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Research on the Digital Narrative Expression Mechanism of Rural Intangible Cultural Heritage in the Context of Mediatization

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SUMMARY: *With the development of the digital age, the protection and transmission of rural intangible cultural heritage have encountered new challenges which cannot be solved by traditional means. To this end, this paper puts forward a digital narrative expression mechanism based on digital twin technology and builds a specific ecosystem model of rural intangible cultural heritage. The collection of primary information depends on the application of web scraping technology. Based on this, BIM technology and CIM technology can be used to create digital twins of physical spaces, thus ensuring spatial continuity of the rural intangible cultural heritage. As physical limitations, street width and building function obtained by BIM/CIM can regulate the behavior of the agent, and cultural inheritance rules stored in the knowledge graph of intangible cultural heritage will impose constraints on the decision-making process of the agent. The combination of the two produces a consistent space-behavior simulation. Through empirical research, fuzzy comprehensive evaluation of the digital narrative expression mechanism suggested above yields results as follows: Excellent (0.3969), Good (0.2081), Moderate (0.2067), Poor (0.1395), and Very Poor (0.0488). According to the maximum membership principle, the evaluation result of this mechanism is Excellent.*

KEYWORDS: *digital twin technology; intangible cultural heritage; knowledge graph; narrative expression mechanism*

1 Introduction

The constant evolution of technology and the changes taking place in society as a whole have led to digital archiving becoming a realistic approach to the protection of intangible cultural heritage (ICH) in recent years [1, 2]. Particularly when considering rural environments, where ICH represents the embodiment of traditional culture, the implementation of new digital technologies in the context of media is quite helpful [3, 4].

The intangible cultural heritage of rural regions takes up an important position in Chinese traditional culture. It is made up of various dialects, folklore, arts, and other forms associated with their specific culture [5, 6]. However, modern lifestyles and urbanization processes threaten the safety of this heritage [7, 8]. Conventional ways of dissemination like oral traditions and drawings are increasingly being deprived of their means of transmission. Thus, the problem of bottlenecks in inheritance of culture is becoming more apparent [9]. With digital

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technologies used for preserving intangible cultural heritage, there emerge many opportunities in the area of the rural transmission of such heritage [10, 11]. With the help of digital technologies, one can transform information about intangible heritage into digital documents, thus helping preserve it and ensuring that it remains available for study by future generations [12, 13]. Digital technologies in the area of the preservation of intangible heritage will ensure an expansion of the means of disseminating this heritage. Moreover, digital preservation of the heritage increases the efficiency of this process, saves time, and expands the scope of dissemination [14-16]. Digital technologies in heritage preservation include different ways of organizing heritage, among which are digital archives, digital exhibitions, and online learning platforms [17, 18]. Digital organizing and archiving of information related to intangible heritage provide convenient access to this information and facilitate further studying of it by future generations [19-22]. Virtual displays take advantage of multimedia approaches, utilizing imagery, videos, and audio content to showcase traditional cultures in ways that can make them more appealing and accessible. In turn, virtual exhibitions enhance the appreciation of audiences and create additional avenues for the propagation of intangible culture [23-25]. Online educational portals designed specifically for rural intangible heritage offer learners a chance to gain insight into their interests [26, 27]. Using such resources, the skills and knowledge inherent in the processes of intangible culture can be easily disseminated among future generations [28, 29].

Digital storytelling has become an important direction for rural ICHs in today's era. Apart from the preservation and transmission of ICHs, it has the potential to take them beyond their usual audience base. Reference [30] highlights the concept of interactive long-form digital storytelling as a way of disseminating information about ICHs, with special emphasis on the issues facing rural areas in terms of showcasing their cultural, social, and artisanal ICHs. Reference [31] discusses the importance of rural tourism for ICHs and elaborates on how technology is important in this context as an aid to online preservation, the development of learning tools and guidelines for ICHs, which would help rural companies design tourism products for sustainable tourism. Reference [32] discusses a project named "rurAllure," which aims to enhance the experience of pilgrims visiting heritage sites by developing culturally rich products based on rural heritage sites, using digital technology as the main mode of content delivery. Reference [33] evaluates the use of augmented reality technology in making cultural heritage tourism more feasible for less developed areas and its potential for contributing to sustainable rural development through tourism. Reference [34] analyses the application of mixed reality technology for heritage preservation and its effectiveness as an ICH presentation strategy along with its contributions to narrative theoretical frameworks. Reference [35] discusses a "physical-digital convergence" model for rural cultural heritage tourism, with strategies for consumer interaction and building destination resilience in both physical and digital modes. Reference [36] looks into the role played by social innovation in the context of rural Spain and shows how digital cultural heritage helps preserve and transmit local culture and tradition and social innovation boosts rural resilience. Reference [37] evaluates the impact of AI-generated content on cultural heritage through a case study on Cantonese cuisine ICHs, showing that AIGC narrative strategies work well for heritage promotion.

First, this paper conducts a discussion of the existing challenges in disseminating the rural intangible cultural heritage. Based on the existing challenges, this paper creates a digital framework of the rural ICH through the lens of the digital twin technology. In recognition of the complexity and multiple aspects of the preservation and development of rural ICH, the design of the rural intangible cultural heritage digital twin must accord with its essential characteristics, internal contradictions, and governance needs. This paper proposes the concept of digital twin ecosystem based on the existing demands regarding the digitalization of rural intangible cultural heritage. Web scraping technique can be adopted in raw data collection, and some relevant tools will also be applied in data preprocessing to guarantee the feasibility of the research findings. A narrative expression model of rural intangible cultural heritage will be created based on the application of the Building Information Modeling, City Information Modeling, knowledge graph constructed on the BERT-BiLSTM-CRF hybrid model, and multi-agent interaction.

2 Research on Rural Intangible Cultural Heritage Supported by Digital Twin Technology

2.1 Exploring the Challenges in Disseminating Rural Intangible Cultural Heritage

With the rapid urbanization of rural areas, fragmented media portrayals have led to the loss of authenticity in intangible cultural heritage transmission. Imbalanced rural power structures and the absence of cultural identity among villagers have caused the decontextualized development of intangible cultural heritage. Meanwhile, distorted value perceptions among villagers have resulted in chaotic commercialization. These phenomena not only pose a destructive impact on the authenticity and cultural substance of intangible cultural heritage transmission but also undermine the continuity of rural cultural inheritance and alter the original spatial character of these communities.

2.1.1 Fragmentation of Intangible Cultural Heritage Transmission Media and Loss of Authenticity

From the perspective of information reception and output in rural intangible cultural heritage dissemination, the public's curiosity-driven mindset, coupled with the fast-paced, fragmented nature of media transmission, has led to a sense of disorientation among audiences due to the limited nature of information input and reception [38]. The portrayal of intangible cultural heritage by media in fragments leads to distorted public recognition of its cultural essence. Being fixated merely on some surface and isolated phenomena makes it hard to connect to the humanistic values and local importance associated with them. In such a way, after being fed large volumes of content via mass media, people see only some modified version of intangible cultural heritage. Partiality of information dissemination and precise targeting in big data lead to trapping of users in the information bubbles. The consequences become obvious, with an extremely polarized public reception of messages about ICH via media.

