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2024 (3)

CONTENTS

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http://www.viserdata.com/journal/jsa

2024(3)

目　次

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Journal of South Architecture

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Research on Villages Classification and Development Strategy under the Concept of "Five States" Fusion ——Taking Traditional Villages in Southern Shaanxi as an Example

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ABSTRACT: As the origin and an important carrier of Chinese traditional culture, traditional villages have been irreversibly affected by population loss, unused land, ecological damage and cultural annihilation through urbanisation and modernisation. Accordingly, their protection and development are facing practical problems, such as recession, disappearance and transformation. Based on the embeddedness of local characteristics and local culture in the traditional villages, and combined with the evolution characteristics and resources endowment of traditional villages, the multi-disciplinary, multi-dimensional, and dynamic research perspectives are applied to explore the suitable and efficient strategies classified protection and development for traditional villages. Traditional villages are structural organisms in which humans and nature symbiotically interact in a specific time and space process, confirming the trajectories of activities and true effects of economic and social development in different historical stages. This paper constructs a ternary regional system for traditional villages by incorporating the traditional village spatial subject research into the traditional dual analysis framework of 'Human and Land'. This paper further proposes the traditional village analysis method centring on 'Five States' fusion, focusing on the village's ecology, culture, industry and space and the endogenous linkages and co-progress between these elements. A diversified, adaptable and complicated traditional village collaborative development mechanism is summarised by analysing the multiple types of interactions and combination relationships generated by each element. At the same time, combined with the life cycle evolution process of traditional villages covering 'Formation-Development- Maturity-Decay-Rejuvenation' and based on the analysis of dynamic transformations and transformations between ecology, culture, industry and space, the following is put forward in the paper. First, in the 'Formation-Development' stage, the traditional villages present the development characteristics of 'Ecological Resource Concentration'. Second, in the 'Development-Maturity' stage, the traditional villages present the development specialty of 'Industrial function Symbiosis'. Third, in the 'Mature-Decay' stage, the traditional villages present the development impetus of 'Differentiated Collage Organisation'. Finally, in the stage of 'Decay-Rejuvenation', the traditional villages present the development change of the 'Adaptation and Regulation Between Culture and Landscape'.

KEY WORDS: five states; traditional villages; classification; development strategy; Southern Shaanxi

Traditional villages, as the root and important carrier of Chinese traditional culture, embody a unique blend of local characteristics and ethnic styles. These vernacular cultural elements are pivotal in implementing the rural re-

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vitalization strategy under the context of the new era. The protection of traditional villages has been identified by the academic community as one of the most significant research areas within the domain of Chinese traditional culture for the next decade[1]. Since the first announcement of the Chinese Traditional Village List in 2012, the Ministry of Housing and Urban-Rural Development, along with other governmental bodies, has released five batches, totaling 6819 traditional villages across 30 provinces, municipalities, and autonomous regions. Several laws and regulations have been enacted, elevating the protection and development of traditional villages to a national strategic level. However, the rapid advancement of urbanization and modernization in China has increasingly highlighted the conflict between the economic and social development needs of rural areas and the protection of traditional villages, naturally leading to challenges in the development and transformation of these villages[2]. Today, many traditional villages, after undergoing "reformation" or "revolution," are facing issues such as conceptual deviations leading to the destruction of their original appearance, extensive development resulting in malignant outcomes, and the intensification of conflicts due to multiple competing demands. Thus, as efforts to protect and develop traditional villages continue, it is crucial to employ a multi-methodological theoretical perspective to scientifically understand these villages, explore the characteristics of their evolution and classify their development, and propose targeted, more efficient classification-based development strategies.

As a scientific and intuitive research method, the classification of traditional villages has gained recognition and attention from the academic community, with research interest continuing to rise. Reviewing existing research by domestic and international experts and scholars, the classification of traditionalvillages aids in identifying common characteristics, thereby promoting the living inheritance of local resources and traditional culture, and advancing the classified protection and development of traditional villages. Currently, research directions and focuses within the academic community vary, with most studies categorizing traditional villages based on single factors such as topography, cultural characteristics, spatial form, functional composition, intrinsic value, or residential types[3-5]. A smaller number of scholars have employed a comprehensive classification approach, considering the interconnections and interactions of multiple elements within traditional villages[6]. In terms of research theories and methods, most classifications rely on qualitative or quantitative evaluations of traditional villages based on comprehensive evaluation results derived from systematic evaluation theories. The application of new technologies and theories, such as big data, has also enhanced the objectivity and scientific rigor of traditional village classification[7-9]. In summary, academic research on traditional village classification demonstrates diversity and multi-perspective approaches. However, in the current context of rural revitalization and the transformation of urban-rural relationships, traditional villages are entering a new phase of transformative development. Existing studies still lack a dynamic, multi-factor comprehensive classification method to address the transformation, protection, and development of traditional villages.

This article, based on an understanding of the current state of 22 nationally recognized traditional villages in southern Shaanxi, adopts a dynamic and multi-dimensional research perspective to focus on the dynamic evolution and combination of four major elements: ecology, culture, economy, and space. It explores the applicability and operational mechanisms of the "Five States" research concept in the process of traditional village classification. Furthermore, the study attempts to construct a "Five States" integrated classification method at the regional scale of southern Shaanxi, based on the development characteristics of different types of traditional villages. This method aims to explore various development paths and propose scientifically effective strategies for protection and development, with the ultimate goal of promoting the sustainable development of traditional villages.

1 Theoretical foundations and analysis of the "Five States" integration

1.1 Origins of the "Five states" integration theory

Traditional villages are rich repositories of diverse historical and cultural information specific to their regions, reflecting the real impacts of different historical periods and socio-economic developments. These villages embody an organic human-environment relationship that was established during the agrarian era, characterized by a harmonious coexistence between humans and nature. Throughout the evolution of the human-environment system in traditional villages, the relationship between human and the natural environment has consistently been the contradictory one of guided feedback, mutual-constraint adaptation, and collaborative development. As a result, scholars have gradually decomposed the human system and natural system into various elemental types such as lifestyle, behavioral habits, social structure, economic types, cultural beliefs, and ecological environments, and have systematically studied the interactions among these elements. Li Bohua, Zeng Rongqian, and others categorized traditional villages into four major systems: ecological environment, spatial subject of traditional villages, social culture, and material support, and investigated the nonlinear evolution mechanisms presented by the complex interactions within these systems[10]. Zhou Shangyi further decomposed the human sphere into layers of livelihood, institutional framework, and ideology, integrating them with the natural layer as a comprehensive analytical framework, and constructed the "four-layer integrated" regional analytical system theory and method for the human-environment relationship in traditional villages[11]. Building on theories of synergy, dissipative structures, and complex adaptive systems, I have introduced the spatial subject of traditional villages within the framework of binary analysis of "human and environment" to construct a "three-aspect" analytical framework. This framework focuses on the dynamic interactions and synergies among the four elements of ecology, culture, economy, and form in traditional villages, and proposes the "Five States" analytical method, aiming to uncover the local characteristics of traditional villages to better guide their protection and development.

1.2 Composition of the "Five States" integration

The "Five States" approach is rooted in a longitudinal perspective on the dynamic interactions between the traditional village inhabitant (economy and culture), village space (form), and environment (ecology). These four elements, as a complete structural organism, exhibit intrinsic linkage and collaborative progression, fully embodying the dynamism, unity, and integrity of the "three-aspect" relationship system among humans, environment, and village space[12](Figure 1). In the system:

(1) Ecology refers to the totality of geographical location and associated natural conditions of a social unit, which forms the natural foundation and resource base for the formation and development of traditional villages. As an external driving force, it lays the initial framework for the village's generation and development.

(2) Culture is the sum of the influences that social existence exerts on human consciousness, value orientations, and related factors, reflecting the social behavior norms and collective cultural consensus of traditional villages, including historical culture, spiritual consciousness, and survival rules and so on. This cultural state subtly shapes and constrains the villagers.

(3) Economy refers to the comprehensive system of livelihood activities and behavior systems formed by the long-term interaction between people and the natural ecological environment within a social unit under local conditions. It epitomizes the village's modes of production, survival wisdom, and intrinsic driving forces.

(4) Form pertains to the physical spatial representation and structural sequence resulting from the interaction between natural ecological factors and social factors of a social unit. The evolution of form, from singularity to diversity, from disorder to order, and from privacy to openness, fully reflects the transformation in local villagers' cultural spirit, value pursuits, and collective psychological consensus.

(5) Dynamism recognizes that traditional villages, as living organisms, are characterized by complexity and comprehensiveness. Their protection and development must satisfy the basic requirements of ecological foundation support, economic model promotion, spatial form guidance, and cultural spirit shaping, thereby promoting the dynamic balance and coordinated advancement of the "five states"[13].

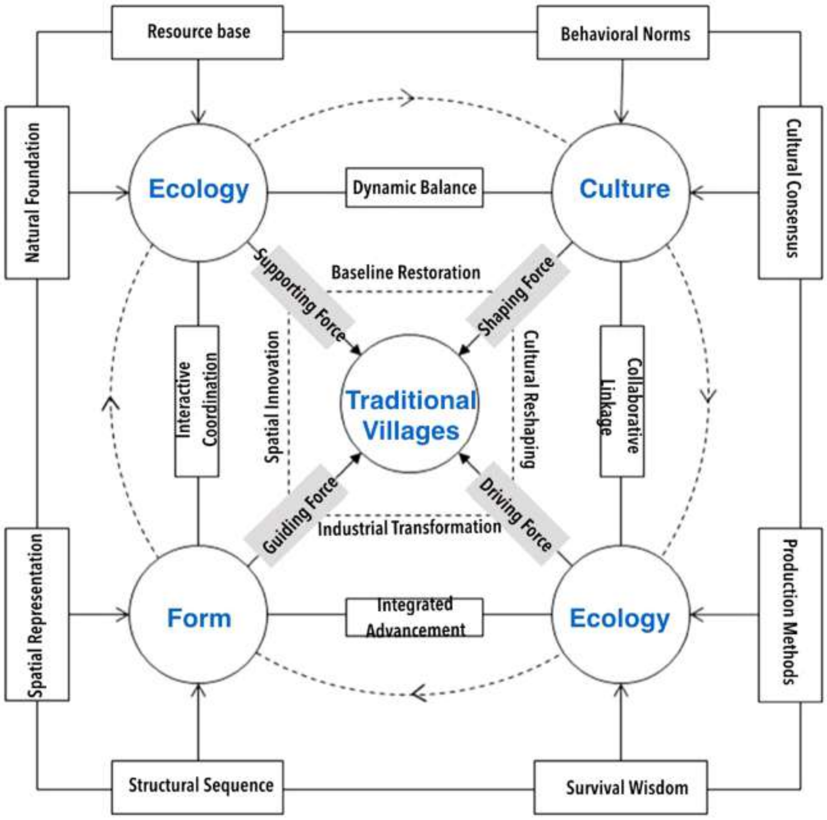

Figure 1 Analysis of the elemental connotations of the "Five States" of traditional villages

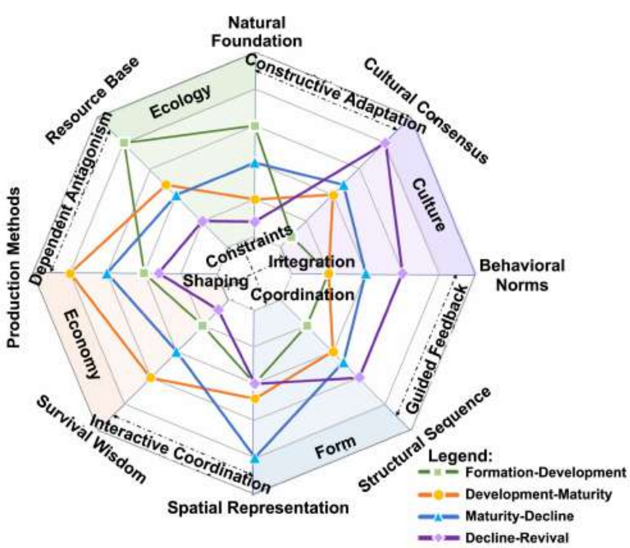

Figure 2 Research on the Interaction and Collaborative Relationship of the 'Five States' in Traditional Villages

1.3 Synergistic mechanisms of the "Five States" integration

Within the "Five States" framework, the elements exhibit diversity, functionality, and dynamism as they evolve across both temporal and spatial dimensions, resulting in a variety of interactive combinations. By systematically analyzing the interactive logic of the "Five States" throughout the dynamic evolution of traditional villages, we can dissect the synergisticdevelopment mechanisms formed during the prolonged interaction between the cultural system, material space, and natural system of these villages (Figure 2). The specific relationships are as follows:

(1) Ecology and culture display the constructive adjustment relationship: Ecology serves as the local source of cultural identity in traditional villages, giving rise to the cultural spirit and psychological consensus unique to the village. Culture, in turn, reflects the value system underpinning the human-environment relationship in traditional villages, profoundly influencing the villagers' systematic and holistic understanding of the natural environment.

(2) Ecology and economy display the dependent antagonistic relationship: Ecology provides the foundational production platform and essential living resources, serving as the physical basis forfor the village's economy. The economy, on the other hand, represents the fundamental approach through which villagers engage with, utilize, and modify the natural environment, demonstrating their survival wisdom.

(3) Ecology and form display the constraining coordination relationship: Ecology is the fundamental external factor shaping the physical form of traditional villages, defining the natural geographical boundaries of the village's material space and limiting the disorderly extension of its basic spatial structures. Form, as the outcome of human-environment interaction and coordination, is the physical manifestation of the villagers' passive adaptation to and active transformation of the natural environment.

(4) Culture and economy display the shaping and Integration relationship: Culture encompasses the collective consensus of the village's production activities, guiding the transformation of the material space, the updating of production techniques and tools, and the evolution of production-related thinking and behavior. The economy integrates the village's survival culture, reflecting the collective psychology, lifestyle attitudes, and survival perspectives of the local community.

(5) Culture and form display the guiding feedback relationship: Culture is the fundamental essence and cultural core of the village's material space, functioning as the informal force guiding the transformation of spatial representations, the construction of structural sequences, and the establishment of geographical relations. Form, as the physical carrier and external representation of the villagers' ideological concepts, reinforces and intensifies the collective cultural consciousness through its renewal and feedback.

(6) Economy and form display the interactive coordination relationship: The economy is a crucial internal driving force for the survival and development of traditional villages, with adjustments and optimizations in the village's industrial structure leading to changes in its material spatial form. The form, in turn, provides the essential material foundation for social production, with its elastic properties supporting and promoting the transformation of the village's production networks and industrial structures.

Throughout the life cycle of a traditional village—from formation to development, maturity, decline, and revival—the ecological, cultural, economic, and formal elements undergo a series ofdynamic transitions that drive the spatial-temporal evolution of this complex macro-system.

(1) Formation to development: The shift from passive adaptation to active transformation of nature by villagers characterizes a development phase of "ecological resource convergence," where ecology primarily drives development, followed by the economy.

(2) Development to maturity: Changes in internal land use and population growth lead to "industrial symbiosis," disrupting the traditional stable economic structure of the village, resulting in a mechanism where the economy becomes the primary driver, with form playing a secondary role.

(3) Maturity to decline: Under the influence of urbanization and modernization, the number of traditional villages dominated by singular or homogeneous factors gradually decreases, forming a "differentiated patchwork organization" dynamic, where form and economy lead, followed by culture, with ecology becoming subordinate.

(4) Decline to revival: The significance of local cultural factors becomes more prominent during the revival of traditional villages. Driven by market forces and capital, a dynamic shift towards "cultural-landscape adaptive regulation" emerges, where culture leads and interacts adaptively and synergistically with economy, ecology, and form[14].

2 Classification of traditional villages in southern Shaanxi from the perspective of the "Five States"

2.1 Selection of research samples

Southern Shaanxi refers to the southern region of Shaanxi Province, encompassing the prefecture-level cities of Hanzhong, Ankang, and Shangluo, with a total of 28 districts and counties. Bordered by the Qinling Mountains to the north and the Daba and Micang Mountains to the south, this region is traversed from west to east by the Han River, characterized predominantly by hilly and mountainous terrain with numerous rivers. Situated at the boundary between northern and southern China, Southern Shaanxi's unique natural environment has fostered a diverse and integrated socio-cultural atmosphere. This environment has provided the local population with abundant material resources and an ecological foundation, resulting in a rich and distinct traditional village cultural landscape shaped by both natural and cultural influences. However, the late start of traditional village conservation efforts in China, incomplete scientific theoretical guidance, and the lagging socio-economic development in rural areas have exacerbated the urgency of addressing the protection and transformation of traditional villages in southern Shaanxi. Currently, among the five batches of national-level traditional village protection lists published in China, 22 are located in southern Shaanxi: 15 in Ankang, 5 in Hanzhong, and 2 in Shangluo. This study uses these 22 nationally recognized traditional villages as samples to develop a classification and evaluation framework, aiming to analyze specific types and development strategies for traditional villages in southern Shaanxi, thereby providing references for future protection and development efforts (Table 1) (Figure 3).

Table 1 Statistics of national-level traditional villages by district and county in the southern Shaanxi region

Municipalities	Counties	National-level traditional village names	Number of national-level traditional villages
Ankang	Ziyang County	Yingliang Village, Xiangyang Town	15
	Shiquan County	Changxing Village, Houliu Town	
		Changling Village, Yundou Town	
	Xunyang County	Miaowan Village, Qili Village, Chiyan Town	
		Wanfu Village, Chiyan Town	
		Zhanjiawan Village, Chiyan Town	
		Zhongshan Village (Guojia Laoyuan), Zhaowan Town	
		Niuyin Jiapo Village, Xianhe Town	
	Hanbin District	Shuangqiao Village, Yeping Town	
		Wangzhuang Village, Zaoyang Town	
		Gaoshan Village, Gongjin Town	
		Qianhe Village, Tanba Town	
		Mahe Village, Tanba Town	
		Tianbao Village, Shuanglong Town	
		Shuangbai Village, Shizhuan Town	
Hanzhong	Liuba County	Chengguan Village, Chengguan Town	5
		Miaotaizi Village, Liuhou Town	
		Moping Village,Jiangkou Town	
	Chenggu County	Lefeng Village, Shangyuanguan Town	
	Ningqiang County	Qingmuchuan Village, Qingmuchuan Town	
Shangluo	Shanyang County	Guzhen Community, Manchuan Pass Town	2
	Zhen'an County	Yunzhen Village, Yungai Temple Town	

2.2 Constructing of the evaluation system

Traditional villages are complex, multi-dimensional regional systems with temporal characteristics. To analyze the development status of traditional villages in southern Shaanxi, a combined qualitative and quantitative approach was employed. The qualitative aspect, primarily based on group perception, interprets and transforms the specific characteristics of village development. The quantitative aspect relies on textual materials and statistical data to provide objective and scientific analysis. The specific analytical framework considers ecological enhancement, cultural integration, economic transformation, and spatial reconstruction as key driving forces, leading to the development of an evaluation index system based on the "Five States" integration concept.

The hierarchical structure of the classification evaluation system comprises four levels: the target level, criterion level, factor level, and indicator level. The criterion level includes ecology, cultural, economy, and form.To enhance operability, the system draws on the "Traditional Village

Table 2 Evaluation index system for the development of traditional villages in southern Shaanxi based on the "Five States" integration concept

Target level	Criteria level	Factors level	Indicators level	Indicator factor abbreviations	Standard description
Dynamic development of traditional villages in southern Shaanxi	Ecology	Resource richness	Plant and animal resource richness	Reflects the landscape of animal and plant, indicating the diversity of plant and animal resources.	Constraint (↓) / support (↑)
			Water resource richness	Reflects the water landscapes in the village area, indicating the uniqueness.	
			Mineral resource richness	Reflects the mineral resources, indicating the abundance.	
		Land carrying capacity	Arable land ratio	Reflects the proportion of cultivated land to total land area, indicating agricultural productivity.	
			ResidentialLand ratio	Reflects the proportion of residentialconstruction land to total land area, indicating the current state of village development.	
	Culture	Local cultural preservation	Cultural longevity	Reflects the historical depth of material culture.	Restriction (↓) / shaping (↑)
			Local cultural retention rate (material cultural heritage)	Refers to the preservation status of material cultural heritage, indicating the degree of local culture preservation.	
		Culture activation	Proportion of inheritors (intangible cultural heritage)	Refers to the proportion of intangible cultural heritage inheritors in the village population, indicating the degree of local culture inheritance.	
			Cultural industry output ratio	Refers to the proportion of cultural industry output in the village's total production value, indicating the utilization of local culture.	
	Economy	Socio-Economic growth	Per capita net income	Reflects the standard of living and affluence of local villagers.	Driving (↓)/promoting(↑)
			Income source distribution	Reflects the distribution of income sources, indicating economic activity levels.	
			Annual income growth rate	Reflects the proportion of income growth relative to total income, indicating economic development in the village area.	
		Industrial structure transformation	Industry structure ratio	Reflects the proportion of primary, secondary, and tertiary industries, indicating the level of industrial structure development.	
			Value added ratio	Reflects the proportion of value added to total production value, indicating economic development in the village area.	
			Agricultural employment ratio	Reflects the proportion of the population engaged in agriculture, indicating the development level of local agricultural industry.	
	Form	Form integrity	Preservation of traditional patterns	Proportion of area occupied by traditional streets and alleys.	Dispersal (↓) / concentration (↑)
			Preservationof traditional style	Proportion of buildings preservingtraditional architectural style.	
		Spatial dispersion	Original resident retention rate	Refers to the proportion of original residents among the current permanent population, reflecting population concentration.	
			Population density	Reflects the dispersion of living spaces.	

Evaluation and Recognition System (Trial)" and various scholarly rural development evaluation frameworks. The four criteria were further refined into eight factor indicators, incorporating data from various villages, resulting in 19 evaluation indicators for constructing the "Five States" integration concept-based evaluation index system (Table 2). The components are as follows: (1) Ecological Enhancement: Natural ecological environment serves as the foundational support, with resource richness and land carrying capacity as indicators to assess the ecological development conditions of traditional Villages; (2) Cultural Cultivation: Local cultural concepts are the core of development, with indicators for cultural preservation and activation used to evaluate the transmission and development of local culture; (3) Economic Transformation: Village industrial development is a fundamental driving force, with indicators for socio-economic growth and industrial structure transformation reflecting the modernization level and trends in the village economy; (4) Spatial Reconstruction: Spatial form characterizes village identity, with changes in village spatial forms assessed through indicators of form integrity and spatial dispersion.

Based on practical understanding and data processing of the national-level traditional villages in southern Shaanxi, expert scoring methods were used, incorporating a five-ranking scale andpairwise comparison matrices to determine and rank the weights of each evaluation indicator (Table 3). Using the newly constructed "Five States" integration concept evaluation index system, the 22 national-level traditional villages in southern Shaanxi were evaluated and scored. The evaluation results classified the impact on village development as positive (↑) or negative (↓), ultimately leading to a systematic evaluation of southern Shaanxi's traditional villages and the identification of corresponding types through comparative analysis.

2.3 Classification of village types

By clarifying the positive and negative correlations of the indicators of ecology, culture, economy and form in relation to the development of traditional villages, a theoretical classification into 16 distinct types of traditional villages in southern Shaanxi is proposed. This classification is based on combinations of the four elements' "↑" or "↓" states. Additionally, the interaction and synergy of

Table 3 Weights and ranking of evaluation indicators for the development of traditional villages in southern Shaanxi based on the "Five States" integration concept

Criteria layer	Weight	Ranking	Factors layer	Weight	Ranking	Indicators layer	Weight	Ranking
Ecology	0.197	3	Resource richness	0.400	2	Plant and animal resource richness	0.343	2
						Water resource richness	0.499	1
						Mineral resource richness	0.158	3
			Land carrying capacity	0.600	1	Arable land ratio	0.706	1
						Residential land ratio	0.294	2
Culture	0.358	1	Local cultural preservation	0.667	1	Cultural longevity	0.250	2
						Local cultural retention rate (material cultural heritage)	0.750	1
			Culture activation	0.333	2	Proportion of inheritors (intangible cultural heritage)	0.250	2
						Cultural industry output ratio	0.750	1
Economy	0.347	2	Socio-economic growth	0.417	2	Per capita net income	0.222	3
						Income source distribution	0.413	1
						Annual income growth rate	0.365	2
			Industrial structure transformation	0.583	1	Industry structure ratio	0.376	2
						Value added ratio	0.424	1
						Agricultural employment ratio	0.200	3
Form	0.098	4	Form integrity	0.417	2	Preservation of traditional patterns	0.400	2
						Preservation oftraditional style	0.600	1
			Spatial dispersion	0.583	1	Original resident retention rate	0.375	2
						Population density	0.625	1

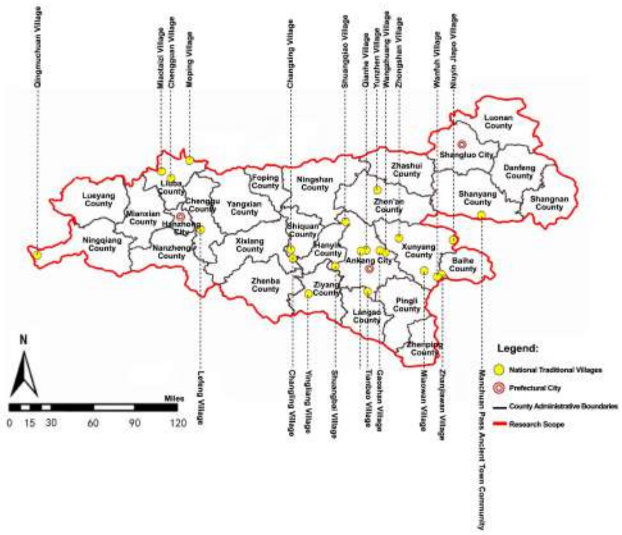

Figure 3　Distribution of national-level traditional villages in southern Shaanxi

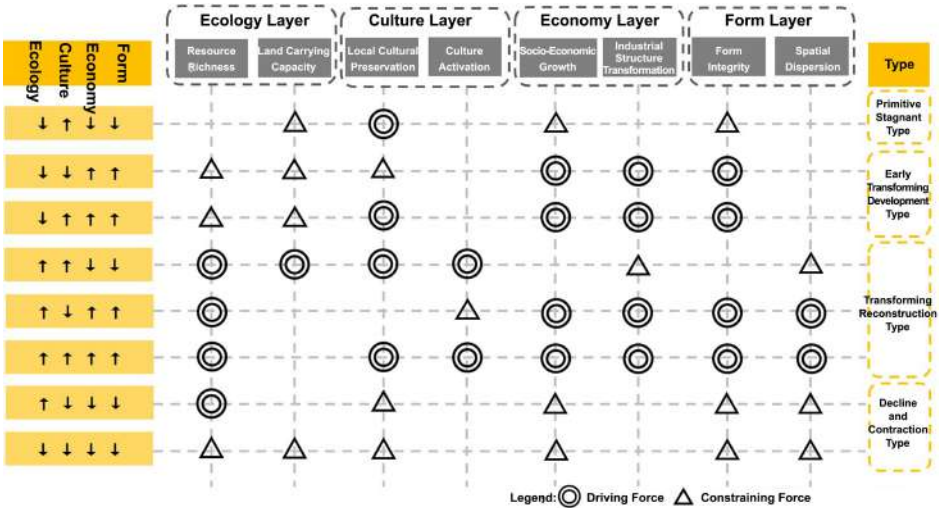

Figure 4　Evaluation criteria mechanism for the classification of traditional villages in southern Shaanxi

these elements in practice indicate that economic updates are inherently based on spatial transformations, while spatial expansion is driven by economic development [6]. Consequently, eight combinations where economic and spatial developments are mismatched are excluded (Figure 4). Building on the previous development indicators, a classification model from the "Five States" perspective is developed, summarizing the following four types (Table 4):

(1) Primitive stagnation type: These traditional villages possess rich historical and cultural heritage and are generally well-preserved. Typically located in remote, underdeveloped mountainous areas with minimal external interference, these villages continue in a state of natural evolution with production, life, and ecological aspects retaining their original forms without modern economic interventions. An example is Zhanjiawan Village in Xunyang County, Ankang City, which, built on the mountainside, retains its Ming and Qing period village layout and traditional architectural style, with the local lifestyle largely unaffected by modern elements.

(2) Early transforming development type: These villages have a solid foundation for current development with minimal outflow of population. Despite substantial infiltration of external culture and advanced ideas, some modernization has occurred in traditional industrial models, material spatial forms, and village functions. Local characteristics and traditional historical cultures have been protected and developed, revitalizing cultural consciousness among residents. For instance, Miaotaizi Village in Liuba County, Hanzhong City, named after the "Han Zhang Liuhou Shrine" located there, has begun to develop cul-

tural tourism, with a solid foundation for economic development.

Table 4 Classification of traditional village types in southern Shaanxi based on the "Five States" integration concept

Order	Type	Ecology	Culture	Economy	Form	Characteristics	Representative villages
1	Primitive stagnant type	↓	↑	↓	↓	The village has rich historical and cultural heritage, with no socio-economic transformation activities.	Zhanjiawan Village, Wanfu Village, Zhongshan Village
2	Early transforming development type	↓	↓	↑	↑	The village's traditional industries and material space have undergone partial modernization.	Qianhe Village
		↓	↑	↑	↑	The village has certain economic and cultural development conditions; however, its ecological advantages are not prominent.	Miaotaizi Village, Niuyin Jiapo Village
3	Transforming reconstruction type	↑	↑	↓	↓	The ecological environment and cultural resource conditions are favorable, but traditional industry development is slow.	Yingliang Village
		↑	↓	↑	↑	The current development status is positive, but local cultural characteristics are not prominent.	Chengguan Village, Changling Village, Lefeng Village
		↑	↑	↑	↑	The development of various elements is reatively balanced, with an unclear direction for future growth.	Qingmuchuan Village, Guzhen Community of Manchuan Pass Town, Yunzhen Village
4	Decline and contraction type	↑	↓	↓	↓	The village lacks endogenous development motivation and external support.	Mahe Village, Changxing Village, Moping Village, Tianbao Village, Wangzhuang Village
		↓	↓	↓	↓	The ecological environment is relatively fragile, and the village lacks oth endogenous development motivation and external support.	Miaowan Village, Gaoshan Village, Shuangbai Village, Shuangqiao Village

(3) Transforming reconstruction type: Rich in natural ecological and historical cultural resources, these villages have been significantly influenced by urbanization and modernization. With market dynamics, policy support, and capital investment, changes in population and economic structures, as well as the reshaping and inheritance of cultural landscapes, are evident. They face new demands for transformation and development. Examples include Qingmuchuan Village in Ningqiang County of Hanzhong City, and Yunzhen Village in Zhen'an County of Shangluo City, where notable material and intangible cultural heritage has led to cultural tourism becoming a primary economic activity, featuring historical cultural tourism with ancient buildings and facilities, as well as folk cultural tourism representing local legends, beliefs, traditional crafts, and daily customs.

(4) Decline and contraction type: These villages face fragile ecological environments and significant population hollowing, leading to natural degradation and functional loss of material spaces, with many assets becoming idle. Traditional industrial models lag in development, and local historical cultures are eroded, resulting in a lack of internal motivation and external support for village development, making contraction an inevitable trend. An example is Miaowan Village in Xunyang County, Ankang City, where severe population loss, fragile ecological protection, and loss of traditional culture have led the village into a state of natural decline.

