



Mechanisms and effects of the sustainable integration of digital-driven rural cultural tourism from the perspective of symbiosis

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ABSTRACT

On the basis of the principles of symbiosis theory, this paper first analyses the mechanism of the sustainable integration of digitally driven rural cultural tourism and then analyses its driving effect in detail through the construction of an evaluation system and the calculation of the entropy weight via the TOPSIS method. The results indicate that, the sustainable integration system of rural cultural tourism from a symbiotic perspective can be categorized into three subsystems. Specifically, digital technology facilitates the sustainable integration of rural cultural tourism by enhancing the efficiency of symbiotic unit coordination, enabling the visualization of symbiotic environment monitoring, and promoting the intelligence of symbiotic mode innovation. Digital tourism enterprises and merchants, e-commerce platforms, and social engagement levels constitute critical factors influencing the sustainable integration outcomes of digitally driven cultural and tourism resources. These driving forces exhibit a progressive characteristic of "digitalization-digitization-intelligentization" in promoting sustainable cultural-tourism integration. However, problems such as the digital divide, information security, and insufficient talent remain, so the joint efforts of multiple rural actors are needed to achieve innovative, intelligent, and sustainable digital cultural tourism development.

1. Introduction

As digital technologies such as big data, the internet, and artificial intelligence continue to advance rapidly, they have significantly impacted various aspects of tourism, from travel and planning to industrial management and operations, as well as cultural experiences and consumption. These technologies have emerged as crucial drivers of the growth of cultural tourism [1]. The countryside, with its excellent ecological environment, unique folk culture, and rich tangible cultural heritage, has often become a cultural tourism destination for people to cultivate humanistic sentiment and experience national customs [2]. In the era of rapid global digitalization, digital technology can empower cultural tourism in the countryside and promote its high-level, high-quality, and deep-level sustainable integration and development. These technologies also bring fresh vigor and impetus to rural cultural tourism.

The origin of cultural tourism can be traced back to the Grand Tour era in Britain. Since then, tourists have been paying increasing attention to the historical culture of tourist destinations and pursuing both material cultural landscapes and intangible cultural experiences while

traveling [3]. At the start of the 21st century, cultural tourism comprised 40% of global tourism expenditure, emerging as a significant trend in the international tourism sector. UNESCO has recognized it as a vital component of international tourism and an emerging form of travel [4]. The countryside stands out from other tourist destinations because of its distinctive "rurality." Its natural landscape, historical and cultural heritage, and tangible resources provide a strong foundation for the development of cultural tourism, making it a crucial driver of global cultural tourism [5,6]. As rural cultural tourism has developed, problems such as cultural homogenization, overcommercialization, and a single tourism experience have gradually emerged. Thus, researchers have begun to integrate the principle of "sustainable development" into the tourism sector to foster the sustainable growth of rural cultural tourism. This is achieved by maintaining a dynamic balance between the rural ecological environment, the tourism economy, social stability, and cultural authenticity [7–10]. Specifically, the sustainable development of rural cultural tourism is influenced by several key factors, including government policies and tourism planning, local residents' involvement in tourism activities and their cultural identity, and various aspects of

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tourists' experiences and perceptions of rural culture [11,12]. These elements require coordination among different stakeholders to ensure a balanced alignment of interests and social relationships [13]. With respect to the development of the cultural tourism sector, researchers have investigated the integration and evolution of various cultures within the tourism industry. This includes the merging of agricultural culture, folk traditions, or local heritage with tourism. Such studies often employ comprehensive analytical methods, such as mathematical modeling, spatial analysis, or grounded theory [14–16]. Unique cultural experiences can drive the expansion of the tourism economy and enhance the development of cultural tourism in rural regions. Tourism plays a vital role in promoting rural revitalization, enhancing the well-being of local inhabitants, and fostering cross-cultural interactions and integration. Rural culture and tourism have shifted from simple relationship of mutual promotion to symbiotic and integrated development [16–20].

With the rapid advancement of global digitalization, informatization, and intelligence, social productivity has changed greatly, and mankind has stepped into a digital society following agricultural and industrial societies. The digital transformation of global industrial elements, spatial configurations, and social networks has become a prominent trend in their development [21–23]. In the middle of the 20th century, the first generation of digital technology represented by computer technology began to be used in the collection, storage, and management of digital information by transforming information such as objects, text, and sound into a series of digital points or a collection of samples of discrete forms of expression of the data to achieve the permanent storage and online management of digital information [24]. In the 1980s, digital technologies began to be used to develop rural tourism, mainly to record and preserve information in digital images, digital texts, and digital models of traditional landscapes [25,26]. With the rapid advancement and widespread adoption of digital technology, its applications have expanded significantly across multiple facets of the tourism industry, such as regional planning and management, product development, and transportation [27–29]. At the social level of rural tourism sites, digital technology has triggered the reconstruction of rural space, the reorganization of social network relations, the innovation of cultural preservation and inheritance methods, and other changes. Digital technology has been integrated into industry, society, and the culture of rural tourism from a single point of line to a full range of aspects [30–32].

With the innovative development of technology and tourists' pursuit of a high-quality cultural tourism experience, pure digital technology empowerment can no longer satisfy the sustainable integration of cultural tourism, and a more refined, intelligent, and personalized application of digital technology is needed to realize the digital transformation of rural cultural tourism integration [33,34]. As digital technology has been further incorporated into rural cultural tourism, new concepts such as "Tourism 4.0," "Smart Tourism," and "Digital Cultural Tourism" have emerged and gained widespread attention [35–37]. Digital modeling software and technologies such as 3DMAX (3D Studio Max), MAYA (Autodesk Maya), and ArcGIS CityEngine can reshape the traditional cultural landscape of the countryside, and digital technologies such as big data, cloud computing, and artificial intelligence provide more possibilities for the product development and industrial innovation of cultural tourism enterprises. The utilization of virtual reality (VR), augmented reality (AR), and mixed reality (MR) can offer tourists an immersive cultural tourism experience, enhancing their emotional connection and deepening their appreciation of traditional rural culture [38–41]. Numerous studies and practical examples have shown that digital technology can substantially enhance the economic sustainability of rural tourism, foster collaboration and interaction among stakeholders, and facilitate the innovative preservation of cultural heritage [42,43]. It is a critical factor for the sustainable and integrated development of rural cultural tourism [7,44,45].

