creative products, safeguarding the legitimate rights and interests of cultural creators and stimulating cultural innovation vitality.

The core value of technology-driven governance lies in enhancing the precision, efficiency, and adaptability of governance through technology, realizing the rigid constraints and dynamic optimization of ethical norms.

6.3 Innovation and evolution

The governance of AI-driven sustainable cultural communication should not be confined to risk prevention but should further evolve toward responsible innovation and sustainable value creation (Chen et al., 2023; Lu et al., 2024). This means continuous exploration is required in aspects such as forward-looking anticipation, inclusive development, and adaptive governance.

Responsible innovation demands prospective assessment and dynamic adjustment of the long-term impacts of AI-enabled sustainable cultural communication. With the continuous emergence of new technologies such as generative AI, extended reality, and brain-computer interfaces (Gholizadeh HamlAbadi et al., 2024), the forms and impacts of sustainable cultural communication will become increasingly complex and diverse. The governance system needs to possess sufficient forward-looking and flexibility to promptly respond to new issues and challenges brought by technological changes. For instance, regarding the currently embryonic "full-scale intelligent communication," it is necessary to proactively study its potential impacts on the cultural ecosystem and make institutional preparations and ethical reserves in advance.

Inclusive development emphasizes that AI-enabled sustainable cultural communication should accommodate the needs and rights of different groups and cultures (Kolotouchkina et al., 2022). Special attention should be paid to the imbalance in cultural development that may result from unequal distribution of technical resources against the backdrop of the digital divide. Measures such as technology popularization, capacity building, and resource inclination should be adopted to ensure that small and medium-sized cultural institutions, marginalized groups, and underdeveloped regions can also benefit from the innovation of AI-driven sustainable cultural communication.

Ultimately, the governance goal of AI-driven sustainable cultural communication should be to construct an ecosystem where technology, humanity, and ethics coexist harmoniously. In this ecosystem, technological innovation injects vitality into sustainable cultural communication, humanistic spirit guides the direction of technological application, and ethical governance provides guarantees

for sustainable development—forming an organic whole of mutual complementarity and positive interaction. Only in this way can AI truly become a constructive force for promoting cultural prosperity and deepening mutual learning among civilizations, rather than a mere technical tool or potential destructive factor.

7 Discussion

This study systematically analyzes the intrinsic mechanisms, innovation pathways, and synergistic effects of AI-driven sustainable cultural communication, revealing its profound role in reshaping the cultural communication ecosystem. The findings demonstrate that the integration of AI is not merely a technological upgrade but a paradigm shift that redefines how cultural value is created, disseminated, and preserved.

The core of this transformation lies in the multi-level operating mechanisms established by AI. Through technical means such as data intelligence, cross-modal interaction, and scenario perception, AI deconstructs and reconstructs the entire process of cultural communication. Data intelligence enables the deep mining and semantic understanding of cultural resources, transforming intangible heritage into structured, analyzable digital assets. Cross-modal interaction—the ability to translate between text, image, audio, and video—breaks down sensory barriers, allowing ancient scripts to be vocalized and static artifacts to be experienced in dynamic, immersive formats. Furthermore, scenario perception, powered by computer vision and ambient intelligence, allows communication platforms to adapt content in real time to the user's context and emotional state, creating highly personalized and engaging cultural experiences. This reconstruction of production, distribution, and reception is propelled by a powerful, self-reinforcing cycle of demand pull from audiences seeking richer experiences, technology push from continuous algorithmic innovation, and ecological synergy among various stakeholders in the cultural value chain.

Building upon these mechanisms, AI constructs multi-dimensional innovation pathways that move beyond simple digitization. The first pathway is the digital reconstruction of cultural resources, which goes beyond mere preservation to create living, interactive digital twins of cultural assets. The second is the innovation of content production paradigms, where generative AI assists in co-creating content, and algorithmic curation ensures that relevant cultural narratives reach the right audiences. The third pathway involves the intelligent reconstruction of communication channels, fostering the formation of interest-based communities and enabling seamless cross-platform dissemination. This transforms cultural communication from a one-way broadcast into a networked, participatory dialogue.

