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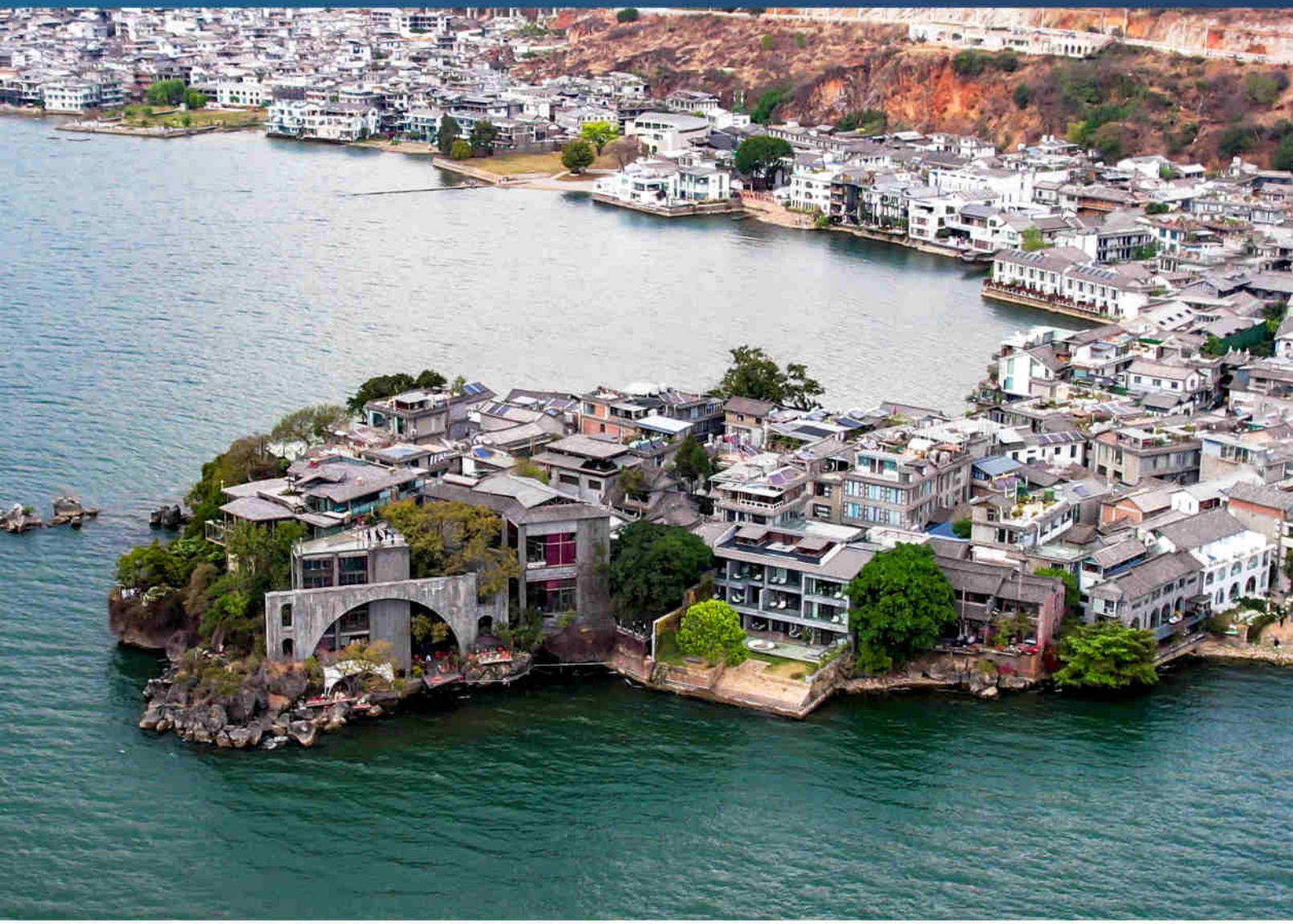

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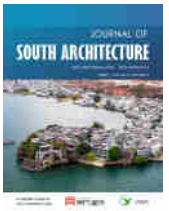

Analysis of Renewal Pathways for Traditional Villages in Yunnan from the Perspective of Top-Down and Bottom-Up Coordination

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ABSTRACT: This paper reviews the evolution and renewal of traditional villages in Yunnan Province and explores pathways for their contemporary renewal. Using self-organization theory and relevant case studies, it analyzes and summarizes both the self-organizing evolution of villages in the agrarian era and hetero-organizational renewal approaches in modern society. The study finds that self-organizing evolution in the agrarian era constituted the intrinsic driving force behind the formation of diverse village cultures, whereas many contemporary problems in village renewal result from excessive reliance on hetero-organizational intervention. On the basis of respecting the systemic and holistic structural framework formed through the self-organizing evolution of villages, top-down intervention strategies such as introducing order parameters, stimulating positive feedback, and promoting coordinated development should be employed to construct a renewal pathway characterized by top-down and bottom-up coordination, integrating "hierarchical nesting at the macro level, coordinated integration at the meso level, and dynamic adaptation at the micro level", so as to achieve the effective renewal and continuity of traditional villages in Yunnan.