To date, many studies have examined topics such as rural cultural

tourism, sustainable cultural tourism, and digital cultural tourism. However, the examination of how digital technology can promote the sustainable integration of rural cultural tourism, including its driving mechanisms and effects, is still relatively limited. Thus, this paper introduces symbiosis theory and builds a theoretical framework for the sustainable integration of rural cultural tourism driven by digital technology. It analyzes the driving mechanism and, through the entropy weight TOPSIS method, deeply analyzes the effects of digitally driven rural cultural tourism sustainable integration with Xijiang Thousand Households Miao Village (XJTHMV) as a case study. This research enhances the theoretical framework of sustainable integration in digital cultural tourism, identifies the challenges and issues faced during the digital transformation of rural cultural tourism, and provides valuable recommendations for achieving the sustainable development of rural cultural tourism.

2. Theoretical framework and mechanistic analysis

2.1. Symbiosis theory

The concept of "symbiosis" was initially introduced by the German biologist Anton de Bary and subsequently enriched and refined by scholars (e.g., Andrei Famintsyn, Paul Buchner), gradually evolving into the theory of symbiosis. The core definition of symbiosis theory posits that different organisms form stable, long-term interactive relationships in a specific environment through the exchange of matter, energy, or information, ultimately achieving dynamic stability and coevolution of the entire system. This theory involves three core elements: symbiotic units, the symbiotic environment, and the symbiosis mode [46]. Symbiotic units are the basic material entities for the production and exchange of symbiotic energy, serving as the direct actors in symbiotic system activities. Composed of qualitative and quantitative parameters, they determine the state and changes of the symbiotic system. The symbiotic environment constitutes the external condition for the existence and development of symbiotic units, which act as the medium and carrier for the circulation of symbiotic energy. The symbiotic mode, also known as the symbiotic relationship, involves the way in which symbiotic units exchange energy and interact with each other. It can be classified into parasitism, commensalism, asymmetric mutualism, and symmetric mutualism based on behavioral differences, and into point, intermittent, continuous, and integrated symbiosis based on organizational operation [47].

In the evolutionary process of the symbiotic system, symbiotic units form the foundation; their organization and interaction shape the symbiotic mode, which in turn influences the state of the symbiotic environment. The symbiotic environment serves as the carrier, constraining the behavior of symbiotic units and the choice of symbiotic mode. The symbiotic mode acts as the link, embodying the interactive relationship between symbiotic units and directly impacting the development of the symbiotic system. These three aspects are interdependent and mutually influential, forming a dynamically balanced symbiotic system through the exchange of matter, energy, and information.

With the development of multidisciplinary cross-fertilization, symbiosis theory has received increasing attention and has been widely applied in the fields of sociology, economics, and management. In 1984, Peter F. Stringer incorporated the concept of symbiosis into geographical studies, emphasized the connection between psychosocial factors and tourism, and pioneered research on tourism symbiosis [46]. Domestic and foreign scholars have explored the cooperative symbiosis of ecological resources, agriculture, and forestry with tourism at the level of environmental protection [48]. At the societal level, scholars have explored the interplay among aspects of employment structure, local politics, and stakeholder relations with tourism and their synergistic development with the tourism industry [49]. In terms of local culture, the emphasis is on the symbiotic relationship between rural culture and tourism. This involves examining symbiotic mechanisms and models

and suggesting effective strategies to promote the mutual development of cultural tourism [50,51]. Overall, the research on tourism symbiosis has focused on the static perspective, the relationships between symbiotic units, the interactions among symbiotic elements, and the mode and other current issues.

However, with the modernization and informatization of rural, digital technology has increasingly become a binding agent for the symbiosis of rural cultural tourism. Elements such as the symbiotic units, environment, and modes of cultural tourism have undergone drastic flux and transmutation. There is an urgent need to focus on the driving role of digital technology in rural cultural tourism and to deepen research from a dynamic perspective on the sustainable integration of digitally-driven cultural tourism, promote the digital transformation of rural cultural tourism.

2.2. Framework for the sustainable integration of rural cultural tourism from the perspective of symbiosis

Symbiosis theory explains the internal mechanism by which symbiotic units form stable and interdependent symbiotic patterns through resource exchange within a specific symbiotic environment. This theory effectively interprets the changes and connections among various elements in the sustainable integration of rural cultural tourism, making it applicable to research on integration [51]. In the symbiotic system of the sustainable integration of rural cultural tourism: ① Actors such as local governments, tourism enterprises, individual merchants, mass tourists, and villagers constitute the symbiotic units of the sustainable integration of rural cultural tourism. Through their control, competition, and cooperation over rural cultural tourism resources, they form a symbiotic relationship characterized by interdependence and collaborative progress. ② The natural ecology, history, culture, and infrastructure of rural areas form the foundation for sustainable cultural tourism integration. These elements evolve with the development of rural cultural tourism, creating a symbiotic environment under specific temporal and spatial conditions. ③ The rural cultural tourism industry acts as the link for resource exchange among symbiotic units. The structure and operation of the industry reflect the symbiotic pattern of rural cultural tourism, which is influenced by the actions of symbiotic units and the conditions of the symbiotic environment [52,53]. In summary, the sustainable integration of rural cultural tourism is a coevolutionary symbiotic system. The actors, spatiotemporal environment, and industrial system of cultural tourism correspond to symbiotic units, the symbiotic environment, and symbiotic patterns, respectively, collectively forming the

symbiotic system of the sustainable integration of rural cultural tourism. Symbiotic units such as local governments, tourism enterprises, individual merchants, mass tourists, and villagers, which use the dynamically stable symbiotic environment as a carrier, gradually form a diverse and mutually beneficial symbiotic pattern through resource exchange and cooperation in the cultural tourism industry (Figure 1). Ultimately, this achieves the goal of sustainable development of rural cultural tourism, namely, the symbiotic effect of collaborative value enhancement in cultural tourism [46].

2.3. Mechanisms of the sustainable integration of digitally driven rural cultural tourism from the perspective of symbiosis

On the basis of the theoretical framework established earlier, the symbiotic system for the sustainable integration of rural cultural tourism has emerged as a coevolutionary system comprising three core elements: symbiotic units, the symbiotic environment, and symbiotic modes. As a form of technological capital, digital technology is being increasingly incorporated into the domain of the sustainable integration of rural cultural tourism. It not only alters the interaction modes of symbiotic units but also constructs a symbiotic environment that blends the virtual and physical realms through data flow and intelligent algorithms, significantly enhancing the operational efficiency and value creation capabilities of the rural cultural tourism industry. By reshaping the capabilities of symbiotic units, reconfiguring the state of the symbiotic environment, and innovating the forms of symbiotic patterns, digital technology is gradually becoming the core driving force behind the sustainable integration of rural cultural tourism, propelling its digital transformation (Figure 2).

