Journal of Construction in Developing Countries, 29(Supp. 1), 209–239, 2024

Evaluating the Residential Environment of Traditional Settlements in Northern Jiangxi, China: A Multi-Dimensional Framework

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Published: 20 December 2024

To cite this article: Quan Wen, Mazran Ismail and Muhammad Hafeez Abdul Nasir (2024). Evaluating the residential environment of traditional settlements in Northern Jiangxi, China: A multi-dimensional framework. *Journal of Construction in Developing Countries*, 29(Supp. 1): 209–239. https://doi.org/10.21315/jcdc.2024.29.S1.11

To link to this article: https://doi.org/10.21315/jcdc.2024.29.S1.11

Abstract: Traditional rural settlements in China have long been recognised for their unique cultural and ecological values. However, rapid urbanisation and rural revitalisation processes pose significant threats to the sustainability of these traditional living environments. This study aimed to develop an innovative multi-dimensional framework based on the SciBERT algorithm in order to evaluate the residential environment of traditional settlements in Northern Jiangxi, China. Drawing on theories from landscape ecology, cultural geography and sustainable development, the framework encompasses four key dimensions: ecological suitability, cultural continuity, liveability and sustainability. A set of quantitative and qualitative indicators was constructed under each dimension based on a comprehensive literature review. The analytic hierarchy process (AHP) was then employed to determine the relative weights of these indicators. Data were collected from interviews with 13 respondents and an analysis of 68 Science Citation Index Expanded (SCIE) articles. The proposed framework was applied to assess the residential environment of three representative traditional settlements in Northern Jiangxi. The results revealed the strengths and weaknesses of each settlement, providing valuable insights for targeted conservation and revitalisation strategies. This study contributes to urban planning research by offering a holistic and empirically validated approach to evaluating the multi-faceted residential environment of traditional settlements, which can inform both academic research and practical policymaking in the context of rural development.

Keywords: Traditional settlements in China, Sustainable preservation and development, SciBERT algorithm, Evaluation framework, Analytical hierarchy process

INTRODUCTION

Traditional rural settlements in China, particularly those in Northern Jiangxi, have great cultural and ecological importance. These settlements embody the unique heritage of their regions, characterised by historical architecture, longstanding cultural practices and a harmonious relationship with the natural environment. However, the rapid urbanisation and rural revitalisation processes in recent years have posed significant challenges to the sustainability and preservation of these traditional environments. As modern development encroaches upon these areas, the need for a systematic and comprehensive evaluation framework becomes increasingly important (Zhang, 2022).

The critical need to balance the preservation of cultural and ecological heritage with the pressures of modern development motivated the current

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study. Despite the recognised value of traditional settlements, there is a lack of comprehensive frameworks that adequately address their multidimensional aspects. This research sought to fill this gap through this research question: How can the residential environments of traditional settlements in Northern Jiangxi be effectively evaluated to ensure their sustainable preservation and development? This study aimed to address this need by developing an innovative multi-dimensional framework for evaluating the residential environments of traditional settlements in Northern Jiangxi, China, leveraging the SciBERT algorithm for enhanced precision in indicator extraction. Drawing on theories from landscape ecology, cultural geography and sustainable development, the framework encompasses four key dimensions: ecological suitability, cultural continuity, liveability and sustainability. Each dimension is supported by a set of quantitative and qualitative indicators, which were constructed based on a comprehensive literature review and the Delphi method. The analytic hierarchy process (AHP) was also employed to determine the relative weights of these indicators, ensuring a balanced and objective assessment.

The selected case study villages in the current study, namely Liukeng in Le'an County, Diaoyuan in Ji'an and Wuxi in Dongxiang County, exemplify the diverse characteristics of traditional settlements in Jiangxi Province. Liukeng Village is renowned for its well-preserved Ming and Qing dynasties architecture and rich cultural heritage, making it an ideal representation of cultural continuity and architectural preservation. Diaoyuan Village, surrounded by mountains and rivers, showcases a diverse ecosystem and the principles of ecological suitability through its harmonious coexistence with the natural environment. Wuxi Village demonstrates a balance between ecological conservation and modern development, integrating sustainable practices with the preservation of its natural landscapes (Xiao et al., 2019). By applying the proposed multi-dimensional framework to these villages, this study would reveal the strengths and weaknesses of each settlement to provide valuable insights for targeted conservation and revitalisation strategies. The findings contribute significantly to urban planning research by offering a holistic and empirically validated approach to evaluating the multi-faceted residential environment of traditional settlements. This approach informs academic research and serves as a practical tool for policymakers and stakeholders involved in rural development and cultural preservation in Northern Jiangxi (Yang, 2023).

LITERATURE REVIEW

Traditional Rural Settlements

Traditional rural settlements in China have been extensively studied for their unique cultural and ecological values. Researchers have emphasised the importance of these settlements in preserving historical architecture, cultural heritage and traditional lifestyles (Bai, Ying and Stancanelli, 2016). The architectural styles found in these settlements, such as those from the Ming and Qing dynasties, are not only aesthetically significant but also embody the cultural and historical narratives of their regions (Bo and Hong, 2021). For example, studies have shown that the intricate wood carvings and classical Chinese architectural elements in villages like Liukeng serve as museums of Chinese cultural heritage (Fang and Liu, 2008).

The ecological suitability of traditional settlements is another critical area of research. Traditional rural settlements are often located in ecologically sensitive areas where the natural environment plays a significant role in shaping settlement patterns and lifestyles (Setijanti et al., 2015). Villages surrounded by mountains and rivers like Diaoyuan demonstrate how human habitation can coexist harmoniously with biodiversity (UNESCO, 2018; *chinadaily.com.cn*, 2024). Research has highlighted the importance of maintaining ecological balance and biodiversity in these areas to ensure sustainability (Cruz et al., 2017). The principles of landscape ecology have been applied to study the spatial organisation and ecological interactions within these settlements, providing insights into their resilience and adaptability (Liu, Zeng and Liu, 2023).

The concept of liveability encompasses various aspects of quality of life, including residential building design, indoor environment and access to social services and public facilities (Yang, 2023). Traditional settlements are often lauded for their high liveability due to their close-knit communities, well-designed residential buildings and harmonious living conditions (Bashari et al., 2021). However, studies have also pointed out the challenges these settlements face in terms of modern amenities and infrastructure, which are crucial for improving living standards (Qin and Leung, 2021). The balance between preserving traditional elements and integrating modern facilities is a recurring theme in the literature on rural development (Djezzar and Bada, 2023). China's initiatives, including World Bank-financed projects, highlight the integration of cultural heritage conservation with rural development, providing a model for leveraging local intangible cultural assets (Cheong, Wang and Li, 2020; World Bank, 2021).