KEY WORDS: traditional village; self-organization; hetero-organization; renewal

Introduction

Located on the southwestern frontier of China, Yunnan is characterized by a complex interplay of natural and cultural environments, diverse ethnic compositions, and a well-defined historical trajectory. Traditional villages in Yunnan are integrally linked to their geographical contexts and cultural lineages, having developed diverse spatial and morphological forms through long-term historical evolution.Among the five batches of the "National List of Chinese Traditional Villages" released between 2012 and 2019, Yunnan accounted for 708 listed villages. In recent years, with the rapid advancement of urbanization, traditional villages in Yunnan have faced common challenges such as so-called "protective destruction", fragmentation of local landscape characteristics, disorderly exploitation of traditional resources, and disruptions in cultural continuity. Against the backdrop of the implementation of the *Strategic Plan for Rural Revitalization* (2018－2022), it is timely to introduce self-organization theory to explore a scientific renewal pathway for traditional villages in Yunnan.

1 Self-organization theory and self-organizing characteristics of traditional villages

1.1 Self-organization theory

Self-organization theory was first proposed by the

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German philosopher Immanuel Kant. It primarily concerns the spontaneous formation of structures during processes of development and evolution—specifically, "how a system, under certain conditions, automatically transitions from disorder to order, and from low-level order to high-level order" [1]. Wu Tong of Tsinghua University integrated theories of dissipative structures, synergetics, dynamics, catastrophe theory, hypercycles, fractals, and chaos to construct a theoretical framework for the self-organization mechanisms of complex systems (Figure 1). He further defined self-organization and hetero-organization explicitly as follows: "Self-organization refers to a system that can organize, generate, and evolve autonomously from disorder to order without external instructions; ... hetero-organization refers to the process by which a system evolves toward order under specific external interventions" [2].

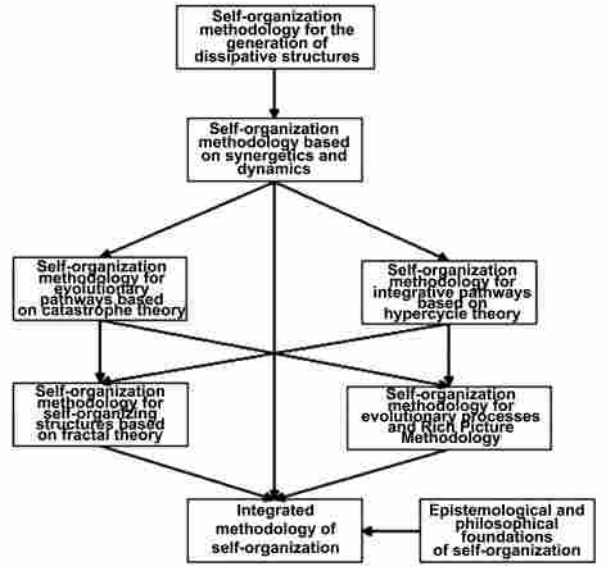

Figure 1 Theoretical framework of self-organization theory

1.2 Coupling relationships among the self-organizing characteristics of traditional villages

Research on traditional villages is primarily grounded in dissipative structure theory, synergetics, and hypercycle theory within the framework of self-organization theory. The exchange of matter, energy, and information between traditional villages and their external environment generates synergistic driving forces that propel the evolution of village systems. Under specific conditions, these forces facilitate the gradual transformation of village systems from disorder to order, from lower-order to higher-order states, and from simplicity to complexity.

The agglomeration, formation, and evolution of traditional villages "follow a series of implicit ordering principles and generative logics", resulting from interactions between villages' self-regulatory mechanisms and the external natural and social environments. The village system selectively responds to factors beneficial to its own development, reflecting the openness of traditional village systems. Differences in how system elements select and adapt to external matter, energy, and information render village systems non-equilibrium in nature. In his theory of the Science of Human Settlements, WU Liangyong divided traditional village systems into five subsystems, namely, natural systems, human systems, social systems, housing systems and support systems" [3]. During the formation and evolution of village systems, these subsystems undergo dynamic changes while mutually constraining and influencing one another, thereby exhibiting non-linear development. This aligns with the three necessary conditions for self-organization: "Openness, non-equilibrium, and non-linearity" [4].

1.3 The process of self-organizing evolution in traditional villages

From the perspective of self-organization theory, the formation and evolution of traditional villages constitute a process of self-organization. A fundamental pattern of settlement development is the gradual expansion of scale and population, together with the transition from functional simplicity to increasing diversity and complexity. This process is generally divided into three stages: (1) Evolution from disorder to organization: The autonomous formation stage based on the optimized selection of environment and location, resulting in relatively stable and independent village organizational structures. (2) Evolution from low-level to high-level organization: The spontaneous accumulation of matter, energy, and information within villages generates spatial agglomeration effects driven by self-organization, forming a differentiated hierarchical structure within the village system. (3) Evolution from simplicity to complexity within the same organizational level: Through exchanges of matter, energy, and information with the external environment, villages allocate and

reorganize system elements according to their own developmental needs, thereby advancing the village organizational structure to a higher level. These three stages represent a bottom-up organizational process that evolves from disorder to order and ultimately toward higher-order states (Figure 2).