2.3.1. Symbiotic units synergize efficiently

Digital technology has changed the way villagers communicate and connect with migrant workers and consumers. The social network of rural cultural tourism has been restructured, which is reflected in the interactions among rural cultural tourism actors, power relations, and identity roles. First, in the interaction mode of actors, rural cultural tourism actors increasingly rely on mobile devices, the internet, and social media for interaction, extending from offline cultural tourism information exchange to online information interaction and sharing, obtaining real-time cultural tourism policies through online platforms, and enjoying online cultural tourism products and services [54]. Traditional family and geographic relationships have been transformed into industrial and network relationships. Second, digital technologies

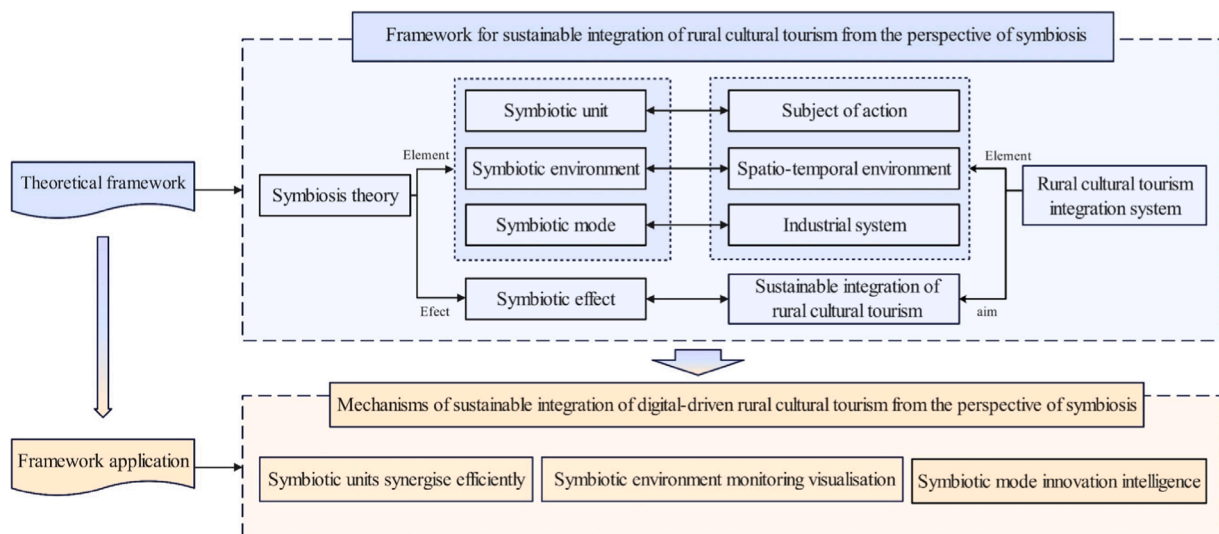


Figure 1. Theoretical framework for the sustainable integration of digitally driven rural cultural tourism.

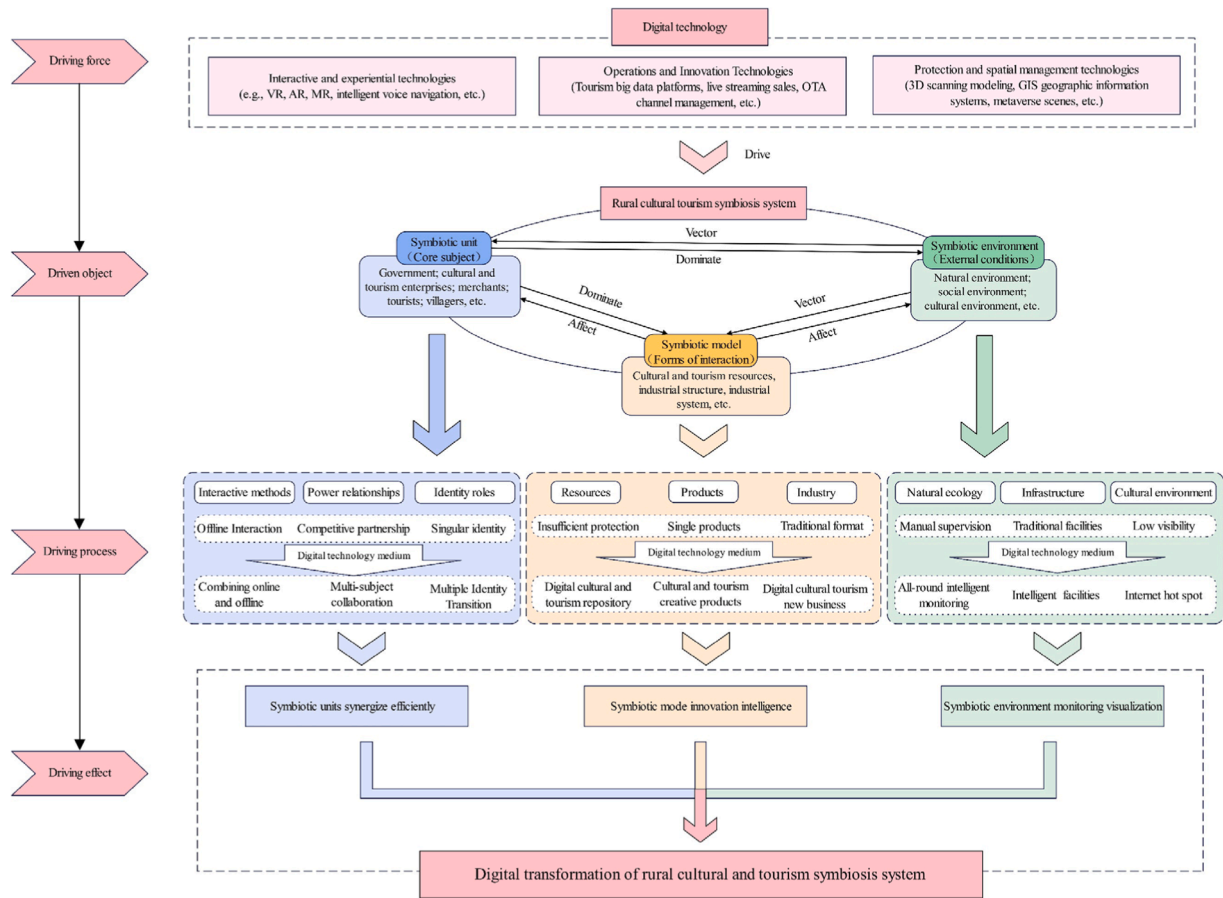


Figure 2. Schematic diagram of the mechanism of sustainable integration of digitally driven rural cultural tourism.