Ultimately, these intertwined mechanisms and pathways generate a cascade of synergistic effects. Internal resource optimization is achieved as AI streamlines archival processes and unlocks the latent value within digital repositories. External network effects are activated as user interactions within intelligent platforms generate new data, which in turn refines algorithms and enhances the ecosystem's value for all participants, creating a virtuous cycle of growth and engagement. The highest-level synergy is social value co-creation, where AI facilitates collaborative projects between institutions and the public, empowers marginalized

cultural expressions, and fosters a global, inclusive dialogue about cultural sustainability. This tripartite synergy ensures that AI-driven cultural communication is not only more efficient but also more resilient, participatory, and aligned with broader societal goals.

This framework breaks through the limitations of prior research that often focused on a singular dimension, providing a holistic explanatory chain that addresses "why it works, how it is implemented, and what effects are produced." It not only parses the role of individual technologies or cases but also reveals the intrinsic linkages and feedback loops among mechanisms, practical innovations, and systemic synergy. This capability contributes to explaining the differential outcomes and evolutionary dynamics of AI-driven cultural dissemination across varying contexts, thereby possessing greater mechanism transparency and contextual adaptability.

In terms of practical value, the framework offers a structured action guide for relevant practitioners, including cultural institutions, technology developers, and policymakers. By distinguishing between mechanisms, pathways, and effects, practitioners can engage in more precise strategic decision-making: they can assess which foundational mechanisms are operative, determine which innovative pathways to adopt, and anticipate which synergistic values might be activated. This process facilitates the formulation of more systematic and forward-looking strategies. Furthermore, the framework's integrated analysis of ethical challenges and governance pathways helps steer responsible innovation. It aids in avoiding short-sightedness and mitigating risks in technology application, thereby promoting the realization of sustainability-oriented goals for AI in cultural dissemination.

However, the integration of AI into cultural communication is not without significant ethical challenges. The very capabilities that drive its benefits also introduce complex dilemmas. A primary concern is algorithmic bias and cultural discrimination (Hermann, 2022). Since AI models are trained on real-world data that often reflects existing cultural prejudices and power structures, they risk amplifying and entrenching these biases in cultural recommendations and content generation (Pavlik, 2023; Van Dis et al., 2023). This can lead to the systematic underrepresentation of minority and marginalized cultures, thereby exacerbating cultural inequality and potentially weakening the cultural identity of vulnerable groups.

Furthermore, AI models optimized for global engagement may inadvertently promote cultural homogenization, eroding local distinctiveness and diversity in favour of globally palatable, mainstream content (Xavier and Korunka, 2025). Another critical issue is the crisis of subjectivity and authenticity. The proliferation of AI-generated content blurs the lines of cultural authorship and innovation, raising questions about copyright, attribution, and the very nature of authentic cultural expression (Divon and Ebbrecht-Hartmann, 2025). Over-reliance on technical mediation may also impoverish the interpersonal and emotional dimensions that are central to profound cultural experiences.

To navigate these challenges, a proactive and multi-faceted governance framework is imperative. This framework should be built upon three core pillars: the construction of ethical norms, pluralistic co-governance, and technology-driven governance (De Almeida et al., 2021). First, it is essential to establish a robust system of ethical norms that moves beyond general principles to address the specificities of cultural communication. This system must prioritize the protection of cultural diversity, value rationality, communication fairness, and user rights, embedding principles like algorithmic fairness and data privacy

directly into the AI development lifecycle (Alsaleh, 2024; Morley et al., 2020). Second, effective governance requires pluralistic collaboration among a network of stakeholders, including governments, technology firms, cultural institutions, academia, and user groups (Birkstedt et al., 2023). Each actor has a distinct role: governments in regulation and guidance, corporations in primary responsibility and ethical-by-design product development, cultural institutions as gatekeepers of cultural value, academia in providing theoretical and technical support, and users in social supervision. Through mechanisms like co-construction of rules and joint evaluation, this network can achieve a synergistic shift from fragmented to systematic governance (Wirtz et al., 2022). Third, technology itself must be harnessed for governance. This involves creating technical solutions such as AI-content identification and traceability systems using digital watermarking and blockchain (Cao, 2022; Clough and Wu, 2022), developing tools for algorithmic transparency and interpretability, and building digital rights management mechanisms to protect cultural intellectual property.