Sustainability is a key dimension in the evaluation of traditional settlements. It focuses on their ability to adapt to contemporary environmental challenges while maintaining their historical and cultural identity (Aklanoglu, 2010). Wuxi Village serves as an example of how traditional settlements can implement sustainable practices, such as renewable energy use and eco-friendly agricultural techniques, to enhance their sustainability (Chen et al., 2023). Accordingly, research has explored various strategies for sustainable development in rural areas, emphasising the need for innovative capacity and economic adaptability (Sun et al., 2022). Therefore, the integration of renewable architecture and sustainable development strategies is critical for the long-term viability of these settlements (Prihatmanti and Bahauddin, 2014).

This study introduced the SciBERT algorithm to enhance the precision of indicator extraction, showcasing an innovative approach in this research field despite the extensive studies on the cultural and ecological values of traditional rural settlements. This study aimed to bridge this gap by developing a multi-dimensional framework for evaluation, drawing on theories from landscape ecology, cultural geography and sustainable development.

Multi-Dimensional Frameworks for Evaluation

Evaluating the residential environments of traditional settlements requires a comprehensive approach that considers multiple dimensions. The development of multi-dimensional frameworks has been a significant advancement in this field, allowing for a holistic assessment of ecological, cultural, liveability and sustainability factors (Setijanti et al., 2015). The use of the AHP to determine the relative weights of various indicators ensures a balanced and objective evaluation (Torfi and

Rashidi, 2011). Previous studies have applied such frameworks to different contexts, providing valuable methodologies and insights that can be adapted for evaluating settlements in Northern Jiangxi (Torfi and Rashidi, 2011). The Chinese government's policies on rural development, cultural preservation and academic initiatives have reinforced the importance of systematic conservation strategies (*chinadaily.com.cn*, 2024; Xie, Zhang and Han, 2024).

METHODOLOGY

Identification and Construction of Evaluation Framework Using SciBERT Model

This study employed quantitative analysis with the SciBERT model to perform text mining on a large number of Science Citation Index Expanded (SCIE) articles, which were previously known as the Science Citation Index (SCI) in Web of Science by Clarivate. The goal was to extract relevant indicators for assessing the residential environment of traditional settlements in Northern Jiangxi. By leveraging deep learning algorithms, the SciBERT model captures the implicit meanings within the texts, ensuring that the extracted indicators are both comprehensive and accurate (Rehman et al., 2023).

Initially, a comprehensive search of the SCIE database was performed to collect articles related to traditional settlements, ecological suitability, cultural continuity, liveability and sustainability (Zhuge et al., 2021). The SciBERT model was then utilised to mine these texts, extracting a preliminary list of indicators (Xu et al., 2020). This study also incorporates data obtained from interviews to supplement the results from the SCIE article analysis. The interviews were conducted with 13 interviewees from a diverse group of respondents: seven residents of traditional settlements, one local government official, three architectural experts and two cultural heritage conservationists. The interview questions were designed to align with the research objectives, covering aspects such as ecological suitability, cultural continuity, liveability and sustainability. Through the analysis of the interview records, key evaluation indicators identified by experts and stakeholders were extracted. These were then integrated with the results of the text mining to develop a more comprehensive indicator system (Mulya and Khodra, 2023).

Case Study

This study selected three representative traditional villages in Jiangxi for evaluation, namely Liukeng Village in Le'an County, Diaoyuan Village in Ji'an and Wuxi Village in Dongxiang County. These villages were chosen based on their unique cultural and ecological characteristics, representing different types of traditional settlements in Jiangxi Province. The selection criteria of these villages were detailed to ensure a comprehensive evaluation of traditional settlement characteristics, as shown in Table 1.

Table 1. Selection criteria for case study villages

Selection Criteria	Description
Cultural heritage and preservation	Villages with well-preserved historical and cultural assets that reflect traditional Chinese architectural styles and cultural continuity.
Ecological environment	Villages located in regions with diverse and rich natural landscapes that illustrate ecological suitability and sustainable practices.
Accessibility for field study	Villages that are accessible for conducting detailed field surveys and data collection.
Representation of diverse settlement types	Villages that together cover a range of different traditional settlement types in Jiangxi Province, providing a broad basis for comparison and analysis.

Liukeng Village (as shown in Figure 1) is renowned for its well-preserved Ming and Qing dynasties architecture and rich cultural heritage. The village features a collection of ancient buildings, ancestral halls and traditional dwellings, showcasing intricate wood carvings and classical Chinese architectural styles. These characteristics make Liukeng a prime example of cultural continuity and architectural preservation in traditional settlements.

Diaoyuan Village (as shown in Figure 2) is noted for its beautiful natural landscapes and biodiversity. Surrounded by mountains and rivers, the village boasts a diverse ecosystem that supports various plant and animal species. The harmonious coexistence of human habitation and natural environment in Diaoyuan illustrates the principles of ecological suitability. This village also reflects the traditional rural lifestyle and community structure, which have remained largely unchanged over centuries.

Wuxi Village, Dongxiang County (as shown in Figure 3) has achieved a balance between ecological conservation and modern development. The village has implemented sustainable practices such as renewable energy use and eco-friendly agricultural techniques, integrating these with the conservation of its natural landscapes. Wuxi exemplifies how traditional settlements can adapt to contemporary environmental challenges while maintaining their historical and cultural identity.

These villages were selected to construct and validate the multi-dimensional framework for evaluating the residential environments of traditional settlements in Northern Jiangxi. Each village represents a unique aspect of traditional settlement characteristics, providing a comprehensive basis for analysis and comparison.

Figure 1. Liukeng Village (Google Maps: 27.2663° N, 115.7718° E)

Figure 2. Diaoyuan Village (Google Maps: 27°11'18.3"N, 114°50'19.0"E)

Figure 3. Wuxi Village (Google Maps: 28.090167° N, 116.634755° E)

Weight Evaluation Using Analytic Hierarchy Process

The AHP is a mathematical method used for multi-criteria decision-making by structuring complex problems into multiple levels and criteria for quantitative analysis (Fiore, Sicignano and Donnarumma, 2020). In this study, the AHP method was employed to evaluate and determine the relative weights of the evaluation indicators.

Initially, a hierarchical structure model of the evaluation indicators was constructed, including the goal layer, criteria layer and indicator layer. Experts then provided scores, comparing the importance of each indicator to construct a judgment matrix. Based on the judgement matrix derived from expert scores, the relative weights of each indicator were calculated. The specific steps included inputting the expert scoring results into AHP software and calculating the consistency ratio (CR) of each judgement matrix to ensure consistency in the scoring. The weights of the indicators were then calculated using the eigenvector method, followed by a consistency check. If the CR met the required standards, the weight distribution of the indicators was finalised. By employing the AHP method, the objectivity and scientific validity of the indicator weights were ensured, providing a solid foundation for the comprehensive evaluation of the residential environments in traditional settlements (Gulum, Ayyildiz and Taskin Gumus, 2021). Table 2 summarises the steps for scoring, weight calculation and the construction of pairwise comparison matrices.