2.1.2 Loss of Cultural Identity and Disconnected Development in Intangible Cultural Heritage

One cannot but emphasize the role of rural culture and the rural spirit since they are the means that allow building stable and harmonious social structures in which rural intangible cultural heritage can be passed and preserved. Rural traditions include some degree of cohesion and regionality as well as the unique character of the regional culture that makes intangible cultural heritage much more important than just the symbol of rural identity. In such a manner, the dissemination and exchange of it becomes an integral part of the process of maintaining and developing rural culture and its engagement with modernity. However, at the same time, such dissemination and exchange are far from being easy and problem-free. With the erosion of rural productive and life practices, the transfer of power over intangible cultural heritage from communities of local people and its bearers to capitalistic interests occurs. This change, in combination with weakened intrinsic connection of people with their culture, can destroy emotional links and lead to separation of cultural heritage from its context.

2.1.3 Misplaced Perceptions of Intangible Cultural Heritage Value and Commercialization Chaos

Fragments of tangible cultural heritage described by media result in misperceptions of their true nature within society. Since the focus lies on some particular aspects which appear superficial and isolated from their context, it is difficult for individuals to relate to their significance. In such a case, after consuming large quantities of information through mass media channels, they can only perceive some distorted form of intangible cultural heritage. Due to the selective nature of content distribution and precise targeting based on Big Data analytics, individuals become trapped within informational bubbles created around them. The results speak for themselves, with a highly polarized audience response to information about ICH via media channels.

2.2 Digitalization of Intangible Cultural Heritage

2.2.1 Primary Framework

Digital twin technology is an example of an emerging application pattern in which IoT, big data, and artificial intelligence are all integrated into a whole. In the case of rural intangible cultural heritage, it makes it possible to create digital replicas of heritage assets, thereby creating a truly novel way of implementing digital narrative expression. Moreover, not only does the technology provide the means for protecting intangible cultural heritage assets, but it also adds to the content of the cultural narrative, thereby stimulating the creation of new cultural tourism products. Further improvements of the technology will allow for even greater integration with artificial intelligence and IoT technologies, thus enhancing digital narrative expression potential for rural intangible cultural heritage assets even more. The future prospects of digital twins in this area look promising for the sake of preserving rural intangible cultural heritage.

2.2.2 Technical Modeling

The basis of technical modeling supports the operation of digital twin technology in the digital narrative expression approach concerning the rural intangible cultural heritage system. Based on technologies like data scraping, agent modeling, knowledge graph, BIM, CIM, and others, it facilitates the highly precise digital transformation of information on rural intangible cultural heritage assets. This not only provides the necessary infrastructure for further preservation and scientific study of rural intangible cultural heritage assets but also serves as an important base for building digital twin ecosystems.

3 Study Design

3.1 Building a Digital Twin Ecosystem

3.1.1 System Division

Rural intangible cultural heritage protection and development is a systemic project involving many fields of knowledge, engaging various participants, and achieving common goals. So complicated a system should always be decomposed into simpler sub-systems, to make the requirements of management bearable. In other words, there should be systematic classification of rural ICH, based on its own features, internal contradictions, and management needs.

Sustainable development of rural intangible cultural heritage can be viewed as dynamic equilibrium comprising preservation, transfer, and development of the object. And behind such an equilibrium lie systemic requirements for its physical protection, cultural revitalization, and the renewal of its social function. To achieve the purpose, rural ICH can be divided into three sub-systems: tangible heritage protection sub-system, intangible cultural heritage transfer sub-system, and neighborhood governance sub-system. This three-part division corresponds entirely to the three dimensions (physical, cultural, and social) of rural intangible cultural heritage. All three sub-systems are equally necessary. The absence of tangible protection would mean the loss of a material base of cultural heritage; the absence of transfer means the transformation of historic districts into mere physical objects; finally, without competent management rural intangible cultural heritage is doomed to gradual deterioration and inefficient administration. These three sub-systems together form an elementary structure for sustainable development of historic cultural districts, which may later be complemented by economic and digital sub-systems.

3.1.2 Digital Twin System Transformation

Digital twin systems act as a highly faithful replica of physical entities in the virtual world with the aim to monitor, predict and optimize physical entities using real-time data synchronization and simulation. As applications become more complicated, limitations of digital twin systems have been slowly revealed. Thus, in order to enable digital twins in the complex context of rural intangible cultural heritage, the idea of digital twin ecosystem should be introduced. Digital twin ecosystem focuses on coordination between entities in complex systems, which consider the system as multilevel network, consisting of entities-subsystems-ecosystems, by means of feedback loops from the physical and virtual side as well as dynamic interaction, making it possible to achieve system’s self-organization and self-optimization. By restructuring digital twin systems in technical and theoretical aspects, digital twin ecosystem offers a new perspective in implementing digital twins.

3.2 Core Steps for Building a Digital Twin Ecosystem

3.2.1 Data Acquisition

Rural Intangible Cultural Heritage Digital Twin Ecosystem Data Acquisition has been completed using web scraping method, thus completing the acquisition process for the data of rural intangible cultural heritage. The acquired data is preprocessed within the import processing software, achieving the maximization of applicability and reliability of future study results. This will provide considerable guidance in designing digital narrative expression mechanism of rural intangible cultural heritage.

3.2.2 Digital Twin of Physical Space

The construction of digital twins requires BIM and CIM data to be constructed first. BIM includes detailed information of single building models, and CIM includes spatial information from neighborhood scale to city scale. These two together form an integrated database for digital twins from "micro-structures to macro-systems". On the other hand, regarding data, BIM includes the static features of physical spaces of neighborhood, and CIM includes dynamic data collected through sensing technology. These two work together to achieve a 3D digital model formation of rural intangible cultural heritage. In this way, the physical space digital twins are formed, which becomes the basis of digital narrative expression mechanism.

3.2.3 Multi-Agent Systems

Multi-agent Simulation (MAS) is a simulation technique based on complex system theories. By designing several virtual agents having autonomous behaviors, it simulates the behavior rules, interactive relationships, and evolution of various entities in practical life situations. The multi-agent modeling technique is the necessary pre-condition for building the digital twins of intangible cultural heritage of rural areas. Neighborhood governance situations may comprise many entities such as residents, tourists, traders, officials, etc. Each entity can be allocated various attributes (age, taste, economy), along with some behavioral rules. Through simulations, it uncovers the dynamic nature of complex social systems to model the interaction and behavior of various entities associated with the dissemination of intangible rural cultural heritage.