3 Protection and development strategies for different types of villages

Based on the intrinsic characteristics of various types of traditional villages, and guided by the principle of "targeted protection and categorized development," this section proposes distinct development directions and strategies. The aim is to achieve differentiated and efficient development of traditional villages, thereby supporting rural revitalization, aiding precise poverty alleviation, and advancing urban-rural integration.

3.1 Traditional villages of primitive stagnation type—focusing on cultural and ecological leadership in building a cultural and scenic community

Addressing the issues of declining natural and cultural heritage, weak cultural awareness, and unsatisfactory inheritance conditions in these traditional villages, the following strategies are proposed based on the approach of "exploring local resources, tracing village memories, restoring material spaces, and recreating living scenarios":

(1) Unearth core values and establish a local cultural resource repository: Identify and catalog various local natural and cultural resources to uncover the core characteristics and values of traditional villages. Utilizing modern internet technologies, such as big data, textual, graphical, and visual tools, enhance research on village genealogy, architectural surveys, and detailed records. Create cultural heritage genealogies, cultural context maps, and virtual village scenarios to establish a local cultural resource repository.

(2) Enhance cultural identity and promote a routine inheritance mechanism: Based on the characteristics and protection status of different types of cultural heritage, adopt an inheritance approach of "preserving original states, extracting values, fostering innovation, and ensuring sustainable use." Utilize family, industry, and societal methods for cultural study, inheritance, and dissemination. Develop collaborative and localized mechanisms for routine, situational, and continuous cultural transmission to strengthen collective consensus and cultural identity, thereby revitalizing the core cultural values of traditional villages.

(3) Reconstruct village memory and build a cultural and scenic community: Leverage the relationship between historical culture and material space carriers to deepen the village's cultural foundation. Repair and update material space landscapes and functions to achieve a temporal and spatial unity of historical elements and scenic spaces. Reconstruct local cultural landscapes, consolidate collective local memories, and establish a cultural and scenic community to enhance local identity and residents' sense of belonging, thereby revitalizing the village's vitality and the symbiosis of residents' memories.

3.2 Traditional villages of early transforming development type—cultivating rural economy and expanding industrial chains

To address the issues of single traditional industry models, weaknesses in developing specialty industries, inadequate facilities, and contradictions in living needs, the following strategies are proposed based on the approach of "extending industrial chains, strengthening economic support, enhancing living environments, and catalyzing development":

(1) Extend industrial chains and increase traditional agricultural value: Build on the existing traditional agricultural industry foundation by introducing modern technologies, agricultural talent, and substantial funding. Develop high-quality, efficient, and specialized ecological and organic agriculture. Leverage agricultural e-commerce, tourism, and contract production to promote deep integration of "agriculture + internet," extending the agricultural industrial chain and enhancing the value-added of traditional industries, thus creating local specialty industry brands.

(2) Incubate potential factors and strengthen specialty industry competitiveness: Integrate unique resources such as natural ecology, agricultural landscapes, historical culture, and folklore. Focus on market demand and tourism development to incubate economic value and promote deep integration of traditional agriculture, handicrafts, local skills, and tourism services. Emphasize differentiation and personalization of specialty industries, develop distinctive industry brands, create brand catalytic effects, and enhance the competitiveness and influence of specialty industries.

(3) Improve service facilities and enhance living environment comfort: Based on ecological circularity concepts, optimize infrastructure configurations, and strengthen public service capabilities to meet both material and spiritual cultural needs of villagers. Preserve local flavors and scenarios, improve living environment comfort, and create "livable, workable, and touristic" eco-friendly, modern, and intelligent villages. This will act as a catalyst

for nurturing rural economies and a haven for pastoral idylls, fulfilling villagers' aspirations for a better life.

3.3 Traditional villages of transforming reconstruction type—linking regional development and innovating village intelligence

To address the issues of homogeneous development directions, balanced content, weak development forces, and singular development actors in these traditional villages, the following strategies are proposed based on the approach of "clarifying development directions, facilitating integrated regional development, encouraging diverse stakeholder participation, and promoting cluster-based development":

(1)Establish unique brands to highlight rural tourism differentiation: Assess the current development trends and examine village resource conditions to define development directions in leisure and wellness, and specialty tourism. Create local specialty tourism brands through tourism project development, establishing a dual-driven mechanism of external and internal development. Focus on personalized, distinctive, and branded tourism, thereby enhancing the quality and appeal of traditional village tourism.

(2)Integrate regional development to create a cultural tourism network: Utilize clustering and complementarity effects to co-develop and share regional infrastructure and service facilities. Focus on traditional villages as "growth poles" and coordinate with neighboring villages to achieve integrated regional development. Construct a cultural tourism network with distinct regional characteristics, aligning with urban-rural integration plans to eliminate homogeneity and establish a well-interactive, comprehensive tourism system.

(3) Innovate development mechanisms for intelligent village operations: Encourage diverse stakeholder involvement to create a development mechanism where villagers actively participate, government provides guidance, and social organizations offer support. Promote integrated development of "people-village-heritage" through intelligent technology platforms, revitalizing diverse resource uses. Develop a "technology-driven, scenic-village integrated, intelligent operation" model for comprehensive, smart, and scenic management and operations of traditional villages.

3.4 Traditional villages of decline and contraction type—introducing limited external intervention and proactively responding to population hollowing

To address issues such as severe population hollowing, fragile ecological environments, difficulties in asset circulation, and insufficient capital support from government and enterprises in these traditional villages, the following strategies are proposed based on the concept of "adapting to natural succession, limited external intervention, strategic measures, and long-term development assurance":

(1)Respect villager preferences and address hollowing issues: Align with natural succession patterns, respect villagers' relocation preferences, and scientifically assess the level of village abandonment. Use minimal human intervention to guide ecological migration and collective resettlement, improving villagers' living standards. Employ digital technologies to document and preserve local characteristics, establish concentrated museums for abandoned village features, and reuse distinctive components and materials for environmental enhancement or other village renovation projects. Address issues related to abandoned land through land relinquishment and ecological restoration to maximize the value of traditional village heritage resources[15].

(2) Resolve property rights issues to ensure long-term resource maintenance: Based on asset clearing and verification, explore breakthroughs in property rights and establish unified management mechanisms for traditional village assets. Transform land ownership through collective or state-owned forms to guide property rights transfer, applying various protection and development methods to revitalize asset value. Support collective economies by attracting corporate capital, forming new village-enterprise cooperative economic organizations, and ensuring sustainable maintenance of traditional villages[16].

Conclusion

The numerous traditional villages in China have been irreversibly affected by urbanization and modernization processes, leading to issues such as population loss, land abandonment, ecological degradation, and cultural erosion. Effectively managing the relationship between the protection and development of traditional villages and socio-economic progress is therefore an urgent issue. This paper employs the "Five States" concept to conduct a classification study of 22 national-level traditional villages in southern Shaanxi, exploring targeted classification and development strategies, and providing new perspectives and methods for dynamic, multi-faceted research on traditional village development in China. The main conclusions of the study are as follows: (1) By examining the internal elements and dynamic synergy of ecological, cultural, economic, and spatial factors in traditional villages, this study analyzes the role of the "Five States" in the evolutionary process of traditional villages and constructs a development evaluation index system and classification method for traditional villages. (2) By clarifying the different combinations of "Five States" factors, traditional villages in southern Shaanxi are categorized into four types: Primitive Stagnation, Early Transformation Development, Transformation and Reconstruction, and Decline and Contraction. Corresponding development strategies are proposed for each type based on their evolutionary characteristics. Given the complexity and uncertainty of traditional village elements, further empirical exploration of the "Five States" classification model is needed. Additionally, case studies of provincial-level traditional villages in Southern Shaanxi should be continued and supplemented.

Figure and table sources

All figures and tables are created by the author.

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Research on the Architectural Generative Design Practices Driven by Optimization Algorithms

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ABSTRACT: The development of technology will eventually lead to industry transformation. By studying the relevant contents of the optimization algorithm and its application cases, the present study aims to provide future architectural design practice methods and create more possibilities. This paper sorts the optimization algorithm's development and the historical evolution of its application in architectural design. Simultaneously, the algorithm- based generative design platform and its corresponding plug-in have been generalized. Based on the analysis of two specific cases, this paper proposes the concept and process of building designs driven by an optimization algorithm. Under the background of transforming architectural practice towards "digitalization" in the new century, the general process of building generative designs driven by the optimization algorithm is summarized from different perspectives. These include the selection of design platform, determination of optimization goals for different design stages, and iterative process of algorithm optimization. Then, the development prospects of the optimization algorithm and its potential impact on architects are discussed.

KEY WORDS: optimization algorithm; generative design; building performance; design practice

Introduction

At the beginning of 2020, the winning proposal for the Shanghai Alibaba Group Headquarters, designed by Norman Foster and his team (Foster+Partners)[1], garnered significant attention from architects. This interest was not solely due to the design itself, but also because the design concept prominently featured the use of "Genetic Algorithms."

"Genetic Algorithms" (GA) are well-known in academic circles, but in architectural practice—particularly bid proposals, the project using it as a design philosophy and finally winning the bid remains rare. The case underscores the growing impact of technological advancements on architecture. Over the past half-century, architectural design practices have undergone remarkable evolution and transformation under computer aid: Transitioning from hand-drawing with tools to 2D computer drafting in the 1980s, then to 3D modeling in the 1990s, and to Building Information Modeling (BIM) technologies emerging in the early 21st century. Recently, artificial intelligence and optimization algorithms have become prominent research topics in the field of architecture (Figure 1) [2]. These

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five stages reflect the evolving focus and perspectives of designers in different periods, and they are not independent or sequential; rather, they often overlap in practice.

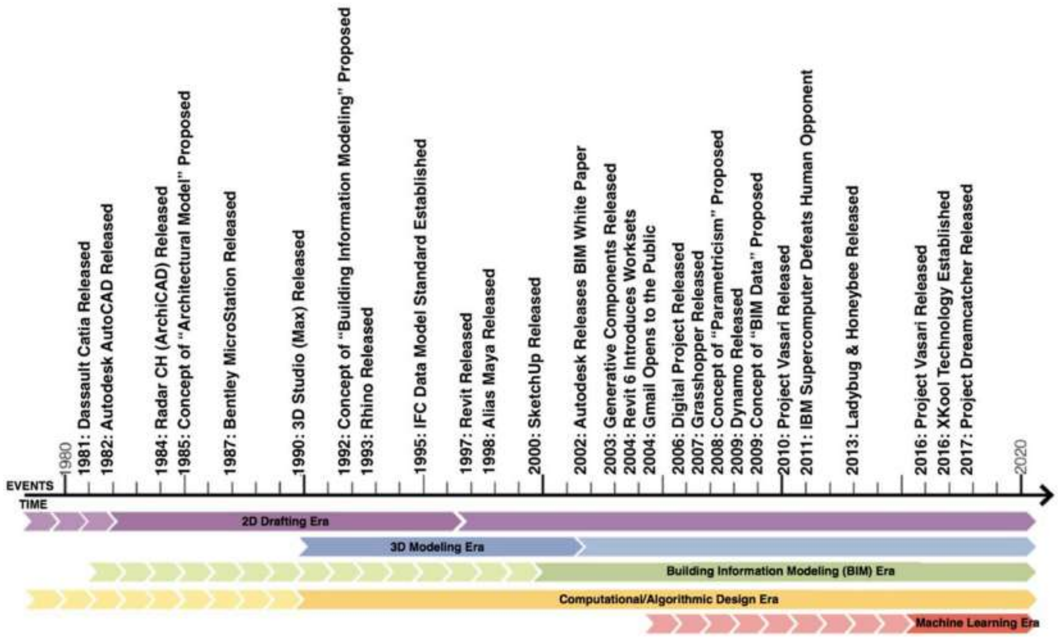

Figure 1 The history of computer-aided architectural design: Five eras

1 Optimization algorithms and their design platforms

An algorithm is a computational process used to solve problems within a finite number of steps. It involves methods such as deduction, induction, abstraction, generalization, and structured logic. An algorithm systematically proposes logical principles and develops a solution that can universally address problems. The strategy of an algorithm lies in its ability to search for repetitive patterns, universal principles, interchangeable modules, and inductive links, while its advantages include inferring new knowledge and extending human cognitive limits [3]. For propositions with unknown, vague, or uncertain outcomes, algorithms can be the optimal choice for seeking potential solutions. Problems solvable by algorithms include P problems (Polynomial Problems) and NP[1)] problems. NP problems are characterized by uncertain computational processes that cannot be strictly defined by mathematical equations, resulting in a vast "solution space." Most problems in architecture are NP problems [4], making optimization algorithms the best approach for addressing them. In engineering practice, optimization algorithms typically refer to "metaheuristic algorithms," which are inspired by random processes in nature, such as biological evolution, swarm intelligence, and immune mechanisms. These algorithms are designed to escape local optima and reliably search the solution space[5].

1.1 History and development of optimization algorithms

Algorithms have historically accompanied the development of disciplines such as mathematics and physics, with their interaction with machines tracing back to the establishment of computer science in the 1950s. With the improvement of computational capabilities and growing pursuit of enhanced performance in the field of engineering , various optimization algorithms have emerged, developed, and spread from computer laboratories to numerous engineering practice fields.

Notable optimization algorithms in engineering include Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Simulated Annealing (SA), Immune Algorithms (IA), General Pattern Search (GPS), Coordinate Search, and Hooke-Jeeves (HJ) Algorithms. These algorithms are used to optimize design parameters in engineering practice. When combined with certain physical simulation processes, they create hybrid algorithms, which are widely applied in the field of building energy [6,7]. Most optimization algorithms derive from mathematical descriptions of natural phenomena or physical processes, relying on these descriptions to find optimal performance results within a vast "solution space." Consequently, different optimization algorithms exhibit varying characteristics for specific engineering problems, and no single optimization algorithm performs optimally for all problems. Christoph Waibel and colleagues have investigated optimization issues related to building energy consumption by comparing various optimization algorithms in terms of search speed and robustness. Their findings reveal that the choice of hyperparameters for different optimization algorithms significantly affects the convergence speed of the optimization process. Without considering prediction speed, Genetic Algorithms and Particle Swarm Optimization consistently yield relatively optimal results across different problems [8].

The Genetic Algorithm (GA), previously mentioned, was proposed by John Holland and his colleagues at the University of Michigan in the 1960s [9]. Inspired by Darwin's theory of evolution, GA is an optimization method based on genetic principles and natural selection. Compared to other optimization algorithms, GA offers a more intuitive physical interpretation and has seen widespread application in engineering due to the development of numerous robust algorithmic tools. GA is suitable for nonlinear, discontinuous problems and is characterized by features such as the use of stochastic operators, handling of large parameter spaces, open-source availability, simultaneous processing of discrete and continuous parameters, and multi-objective optimization using Pareto fronts [10].

1.2 Optimization algorithms and architectural design

The relationship between computers and architectural design dates back to the 1960s and 1970s, when Nicholas Negroponte established computer models that transcended clear-cut divisions in the design process and advocated for a closer relationship between computers and designers [11]. It is noteworthy that in the early stages of 2D CAD, 3D modeling, and even BIM, computers primarily assisted with drafting and drawing, with limited involvement in design optimization [12]. It was not until the advent of Generative Components software in 2003 [13] and the Grasshopper parametric software in 2007 that parametric design and algorithmic design were truly accepted and promoted, with the latter becoming a widely used tool for architectural parametric design [14].

It is important to clarify that "parametric" and "algorithmic" design are often conflated, with some perceiving them as identical or overlapping concepts. However, "parameters," "algorithms," and "results" are all integral components of architectural parametric models [15], with "algorithms" specifically describing the computational methods and generative logic from "parameters" to "results." Additionally, the concept of "Generative Design" complements these two design concepts by focusing on process and outcomes, while parametric and algorithmic design emphasize data and methods. The exploration of generative design by Christiano Sodu has catalyzed a shift in architectural design from a "result-oriented" approach to a "process-oriented" one [16].

Entering the 21st century, architects face a doubling of information quantity and increasing complexity. Optimization algorithms such as GA can serve as both form-generating tools and design optimization tools, offering effective means to address design issues related to form, structure, performance, and facade. Recent applications of optimization algorithms in architectural practice have concentrated on aspects such as energy consumption, structural performance, and daylighting, with simulations and iterations used to achieve optimal building performance. Recent academic research focuses on optimization for structural performance [17-20], building energy consumption and lifecycle costs [21-24], daylighting efficiency [25], integrated energy and daylighting optimization [26, 27], and multi-objective optimization incorporating energy, daylighting, and structural costs [28]. A recent review study by Berk Ekici et al. [29] provides a comprehensive summary of the literature on two representative optimization algorithms, genetic algorithms and particle swarm optimization, within the context of building performance optimization. It is noteworthy that this review also highlights that various variants of PSO and GA are among the most widely applied optimization algorithms in the field of building performance optimization, but as noted by Thomas Wortmann, the extent of application of different optimization algorithms does not directly reflect the quality of their performance. Instead, it is more influenced by researchers' preferences and the constraints of design platforms regarding the ease or difficulty of integrating different algorithms [30].

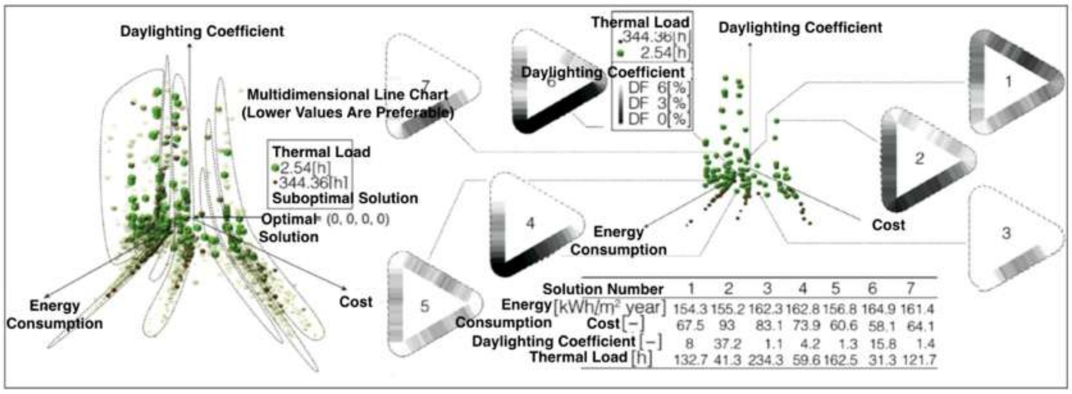

Figure 2 Multi-objective performance optimization algorithm model for an office building design

Table 1 Algorithm-based design platforms (grasshopper & dynamo) and their corresponding plugins

Intervention methods	Design platforms	Plugins	Algorithm descriptions
Built-in plugin approach	Grasshopper	Octopus	SPEA2 and HypE algorithms are applicable to single-objective ormulti-objective optimization tasks within algorithm-based design platforms (such as Grasshopper and Dynamo) and their corresponding plugin tasks.
		Wallacei	Utilizes the NSGA-II algorithm with enhanced custom visualization capabilities.
		Optimus	Developed by TU Delft, this adaptive differential evolution algorithm features a set of mutation strategies (jEDE).
		Silvereye	Based on the Particle Swarm Optimization algorithm, it is suitable for single-objective optimization and can achieve superiorperformance results compared to genetic algorithms in certain optimization problems.
		Opossum	Based on surrogate model concepts, it addresses single-objective optimization problems with rapid early convergence, making it suitable for obtaininghigh-quality solutions with small sample sizes.
		Goat	Introduces gradient-based mathematical optimization algorithms, which provide more stable optimal performance values compared to heuristic methods but are prone to local optima and require integration with global optimization algorithms.
		Nelder-Mead Opt	Utilizes the Nelder-Mead algorithm (Simplex method), a classic non-heuristic mathematical optimization technique that is susceptible to local optima.
	Optimo	Evo	Performs single-objective optimization based on the classic GA algorithm.
		Optimo	Enables both single-objective and multi-objective optimization based on the NSGA-II algorithm.
External interface approach	Grasshopper	FrOG	An open-source optimization framework based on C# ,with limited built-in algorithms, requiring the development of optimization algorithms in C# to interface with its visualization environment.
	Python/C# API Integration	mode FRONTIER	A mature optimization software that includes a variety of built-insingle-objective and multi-objective optimization algorithms.
		MATLAB	Implements optimization algorithms through MATLAB programming.

Building performance does not exhibit a simple trade-off relationship during the design process; optimizing individual element does not necessarily lead to a globally optimal solution. For example (Figure 2), researchers from the Technical University of Denmark analyzed the facade window design of an office building by BIG Architects using the SPEA2 algorithm within GA. They obtained optimal solutions and globally non-dominated solutions for various building performance parameters, such as energy consumption, daylighting coefficients, and costs, associated with serrated windows under different thermal property settings. These results are intended to assist designers in adjusting and optimizing window designs [31]. This algorithmic model met local energy-saving design standards with high precision and rapid computation speed, providing a convenient basis for timely decision-making in the early stages of design.

1.3 Generative design platforms based on optimization algorithms

The application and proliferation of optimizationalgorithms in architectural design have closely followed the emergence of "parametric" design platforms within modeling software. Notably, the Grasshopper platform, developed by Robert McNeel & Associates and based on Rhino software, and the Dynamo platform, developed by Autodesk and based on Revit software, are among the most prominent. Optimization algorithms within these design platforms can be integrated into the architectural design process via built-in plugins or external interfaces. Utilizing various algorithmic tools allows for iterative computation to achieve optimal solutions under single or multiple objectives, thereby providing technical support for architects' design thinking and creative processes and enabling the exploration of greater possibilities.

Integration via Built-in Plugins: In Grasshopper, the Octopus plugin, based on ETH Zurich's SPEA2 and HypE algorithms, is suitable for single or multi-objective optimization tasks. Other notable plugins include Wallacei[32], Optimus [33], Silvereye [34], Opossum [35], Goat [36], and NELDER-MEAD OPTIMISATION[37]. In contrast, the Dynamo platform features fewer optimization plugins, such as Evo [38] and the Optimo [39] developed by the Texas A&M University team. Dynamo's optimization capabilities often require designers to link external optimization programs using its built-in programming interfaces.

Integration via External Interfaces: Both Grasshopper and Dynamo come with Python/C# programming interfaces. By using the MATLAB API, numerical parameters from the design platforms can be imported in real-time into MATLAB, where various optimization algorithms can be introduced through programming languages. Additionally, modeFRONTIER, a specialized performance optimization tool, uses its API for data conversion and serves as a core process control, invoking various single and multi-objective optimization algorithms for performance optimization and visualization. Thomas Wortmann's open-source plugin, FrOG, can interface flexibly with custom optimization algorithms, though this requires a proficient background in C# programming.

Table 1 lists the generative design platforms based on these two integration methods, detailing the various optimization algorithms and plugins used in architectural design.

2 Generative design practice based on optimization algorithms

2.1 Foster + Partners and the Alibaba Headquarters

Foster+Partners is one of the most renowned architectural firms globally, established in 1967. Norman Foster, a prominent figure of high-tech architecture, pioneered "sustainable" design methods in the 1970s, focusing on green and energy-efficient design as core elements of sustainability. His approach involves considering environmental friendliness and energy-saving technologies in architectural solutions [40]. Additionally, the firm actively organized research and development teams to integrate comprehensive design processes through techniques such as computer data analysis, thereby pushing technological control in design to its limits.

2.1.1 The Specialist Modelling Group (SMG)

The Specialist Modelling Group (SMG) within Foster +Partners was established by Hugh Whitehead in 1997, focusing on finding more energy-efficient architectural forms through computer-aided design [41]. The team comprises architects skilled in digital technology and has grown to include experts from fields such as mathematics, industrial design, mechanical engineering, computational physics, manufacturing, and acoustics. Over the next decade, SMG's development focused on two main areas: computational geometry and construction-related issues, and environmental analysis and simulation[42]. They have utilized various algorithms for design optimization and generative design across hundreds of projects, with notable examples including the London City Hall, Swiss Re Headquarters, and Beijing Capital International Airport Terminal 3.

2.1.2 The design of Alibaba Headquarters

The continuous development of specialized teams like SMG, combined with over fifty years of practice and technical accumulation, has enabled Foster + Partners to adeptly handle parameters, algorithms, and related design methods. Therefore, in the Shanghai Alibaba Headquarters design competition (Figure 3), the proposal emphasized the use of a unique architectural form guided by an innovative design process, utilizing genetic algorithms to achieve the optimal solution.

Figure 3 Renderings for the competition of Shanghai Alibaba Headquarters design

The application of algorithmic generative design in this project focused primarily on the following four aspects[1, 43]:

(1) The modular unit assembly and construction approach is employed, utilizing "genetic algorithms" to optimize the design of modules, resulting in a "pixelated" volumetric arrangement. Subsequently, modules are mass-produced off-site to reduce waste and ensure construction quality and efficiency.

(2) Algorithms are used to enhance the design's responsiveness to environmental conditions. For example, the central open public space is designed to provide optimal comfort throughout the year, shielding users from cold winter winds and intense summer sunlight.

(3) Through calculations, the integration of indoor and outdoor spaces and the maximization of external scenic views are significantly enhanced. A key feature of this design is the intention to increase the building's transparency, allowing the public to gain insight into Alibaba's world while enabling employees to enjoy views of the surrounding waterfront.

(4) The design is optimized according to the functional requirements of different areas to achieve the most suitable layout. For example, customized workspaces are designed for various departments within Alibaba, integratingconsiderations such as furniture arrangement and natural light, thereby enhancing user work efficiency.

2.2 The Design of MaRS Office

The MaRS Office project, a three-story building with an approximate total area of 5600 m, was developed by Autodesk in Toronto, Canada. The design vision was to create a dynamic and highly functional innovative workspace.

During the design of the three-story interior layout—covering conference rooms, social spaces, special areas, and equipment—the design team first gathered real demands from over 250 employees, who are often overlooked. The team then established six distinct objective parameters for algorithmic generation and evaluation of the office space [44], including:

Parameter 1: Space Preference—Distances from each employee to their preferred interaction spaces and related facilities.

Parameter 2: Work Style—Assessing whether the lighting or visual elements of work areas match the preferences of users.

Parameter 3: Activity Level—Identifying potential high-activity areas based on the geometric characteristics of the room (Buzz[45]).

Parameter 4: Productivity—Controlling desk density to minimize visual and noise distractions.

Parameter 5: Daylighting—Total number of natural daylight hours throughout the year.

Parameter 6: External Views—Proportion of windows offering unobstructed views from desks, corridors, and other workspaces.

2.2.1 Model generation

Based on a homogeneous office space plan, the logic for further design generation was defined. Initially, a floorplan contour and standard column grid were established from the design layout. Areas requiring optimization were delineated, with axes, boundaries, and capture points set for seven different work team zones. Changes in capture points could automatically trigger boundary modifications. One edge of each zone was automatically designated for meeting rooms, while other areas were arranged with employee workstations. Various combinations of capture points and boundaries generated a range of design options for selection by the designers, as illustrated in Figure 4.

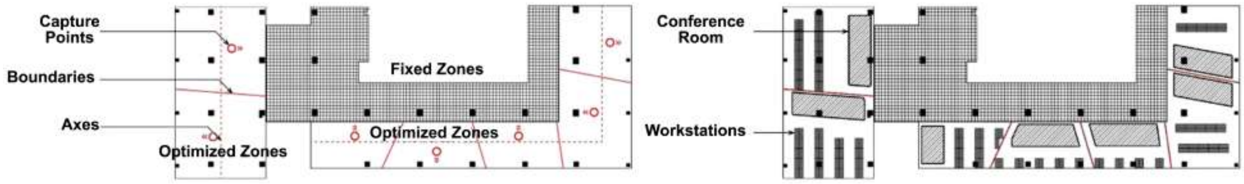

Figure 4 Plan of the generated model and schematic diagrams of various elements

2.2.2 Parameter evaluation

After establishing the basic model generation system, the design teamemployed a Multi-Objective Genetic Algorithm (MOGA) to evaluate different design options. The evaluation results obtained from the calculation of input values across different scenarios and the corresponding variations in the six target parameters, providing real-time feedback on design plans, as illustrated in Figure 5.

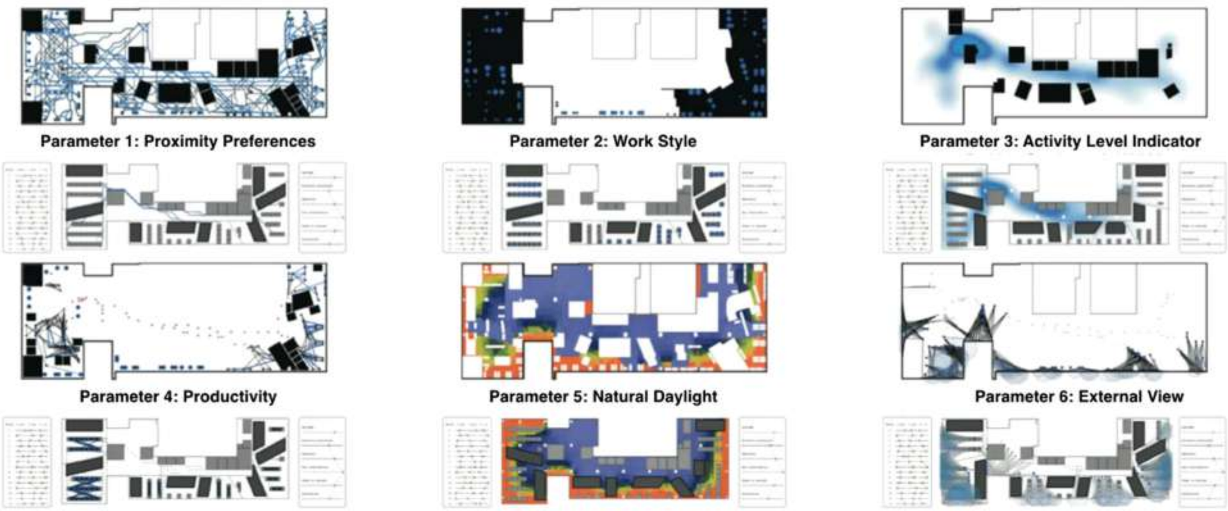

Figure 5 Real-time simulation analysis diagrams corresponding to evaluation parameters

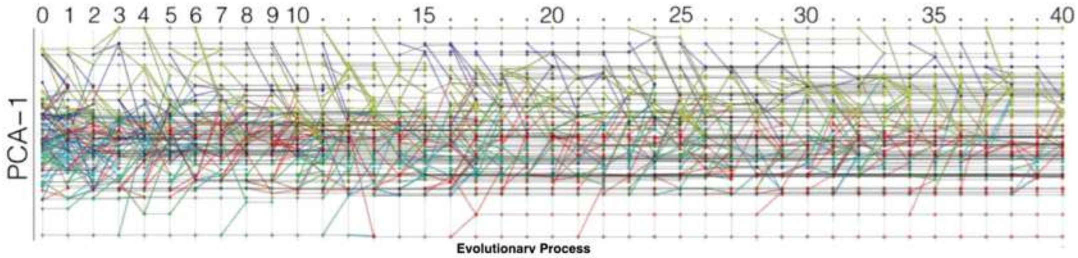

Figure 6 Real-time feedback diagrams of different iteration counts during scheme evolution

2.2.3 Solution evolution

For this project, the genetic algorithm was configured with a crossover rate of 95% and a mutation rate of 0.2%. The process involved 100 designs per generation, with a total of 100 generations, resulting in 10000 generated designs. Figure 6 depicts the evolution process, with each point representing a design solution, each column indicating a generation, and different colors denoting various parameter characteristics. The x-axis shows the number of generations, and the fine black lines connecting the points illustrate the direct transfer of designs to the next generation.