Table 2. Steps for weight calculation using the AHP

Step	Description
Scoring standard	Experts use pairwise comparison matrices to rate the importance of each factor, with scores ranging from 1 = "Equally Important" to 9 = "Extremely Important".
Construction of pairwise comparison matrices	The relative importance of each factor is obtained through expert surveys. Experts rate the importance of each factor based on their professional knowledge and experience.
Normalisation of pairwise comparison matrices	The normalisation steps include dividing each element in the pairwise comparison matrix by the sum of elements in its respective column. The normalised matrix is then summed by rows and each sum is divided by the number of elements in the row to obtain the eigenvector for each factor.
Weight calculation	The eigenvector represents the weight of each factor. The final weights for each factor are calculated using the eigenvector.
Consistency check	The consistency of the pairwise comparison matrices is ensured using the CR. A CR value less than 0.1 indicates acceptable consistency.
Explanation and weights of indicators	Table 11 details the explanations and weights for each indicator. The weights of the indicators are calculated using the AHP method, ensuring a systematic and quantitative approach to the evaluation.

Framework Evaluation and Validation

To comprehensively evaluate the traditional settlements in Northern Jiangxi, this study calculated the scores for each dimension (Cultural Continuity, Ecological Suitability, Livability and Sustainability) for the three case study villages: Liukeng, Diaoyuan and Wuxi. Using AHP, this study first determined the relative weights of the evaluation indicators, reflecting their importance in the overall assessment framework. Each indicator was then assigned a score from 1 to 5 based on its performance in the respective village, derived from quantitative data (i.e., environmental measurements and architectural assessments) and qualitative data (i.e., expert interviews and resident surveys). These scores were multiplied by their respective weights to obtain weighted scores. The weighted scores for each dimension were then averaged to compute a final score for each dimension in each village. Finally, the weighted average scores for all dimensions were aggregated to form a comprehensive evaluation score for each village, ensuring the scores remain within the 1 to 5 range.

RESULTS

Extraction Index

At the beginning stage of the research, this study employed the SciBERT model to analyse 13 interview records and 68 SCIE articles, extracting 55 and 119 indicators related to the residential environments of traditional rural settlements, respectively. This comprehensive list included indicators, including "Cultural heritage", "Ecological balance" and "Natural landscape", each annotated with its frequency of occurrence and citation count, as shown in Table 3 (Fiore, Sicignano and Donnarumma, 2020).

Table 3. Extracted evaluation indicators and their frequency by SciBERT (interview transcript)

Indicator	Frequency	Files	Indicator	Frequency	Files
Environmental sustainability	19	10	Traditional architecture	6	6
Use forest management	12	12	Quality natural	7	4
Environmental responsibility	7	6	Natural materials	5	5
Proactive measures enhance resilience	6	4	Important cultural heritage		
Ecological balance	25	13	Reduce energy consumption improve	5	5
Energy efficiency	6	6	Promotes sustainability	13	13
Enhance functionality	14	11	Human ecological well being	6	6
Thermal comfort	17	13	Functionality comfort homes	7	7
Development responsible sustainable	6	6	Sustainable land use	8	6
Passive solar	11	6	Enhance quality life	7	7
Living environment	59	13	Natural beauty	5	4
Health comfort	6	6	Jiangxi architectural styles	7	7
Biodiversity	10	7	Landscapes	9	7
Conservation natural	13	13	Quality traditional homes designed	11	6
Cultural skills remain	7	5	Impact	7	5
Harmony natural environment	13	13	Natural resources	13	7

(*Continued on next page*)

Table 3. *Continued*

Indicator	Frequency	Files	Indicator	Frequency	Files
Energy efficient systems	6	6	Comfort use traditional	4	4
Architectural styles	7	7	Development	9	6
Environment incorporate natural	4	4	Traditional houses	10	7
Choosing sustainable	6	6	Living conditions	36	13
Famous traditional architecture	4	4	Natural insulation	10	9
Cultural heritage	55	13	Ensuring resource management	12	10
Indoor comfort	6	6	Integral cultural identity	12	12
Enhance environmental sustainability	8	6	Historic architecture	14	8
Preservation	9	7	Functionality comfort	7	7
Quality life	31	13	Energy costs	4	4
Preserve natural	7	7	Ensure development responsible sustainable	6	6
Responsible sustainable housing	7	6			

To further validate the results from the SCIE articles, this study compiled the extracted evaluation indicators and their frequency into Table 4. Table 4 highlights the most significant indicators identified through the analysis of SCIE articles, providing a robust foundation for evaluating the residential environments of traditional settlements.

Table 4. Extracted evaluation indicators and their frequency by SciBERT

Indicator	Frequency	Files	Index	Frequency	Files
Vitality traditional villages	9	6	Resource management	4	4
Spatial research	7	4	Ecological concept	18	5
Rural development	116	38	Living conditions	29	17
Traditional houses	54	16	Structure villages	7	4
Level development	6	4	Landscape environment	14	9
Cultural heritage	467	53	Characteristics natural	4	4

(*Continued on next page*)

Table 4. *Continued*

Indicator	Frequency	Files	Index	Frequency	Files
Wind protection	14	4	Cultural development	13	8
Tourism study	4	4	Traditional architecture	46	22
Architectural culture	16	8	Development sustainable	9	6
Settlement landscape	18	13	Dwellings spatial	5	5
Landscape design	35	6	Culture formed	6	3
Moisture protection	4	4	Shows spatial	11	7
Thermal performance building envelope	4	3	Storage capacity	8	5
Disaster risk	7	4	Studies cultural	6	3
Sustainability conservation	4	4	China ecological	4	3
Related cultural	4	4	Environment area	4	4
Cultural characteristics	32	16	Impact traditional villages	4	4
Village environment	9	6	Natural environment	244	39
Villages chinese traditional	7	7	Living environments	5	4
Energy performance	13	7	Spatial distribution using	4	3
Includes natural	4	3	Regional development	11	8
Development strategies	12	7	Factors natural	10	5
Architecture design	12	5	Traditional villages preserved	6	3
Human settlements	59	19	Local characteristics	14	10
Ecological environment	82	21	Spatial analysis	52	22
Framework sustainable	4	4	Types village	12	3
Architecture renewable	4	4	Process traditional villages	4	3
Rural revitalisation strategy	20	13	Social development	16	9
Architectural details	6	5	Thermal comfort	124	11
Traditional culture	79	26	Changes spatial	7	4

(*Continued on next page*)