3.2.4 Rural Intangible Cultural Heritage Knowledge Graph

Construction of the knowledge graph for rural intangible cultural heritage, which can be performed using a BERT-BiLSTM-CRF hybrid algorithm, will serve as the foundation for forming a digital twin of rural intangible cultural heritage transfer. It constructs a digital indexing system for cultural genes through "entity-relationship-attribute" triplets, then drives real-time updates to the knowledge graph using dynamic data streams such as inheritor activities, visitor interactions, and public sentiment trends, ultimately achieving a digital twin for cultural transmission. The ICH knowledge graph is a knowledge repository organizing ICH-related data as a structured semantic network. It transforms the aforementioned model into "entity-relationship-attribute" triples and establishes cross-dimensional associations, forming a machine-readable, inferable cultural cognition framework.

1) BERT

BERT utilizes the encoding component of the Transformer model for feature extraction. The structure of the Transformer encoder is shown in Figure 1. It simultaneously trains all words in a sequence, adding positional embeddings to each character. Every encoder has three modules: the multi-head attention process, the summation process, and the feed-forward process. The multi-head attention process produces deep bidirectional representations through the automatic creation of weight matrices based on correlation analysis according to equation (1):

$$Attention\left(Q,K,V\right)=soft\max\left(\frac{QK^{T}}{\sqrt{d_{k}}}\right)V \tag{1}$$

$Attention\left(Q,K,V\right)$ is the attention value obtained, which is fed back to the encoder to produce output features. Q, K, and V represent the query vector matrix, key vector matrix, and value vector matrix, respectively. Q, K, and V are obtained by multiplying the input matrix X by the weight matrices W^{q}, W^{k}, and W^{v}, respectively. d_k is the embedding dimension.

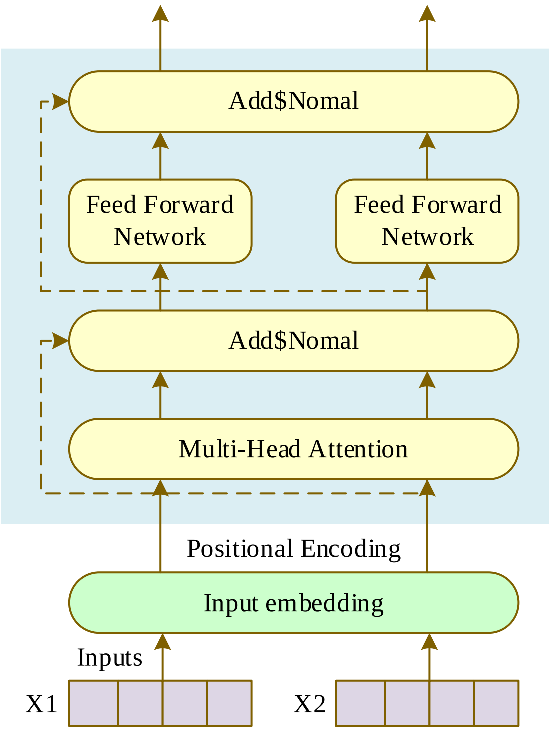

Figure 1: The structure of the Transformer encoder

Its input comprises three components: word embeddings, phrase embeddings, and position-encoded embeddings, represented by Equation (2). Specifically, it is as follows:

$$\begin{aligned} E = & \, TokenEmbeddings + SegmentEmbeddings \\ & + PositionEmbeddings \end{aligned} \tag{2}$$

2) BiLSTM Model

The Long Short-Term Memory (LSTM) networks represent a development of the Recurrent Neural Networks (RNNs). They are aimed at solving the problem of exploding gradient and vanishing gradient in conventional RNNs. These models perform very well when there is need for processing delayed events in time series. The LSTM network is comprised of three gates: the input gate, forget gate, and the output gate. The architecture of the LSTM cell is shown in Figure 2.

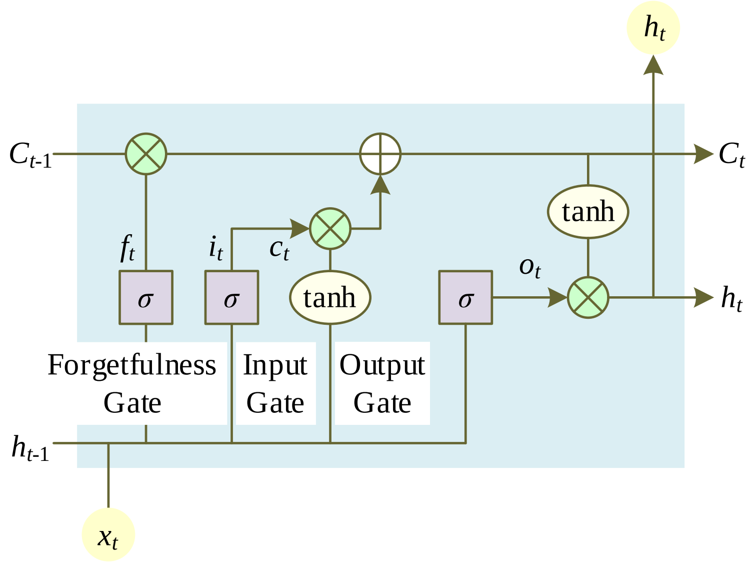

Figure 2: LSTM unit structure diagram

At time step t, the update formula for the LSTM unit is given by Equations (3) to (5):

$$\begin{pmatrix} f_t \\ i_t \\ o_t \\ \tilde{c}_t \end{pmatrix} = \begin{pmatrix} \sigma \\ \sigma \\ \tanh \\ \sigma \end{pmatrix} \left(WX_t + Wh_{t-1} + b\right) \tag{3}$$

$$c_t = f_t \odot c_{t-1} + i_t \odot \tilde{c}_t \tag{4}$$

$$h_t = o_t \odot \tanh\left(c_t\right) \tag{5}$$

where W and b are trainable variables connecting the two hidden layers. σ denotes the sigmoid function. X_t denotes the input sequence at time t. f_t represents the input gate, i_t denotes the forget gate, and o_t signifies the output gate. $\odot$ indicates the dot product operation. h_t represents the output of the LSTM unit at time t. c_{t-1} and h_{t-1} are representations of the preceding information.

Since the entities to be identified occupy different positions within a sentence, the contextual information carries varying significance for the text. The LSTM model cannot process contextual information simultaneously. The BiLSTM network model was proposed to better utilize contextual information. The fundamental concept behind this model is to design a neural network model based on LSTM using two layers of hidden states, as illustrated in Figure 3, with the hidden states from each layer of LSTM arranged in chronological and reverse chronological orders, yielding the sequences $\left[\vec{h}_1, \vec{h}_2 \cdots\cdots \vec{h}_t\right]$ and its reverse $\left[\overleftarrow{h}_1, \overleftarrow{h}_2 \cdots\cdots \overleftarrow{h}_t\right]$ are generated. These sequences are then input into the forward and backward LSTM layers, respectively. By connecting the output vectors of the two hidden layers, a global vector output is generated. The output $\vec{h}_i$ of the BiLSTM is defined as in Equation (6):

$$\vec{h}_i = \delta\left(\overrightarrow{h_i}, \overleftarrow{h_i}\right) \tag{6}$$

Here, δ is the function connecting the forward input and the backward input.

