

Spatial system construction and design strategies for sustainable fire-resistant ancient villages

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Abstract. Ancient village fires have caused serious economic and cultural losses, and the construction of sustainable fire-resistant and disaster-resistant spatial systems and design strategies for ancient villages can effectively prevent and control ancient village fires. This paper uses the Dukezong Ancient City as the study area, chooses the hierarchical analysis method to analyze the factors of the 2014 Dukezong Ancient City fire, the risk assessment method to evaluate the riskiness of its post-disaster reconstruction, and proposes corresponding design strategies. The spatial system design strategy for sustainable fire-resistant ancient villages is designed to improve the risk assessment of disaster-causing factors in ancient villages, establish an evaluation mechanism for the regional characteristics of ancient villages, comprehensively improve the fire-fighting power of ancient villages, and establish a sustainable fire-resistant spatial system. It provides a theoretical basis and reference for the study of ancient village protection.

Keywords: Sustainable Fire Resilience; Ancient Villages; Hierarchical Analysis; Risk Assessment; Design Strategies.

1. Introduction

Although the spatial system of ancient villages has a significant impact on the occurrence and development of potential hazards, it has not received the appropriate attention in the field of disaster reduction research. Historical experience has shown that the rationality of the spatial system of ancient villages plays a pivotal role in achieving sustainable resistance to fire and disaster; at the same time, the spatial system of ancient villages can minimise disaster losses. Therefore, this paper takes the regional characteristics of ancient villages as the starting point and focuses on their disaster prevention dynamics. Firstly, from the perspective of controllable disaster-causing factors, it explores strategies and methods to effectively reduce the probability of occurrence of disasters and reduce disaster losses, and secondly, it explores the spatial mitigation functions and design methods of ancient villages during and after disasters, in order to build a sustainable fire-resistant disaster prevention system for ancient villages^[1].

2. Research Methodology

(1) Hierarchical analysis

Hierarchical analysis is a method of decomposing the elements involved in the decision-making process into levels of objectives, criteria and options, and using these levels as a basis for quantitative and qualitative analysis of the decision. Hierarchical analysis has the advantages of being systematic, practical and concise, taking the ancient village as a system, decomposing it, comparing it, judging it and synthesising it, and combining qualitative and quantitative method. It is suitable for studying the spatial system of ancient villages, but the hierarchical analysis method also has limitations, low accuracy and large errors, so the data used in this paper is mainly based on expert opinion to reduce errors^[2].

(2) Risk assessment

This means that the probability of occurrence, the scale of loss and other influencing factors are combined based on the identification and assessment of risk. By comparing this with existing safety guidelines, the hazards present in the area are identified and, accordingly, the degree of risk in the area is determined and the need for appropriate control measures is judged accordingly.

3. Analysis of data

(1) Sustainable fire prevention capability analysis

The evaluation factor set for the post-disaster reconstruction of the ancient city of Dukezong was adjusted, integrating the content under each secondary factor and eliminating tertiary factors with little relevance to the indigenous people in order to build the evaluation index system.

The expert scores from the Dukezong Ancient City questionnaire were collected to filter and rank the evaluation factors in the evaluation index system, and the results were collected to provide a basis for the construction of the evaluation factor set and weighting of the evaluation index system.

In summary, the process of constructing this evaluation indicator system includes drawing on relevant research findings, collecting the subjective perceptions of the original households, combining the objective evaluations of the experts and the findings of the evaluation system builder, etc. Through the collation, a comprehensive evaluation system indicator system for the Dukezong Ancient City is finally obtained^[3].

Tab.1 Indicator factors

Tier 1 indicators (T1)	Secondary indicators (T2)
a1 Geographical characteristics	a11 Spiritual support
	a12 Life Scenes
	a13 Views of the village
	a14 Green Belt
a2 Spatial pattern	a21 Roads
	a22 Public spaces
	a23 The Village Courtyard
a3 Functional layout	a31 Basic equipment
	a32 Recreational facilities
	a33 Tourism facilities
a4 Design for disaster prevention	a41 Safety design
	a42 Fire protection design
	a43 Anti-vibration design
a5 Operating format	a51 Government
	a52 Public
	a53 Personal

Based on the results of the scoring in the expert questionnaire, the geometric mean of each indicator was calculated separately to determine the relative importance of each indicator in each tier.