have changed the power relations among rural cultural tourism actors. Because of the political dominance of local governments, they often become leaders in the digital development of rural cultural tourism. Building an online intelligent management platform and improving digital infrastructure achieve refinement in managing rural cultural tourism and transparency in governance. Through online media, cultural tourism enterprises and merchants can accurately analyze consumer demand and preferences in the market, make scientific and reasonable industrial development plans and strategies, and understand the right to take the lead and initiative in the digitalization of the rural cultural tourism industry. Digital technology profoundly influences villagers' identity and status, increasing their participation, choice, and voice in the development of rural cultural tourism [55]. Mass tourists use digital information communication equipment and network media to obtain rural cultural tourism information, participate in rural cultural tourism construction and decision-making, increase their consumption demand for high-quality cultural tourism, stimulate the diversification of rural cultural tourism digital products, service intelligence, and experience virtualization. Finally, in the relationship network of rural cultural tourism reconstructed by digital technology, the identities and roles of different actors have changed. Local governments have assumed the roles of policymakers and market regulators in the digitalization of cultural tourism. Cultural tourism enterprises and merchants have become producers and market guides for digital cultural tourism products. Moreover, villagers and mass tourists not only contribute to and consume rural digital cultural tourism but also act as quality supervisors for products and services.

2.3.2. Symbiotic environment monitoring visualization

The ecological, social, and cultural environment of cultural tourism

is the vehicle for sustainable rural cultural tourism development, with flows and changes in the temporal and spatial dimensions occurring under the functioning of symbiotic units and the influence of digital technologies. Digital technologies enable the monitoring of the ecological environment and the optimization of cultural tourism infrastructure and sociocultural settings. In the ecological environment of the countryside, technologies such as remote sensing (RS), global satellite navigation and positioning systems (GPSs), and geographic information systems (GISs) can be used to monitor the situation and changes in the ecological environment, such as water quality, geology, and meteorology, in real time and then intelligently generate e-alarm preventive and responsive programs, thus further improving the early warning system for the ecological environment of the countryside. Comprehensive digital surveillance helps safeguard the pristine and stable ecological environment in rural areas, ensuring the sustainable development of rural cultural tourism. The digital infrastructure constitutes the bedrock for the digital production and consumption processes in rural cultural tourism, incorporating key components such as intelligent transportation systems, 5G communication networks, electronic ticketing services, online reservation platforms, digital surveillance systems, and advanced cultural tourism management platforms. Through this infrastructure, the intelligent monitoring and precise control of the government and cultural tourism enterprises on the production factors and the whole process of production of rural cultural tourism can be realized, and more convenient and intelligent cultural tourism services for public tourists can be provided. The symbiotic environment of rural cultural tourism encompasses not only the fundamental ecological and physical environment but also the important sociocultural environment. From the perspective of the countryside, the development of new media forms such as social network media attention, the popularity of digital

communication devices, and online live streaming have promoted the visibility and service improvement of rural cultural tourism, thus occupying a favorable position in the cultural tourism market. Mass tourists can access information about rural culture on the internet at any time and from anywhere and experience it through the virtual world of digital cultural tourism. This not only enhances tourists' cultural literacy but also facilitates the dissemination, exchange, and integration of rural culture. Within rural areas, the government has embraced the momentum of cultural tourism development by formulating and revising relevant plans and policies. It has also proactively introduced new cultural tourism enterprises and projects, providing essential institutional support for the sustainable integration of rural cultural tourism. A growing number of digitally savvy individuals from rural backgrounds are returning to their hometowns to establish businesses and dedicate themselves to the preservation and transmission of traditional rural culture, thereby driving the growth of the rural cultural tourism industry.

2.3.3. Symbiotic mode innovation intelligence

The ongoing progress of digital technology has continually fueled innovation within the rural cultural tourism sector. In this sector, digital innovation has become essential for the sustainable integration of cultural tourism. Digital technology boosts the innovative capabilities of the rural cultural tourism sector and expedites its digital transformation [56]. This is accomplished through broadening the foundation of rural cultural tourism resources, designing creative cultural tourism products, and promoting new industry models [56]. Rural cultural resources serve as the foundation for the sustainable integration of cultural tourism and constitute the core of this integration [39]. Technologies, including 3S (Remote Sensing, Global Positioning System, and Geographic Information System), close-range photogrammetry, and 3D laser scanning, can be utilized to gather a diverse array of rural cultural tourism resources. These resources can then be managed using computers and big data science to build a database and digital sharing platform for rural cultural tourism resources. This facilitates the permanent storage and shared management of rural cultural tourism resources, offering reliable and extensive data resources for the visual production and innovative development of these resources. The primary methods through which digital technology can promote rural cultural tourism products include the following: computer technology can be used to creatively design symbols of rural cultural landscapes and iconic heritage, producing rural cultural and creative products that are representative, commemorative, and artistic; and VR, AR and MR technologies can be used to integrate

rural folk culture, festivals, and dance performances with specific scenarios, creating immersive performance theatres, digital cultural experience halls, and virtual cultural experience projects. With the help of internet transaction platforms and intelligent logistics systems, an increasing number of Taobao villages are emerging, resulting in an integrated transaction system that combines online and offline transactions centered on consumers. Driven by digital technology, new business formats such as rural "cultural tourism + travel photography, wellness, and games" have emerged, and the cultural tourism industry has shown innovation, diversification, and high-quality development.

3. Empirical research: The effect of digitally driven sustainable integration of rural cultural tourism from the perspective of symbiosis

3.1. Research case and research methodology

In accordance with principles such as the typicality of the case site, information richness, and research feasibility, this study selected XJTHMV in Leishan County, Guizhou Province, as the research case (Figure 3). This village consists of over 1,400 households and a population exceeding 6,000, with the Miao ethnic group comprising 99.5% of the inhabitants. It is recognized as the world's largest Miao village. The village is built along the Baishui River along the mountainside, with more than a thousand stilt houses scattered at different elevations, resulting in a rich and diverse Hmong history and culture. It is thus also known as the "Spirited Away" world of Miao ethnic customs [57].

In 2008, the third Guizhou Tourism Development Conference took place in XJTHMV, marking the beginning of its cultural tourism development. In 2014, the cultural tourism industry in the village developed a collaborative model involving multiple stakeholders, with government leadership, enterprise management, and villager participation. In 2019, the COVID-19 pandemic presented major challenges to the cultural tourism development of the village, yet it also expedited the digital transformation of the cultural tourism sector. Since the initiation of cultural tourism in XJTHMV, diverse stakeholders have worked together, achieving mutual advancement. They have underscored the equal significance of preserving culture and fostering tourism growth alongside the fusion of cultural heritage with technological advancements. This collaborative effort has propelled the digital evolution of cultural tourism in the Village.