2.2.4 Data analysis

Following the evolutionary process, the performance of different design solutions was analyzed and filtered. The MOGA approach yielded a Pareto-optimal set that satisfied all performance criteria, narrowing down the design options. As shown in Figure 7, the design identified as #3251 was selected based on its superior performance in a radar chart evaluating six parameters, with relatively balanced scores across parameters. Figure 8 presents the final plan corresponding to design #3251, categorized into four functional spaces: basic office (blue), team meetings (green), equipment (red), and support services (orange), addressing users' primary needs and preferences.

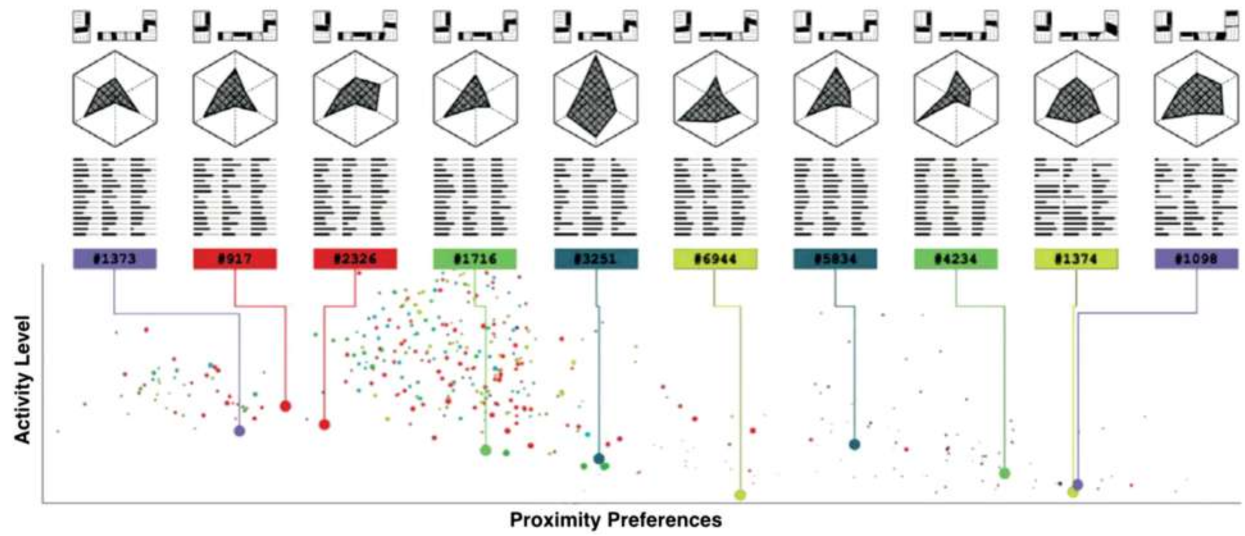

Figure 7 Scheme groupings and selected optimal solutions after data analysis

2.2.5 Summary

The complete design process of this project highlights several advantages of algorithm-driven generative design: first, it truly realizes "human-computer collaboration" in design; second, it evolves solutions by establishing goals, constraints, and geometric systems rather than producing a final form directly; third, it explores thousands of options to find optimal solutions for predefined parameters; fourth, it enables data exchange, creating possibilities for innovative designs; and fifth, it allows for iterative reuse of algorithms and evolution processes, offering valuable references for future project planning and design.

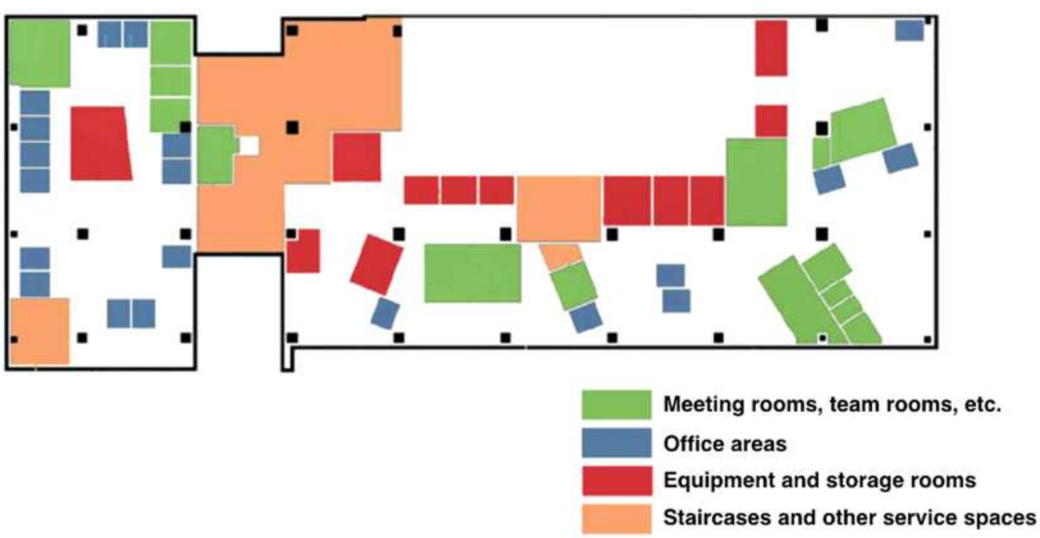

Figure 8 Floor plan of the corresponding generated scheme after optimization calculations

2.3 Other relevant projects

In recent years, generative design practices driven by optimization algorithms can be categorized into five main types, distinguished by the specific optimization goals addressed for different architectural contexts, as summarized in Table 2.

Table 2 Statistical overview of algorithm-driven generative design practices based on different optimization objectives

Optimization objectives	Application phase	Algorithm type	Representative case studies	Illustrations
Floor plan layout	Planning and design: Volume design and interior detailing	Genetic algorithm	Las Vegas Convention Center [46] (2017 Exhibition hall layout)	
Structural form	Volume design during construction phase	Particle swarm algorithm	Japan's "Meditation Forest" Crematorium [47] (Roof structure optimization)	
Morphological envelope	Performance in the latter construction phase of volume design	Unknown	Dubai Future Museum (Facade material assembly)	
Building performance	Planning and design: Volume design during construction phase	Genetic algorithm	Nanhai Museum (Hainan, China) [48] (Facade shading design and optimization)	
Other (e.g., 3D printing, virtual simulation)	Post-construction performance of volume design	Unknown	Kazakhstan National Pantheon (3D printing of model)	

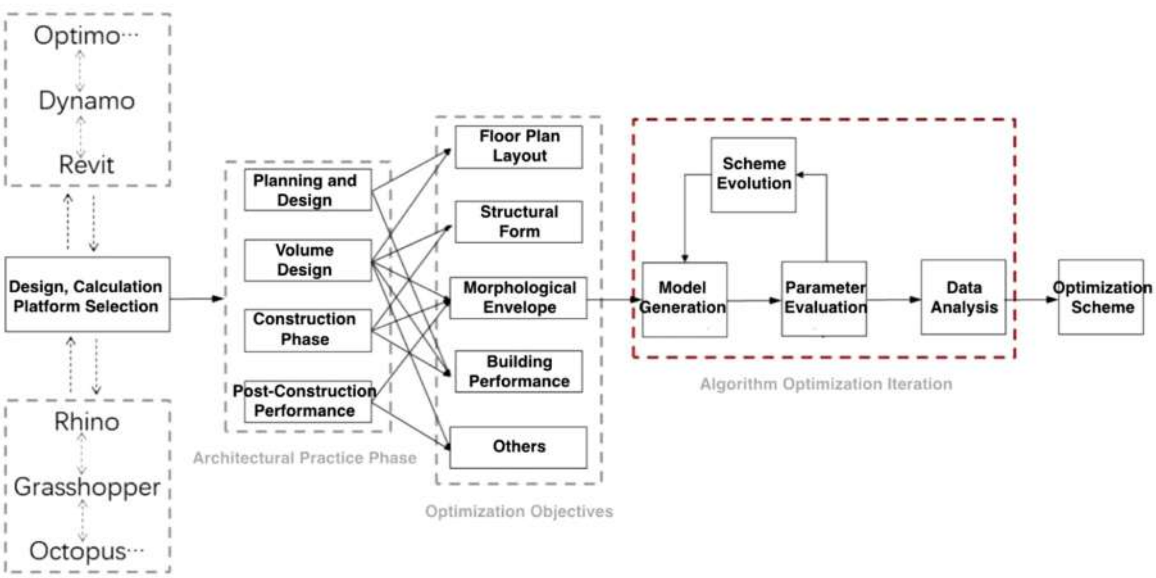

Figure 9 General workflow of optimization algorithm-driven generative design practice

3 General process of optimization algorithm-driven generative design

The concept of "optimization algorithms" is closely related to contemporary architectural practices and has been increasingly applied and developed in the field. Based on the analysis of related concepts and case studies, a typical process for algorithm-driven generative design in architecture includes several key stages: design, selection of computational platforms; determination of optimization goals for different stages of architectural practice, and the iterative process of algorithm optimization, leading to an optimized solution, as shown in Figure 9.

The selection of design and computational platforms is primarily based on commonly used platforms such as-Revit and Rhino (refer to Section 1.3). Optimization goals and stages of architectural practice can be referenced from the cases in Table 2, where designers select goals based on desired outcomes for the project. The iterative process of algorithm optimization involves four main steps detailed in the MaRS Office case (refer to Section 2.2). Through a series of filtering, evolution, analysis, and evaluation processes, a relatively optimal solution is achieved, representing the designer's desired outcome.

Conclusion and outlook

Technological advancements invariably drive industry transformation, and emerging terminologies in architectural practice such as "digitalization," "sustainability," "industrialization," "information technology," and "intelligence" are closely linked to the evolution of computer software. In the 21st century, architects are tasked not only with addressing the form and spatial aspects of buildings but also with focusing on their inherent performance and external impacts. Optimization algorithms provide a valuable pathway and method for architects to obtain a more comprehensive understanding of buildings through relatively scientific approaches.

Undoubtedly, the widespread application of optimization algorithms across all steps of design practice presents significant challenges. Nevertheless, these algorithms are highly beneficial for specific aspects of current design practices and for research into future comprehensive design methodologies. With changing lifestyles and increasing attention to spatial quality, architectural design must meet more complex functional demands and pursue innovative forms, resulting in greater design complexity. Algorithm-driven generative design allows architects to explore a broader range of problem-solving possibilities through computation. Moreover, algorithms, devoid of human intuition or biases, help architects overcome subjective judgments in traditional design processes, leading to novel and high-performance design solutions. As David Benjamin, the technical lead for the MaRS office project, states, "Ideally, an algorithm-based automated process can make design decisions more inclusive. Computation assists designers in making better trade-offs, not by removing subjective judgment but by enabling them to avoid relying on vague concepts to explain why one design is effective and another is not" [49].

Algorithmic design does not imply that the role of architects will be replaced. Architects must contextualize and simplify relevant design issues, ensuring alignment with their design concepts and visions. Thus, the translation between design solutions and algorithmic data, the inclusion and exclusion of effective evaluation or optimization parameters, and the balancing of rational indicators with humanistic factors are crucial. In the human-computer interaction of architects and optimization algorithms, architects' decision-making remains pivotal, demanding elevated comprehensive skills and presenting ongoing challenges [50].

Figure and table sources

Figure 1: Prepared by the author based on reference [2].
Figure 2: Prepared by the author based on reference [31].
Figure 3: Foster+Partners official website.
Figures 4-8: Redrawn by the author based on project video materials from ARCHITECT website.
Figure 9: Prepared by the author.
Tables 1 and 2: Prepared by the author, with images sourced from the web and references [46-48].

Notes

1)NP: The term stands for Non-deterministic Polynomial, which denotes problems that can be verified to a correct solution within polynomial time. Problems classified as P (polynomial) are those solvable by polynomial-time algorithms; NP problems are those for which it is unknown if a polynomial-time algorithm exists but can be verified to a correct solution within polynomial time.

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"The Last Waterfront in Pearl River Delta": Space Generation and Cultural Ecological Characteristics of Traditional Village in Gulao Waterfront

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ABSTRACT: Lingnan waterfront is a relatively complete cultural ecosystem formed under the influence of unique natural environment, social economy and regional culture. However, the existing researches on Lingnan waterfront pay more attention to the physical space of traditional settlements than the overall natural environment surrounding the settlements. Taking Gulao Waterfront as an example, this paper analyzes it from the perspective of interactions between human and natural environment, social economy and regional culture by using the theory of cultural ecology. This paper also analyzes the spatial generation process of Gulao Waterfront, systematically sorts out the overall village pattern, water network and water conservancy space, settlement space, agriculture and fairs space, folk beliefs and ritual space, and conclude that the cultural ecological characteristics of Gulao Waterfront is under the law of water. The important value in Gulao Waterfront of the cultural ecological characteristics and integrated historical heritage protection for the Pearl River Delta has been excavated, which enriches and deepens the cultural heritage research of traditional village in Lingnan waterfront.

KEY WORDS: Lingnan waterfront; traditional village; cultural ecology; Gulao

Introduction: Traditional villages in Lingnan waterfront from a cultural ecology perspective

Traditional villages in Lingnan waterfront are primarily distributed across the present-day Pearl River Delta region. This delta is formed by sediment deposition from the Xijiang River, Beijiang River, Dongjiang River, and several smaller streams [1], known for its complex natural geography and frequent flood hazards. Due to environmental constraints and the level of productivity, the Lingnan waterfront developed relatively slowly before the Ming and Qing dynasties, with a limited number of villages. During the Ming Dynasty, in response to local defense needs, many coastal fishermen and boat people were incorporated as "households" [2]. At the same time, the migration of people from the North brought advanced agricultural techniques and water management skills [3], accelerating population concentration and village development in Lingnan waterfront. Thus, traditional villages in Lingnan waterfront were shaped by a combination of complex natural environments and diverse socio-economic conditions.

Current research on traditional Lingnan waterfront is extensive, focusing mainly on three areas. First, there is classification of the settlement spatial patterns of tradition-

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al villages in Lingnan waterfront [4-6]. Second, research dissects the traditional villages into various independent systems such as architecture, streets, water networks, and agriculture to study their characteristics [4, 7-9]. Third, studies explore the formation mechanisms of the spatial patterns of these villages [6,10,11], suggesting that the development of the traditional villages is closely related to the dense water network environment. Overall, existing research on Lingnan waterfront tends to focus more on the physical space of the villages. While some scholars have examined the relationship between the villages and the water network, there has been insufficient comprehensive attention to the broader natural, social, and economic contexts. This has led to a lack of in-depth analysis of the interactive relationship between the villages and their environment, resulting in an incomplete understanding of the overall development, evolution, and spatial characteristics of traditional villages in Lingnan waterfront.

The cultural ecology theory proposed by J.H. Steward emphasizes the relationship between human culture and its natural environment. It posits that the driving forcebehind cultural development and evolution is culture's adaptation to the environment and asserts that culture forms a complete cultural ecological system through continuous interaction with its natural, social, and economic surroundings [12-14]. In recent years, many domestic scholars have applied cultural ecology theory to the study of traditional villages. This includes analyses of the spatial and landscape characteristics and evolutionary processes of traditional villages [15-17], research on the protection of cultural heritage in traditional villages [13,18-20], and investigations into the characteristics of traditional regional cultural landscapes and their inherent genes and formation mechanisms [21-22]. However, there has been limited application of this theory to the Lingnan region. For traditional villages in Lingnan waterfront, humans are both the producers and consumers of culture, while the surrounding dense water network serves both as the object the culture is adapted for and the subject it works to transform. The settlement space, dike-pond agriculture space, market spaces, and spaces for rituals and folk beliefs represent the spatial manifestation of the interaction between culture and the natural environment. Thus, humans, the natural environment, settlement space, dike-pond agriculture, market spaces, and ritual and folk belief spaces collectively constitute a cultural ecological whole. This paper adopts a cultural ecology perspective, treating traditional villages in Lingnan waterfront as a complete cultural ecological system, to analyze the interactive relationship between the villages and their environment and to explore the spatial generation process and cultural ecological characteristics of these villages.

1 Case overview and oesearch oethodology

1.1 Case overview

Gulao Waterfront, situated on the banks of the Xijiang River in the northern part of Heshan City, Guangdong Province, has developed and prospered since the early Ming Dynasty when the Gulao Enclosure was established, giving it a history of over 600 years. Generally, Gulao Waterfront has been relatively undisturbed by urbanization and industrialization processes, allowing it to retain its traditional cultural ecological features. In contrast, other regions in the Pearl River Delta, although home to numerous distinctive Lingnan water towns, sharing the similar natural, economic, and social environments historically, have experienced significant damage to their traditional cultural ecological characteristics due to rapid urbanization and industrialization. Consequently, Gulao Waterfront has been referred to as "the last pristine waterfront of the Pearl River Delta" by the CCTV program "Remembering Our Homeland," and its Shangsheng Village has been listed as one of the fifth batch of ancient villages in Guangdong Province. Research on Gulao Waterfront is valuable for tracing the formation process of cultural ecological characteristics in traditional villages of Lingnan waterfront in the Pearl River Delta and is significant for the protection of historical heritage in these villages. This study focuses on Gulao Waterfront in Heshan City, which is both typical and relevant.

To ensure the integrity of the research subject and to thoroughly reconstruct the spatial generation process of Gulao Waterfront and analyze its cultural ecological characteristics, this study encompasses the Dongning Community, Gulao Village, Shuangqiao Village, Shangsheng Village, Xinxing Village, and Poshan Village in Shaping Street (Poshan Village was administratively separated from Gulao Town in the 1990s), covering a total area of approximately 17 km^2 (Figure 1). By the end of 2018, the registered population was about 15000, and the area of fish ponds was approximately 6700 acres.

Figure 1 Study area and location map of Gulao water town

1.2 Research methodology

The data for this study were primarily obtained through historical archive reviews, field surveys, and in-depth interviews. The main sources of information include: (1) Historical Archives: In addition to local chronicles, this category encompasses specialized records and genealogies. Given the limited references to Gulao Waterfront in ancient official documents like county chronicles, it is necessary to explore various specialized records and local genealogies to uncover clues about the spatial generation of Gulao Waterfront. (2) Field Survey Reports resulting from extensive fieldwork and in-depth interviews: Between April 2019 and July 2020, the author conducted nine field surveys and several supplementary investigations in Gulao Waterfront, focusing on aspects such as settlement space, water systems and hydraulic engineering, dike-pond agriculture, and traditional customs. During the research process, in-depth interviews were conducted with Gulao Town government staff, village committee members, some village group leaders, general villagers, and local scholars responsible for compiling genealogies. These interviews were instrumental in refining and revising the research conclusions.

2 Analysis of spatial generation in Gulao Waterfront

Gulao Waterfront is situated in the northwestern part of the Xijiang River Delta, formed by sediment deposition from the Xijiang River[23] (Figure 2). The terrain is characterized by slightly elevated areas to the east and west with a low-lying center. Despite the relatively early formation of the delta [24] (Figure 3), frequent flooding due to its proximity to the Xijiang River severely constrained the development of Gulao Waterfront in the absence of effective flood control measures. Prior to the Song and Yuan dynasties, the region experienced minimal human activity due to harsh natural conditions[1)]. However, from the Song and Yuan periods onwards, with the increase of northern migrants, improved flood management capabilities, and advancements in agricultural techniques, development activities gradually expanded.

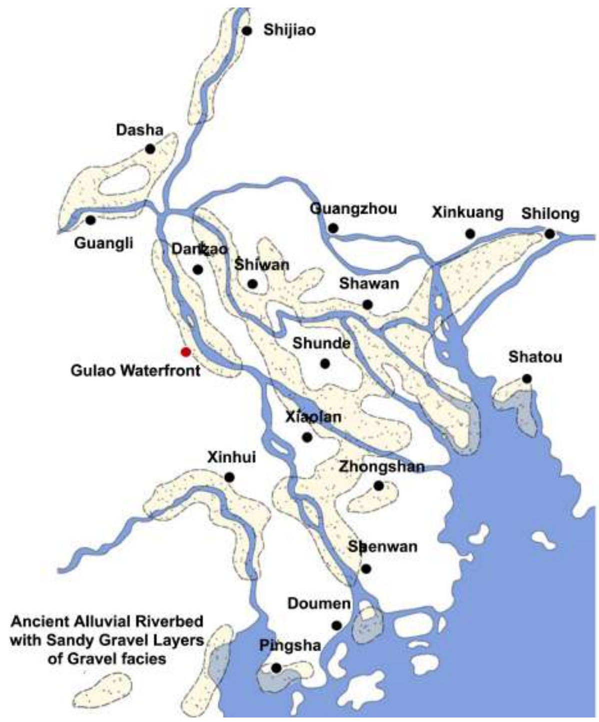


Figure 2 Simplified distribution map of ancient alluvial riverbeds in the pearl river delta

2.1 Song and Yuan dynasties sporadic development phase

From Song to Yuan dynasties, Gulao Waterfront lacked continuous levees, making it vulnerable to flooding from the Xijiang River. The entire waterfront faced the risk of inundation, with the central low-lying areas particularly prone to frequent flooding. Development was confined to the higher terrain on the eastern and western sides of the waterfront, resulting in a dispersed pattern of settlement avoiding flood-prone areas.

In the eighth year of the Xianchun era of the Southern Song Dynasty (1272 AD), the court-admonishing official Lao Wei, fleeing the turmoil caused by the imperial concubine Hu, relocated with his family from Zhujixiang to the elevated area at the foot of Chashan in the western part of Gulao Waterfront[2). During the same period, his relatives, the Gu family, also moved to this area, gradually establishing Gulao Village [25] 18. Shortly after the fall of the Song Dynasty, the Yi family migrated from Yuqiao in Heshan to the elevated terrain in the eastern part of Gulao Waterfront, eventually forming today's Pingshan Village[3-4)](Figures 4-5). At this time, Gulao Waterfront saw the emergence of two independently developing, dispersed settlement clusters.

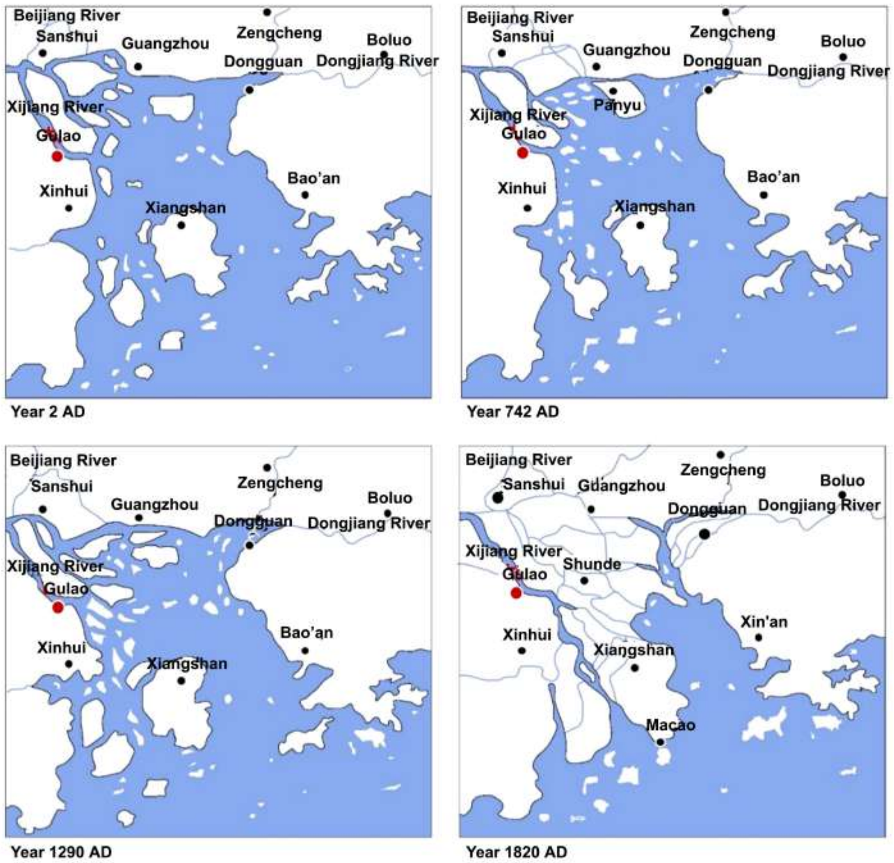


Figure 3 Evolution of the Pearl River Delta

Figure 4 The relationship between villages of Song and Yuan Dynasties and their environment

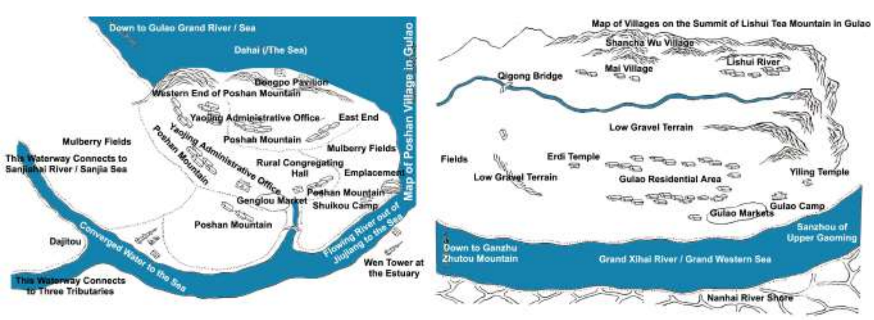


Figure 5 Poshan mountain, Gulao settlements and the environment

2.2 Ming Dynasty comprehensive development phase

From the Ming Dynasty onwards, with the gradual increase in population, the conflict between the growing people and limited land began to emerge, making the reclamation of the low-lying tidal flats in the central part of the waterfront a significant topic. To protect the newly reclaimed land, extensive levee construction was undertaken. This marked a profound shift in the relationship between humans and water, evolving from merely avoiding flooding to actively interacting with it. Consequently, the spatial development of Gulao Waterfront transitioned from a dispersed to a comprehensive development pattern (Figure 6).

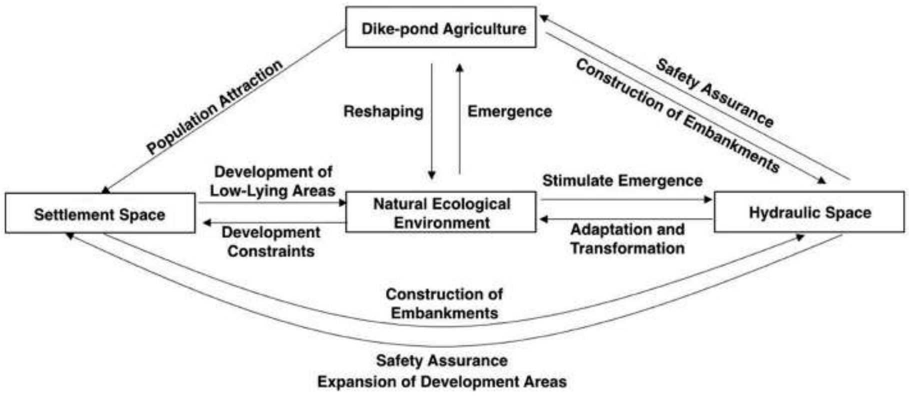


Figure 6 Relationship between Ming Dynasty villages and their environment

During the mid-Ming Dynasty, in order to control flooding from the Xijiang River, villagers constructed several levees along the Xijiang River and Shaping River, including the Gulao Enclosure, Tie Enclosure, and Dugang Enclosure. These levees represented a substantial improvement in scale and quality compared to previous ones, effectively protecting the newly reclaimed land and laying the groundwork for the development of the central low-lying areas. For instance, the Gulao Enclosure irrigated 223 hectares, and the Tie Enclosure irrigated 7 hectares[5)].

Although the levees prevented floods from the Xijiang River, severe internal flooding occurred within the enclosures due to difficulties in water drainage. To effectively manage flooding and fully utilize space, a unique land-use method known as "digging ponds and building mud foundations" emerged. The natural environment, characterized by dense ponds, led to the development of a dike-pond agricultural model in Gulao Waterfront. By the late Ming and early Qing Dynasties, a mature mulberry-dike-fish-pond agricultural model had appeared[7,26].

The control of flooding and the improvement of agricultural conditions stimulated the migration and development of populations into the central low-lying areas of Gulao Waterfront. Prominent clans such as the Ye, Huang, and Wen families migrated to areas known today as Shangsheng Village and Shuangqiao Village during the Ming Dynasty[6-8)]. Thus, the development of Gulao Waterfront expanded from the eastern and western regions to the central area, marking the beginning of a period of comprehensive development.

2.3 Qing Dynasty to republic of China: multi-center development phase

During the Qing Dynasty, the further construction and reinforcement of water management infrastructure in Gulao Waterfront provided a stable environment for the development of "mulberry-dike-fish-pond" commercial agriculture. This stability fostered the growth of market trade, leading to the emergence of markets of various sizes and marking the onset of a multi-center development phase in Gulao Waterfront (Figures 7-8).

As the construction and management of levees improved, control over flooding from the Xijiang River became more effective. The levee construction and management system evolved from being government-constructed to a model where the government supervised but villagers undertook construction[9)]. The management authority shifted from government agencies to village-led "public offices"[10)], and funding sources transitioned from voluntary contributions by villagers to rents and taxes from fishponds[11)], which enhanced management efficiency. In the

128 years following 1837, there were no recorded breaches of the Gulao levees.