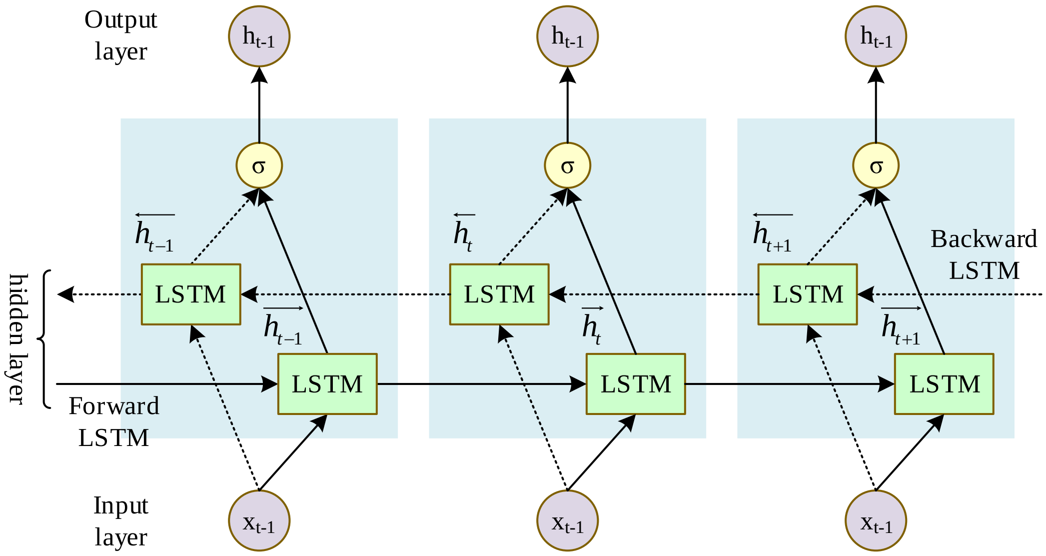

Figure 3: BiLSTM model structure

3) CRF Model

CRF is a kind of discriminative probabilistic model that has been extensively used for sequence labeling and data sequences analysis. For the task of named entity recognition (NER), the CRF model uses the result of the BiLSTM layer and finds the best sequence of predictions using the relationship between nearby labels. There are four major processes involved in the CRF layer:

(1) Computing the tag sequence score. Through calculating the transition score, we can constraints between labels to reduce the number of invalid predicted labels. For a given text, where $X = (x1, x2, \ldots, xn)$ is the input sentence and $y = (y1, y2, \ldots, yn)$ denotes the output, the tag sequence formula is shown in Equation (7):

$$Score(x, y) = \sum_{i=1}^{n}\left(P_{i,y_i} + A_{y_{i-1},y_i}\right) \tag{7}$$

Among these, A denotes the transition scores between sequence labels. The output results from the previous layer are recorded as the P matrix, $P = (p1, p2, \ldots, pn)$.

(2) Normalization. CRF normalizes to obtain the final output sequence y_t corresponding to the input sequence x_t. Given an input sequence x, the conditional probability formula for predicting the output sequence y is shown in (8):

$$P\left(y \middle| x\right) = \frac{e^{Score(x,y)}}{\sum_{y' \in Y_x} e^{Score(x,y')}} \tag{8}$$

Here, y denotes the true label value, and y' represents the predicted label value. Y_x denotes the sequence of all possible labels.

(3) Maximizing the probability of correct labels. During training, the log-likelihood of the correct label sequence is maximized through maximum likelihood estimation, as shown in Equation (9):

$$\log\left(p\left(y|x\right)\right) = Score(x, y) - \sum\nolimits_{y' \in Y_x}^{n} Score(x, y') \tag{9}$$

(4) Calculate the optimal sentence-level label sequence. Using the Viterbi algorithm, select the sequence with the highest total prediction score as the optimal sequence, as shown in Equation (10):

$$\bar{Y} = \arg\max Score(x, y'), (y' \in Y_x) \tag{10}$$

4) Knowledge Graph Construction

Construction of knowledge graphs includes two aspects: creation of the schema layer and expansion or modification of the data layer. Based on the analysis of ontology and text knowledge extraction technologies above, it is evident that domain ontology creation provides schema layer modeling for knowledge graphs, while text knowledge extraction enriches the data layer with domain-specific knowledge. Together, they form the architecture of knowledge graphs, serving as the foundation for domain knowledge representation and storage.

Knowledge representation and storage form the foundation for knowledge graph management and application. Knowledge representation templates such as RDF, RDFS, and OWL can all be used to construct knowledge graphs, employing a graph structure representation where vertices represent entities and edges represent relationships between entities. Knowledge storage involves retaining the knowledge graph in one or more knowledge representation models while being able to visualize the knowledge stored in it. Visualization in turn can be performed through knowledge database storage and visualization tools like Neo4j, FlockDB, and GraphDB. Amongst these, Neo4j is an important open-source graph database that can be used for visualizing knowledge graphs conveniently. The basic architecture of Neo4j graph database is based on four essential components: nodes, relationships, properties, and labels. Data is stored in Neo4j in a flexible graph network model format. Nodes are the main components of Neo4j database and are connected to each other through directed relationships. Labels identify the class of the node and help in categorization of nodes. Unlike traditional databases like MySQL, Neo4j graph database uses its own query language Cypher which enables easy query and update operations. One difference between Neo4j graph database and traditional databases like MySQL is the storage of data in flexible graph network models. Data in Neo4j is stored not in tabular form but semantically in relation to connections between entities. The architecture of Neo4j graph database comprises three vertical layers: interface layer, data management layer, and storage layer. Interface layer includes interfaces like traversal API, core API, and Cypher language. Data management layer includes concurrency locks, transactions, caching, and data storage facilities. Disk storage space forms the third and final layer.