Tab.2 Indicator weighting

T1	Importance	T2	Importance
a1	4.9	a11	4.3
		a12	4.6
		a13	4.8
		a14	4.2
a2	4.6	a21	4.8
		a22	4.6
		a23	4.5
a3	4.4	a31	5
		a32	4.5
		a33	4.3
a4	4.8	a41	4.6
		a42	4.9
		a43	4.7
a5	4.7	a51	4.9
		a52	4.8
		a53	4.5

Based on the spatial post-disaster built environment evaluation index system for the ancient settlement of Dukezong, a structural model was established as shown in Fig. 1.

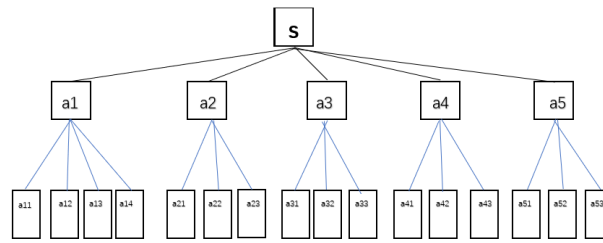


Fig. 1 structural model

The quantitative scaling method was used to construct the priority relationship matrix.

Tab.3 AHP data

	a1	a2	a3	a4	a5
a1	1.000	1.250	1.667	1.000	1.250
a2	0.800	1.000	1.250	0.833	0.833
a3	0.600	0.800	1.000	0.833	0.833
a4	1.000	1.200	1.200	1.000	1.250
a5	0.800	1.200	1.200	0.800	1.000

In addition to this, the maximum characteristic root (5.014) can be calculated by combining the eigenvectors, and then the CI value (0.004) is calculated using the maximum characteristic root value.

Tab. 4 AHP Analysis Results

Item	Eigenvectors	Weighting values (WV)	Maximum Eigenvalue	CI value
a1	1.197	23.942%	5.014	0.004
a2	0.920	18.394%		
a3	0.796	15.916%		
a4	1.114	22.281%		
a5	0.973	19.466%		

The current study constructs a 5th order judgement matrix that can be queried to obtain a random consistency RI value of 1.120.

A CR value of $0.003 < 0.1$ was calculated, meaning that the judgement matrix of this study met the consistency test and the weights calculated were consistent.

Data processing of the weight values of the primary indicators based on the values of the secondary indicators was carried out to produce the decision results.

Tab.5 Weighting values

T1	WV	T2 / Importance				Results
a1	0.2394	A11 4.3	A12 4.6	A13 4.8	A14 4.2	4.28526
a2	0.1839	A21 4.8	A22 4.6	A23 4.5		2.55621
a3	0.1592	A31 5	A32 4.5	A33 4.3		2.19696
a4	0.2228	A41 4.6	A42 4.9	A43 4.7		3.16376
a5	0.1947	A51 4.9	A52 4.8	A53 4.5		2.76474

According to Table 5, the highest scores were obtained for the regional characteristics, indicating that the most important and important element to be considered in the post-disaster reconstruction process of the Dukezong Ancient City is the local regional characteristics of the Dukezong Ancient City, according to the experts' opinion. This also proves that the spatial system for building a sustainable fire-resistant ancient village should focus on the local characteristics of the ancient village^[4].

Based on this, secondary and tertiary indicators were selected for the risk assessment of the Dukezong Ancient City, with a focus on the impact of regional characteristics on overall risk in the secondary indicators.

Risk assessment of ancient villages for sustainable resistance to fire and disaster

In order to calculate the risk value of the ancient city of Dukezong, a risk assessment was carried out, and the risk value of the ancient village was calculated by selecting the disaster-causing factors and geographical characteristics as the primary indicators. In order to improve the resistance of the ancient village to fire and disaster, fire-fighting forces were added as a first-order indicator.