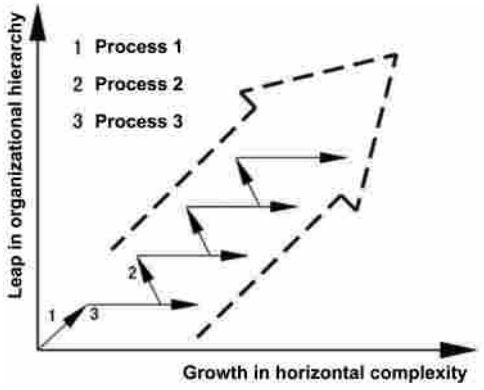

Figure 2 Theoretical framework of self-organization

2 Bottom-Up self-organizing evolution of traditional villages in Yunnan

2.1 Self-organizing evolution

As one of the earliest regions of intensive human activity, Yunnan exhibits primitive scenes of village formation in Neolithic rock paintings discovered in Cangyuan County. These depictions show village spaces with distinct boundaries, living conditions, as well as hunting and farming activities on the periphery. This reflects how ancient inhabitants, driven by survival-oriented organizing forces, coordinated with and adapted to the natural environment, demonstrating a collective consciousness that evolved from the disorder of nomadic dispersion toward the initial order of settled habitation (Figure 3). By the Western Han Dynasty, most indigenous ancestors in Yunnan had entered a stage characterized by "agricultural cultivation and clustered settlements." As their understanding and utilization of nature deepened, a growing sense of ethnic identity emerged, leading ancestors to deliberately select geographical locations when facing complex natural environments. For instance, the settlement pattern in which "ancient residents of Dali mostly lived on high mountain slopes" [5] represents an environmental choice made by the ancestors of the Bai ethnic group[1)], who adapted to and made use of the mountainous terrain of the northwestern Yunnan Plateau (Figure 4).

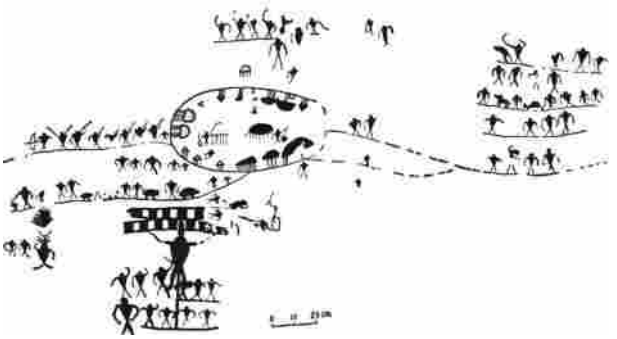

Figure 3 Schematic representation of ancient villages in the Cangyuan rock paintings

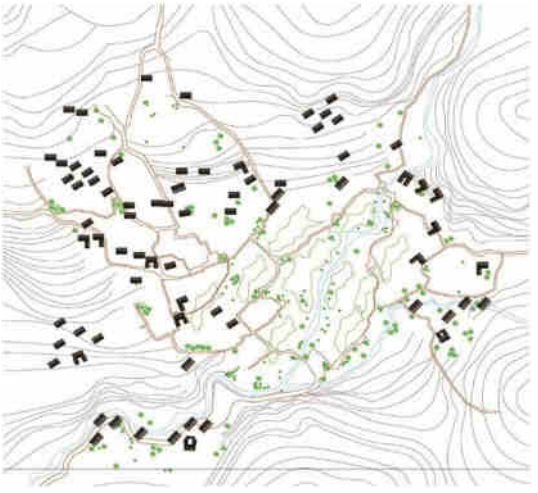

Figure 4 Early spatial form of the Nuodeng Village settlement

As the number and scale of villages expanded, exchanges of matter, energy, and information among villages and between villages and the external environment became increasingly frequent. This greatly enhanced the openness of village systems and enriched production and daily life. To meet diverse living needs, self-organized clustering of matter, energy, and information emerged within villages, enabling different organizational elements to achieve complementary integration within specific spatial and temporal contexts. This stimulated more complex self-organizing orders, giving rise to functional buildings, spatial environments, landscape landmarks, and boundary structures distinguishing the interior from the exterior of villages, thereby greatly diversifying the types of traditional villages in Yunnan. For example, the emergence of trade routes such as the Wuchi Road, Lingguan Road, Tea Horse Ancient Road, Bonan Road, and Yongchang Road facilitated the

formation of transportation- and trade-oriented traditional villages along these routes, driven by commercial forces (Figure 5). Since the Western Han Dynasty, successive dynasties implemented military garrison policies after conquering Yunnan and established defensive passes at strategic routes and border checkpoints, giving rise to garrison and defensive traditional villages shaped by military forces (Figure 6). During the Yuan and Ming dynasties, the Tusi system, under which local hereditary officials governed ethnic minority populations in frontier regions, fostered traditional villages characterized by Tusi culture (Figure 7). In the process of religious dissemination and integration, religious-cultural traditional villages also emerged around religious structures such as Theravada Buddhist temples, Tibetan Buddhist monasteries, Hui mosques, and local temples dedicated to Benzhu, Tuzhu, the Earth God, and the City God, which functioned as "magnetic centers" within village settlements (Figure 8).