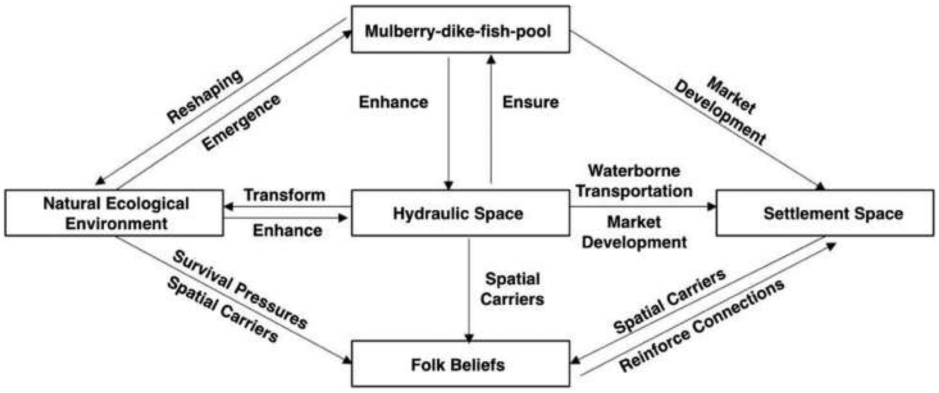


Figure 7 Relationship between villages and their environment during Qing Dynasty and Republic of China

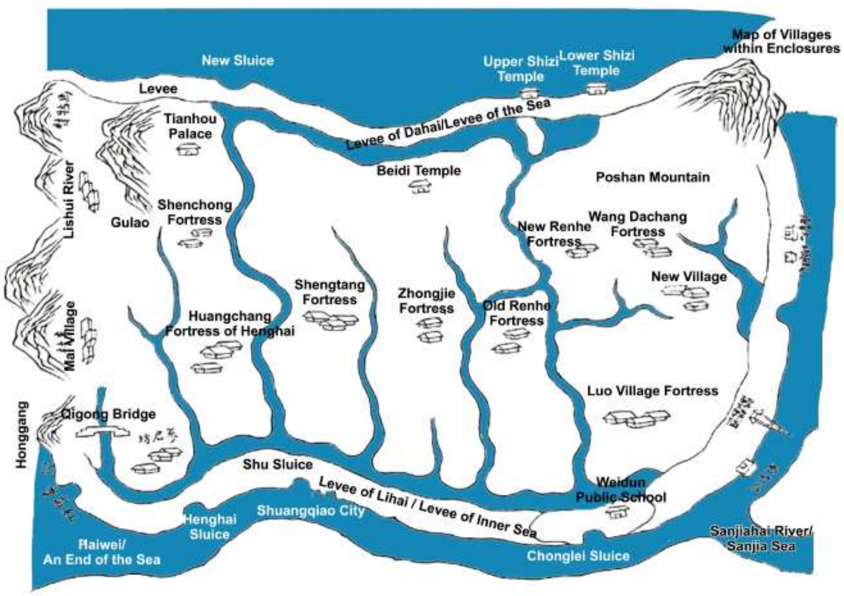


Figure 8 Map of villages in Gulao Waterfront during Qing Dynasty

Simultaneously, the mid-to-late 18th century saw a dramatic increase in the price of raw silk due to foreign merchant demand, which triggered a peak in the "abandonment of rice fields for mulberry cultivation" in the Pearl River Delta[27]. The solid levees provided a foundation for the rapid development of the "mulberry-dike-fish-pond" model in Gulao. By the early Qing Dynasty, the mulberry-dike-fish-pond agricultural model in Gulao Waterfront had become highly developed, known for reports such as "women from the Poshan Enclosure and above are engaged in sericulture" and "fish from the Villages within Enclosures are highly profitable, frequently transported and sold in provincial capitals"[12)]. By the mid-to-late Qing Dynasty, the Gulao Waterfront area had reached a state where "Poshan Enclosure... had no land without mulberry trees and no person without silkworms"[13)].

The development of commercial agriculture in the mulberry-dike-fish-pond system and the enhancement of water conservancy infrastructure significantly accelerated the growth of market trade in Gulao Waterfront. Along transportation hubs such as sluices and docks, various market towns emerged with differing scales and service scopes. Larger markets, such as Gulao Market, with "more than two hundred shops"[14)], had extensive trade networks reaching Guangzhou, Nanhai, and even Wuzhou. Shengping Market, due to its convenient water transport, experienced "daily markets"[15)]. The number of markets increased from one in the Ming Dynasty's Wanli period to five in the early Republic of China[28], indicating a shift to a multi-center development phase.

The growing prosperity of Gulao Waterfront also led to the expansion of water-based folk activities. For instance, dragon boat racing evolved from simple "gatherings to watch races"[16] to an event where "no fewer than ten thousand spectators line the riverside two days before the Dragon Boat Festival"[17], becoming one of the most significant annual festivals.

2.4 Post-1949 transformation and development period

Following the establishment of New China and before the reform and opening-up period, the development of water infrastructure and changes in the social environment had a profound impact on Gulao Waterfront. After years of warfare, by the time New China was founded, the Gulao embankments were in disrepair, and dike-pond agriculture had declined. In the 1950s, the original Gulao enclosure was integrated with Tie enclosure to enhance flood control along the Xijiang River[29]. Modern water management techniques effectively addressed issues of waterlogging within the embankments[30]. This improvement in water infrastructure facilitated the restoration of dike-pond agriculture, and with policy support, the mulberry-dike-fish-pond farming model gradually recovered through the 1950s[31]. However, the embankment breach in 1962 resulted in extensive flooding that devastated mulberry fields, causing sericulture to enter a downturn that persisted until the eve of the reform and opening-up period. Furthermore, the 1962 floods and the "Four Olds" campaign led to the destruction of numerous traditional residences and ceremonial spaces, such as ancestral halls and temples. After the reform and opening-up, traditional cultural and ecological features of Gulao Waterfront faced intense challenges from urbanization and industrialization (Figure 9).

2.5 Summary

The spatial development process of Gulao Waterfront reveals that its growth represents a cultural-ecological adaptation to the environment. Central to this process is how the early inhabitants of Gulao Waterfront adapted and transformed the densely interlaced water network through the construction of embankments and the development of dike-pond agriculture. This adaptation led to the emergence of distinctive settlement spaces, market trade, and cultural beliefs characteristic of waterfront. Throughout this process, a complex cultural-ecological system formed, integrating the early settlers, natural environment, settlement spaces, and both economic and cultural dimensions. Consequently, waterfront villages evolved into spatial carriers of human-environment interactions.

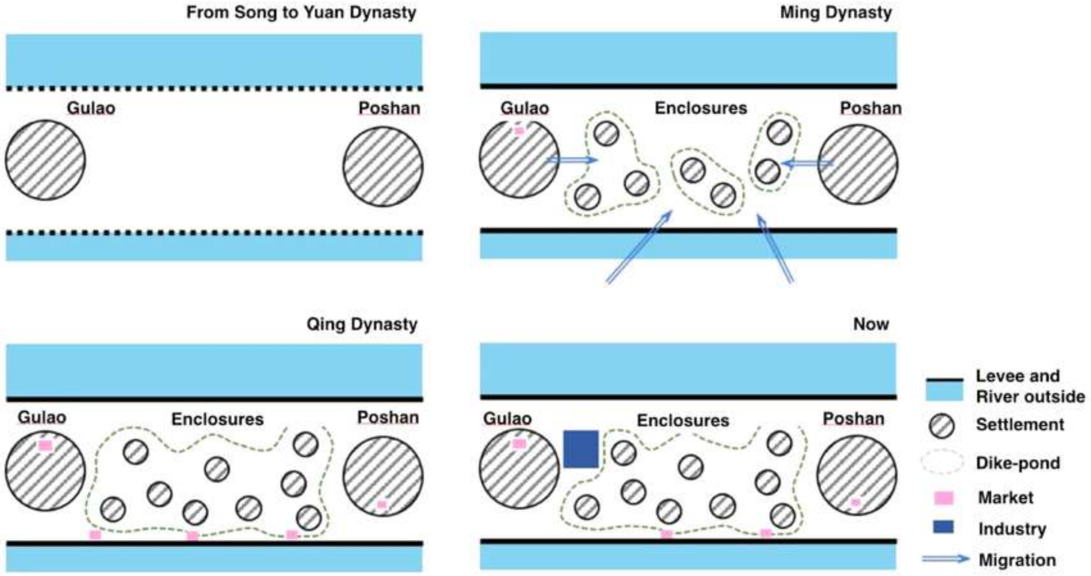


Figure 9 Schematic Diagram of the Evolution of Gulao Waterfront

3 Cultural-Ecological characteristics of the traditional villages in Gulao Waterfront: "water as the lifeblood"

The spatial development of Gulao Waterfront demonstrates that it emerged and developed through intense interaction between humans and the environment. It represents a comprehensive cultural-ecological system encompassing humanity, settlements, natural elements, and socioeconomic conditions. Within this system, the water network of the natural environment plays a particularly significant role, and the cultural-ecological characteristics of Gulao Waterfront distinctly embody the theme of "water as the Lifeblood."

3.1 Overall waterfront pattern—Ancient Embankments Bordering Three Rivers; meandering channels within enclosures with Oceanic dike-pond and Island-like villages

The spatial configuration of Gulao Waterfront, characterized by "Ancient Embankments Bordering Three Rivers; meandering channels within Enclosures with Oceanic dike-pond and Island-like villages," epitomizes the traditional Lingnan waterfront characteristics (Figure 10). Located to the north of the Xijiang River and bordered to the south and east by Shengping River and Shaping River, Gulao Waterfront is defined by a natural geographical pattern encircled by these three rivers. The embankments, constructed since the Ming Dynasty, outline the town with rivers and encircling embankments creating a distinctive layout. Inside the embankments, a dense network of rivers and channels forms a complex water system extending throughout Gulao Waterfront. Additionally, dike-pond agriculture holds a crucial role in local agriculture, with extensive areas of dike-ponds still present. Settlements are situated on larger dikes or on contiguous land with fewer ponds, creating varied forms of settlement spaces that are embedded within the natural ecological base of dike-ponds and water networks, akin to numerous small islands.

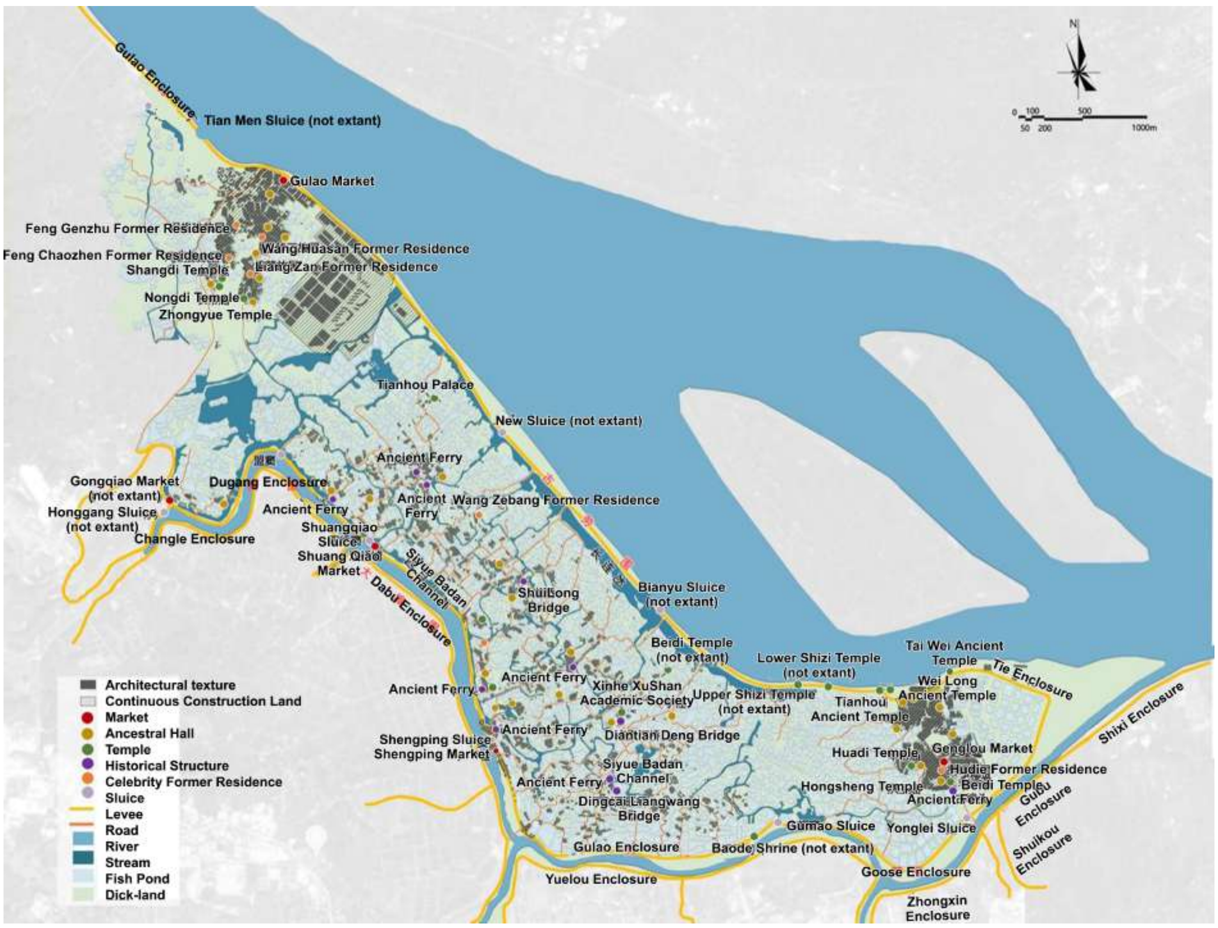
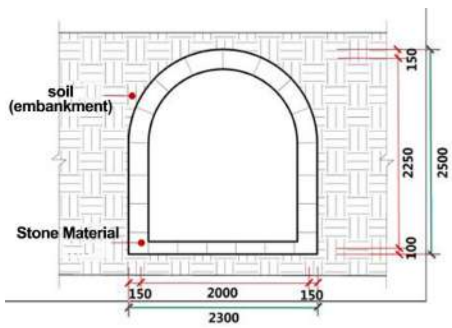
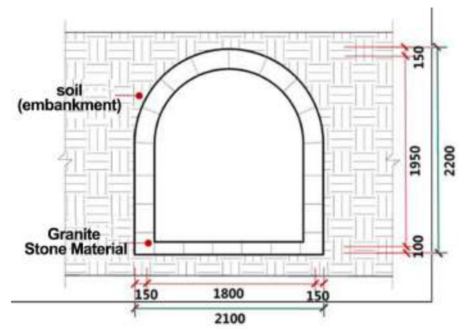


Figure 10 Overall spatial pattern of Gulao Waterfront

3.2 Waternetwork and hydraulic space—encircling rivers and networked water system

The fundamental characteristics of Gulao Waterfront's hydraulic spatial layout are its encircling rivers and networked water system. Surrounded by Shaping River, Shengping River, and Xijiang River, the town has established external embankments such as Gulao Enclosure, Tie Enclosure, and Goose Enclosure to mitigate flood risks, resulting in an external geographical pattern of the triadic encirclement formed by the outer river and these embankments. While the embankments provide protection, they also impede water flow and the town's connection with the outside. To facilitate communication between the inside and outside of the embankments, nine traditional sluices were originally installed under the embankments, serving both drainage and irrigation purposes and functioning as crucial nodes for water transport (Table 1).

Table 1 Schematic cross-section of traditional sluices

Representative sluices	Gumao sluice, Shengping sluice, Shuangqiao sluice, Meng sluice, Tianmen sluice, Honggang sluice, Bianyu sluice, New sluice	Hengchong sluice
Cross-sectional schematic		
Sluice gate type	Shengping outlet and Shuangqiao outlet retain existing wooden double-leaf square sluice gates, while other sluices are currently without gates.	

Within Gulao Waterfront, the river channels and ponds create a complex networked water system. On the northern and southern sides, there are major river channels flowing northwest-southeast through numerous villages, known as Suyueba Channel and Changlian Channel. Other primary river channels generally flow southwest-northeast, connecting Suyueba and Changlian Channels. Additionally, secondary river channels, flowing roughly northwest-southeast, connect the primary channels laterally, forming a comprehensive networked water system.

3.3 Settlement spaces in the waterfront—"clustered villages at eastern and western sides and weidun in the center"

3.3.1 Settlement spatial patterns

The spatial patterns of settlements in Gulao Waterfront are categorized into two primary types: clustered and dispersed, reflecting an adaptation to the natural hydrological environment and an integration with the water network.

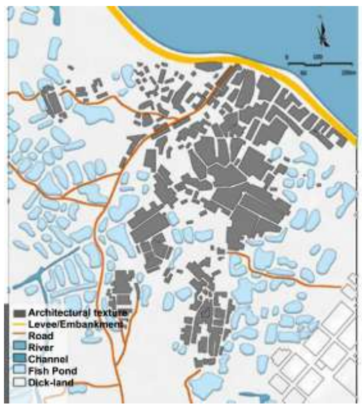
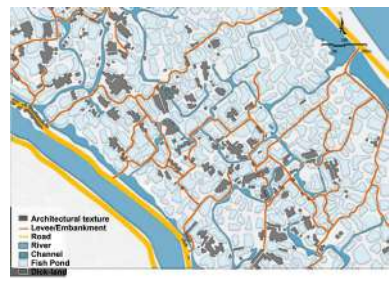
Clustered settlements are predominantly found on the higher terrain on the eastern and western sides of Gulao Waterfront, such as Gulao and Poshang villages. These settlements are situated on contiguous land areas, with a concentrated layout of buildings and minimal division by the water network. Surrounded by a network of ponds and river channels, these settlements exhibit a characteristic of being "embraced by ponds and channels." Due to their larger development space, clustered settlements tend to be more extensive.

Dispersed settlements are primarily located in the central regions of Gulao Waterfront, such as Shuangqiao, Shangsheng, and Xinxing villages, where the area is densely covered with ponds and channels. These settlements, collectively referred to as "Weidun," consist of individual building clusters known as "Dun." These dispersed settlements generally develop on the dike, with limited space leading to smaller settlement sizes, typically ranging from a few households to several dozen. The "Dun" are separated by the water network and are embedded in the pond and water network base in a patchwork pattern (Table 2).

3.3.2 Alley layouts—"following the flow" and "alleyways facing water"

In Gulao Waterfront, adapting to the densely interlaced water network and making optimal use of limited land resources are crucial factors influencing settlement alley layouts. In clustered settlements, main roads connecting to other villages typically serve as primary thoroughfares, with secondary alleys arranged perpendicular to them, creating a comb-like pattern typical of traditional "comb-style" layouts in the Guangfu region. However, the layout of these main roads varies with the natural hydrological environment, resulting in two types of comb-style alley layouts: those positioned away from and those adjacent to the water, embodying the "following the flow" characteristic. In the former, main roads are situated within the settlement, with alleys extending sideways and often leading to the dike-ponds; in the latter, main roads are located near the ponds, at the settlement's periphery, with alleys extending away from the ponds.

Table 2 Spatial pattern of settlements

Settlement patterns	Clustered pattern	Dispersed pattern
Layout		
Photograph		

Dispersed settlements, embedded within the water network, face limited construction space. To maximize land use, larger "Dun" settlements often adopt a grid-like alley layout. This grid layout provides excellent connectivity, with alleys typically offering direct access to surrounding channels and ponds, establishing a strong interactive relationship with the water system and reflecting the "alleyways facing water" characteristic of the waterfront. In this layout, buildings within the settlement are arranged in orderly rows, with deviations from this pattern occurring only at the settlement's edge. For smaller "Dun," while a complete alley system may not be feasible, a regular and compact layout is still employed to conserve land resources.

3.3.3 Waterway transportation spaces—"hundreds of bridges and thousands of wharfs connecting thousands of houses"

In the intricate water network environment, traditional waterfront residents in Lingnan have developed a transportation system heavily reliant on waterways, resulting in a diverse array of waterway transportation spaces, with wharfs and bridges being the most characteristic. According to incomplete statistics, there are over 50 wharfs and more than 30 bridges in Shangsheng Village alone. The Duns within the waterfront are closely connected through various waterway transportation spaces such as wharfs and bridges (Figure 11). Wharfs, which facilitate access from land to water, are typically constructed along the riverbanks and feature steps descending into the water, allowing residents to dock boats, transport goods, and conduct washing activities.

Bridges, serving as essential systems crossings over water, reflect the adaptation and transformation of the natural water network by the local inhabitants. Gulao Waterfront's bridges include stone slab bridges, arch bridges, and flat bridges. Stone slab bridges, designed to span one or more large ponds, can extend several hundred to over a thousand meters and are particularly emblematic of waterfront. Arch and flat bridges, usually built from granite blocks, are employed to cross smaller channels, with lengths of about 5-6 meters. These bridges are often positioned at the entrances to dispersed settlements, such as the Toudu Bridge and Erdu Bridge of Shangsheng Village.

Figure 11 Wharfs, bridges and settlements

3.4 Dike-pond agriculture and market spaces—born from water，thriving for water

3.4.1 Dike-pond agriculture—"ponds and fields interwoven, fish pools arranged like a chessboard"

Many regions within Gulao Waterfront still retain a well-preserved traditional dike-pond agriculture pattern. Traditional fish ponds vary in size and shape, with a naturally flowing and seemingly organic layout. The main connecting roads between settlements are constructed on broader dikes, winding through the fish ponds and villages. The picturesque landscape of interwoven dikes and ponds with shimmering water remains a true reflection of the waterfront scenery. However, contemporary dike-pond agriculture in Gulao Waterfront differs significantly from historical practices. Historically, the mulberry-dike-fish-pond agriculture model followed a cycle: pond mud fertilized mulberry trees, mulberry leaves fed silkworms, and silkworm excrement and cocoon debris nourished fish, creating a beneficial agricultural cycle. Today, however, there is minimal connection between crop cultivation on dike surfaces and fish farming. On one hand, mulberry trees have been replaced by economic crops such as bananas, corn, and vegetables, while fish ponds are primarily fed with modern feed, irrelevant from cultivation. On the other hand, lands of dike-pond are allocated by village groups, while fishing rights are auctioned separately, often leading to different operators managing the ponds and the cultivation, further disrupting the traditional linkage. Additionally, since the 1990s, Poshang Village has implemented standardized modifications to the dike-pond system to facilitate the bidding process for fish farming, exacerbating the degradation of the traditional pond landscape (Figure 12).

Figure 12 Comparative analysis of modern and traditional dike-pond textures in Gulao Waterfront

3.4.2 Market spaces—"thriving by the ferries"

The development of markets in Gulao Waterfront is built upon the commercial dike-pond agriculture and facilitated by convenient water transportation. Markets are typically located in conjunction with transportation facilities such as ferry terminals and docks, reflecting the characteristic of "thriving by the ferries." For example, the Shengping Market in Shangsheng Village is situated atop an embankment, with the embankment serving as the main street and the Shengping Sluice located beneath it. Nearby, three docks were present during the Republic era[14)], which contributed to its status as a bustling market that operated daily due to the efficient water transport.

Another manifestation of the market's dependence on ferry services is the relationship between ferry terminal hierarchy and market scale. The largest market,Gulao Market, once had three docks and offered ferry services to Nanhai, Jiujiang, Guangzhou, and even Wuzhou. Its service area extended beyond Gulao to neighboring regions such as Gaoming, Nanhai, and Jiujiang, making it the largest and most expansive market in Gulao Waterfront. In contrast, Shuangqiao Market, with only one ferry crossing to Shaping, served only Shuangqiao Village, demonstrating a more localized scale and service area (Table 3).

Table 3 Relationships between markets and related rerries

Market name	Number of docks	Dock name	Ferry destinations	Service area	Notes
Gulao Market	3	Sanbao Tongjin Dock Yanbu Dock Passenger Dock	Guangzhou, Wuzhou, Jiangmen, Nanhai, Jiujiang	Gaoming, Nanhai, Jiujiang, Gulao Village	
Genglou Market	2	Poshang Dock	Haishou Sha, Jiujiang	Jiujiang, Shaping, Poshan Village, Haishou Sha	
		Guibu Dock	Guangzhou, Zhaoqing, Nanhai, Jiujiang, Shaping		
Shengping Market	3	Shengping Hengshui Ferry	Shaping	Shenping Village, Shuangqiao Village, Dabu Village, Xinxing Village, Shaping	
Shuangqiao Market	1	Shuangqiao Hengshui Ferry	Shaping	Shuangqiao Village	
Gongqiao Market	—	—	—	—	Originally had few shops; no longer exists after the 1950s.

3.5 Ritual and folk belief spaces—water as a link connecting villages and clans

3.5.1 Ritual spaces—worship of water deities

In traditional agrarian societies reliant on natural economies, frequent natural disasters often left villagers with limited means to address their challenges. To seek benefits and avoid harm, numerous local deities were created and worshipped in the Lingnan waterfront. Gulao Waterfront also features a diverse and complex system of deities, with water deity worship being particularly widespread across various villages. This form of worship occupies a significant place within the local pantheon and represents a common belief among the villages of Gulao Waterfront. The prevalence of water deity worship can be attributed to the town's location along the Xijiang River, an area prone to frequent flooding. Given the high dependency of early inhabitants on water management and transportation, seeking the aid of water-related deities became a necessity. Ritual spaces dedicated to water deities, such as the Beidi Temple, Tianhou Palace, and Hongsheng Temple, are among the most numerous and are widely distributed throughout the villages within the waterfront. These temples are often situated near the Xijiang River and Shaping River, reflecting their alignment with the rivers(Table 4), and indicating a common belief in the divine power to control flooding [32]. Many of these ritual spaces continue to thrive, demonstrating the enduring nature of water deity worship among the local populace.

Table 4 Traditional beliefs and ritual spaces dominated by water deity worship in Gulao Waterfront

Temple	Location	Deity worshiped	Primary festival dates	Ritual practices	Service area	Preservation status	Photograph
Beidi Temple	West of Xinrenhe Village, Shangsheng Village	Beidi	—	—	—	No longer extant	—
	Poshang Shuizhai Village, relocated from the embankment in 1997	Beidi	Major festivals such as Lunar New Year and the Lantern Festival	Prayers for favorable weather and safety	Poshang Shuizhai Village	Relocated in the 1990s	
Hongsheng Temple	Poshang South Gate Village	Hongsheng Gong	Lunar February 13th, HongSheng's Birthday	Prayers for safety and marital bliss	Poshang South Gate Village	Relocated in 2011	
Tianhou Palace	Shuangqiao Village	Shengmu, Guangong	Lunar New Year, Qingming Festival, Buddha's Birthday on the 8th day of the 4th lunar month, and Guanyin's Birthday on the 19th day of the 2nd lunar month	Prayers for safety	Shuangqiao Village	Well-preserved	
	North of the embankment, Poshang Village	Shengmu, Madam Huifu	Major festivals such as the Lantern Festival and Qingming Festival	Prayers for favorable weather, safety, and marital bliss	Poshang West End Village	Well-preserved	
Weilong Temple	North of the embankment, Poshang Village	Weilong Gong, Zhangwang	Lunar March 23rd, Wei Long's Birthday	Prayers for favorable weather, academic success, and marital bliss	Poshang West End Village	Well-preserved	
Baode Shrine	Next to Gumao Sluice, Xinxing Village	Fengbaxiu	—	—	—	No longer extant	—
Upper Shizi Temple	West of the Gulao Enclosure, Poshang Village	—	—	—	—	No longer extant	—
Lower Shizi Temple	West of the Gulao Enclosure, Poshang Village	—	—	—	—	No longer extant	—

3.5.2 "Sanjia flying dragon" folk activity spaces—cross-village and clan unity

One of the most distinctive folk activities in Gulao Waterfront is the dragon boat racing held annually during the Dragon Boat Festival. This event, known as "Sanjia Flying Dragon," takes place at the confluence of Shaping River and Shengping River. Dragon boat racing in Gulao transcends individual villages and clans, fostering a communal belief system across settlements. First, the dragon boat races involve not only the villages within Gulao Waterfront, such as Shuangqiao, Shangsheng, Xinxing, and Poshang, but also several villages on the southern banks of Shengping River and Shaping River. "Sanjia Flying Dragon" has become a collective memory and cultural symbol for the communities along these rivers. Second, the composition of dragon boat teams spans across clans. For example, the Qixing Dragon Boat team from Shangsheng Village includes natural villages with surnames Li, Feng, Wang, Zhang, Wen, Yi, and Zhong, while the Xinlai Dragon Boat team from Shuangqiao Village represents all the surnames in the village. Thus, dragon boat racing has become a means of clan cohesion. Moreover, villagers believe that dragon boats are symbols of good fortune. They hold that "performing dragon dances, paddling the dragon boat, and taking a shower in the water with the dragon boat will ensure favorable weather, peace, and prosperity" [25]231. This belief reflects the villagers' simple wish for safety amidst the unpredictable natural environment and underscores the shared concerns for collective well-being in an area frequently affected by floods [33].

4 Conclusions and discussion

Cultural ecology theory emphasizes the interaction between regional culture and the environment, studying them as an integrated whole. It posits that cultural heritage encompasses not only the material accumulation of the culture itself but also its natural, social, and cultural environments. This perspective offers a more comprehensive approach to understanding and protecting the heritage value of traditional Lingnan waterfront.

From this viewpoint, Gulao Waterfront has evolved through the adaptation and transformation of its environment by its inhabitants. The town's proximity to the Xijiang River and frequent flooding led early settlers to construct embankments to protect their fields, altering the internal water network and creating a distinctive settlement pattern characterized by intertwined water villages. Dike-pond agriculture emerged as a commercial agricultural practice designed to address the hydrological challenges of waterlogged areas within the embankments, which, in turn, spurred the growth and prosperity of market spaces. Additionally, in response to the frequent floods, Gulao Waterfront developed water deity worship and reinforced inter-village connections through folk activities such as the "Sanjia Flying Dragon" dragon boat races.

The spatial development and cultural ecological characteristics of Gulao Waterfront are thus marked by a central theme of "water as the lifeblood." In the context of rapid urbanization in the Pearl River Delta, the holistic historical heritage and conservation value of Gulao Waterfront are increasingly significant and precious.

Despite Gulao Waterfront being one of the "last remaining areas with an original waterfront appearance" in the Pearl River Delta, its cultural ecological heritage has not been sufficiently recognized, leading to increasingly concerning protection conditions. On one hand, there is a lack of adequate awareness regarding the importance of preserving Gulao Waterfront's heritage. Both the overall planning of Heshan City and Gulao Town lack specific provisions for heritage conservation, and local efforts to apply for traditional village status have been limited. The focus of Gulao Town remains predominantly on industrial development, which has resulted in the encroachment of urbanization and industrialization on the town's periphery, with numerous pond spaces being repurposed for industrial use. Furthermore, the economic changes have led to the decline of traditional mulberry cultivation and sericulture, with pond-based agriculture rapidly diminishing. On the other hand, increasing regional tourism demand has led to recent involvement by the OCT Group in the tourism development of Gulao Waterfront. This intervention poses significant challenges to the holistic protection of the town's heritage.

Figure and table sources

Figures 1, 4, 6, 7, 9, 10,11: Created by the author.

Figure 2: Adapted from "Historical changes of river channels in the pearl river delta".

Figure 3: Adapted from "Historical atlas of china".

Figures 5, 8: Adapted fromqing dynasty dao guang's "Heshan county annals".

Figure 12: Source:google maps.

Table 1: Compiled from "Heshan county water conservancy engineering annals" and field investigations.

Tables 2, 3,4: Created by the author.

Notes

1.The Tang Dynasty mid-late period ceramic kiln site was discovered in Poshang Village.

2. "Lao Clan Genealogy": "The founding ancestor, named Wei and courtesy name Zhenyuan, was granted the title of 'Counselor,' originally residing in Zhuji Li, Nanhong. After the upheaval of Empress Hu of the Song Dynasty, he relocated to Gugangzhou, Xinhui, Guangdong (later renamed Heshan Gulao during the Qing Dynasty's Kangxi period, which is now Gulao Village in Longxi Township)."

3. "Gugang Yi Clan Genealogy," Volume 7: "The fourth generation, named Boyan, son of Kangsun… Admiring the scenic beauty of Poting Mountain, with remnants of Su Wen Zhong, settled separately from Yubridge and was born in the Yuan Dynasty's Zhiyuan year and died in the Yuan Dynasty's Zhizheng year."

4. "West End Village History": "The fourth-generation ancestorBoyan (1285-1357) of the Yishan family in Heshan was attracted to the scenic beauty of Poting Mountain and the remnants of Su Dongpo. He moved from Yubridge to Poshang and became the progenitor of the Poting clan, dividing into eastern and western villages."

5. Liu Ji et al., "Heshan County Annals," Volume 4, "Water Conservancy"

6. " Genealogy of the Wen Clan of Gulao Jiangtou," preface: "The fourth-generation ancestor, named Shineng and courtesy name Mengzuo… In the sixteenth year of Hongwu… appointed to the Nanjing Shence Guard… married Huang Shi… and had five sons: the eldest, Youren (courtesy name Dongyin); the second, Youyi (courtesy name Dongqi); the third, Youli (courtesy name Dongya); the fourth, Youzhi (courtesy name Dongzhuang); and the youngest, Youxin (courtesy name Dongqiao). He married Lv Shi and had two sons: the eldest, Qiong (courtesy name Rubi), settled in Weidun Township."