This research examines the influence of digital technology on the sustainable development of rural cultural tourism, focusing on Xijiang

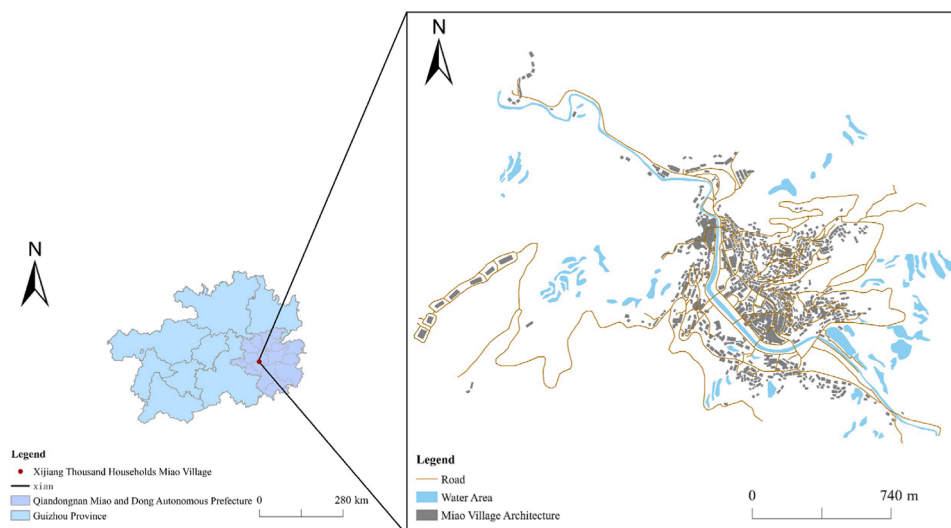


Figure 3. Overview of the Xijiang Thousand Households Miao Village area.

Miao village as a case study and utilizing the entropy weight TOPSIS approach. First, the entropy weight TOPSIS method can be used to comprehensively consider information on digital infrastructure, digital talent, digital culture, and the tourism economy. This approach ensures a thorough and precise representation of the current state of digitally driven sustainable integration in rural cultural tourism. Second, the entropy weight TOPSIS method can dynamically evaluate trends in the sustainable integration of digitally driven rural cultural tourism and objectively illustrate the process and impact of digital transformation in this sector. Finally, the method can periodically evaluate and analyze the effectiveness of the sustainable integration of digitally driven rural cultural tourism, enabling the timely identification of issues and shortcomings and the development of locally tailored digital transformation plans and strategies. The entropy weight TOPSIS method also has limitations, particularly in the selection of indicators, which can be influenced by the researcher's subjective factors, potentially leading to biases and robustness issues [58]. Thus, this study first develops a framework and analyzes the mechanism of the sustainable integration of digitally driven rural cultural tourism using symbiosis theory. This approach can effectively mitigate issues such as subjective bias and aid in a deeper interpretation of the driving effect results.

3.2. Selection of indicators and data sources

On the basis of a combination of the theoretical framework and mechanism analysis of the "digital-driven sustainable integration of rural cultural tourism" discussed above, nine indicator factors from the three aspects of the symbiosis unit, symbiosis environment, and symbiosis mode are selected for this study. These are combined with the actual development of Xijiang Miao village to establish an effect evaluation system for the sustainable integration of digital-driven rural cultural tourism. The symbiotic unit includes local governments, villagers, tourists, digital cultural tourism enterprises, and other actors. Local authorities propel the digital transformation of cultural tourism by making investments. Digital cultural tourism enterprises and merchants are the primary producers in the digital cultural tourism industry. Villagers and tourists engage in the sustainable integration of digital cultural tourism via online platforms, including digital government services and tourism websites. In terms of the symbiotic environment, intelligent monitoring systems such as geology, meteorology, and traffic can effectively monitor changes in the physical surroundings of rural cultural tourism. The popularity of digital mobile devices has improved the efficiency of cultural tourism transactions and the convenience of communication, and the Baidu search index reflects the degree of attention and cultural tourism influence of Xijiang Miao Village across the country. With respect to the symbiosis model, cultural heritage is digitized and stored as cultural tourism resources, and innovative digital cultural tourism products are developed to achieve the digital transformation of cultural heritage. Digital cultural tourism professionals are a vital force in the innovation and development of this industry, and their proportion can indicate its growth potential. The transaction volume of digital cultural tourism products also reflects the extent of the sustainable integration of digitally enabled rural cultural tourism. Overall, this indicator system provides a comprehensive and systematic evaluation of the digitally driven sustainable integration of rural cultural tourism.

Drawing on the historical development of cultural tourism in Xijiang Miao village, this study examines and gathers data on the digital advancement of cultural tourism in the village from 2008 to 2023. First, data on digital cultural tourism from online channels and platforms, including online platforms such as the "Guizhou Provincial Government Data Open Platform," "Leishan County People's Government Website," "Xijiang Thousand Households Miao Village Official Website" and "Tianyancha (China's leading business query platform)" and e-book data such as "The Xijiang Model – Xijiang Thousand Households Miao Village Scenic Area Ten-Year Development Report (2008–2018)" and "Research

on Xijiang Thousand Households Miao Village" were collected for this study. The administrative boundary data used in this study were sourced from China's official public geographic information service platform, "Tianditu National Platform" (<http://www.tianditu.gov.cn>). The base map of the XJTHMV was derived from Google Earth satellite imagery. All the raw datasets were vectorized using ArcGIS 10.8 software and georeferenced using the WGS 1984 coordinate system for consistency. In terms of offline data collection, a preliminary survey was conducted in the village in February 2024, followed by a 7-day field visit in April of the same year. In accordance with the principles of purposeful sampling, diversity, and saturation for interviews, 34 individuals, including government staff, executives and employees of digital cultural tourism enterprises, tourists, and villagers, were interviewed offline. Each interview lasted between 30 and 100 minutes and focused on the digital development of cultural tourism. Subsequently, follow-up interviews were conducted with some of the interviewees via email or WeChat to supplement and complete the relevant data. This study integrated data collected online and offline, ensuring the authenticity, accuracy, and scientific rigor of the research data through manual screening, follow-up verification, multiparty cross-checking, and comparison.

Following scholars such as Xin Wang, Le Zhang, Zhicai Wu, Xudong Guo and Hosseini, Seyyed Mehdi on entropy weight TOPSIS methods [59–62], the data were first normalized to obtain standardized values. To solve the potential problem of zero values, the standardized data were uniformly offset by 0.0001. Next, the entropy value for each index was computed, the weight of each index and the criterion layer were determined, and the system's performance evaluation was ultimately obtained through the calculation of the Euclidean distance and, subsequently, the relative closeness.