Figure 5 Master plan of Heijing Ancient Town

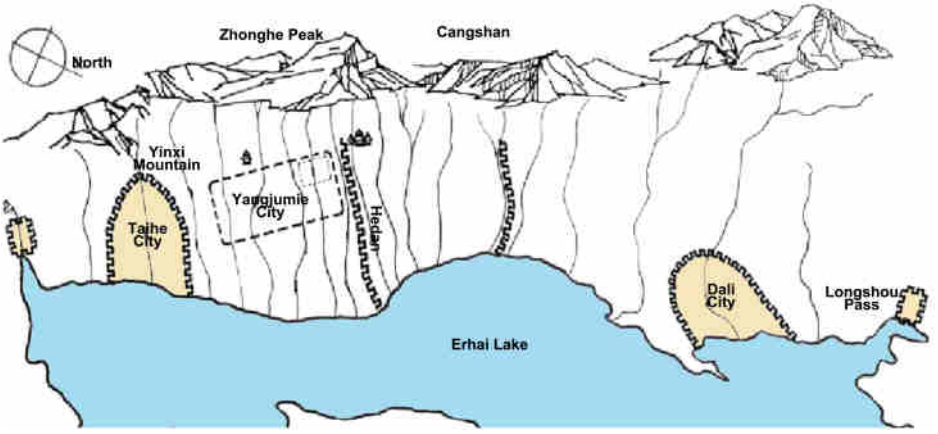

Figure 6 Longshou Pass and Longwei Pass in Dali

Figure 7 Aerial view of Huixin Village

Figure 8 Master plan of Donglianhua Village

The "regional characteristics of local culture and architectural culture in Yunnan traditional villages were formed through spontaneous mechanisms within regional social systems under relatively independent environmental contexts" [6]. The evolutionary drive of villages stems from the dynamic adaptation and autonomous selection of the external environment by internal forces based on their own developmental needs, thereby exhibiting the characteristics of bottom-up self-organizing evolution.

2.2 Reflections on self-organizing renewal

Through bottom-up self-organizing evolution, traditional villages in Yunnan have developed into numerous settlements of varying scales and types with distinct regional characteristics, leaving behind a rich and valuable cultural heritage. However, this evolution has not ceased with the changing eras; it continues to develop. Generally, the self-organizing evolution of traditional villages results in four outcomes:

(1) Villages with high degrees of openness engage in frequent exchanges with the external environment. Through the integration and redistribution of elements, spatial agglomeration effects emerge so that adjacent small villages are merged to gradually evolve into towns.

(2) Some villages with a certain degree of openness develop new spatial forms and structures as the dominant driving forces(i.e., order parameters governing system evolution) change, while their original characteristics gradually disappear (Figure 9).

Figure 9 Qudong Village in Yongping

(3) Some remote villages constrained by geographical conditions experience limited external influence and maintain a relatively balanced state, thereby preserving traditional village culture (Figure 10).

Figure 10 Lisu Village in Tongle

(4) In some villages, severe disruption of self-organizing systems during the development process leads to the loss of vitality and developmental momentum, resulting in the outflow of internal vitality and the emergence of "hollow villages".

With the expanding influence of urbanization, traditional villages face unprecedented challenges in the self-organizing evolution. On one hand, self-organizing evolution in the agrarian era was an extremely slow process. In today's rapidly developing information society, traditional villages engage in increasingly frequent exchanges of matter, energy, and information with the outside world, while various system elements interact continuously within self-organizing systems, making it difficult to identify order parameters quickly and accurately. Meanwhile, compared with the internal evolution of traditional villages, the external environment changes much more rapidly, exerting significant impacts on village systems. As villages become increasingly dependent on external environments, their self-organizing characteristics gradually weaken, and their capacities for self-adaptation and self-healing progressively decline. Consequently, under strong external intervention, villages may undergo distortion or even fragmentation.

3 Top-down hetero-organizational renewal of traditional villages in Yunnan

3.1 The necessity of hetero-organizational intervention

"When the evolutionary complexity of a system reaches a certain level, self-organization among subsystems alone becomes insufficient to rapidly meet the requirements for effective coordination of subsystem behaviors. Information must therefore be processed at a higher level, and specialized subsystems dedicated to coordination and control may even need to emerge to resolve such prob-

lems, thus giving rise to hetero-organization" [7]. Conceptually, hetero-organization corresponds to self-organization; however, it refers to the process through which complex organizational systems achieve ordered structures under specific forms of external intervention. In essence, it serves as an important complement to self-organizing systems.