Table 4. *Continued*

Indicator	Frequency	Files	Index	Frequency	Files
Agricultural landscape	7	4	Building environment	52	11
Mechanism traditional villages	18	8	Architecture Chinese	6	4
Cultural landscape	270	34	Traditional villages	4	3
Rural settlement	35	16	Location environment	4	3
Areas spatial	4	3	Sustainable rural development	10	7
Ecological balance	9	5	Environment architectural	4	3
Culture such	5	4	Cultural factors	33	12
Natural landscape	61	16	Agricultural cultural	4	4
Promotion cultural	4	3	Indoor environmental	4	3
Local architecture	7	4	Natural ventilation	79	13
Design rural	6	3	Environmental sustainability	9	5
Residential architecture	54	9	Characteristics based	4	4
Landscape characteristics	16	8	Application traditional villages	4	3
Revitalisation development	4	3	Culture change	7	6
Settlements traditional	6	5	Living standards	14	8
National culture	11	7	Layout residential	6	3
Development traditional villages	135	29	Interaction natural	13	6
Form traditional villages	16	9	History architecture	7	5
Traditional villages influence	7	5	Regional environment	10	5
Protection project	5	4	Spatial characteristics	85	23
Heritage conservation	73	18	Sustainable development	368	52
Architectural space	17	9	Different characteristics	4	4
Cultural landscapes	51	17	Distribution spatial	5	3
Environmental impact	8	3	Dispersed villages	21	3

Framework Construction

This study applied several screening criteria to refine this extensive list. First, the indicators were evaluated based on their direct relevance to four key dimensions: (1) Ecological suitability, (2) Cultural continuity, (3) Liveability and (4) Sustainability. Indicators with high frequencies and appearances in multiple papers were prioritised, highlighting their significance in the literature. Then, the next step employed the Delphi method. A panel of seven experts, including scholars, architects, urban planners and cultural heritage conservationists, were hired to assess the practical importance and applicability of each indicator as well as to ensure a diverse range of perspectives. Details of the experts are detailed in Table 5.

Table 5. Expert group information

Expert Code	Gender	Title	Research Field
Expert A	Male	Lecturer	Heritage conservation
Expert B	Male	Lecturer	Heritage conservation
Expert C	Male	Senior designer	Architecture
Expert D	Male	Lecturer	Sustainable development
Expert E	Male	Lecturer	Sustainable development
Expert F	Female	Senior engineer	Landscape design
Expert G	Female	Associate professor	Ecological environment

This iterative process involved multiple rounds of surveys, enabling the experts to reach a consensus on the most critical indicators. Through this method, this study ensured that the final selected key indicators were both comprehensive and relevant. Based on field surveys, literature analysis and following discussions with experts, a comprehensive set of evaluation indicators was developed to assess the residential environments of traditional settlements in Northern Jiangxi.

Figure 4 explains how these indicators were meticulously chosen to capture the multifaceted aspects of ecological suitability, cultural continuity, liveability and sustainability within the selected villages. Each indicator was selected based on its relevance and impact on the overall goal of preserving and developing traditional settlements in a sustainable manner. For example, "Disaster risk" under "Ecological Suitability" highlighted the importance of resilience to natural hazards, ensuring long-term sustainability. "Cultural features" under "Cultural Continuity" emphasised the preservation of unique cultural elements, crucial for maintaining the identity of traditional settlements. "Safety" under "Habitability" ensured that the living conditions were secure for residents, enhancing their quality of life. "Sustainable development strategies" under "Sustainability" focused on the implementation of practices that promoted long-term environmental and economic viability. These indicators were derived from both qualitative insights and quantitative data, ensuring a robust and holistic assessment framework.

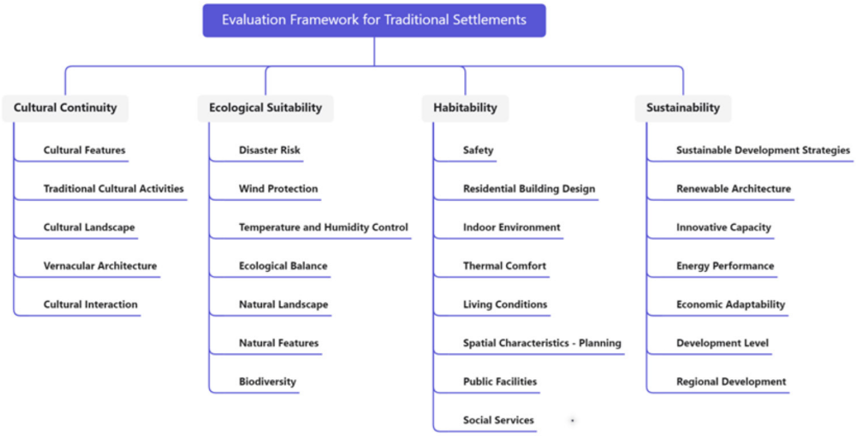

Figure 4. Multi-dimensional evaluation framework for traditional settlements in Northern Jiangxi

Weight Calculation

To ensure the reliability and consistency of the evaluation framework, this study employed the AHP method. A group of seven experts (as shown in Table 5) were invited to participate in the weight calculation process. These experts, specialising in fields such as heritage conservation, sustainable development, architecture, landscape design and ecological environment, provided their professional judgments on the relative importance of each indicator. They were selected based on their extensive knowledge and experience in the relevant fields, ensuring a diverse and authoritative panel. Selected experts held significant academic or industry positions, including lecturers, associate professors, senior designers and senior engineers, underscoring their authority and professionalism. Additionally, gender diversity was considered in the selection process, ensuring the inclusion of female experts to provide a more comprehensive and diverse perspective. Ultimately, the seven experts included three lecturers, one senior designer, one senior engineer and one associate professor, all of whom possess profound knowledge and extensive experience in heritage conservation, architecture, sustainable development, landscape design and ecological environment. This diverse expertise was integral to achieving a well-rounded and credible evaluation framework.

The experts used pairwise comparison matrices to rate the importance of each factor on a scale from 1 = "Equally Important" to 9 = "Extremely Important". CR values were calculated to ensure the matrices' consistency, with a CR value less than 0.1 indicating acceptable consistency. The hierarchical structure model comprised five levels; the first level represented the goal evaluated the residential environments of traditional settlements in Northern Jiangxi, the second level included the four main dimensions, namely "Ecological Suitability", "Cultural Continuity", "Liveability" and "Sustainability", the third level consisted of specific indicators under each main dimension, the fourth level involved the final weight calculation and the last level focused on constructing pairwise comparison matrices (Al-Saggaf, Nasir and Hegazy, 2020).