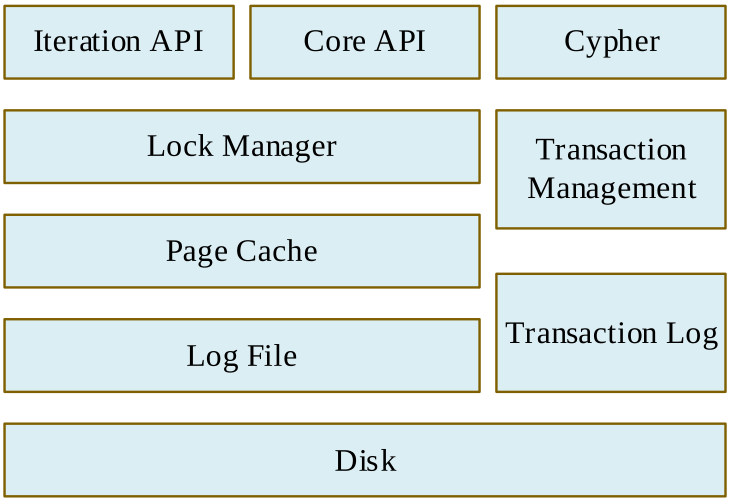

Figure 4: Neo4j architecture

3.2.5 Establish a Digital Narrative Expression Mechanism

To facilitate the implementation and preservation of rural intangible cultural heritage, a narrative presentation approach that is based on the "data interoperability-model linking" framework needs to be designed. In relation to data interoperability, the use of a standard semantic framework based on CityGML/IFC will ensure that BIM/CIM models, RDF triples of intangible cultural heritage knowledge graphs, and rules for multi-agent data behavior can coexist in an interoperable way, facilitating the integration of spatial coordinates, cultural features, and governance indicators across different domains. In the context of model linking, physical constraints such as street flow limits, spatial infrastructure constraints, and safety constraints will be provided by BIM/CIM models, while cultural knowledge graphs will contribute to the inclusion of rules related to the protection of intangible heritage. Multi-agent systems simulate merchant and resident behaviors, feeding back into spatial and cultural models to create dynamic “physical-cultural-social” interactions.

4 Empirical Research Analysis

4.1 Analysis of Rural Intangible Cultural Heritage Knowledge Graphs

4.1.1 Empirical Analysis of the BERT-BiLSTM-CRF Combined Model

(1) Evaluation Metrics

The commonly used measures in such cases are precision (P), recall (R), and their harmonic mean F1, as shown in Eqs. (11) to (13). In Eq. (11), TP represents the number of entities identified and also successfully mapped to labeled entities. FP represents the number of entities recognized but could not be mapped to any labeled entities. FN indicates the number of labeled entities which are not recognized by the model.

$$P=\frac{TP}{TP+FP} \tag{11}$$

$$R=\frac{TP}{TP+FN} \tag{12}$$

$$F1 = \frac{2PR}{P+R} \tag{13}$$

Traditional evaluation metrics can only compare results across different models but fail to identify relative advantages between models or the feature factors influencing model performance. Therefore, the Discrimination Power (DP) metric is introduced. That is:

$$DP = \frac{\text{The number of terms correctly identified by the model}}{\text{The number of terms that appear in the corpus}} \tag{14}$$

This study evaluates the model's performance in recognizing new words using accuracy, as shown in Equation (15). That is:

$$P = \frac{\text{The number of new terms correctly identified by the model}}{\text{Number of candidate terms}} \tag{15}$$

(2) Empirical Results Analysis

The characters in the existing vocabulary list were sorted by frequency from highest to lowest. Character frequencies were counted, with the top x% of characters classified as high-frequency and the remaining (1-x%) as low-frequency. Since multiple characters often share the same frequency, the frequency threshold closest to the target proportion was selected for segmentation when dividing the vocabulary list by frequency. The experiment divided the vocabulary into segments where high-frequency words constituted 0%, 10%, 20%, 30%, 40%, and 50% of the total. Results are shown in Figure 5. The model's accuracy increased as the proportion of high-frequency words rose, peaking at 98.88% when the proportion reached 18.44%. Beyond this point, accuracy showed an overall downward trend. The term discrimination capability DP value peaks at 89.26% when the proportion is 6.23%. Beyond this point, the DP value shows an overall downward trend as the proportion continues to increase.

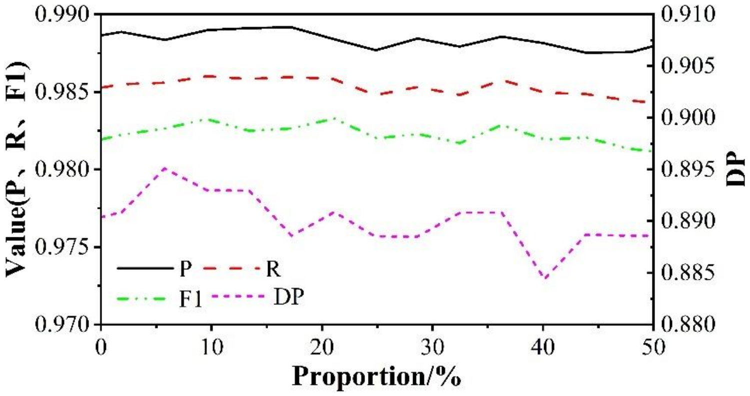

Figure 5: Experimental results of word list features

First, experiments were conducted by combining term annotation with dictionary features (DICT), part-of-speech features (POS), radical features (Radical), and pinyin features (Pinyin) to determine the impact of different features on the recognition accuracy of intangible cultural heritage ceramic terminology and the ability to distinguish between terms. The lexical feature (DICT) introduced in this and subsequent experiments represents the ratio of high-frequency to low-frequency characters identified during validation as yielding the highest F1 score. This involves sequence annotation of the text, with results shown in Figure 6. Comparative analysis revealed that the four features exerted minimal influence on the model's P-value, R-value, and F1 score. The term discrimination capability DP value showed a positive impact. After introducing the lexical feature (DICT), the DP value increased by 2.84%. The features with positive effects on DP value were ranked as follows: DICT > Pinyin > POS > Radical.

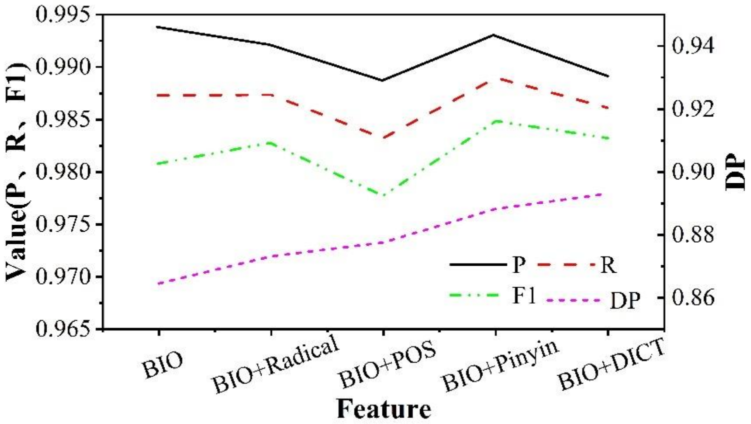

Figure 6: Experimental results of CRFs individual feature comparison

Then, we conducted combination experiments with the dictionary feature (DICT)—which showed the most significant improvement in DP values in the single-feature comparison experiments—and the remaining three features to determine the impact of feature combinations on model recognition performance and term discrimination capability. The experimental results are shown in Figure 7. Adding features to the dictionary feature (DICT) in combination had both positive and negative effects on accuracy, recall, F1 score, and the DP value for term discrimination capability. Introducing the radical feature (Radical) positively impacted P-value, R-value, and F1 score, but negatively affected DP value. Incorporating the part-of-speech feature (POS) degraded model performance. Adding the pinyin feature (Pinyin), however, effectively improved model performance. It can therefore be concluded that simply collecting the features during training will not necessarily improve the performance of the model. The selective combination of the features is key to improving performance. Experimental findings indicate that the best combination of features for BERT-BiLSTM-CRF model comprises dictionary features (DICT) and pinyin features (Pinyin).