3.3. Analysis of results for driver effects

3.3.1. Analysis of the indicator layer and subsystems of the assessment system

On the basis of the weights of system indicators and subsystems determined using the entropy weight method, we can analyze the impact of these indicators on the sustainable integration of rural digital cultural tourism as well as the significance of the three subsystems. As shown in Table 1, the "number of digital cultural tourism enterprises and merchants," "digital cultural tourism product transaction volume," and "average daily Baidu search index" are the three indicators that most significantly influence the results of the driving effect. Among these, the indicator 'number of digital cultural tourism enterprises and businesses' has a weight of 0.209, indicating that these entities in XJTHMV are key participants in the digital cultural tourism network and the primary drivers of the development of the digital cultural tourism economy. The "digital cultural tourism product transaction volume" indicator also accounts for a large weight; the digital cultural tourism economy is the basis for achieving overall digital transformation. The transaction volume directly affects the economic status of digital cultural tourism and the entire process of the digital transformation of cultural tourism. The digital cultural tourism products of the village have gradually realized offline and online dual-channel sales, which has not only increased product sales but also improved the quality of tourism services and promoted the sustainable development of digital cultural tourism. The indicator "average daily Baidu search index" is weighted at 0.112, and as the largest search engine in China, the Baidu index represents the attention given to XJTHMV by all sectors of society and reflects the social environment for the development of digital cultural tourism. The Village has been reported and promoted by various media platforms such as Guizhou TV, CCTV (China Central Television), and Tencent News and has won the honorable titles of "New Landmark of China's Culture and Tourism" and "Open-air Museum of the Miao Ethnic Group," etc. Widespread media coverage has fostered a favorable social environment for the development of digital cultural tourism in the Village, attracting numerous visitors from both domestic and international

Table 1

Assessment system and indicator weights of the sustainable integration effect of digitally driven rural cultural tourism from a symbiotic perspective.

System level	Subsystems	Indicator layer (unit)	Indicator properties	Indicator weights	
Assessment system of sustainable integration effect of digitally driven rural cultural tourism under symbiosis perspective	Digital cultural tourism symbiosis unit	Amount of local government investment in digital cultural tourism (millions of yuan)	+	0.085	0.359
		Number of digital cultural tourism enterprises and merchants (number)	+	0.209	
		Number of valid opinions on tourism platforms (pieces)	+	0.065	
	Digital cultural tourism symbiotic environment	Intelligent surveillance coverage (%)	+	0.060	0.237
		Digital mobile device penetration (%)	+	0.065	
		Average daily Baidu search index (times)	+	0.112	
	Digital cultural tourism symbiosis mode	The proportion of cultural heritage that is digitized (%)	+	0.089	0.404
		Percentage of employed persons in digital cultural tourism (%)	+	0.109	
		Digital cultural tourism product transaction volume (single)	+	0.206	

markets and accelerating the growth of cultural tourism in the region.

Apart from the three indicators with the highest weights, the roles of the remaining indicators cannot be overlooked. Local governments play a pivotal role in digital cultural tourism infrastructure construction, scenic area management, and development planning for XJTHMV, serving as foundational support for the village's digital cultural tourism. Effective feedback from tourism platforms is a means for tourists to participate in and supervise cultural tourism development, facilitating a benign interaction between cultural tourism production and consumption and promoting personalized, distinctive, and intelligent development. Each indicator, to varying degrees, influences the state and outcomes of cultural tourism integration. Therefore, it is essential to adhere to the principles of multidimensional collaboration and precise policy implementation. This involves not only emphasizing the comprehensive balance between the digital cultural tourism economy, social development, and the ecological environment but also focusing on key areas to achieve breakthroughs, thereby driving the transformation

and upgrading of the village from a "resource-rich area for cultural tourism" to a "paradigm region for digital cultural tourism."

Through the calculation of the indicator layer score of the XJTHMV digital cultural tourism sustainable integration effect evaluation system and the scores of the three subsystems of the "symbiosis unit," "symbiosis environment," and "symbiosis mode," the impacts of the three subsystems on the development of the total system and their dynamic changes can be analyzed (Figure 4). The scores of the three subsystems show an overall gradual upward trend, but there are variations in the growth rates. The scores of the digital cultural tourism symbiosis unit and symbiosis mode subsystems exhibit a pattern of initial slow growth followed by rapid growth. In contrast, the score of the symbiosis environment subsystem demonstrates a trend of rapid initial growth followed by slower growth.

In the initial phase of the digital transformation of cultural tourism at XJTHMV, the local government first focused on the investment in digital infrastructure, the preservation of the Miao people's original ecological environment, and the publicity of social network media, so the comprehensive score of the symbiotic environment showed a significant upward trend. Moreover, the symbiotic unit relies mainly on the local government, the number of digital cultural tourism enterprises and merchants is insufficient, and many villagers do not participate; thus, both subsystems are in a relatively unstable development stage, which explains the relatively low score. In 2014, the digital infrastructure within Xijiang Miao Village gradually improved. Digital cultural tourism enterprises underwent structural reforms and industrial clustering, establishing relatively stable symbiotic relationships with the local government, residents, visitors, and other major digital cultural tourism sector stakeholders. The digital cultural tourism market is characterized by a diverse array of products and high-quality services, facilitating the industry's rapid growth. All three subsystems have entered a stage of stable growth. The scores of the three subsystems showed a smaller decline between 2019 and 2020 due to the COVID-19 pandemic, but between 2020 and 2023, Xijiang Miao village was able to seize online media traffic, focus on the application and innovation of digital technology, and expedite the digital transformation of cultural tourism.

3.3.2. Holistic analysis of the assessment system

Using the index weights obtained, we applied the TOPSIS model to compute the comprehensive score of the evaluation system for the sustainable integration of digitally driven cultural tourism at XJTHMV. Overall, the evaluation system's score shows a continuous upward trend, experiencing a process curve of initial growth, stable development, and rapid growth after changes in both directions. On the basis of the comprehensive score of the assessment system and the analysis of the subsystems, combined with the history of the evolution of digital cultural tourism in the village, the process of sustainable integration of digital-driven cultural tourism can be segmented into three stages: the digitization stage, the digitalization stage and the digital intelligence stage of cultural tourism (Figure 5).