Rapid urbanization has led to significant changes in the population, society, economy, and culture of villages. The original spatial structures and functional forms of traditional villages can no longer meet the increasingly complex demands of contemporary society. Relying solely on the bottom-up development of self-organizing village systems makes it difficult to identify a clear development path through internal coordination alone. Consequently, village evolution has begun to tend toward disorderly development. "Some traditional villages have been damaged or have even disappeared. As village protection systems remain inadequate, the protection of traditional villages has become an urgent task" [8]. Unlike the conventional protection of tangible and intangible cultural heritage, the indigenous historical culture of traditional villages is not "rigid and two-dimensional, but living and multidimensional". In the contemporary era, both production and daily life must undergo modernization. The protection of traditional villages must therefore avoid rigid preservation and instead involve the "decoding and reinterpretation" of rural geo-cultural landscapes [9] in order to achieve the renewal and continued development of traditional villages. Therefore, top-down hetero-organizational intervention in traditional villages is imperative.

3.2 Reflections on hetero-organizational renewal

In the agrarian era, the long-term self-organizing evolution of traditional villages was inevitably subject to varying degrees of human intervention. In other words, the morphological evolution of traditional villages exhibited characteristics of both self-organization and hetero-organization, as reflected in the influence of concepts such as "Feng Shui" and ritual systems on village spatial forms. Compared with hetero-organizational interventions in the agrarian era, contemporary interventions have become more systematic and scientifically grounded with advances in science and technology and the continual refinement of theoretical systems.

Through years of theoretical research and practical implementation, Yunnan has achieved significant results in the hetero-organizational protection and renewal of traditional villages and has developed several relatively mature models, including the Shaxi Model of "Authentic Restoration[2]" (Figure 11), the Shuhe Model of "New District Development[3]" (Figure 12), the Lijiang Model of "Economic Feedback[4]", the Xizhou Model of "Organic Renewal[5]" (Figure 13), the Heshun Model of "Harmonious Integration[6]", and the Chengzi Village Model of "Authenticity Restoration and Preservation[7]" (Figure 14). However, these models also exhibit certain limitations:

(1) In the process of formulating protection and development plans, disorderly competition for dominant cultural resources often arises in order to secure external opportunities and resources for village development. This neglects the differences that emerged from the self-organizing evolution of different villages and leads to an imbalance in the diversity of traditional villages.

(2) Excessive hetero-organizational intervention often overemphasizes the development of a single order parameter (such as economic or political factors) while neglecting coordination with other internal system elements, resulting in the deterioration of village system functions and the loss of local characteristics.

(3) Although protection and renewal can promote economic development, they often overlook the feedback from villagers—the most crucial order parameter in the village's self-organizing development. The villagers' aspirations for a better life have not been fundamentally addressed.

(4) Influenced by successful cases, regions across Yunnan have actively imitated or even directly copied these models, resulting in increasing homogenization of traditional village protection and renewal approaches.

4 Synergistic approaches to traditional village renewal in Yunnan

The process of self-organizing evolution in traditional villages can be summarized as follows: "Competition triggers fluctuations, adaptive selection occurs during these

fluctuations, and such selection subsequently influences the system through feedback mechanisms, ultimately manifesting itself as the successional evolution of the system as a whole." In short, the process follows: Competition—fluctuation—feedback—successional evolution [10]. During this evolution, the competition arising from external opportunities and environmental conditions, as well as the competition for developmental opportunities among internal elements, are uncontrollable factors that keep the village system in a state of non-equilibrium. Once a village enters a state of fluctuation, hetero-organizational methods such as "introducing order parameters, stimulating positive feedback, and promoting coordinated development" should be flexibly integrated into the evolutionary process. This enables traditional villages to develop in a predetermined direction, thereby achieving the renewal of traditional villages in Yunnan (Figure 15). Specific approaches may be considered from the following aspects.