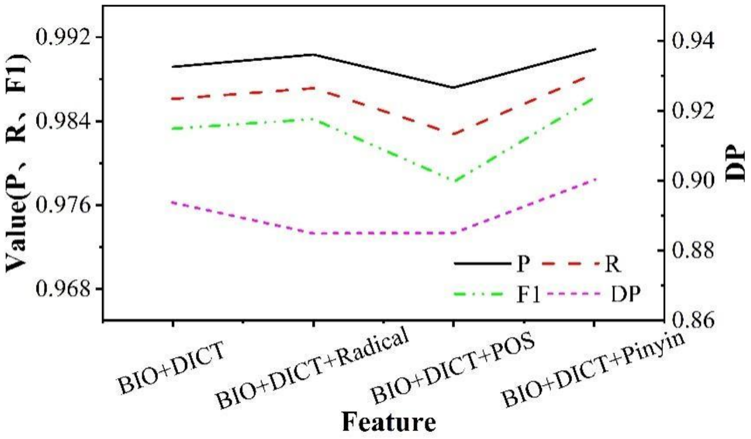

Figure 7: The results of the CRF feature combination comparison experiment

Finally, a comparative analysis of models was conducted, with RNN, LSTM, BiLSTM, and BERT-BiLSTM serving as reference models. Conclusion of comparative analysis is presented in Figure 8 below. According to Figure 8 above, among the models RNN, LSTM, BiLSTM, and BERT-BiLSTM, the model BERT-BiLSTM-CRF presents a higher priority in building knowledge graphs of the rural intangible cultural heritage with the maximum scores on all criteria. This concludes that the suggested model is highly applicable for knowledge graph construction.

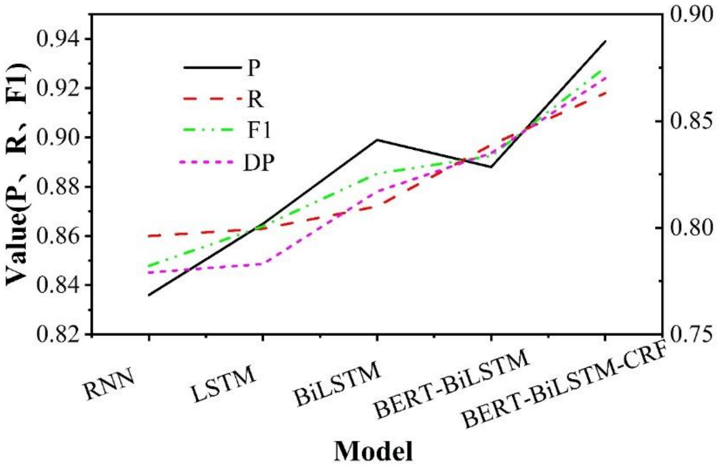

Figure 8: The results of model comparison and analysis

4.1.2 Visual Analysis of Knowledge Graphs

The rural intangible cultural heritage knowledge graph belongs to domain-specific vertical knowledge graphs, with a large amount of data collected. The Neo4j is a proper choice to store data. Nodes stand for entities, and edges represent relationships between head entities and tail entities, which allows visualizing the knowledge graph directly. Based on this study, entity recognition results from the BERT-BiLSTM-CRF model are supplemented by manually extracted entity relationships. Ultimately, the rural intangible cultural heritage knowledge graph is created in the Neo4j graph database. The rural intangible cultural heritage knowledge graph consists of 10,211 entity nodes and 13,681 relationships. In order to show the graph, some rural intangible cultural heritage entities and relationships are chosen. As shown in Figure 9, it demonstrates examples under the thematic category of "Rural ICH Cultural Projects." It extracts "rural ICH culture" knowledge graph contents for display purposes only, which is conducive to studying instances under a particular thematic category. As Figure 10 shows, it is an illustration of a music-related knowledge graph about ICH projects, with an example of "Xiangxi Miao Folk Songs" showing some relationships between rural ICH cultural entities. After extracting the instance level of rural intangible cultural heritage knowledge graph and establishing relationship networks with consecutive relationships to construct the knowledge map, it turns out that because of the autonomy of rural intangible cultural heritage knowledge, there will appear the phenomenon of sparsity in the map. The built rural intangible cultural heritage knowledge map takes a networked pattern. Different kinds of rural intangible cultural heritage knowledge can communicate with each other through sharing the same tail entity nodes. With the help of the relational connections one time or many times, we are able to find the detailed information of target entities efficiently. Moreover, the data in the knowledge graph is rich with sematic meaning, which accurately captures the attributes of entities, enhancing the accuracy of information retrieval and data analysis process. All entities mentioned above have become an information cluster of rural intangible cultural heritage.