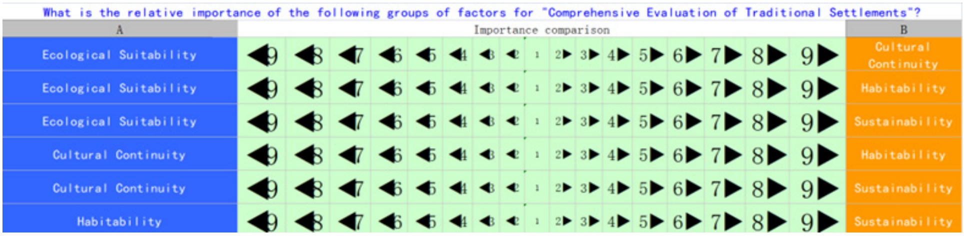

Figure 5. PHP expert comparison of importance between indicators for comprehensive evaluation of traditional settlements

This study obtained pairwise comparison data for the factors at each level through expert surveys. Experts rated the importance of each factor based on their professional knowledge and experience. The ratings used the Saaty scale, ranging from 1 = "Equally important" to 9 = "Extremely important". Figure 5 shows an example of a pairwise comparison matrix for some of the levels (Bostancioglu, 2021). After constructing the pairwise comparison matrices, this study normalised these matrices and calculated the eigenvectors and weights for each factor. This study ensured the consistency of the comparison matrices through the CR (Fiore, Sicignano and Donnarumma, 2020). If the CR value is less than 0.1, the matrix is considered consistent. The specific steps for weight calculation are shown in Table 6.

Table 6. Pairwise comparison matrix for main dimensions in the comprehensive evaluation of traditional settlements

Comprehensive Evaluation of Traditional Settlements	**Ecological Suitability**	**Cultural Continuity**	**Liveability**	**Sustainability**	**Weights (Wi)**
Ecological suitability	1.0000	2.0000	1.4375	2.1250	0.2463
Cultural continuity	2.7857	1.0000	2.1458	2.3750	0.3004
Liveability	1.7083	1.8833	1.0000	1.6875	0.2375
Sustainability	2.3833	0.8000	1.6875	1.0000	0.2159

First, each element in the pairwise comparison matrix was divided by the sum of elements in its respective column to normalise the matrix. Then, the normalised matrix was summed up in rows and each sum was divided by the number of elements in the row to obtain the eigenvector for each factor. Finally, the eigenvector represented the weight of each factor.

Table 6 illustrates the pairwise comparison matrix for the main dimensions used in the comprehensive evaluation of traditional settlements. The weights indicated the relative importance of each dimension, with "Cultural Continuity" being the most significant, followed by "Ecological Suitability", "Liveability" and "Sustainability".

Table 7 shows the pairwise comparison matrix for "Ecological Suitability" indicators. Disaster Risk had the highest weight, reflecting its critical importance in evaluating ecological suitability, followed by "Temperature" and "Humidity control and ecological balance".

Table 8 illustrates the pairwise comparison matrix for "Liveability" indicators. "Safety" had the highest weight, indicating its paramount importance in assessing liveability, followed by "Residential building design" and "Indoor environment".

Table 9 shows the pairwise comparison matrix for "Sustainability" indicators. "Sustainable development strategies" had the highest weight, indicating their critical role in sustainability assessments, followed by "Innovative capacity" and "Renewable architecture".

Table 10 presents the pairwise comparison matrix for "Cultural Continuity" indicators. "Cultural features" and "Traditional cultural activities" had the highest weights, emphasising their significance in evaluating cultural continuity within traditional settlements.

Following the detailed pairwise comparison matrices, this study synthesised the results to derive a comprehensive list of indicators for evaluating traditional settlements. Each indicator was accompanied by an explanation and its corresponding weight, reflecting its relative importance in the overall evaluation framework (Torfi and Rashidi, 2011). The weights were calculated through the AHP, ensuring a systematic and quantitative approach to the assessment. The specific indicators, their explanations and weights are presented in Table 11.

Table 7. Pairwise comparison matrix for ecological suitability indicators

Ecological Suitability	Wind Protection	Temperature and Humidity Control	Ecological Balance	Natural Landscape	Natural Features	Disaster Risk	Biodiversity	Wi
Wind protection	1.0000	0.5833	1.8125	2.0625	1.8833	0.2500	1.7813	0.1095
Temperature and humidity control	2.0000	1.0000	2.5625	2.0417	2.0625	0.2708	1.7917	0.1383
Ecological balance	1.3333	1.2292	1.0000	2.2500	2.6250	0.2792	2.2500	0.1274
Natural landscape	1.2917	1.8125	0.5417	1.0000	1.3333	0.2292	1.7500	0.0966
Natural features	2.1458	1.2917	0.7292	1.3333	1.0000	0.3000	1.6458	0.102
Disaster risk	4.2500	4.0000	3.7500	4.5000	4.0000	1.0000	4.2500	0.3143
Biodiversity	2.4167	1.9167	0.6750	0.7083	1.9167	0.3917	1.0000	0.1120

Table 8. Pairwise comparison matrix for "Liveability" indicators

Liveability	Residential Building Design	Indoor Environment	Thermal Comfort	Living Conditions	Spatial Characteristics (Planning)	Social Services	Public Facilities	Safety	Wi
Residential building design	1.0000	1.7083	2.8333	4.2500	3.2083	3.3125	3.0500	0.3000	0.1485
Indoor environment	1.4167	1.0000	3.1250	3.7500	3.3750	3.0417	2.6750	0.4375	0.1439
Thermal comfort	0.9667	0.6958	1.0000	1.8750	2.0833	1.8750	2.3000	0.2607	0.0862
Living conditions	0.2458	0.4167	0.8333	1.0000	1.6875	2.3958	2.6333	0.2524	0.0723
Spatial characteristic (planning)	1.3357	0.6833	1.0417	1.6667	1.0000	2.7917	3.0500	0.2107	0.0929
Social services	1.3611	1.7440	2.425	1.875	1.7083	1.0000	2.2500	0.3357	0.1034
Public facilities	1.4583	1.8690	1.6333	2.119	1.4458	0.4583	1.0000	0.2653	0.0861
Safety	4.0000	3.5000	4.7500	5.0000	5.2500	4.0000	5.0000	1.0000	0.2668

Table 9. Pairwise comparison matrix for "Sustainability" indicators

Sustainability	Renewable Architecture	Sustainable Development Strategies	Innovative Capacity	Development Level	Energy Performance	Regional Development	Economic Adaptability	Wi
Renewable architecture	1.0000	1.1958	1.9250	2.4583	2.0833	2.3333	1.6875	0.1625
Sustainable development strategies	3.0625	1.0000	2.2500	2.3750	2.0625	3.7500	3.2500	0.2244
Innovative capacity	1.9250	0.5417	1.0000	2.0625	2.5000	2.6250	2.7500	0.1635
Development level	1.3625	0.7708	1.2917	1.0000	1.3625	1.6750	0.7375	0.1088
Energy performance	1.0417	1.2917	0.5208	2.4583	1.0000	1.9167	1.9583	0.1289
Regional development	1.1333	0.4125	0.7292	1.9167	1.6458	1.0000	1.2500	0.1007
Economic adaptability	1.8000	0.4458	0.5083	2.8750	1.3958	0.875	1.0000	0.1113