Figure 11 Authentic restoration in Shaxi Ancient Town

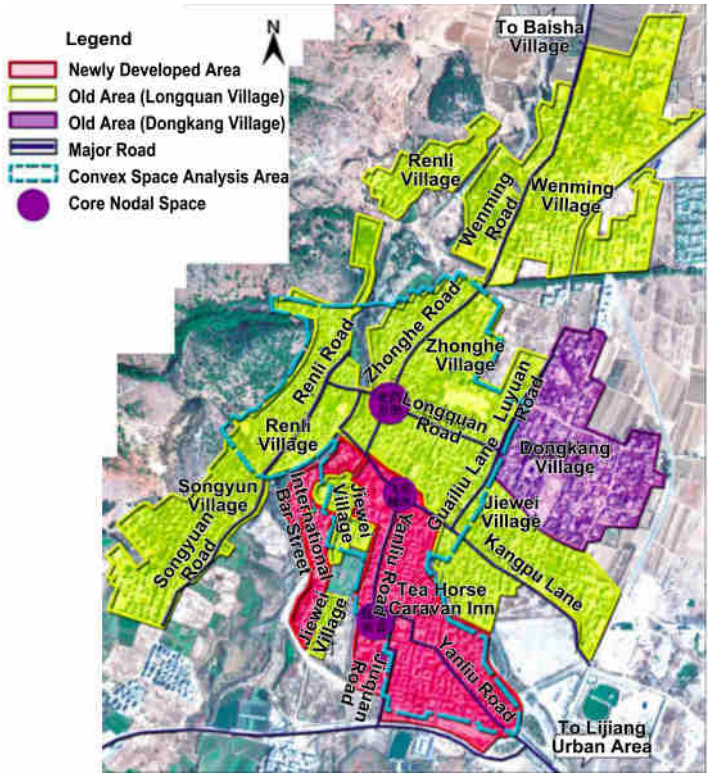

Figure 12 New district development in Shuhe Ancient Town

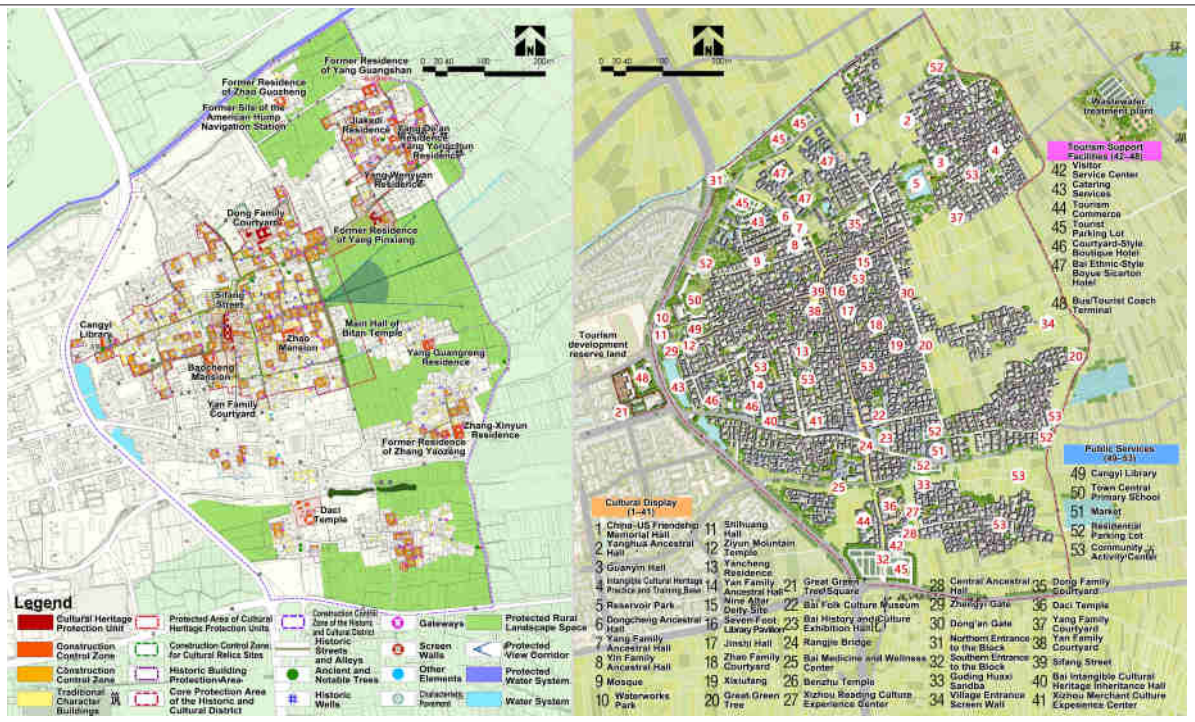

Figure 13 Organic renewal in Xizhou Ancient Town

Figure 14 Authenticity Restoration and Preservation in Chengzi Village

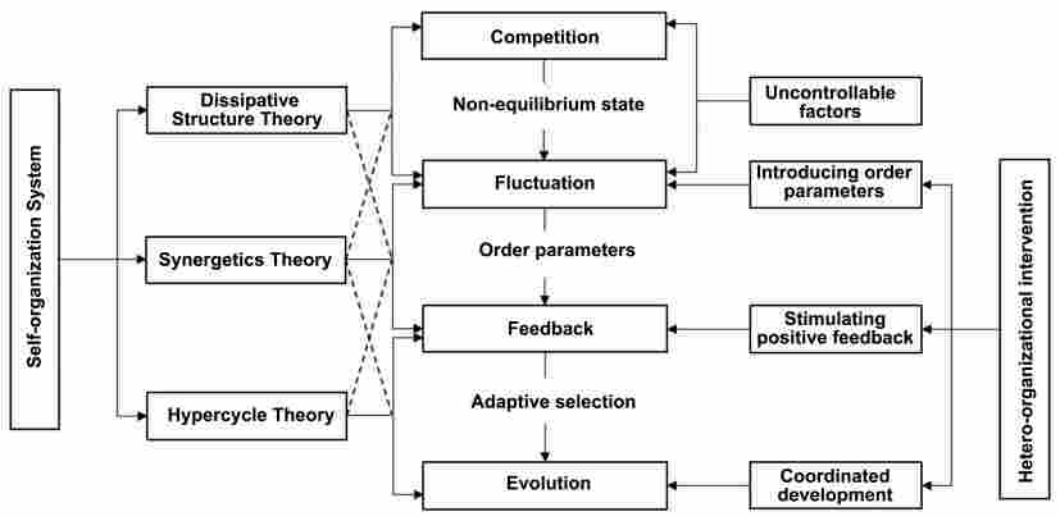

Figure 15 Self-organizing evolutionary process and the integration of hetero-organizational intervention