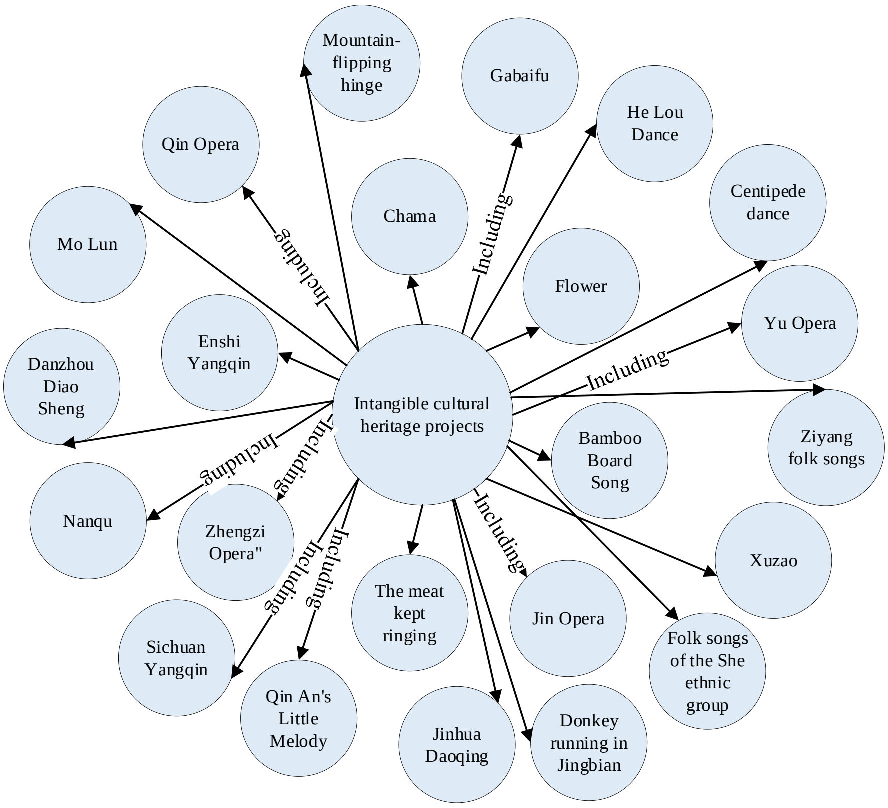

Figure 9: Examples of intangible cultural heritage project maps

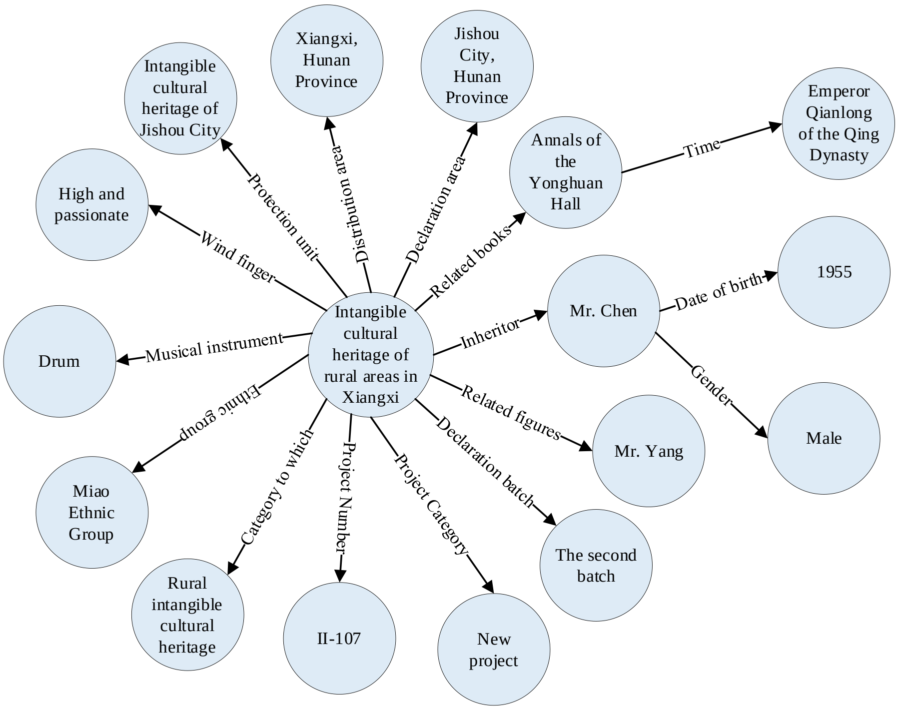

Figure 10: An example of the folk song map of the Miao ethnic group in Xiangxi

4.1.3 Distribution of Knowledge Graph Quality Metrics

The evaluation of the knowledge graph relationship prediction data set for rural intangible cultural heritage was based on the metrics commonly used to evaluate knowledge graphs, and the findings are presented in Table 1. The minimum query time is the shortest query time for a node, the maximum query time is the longest query time for a node, and the average query time is the mean value of all nodes in the graph. Collectively, the three metrics mentioned above can reflect the overall distribution of efficiency in the graph. The longest inference time is the time needed for the traversal of the longest path in the graph and therefore can be seen as a reflection of the topological complexity of the knowledge graph. From the analysis of the evaluation results, the minimum query time is found to be 0.0005 seconds, which could be due to the existence of many isolated nodes in the knowledge graph. The other three metrics exhibit satisfactory performance, reflecting the high efficiency of the knowledge graph.

Table 1: Evaluation index results

Evaluation indicators	Indicator value
Minimum query time	0.0005
Maximum query time	0.004
Average query time	2.29×10^{-6}
The longest reasoning time	0.002

4.2 Evaluation and Analysis of Digital Narrative Expression Mechanisms

This part will create the evaluation indicator system according to the digital narrative expression mechanism of rural intangible cultural heritage (ICH) by employing digital twin technology, based on literature and data. With the help of the Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation Method, this study conducts quantitative analysis of the digital narrative expression mechanism of rural ICH. The detailed analysis process is as follows:

4.2.1 Evaluation Indicator System

Through a series of in-depth literature review and data collection, this paper adopts questionnaire survey method to form the evaluation indicator system of the digital narrative expression mechanism of rural intangible cultural heritage. The indicator system includes five parts, namely the narrative content, the application of technology, the effect of dissemination, cultural value, and sustainability. The indicator system of the digital narrative expression mechanism of rural intangible cultural heritage is illustrated in Table 2. In detail, it contains five major indicators and 19 minor indicators.

Table 2: Evaluation index system

First-level indicator	Symbol	Secondary indicators	Symbol
Narrative content	A1	Authenticity	A11
		Integrity	A12
		Uniqueness	A13
		Story-telling	A14
Dimension of technology application	A2	Adaptability	A21
		Usability	A22
		Immersion	A23
		Stability	A24
Dimension of communication effect	A3	Coverage	A31
		Interactivity	A32
		Awareness	A33
		Conversion rate	A34
Cultural value dimension	A4	Inheritance and promotion	A41
		Cultural identity	A42
		Living continuation	A43
		Educational function	A44
Sustainability dimension	A5	Operational sustainability	A51
		Content sustainability	A52
		Ecological compatibility	A53

4.2.2 Analysis of Evaluation Results

Based on the evaluation indicator system, the weights for each indicator were calculated using the Analytic Hierarchy Process (AHP). The results of the indicator weighting are shown in Figure 11. The results indicate: A53 (0.0772) > A31 (0.0756) > A14 (0.0732) > A23 (0.0645) > A44 (0.0620) > A42 (0.0617) >A24 (0.0611) > A12 (0.0605) > A34 (0.0531) A22 (0.0522) > A32 (0.0512) > A13 (0.0497) > A41 (0.0491) > A21 (0.0454) >A33 (0.0417) > A51 (0.0374) > A43 (0.0318) > A52 (0.0306) > A11 (0.0222), comprehensively demonstrating the weight distribution of each indicator in the digital narrative expression mechanism for rural intangible cultural heritage. This provides robust data support for the fuzzy comprehensive evaluation results.

Figure 11: Evaluation index weight results

The opinion of ten professionals was solicited through an expert panel on various indicators related to the digital narrative expression mechanism of rural intangible cultural heritage using a systematic questionnaire. The scale used is as follows: Excellent (5), Good (4), Average (3), Poor (2), and Very Poor (1). The results are provided in Table 3 below. A distinct trend can be observed in the results; that is, most of the experts who participated rated the digital narrative expression mechanism as either excellent or good.