7. "The Eighth Generation Ye Clan Genealogy" states: "YeHao… a scholar in the first year of Shaoxing, Song Dynasty (1131)… passed down to the eighth generation, with Jingxiu Gong's two sons migrating to Weidun." Based on the temporal gap between the first and eighth generations and corroborated by village interviews, it can be inferred that the Ye clan migrated to Gulao Waterfront during the Ming Dynasty.

8. "Brief Biography of Mo'an of the Huang Clan": "Mo'an initially moved to Poshang… After the completion of Gulao Weir, he relocated to the present site of Renhe Village."

9. Guangdong Provincial Local History and Chronicles Editorial Committee, "Historical Materials of Guangdong during the Qing Dynasty (Volume I)"[M]. Guangzhou: Guangdong Map Publishing House, 1995: "In the Guangzhou and Zhaoqing regions, the embankments along the river have long experienced breaches… In the first year of Qianlong, Supervisor E Mida and Zou Qing utilized salt revenue for repairs… The local officials were still required to supervise the people in repairing the embankments during agricultural off-seasons… In the event of erosion or damage, the embankment residents were required to make repairs themselves, as a permanent practice."

10. Song Sen et al., "Heshan County Annals," Volume 4, "Chronological Records": "In the twentieth year of Jiaqing… the Gulao Weir embankment collapsed… In the autumn of that year, County Magistrate Zhang Chexun established a repair office for the embankment."

11.Xu Xiangzu et al., "Heshan County Annals" during the Daoguang Era, Volume 1, "Administrative Structures": "In the fourteenth year of Qianlong, Zhang Zhentao's detailed account of the repair costs for the Gulao Great Embarkment, with annual calls for tenancy, the rental amount was undetermined. In the eighteenth year of Jiaqing, it was still assigned to gentry for tenancy approval."

12. Liu Ji et al., "Heshan County Annals" during the Qianlong Era, Volume 7, "Resources."

13.Xu Xiangzu et al., "Heshan County Annals" during the Daoguang Era, Volume 2, Part 2, "Geography."

14. Song Sen et al., "Heshan County Annals" during the Republic of China, Volume 1, "Territorial Records."

15. Same as above.

16. Liu Ji et al., "Heshan County Annals" during the Qianlong Era, Volume 1, "Customs."

17.Xu Xiangzu et al., "Heshan County Annals" during the Daoguang Era, Volume 2, Part 2, "Geography."

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An Inquiry into the Preservation and Renewal of Historic District, Grounded Within the Theoretical Framework of Catalyst Theory ——With a Case Study of Panxi Restaurant

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ABSTRACT: The philosophical approach to urban design in China has been converted from new-built to re-built. Historic districts are hence leading to a heightened appreciation and delicate handling. WU Liangyong, a prominent Chinese academician, has concluded that plans for historic districts should be implemented with gradualness and carefulness, forming the cornerstone of the Organic Renewal Theory. On the other hand, the Catalysts Theory, an urban design theory originated from the progress of American reconstruction, offers an elastic design framework for our ongoing research. From this line of works, the Organic Renewal Theory could be advised in at least two lenses: its systematic perspective and its practical feasibility. Furthermore, the Catalyst Theory could introduce a potential for a chain reaction, facilitating the progress while safeguarding the integrity of authentic lifestyle. To illustrate how the Catalyst Theory guides practical application, this article examines an ongoing project in Guangzhou as a case study, showcasing its implementation and establishing a framework adaptable to the designs of nearby neighborhoods.

KEY WORDS: re-built of historic district; Catalyst Theory; Organic Renewal Theory

Introduction

In recent decades, the preservation of historical architectural contexts and the approach of small-scale neighborhood transformations have become increasingly prevalent in urban planning. As Professor Wu Liangyong has observed, "While the preservation of historic cities is undeniably fraught with challenges, once the direction is established, overcoming short-term challenges will lead to smoother paths and progressively more expansive achievement." [1]. His Organic Renewal Theory underscores the city's functionality as an organism, necessitating appropriate models and scales that address the relation between the present and the future, based on the specifics and requirements of the renovation. This theory advocates for strengthened research into small-scale transformations and governance mechanisms, and the exploration of "small and nimble" renewal methodologies [2]. Furthermore, This theory has become a seminal source of inspiration for subsequent urban planners engaged in small-scale renovation projects, as well as a methodology for the preservation and

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renewal of historic districts. Despite its origin in different context, the Catalyst Theory from the United States aligns with the principles of the Organic Renewal Theory, offering valuable practices for reference.

1 Urban Catalyst Theory and operational principles

1.1 Emergence of the Catalyst Theory

The Urban Catalyst Theory emerged as a result of American urban planning scholars' contemplation on the "gentrification" in post-World War II city centers. During this era, in response to the deteriorating urban security conditions, many cities began exploring revitalization strategies. Initially, the United States lacked a localized urban planning theory, leading to an extensive reliance on European theories rooted in "monarchical" contexts. Consequently, many revitalization initiatives involved substantial demolition and reconstruction. Large numbers of low-rent housing were quickly demolished, and the subsequent new constructions, owing to disparity in rent, expenses, insurance premiums, and taxation, surpassed the financial reach of the original residents. Consequently, low-income residents were forced to relocate from the revitalized neighborhoods, while wealthier communities further encroached upon the living spaces of the less well-off [3]. Ostensibly alluring urban renewal projects actually morphed into processes of neighborhood "gentrification", eliciting mounting criticism from the public.

Thus, enhancing the living conditions of original residents via urban renewal rather than exacerbating them, became a critical issue for urban planners. Among the various contributors, American architects Don Logan and Wayne Otto, in their work, *American Urban Architecture: The Urban Design Catalyst*, introduced a significant perspective through their Urban Catalyst Theory. Their framework not only critically examined the previously "imported" approaches adopted in the United States but also creatively proposed, with a view to improving rather than radically transforming the living environment within the context of neighborhood revitalization, a planning paradigm centered on "mutual stimulation of elements," which became known as the Urban Catalyst Theory.

1.2 The mechanism of the Catalyst Theory

The principles underlying the Urban Catalyst Theory are concise and coherent. This theory posits that the elements within a neighborhood inherently possess mutual-complementary attributes, signifying that strategic urban planning can enhance the worth of existing elements by integrating novel ones. This process is analogous to the functioning of a chemical catalyst, which not only possesses intrinsic value but also augments the worth of surrounding substances. The objective of the Catalyst Theory is to instigate the revitalization of adjacent territories through the introduction of one or a select few novel elements. These elements, akin to catalysts, interact with preexisting elements, thereby igniting localized transformation. Ideally, these catalysts would spawn fresh catalytic points among the preexisting elements within the surrounding neighborhood, provoking a cascade of catalytic reactions that propel a chain reaction and foster continuous rejuvenation throughout the entire area.

Past applications of the Catalyst Theory has generally been categorized into two domains. The first domain involves the creation of iconic buildings that exert a centralized catalytic effect on their vicinities, often employed as a means to revitalize declining regions. A paramount illustration of this approach is the Guggenheim Museum in Bilbao, Spain. Designed by architect Frank Gehry in the 1990s, the museum served as Bilbao's first landmark, aimed at reversing the city's economic decline. Its distinctive architecture gathered substantial attention, creating the influx of €166 million in investment on Bilbao within six years since its opening and consistently attracting over 4 million visitors annually. Notably, the museum's ticketing revenue continues to contribute approximately 6% to the municipal revenue stream. This catalytic effect of the museum transformed Bilbao from a traditional industrial city into a hub for art and creative industries, significantly boosting both its economic development trajectory and urban identity (Figure 1)[4].

The second domain involves the establishment tailored to attracts specific demographics and fosters distinct activities, embodying both a decentralized catalytic influence and a clustering effect, typically aimed at introducing novel elements into established neighborhoods. A prominent illustration is the Hackescher Markt in Berlin, Germany, which exemplifies a classic Jewish "Hofgarten-Straßenbau" (inner courtyard, outer street) community layout, comprising eight courtyards. After redevelopment efforts, two of these courtyards, alongside with the ground floors and public spaces of all courtyards, underwent a transformation into commercial and cultural hubs [5](Figure 2). The "Hofgarten"(inner courtyards) are accessible during daylight hours, enhancing the commercial vitality of the community, while they are secure at night to maintain tranquility. This integration of commercial and residential activities quickly attracted the attention of numerous fashion studios and thousands of visitors upon its initial public opening in 1995. Presently, Hackescher Markt stand as a benchmark for Berlin's fashion scene and nightlife, epitomizing a paradigm where "the government sets the stage, with the community performing."

Figure 1 Guggenheim Museum in Bilbao, Spain

Figure 2 Hackescher Markt in Berlin

2 Integrating the Catalyst Theory into the preservation and renewal for historic districts

2.1 The relevance of the Catalyst Theory to historic district preservation

The endeavors aimed at preserving historical districts, primarily guided by the principles of the Organic Renewal Theory, are highly compatible with the notions of the Urban Catalytic Theory. Both methodologies emphasize the implementation of "small and nimble" micro-transformations within neighborhoods; they both acknowledge the inevitability of changes over time and emphasize the need of adaptive management strategies; furthermore, both advocate for enhancing the overall (cultural) value through the introduction or renovation of a select key elements within a systematic conceptual framework over a defined time horizon.

The primary divergence lies in their respective objectives: Historic district preservation focuses on safeguarding the historical and cultural value of neighborhoods while acknowledging their inevitable evolution over time with a primary focus on preserving the "ancient" and "original" aspects of these districts. In contrast, Urban Catalyst Theory concerns itself with the intersection between a neighborhood's historical continuity spanning the past one or two generations and its development across subsequent generations. It primarily addresses the "present" value of human activities, economic worth, and environmental quality. Recent literature has, however, increasingly integrated the cultural value of catalytic effects into Urban Catalyst Theory [6-7], demonstrating progress in the practical application of this theory. This way, the Urban Catalyst Theory can augment the dimensions of considerations, systematic ideas, and implementation pathways employed in the context of historic district preservation.

2.2 Theoretical underpinnings for Incorporating modern design exemplars in the historic district preservation

The complexity of preserving historic districts lies in the fact that many instances not only embody historical and cultural values but also serve as vital spaces or vessels for residents' daily lives. As time elapses, subtle shifts in residents' daily activities leads to pronounced disparities between the "present" and the "original" state of these districts. If preservation efforts fail to enhance, or indeed deteriorate, the quality of life for the original residents, such efforts, with their gradual advancements, will inevitably and progressively exacerbate the tension between the routine of the daily life and the preservation of the historic district. This tension can only be resolved through a significant decline in one of the opposing side.

The vitality of the Urban Catalyst Theory, on the other hand, stems from its focus on the contemporary significance of residents' lifestyles. When harmoniously integrated with the Organic Renewal Theory, it unifies disparate design approaches under a unified evaluative framework, thereby offering theoretical underpinnings for comparing and referencing modern design exemplars in the context of historic district preservation. Furthermore, this integration underpins the theoretical possibility of bringing historic district preservation closer to contemporary living.

2.3 Maintaining consistency and continuity in design decisions

The preservation and development of historic districts entail a gradual progression where the outcomes of previous stages serve as the foundation for subsequent endeavors. However, given the protracted timeline, it is conceivable that different phases may involve different design entities, and even within the single phase, multiple teams with varying technical expertise may collaborate. This scenario poses a formidable challenge in maintaining consistency and continuity amidst these endeavors.

To address this challenge, the Organic Renewal Theory incorporates the perspective of original residents into the preservation planning process, thus aligning design proposals with residents' needs [8]. On the other hand, the Urban Catalyst Theory, exemplified by its application in American neighborhood designs, exhibits a flexible design approach that fosters inclusivity. This approach not only takes into account residents' opinions but also establishes a relatively standardized list of elements and design procedures, allowing designers to work within this framework while maintaining flexibility. In scenarios where multiple catalytic elements coexist within a neighborhood, the adoption of systematic design principles encourages collaboration among different design teams, ensuring cohesion in terms of appearance, functionality, and content. This approach ensures that various catalytic elements are capable of functioning either independently or collaboratively, thereby optimizing their collective catalytic effect [9]. Furthermore, the design decision-making assistance provided by the Urban Catalyst Theory prompts planners, architects, and policymakers to propel the chain reaction within urban development, offering valuable insights for the Organic Renewal Theory[10].

2.4 Challenges of Catalyst Theory

Catalyst Theory faces several challenges at both theoretical and practical levels. Historically, numerous buildings have touted as "catalytic agents," yet frequently, these assertions merely reflect designers' personal agenda to innovate under the guise of catalyst theory. While such avant-garde buildings may exhibit some catalytic effects, they are frequently driven by designers' egos rather than being responsive to the neighborhood's necessities and functional requirements. As a result, these so-called "catalytic agents" often diverge from the neighborhood's historical continuity and disrupt the original residents' living environment, ultimately becoming burdens to urban development. Such practices undermines the fundamental intent of The Urban Catalyst Theory [11].

Furthermore, the practical application of catalytic effects often suffers from adisparity between theoretical ideals and real-world implementation. The Catalyst Theory embodies a comprehensive approach that bridge the gaps between expansive planning and detailed architectural design. However, in practical scenarios, a designer applying this theory often finds his influence limited to short-term renovations or designs for isolated segments or individual buildings within a neighborhood. Consequently, their influence on broader, district-wide transformations is often constrained, making it challenging to maintain the coherence and unity of the intended catalytic effect. Such complexities cannot be solely overcome by the efforts of individual designers. Only through the intervention and regulation of the local government can the one designer be entrusted as the principal consultant for significant renovations or new constructions within a neighborhood over an extended period, enabling subsequent projects to adhere fully to the framework established by preceding designs. Without this arrangement, it becomes significantly challenging to genuinely achieve the maximization of the envisioned catalytic effect or even propel chain reactions.

Lastly, while catalyst theory appears to focus on architectural design, it effectively centers on designing user experiences, which often stands in contrast to contemporary urban planning principles. The pursuit of catalytic effects entails crafting an organic unity, rather than merely assembling discrete functional modules within the planning area. This approach blends various elements into a cohesive system, integrating them into the naturally evolving community ecology. This methodology not only increases the designer's workload and necessitates a paradigm shift from perceiving functions as piece-patched modules to embracing them as integral elements. Such a shift presents challenges, as it diverges from conventional modern urban planning practices and complicates the process of adaptation.

In summary, these issues pose a dilemma: achieving catalytic effects through design requires gradual, time-consuming, and complex processes; while designers often opt for short-term innovations that may undermine the existing urban character and ecology.

2.5 The Catalyst Theory modified within the context of historic district preservation and renewal

By integrating the characteristics of the Organic Renewal Theory and the Catalyst Theory, and addressing the practical challenges encountered in applying the latter, the following principles can be established for advancing historic district preservation and renewal:

(1) Preserving the Integrity and Vitality of the District's Historical Fabric: Any new elements introduced must integrate seamlessly into the district's historical and daily life. Therefore, it is crucial to first understand the district's architectural traits, street layouts, and lifestyle patterns, ensuring minimal disruption to traditional living spaces and pathways that are intimately connected to the original residents.

(2) Implementing a Gradual Strategy for Preservation and Renewal: The process of the district development ought to be incremental and progressive [12]. This process necessitates small-scale interventions and adjustments, with subsequent plans adapted based on the catalytic effects observed during previous phases.

(3) Ensure Distinct Recognizability of New Elements and Catalysts: The design of catalysts should aim to create projects that are not only integrated seamlessly but also make a distinctive contribution to the original fabric, ensuring a certain level of uniqueness. Thus, while preserving the overall aesthetic coherence of the district, new projects should maintain their distinct recognizability.

(4) Comprehensive Coordination for Preservation and Renewal Efforts: Historic district preservation and renewal are long-term endeavors where any missteps can result in failure. Designing catalysts also requires coordination with previous efforts to enhance their effectiveness. Throughout this process, it is imperative to maintain consistency in guiding principles, underlined by comprehensive planning that identifies and organizes functional and value-bearing elements of the district. This exhaustive planning encompasses the compilation of architectural and intangible heritage related to the district, as well as the establishment of a robust framework to facilitate subsequent design endeavors.

(5) Engage Government Oversight and Resident Participation [13]: The preservation and renewal of historic districts have profound social significance that transcends the mere commercial worth of the endeavors themselves. Optimal catalytic elements exhibit substantial spillover effects, where their value and impact extending well beyond the confines of the project. The societal implications embedded in such projects require the involvement of governmental oversight and the active participation of local residents.

Following these principles, the specific approach can be divided into four steps:

Step 1: Identify and categorize existing elements in the district [14](Table 1).

Step 2: Analyze theattributes and functions of the project as a district element. This step involves examining the project's attributes and functions from four main perspectives:(1) Location: Assess the project's geographical positioning within the district and the functionalities of adjacent buildings.(2) Culture Context: Evaluate the architectural idiom, historical trajectory, and cultural significance of the project.(3) Pedestrian Circulation: Analyze the existing pedestrian flow patterns and volumes in the area.(4) Potential for Transformation: Determine the project's capacity for renovation and the potential for new construction initiatives.

Table 1 Available Elements of Historic District

Carrier	General definition	Catalytic element
Streets, lanes, and nongs	Pedestrian or vehicular areas.	Streets, lanes, and nongs serve as connectors between various points, and important venues for residential and economic activities. Additionally, they have the function of linking different aspects of the urban landscape, fostering a cohesive and interconnected urban environment.
Historical buildings	Buildings or complexes processing historical significance and enduring value.	Historical buildings serve as tangible embodiments of the district's historical narrative and continuity. While the streetscape may evolve over time, historical buildings largely remain steadfast. Additionally, they function as temporal repositories, reflecting the transformation of the district's living culture across generations.
Landscape architecture	Classical gardens or parks.	The purpose of landscape architecture is to create visually pleasingscenes that delight and invite exploration. Areas of transition, where one scenic element gives way to another, provide ample space for the imagination to wander.
Time-honored brands	Traditional old shops related to neighborhood life.	The interdependence between time-honored shops and historical districts is profound: the existence of historical district supports the emergence of time-honored shops, while these shops, in turn, serve as shared memories and life experiences across generations of the original residents.
Structures	Objects within a district designed to display, indication, or the delivery of municipal services, such as monuments, signage etc..	Structures convey the historical and contemporary narratives of a district, serving as the carriers of the history.
Activity squares	Open spaces within the district for residents and tourists to engage in activities.	The activity squares are public activity spaces that serves as the most adaptable and inclusive catalytic carriers. By incorporating different (activity) elements at various time points and stages, they can reflect different types of values.
New buildings	Newly constructed or renovated buildings in historical districts.	New buildings represent a new historical phase of the district,which may interact with the older history in diverse manners including integration, juxtaposition, or confrontation, shaping a multi-faceted temporal context.

Step 3: Assess the intrinsic value of the project.This step is divided into tangible and intangible elements:(1) Tangible Elements: Repair any damage to existing buildings to enhance their overall quality. Restore or add tangible components such as interior and exterior finishes, decorative elements, and fixtures. If necessary, reconfigure internal spaces for functional optimization or construct new buildings to address functional deficiencies.(2) Intangible Elements: Intangible catalysts, such as traditional crafts, arts, and public events, represent elements with widespread influence [15].

Step 4: Evaluate and foster the project's catalytic effects within the district.(1)Scope of Catalytic Effects Assessment: Determine the project's reach within a 10-minute walking distance. Based on the project's functionalities and values, estimate the number of buildings within this radius that could potentially be influenced.(2) Enhancing Connections with Neighboring Buildings: Leverage the value of tangible and intangible elements as creative elements to design streetscape structures and organize activities that foster connections with surrounding buildings. (3) Iterative Refinement: Post-construction, continually refine or augment elements based on public feedback and project outcomes to maximize the catalytic effect [16].

3 Case study: an analysis of Panxi Restaurant

The following section provides an overview of the application of Catalyst Theory within the framework of historic district preservation and renewal, using the renovation of Panxi Restaurant as an illustrative case study.

3.1 Accessible catalytic elements in the vicinity of Panxi Restaurant

3.1.1 Catalytic elements in the vicinity of Panxi Restaurant: (Table 2) (Figure 3)

3.1.2 Value elements of the Panxi Restaurant district

(1) Xiguan Area: Since Qing Dynasty, Xiguan has flourished as a prosperous area known for its vibrant commercial activities. The district features well-preserved historical architectural complexes, including the Xiguan Mansion and the Qilou streets.

Table 2 Available Elements in the Vicinity of Panxi Restaurant

Carrier	Instance
Streets, lanes, and nongs	Panxi Restaurant is located on Longjin West Road, intersecting with Enning Road and Pantang Road, thereby facilitating the integration of catalytic elements at the street level.
Historical buildings	Qilou Buildings (a type of building architecture in southern China where the upper floors extend over to offer shade for pedestrians), Liwan Museum, Liangjia Ancestral Hall, Xiao Huafang Studio, Xiguan Mansion, Haishan Xian Pavilion, Ciwei Pavilion, Renwei Temple, Bruce Lee's Former Residence, Bahe Artists Association of Guangdong, etc.
Landscape architecture	Haishan Xian Pavilion, Liwan Lake Park, Liwan Scenic Area, etc.
New buildings	the Renovated Pantang Wuyue Cultural Area, Cantonese Opera Art Museum, Yongqing Square, etc.
Structures	Wen Tower, Moon Shadow, etc.
Time-honored brands	Guangzhou Restaurant,Xiangqun Hotel, Royal Fine Dim Sum, Xiguan Clan House, Lingji, Provincial City Rice Noodles.
Activity squares	Plaza withinLiwan Park, Liwan Children's Activity Center.

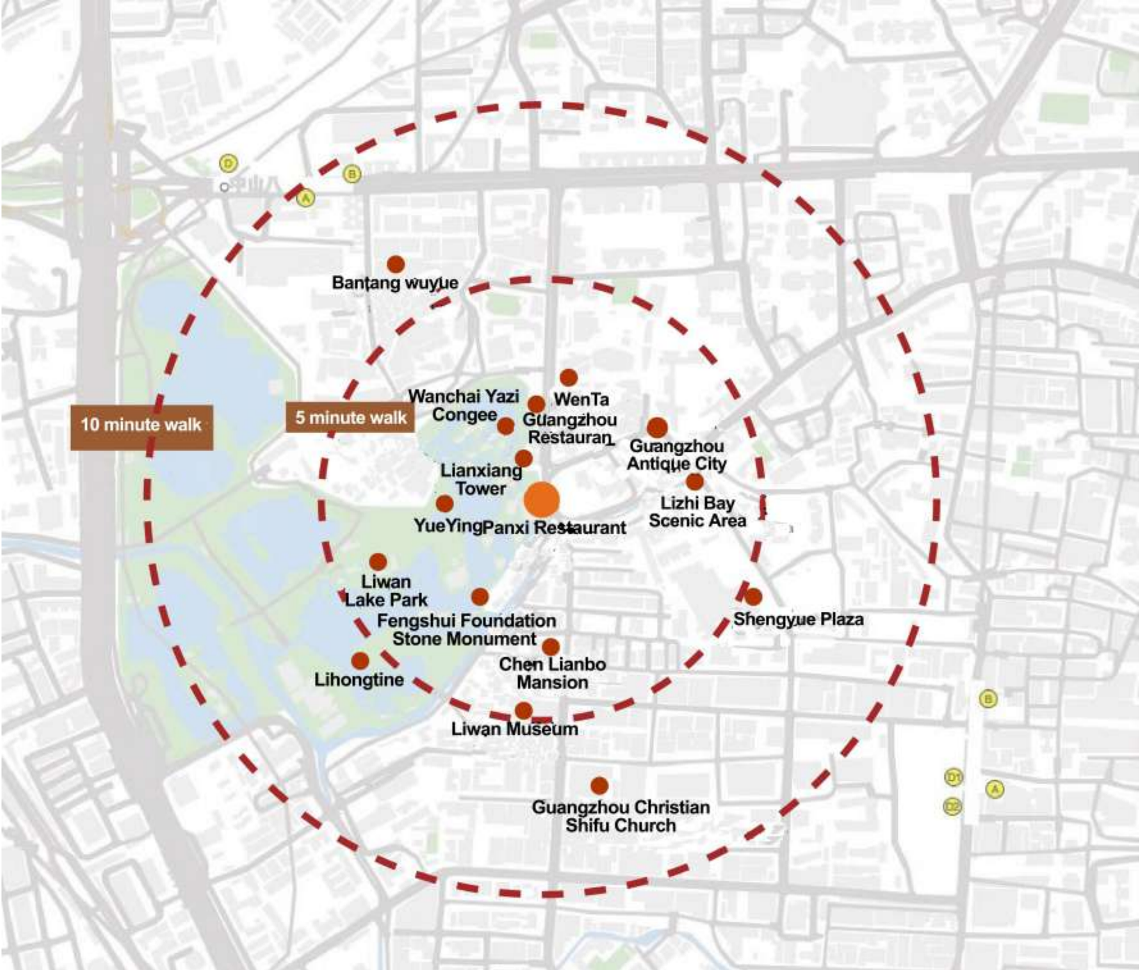

Figure 3 Available elements around Panxi Restaurant

(2) Lingnan Gardens: Lingnan gardens are distinguished by three main characteristics: (i) The integration of influences from Central Plains culture, Jingchu culture, Wu-Yue culture, Min-Gan culture, and various overseas cultures with local traditions; (ii) The blend of pragmatism and innovation within commercial culture; (iii) The influence of water and maritime culture, leading to garden designs that emphasize water elements [17]. Historically, the district boasted many classic gardens, such as the Haishan Xian Pavilion and the Changhua Garden of the Southern Han Dynasty.

(3)Cuisine: Since the Qing Dynasty, Xiguan has been a central hub for Cantonese cuisine. The area surrounding the Panxi Restaurant is populated with numerous renowned, bustling eateries, where famous chefs and signature dishes continue to emerge.

(4) Cantonese Opera: The district has long been recognized as a community of Cantonese opera, housing many prominent performers lived during the Republic of China and the early years of People's Republic of China.

(5) Traditional Crafts: The traditional architecture in the district prominantly features Guangdong's traditional "three carvings" (stone carving, wood carving, brick carving) and "two sculptures" (plaster sculpture, ceramic sculpture).

3.2 Historical regrets of Panxi Restaurant

Panxi Restaurant, designed by academician Mo Bozhi in the 1950s and 1960s, exemplifies Lingnan garden-style dining, featuring a thoughtfully arranged layout (Figure 4). This establishment seamlessly integrates distinctive elements of Lingnan gardens with Qing Dynasty architectural decorations, functioning as a living art museum. It houses rare and valuable artifacts, including antique flower covers, door panels, intricate wooden carvings, colored floral window screens, rosewood furniture, and calligraphy and paintings by notable figures. In addition to its representation of Lingnan garden culture, the restaurant embodies vital aspects of local dining and Cantonese opera traditions.

Despite its many virtues, Academician Mo Bozhi acknowledged certain shortcomings in the design of the restaurant. He pointed out that the layout did not fully accommodate the logistical needs of the operation. The service areas were undersized, and the kitchen lacked provisions for gas-fired equipment. Additionally, there were no provision for a staff cafeteria or childcare facilities, and the overall space allocation was insufficient. As the implementation phase began, the team discovered that the operational area was too limited, leading to a reduction in the courtyard space to expand dining capacity, which resulted in a cramped courtyard landscape and skyline [18].

To address these challenges, the restaurant operators constructed a four-story logistics office building to increase operational space. However, this purely functional addition stands in starkly contrasts to the original architectural style, creating a discord between the old and new aesthetics. Over time, the original buildings have also deteriorated, with many of the furnishings and structures showing significant wear and damage, diminishing the once vibrant ambiance.

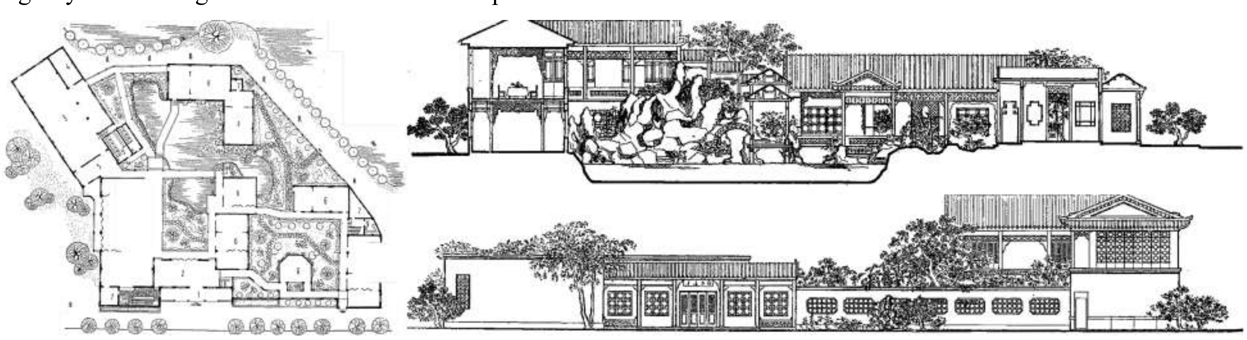

Figure 4 Panxi Restaurant blueprint (manuscript by academician Mo Bozhi)

3.3 The restoration of the tangible carriers

The ongoing restoration work at Panxi Restaurant primarily addresses the aforementioned historical issues while striving to minimally disrupt the environment and maximize the restoration of academician Mo Bozhi's original vision, particularly regarding academician Mo Bozhi's thought on the fabrication of the mounts and water. Due to space limitations, this paper will not cover all aspects of the restoration but will highlight a few key elements.

One significant aspect is the renovation of the lakeside façade of the logistics office building. This building, which has undergone several expansions since the 1990s, presents various structural and functional challenges. Its lakeside façade features a protruding elevator shaft and large ventilation ducts extending from the first floor to the roof, which significantly disrupts the surrounding historical environment and stands out as a major discordant element on the boundary between Panxi Restaurant and Liwan Lake South.

The objective of the façade renovation is to restore, to the greatest extent possible, the characteristics of Lingnan garden architecture, specifically the integration of extensive courtyards and elevated terraces [19], while continuing academician Mo Bozhi's vision for Lingnan garden aesthetics. The renovation involves several key strategies:

(1) Focus shift: The large ventilation ducts are concealed behind partition walls, and the protruding elevator shaft is decorated as a Western-style tower. As the central and highest point of both the restaurant and the lake south boundary, the Western-style pavilion at the top of the tower serves to draw visual focus, thereby mitigating the adverse effects of surrounding high-rise buildings on the restaurant's skyline. The Western-style tower design is inspired by the technique of blending Eastern and Western styles found in Lingnan gardens. It not only creates an exotic atmosphere but also complements the existing Meeting of Winds and Clouds Dome on the Liwan Lake South boundary, enhancing the overall visual appeal.

(2) Minor adjustments to façade details: Some flat roofs have been converted to pitched roofs, incorporating elements common in Guangdong folk architecture, such as Xieshan-style roofs, connecting corridors, and window cornices. These modifications refine the partition walls and façade style, softening prominent features and altering the visual rhythm of flat sections through thoughtful arrangement of doors and windows (Figure 5).