From 2008 to 2013, digital cultural tourism at XJTHMV was just beginning, and the comprehensive score of the assessment system was low; however, owing to government policy support, the continuous progress of digital technology, and the effective fusion of cultural and tourism resources, the comprehensive score has steadily increased. Through the collaborative efforts of local government planning and investments from digital cultural tourism enterprises, the village has established a comprehensive intelligent visitor service center with 25 perimeter alarm systems, more than ten geological disaster monitoring devices, harmful oxygen ion monitoring equipment, and other digital infrastructure. These initiatives aimed to safeguard the ecological environment and social security of the village. In partnership with the village councils, the Leishan County government has implemented various cultural tourism programs and policies. They have also integrated advanced digital technologies, including GIS, satellite remote sensing, and photogrammetry, to gather, document, and preserve digital

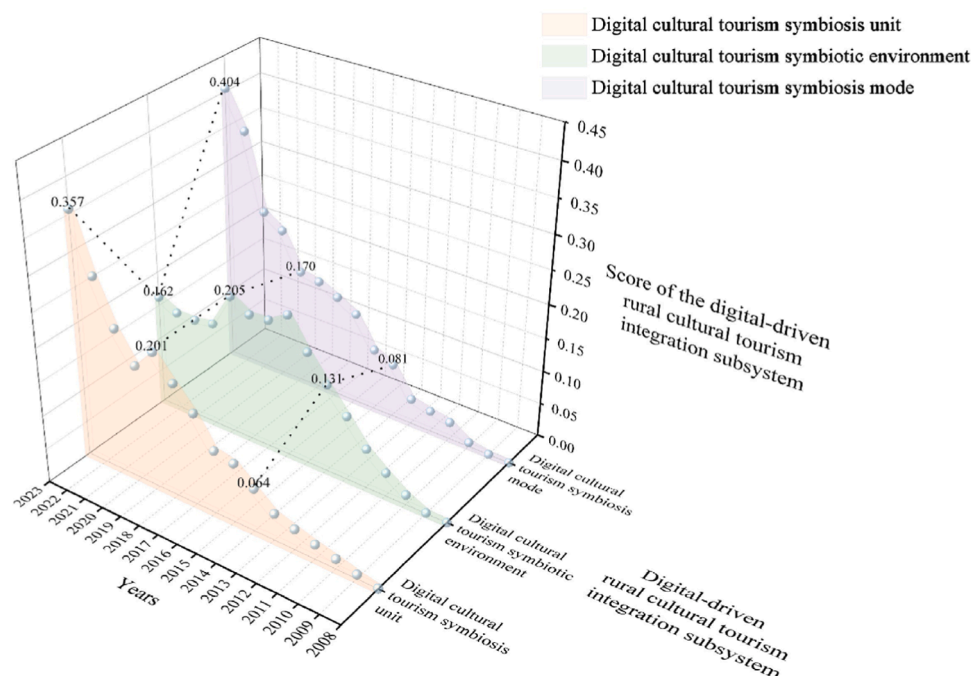


Figure 4. Subsystem scores of the assessment system for the sustainable integration effect of digitally driving Xijiang Thousand Households Miao Village cultural tourism, 2008-2023.

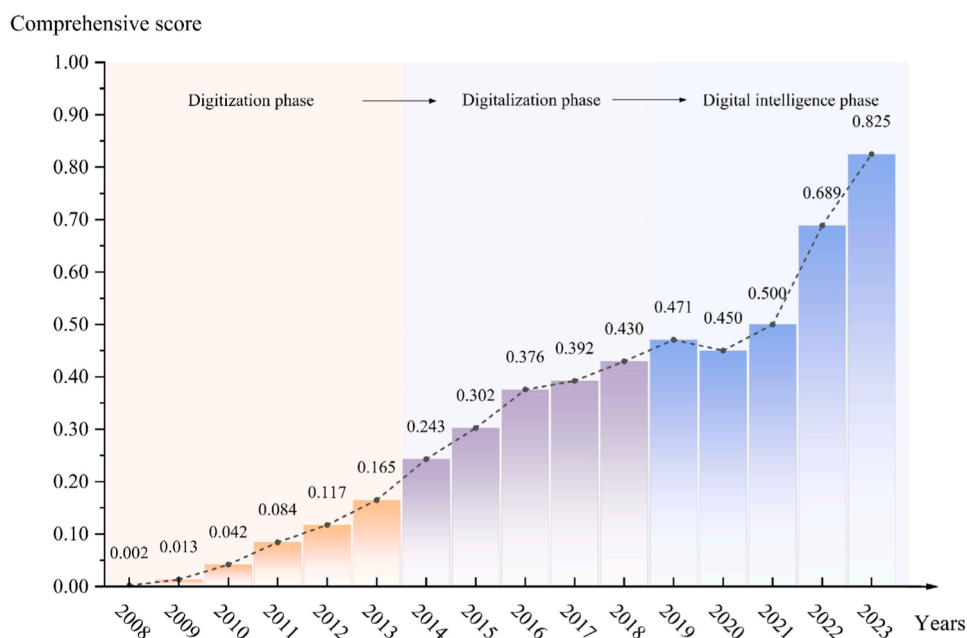


Figure 5. Assessment system score for the sustainable integration effect of digital drive culture tourism in Xijiang Thousand Households Miao Village from 2008 to 2023.

data on national, provincial, and significant local cultural heritage sites within the village. Additionally, they established a comprehensive digital cultural tourism database for XJTHMV. Additionally, an increasing number of villagers are taking the initiative to learn about digital technology, participate in training on digital cultural tourism services, and engage in the development of digital cultural tourism. From 2008 to 2013, the overall score of the evaluation system rose from 0.002 to 0.165, with a focus on developing digital infrastructure, gathering cultural tourism resource data, and promoting the use of digital devices.

Through the collaborative efforts of the local government of

XJTHMV, as well as its digital cultural tourism companies, residents, and visitors, digital cultural tourism has grown rapidly. From 2014 - 2018, the comprehensive score of the evaluation system increased from 0.243 to 0.430, demonstrating a consistent and stable upward trend. As digital cultural tourism has rapidly developed in the village, a symbiotic digital cultural tourism ecosystem has gradually emerged, with the local government as the legal subject of planning and management, digital cultural tourism enterprises and merchants as the market subjects that increase services and drive industrial innovation, villagers as the natural subjects of Miao cultural promotion and tourism development, and the

general public as the supervisory subjects of the tourist experience and feedback. A sound digital infrastructure has provided a solid basis for the development of the digital cultural tourism industry in the village. This infrastructure has facilitated the creation of digital cultural and creative products, such as AR postcards, AR stamp books, and Miao cultural fridge magnets, enabling the whole process of digital cultural tourism services, including pretrip online ticket purchases and accommodation bookings, in-trip smart guided tours and virtual scene experiences, and posttrip platform feedback and online shopping of products. According to the statistics of the cultural tourism enterprises, 90% of the villagers in the village are directly or indirectly engaged in the development of digital cultural tourism. Over 85% of the tourists discovered Xijiang Miao Village through mobile web pages, Xiaohongshu recommendations, Jieyin live broadcasts, and other online platforms. Additionally, 80% of the tourists complete ticket purchases, hotel and catering booking, and other online services.