Table 3: Summary of scoring results

Index	Excellent	Good	Medium	Poor	Very bad
A11	3	3	1	3	0
A12	5	3	2	0	0
A13	4	2	2	1	1
A14	4	2	2	1	1
A21	4	2	2	2	0
A22	3	2	1	1	3
A23	4	2	2	2	0
A24	4	2	2	2	0
A31	4	2	2	2	0
A32	4	2	3	1	0
A33	4	1	1	1	3
A34	3	2	3	1	1
A41	4	2	2	2	0
A42	4	2	2	2	0
A43	3	2	3	2	0
A44	4	2	2	2	0
A51	5	1	2	2	0
A52	5	2	1	1	1
A53	4	3	3	0	0

Based on Table 3, data preprocessing was performed, with the results shown in Table 4. The results indicate that all metric data fall within the range of 0 to 1.

Table 4: Data preprocessing results

Index	Excellent	Good	Medium	Poor	Very bad
A11	0.3	0.3	0.1	0.3	0
A12	0.5	0.3	0.2	0	0
A13	0.4	0.2	0.2	0.1	0.1
A14	0.4	0.2	0.2	0.1	0.1
A21	0.4	0.2	0.2	0.2	0
A22	0.3	0.2	0.1	0.1	0.3
A23	0.4	0.2	0.2	0.2	0
A24	0.4	0.2	0.2	0.2	0
A31	0.4	0.2	0.2	0.2	0
A32	0.4	0.2	0.3	0.1	0
A33	0.4	0.1	0.1	0.1	0.3
A34	0.3	0.2	0.3	0.1	0.1
A41	0.4	0.2	0.2	0.2	0
A42	0.4	0.2	0.2	0.2	0
A43	0.3	0.2	0.3	0.2	0
A44	0.4	0.2	0.2	0.2	0
A51	0.5	0.1	0.2	0.2	0
A52	0.5	0.2	0.1	0.1	0.1
A53	0.4	0.3	0.3	0	0

With the use of expert evaluation score data, evaluation indicators, evaluation weight coefficients, and fuzzy comprehensive evaluation model, the fuzzy comprehensive evaluation matrix was generated. The results of the calculations of the digital narrative expression mechanism for rural intangible cultural heritage using the fuzzy comprehensive evaluation model are: Excellent (0.3969), Good (0.2081), Moderate: 0.2067, Poor: 0.1395, Very Poor: 0.0488). According to the principle of maximum membership degree, the digital narrative expression mechanism for rural intangible cultural heritage based on digital twin technologies is Excellent. Therefore, the digital narrative expression mechanism satisfies the present-day development and distribution needs for intangible cultural heritage and greatly promotes the digitalization of rural intangible cultural heritage.

Table 5: Fuzzy comprehensive evaluation matrix

Index	Excellent	Good	Medium	Poor	Very bad
A11	0.0067	0.0067	0.0022	0.0067	0.0000
A12	0.0302	0.0181	0.0121	0.0000	0.0000
A13	0.0199	0.0099	0.0099	0.0050	0.0050
A14	0.0293	0.0146	0.0146	0.0073	0.0073
A21	0.0181	0.0091	0.0091	0.0091	0.0000
A22	0.0156	0.0104	0.0052	0.0052	0.0156
A23	0.0258	0.0129	0.0129	0.0129	0.0000
A24	0.0244	0.0122	0.0122	0.0122	0.0000
A31	0.0302	0.0151	0.0151	0.0151	0.0000
A32	0.0205	0.0102	0.0154	0.0051	0.0000
A33	0.0167	0.0042	0.0042	0.0042	0.0125
A34	0.0159	0.0106	0.0159	0.0053	0.0053
A41	0.0196	0.0098	0.0098	0.0098	0.0000
A42	0.0247	0.0123	0.0123	0.0123	0.0000
A43	0.0095	0.0064	0.0095	0.0064	0.0000
A44	0.0248	0.0124	0.0124	0.0124	0.0000
A51	0.0187	0.0037	0.0075	0.0075	0.0000
A52	0.0153	0.0061	0.0031	0.0031	0.0031
A53	0.0309	0.0231	0.0231	0.0000	0.0000

4.3 Evaluation and Analysis of Digital Twin Systems

4.3.1 Accuracy Testing

The main focus of the accuracy test is to measure the performance of the system in carrying out different tasks such as the rural intangible cultural heritage knowledge graph, digital twin of physical spaces, and multi-agent modeling. The results of the accuracy tests are given in Table 6. For the rural intangible cultural heritage knowledge graph test sample: 200 questions on the aspects of intangible cultural heritage arts, history, items, famous masters, and crafts. Accuracy Testing: In order to perform the accuracy testing, the system-generated knowledge graph was compared with the manually annotated knowledge graph. This comparison resulted in an accuracy of 99%, that is, 198 questions were answered successfully while only two questions had slight errors related to the specialized knowledge of ICH.

Table 6: Accuracy test

Test type	Test Content	The number of test samples	Test results	Accuracy(%)
Knowledge Map of Rural Intangible Cultural heritage	Test the knowledge graph of rural intangible cultural heritage of the test system	200	198	99.00
Digital twin of physical space	The physical space digital twin of the test system	100	95	95.00
Multi-agent modeling	Multi-agent modeling of the test system	100	95	95.00

4.3.2 Response Time Testing

One of the most important criteria used to test the system performance is the response time, especially in systems that require real-time interaction where response speed is critical to the performance of the task and quality of experience. In order to evaluate the system performance, response times were measured under different loads, and results are shown in Table 7. It can be observed from the results that the average response time of the system is always less than 3 seconds.

Table 7: Response time test

Test type	Test Content	Average response time/s	Test results
Knowledge Map of Rural Intangible Cultural heritage	System testing	2.53	Fast and accurate
Digital twin of physical space	System testing	2.27	Fast and accurate
Multi-agent modeling	System testing	2.18	Fast and accurate

5 Conclusion

Rural intangible cultural heritage consists of profound historical and cultural significance alongside remarkable achievements in arts, constituting a vital part of the extensive heritage of traditional culture. However, studies concerning the digitization and intelligent transformation of rural intangible cultural heritage are still at a rudimentary stage of exploration, and existing information resource materials are scattered, making it difficult for the latter to be effectively utilized. In this case, the current study proposes a research framework of the digital narrative expression mechanism of rural intangible cultural heritage under the paradigm of digital twin technology and examines the framework through multi-dimensional empirical research. Specifically, it turns out that the knowledge graph built under the BERT-BiLSTM-CRF model is feasible and flexible, since all the metrics exceed 0.9. In other words, the model demonstrates superiority over the four alternative models by performing well in knowledge graph construction, which serves as a sound foundation for developing the digital narrative expression mechanism. The final evaluation of the mechanism results in its Excellence grade, with the specific figures standing at Excellent (0.3969), Good (0.2081), Average (0.2067), Poor (0.1395), and Very Poor (0.0488). Finally, the digital twin technology applied to rural intangible cultural heritage is tested and analyzed, proving all its indicators to meet existing standards of digitization, thus allowing for maximum dissemination and transmission of rural intangible cultural heritage.

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