Table 10. Pairwise comparison matrix for "Cultural Continuity" indicators

Cultural Continuity	**Vernacular Architecture**	**Traditional Cultural Activities**	**Cultural Landscape**	**Cultural Features**	**Cultural Interaction**	**Wi**
Vernacular architecture	1.0000	0.7292	1.1667	0.4458	2.7500	0.1452
Traditional cultural activities	2.6250	1.0000	2.1250	1.3333	3.5000	0.2806
Cultural landscape	1.8333	0.7917	1.0000	1.0417	3.5000	0.2003
Cultural features	3.2500	1.8125	2.0833	1.0000	3.5000	0.3142
Cultural interaction	0.3750	0.3208	0.3000	0.3208	1.0000	0.0597

Table 11. Indicators, explanations and weights for evaluating traditional settlements

Indicator	Explanation	Wi
Cultural continuity	Measures the preservation and continuation of traditional cultural practices and values (Aklanoglu, 2010)	0.3004
Ecological suitability	Assesses the environmental compatibility and adaptability of the settlement to its natural setting (Hobbs, 1997)	0.2463
Liveability	Evaluates the quality of life and comfort provided by the living environment	0.2375
Sustainability	Determines the long-term viability and environmental impact of the settlement (Han, Hu and Xu, 2024)	0.2159
Cultural features	Evaluates the presence and preservation of unique cultural elements within the settlement (Du, 2019)	0.0944
Traditional cultural activities	Assesses the frequency and quality of traditional cultural events and activities (Du, 2019)	0.0843
Disaster risk	Measures the susceptibility of the settlement to natural disasters and the effectiveness of mitigation measures (Amburgey et al., 2023)	0.0774
Safety	Evaluates the overall safety and security conditions of the settlement (He, Chen and Chou, 2019)	0.0634
Cultural landscape	Assesses the integration and significance of cultural elements within the landscape (Fang and Liu, 2008)	0.0602
Sustainable development strategies	Measures the implementation and effectiveness of strategies aimed at sustainable development (Ghasemi, Behzadfa and Hamzenejad, 2021; Shao and Fu, 2012)	0.0484
Vernacular architecture	Evaluates the presence and preservation of traditional architectural styles (Revuelta and Merino, 2014)	0.0436
Innovative capacity	Assesses the ability of the settlement to innovate and adapt to changing conditions	0.0353
Residential building design	Evaluates the design and functionality of residential buildings within the settlement (Kim et al., 2022; Mekonnen, Bires and Berhanu, 2022)	0.0353
Renewable architecture	Measures the integration and use of renewable materials and energy in building designs	0.0351
Indoor environment	Assesses the quality of the indoor living environment, including air quality and lighting (Prihatmanti and Bahauddin, 2014)	0.0342
Temperature and humidity control	Evaluates the effectiveness of temperature and humidity control measures in the settlement	0.0341
Ecological balance	Measures the balance between human activities and ecological preservation	0.0314
Energy performance	Assesses the efficiency of energy use within the settlement (Bordass et al., 2001)	0.0278

(*Continued on next page*)

Table 11. *Continued*

Indicator	Explanation	Wi
Biodiversity	Evaluates the diversity and health of local flora and fauna	0.0276
Wind protection	Measures the effectiveness of structures and vegetation in protecting the settlement from wind	0.0270
Natural features	Assesses the presence and significance of natural features within the settlement	0.0251
Social services	Evaluates the availability and quality of social services provided to residents	0.0245
Economic adaptability	Measures the economic resilience and adaptability of the settlement (Bampatsou and Halkos, 2019)	0.0240
Natural landscape	Assesses the aesthetic and functional value of the natural landscape within the settlement (Cao, 2023)	0.0238
Development level	Measures the overall level of development and infrastructure within the settlement	0.0235
Spatial characteristic (planning)	Evaluates the spatial organisation and planning of the settlement	0.0221
Regional development	Assesses the settlement's integration and contribution to regional development (Jia et al., 2021)	0.0217
Thermal comfort	Measures the thermal comfort experienced by residents within the settlement (Nawayai, Denan and Majid, 2020)	0.0205
Public facilities	Evaluates the availability and quality of public facilities in the settlement	0.0204
Cultural interaction	Measures the opportunities for cultural exchange and interaction within the settlement (Eppich, 2014)	0.0179
Living conditions	Assesses the overall living conditions and quality of life for residents (Bashari et al., 2021)	0.0172

According to Table 11, indicator weights reveal the varying importance of different factors in evaluating the residential environments of traditional settlements in Northern Jiangxi. "Cultural Continuity" emerged as the most significant indicator, followed closely by "Ecological Suitability", "Liveability" and "Sustainability". These primary indicators underscored the critical aspects necessary for the holistic preservation and development of traditional settlements. Other indicators, such as "Cultural features", "Traditional cultural activities" and "Disaster risk", also contribute notably to the evaluation framework, though to a lesser extent.

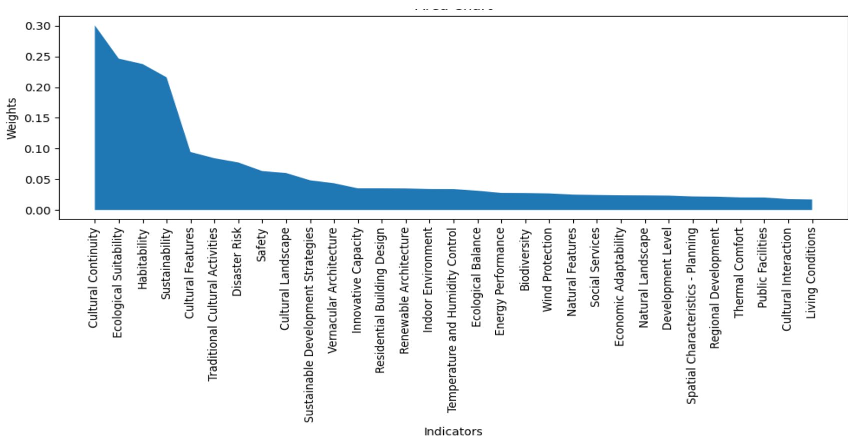

Figure 6. Weights of indicators for evaluating residential environments in traditional settlements of Northern Jiangxi

Application Framework Validation

The evaluation results indicate significant differences in performance across various dimensions for the three villages as shown in Table 12.