Secondly, the restoration of handcrafted artifacts and the display of traditional craftsmanship are key components of the project. Panxi Restaurant, a quintessential Lingnan garden restaurant, originally employed handcrafted products and building techniques prevalent in Guangdong during the renovation overseen by academician Mo Bozhi. Building materials such as bricks, stones, wood, screens, windows, lintels, and wooden carvings predominantly came from salvaged materials of the "Xiguan Mansion," thereby preserving many characteristics of Lingnan garden aesthetics and Qing Dynasty architectural decoration (Figure 6). Additionally, government departments of the time selected period-specific artworks, including Li Guohua's woodcut "Red Ridge Sunrise" and Mao Zedong's calligraphic inscriptions, to decorate partitions and doors.

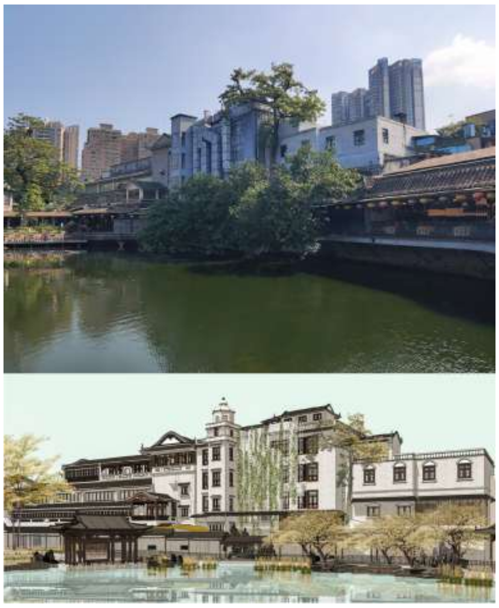

Figure 5 Before and after renovation of the logistics office building

Academician MoBozhi and the Panxi staff also collected furniture from the Qing Dynasty to the early Republican era [20], which was once displayed in the restaurant's main hall. Through the collaborative efforts of Mo Bozhi's team, Panxi staff, and government agencies, Panxi Restaurant had preserved the essence of the Xiguan architectural spirit and Lingnan building culture that might otherwise have been lost. The external decorations, components, and furnishings possess significant cultural and aesthetic value, making it one of the most notable examples of Guangdong's heritage. In 2016, Panxi Restaurant was included in the "First Batch of 20th Century Chinese Architectural Heritage" list [21].

As Panxi Restaurant underwent restructuring, valuable historical furniture was collected by the Liwan Cultural Relics Bureau, with some pieces displayed in the Liwan Museum. Due to the passage of time, the remaining furniture, components, and decorations have suffered various degrees of damage. The design team plans to collaborate with renowned traditional craftsmen to restore or reconstruct architectural decoration components, doors, windows, and railings. Notable works include ceramic ridge pieces such as "Longevity Celebration," "Joyful Mood," and "Dragon Rising" (Figure 7). Through this restoration and limited new construction, the design team aims to more fully integrate Guangdong's traditional "three carvings" and "two sculptures" into the restaurant's interiors and exteriors, transforming Panxi Restaurant from a culturally rich garden restaurant into a showcase of Guangdong's traditional craftsmanship.

Figure 6 Interior decoration of Panxi Restaurant

Figure 7 Ceramic sculptures by master He Zhanquan

3.4 The introduction of the intangible carriers

Panxi Restaurant naturally embodies various intangible catalytic carriers. First, it seamlessly integrate the traditional craftsmanship of Guangdong, including Lingnan garden design techniques, the "three carvings" and "two sculptures", as well as traditional furniture-making processes. Second, the restaurant is renowned for its culinary heritage. During the 1970s and 1980s, it became a national center for Cantonese cuisine, earning the reputation of "Half of Cantonese cuisine masters come from Panxi," featuring classic dishes such as the "Eight Great Dishes," "Eight Great Dim Sum," and "Shape-Representing Dim Sum Banquet." Prominent chefs like Luo Kun, Lin Rangming, and He Jixiong have significantly contributed to this illustrious culinary tradition. Third, Panxi Restaurant is situated in the traditional Cantonese opera community of Xiguan, which was frequented by many renowned Cantonese opera performers from the Republican era and the early People's Republic of China, creating an intrinsic connection with Cantonese opera culture.

These inherent attributes make it logical for Panxi Restaurant to incorporate existing public activities and events from the district as intangible carriers. For instance, Panxi Restaurant could serve as a venue for the district's longstanding traditional craft exhibitions and Cantonese opera seminars, and it could also participate in themed food events organized by the district. By introducing these intangible catalysts, Panxi Restaurant not only enhances the recognition of its components among specific audiences but also contributes to enriching the overall cultural value of the district.

4 Conclusion

The protection of historic districts is an emerging field that often requires gradual, step-by-step progress due to external constraints. This process involves more than just government investment; it demands broader participation and collective effort. The systematic framework provided by the Urban Catalytic Theory offers a theoretical foundation for historic preservation work and refines the implementation path for specific design steps. The Panxi Restaurant renovation project aims for a non-centralized catalytic effect, focusing on minimal intervention to restore the original design intent and enhance the historical and cultural value of Panxi Restaurant while highlighting the district's historical character. The renovation of Panxi Restaurant, along with the integration of nearby available elements, sets new standards and higher expectations for the protection of adjacent historic districts.

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Place-Making in Healthy Communities Using the Theory of Scenes

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ABSTRACT: Currently, both in practice and theoretical studies, the construction of healthy communities predominantly focuses on enhancing physical spaces. However, there is limited guidance on promoting healthy lifestyle behaviors and only superficial discussions regarding operation and maintenance systems. The theory of scenes holds profound significance in urban research and spatial quality improvement, addressing not only the physical environment but also forms of social organization. The healthy community is the basic unit in social space for the construction of the health scene. Therefore, applying the new perspective of scene theory respects the established standards and guidelines while exploring the creation of healthy communities to guide people's healthy lifestyles and direct design practice. The research analyses the domestic healthy community research, summarizing the connotations and the development history of healthy communities both domestically and internationally, and compares the content of concern, research units, and the connotation composition of healthy communities internationally. Based on scene theory, it analyses the relationship between the physical environment of a healthy community and the behavioural styles of people in a healthy community. With the help of scene theory, it proposes five elements of healthy communities (residents and collaborators, physical space, health service facilities, health activities, and community values) and nine sub-scenes (healthy environment, healthy living, healthy transportation, health services, healthy facilities, healthy hygiene, healthy activities, healthy society, and healthy policies). At the same time, it conducts a comparative analysis of the typical standards of domestic and foreign healthy communities, and incorporates the differences in the creation of healthy communities at home and abroad to improve the content and operation systems of healthy communities.

KEY WORDS: healthy community; healthy community standard; the theory of scenes; place-making; community planning; public healthy

Introduction

Over the past half-century, healthy communities have emerged as a hot topic in both theoretical research and design practice globally. In 1986, the World Health Organization (WHO) launched the Health Promotion Program, outlining an agenda for action that includes enhancing public participation and reinforcing community actions to further promote community health [1]. For instance, the UK's National Planning Policy Framework identifies the critical role of planning in health and well-being, explicitly stating in Chapter 8 the need to "promote healthy and safe communities." In 2016, China's "Healthy China 2030" blueprint emphasized the widespread development of healthy communities. By 2019, the construction of healthy communities became a key component of the "universal participation, co-construction, and shared bene-

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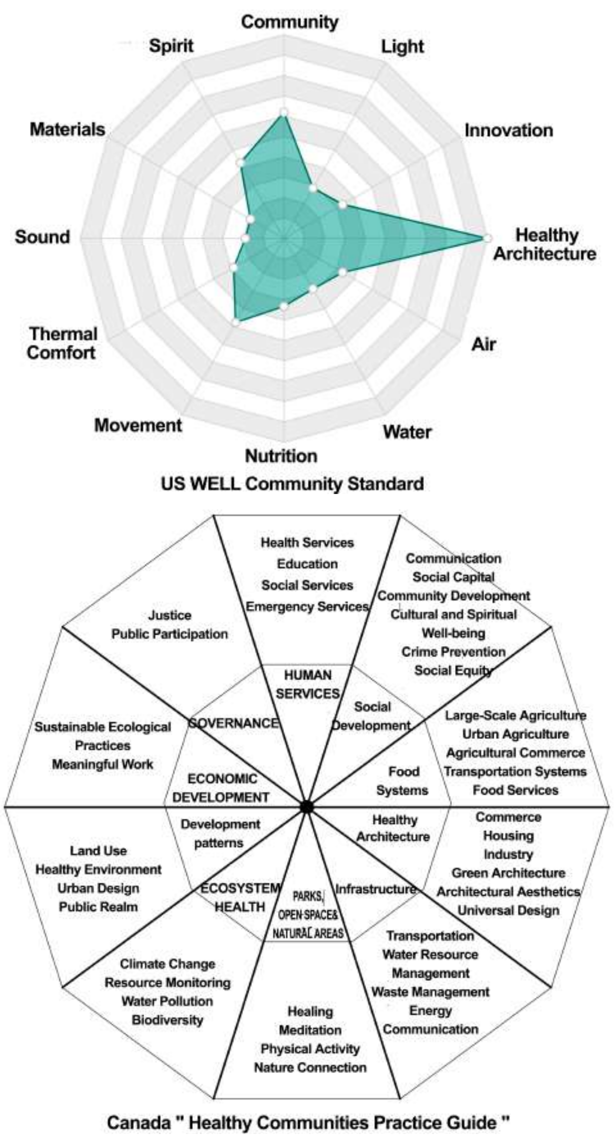
fits" principle fundamental to the Healthy China initiative.

The concept of healthy communities is continually evolving. Primarily, healthy communities emphasize the organic integration of people, the physical environment, and the social environment, promoting residents' health through improvements in both physical and social contexts. For instance, Japan considers the safety of natural, social, and transportation environments as fundamental to healthy communities, where residents' physical activities are inherently linked to thesefactors[2]. Take Fujisawa community in Japan as a case study, which integrates smart infrastructure to advance community development across five key areas: energy, safety, transportation, health, and overall community wellbeing, fostering a health-conscious environment for all age groups. This includes a "local integrated care system" that offers a chain of medical, nursing, elder care, and pharmaceutical services, while community centers organize various health promotion activities[3]. Furthermore, beyond supporting and promoting healthy lifestyles, healthy communities provide vibrant public spaces that facilitate social interaction and neighborhood engagement, ultimately reducing crime[4]; For example, the WELL Community Standard in the United States envisions communities characterized by inclusivity, integration, resilience, strong social identity, and high levels of social interaction participation[5].

Internationally, healthy communities emphasize different aspects such as safety, intelligence, community engagement, policy mechanisms, collaborative interactions, and elder care and medical services (Figure 1 and Table 1). The Centers for Disease Control and Prevention in the United States highlight that the creation and maintenance of healthy communities rely on the collective efforts of government, residents, social organizations, and community enterprises. This collaboration helps residents form organized groups to work together for disease prevention and healthmaintenance[6]. In the UK, the focus is on harnessing endogenous community strengths to build healthy communities. Key measures include strengthening community organizations, building volunteer teams, enhancing cooperation and communication, and ensuring the accessibility and efficient use of community service facilities[7]. Canada's approach to healthy communities emphasizes softer aspects such as developmental models, ecological considerations, cultural and social factors, and policy mechanisms. Planners engage with multidisciplinary organizations to lead the implementation of healthy community projects[8]. For instance, in Airdrie, Canada, the goal is to establish the nation's healthiest community by organizing and coordinating residents and various resources. A series of initiatives have been undertaken, including enhancing economic vitality, reducing healthcare costs, creating age-friendly social networks, and developing smart community platforms[9].



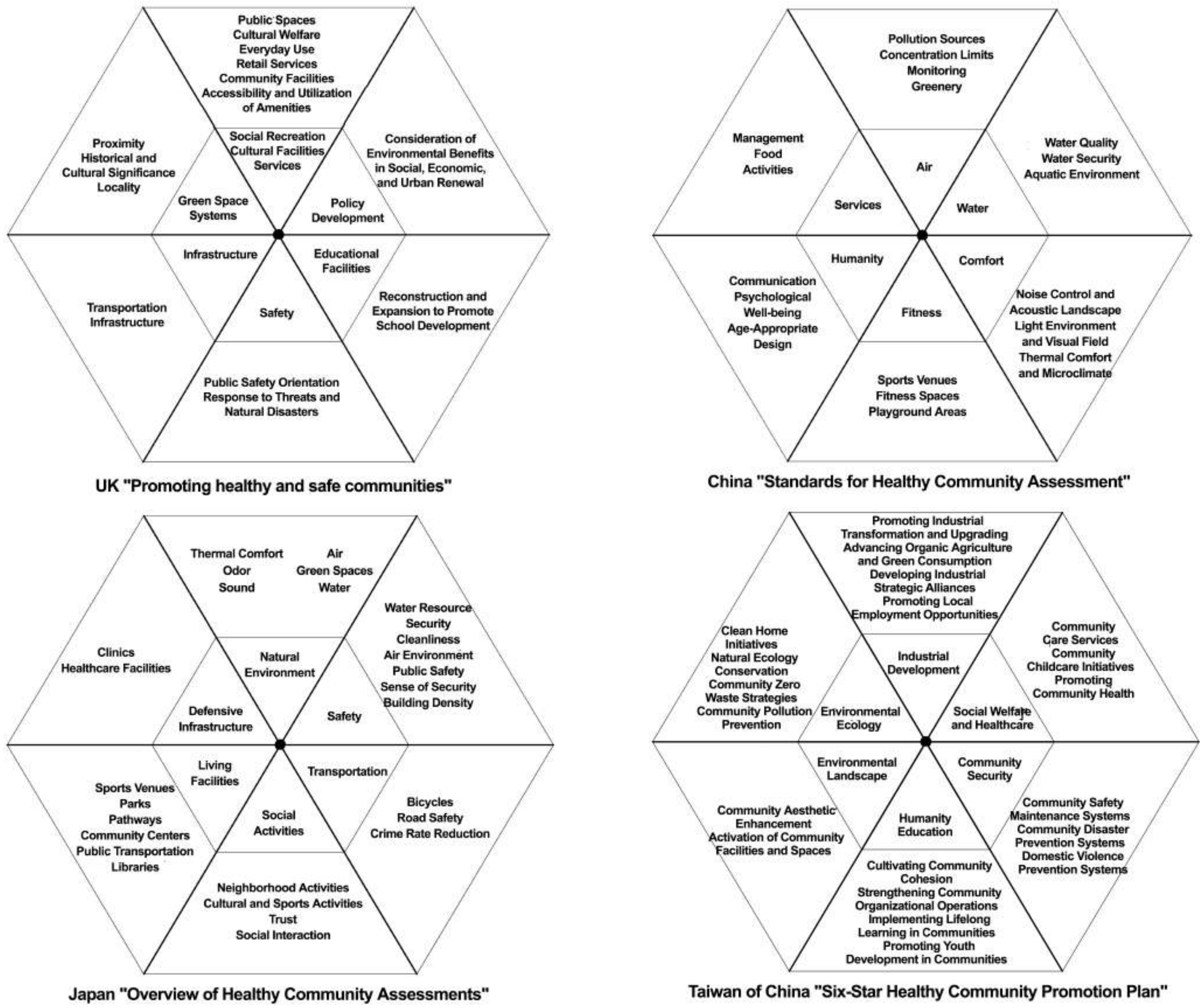


Figure 1 Comparative Analysis of the Content of Healthy Communities Domesticallyand Internationally

Table 1 Overview of healthy community standards in domestic and international contexts

	United States	Canada	Japan	United Kingdom	China	Taiwan of China
Name	WELL Health-Safety Rating	Guidelines for Healthy Community Practices	Overview of Healthy Community Assessments	Promoting Healthy and Safe Communities	Standards for Healthy Community Assessment	Six-Star Healthy Community Promotion Plan
Year	2020	2018	2013	2019	2020	2006
Research unit	IWBI (International WELL Building Institute)	CIP (Canadian Institute of Planners)	CSABEE (Council for the Sustainable Aging and Better Environment)	MHCLG (Ministry of Housing, Communities and Local Government)	China Urban Planning Society et al.	Executive Yuan
Highlights	Built Environment, Nutrition, and Fitness	Policy Mechanisms, Multi-party Collaboration	Safety Intelligence, Elderly Care and Healthcare	Engagement and Cooperation, Service Facilities	Built Environment, Humanity, and Fitness	Community Development, Multidimensional Consultation

The development of healthy communities in China primarily focuses on four key areas: the establishment of planning standards, enhancement of the physical environment, social governance, and theoretical research. For instance, in terms of planning integration, Shanghai's "15-Minute Community Life Circle Planning Guidelines" provide guidance on improving built environment quality, addressing indoor environments, city slow traffic systems, public interaction spaces, and fitness areas. Additionally, these guidelines set standards for health service facilities such as health service centers and rehabilitation centers [10]. The "Healthy Community Evaluation Standards" developed by organizations like the Chinese Society for Urban Studies emphasize that, beyond basic functions, healthy communities must offer a healthy environment, facilities, and services, thereby enhancing health performance[11]. Chinese Taiwan's "Six-Star Healthy Community Promotion Plan" covers six aspects: Industrial development, social welfare and healthcare, community safety, humanity education, environmental landscape, and ecological conservation[12], promoting a self-directed community-building model. In terms of enhancing the physical environment, cities such as Suzhou, Shanghai, and Hangzhou have made progress in constructing healthy communities as a vital component of healthy urban development[13]. Regarding social governance, Chengdu focuses on resident needs, utilizing resources from healthcare, the health industry, and the internet plus to innovate community governance models. In the renovation of old urban communities in Chengdu, models for livable environments, cultural activities, business offices, and tourism consumption have been developed[14]. In Taipei, a community has engaged in long-term empowerment efforts, involving professionals in health assessments to gauge resident preferences. This community has integrated local resources to establish organizations focused on chronic disease management and reading classes for mothers, playing a significant role during the SARS outbreak[15]. Diverse grassroots negotiations and the establishment of grassroots-community networks have fostered bottom-up self-driven construction initiatives. Theoretical research on healthy communities encompasses content refinement, governance systems, and strategy formulation. The concept has been increasingly delineated across macro categories of physical, economic, and social environments[16], as well as six dimensions: housing, environment, facilities, transportation, society, and activities[17]. Evaluations of health performance have focused on sustainability, balance, and quality, encompassing six target areas: vitality, carrying capacity, development capacity, coordination, resilience, and cyclical capacity[18]. Community governance plays a crucial role in healthy communities. Researchers like Yuan Yuan propose collaborative governance mechanisms among diverse parties in response to public health crises[19]. Zhang Tianyao suggests institutional frameworks for healthy community construction from three perspectives: institutional guarantees, collaborative networks, and support systems [20]. Furthermore, strategies for building healthy communities have expanded beyond physical space to focus on specific groups, such as children, women, and the elderly. Under the theme of "age-friendly healthy communities," Yuan Yuan and colleagues discuss strategies for fostering these inclusive environments[21-23].

Current research on healthy community theories and standards in China has achieved notable progress, primarily focusing on enhancing the physical environment. However, there is limited guidance on promoting healthy lifestyles and insufficient exploration of operational maintenance systems, resulting in unclear construction directions. Additionally, further development is needed in areas such as public health, medical resources, and health services. In scene theory, studies indicate that health-related comforts within communities remained largely unaffected during the Great Depression, underscoring the enduring importance of health as a community need. Community scenes have long been a focal point of scene theory research. On one hand, they reflect the collective needs of residents, indicating new directions for community vitality; on the other, applying scene theory to community development can shape the specific values and lifestyles of community members, thus promoting overall community growth. Therefore, it is both necessary and feasible to apply scene theory to the construction of healthy communities. How to refine the content and operational systems of healthy communities based on this foundation, in order to meet current demands for health and well-being, requires further exploration in both theoretical and empirical research. This paper advocates for a new perspective through the lens of scene theory, respecting existing standards and guidelines while investigating the construction of healthy communities. The goal is to guide healthy lifestyles and inform design practices. By analyzing the relationship between the environment of healthy communities and the behaviors of participants, this study identifies the essential components and scenes of healthy communities. Additionally, it conducts a comparative analysis of typical standards for healthy communities both domestically and internationally, thereby offering differential enhancements to the construction content and operational systems of healthy communities.

1 Scene theory and its implications

1.1 Scene theory

In the post-pandemic era, health and well-being have emerged as essential aspirations for the public in pursuit of a better quality of life. Beyond existing research on aesthetics, vitality, and culture, health and well-being represent a new trend in scene studies. As previously mentioned, the current development of healthy communities requires enhancement in operational systems and construction directions, which is closely linked to the social organizational forms underlying the physical space. Scene theory offers a fresh perspective for the construction of healthy communities. Terry Nichols Clark and Daniel Aaron Silver have proposed the Theory of Scenes, which analyzes the natural and social attributes of urban space, integrating cultural and aesthetic dimensions within a sociological framework[24,25]. This approach facilitates healthy communities to focus not only on physical spaces and material production, but also on the underlying social organizational forms, which is particularly essential in the current development of healthy communities.

Scenes are defined as social spatial units where people congregate, encompassing cultural and aesthetic characteristics specific to particular areas. They reflect the lifestyle and consumption behaviors of residents, encapsulating the emotional atmosphere of a place. In the theory of scenes, Clark emphasizes that the most suitable unit for analyzing scenes is the community, rather than broader categories such as nations, provinces, ethnicities, or cities and metropolis, because communities can effectively avoid overly macro perspectives while simultaneously reflecting significant distinctions[26]. Thus, healthy communities can be viewed as the "cellular engineering" of healthy cities, serving as the fundamental social spatial units for the creation of healthy scenes, underscoring the rationale for applying scene theory to healthy communities. Consequently, by utilizing the tools and perspectives of scene theory, it is essential to incorporate this framework into the development of healthy communities, emphasizing the significant roles of social organizational forms, cultural activities, and service facilities in guiding the health behaviors of community residents.

1.2 The inspiring role of scene theory in the development of healthy communities

1.2.1 Guiding residents toward healthy lifestyles

Guiding residents toward healthy lifestyles is the primary objective and core of constructing health scenes within communities. Public behavior, as a crucial component of scenes, is influenced by the surrounding environment. Specific health scenes foster a sense of belonging and identity among individuals, providing direction for those with health needs. A human-centered approach in healthy communities addresses the diverse and individualized health demands of residents, encouragingthem to make healthy choices throughout their daily routines and thereby promoting positive health behaviors. This demand-driven focus emphasizes the enhancement of the physical environment, the implementation of specialized community infrastructure, and the realization of intelligent community management.

1.2.2 Matching amenities with community health needs

As the demand for healthy living continues to rise, the spatial applications in China remain relatively limited, and corresponding facilities and services require innovation. Previous efforts in healthy community construction have largely concentrated on improving building systems related to air and water quality[27], while attention to the quality and environmental sustainability of the indoor built environment has also been significant[28]. However, aspects such as public services, scene design, and specialized facilities have not adequately addressed residents' needs. For example, many community public spaces lack professionally designed health activity facilities, and the design of community streets and green spaces often overlooks health-oriented landscape considerations. Additionally, the placement of facilities does not sufficiently promote healthy lifestyles. The design of pedestrian systems is often inadequate, failing to effectively encourage social and health-related activities among residents. Insufficient public facilities, a lack of age-friendly designs, and inadequate provision for all age groups, coupled with insufficient public health and medical facilities, highlight the need for enhanced safety and resilience measures.

Scene theory facilitates the precise alignment of amenities with community needs. Amenities are those services and commercial offerings that provide users with pleasure and possess market value, manifesting in facilities, activities, and services. The accurate matching of different amenity elements creates diverse scenes that attract specific demographics and foster particular values and cultural sentiments. In healthy communities, amenities may include community lounges that promote social interaction, markets and supermarkets that provide healthy food options, health facilities catering to all age groups, digital smart facilities, and pharmacies. High accessibility to activity facilities can stimulate habitual use among residents. Moreover, public environments should actively mitigate health risks, integrating Internet of Things (IoT) technologies to enable seamless health monitoring. The synergy of logistics and internet technologies can enhance service delivery, while the incorporation of technological products into healthy environments can facilitate visible interactions.

1.2.3 Intrinsic motivation and new urban dynamics

Scene theory underscores the significance of meaningful social organizational forms. Within a top-down planning framework, health scenes foster intrinsic motivation within communities, encouraging individuals to gather and integrate. This combination of amenities and distinctive activities cultivates a sense of belonging and nurtures grassroots cohesion. Scenes stimulate consumer behavior, intertwining cultural and aesthetic elements to provide residents with enjoyable experiences thatfoster connections with others and themselves. By constructing healthy communities, there is an opportunity to upgrade facilities and spaces, targeting new business models in health, sanitation, sports, wellness, education, food, and agriculture. The spatial interfaces embedded within communities can create new employment opportunities and enhance wages, thereby driving new urban dynamics.

2 Healthy community scenes through the lens of scene theory

From the perspective of scene theory, the objective qualities of amenities and subjective values can be harmoniously integrated. Applying scene theory to healthy communities will establish a new academic language that closely connects physical facilities and environments with the behaviors of individuals within the community, ultimately fostering a symbiotic integration of health values.

In existing operational frameworks for healthy communities, entities such as street offices, community party committees, neighborhood committees, and property management companies play crucial roles in organization and service delivery, particularly in community health responses. Scene theory emphasizes empowering residents in community management, enabling more individuals to engage in self-improvement while accommodating a broader range of stakeholders for collaborative discussions aimed at achieving sharedobjectives[24]. Therefore, in the operational management of healthy community construction, it is essential to leverage the proactive agency of residents as key participants. This involves mobilizing residents to collaborate with other partners and coordinating diverse professional resources—ranging from individual residents to the formation of resident communities, transitioning from passive management to active participation, and evolving from fixed agendas to dynamic activities.

To identify specific directions for constructing healthy scenes, this analysis begins with the five dimensions of scene composition: 1) Community Neighbors: the interactions within community spaces; 2) Physical Structures and Amenities: the specific physical environments or locations where people gather; 3) Diverse Populations: participants in the region, categorized by multiple dimensions such as ethnicity, education, age, and gender; 4) Distinctive Activities: events that reflect local characteristics; 5) Values and Cultural Identity[24,25]. Based on the definition and evolving context of healthy communities in China, and in consideration of the country's unique conditions, this study applies scene theory to propose a sub-scene system for healthy communities. The translation of healthy community elements is structured around these five dimensions, leading to the identification of five categories of elements for healthy communities and further subdivides them into sub-scenes. This approach allows for a comprehensive consideration of spatial behaviors, in terms of their construction, across four key dimensions such as people, physical space, behavioral activities, and cultural significance: 1) Residents and Collaborators: Populations primarily consisting of residents, along with those involved in planning, construction, and operational management of the healthy community; 2) Community Physical Space: Encompassing healthy environments, healthy living, and healthy transportation; 3)Health Service Facilities: including health services, health facilities, and sanitation; 4) Health Activities; 5) Community Values: Healthy society and health policies (Figures 2-4).

2.1 Residents and collaborators

The concept of a healthy scene is intrinsically linked to specific populations, with its definition contingent upon the characteristics of these groups. Residents and participants form the core of a healthy community, encompassing both individual units and collectives predominantly composed of residents. They contribute to the diversity of the community and foster a positive atmosphere, which attracts potential residents and encourages the adoption of healthy lifestyles.

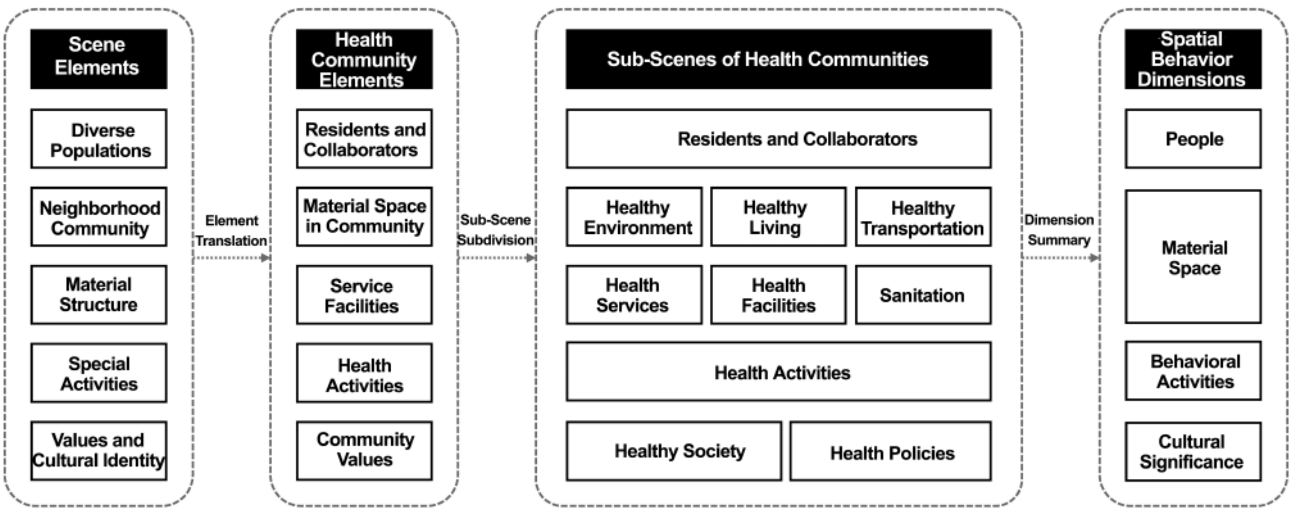


Figure 2 Translation process of scene elements in healthy communities

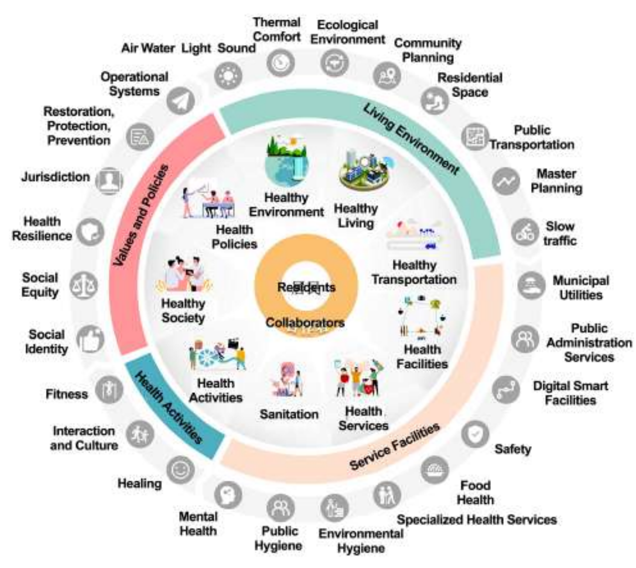


Figure 3 Relationship diagram of healthy community elements and sub-scenes

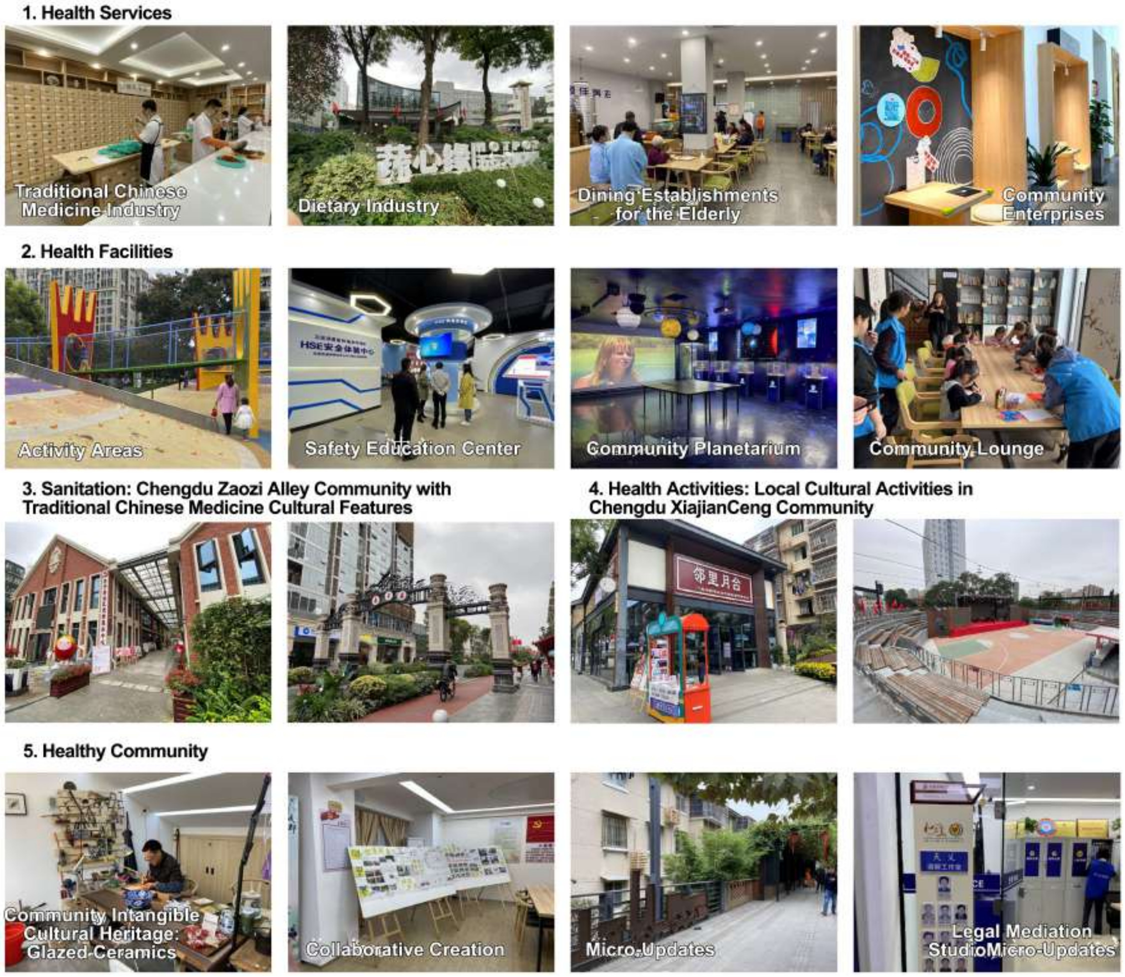


Figure 4 Case studies of healthy community sub-scenes

2.2 Living and environment

(1) Healthy environment.On one hand, a healthy environment includes physical factors such as air quality, water quality, acoustic conditions, and thermal comfort. Maintaining these aspects is foundational to other health-related scenarios, including exercise, mental restoration, and healthy diet[29,30]. For instance, utilizing physical sensors to gather dynamic environmental data within the community can be uploaded to a big data processing platform, enabling timely interventions to enhance and maintain the environment. On the other hand, ecological factors and biodiversity are crucial. Protecting community gardens and green spaces, as well as creating indoor and outdoor environments that are conducive to nature, significantly contribute to the promotion of a healthy community[31].