4.1 Hierarchical nesting at the macro-level

"A structure is more or less ordered at any level of complexity; ordered complexity is the level of order" [11].Regarding the renewal of traditional villages in Yunnan from a macro-regional perspective, the core lies in conducting an in-depth analysis of the spatial self-organizing evolution of Yunnan Province and integrating constituent elements such as time, space, and culture to construct a multi-level and integrated framework for regional socio-economic and cultural conservation. This approach extends isolated village-level renewal to the integrated renewal of the broader environment on which villages depend, shifting from "point-based" renewal toward "linear" and "regional" renewal, thereby constructing a more systematic and integrated organizational framework at the macro level.

For example, Kunming, as the central city of central Yunnan, has fostered an integrated urban-rural spatial pattern composed of dozens of densely distributed traditional villages within the broader regional sphere shaped by its urban influence. Along "linear" cultural corridors such as the Tea Horse Ancient Road, traditional villages situated within different geographical units are linked into an interconnected whole. This forms a spatial structure in which "points", "lines", and "regions" are hierarchically nested, creating a pattern that is "dispersed in form but unified in essence" (Figure 16).

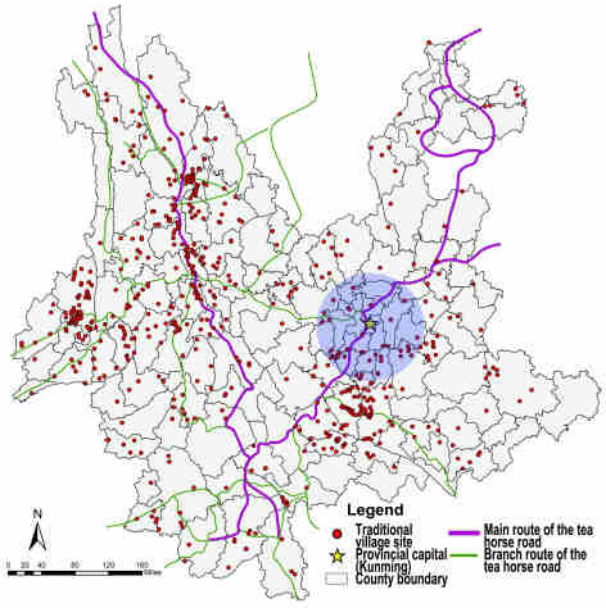

Figure 16 Hierarchical spatial nesting of "points", "lines", and "regions" in traditional villages of Yunnan

Therefore, in the renewal of Yunnan's traditional villages, a profound understanding of the laws governing spatial self-organizing evolution is an essential prerequisite for hetero-organizational intervention. From a macro-regional perspective, all relevant parameters linked through regional relationships within a given area should be incorporated into the analytical framework in order to explore hierarchical nesting relationships. By introducing-coordinated order parameters at different system levels, the logical relationships among system elements can become more coherent and the hierarchical structure more closely integrated. This allows individual traditional villages to be incorporated into the broader hierarchical system, thereby forming an integrated regional renewal pattern and overcoming the previous fragmented and isolated renewal approach that focused solely on individual villages operating independently.

4.2 Coordinated integration at the meso-level

Synergetics is the study of "how the parts of an open system in a non-equilibrium state cooperate, and how such cooperation gives rise to ordered structures in space, time, and function" [12]. Coordinated integration at the meso-level applies the principles of synergetics within self-organization theory by treating a specific spatial region as a relatively independent system, with villages functioning as constituent elements within the regional system. By understanding and applying the endogenous principles underlying the developmental dynamics and overall structure of regional systems, we can theoretically analyze the operational mechanisms governing dynamic system evolution. Subsequently, the principles of synergetics are employed to analyze the interrelationships and interactions among system elements. While respecting the principle of systemic integrity, hetero-organizational approaches are adopted to introduce necessary order parameters, enabling villages to develop functional cores characterized by "supply-demand" relationships. Different functional cores exhibit mutual responsiveness and interaction, thereby forming a functional system within a given region in which villages are interdependent and mutually exchange information and energy, ultimately achieving coordinated development among system elements.

For instance, Manghuang Village and Mangman Village in Mangshi Town, western Yunnan are less than 2 kilometers apart. Both are traditional Dai ethnic villages with clear traces of self-organizing evolution. In the renewal process, Mangman Village's emerging rural tourism catering sector was taken into consideration, with Dai culinary culture positioned as its functional core. Meanwhile, Manghuang Village leveraged its distinctive mountain-and-water landscape setting to develop into an ethnic cultural tourism village centered on Dai indigenous culture as its functional core [13]. Both villages share similar backgrounds in ethnic culture, architectural character, and natural resources. During the renewal process, corresponding order parameters were introduced according to their micro-locational differences and respective resource advantages. In the course of system evolution, these order parameters served to integrate and stimulate system elements while regulating the relationships between system elements and the overall structure. They guided the direction of system evolution and coordinated interactions among system elements, thereby creating a functionally complementary and mutually interdependent relationship between the two villages (Figure 17). This, in turn, facilitated the formation of systemic order and promoted the evolutionary upgrading of the system as a whole.