Table 12. Comprehensive evaluation scores for case studies

Index	Liu Keng	Diao Yuan	Wu Xi
Cultural continuity	1.262	1.0457	1.0213
Ecological suitability	0.9506	0.8503	0.8745
Liveability	0.9098	0.8444	0.7534
Sustainability	0.8345	0.7517	0.6015
Total	3.9569	3.4921	3.2507

The results in Table 12 indicate that Liu Keng scored highest in the overall assessment with a total score of 3.9569, followed by Diao Yuan with 3.4921 and Wu Xi with 3.2507. This comprehensive evaluation underscored Liu Keng's better performance across the four dimensions, particularly in "Cultural Continuity" and "Ecological Suitability".

The results in Table 13 indicate that Liu Keng exhibited the highest cultural continuity with a total score of 1.262, followed by Diao Yuan at 1.0457 and Wu Xi at 1.0213. Liu Keng's high scores in "Cultural features" and "Traditional cultural activities" highlighted its strong preservation and continuation of cultural practices and elements (Du, 2019).

Table 13. Cultural continuity index scores for all case studies

Index	Liu Keng	Diao Yuan	Wu Xi
Cultural features	0.3776	0.2832	0.3776
Traditional cultural activities	0.3372	0.3372	0.2529
Cultural landscape	0.3010	0.2408	0.1806
Vernacular architecture	0.1744	0.1308	0.1744
Cultural interaction	0.0716	0.0537	0.0358
Total	1.2620	1.0457	1.0213

The results in Table 14 indicate Liu Keng demonstrated a relatively balanced performance across most indicators, achieving a total score of 0.9506, indicating a slightly better performance in "Ecological Suitability". Diao Yuan, with a total score of only 0.8503, was smaller than the rest of the case studies, especially in "Natural landscape" and "Natural features", but remains relatively stable in other indicators. Wu Xi scored 0.8745 overall, performing best, especially in "Disaster risk", "Temperature" and "Humidity control and ecological balance", although it falls behind in "Wind protection" and "Natural features" (Fang and Li, 2022).

Table 14. Ecological suitability index scores for all case studies

Index	Liu Keng	Diao Yuan	Wu Xi
Disaster risk	0.2322	0.2322	0.3096
Wind protection	0.1080	0.108	0.081
Temperature and humidity control	0.1023	0.1023	0.1364
Ecological balance	0.1256	0.1256	0.0942
Natural landscape	0.1190	0.0714	0.0952
Natural features	0.1255	0.1004	0.0753
Biodiversity	0.1380	0.1104	0.0828
Total	0.9506	0.8503	0.8745

The results in Table 15 indicate the "Liveability" scores for three traditional settlements in Northern Jiangxi: Liu Keng, Diao Yuan and Wu Xi. Liu Keng had the highest overall score of 0.9098, indicating strong performance across most indicators. Diao Yuan scored 0.8444 in the overall index, with smaller indexes in "Thermal comfort" and "Public facilities". Wu Xi, with a total score of 0.7534, performed well in "Safety" but poorly in "Public facilities" and "Social services". These results highlight Liu Keng's overall outstanding liveability performance and the specific strengths and weaknesses of each settlement.

Table 15. Liveability index scores for all case studies

Index	Liu Keng	Diao Yuan	Wu Xi
Safety	0.1902	0.1902	0.2536
Residential building design	0.1412	0.1412	0.1059
Indoor environment	0.1368	0.1368	0.1026
Thermal comfort	0.0820	0.0615	0.0615
Living conditions	0.0688	0.0688	0.0516
Spatial characteristic (planning)	0.0663	0.0663	0.0884
Public facilities	0.1020	0.0816	0.0408
Social services	0.1225	0.0980	0.0490
Total	0.9098	0.8444	0.7534

Table 16 shows the results of the "Sustainability" scores for the three case studies. Liu Keng had the highest overall score of 0.8345, indicating outstanding performance across most of the indicators. Diao Yuan scored 0.7517, with notable weaknesses in "Innovative capacity" and "Economic adaptability". Wu Xi, with a total score of 0.6015, performed well in "Sustainable development strategies" and "Renewable architecture" but poorly in "Economic adaptability" and "Regional development". These results highlighted Liu Keng's overall sustainability advantage and the specific strengths and weaknesses of each settlement.

Table 16. Sustainability index scores for all case studies

Index	Liu Keng	Diao Yuan	Wu Xi
Sustainable development strategies	0.1452	0.1452	0.1452
Renewable architecture	0.1404	0.1404	0.1404
Innovative capacity	0.1412	0.1059	0.0706
Energy performance	0.0834	0.0834	0.0834
Economic adaptability	0.1200	0.0960	0.0480
Development level	0.1175	0.0940	0.0705
Regional development	0.0868	0.0868	0.0434
Total	0.8345	0.7517	0.6015

Figure 7 illustrates the comprehensive evaluation scores for Liu Keng, Diao Yuan and Wu Xi across four dimensions: (1) Cultural Continuity, (2) Ecological Suitability, (3) Habitability and (4) Sustainability. Liu Keng showed the highest overall performance, particularly excelling in "Cultural Continuity" and "Sustainability". Diao Yuan performed moderately across all dimensions, with a slight advantage in "Sustainability". Wu Xi, while comparable in "Cultural Continuity" and "Ecological Suitability", fell behind in "Habitability" and "Sustainability". These results highlighted Liu Keng's strong cultural preservation and sustainable practices, while Diao Yuan and Wu Xi had specific areas needing improvement.

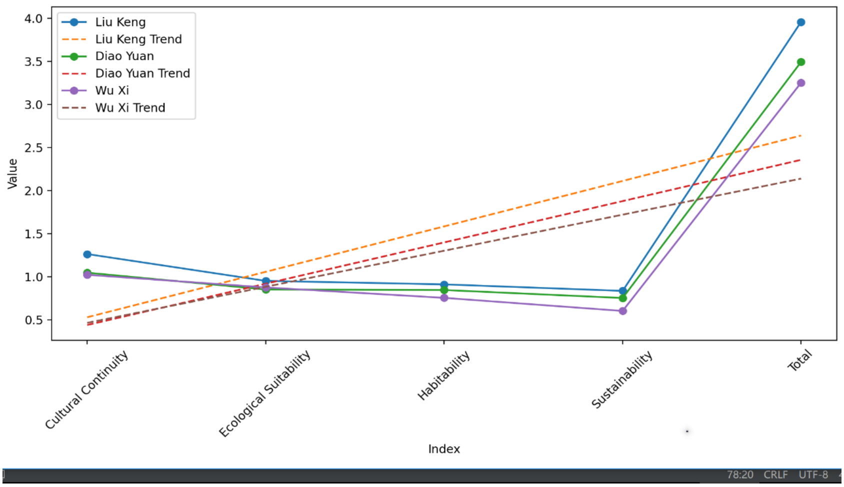

Figure 7. Comprehensive evaluation scores for traditional settlements in three cases

DISCUSSION

Performance of Case Study Villages

Liukeng Village achieved the highest overall score (3.9569) among the three case study villages, excelling particularly in "Cultural Continuity" (1.262) and "Ecological Suitability" (0.9506). The village's well-preserved Ming and Qing dynasties architecture and rich cultural heritage underscore its strong commitment to cultural preservation, directly contributing to the high score in "Cultural Continuity". The indicator "Cultural features" highlights the presence of well-maintained historic buildings and public spaces that continue to serve as cultural hubs for the community. Similarly, "Traditional cultural activities" indicate the frequency and richness of events that help sustain cultural practices and social cohesion. Additionally, Liukeng's balanced performance across ecological indicators reflects effective disaster risk management and environmental adaptation, which are critical for its sustainability.