(2) Healthy living.Healthy living encompasses community planning and residential spaces. Harmful building materials, overcrowded housing conditions, and unsafe structural designs pose significant threats to mental well-being. Inappropriate site selection and architectural design can foster crime and vandalism. Effective community planning should integrate functional amenities, environmental design, and patterns of openness and sharing, emphasizing public spaces, green systems, and mixed-use development. Within residential spaces, optimizing floor plans, incorporating health monitoring rooms, and designing circulation routes facilitate health management. Enhancements in indoor design, such as improved ventilation systems and water supply infrastructure, contribute to overall health. Building upon the principles of healthy housing, it is essential to create stress-reducing and therapeutic living environments.

(3) Healthy transportation.Healthy transportation includes public transit, overall planning, and non-motorized transport. A multi-tiered public transportation system should be established, featuring well-planned pedestrian

grids, suitable community roadways, and efficient parking systems. The design and integration of bicycle routes and pedestrian pathways should be prioritized, incorporating them into urban greenway planning. Furthermore, it is crucial to develop and manage a comprehensive community logistics system.

2.3 Service facilities

(1) Health services. Health services encompass both foundational and developmental aspects. Foundational services include safety and food health, while developmental services build upon these foundations to provide specialized health services targeting key demographics. Health services operate through various models, including community welfare, commercial activities, and support initiatives, serving as the final outlet for the health industry's marketization within healthy communities.

Safety measures include the implementation of comprehensive security systems leveraging digital technologies, such as facial recognition for contactless entry and robotic food delivery.

Food health encompasses various elements, including cultivation, sales, and education. Examples include urban farming initiatives, integrated online and offline sales, direct-from-farm produce markets, culinary gardening courses, and dining options tailored for the elderly.

Specialized health services focus on vulnerable groups such as women, children, and the elderly, advocating for personalized approaches to alleviate sub-health conditions. For instance, medical and wellness services for seniors may include exercise rehabilitation and physical therapy; women and children-focused initiatives might feature entrepreneurship programs, maternal and infant care, and early education courses; while services for young and middle-aged adults could involve physical therapy, health product retail promotion, and health education. Additionally, community public spaces can serve as incubation platforms for local enterprises, providing essential office spaces.

(2) Health facilities. Health facilities encompass municipal utilities, public service amenities, and digital smart infrastructures. Building upon the optimization of energy and water resource supply, there is a need to enhance cultural facilities and community services tailored for all age groups. Examples include parent-child classrooms, community gathering spaces, health libraries, pop-up health shops, child-friendly amenities, safety education facilities, and small community art exhibition spaces. Additionally, the effectiveness of big data centers and smart business facilities in managing and promoting residents' health is crucial. However, the collection, storage, analysis, and sharing of health data raises significant privacy concerns, necessitating the establishment of regulatory frameworks and legal standards.

(3)Sanitation.Sanitation comprises environmental hygiene, public health, and mental health. Environmental hygiene advocates for practices such as waste sorting, pet management, and composting. Public health serves as the foundational safeguard for healthy communities. On one hand, it is essential to ensure an adequate proportion of general practitioners within the community, enhance the accessibility of community health service centers, and improve access to higher-level medical resources, such as establishing general practice clinics, offering online consultations, and facilitating visits by top-tier physicians to the community. On the other hand, promoting health record management, health education, and the establishment of smart clinics through health facilities is crucial. Additionally, ensuring mental health involves improving psychological counseling services, emphasizing environmental psychology in design, and encouraging neighborhood mutual aid and community volunteer services.

Integration of surrounding medical, research, and health resources is also essential. An example is the Zao Zi Lane community of Chengdu's Jinniu District, proximity to the Traditional Chinese Medicine University and its affiliated hospital. In the process of renovation and upgrading, it is vital to promote the integration of communities with hospitals and universities through open blocks. Establishing Traditional Chinese Medicine (TCM) innovation hubs can facilitate TCM wellness, beauty, and rehabilitation therapies. Additionally, introducing specialty TCM brands, such as health-focused hotpot restaurants and TCM clinics, enhances community offerings. Services such as health record inquiries, health assessments, and expert consultations should be provided to residents. By guiding businesses toward transformation and encouraging multi-party participation, a culturally distinctive TCM-themed district can be developed.

2.4 Health activities

Health activities encompass healing, social interaction, cultural engagement and fitness. By leveraging healthy environments, spaces such as natural oxygen bars and therapeutic water features can be developed. Shared facilities, including community libraries, gathering spaces, performance stages, after-school programs, and entrepreneurial hubs, facilitate social interactions and cultivate a vibrant community culture. Artists can organize activities such as "Childhood Secrets" and "Claiming Community Flora" to strengthen residents' sense of belonging. Designing fitness areas and playground spaces can involve utilizing underused spaces, such as elevated floors, undeveloped green areas, and vacant sales offices. Building upon healthy transportation, facilities like walking paths and community fitness centers can integrate virtual fitness equipment, promote fitness sharing, and host family competitions and recreational events to encourage physical activity.

Locally culture-distinctive activities form a crucial part of health activity scenes. For example, the cultural activity center in Chengdu's Xiajiancao community creates a hub for courtyard culture, hosting various Sichuan cultural events—including Chinese Hanfu (traditional clothing of the Han Chinese), paper-cutting, weaponry exhibitions, Sichuan opera, and the Face-changing Performance—with live-streaming capabilities for online and offline cultural integration.

2.5 Values and policies

(1) Healthy society. A healthy society encompasses social recognition, equity, and resilience. It involves uncovering community history and culture, protecting industrial, cultural, and heritage sites, and fostering neighborhood harmony through micro-community updates. Engaging retired professionals to provide legal counsel and mediation services enhances community support. Organizing co-creation initiatives boosts resident participation and strengthens their sense of community identity.

Preparedness, recovery, and emergency management in the context of healthy communities, along with disease control and the flexible utilization of spatialresources[32], ensure that healthy communities can effectively respond to public health emergencies.

In the revitalization of aging neighborhoods, leveraging existing building stock while seeking policy support to attract investors is essential. Through spatial exchanges or compatible uses, transformation and upgrades can achieve a balance among diverse stakeholders. For instance, the Xiajian Cang community in Chengdu's Chenghua District repurposes former industrial sites, such as an old locomotive factory, into a community service center, creating a neighborhood hub that preserves industrial heritage while providing an incubation platform for local enterprises and fostering new community scenes.

(2) Health policy mechanisms. Health policy mechanisms encompass governance, restorative protection and prevention, and operational frameworks. To facilitate the renovation of aging neighborhoods, establishing community foundations is essential to mobilize funding. Encouraging resident participation is vital, fostering a community partnership model that promotes collaboration between businesses and the community, thereby enhancing local agency and stimulating community employment.

3 Health scene analysis

Existing domestic and international evaluation standards for health communities vary in focus and contribute differently to guiding the development of healthy communities. The nine sub-scenes of healthy communities serve as a unified measurement tool to address discrepancies in the content of healthy community development across different contexts. The evaluation criteria reflect, in an objective and rational manner, the directions that governing bodies believe require enhancement and attention in healthy communities.

In contemporary healthy community development, these standards have been adopted as benchmarks for practitioners to aspire to. Compared to national planning guidelines and regional action frameworks, evaluation standards exert a more direct influence on the operation and implementation of healthy communities. While they may not capture the diversity of specific projects, they provide a macro-level significance. The "Health Community Evaluation Standards" compiled by the Urban Planning Society of China and the "WELL Health Community Standard" developed by the International WELL Building Institute feature more established and representative evaluation metrics, each with a robust calculation system. Therefore, a comparative analysis of these two standards in relation to the sub-scenes of healthy communities is warranted.

Table 2 Scores and Weights of the Domestic Version of Standards for Healthy Community Assessment

Categories \ Evaluation indicators	Air α1	Water α2	Comfort α2	Fitness α4	Culture α5	Service α6	Innovation α7
Maximum score (α)	100	100	100	100	100	100	10
Weight (β)	0.175	0.185	0.185	0.175	0.205	0.075	0.1

For instance, using the "Health Community Evaluation Standards" as the analytical framework, the categories of air, water, comfort, fitness, culture, and services are each assigned a score of 100, while the innovation category is awarded additional points, capped at a maximum of 10. The weights of each indicator and the total score are presented in Table 2. A comparison is conducted using the nine-scene model framework established earlier, analyzing the correlation between these standards and the nine scene models (Table 3). The emphasis index γ of the "Health Community Evaluation Standards" on the nine scene models is calculated as $\gamma = Q \times \beta$ (Table 4).

Table 3 Indicators' Meanings and Correspondence with Nine Sub-scenes in the Domestic Version of Standards for Healthy Community Assessment

Scene model	Indicators from the "Healthy Community Evaluation Standards"						
	Air Q1	Water Q2	Comfort Q3	Fitness Q4	Culture Q5	Service Q6	Innovation Q7
Healthy environment	74	100	52				
Healthy living			48				3.53
Health facilities					73		
Healthy transportation					10		
Health activities				100		20	
Healthy society					5		2.94
Public health	26				12	33	
Health services						43	3.53
Health policies						4	

Table 4 Importance Index of the Nine Sub-scenes in the Domestic Version of Standards for Healthy Community Assessment

Scene model	Indicators from the "Healthy Community Evaluation Standards"							
	Air	Water	Comfort	Fitness	Culture	Service	Innovation	γ
Healthy environment γ1	13	18.5	9.62					41.07
Healthy living γ2			8.88				0.35	9.233
Health facilities γ3					15			14.965
Healthy transportation γ4					2.05			2.05
Health activities γ5				17.5		1.5		19
Healthy society γ6					1.03		0.29	1.319
Public health γ7	4.55				2.46	2.48		9.485
Health services γ8						3.23	0.35	3.578
Health policies γ9						0.3		0.3

Using the same methodology, an analysis of the "WELL Health Community Standard" is conducted, accompanied by a visual representation (Figure 5). Within the "WELL Health Community Standard," significant weight is placed on healthy environments and healthy living, followed by healthy societies. Conversely, the "Health Community Evaluation Standards" emphasize healthy environments, health activities, and health facilities. Both standards focus on enhancing the health-oriented performance of the built environment, relying on the built environment to facilitate social activities.

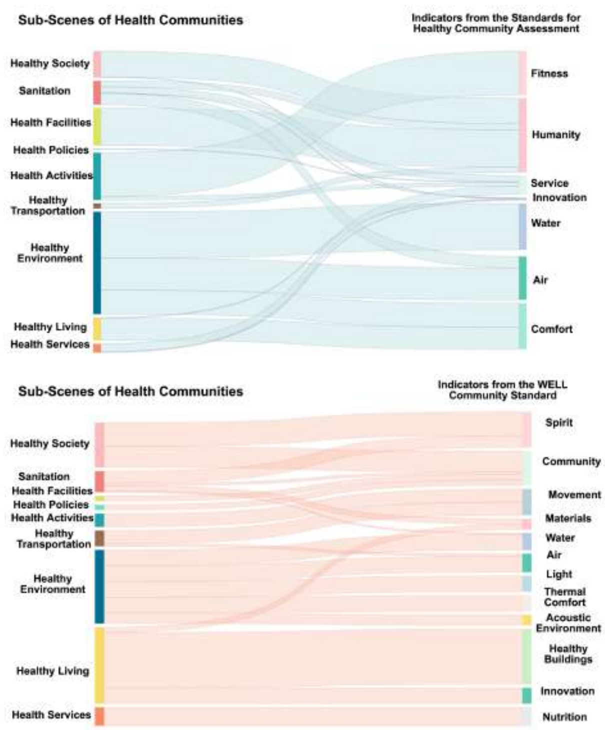


Figure 5 Comparison between Sub-scenes of Healthy Community and the Indicators of Existing Standards

However, both standards address health services and health policies to a lesser extent, as they are classified as standards rather than guidelines. The most significant difference between the two lies within the healthy living sub-scene, where the "WELL Health Community Standard" demonstrates notably higher attention. This heightened focus is attributable to the emphasis that the research bodies associated with the "WELL Health Community Standard" place on health-certified and green-certified buildings, which are weighted more heavily in their assessment criteria.

Building upon existing standards and guidelines for health communities, the enrichment of scene theory can enhance the discourse surrounding the development of healthy communities, facilitating a more visualized representation of these environments. For instance, beyond their role as mere "residents," individuals in healthy communities engage in life as consumers, encompassing activities such as working, resting, and seeking medical care. This shift emphasizes the cultural health values present in specific health scenarios. Health facilities and services play a crucial role in promoting resident consumption, contributing to vitality and positive health experiences, which in turn fosters high-quality community development. In guiding community development, it is essential to build upon existing standards and guidelines by advancing the sub-scenes related to health facilities and services, as well as refining health service and policy frameworks.

4 Health community development from the perspective of scene theory

Through existing theoretical research and comparative studies of established standards, scene theory enriches the human-centric nature of health community scenarios and advances theoretical practices, providing a visual direction for community development. This focus on content and operational frameworks will promote healthy behaviors among residents within health communities.

4.1 Health Community Scene Development Toolkit

The Health Community Scene Development Toolkit aims to leverage the aforementioned five elements and nine sub-scenes to activate existing and potential comforts within the community, based on the needs of residents and collaborators. This approach will facilitate diverse health activities and foster social values aligned with the principles of healthy communities. The toolkit's database includes both domestic and international case studies of community development practices, as well as policies, guidelines, directives, and evaluation standards related to healthcommunities, providing essential case support for health community construction (Figure 6).

(1) Collaborative needs assessment and blueprint development: Initially, demographic profiling and basic surveys of residents and collaborators will be conducted. This involves collecting data on residents' age, education level, and occupation

through questionnaires, interviews, and focus groups to understand their activity types, health needs, and satisfaction with community spaces and activities. Subsequently, an investigation of the community's physical spaces and service facilities will be undertaken, focusing on enhancing the quality of the physical environment within the three sub-scenes: Healthy environment, healthy living, and healthy transportation. Simultaneously, emerging technological methods, such as new urban science, will be employed to evaluate health service facilities. This will result in a comprehensive checklist and indicators for health services, health facilities, and health hygiene, addressing community shortcomings and ensuring an appropriate number and scale of service facilities within a reasonable living circle.

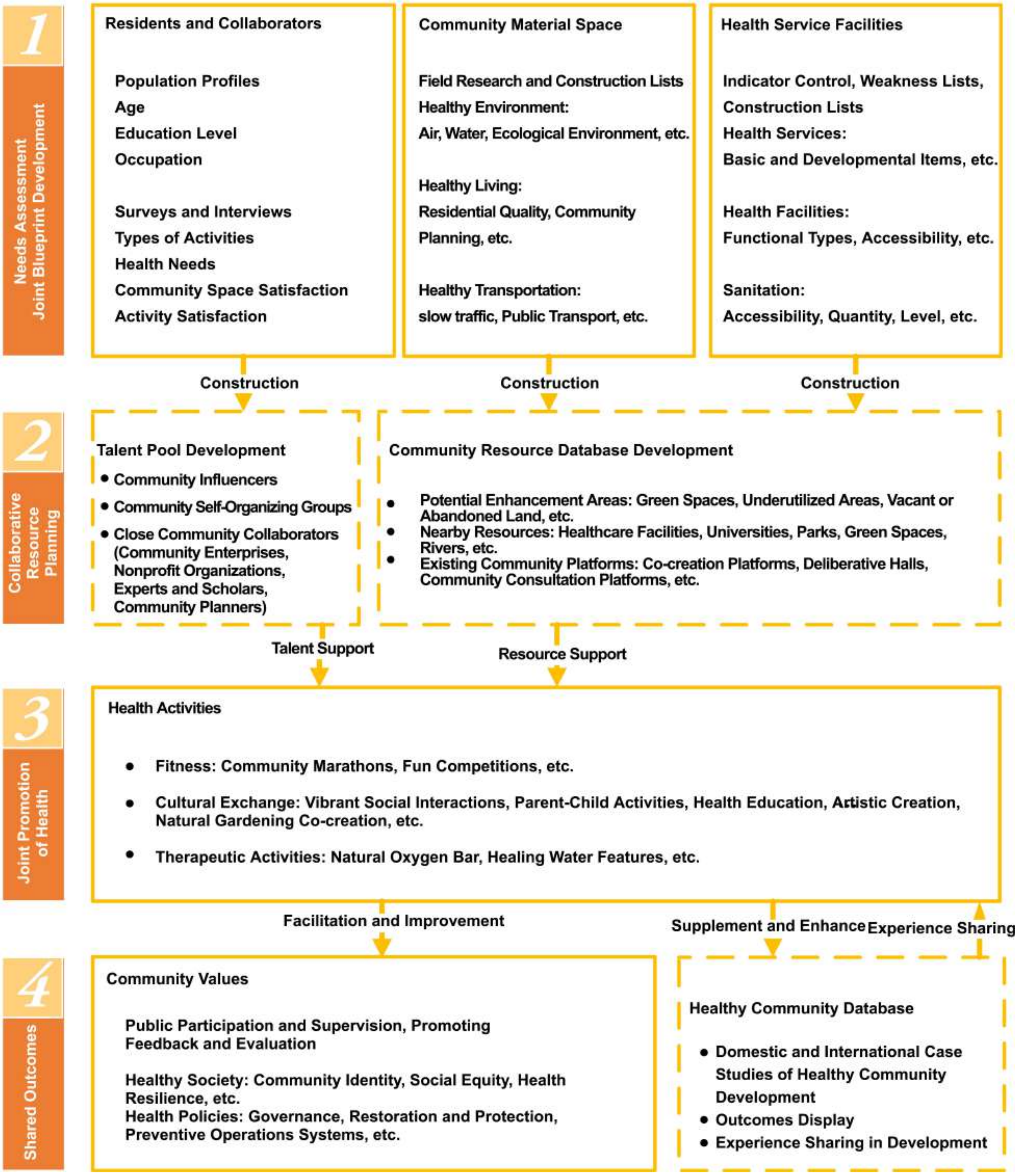


Figure 6 Toolkit for Building the Scenes of Healthy Community

(2) Collaborative resource mobilization: Based on surveys of residents and collaborators, the process involves identifying community talents, self-organized groups, and close collaborators to establish a talent pool for health community development. Collaborators include community enterprises, nonprofit organizations, experts, scholars, and community planners. Additionally, through the investigation of the community's physical spaces and health service facilities, potential areas for enhancement will be identified, such as community green spaces, underutilized corners, and vacant or abandoned land. This phase also includes integrating nearby resources—such as healthcare facilities, universities, parks, green areas, and rivers—to develop the health community, while linking to existing community platforms such as co-creation platforms, deliberative halls, and community negotiation spaces.

(3) Collaborative promotion of health: In response to the community's specific context, distinctive health activities that cater to different residential types will be developed, encompassing aspects of health, social interaction, culture, and healing. Throughout this process, the established talent pool will be leveraged to seek support, while the community resource database will be accessed for resource assistance. Additionally, the health community database will be explored for benchmarking case studies that can inform development.

(4) Shared outcomes: The development process will emphasize public participation and oversight, facilitating evaluation and feedback mechanisms. For example, the use of mobile applications and other technological platforms will enable the collection of opinions and feedback from the health community development process both online and offline. Results of the development will be showcased, experiences shared, and the existing health community database enriched. This approach aims to advance the creation of healthy social and policy environments, stimulating development across provinces and cities nationwide, and promoting the integration of health community development frameworks into national land-use planning systems.

4.2 Operational system for diverse participation in health communities

The realization of health communities relies on the collaboration of various organizations and populations within the community, encompassing both macro-level government planning and grassroots participation from diverse urban forces. Within the nine sub-scenes of a health community, a robust model of diverse participation emerges, centered on residents and the community, integrating a variety of collaborators. This includes expertise in architectural planning, social sciences, and data analytics, which will serve as foundational support for the advancement and implementation of health communities (Figure 7). Diverse participation facilitates consumption and drives economic development in the construction of health scenarios, while simultaneously guiding residents toward the formation of healthy behaviors and fostering the emergence of a healthy society.

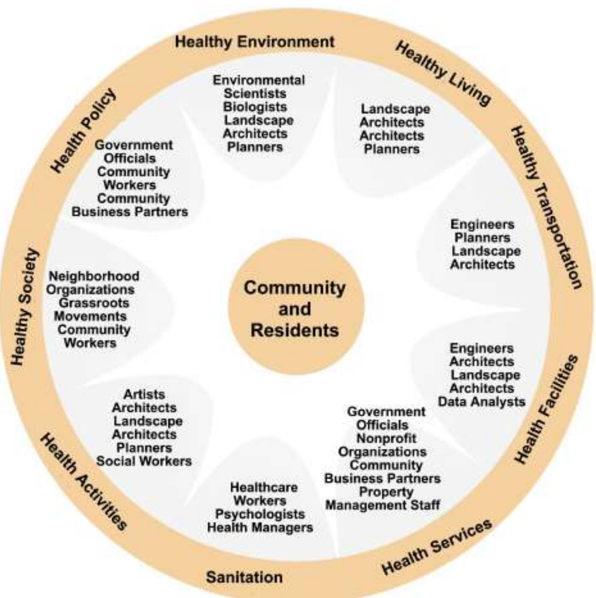


Figure 7 Community, residents and collaborators

The approach advocates for government leadership to secure policy formulation and funding support, while gradually introducing market-driven entities to cultivate new business models for sustainable development. Collaboration with community organizations enriches cultural life and establishes a cooperative mechanism for diverse participation. For example, in Chengdu's Hemei Community, a social enterprise community service station was established. Through clear delineation of responsibilities among the management committee and social enterprises, a service network was created based on market operations and nonprofit organization models, leading to the development of a new operational model for community complexes.

Conclusion

This analysis of the current state of health community research in China summarizes the definitions and developmental trajectories of health communities both domestically and internationally. It conducts a comparative review of the forefront issues, research entities, and conceptual frameworks surrounding health communities worldwide. Utilizing scene theory, the relationship between the material environment of health communities and the behavioral patterns of their inhabitants is explored. By applying the tools of scene theory, this study identifies five essential elements of health communities—residents and collaborators, community material spaces, health service facilities, health activities, and community values—along with nine sub-scenes categorized under these elements: Healthy environment, healthy living, healthy transportation, health services, health facilities, health hygiene, health activities, healthy society, and health policy. A comparative analysis of typical standards for health communities, both domestic and international, is conducted using these sub-scene tools, further enriching the content of health community development and refining the scene content system. The analysis emphasizes the core of these sub-scenes—residents and collaborators—and proposes an operational system characterized by diverse collaborative participation.

Health and well-being represent significant demands in contemporary settings and are critical areas of focus for communities in the post-pandemic era. Future theoretical research should integrate more health community practices, fostering interdisciplinary studies across planning, medicine, psychology, and sociology, ultimately leading to the formulation of improved guidelines for health community development based on existing standards and frameworks.

Figure and table sources

Figure 1, Table 1: Compiled and illustrated based on information from references [2], [4], [5], [8], [11], and [12].

All other figures and tables were created or photographed by the author.

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Research on the Measurement and Influencing Factors of Street Vigor in Historic District: A Case Study of Wenming Street Historic District in Kunming

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ABSTRACT: Analyzing the distribution characteristics of the vitality of traditional streets and its influencing factors is of great significance to the sustainable development of historic streets. Taking the Wenming Street Historic District in Kunming City as an example, combining field research and online open-source data to construct a street vitality evaluation index system for historic districts, measuring the distribution characteristics of its street vitality, and analyzing the impact of built environmental indicators on street vitality through stepwise multiple linear regression. Studies have shown that: (1) The street vitality of Wenming Street Historic District presents a spatial distribution characteristic of high in the southeast and low in the northwest, and the distribution of vitality is obviously uneven; (2) accessibility and functional density are significantly positively correlated with street vitality, and street length is significantly negatively correlated. The order of influence is accessibility> functional density> street length. On this basis, the strategy of optimizing the vitality of the streets in the historic districts is proposed in order to provide a reference for the revitalization of the historic districts.

KEY WORDS: historic district; street vitality; sDNA; Wenming Street

Introduction

As a crucial means of promoting the sustainable development of historical districts, vitality revitalization has consistently been a central concern in the conservative and renewal practices of historical districts[1]. In recent years, the concept of dynamic preservation of historical districts has gained significant recognition[2], with moderate commercial development and renovation deemed effective strategies for revitalizing urban vitality[3]. However, it is evident that, in the current process of prudent and incremental revitalization of historic districts, a considerable number of these areas exhibit a coexistence of prosperity and decline, along with an uneven distribution of vitality. Traditional streets, as essential public spaces, serve as the primary venues for interactions and activities among residents and visitors, representing the most direct manifestation of vitality levels within historical districts. This raises critical questions regarding the distribution characteristics of street vitality in revitalizing historical districts and the built environment factors influencing these characteristics.

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Research into these issues will help unveil the deeper driving mechanisms behind the distribution of street vitality, providing support for the comprehensive revitalization of historical district vitality.

Current research methods examining the impact of the built environment on behavioral activities can be categorized into three types: descriptive categorization, subjective preference assessment, and correlational analysis [4]. Early studies primarily employed an environmental behavioral framework, relying on empirical observation and classification of street environments and population activities to reveal intrinsic patterns affecting spatial vitality[5-6]. However, this approach often struggles to ascertain the specific weights of vitality influencing factors. The subjective preference assessment method typically gathers data through expert scoring, surveys, and interview records, utilizing mathematical analyses such as Analytic Hierarchy Process [7] semantic differential method[8], and factor analysis[9] to quantify the weights of various factors impacting specific populations, demanding a high sample size. Correlational analysis predominantly employs statistical methods like correlation and regression analysis to explore the interplay between spatial vitality and the built environment. Due to its objective, intuitive, and detailed characteristics, this method has gained widespread application in recent studies on street vitality. It requires foundational data reflecting vitality indicators and their components, which can be acquired through field research [10-14] or web-scraped open-source data[15-18].

In the realm of research content, current studies primarily focus on the contributions of specific elements to the vitality of historic districts[19-20]. However, it is widely acknowledged that the formation of vitality is influenced by a combination of multiple factors. In this context, Zhang Yuyang and colleagues established an evaluation system for the vitality of historical streets based on Point of Interest (POI) data and WeChat mobility heatmaps. They utilized stepwise multiple linear regression to analyze the influencing factors of vitality in the Shichahai area, highlighting the significant role of historical resources and suitable commercial formats in enhancing the vitality of traditional streets[21]. Similarly, Gao Yuan and others verified the positive effects of functional density and mixed-use development on the vitality of historical districts in Guangzhou through the integration of Baidu heatmaps and POI data[22].

In summary, while existing research has emphasized the contributions of specific elements to the vitality of historical districts, and some scholars have explored the impact of multiple factors using open-source data, several shortcomings remain: (1) Although the methods for scraping open-source data are efficient and convenient, the precision of current datasets is insufficient to support more nuanced research at the scale of historical districts; (2) Previous studies have primarily focused on "population activity density" as a measure of street vitality. However, the public life of streets is diverse and rich, necessitating a comprehensive consideration of the varied contributions of different types of public activities to street vitality.

To address these gaps, this paper examines the historical and cultural district of Wenming Street in Kunming, combining field research and open-source data to construct an evaluation index system for street vitality. This study aims to measure the distribution characteristics of street vitality, employ correlational analysis to uncover specific factors influencing this vitality, and propose corresponding optimization strategies for enhancing street vitality.

1 Research design and indicator system construction

1.1 Conceptual definition

The vitality of streets is fundamental to the vibrancy of cities[5]. While traffic thoroughfares primarily support economic vitality, streets, as venues for public activities, are closely tied to social vitality[23]. The essence of street vitality lies in the diverse activities engaged in by people within these spaces[24]. A vibrant street should cater to the varied needs and experiences of individuals from different backgrounds and age groups[11]. Thus, the "street vitality" examined in this study encompasses both the intensity and frequency of crowd activities as well as the richness of activity types.