The indicators for the disaster-causing factors were selected as fire spacing, building structure, fire resistance rating of the building, age of the building, use of fire, age of electrical circuits and use of electricity. The secondary assessment indicators for the disaster-causing factors are

The secondary assessment indicators of climatic environment, building density and the proportion of mobile population are selected as secondary assessment indicators of geographical characteristics.

The layout of fire stations, fire fighting water supply capacity, width of fire fighting channels, number of fire fighting equipment, fire fighting publicity and education, are selected as secondary assessment indicators of fire fighting capability^[5].

The weighted values of the indicators and expert scores value (SV) were brought in to produce the Dukezong Ancient City Fire Risk Assessment Form.

Where A1 is Causal factors, B1 is Geographical characteristics and C1 is Fire fighting forces.

Tab.6 Fire Risk Assessment Form

T1	WV	T2	SV	WV	T3	WV
A1	0.3	A11	3	0.1294	A112	0.5333
		Fire spacing			Less than 8m	
		A12	5	0.1739	A121	0.3667
		Building construction			Wooden structures	
		A13	4	0.1592	A132	0.3167
		Building resistance rating			Level 3	
		A14	3	0.2128	A141	0.5333
		Building age			50+ years	
		A15	4	0.147	A151	0.5676
		Use of fire			Use of open fire	
A16	3	0.1777	A161	0.4333		
Electricity consumption			Circuit deterioration			
B1	0.3	A16	3	0.1777	A164	0.3167
		Electricity consumption			Overload power consumption	
		B11	3	0.423	B111	0.3755
		Climatic environment			Dry season	
B12	2	0.347	B121	0.6432		
Building density			More than 50%			
B13	2	0.23	B131	0.6766		
Percentage of mobile population			More than 30%			
C1	0.3	C11	4	0.175	C111	0.5462
		Fire station layout			Unreasonable	
		C12	5	0.25	C121	0.2833
		water supply capacity			Some fire hydrants are not working	
		C13	4	0.2	C132	0.4
Fire escape width	Less than 4m					
C14	4	0.2	C14	0.25		
No. of equipment			Inadequate fire extinguishers			
C15	2	0.175	C152	0.533		
		Fire Prevention Education			No relevant education	

The final calculation is that Dukezong is at high risk of fire, which is reasonable in light of the fact that the fire in Dukezong was caused by human arson, but also reflects the fact that Dukezong has serious fire hazards and needs to be made more resilient to fire.

To improve fire resilience, Dukezong was rebuilt after the 2014 fire, and the risk assessment after improving fire resilience was calculated by reviewing the Shangri-La Yearbook and changing some of the 3 levels of indicators based on their post-rebuilding process^[6].

Tab. 7 Indicator evaluation

T1	WV	T2	SV	WV	T3	WV
A1	0.3	A11	3	0.1294	A111 8~12m	0.2833
		A12	5	0.1739	A123 Reinforced concrete	0.125
		A13	4	0.1592	A131 Level 1 or Level 2	0.175
		A14	3	0.2128	A143 Under 50 years	0.4666
		A15	4	0.147	A152 Electrical	0.4323
		A16	3	0.1777	A162 Circuit not aged	0.1417
B1	0.3	A16	3	0.1777	A163 Regulating electricity use	0.1083
		B11	3	0.423	B113 Other	0.3053
		B12	2	0.347	B121 Not more than 50%	0.4568
C1	0.3	B13	2	0.23	B131 Over 30%	0.6766
		C11	4	0.175	C112 Reasonable	0.4538
		C12	5	0.25	C121 Stable water supply	0.1167
		C13	4	0.2	C131 Not less than 4m	0.4
		C14	4	0.2	C141 Configured to specification	0.15
		C15	2	0.175	C151 Have some knowledge	0.3083

The final result is an R2 risk score of approximately 3.0, indicating that the Dukezong Ancient City is at average risk at this time, but still has the potential for disaster. The primary indicators show a reduction of 44.4% in the disaster-causing factor score, 37% in the geographical characteristics score and 37.5% in the fire fighting force score. According to Table 4-3, the lower the risk score, the lower the risk potential of the village, the lower the probability of a disaster occurring or the lower the damage received in the event of a disaster. Among the secondary factors, the lowest score and the lowest reduction in geographical characteristics indicate that geographical characteristics play the most important role in the process of improving the resilience of ancient villages to fire and disaster, which is consistent with the conclusions drawn from the previous hierarchical analysis. The calculated increase: $H1 = 0.348$, indicating a 34.8% reduction in the fire risk of Dukezong Ancient City after the addition of the fire resilience factor, demonstrating an increase in its fire resilience.