Diaoyuan Village scored moderately, with a total score of 3.4921, showing strengths in "Sustainability" (0.7517) and a diverse ecosystem. However, its weaknesses in "Natural landscape" and "Natural features" impacted its overall "Ecological Suitability" score (0.8503), highlighting the need for improved environmental management and conservation practices. Indicators like "Ecological balance" and "Natural landscape" measure the village's ability to maintain biodiversity and integrate human habitation harmoniously with the natural environment. The lower scores in "Natural landscape" and "Natural features" suggest a need for enhanced conservation efforts and ecological restoration projects to preserve the village's natural beauty and biodiversity. Enhancements in infrastructure and public facilities are necessary to improve Diaoyuan's liveability and support its ecological strengths, indicating a direct correlation between infrastructure improvements and enhanced liveability scores.

Wuxi Village, with a total score of 3.2507, performed well in "Sustainability" (0.6015) but lagged behind in "Liveability" (0.7534). The village's successful implementation of "Sustainable development strategies" and "Renewable architecture" highlights its potential for environmental conservation. Indicators like "Sustainable development strategies" and "Renewable architecture" reflect the village's adoption of modern environmental practices and the integration of renewable energy sources into its infrastructure. However, the need for improvements in economic adaptability, innovative capacity and public services is evident. The relatively low scores in "Economic adaptability" and "Regional development" indicate challenges in diversifying the local economy and ensuring that development benefits the broader region, suggesting areas for policy intervention to enhance economic resilience. These improvements are essential for enhancing overall liveability and resilience, which are crucial for the village's long-term sustainability and quality of life for its residents.

Implications for Policy and Practice

The results of this study have several significant implications for policymakers and stakeholders involved in rural development and cultural preservation. The multi-dimensional framework developed here, based on the SciBERT algorithm, serves as a robust tool for systematically assessing traditional settlements. It provides detailed insights into each village's strengths and weaknesses, enabling the formulation of targeted conservation and revitalisation strategies. Indicators such as "Cultural features" and "Traditional cultural activities" are critical in assessing the richness and frequency of cultural events and the preservation of unique cultural elements within the settlements.

The high weight of "Cultural Continuity" (0.3004) underscores the importance of preserving traditional cultural practices and values in policymaking. Policymakers should prioritise initiatives that support cultural heritage preservation, such as funding for the restoration of historical buildings and the promotion of traditional cultural activities. This focus ensures that cultural heritage remains a central aspect of rural development strategies.

The significant weight assigned to "Ecological Suitability" (0.2463) highlights the need for environmental compatibility and adaptability. Strategies should include measures to manage disaster risk, control temperature and humidity and maintain ecological balance. Policies could focus on improving natural landscape and biodiversity, which were identified as areas needing enhancement. Indicators such as "Disaster risk" and "Temperature and humidity control" are crucial for understanding and mitigating the environmental vulnerabilities of traditional settlements. These measures are vital for maintaining ecological health and ensuring that traditional settlements can adapt to environmental changes.

"Liveability" (0.2375) is also crucial, emphasising the importance of safety, residential building design and indoor environment. Policies aimed at improving living conditions, such as upgrading infrastructure, providing better social services and enhancing public facilities, are essential. "Liveability" indicators, including "Safety", "Residential building design" and "Indoor environment" provide a comprehensive view of the living conditions within traditional settlements. The data suggests that enhancing spatial characteristics and planning can significantly impact residents' quality of life, making liveability improvements a priority for local governments.

"Sustainability" (0.2159) remains a key dimension, indicating the need for long-term viability and minimal environmental impact. Policies should promote sustainable development strategies, renewable architecture and innovative capacity. Indicators like "Sustainable development strategies" and "Renewable architecture" reflect the effectiveness of environmental practices and the integration of renewable energy sources. Emphasising economic adaptability and regional development can also foster resilience and growth in traditional settlements. These policies are essential for ensuring that traditional settlements can thrive in the long term, balancing development with conservation.

CONCLUSIONS

This study developed and validated a comprehensive multi-dimensional framework for evaluating the residential environments of traditional settlements in Northern Jiangxi, China, leveraging the SciBERT algorithm for enhanced precision in indicator extraction. By focusing on four key dimensions: "Ecological Suitability", "Cultural Continuity", "Liveability" and "Sustainability", this framework addresses the urgent need for systematic and balanced assessment methods in the context of rapid urbanisation and rural revitalisation.

The case studies of Liukeng, Diaoyuan and Wuxi Villages revealed significant insights. Liukeng Village emerged as the top performer across all four dimensions, particularly excelling in cultural continuity and ecological suitability. This underscores Liukeng's successful preservation of historical architecture and effective environmental adaptation strategies. The high scores in "Cultural features" and "Traditional cultural activities" in Liukeng reflect the village's strong commitment to maintaining its cultural heritage. Diaoyuan Village, with its strong ecological base, highlighted the importance of biodiversity and harmonious human-environment interactions but also showed the need for improved infrastructure and public facilities. Indicators like "Ecological balance" and "Natural landscape" in Diaoyuan suggest the need for enhanced conservation efforts to better preserve the village's natural beauty and biodiversity. Wuxi Village demonstrated commendable sustainability practices but lagged in liveability, indicating a need for enhanced economic adaptability and public services. The low scores in "Economic adaptability" and "Public facilities" in Wuxi highlight areas for potential policy intervention to improve economic resilience and public services.

Future research should aim to refine the indicators and methodologies used in this framework to better capture the evolving dynamics of traditional settlements. Investigating the impact of external factors such as policy changes, economic shifts and environmental threats on these settlements will be essential. Collaborative efforts between researchers, policymakers and local communities are critical for ensuring the sustainable development and preservation of traditional settlements.

ACKNOWLEDGEMENTS

The authors would like to express sincere gratitude to Universiti Sains Malaysia, Pulau Pinang and Henan University of Technology, China, for their invaluable support in the completion of this work.

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