Ultimately, the governance of AI-driven cultural communication must evolve towards a model of responsible innovation and adaptive governance. This requires forward-looking assessment of long-term impacts, especially with the advent of technologies like generative AI and brain-computer interfaces (Gholizadeh HamlAbadi et al., 2024). It also demands a commitment to inclusive development, ensuring that the benefits of AI are equitably distributed and do not exacerbate the digital divide for smaller cultural institutions or marginalized communities (Kolotouchkina et al., 2022). The final goal is to construct a harmonious ecosystem where technological innovation, humanistic spirit, and ethical governance mutually reinforce one another, ensuring that AI acts as a constructive force for cultural prosperity and sustainable development (Chen et al., 2023; Lu et al., 2024).

8 Conclusion

The findings of this research contribute significantly to both theory and practice. Theoretically, they enrich the understanding of the underlying principles governing sustainable cultural communication in the AI era. Practically, they offer critical implications for innovation at multiple levels. At the micro level, cultural institutions and technology enterprises are advised to seize the opportunities for full-chain transformation offered by AI, moving beyond single-point applications toward systematic innovation. At the meso level, the cultural industry as a whole needs to foster an open and collaborative ecosystem to facilitate resource sharing and capability complementarity. At the macro level, policymakers must strive to strike a balance between incentivizing innovation and preventing potential risks, thereby guiding the healthy and orderly development of AI-driven sustainable cultural communication.

9 Limitations and future directions

This study is subject to certain limitations. First, the application of AI in sustainable cultural communication is still in a phase of rapid evolution, with new models and case studies continuously emerging, making it challenging for a single study to capture all existing practical forms exhaustively. Second, constrained by data availability, the research relies primarily on public case studies and literature analysis,

lacking support from large-scale empirical data. Third, although both WOS and Scopus are internationally recognized comprehensive academic literature databases, boasting advantages such as extensive journal coverage and high academic recognition, and thus capable of providing representative literature sample support for this study, they have obvious linguistic biases. The included literature is dominated by English-language outputs, which may lead to the omission of relevant research findings in non-English contexts. Meanwhile, some unpublished research results and grey literature in emerging fields have not been fully covered. Finally, the evaluation of the effects of AI-driven cultural communication, particularly the assessment of its long-term cultural impacts, necessitates sustained and longitudinal research.

Future research should explore several promising directions. First, there is a need to construct a comprehensive evaluation system for AI-driven sustainable cultural communication, which requires establishing a multi-dimensional and long-term indicator framework. Second, cross-cultural comparative studies are essential to investigate the application differences and effect variations of AI across diverse cultural contexts. Third, future research could further integrate regional academic databases such as China National Knowledge Infrastructure (CNKI), and proactively incorporate multilingual research literature, thereby expanding the geographical and linguistic coverage of the literature and enhancing the comprehensiveness and representativeness of the research sample. Fourth, research could focus on AI communication models within specific cultural domains (e.g., intangible cultural heritage, ethnic minority cultures) to enhance the targetedness and adaptability of solutions. Finally, exploring the compound impacts arising from the integration of AI with other emerging technologies (such as blockchain, the Internet of Things, and brain-computer interfaces) on cultural communication will be crucial for understanding future trends under the effect of converging technological clusters.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

BZ: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. YY: Conceptualization, Formal

analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. RX: Resources, Software, Visualization, Writing – original draft, Writing – review and editing..

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that Generative AI was not used in the creation of this manuscript.

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