4. Spatial construction and design strategies for sustainable fire resilient ancient villages

Based on the above research, a design strategy is proposed for the construction of a sustainable fire-resilient ancient village spatial system based on the risk assessment of the Dukezong Ancient City, its causal factors, local characteristics and fire-fighting capabilities.

Based on the existing risk assessment, the main hazard factors affecting the ancient village are included, such as floods, landslides and earthquakes. In the assessment, the role of multiple factors, such as the natural and social environment of the ancient village, and the effects produced by multiple disaster-causing factors are fully taken into account to truly reflect the scope and extent of the impact of each disaster-causing factor. Firstly, the assessment of individual disaster-causing factors clearly reflects the potential impact of ancient villages in natural disasters; secondly, according to the different degrees of impact of plural disaster-causing factors on ancient villages, decision methods such as AHP are used to determine the weights of each factor, so as to evaluate the risk of multiple disaster-causing factors and improve the risk assessment system for disaster-causing factors in ancient villages.

According to the regional characteristics of ancient villages, the vulnerability assessment system of ancient villages is constructed; firstly, the vulnerability index of ancient villages can be determined according to their social, economic and ecological conditions, with reference to the criteria for selecting vulnerability indicators in various European regions, and the weight index is used as a basis to determine the vulnerability of each spatial subdivision. Secondly, the vulnerability of various

disaster factors was classified. For example, in the case of the Dukezong Ancient City fire, the risk level after the fire was analyzed according to the actual situation of the Dukezong Ancient City, and the risk level of different areas was determined and given a corresponding risk level, and a chart was used to clarify the risk level of each area. The map shows not only the risk level of each area, but also the location of shelters and rescue organization.

Firstly, according to the map of the vulnerability of ancient villages, attention is paid to areas of higher vulnerability, i.e. disaster-prone, and suitable locations are selected for additional fire stations or temporary fire stations. Secondly, widen roads to meet the minimum width required by the National Fire Code to allow for the passage of fire-fighting vehicles, and provide additional roads and expressways to facilitate the evacuation of people and the transportation of relief supplies in the event of a disaster. Then, improve the design strategy of the spatial system of disaster-relief shelters, increase the number of central shelters and optimize their layout, increase the area of disaster-relief shelters and adjust the scope of application of fixed shelters^[7]. Finally, a sound emergency management supervision system should be established, and safety checks should be carried out on ancient village communities from time to time, for example, to check whether fire extinguishers are equipped in the streets and households, whether they are in normal use, and whether they are within their shelf life; at the same time, popularize safety knowledge, and safety knowledge manuals should be issued so that each household has a certain amount of safety knowledge, so that they can effectively save themselves and each other in the event of a disaster, thus enhancing the community's sustainable development. This will enable each household to have a certain amount of safety knowledge, so that they can effectively save themselves in case of disasters and enhance the community's ability to resist fire and disasters.

5. Conclusion

Based on the perspective of sustainable fire resilience in ancient villages, the Dukezong Ancient Town was used as the research object, combining questionnaires and opinions of relevant experts, the hierarchical analysis method was chosen to analyse the factors that caused the 2014 fire in Dukezong Ancient Town and the risk assessment method was applied to evaluate the riskiness of its post-disaster reconstruction, and corresponding design strategies were proposed from the perspective of sustainable development. The results show that geographical characteristics are closely related to the resilience of ancient villages to fire and disaster. From the perspective of disaster response, the inclusion of fire resilience factors in the design of the spatial system of ancient villages can enhance the resilience of ancient villages to disasters, reduce losses in the face of disasters, and achieve sustainable development in the post-disaster period.

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