1.2 Research scope

The historical district of Wenming Street in Kunming dates back to the Dali Kingdom, with its street pattern established during the Kangxi period of the Qing Dynasty. During this time, the area served as a hub for government offices and post stations, characterized by a strong official atmosphere. With the subsequent development of the South Gate commercial area in modern Kunming, the district became home to numerous time-honored brands such as "Fulintang," "Tongqingfeng," and "Liuhuan," gradually transforming into a gathering place for merchants. Benefiting from protective policies, the fabric and streetscape of the Wenming district have been well-preserved, featuring six main streets, including Wenming Street and Jingxing Street, along with 15 smaller alleys[25]. This research focuses on the area delineated by the "Wenming Street Historical and Cultural District Protection Plan (2012-2020)," supplemented by field investigations. The boundaries extend from Wuyi Road in the west to Zhengyi Road in the east, and from Dongfeng West Road in the south to Huashan South Road in the north, encompassing a total area of 23.26 hm^2. The study selects 26 major street segments within this area, divided by intersections, as the research subjects (Figure 1).

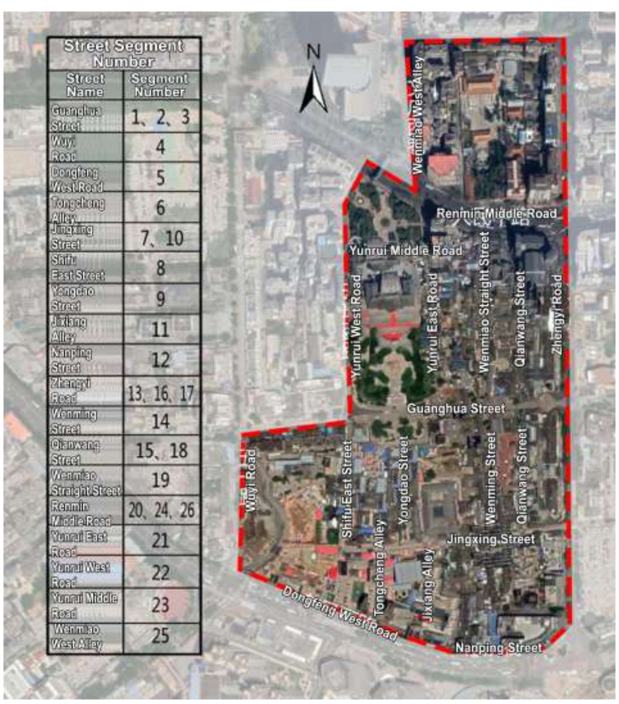

Figure 1 Study area and street segmentation

1.3 Research methodology

First, this study constructs an evaluation index system for the vitality of historical streets by integrating survey data and open-source data. Subsequently, field research and street vitality index analysis are employed to assess the distribution characteristics of street vitality. Finally, stepwise multiple linear regression is applied to reveal specific factors influencing street vitality, and targeted optimization strategies for the built environment are proposed based on the analysis results.


Figure 2 Locations of observation points

1.4 Indicator selection

Drawing on evaluation indicators proposed by relevant scholars[10-22] and considering the unique environmental elements of the district—such as local historical culture and intangible cultural heritage resources—this research develops an index system for evaluating the vitality of historical streets based on external representations and compositional factors.

The external representations of street vitality are primarily synthesized through four indicators: crowd activity density, crowd retention index, diversity of activity types, and diversity of age composition. Crowd activity density is represented by the ratio of measured pedestrian flow to street segment area. The crowd retention index is calculated as the sum of the products of weighted retention time and the number of people retained[26], with the weights determined through expert scoring. Diversity of activity types and age composition diversity are derived using an evenness index approach[11].

The compositional factors of street vitality encompass an analysis of the material spatial attributes and socio-economic characteristics of the streets. This analysis selects indicators across five dimensions: location, accessibility, functionality, interface, and facilities. The "location" is represented by the attractiveness of historical and cultural resources; "accessibility" is assessed through sDNA analysis and transportation convenience; "functionality" includes functional density and functional mix; the "interface" incorporates nine indicators reflecting the physical properties of the street; and "facilities" primarily focus on seating area ratio, billboard density, and trash can density.

1.5 Data sources

The foundational data for this study was obtained from both field research and web-scraped open-source data. Field research documented crowd activity data, street interface data, the quantity of street facilities, street scene photographs, and the distribution of historical resource points. The open-source data included street network information and Points of Interest (POI) from Baidu Maps.

Crowd Activity Data: This was recorded using a cross-sectional pedestrian counting method, categorizing age structure into five groups according to Chinese age segmentation standards: Children, adolescents, young adults, middle-aged individuals, and seniors. To minimize the impact of intersections on pedestrian flow distribution, the midpoints of the 26 streets were designated as observation points (Figure 2). Field research was conducted over four days—two clear weekdays and two clear holidays—during observation periods from 9:30 AM to 12:30 PM and 2:30 PM to 7:30 PM, with data collected every two hours for five-minute intervals.

Street Interface Data: This involved field measurements recording the length and width of streets in the Wenming district, the suitable width for pedestrian movement, the height of adjacent buildings, and the lengths of continuous street wall facades on both sides.

Street Facilities: The field survey quantified the area of seating facilities (including suitable seating areas such as tree pits, flower beds, and stones categorized as "seats"), as well as the number of billboards and trash cans.

Street Scene Photographs: After on-site investigations, specific points that could effectively reflect the overall condition of the streets were identified for photography. Photos were taken from a standing perspective at a height of 1.72 meters, aiming to authentically capture the visual experience of pedestrians engaging in street activities (Figure 3).

Distribution of Historical Resource Points: Based on the "Wenming Street Historical and Cultural District Protection Plan (2012-2020)" and supplemented by field research, the locations of 26 historical and cultural resource points were calibrated and recorded in ArcGIS according to their entrance and exit positions (Figure 4).

Vector Street Network: Baidu Maps street network raster images were scraped and then vectorized in ArcGIS according to actual connectivity.

Baidu Maps POI: Data was scraped in May 2020 using Python 3.6, categorized into five functional types: Dining, shopping, accommodation, leisure and entertainment, and life services. Based on the scale and composition of buildings on either side of Wenming Street, a buffer zone of 30 m on each side of the street centerline was established in ArcGIS, yielding a total of 1633 POI data points.

Figure 3 Street walking perspectives

sDNA is an enhanced spatial syntax program that quantifies and visualizes complex spatial relationships through algorithms, aiding research and design processes [27]. In this context, "proximity" is interpreted as the potential of a space to serve as a destination relative to others, while "throughput" reflects the potential of a space to function as a pathway. For the accessibility analysis based on crowd mobility in the Wenming district, standard metric distances of 400 m, 800 m, and 1200 m were chosen, corresponding to walking times of 5, 10, and 15 minutes, respectively, for the sDNA analysis radius.

1.6 Quantification of indicators

This section outlines the quantification of various street vitality evaluation indicators for the Wenming street block, integrating foundational data with relevant statistical methods (Table 1) to facilitate the construction of a multiple regression model.

Table 1 Evaluation index system for street vitality in historic districts

Dimensions	Characteristics	Indicators		Quantification models
Externalrepresentation of street vitality	Vitality	Street vitality index	Crowd-activity Density	Average pedestrian flow per street area
			Crowd Retention Index	Sum of the product of dwell time weight and number of visitors
			Diversity of Activity Types	Diversity of activity types calculated using the evenness index
			Diversity of Age Composition	Diversity of age composition calculated using the evenness index
Constituent elements of street vitality	Location	Attractiveness of historical resources		Total shortest distance from the midpoint of the street to various historical resource points
	Accessibility	sDNA proximity		Proximity analysis using sDNA with analysis radii of 400 m, 800 m, and 1200 m
		sDNA passage		Passage analysis using sDNA with analysis radii of 400 m, 800 m, and 1200 m
		Traffic convenience		Total shortest distance from the midpoint of the street to nearby subway and bus stops
	Functionality	Functional density		Number of Points of Interest (POI) within a 40 m buffer of the street divided by street length
		Functional mix		Functional mix calculated using information entropy, where the functional mix is represented as the ratio of the number of a specific type of POI to the total number of POIs on the street
	Interface	Street length		Length of street centerline
		Street width		Average street width
		Building height		Average height of buildings along the street
		Street aspect ratio		Ratio of average street width to average building height
		Pedestrian-friendly width		Average pedestrian-friendly width
		Continuity of interface		Total length of continuous street wall facades on both sides divided by street length
		Spatial enclosure		Spatial enclosure calculated using pixel values extracted from streetscape photos using Photoshop's histogram function, defined as wall pixel values divided by total pixel values
		Spatial openness		Spatial openness calculated using pixel values from streetscape photos in Photoshop, defined as sky pixel values divided by total pixel values
		Green view ratio		Green view ratio calculated using pixel values from streetscape photos in Photoshop, defined as greening pixel values divided by total pixel values
	Facilities	Seating area ratio		Seating facility area divided by street length
		Density of waste bins		Number of waste bins divided by street length
		Billboard density		Number of billboards divided by street length

Figure 4 Distribution of historical resource points

2 Distribution characteristics of street vitality

2.1 Analysis of survey results

The field survey provided data on pedestrian flow, age distribution, dwell time, and the variety of activities across various streets over a four-day period.

2.1.1 Distribution of crowd-activity density

Average pedestrian flows for weekdays and holidays were calculated and divided by the street area to derive the crowd-activity density distribution for these two time periods (Figure 5). Overall, the activity density during holidays significantly exceeds that of weekdays, with pedestrian concentrations peaking in the afternoon from 14:30 to 19:30 compared to the morning hours. From the perspective of average activity density, Nanping Street (Segment 12), Zhengyi Road (Segment 13), and Jingxing Street (Segment 10) ranked highest with densities of 0.175 people/m^2, 0.156 people/m^2, and 0.151 people/m^2, respectively. In contrast, Yunrui East Road (Segment 21), Yunrui West Road (Segment 22), and Wenmiao West Alley (Segment 25) exhibited sparse activity, with average densities of only 0.008 people/m^2, 0.009 people/m^2, and 0.011 people/m^2. The analysis of crowd activity density reveals a significant uneven distribution of pedestrian flow within the current block.

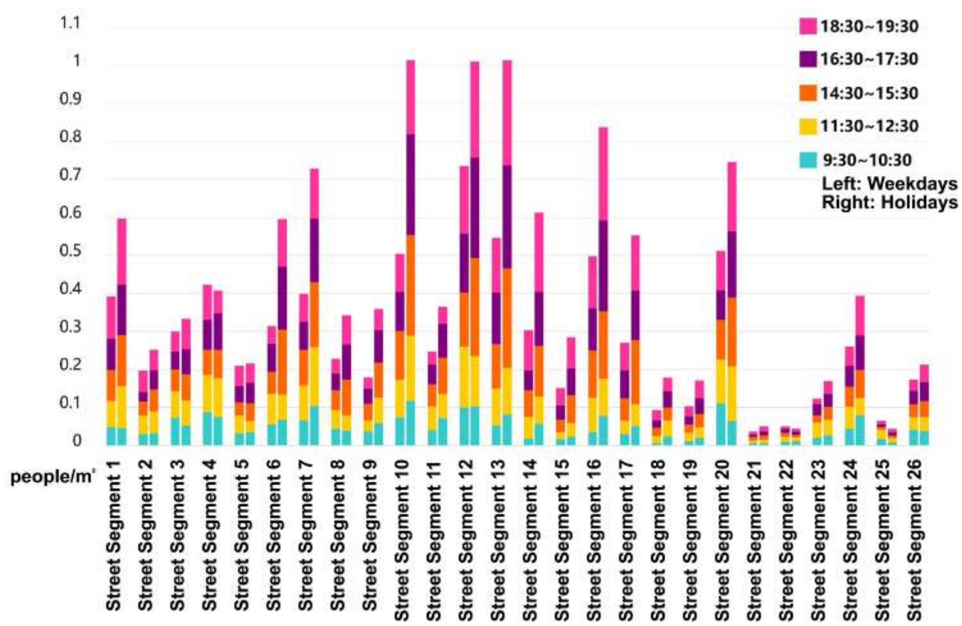

Figure 5 Crowd-activity density

2.1.2 Distribution of crowd age composition

The age composition of pedestrians reflects their preferences to some extent. Analyzing the average values from the four-day survey (Figure 6), it is evident that Zhengyi Road (Segments 13, 16, 17), Wenming Street (Segment 14), and Qianwang Street (Segment 15) have a high proportion of youth, whereas Jixiang Alley (Segment 11), Yunrui West Road (Segment 22), and Wenchang West Alley (Segment 25) exhibit a higher presence of middle-aged and elderly individuals. Observations indicate that streets with a higher proportion of youth are often lined with modern dining and entertainment venues, which attract tourists. In contrast, streets with a significant elderly population, such as Jixiang Alley, are renowned for their flower and bird markets, embodying the daily life memories of "old Kunming residents." Comparatively, streets concentrated with retail and creative commercial culture tend to attract younger demographics, while middle-aged and elderly individuals prefer to engage in activities along streets that maintain traditional functions.

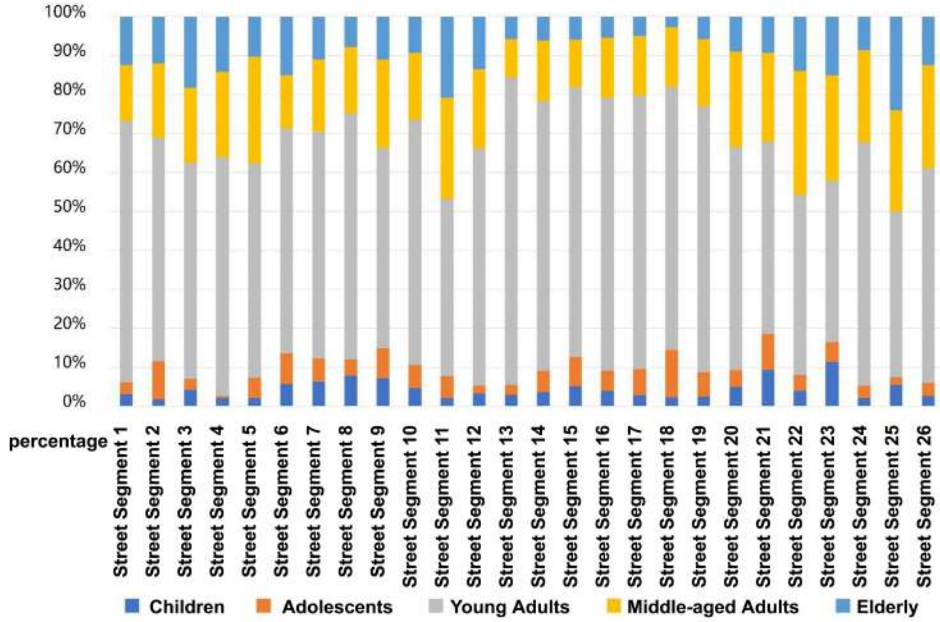

Figure 6 Age composition of the crowd

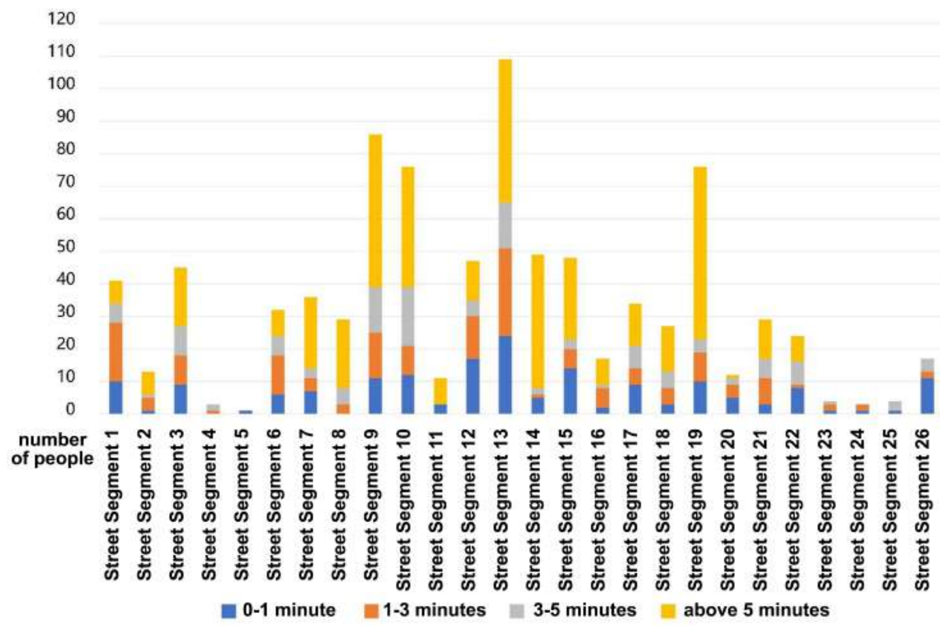

Figure 7 Crowd retention time

2.1.3 Distribution of crowd dwell time

Dwell time is another critical indicator of street vitality, calculated as the average from the four-day survey data (Figure 7). In terms of the number of people lingering, Zhengyi Road (Segment 13), Yongdao Street (Segment 9), Jingxing Street (Segment 10), and Wencheng Straight Street (Segment 19) demonstrate a significant number of individuals, with a considerable proportion staying for over 5 minutes. Field observations reveal that Yongdao Street and Jingxing Street feature numerous movable shops selling cultural goods and snacks, attracting crowds who linger to shop and explore. Conversely, Zhengyi Road and Wencheng Straight Street have commercial setups on both sides, where people gather to rest or dine. In contrast, streets like Wuyi Road (Segment 4) and Dongfeng West Road (Segment 5), which lack resting facilities and have sparse shops, primarily serve as thoroughfares, leading to minimal dwell time for pedestrians.

2.1.4 Distribution of crowd activity types

A vibrant street fosters diverse activities and attracts more passersby. According to Jan Gehl's theory, pedestrian activities were categorized during the survey into necessity activities, spontaneous activities, and social activities (Figure 8). Necessity activities encompass those necessary for daily life, such as commuting and cleaning; as seen in Figure 8, Guanghua Street (Segment 3) records four types of necessity activities, indicating that this segment serves as a vital route to the community hospital, fulfilling essential daily functions. Spontaneous activities refer to those undertaken at individuals' discretion, such as sunbathing, shopping, and strolling. Yongdao Street (Segment 9) excels in this regard, showcasing ten types of spontaneous activities. Social activities involve interactions, such as conversations and gatherings; Jixiang Alley (Segment 11) and Zhengyi Road (Segment 13) exhibit three types of social activities, suggesting that their environments are conducive to interaction. The variety of activity types provides insight into the street's activity atmosphere, with segments like 9 and 13 offering a lively and comprehensive environment. In contrast, Dongfeng West Road (Segment 5) sees hurried pedestrians, as its environment does not support diverse activities.

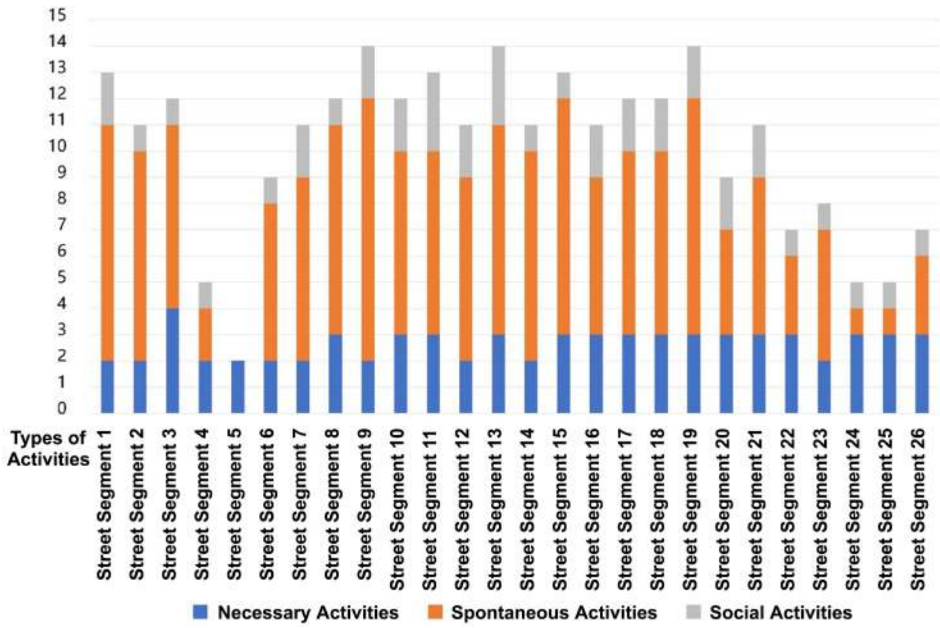

Figure 8 Types of crowd activities

2.2 Distribution characteristics of street vitality

2.2.1 Street vitality index

Given that the assessment of street vitality levels is significantly influenced by subjective factors, it is challenging to determine the contributions of the four aforementioned indicators through the objective weighting method. Therefore, the expert scoring method and statistical averaging were employed. The arithmetic mean of the scores from ten experts, which underwent consistency testing, was used to establish the weights for the four indicators. The average values of the data collected over four days were normalized accordingly.

2.2.2 Distribution characteristics of street vitality

As illustrated in Figure 9, the streets within the Wenming street block exhibiting the highest vitality are Zhengyi Road (Segment 12), Nanping Street (Segment 13), and Jingxing Street (Segment 10), with vitality indices of 0.068, 0.067, and 0.065, respectively. Conversely, the three streets with the lowest vitality indices are Wenmiao West Alley (Segment 25), Yunrui East Road (Segment 22), and Yunrui West Road (Segment 21), which have vitality indices of 0.015, 0.017, and 0.017, respectively. The vitality indices indicate a spatial distribution of vitality in the Wenming street block characterized by high levels in the southeast and low levels in the northwest. Notably, the vitality index of Zhengyi Road is over four times greater than that of Wenmiao West Alley, highlighting a significant unevenness in the current vitality distribution. From the perspective of the built environment, the question arises: what factors contribute to these observed phenomena? To explore this further, the author conducted a stepwise multiple linear regression analysis to identify the specific factors influencing the differential distribution of street vitality.

Figure 9 Street vitality index

3 Factors influencing street vitality

Due to significant differences in values of the independent variables, which may lead to unstandardized coefficients approaching zero (less than 0.0001), all 22 independent variables were normalized before constructing the multiple linear regression model. The model is represented by the following equation:

$$Y = \beta_0 + \beta_i X_i + \varepsilon, i = 1, \cdots, 22$$

Figure 10 sDNA accessibility (r=1200 m)

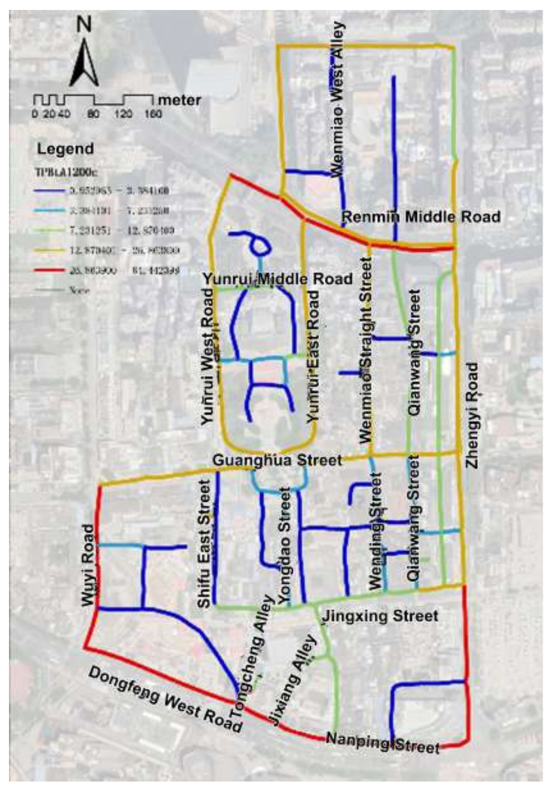

Figure 11 sDNA permeability (r=1200 m)

In this equation, the dependent variable Y represents the street vitality index, while the independent variable X_i

corresponds to various elements constituting street vitality.

In the first step, each of the 22 independent variables was sequentially introduced into the model for stepwise regression analysis. Variables that did not pass the significance tests were removed from the model.

In the second step, four variables remained in the model: sDNA proximity (r= 1200 m), sDNA passage (r= 1200 m), functional density, and street length. The adjusted R^2 value was found to be 0.702, indicating a good fit.

In the third step, the model passed the F-test (F= 15.716, p= 0.0000, α= 0.05), represented by the equation:

Street Vitality Index= 0.077+ 1.449×sDNA Proximity (r= 1200 m)+0.354×sDNA Passage (r= 1200 m)+0.368× Functional Density+0.265×Street Length.

The variance inflation factor (VIF) for all independent variables was less than 5, and the Durbin-Watson (D-W) statistic was approximately 2, indicating that the model does not suffer from multicollinearity or autocorrelation, thus confirming the overall robustness of the constructed model (Table 2).

Table 2 Results of stepwise regression analysis

	Unstandardized coefficient		Standardized coefficient	t	p	VIF	R^2	The adjusted R^2	F
	B	Standard error	Beta						
Constant	0.077	0.018	—	4.251	0.000**	—	0.75	0.702	F(4,22)= 15.716, p= 0.000
sDNA proximity (r= 1200 m)	1.449	0.52	0.464	2.79	0.011*	2.319			
sDNA passage (r= 1200 m)	0.354	0.079	0.743	4.463	0.000**	2.327			
Functional density	0.368	0.068	0.619	5.436	0.000**	1.088			
Street length	-0.265	0.123	-0.247	-2.152	0.043*	1.106			
Dependent variable: street vitality index									
D-W value: 2.045									
* p< 0.05 ** p< 0.01									

Based on the standardized coefficients and p-values, it is evident that sDNA passage (r= 1200 m), sDNA proximity (r= 1200 m), and functional density have a significant positive impact on the street vitality index, while street length exhibits a significant negative impact. The influence of these factors, ranked from greatest to least, is as follows: sDNA passage (r= 1200 m) > functional density > sDNA proximity (r= 1200 m) > street length.

3.1 Accessibility

The influence of sDNA passage and proximity (r= 1200 m) on the vitality of streets within the Wenming street block is substantial (Figures 10-11). According to space syntax theory, this suggests that the likelihood of streets being selected as destinations or routes within a 1200 m range increases, thereby enhancing their vitality. Given that the Wenming street block prioritizes pedestrian movement, it can be argued that the accessibility of streets within a 1200 m (15-minute) walking radius significantly influences people's natural travel choices within the district. This assertion is predicated on the angular connectivity between the streets.

3.2 Functional density

Functional density along both sides of the street is another crucial factor influencing the vitality of streets within the Wenming street block. Streets with higher functional density tend to attract greater pedestrian traffic. For instance, Nanping Street (Segment 12), a typical commercial pedestrian thoroughfare, achieves a functional density of 1.09 (Figure 12) and a vitality index of 0.067. In contrast, streets in the southwestern corner of the Wenming street block demonstrate low functional density and vitality indices. This phenomenon reflects the potential for a positive feedback loop, where higher functional density along the street fosters increased crowd activity, thus promoting mutual enhancement between street functions and pedestrian engagement.

3.3 Streetlength

There exists a significant negative correlation between street length and the street vitality index, indicating a potential aversion among pedestrians towards streets that lack visible endpoints. For example, Yunrui West Road (Segment 22), the longest street in the block, measures 364 m in length (Figure 13), yet has a vitality index of only 0.017. This underscores the importance of appropriate street lengths in maintaining street vitality. However, it is crucial to note that the lengths of streets in historical blocks are the result of many years of evolution, reflecting a complex spatial fabric developed over time. Therefore, in the context of preservation and renewal practices, attention must be paid to the accessibility of longer streets and the functional density along their corridors.

Figure 12 Functional density

4 Strategies for optimizing street vitality in historical blocks

Empirical research indicates considerable variations in street vitality within the Wenming street block, with accessibility, functional density, and street length significantly influencing vitality in historical areas. Given the context of existing stock planning, addressing the preservation and renewal of historical blocks is vital for enhancing urban quality. Thus, exploring how to revitalize traditional streets is critical for guiding new rounds of renewal design.

Figure 13 Street length

4.1 Enhancing pedestrian accessibility

According to space syntax theory, the interaction between space, function, and pedestrian flow creates a multiplicative effect: streets with higher accessibility attract more people, which in turn stimulates the development of functions along the street. This enrichment of functions contributes to increased street network density, establishing a positive feedback loop. For instance, while Shifu East Street exhibits appropriate functional density and street length, its vitality is compromised by low accessibility. To address this, measures can be taken to maintain the original spatial fabric while selectively opening alleyways to improve connections with main streets. Additionally, redesigning signposts and related facilities can enhance visual guidance for visitors, thereby attracting pedestrian traffic and fostering functional density.

4.2 Encouraging the design of public open spaces

Street length significantly influences street vitality;

however, adherence to the authenticity of historical blocks necessitates that the spatial fabric of these areas not be easily altered. Excessively long streets can lead to visual fatigue for pedestrians. Therefore, encouraging the creation of diverse and engaging public open spaces is a feasible approach. On one hand, it is essential to design open spaces in areas adjacent to traditional streets where conditions allow, to meet the diverse needs of pedestrian activities. On the other hand, the addition of commercial outdoor seating and movable shops can enhance the shopping and visiting experience for pedestrians.

4.3 Diversifying business types and strengthening thematic guidance

Functional density is correlated with the number of storefronts along the street; thus, increasing storefront density can enhance the pedestrian experience and offer varied shopping options. For instance, Wenmiao Straight Street benefits from good accessibility and suitable street length, yet its low functional density hampers the enhancement of street vitality. Observations reveal that the street primarily features dining and general hardware outlets, indicating that a lack of diverse business types and sparse storefront density restricts vitality. Therefore, it is crucial to diversify business types and increase store density, encouraging street vendors to engage passersby in public life. Additionally, it is important to strengthen thematic guidance for street functions; for example, Jixiang Alley is renowned for its flower and bird market, while the adjacent Yongdao Street attracts tourists through the sale of antiques and collectibles. Strengthening the thematic guidance of street functions helps create differentiated competition and reinforces pedestrians' awareness of the historical block's overall environment.

5 Conclusion and discussion

Through field research and the aggregation of open-source data, this study attempts to construct an evaluation index system for street vitality in historical blocks, measuring the distribution characteristics of vitality within the Wenming street block. Based on the identification of factors influencing street vitality, corresponding optimization strategies are proposed. The research indicates that: (1) The street vitality in the Wenming street block exhibits a spatial distribution characterized by higher levels in the southeast and lower levels in the northwest, revealing a pronounced imbalance; (2) Accessibility and functional density have a significant positive correlation with street vitality, while street length shows a significant negative correlation, with their respective influence ranked as accessibility > functional density > street length.

In addition to pedestrian activity intensity, street vitality is represented by age composition, dwell time, and activity types. The public life within street spaces is vibrant and diverse, and field observations confirm that the composition of the crowd and the variety of activities collectively contribute to the formation of lively public spaces. The new data environment offers opportunities for studying urban spaces at macro and meso scales. The innovative combination of open-source data and field research at the neighborhood scale presents a novel approach. Future research can analyze the differing experiences of various individuals regarding traditional street vitality while increasing the collection and analysis of subjective and objective information from community residents, designers, and managers. This will facilitate the implementation of strategies to enhance pedestrian accessibility, encourage the creation of public open spaces, and diversify business types in urban historical blocks. Ultimately, this fosters a spontaneous awareness across society for preserving the essence of historical culture, allowing historical blocks to retain cultural memory while evolving into vibrant public spaces.

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Figure and table sources

All figures and tables in this manuscript were prepared by the author.

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