The 2019 COVID-19 pandemic had a substantial impact on the cultural tourism industry of XJTHMV, with the overall score decreasing from 0.471 to 0.450. However, the pandemic also presented opportunities for the digital transformation of cultural tourism. This village has progressively shifted from basic digital production to advanced digital and intelligent cultural tourism, aiming to innovate in the cultural tourism sector and develop new integrated business models. The overall score rose sharply from 0.500 to 0.825 between 2020 and 2023. Ctrip, Tongcheng, Meituan, Qunar, and other major online travel agencies have set up business in XJTHMV. The cultural tourism businesses in the village have largely established connections and collaborations through e-commerce channels, effectively promoting Miao-characteristic cultural tourism products and selling online virtual cultural and creative items. This fully leverages the advantages of the O2O e-commerce operational model. With the growth in demand for high-quality cultural tourism consumption, the government and cultural tourism companies have fully integrated Miao's stilt house architecture with nightscape modeling lighting and holographic projection technology to create the unique nightscape of "Spirited Away World — Xijiang Thousand Households Miao Village," enhancing the growth of the nighttime cultural tourism sector, including nighttime sightseeing, nighttime performance, and nighttime shopping. Through media platforms, digital cameras, and intelligent image processing technologies, the village has facilitated the enhancement and upgrading of its travel photography industry chain, achieving the integrated development and fusion of the "cultural tourism + travel photography" business model. By collaborating with NetEase games, a virtual game environment featuring authentic Miao ethnic elements has been developed, allowing players to explore Miao history and experience the allure of Miao culture. With the support of digital intelligence technology from Chongqing Lian'ou Technology Co., the "Xijiang Fantasy" metaverse cultural tourism project was created. Visitors wear MR glasses and travel through the ancient Miao village, experience the fusion of real and virtual scenes and gain an interactive, immersive, and in-depth cultural tourism experience.

4. Conclusions and discussion

4.1. Conclusion

In this paper, a theoretical framework for the sustainable integration of rural cultural tourism from the symbiotic perspective is developed, and the mechanisms of digitally driven sustainable integration in rural cultural tourism are examined. Using XJTHMV as an empirical case, the effectiveness of digitally driven sustainable integration of cultural tourism in this village is subsequently assessed through the entropy weight TOPSIS method. The key findings of this study are as follows:

- (1) Sustainable integration of rural cultural tourism constitutes a symbiotic system featuring coevolution among "symbiotic units - symbiotic environment - symbiotic modes". Grounded in

symbiosis theory, the system comprises three interconnected components: First, symbiotic units represent the key stakeholders (including local governments, tourism enterprises, visitors, and villagers) that collectively steer tourism development. Second, the symbiotic environment encompasses the physical and cultural contexts that serve as the foundation for these interactions. Third, symbiotic modes manifest through the structural and operational frameworks of cultural tourism industries, facilitating resource exchange among units. These subsystems exhibit mutual dependence and interaction jointly promoting sustainable rural cultural tourism development.

- (2) From a symbiotic perspective, digital technologies drive sustainable rural cultural tourism integration through three mechanisms. First, they reorganize social networks to enhance the coordination efficiency among symbiotic units. Second, their technological penetration enables real-time monitoring and visualization of the symbiotic environment. Third, they innovate industrial formats to intelligentize symbiotic modes. These digital transformations have emerged as the core drivers advancing the digital transition of rural cultural tourism.
- (3) The digitally driven effects on rural cultural tourism integration demonstrate progressive multifactor characteristics. Three indicators—digital tourism enterprises/ merchants, transaction volume of digital cultural tourism products, and the daily Baidu search index—significantly affect the results. While all three subsystems show steady score increases, their growth rates vary considerably. The comprehensive evaluation reveals a stepped growth pattern, illustrating a three-phase progression of "digitalization–digitization–intelligentization" in digitally driven sustainable tourism integration.

4.2. Discussion

The sustainable integration of digitally driven rural cultural tourism is a systematic, comprehensive, diverse process that involves the integration of multidisciplinary knowledge such as geography, information science, and sociology. The case of XJTHMV serves as a microcosm of China's rural cultural tourism digital transformation, offering valuable insights for systematically understanding digital tourism and promoting the integrated development of digital villages and cultural tourism. However, our evaluation results and observations of rural development reveal several problems, such as technological disparities, skilled labor shortages, funding gaps, cybersecurity risks, and digital literacy limitations—all requiring multistakeholder solutions [63].—as follows:

First, establishing a collaborative the governance system involving government, enterprises, and villagers is crucial. Local governments should actively formulate and implement regulations for rural digital tourism development, clarify digital intellectual property rights, and optimize benefit distribution among stakeholders. Innovative financing mechanisms such as special digital tourism bonds and financing platforms can address capital constraints while enhancing tripartite collaboration. The Wuzhen model ("government-guided fund + professional operators") in Zhejiang Province has successfully developed digital tourism products such as VR intangible cultural heritage experiences. Second, fostering value symbiosis among talent, technology, and data is essential. Enterprises can leverage platforms such as Douyin and Kuaishou to implement "new farmer training programs" focused on short video production and live-streaming e-commerce. Establishing distributed production networks connecting enterprise data platforms with mobile talent terminals, along with implementing "migratory engineer" programs for seasonal technical guidance, can increase local capacity. The JD.com "Jingzao" model demonstrates the successful application of digital order distribution and quality traceability systems, significantly improving production efficiency and service quality. Third, implementing a three-phase digital infrastructure development plan is recommended: government-led 5G network coverage and smart

monitoring equipment installation for basic smart scenic area construction; enterprise-supported digital tourism innovation projects developing specialized big data algorithms to cultivate digital capabilities; and the progressive establishment of digital tourism twin systems for optimizing business layouts and adjusting intangible cultural heritage experience routes based on visitor behavior data.

In addition to the above measures, an annual digital tourism integration evaluation system should assess smart device coverage, digital conversion rates of cultural resources, and digital transaction proportions, incorporating these metrics into local government performance assessments to ensure policy continuity. While this study provides an in-depth analysis of digitally driven sustainable rural tourism integration from a symbiotic perspective, certain limitations warrant attention. The research insufficiently addresses implicit dimensions such as local identity and cultural resilience under digital transformation. Future studies could integrate geographical and sociological theories with multidisciplinary methods to develop assessment models for intangible cultural elements.

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CRediT authorship contribution statement

Liguo Yang: Writing – review & editing, Conceptualization.
Wangfen Ning: Writing – original draft, Investigation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Liguo Yang reports financial support was provided by National Natural Science Foundation of China. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that has been used is confidential.

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