Figure 17 Master plan for the renewal planning and design of Manghuang and Mangman Villages

4.3 Dynamic adaptation at the micro-level

The diverse indigenous historical culture formed through the long-term self-organizing evolution of traditional villages in Yunnan constitutes the foundation for their survival and development. The implementation of the Rural Revitalization Strategy and the advancement of urbanization have introduced new evolutionary variables, leading to the complex evolution of village system components and thereby generating the fluctuations that initiate system evolution. The feedback mechanisms triggered by system responses subsequently determine the direction of system evolution. Under new circumstances, the key to micro-level renewal of traditional villages lies in expanding the hypercycle chain. Based on local cultural characteristics and the demands of modern life, traditional villages should stimulate positive feedback and dynamically adapt to different forms of external energy input in ways that correspond to their own living environments. This enables villages to undergo gradual rather than abrupt adaptive transformation along predetermined developmental pathways, as exemplified by the "internal renovation and external preservation" approach adopted in Azheke Village, Yuanyang [14]. In this way, the integrity of the village system can be maintained while promoting its evolution toward a higher state of equilibrium, gradually forming "traditional villages" that retain local traditional spirit and forms and are recognized over time. This is reflected in the following four aspects:

(1) Integrated use of production space: Full use should be made of the resource advantages of traditional villages in Yunnan through the scientific delineation of agricultural production zones and the strict protection of agricultural production spaces. Efforts should be coordinated to promote the development of agricultural industrial parks, science and technology parks, and entrepreneurship parks, while moderately developing sightseeing agricul-

ture, tourism agriculture, and integrated healthcare and wellness industries.

(2) Rational layout of living space: Land should be used economically and intensively while preserving the original ecological character of settlements and respecting traditional settlement fabric and spatial patterns. Living-space planning should ensure appropriate scale, coordinated layouts, and complete supporting facilities so as to provide village residents with healthier and more comfortable living environments.

(3) In-Depth exploration of traditional culture: The distinctive cultures of traditional villages in Yunnan should be deeply explored in order to strengthen confidence in local ethnic cultures and revitalize the unique cultural resources of different regions and ethnic groups. Ethnic cultural elements should be integrated into settlement construction so as to recreate poetic and leisurely cultural settings alongside verdant pastoral landscapes, thereby restoring the original pastoral scenery and a sense of attachment to rural homeland.

(4) Targeted development of cultural industries: Local talent should be identified and cultivated while implementing revitalization programs for traditional crafts and fostering traditional craft products with ethnic and regional characteristics. Effective integration between cultural resources and modern consumer demand should be promoted so as to improve the quality and branding of traditional village crafts and stimulate rural employment.

Conclusion

As the *Great Learning* (from the *Book of Rites*) puts it: "*The extension of knowledge lies in the investigation of things. Things being investigated, knowledge becomes complete.*" This implies applying known principles to thoroughly explore the nature of all things; through persistent effort, one eventually achieves a sudden enlightenment and comprehends both the internal and external aspects of things to acquire new knowledge—a process known as *gewu zhizhi*. Similarly, the renewal of traditional villages should be based on the general principles of "considering multiple stakeholders, integrating top-down and bottom-up approaches, complementing internal and external factors, and implementing incremental modification" [15]. It requires a profound investigation into the logic of the bottom-up self-organizing evolution of traditional villages and the regional spaces in which they are situated to uncover their cultural foundations and the multifaceted cultural values within. Only by doing so can we accurately identify the intervention points for top-down hetero-organization, flexibly apply methods such as "introducing order parameters, stimulating positive feedback, and promoting coordinated development", and combine these methods with a multi-level renewal path of "hierarchical nesting at the macro-level, coordinated integration at the meso level, and dynamic adaptation at the micro-level", to form a renewal strategy characterized by "coordination between self-organization and hetero-organization, coordination across hierarchical levels, and coordination among system elements". The revitalization of traditional villages "can be hopeful and sustainable only when internal forces play the primary role and external forces play a supporting role" [16].

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Figure 12: Cited from *Research on Tourism Villages' Spatial Form Transform Based on Space Syntax: Taking ShuHe Ancient Town of LiJiang for Example* by CHE

Zhenyu;

Figure 13: Provided by the Village and Town Construction Division of the Yunnan Provincial Department of Housing and Urban-Rural Development;

Other figures were drawn or photographed by the authors.

Notes

1) According to the Neolithic cultural sites discovered at Guolang Tianchi in 1981 and bronze artifacts (swords and axes) unearthed at Xiakelang Village in Baofeng, Yunlong County in 1986, these finds belong to the same type as the Neolithic bronze artifacts discovered around Erhai Lake. They date from the early Xia Dynasty (approx. 4,000 years ago) to the early Warring States period (approx. 2,460 years ago). It is thus inferred that the ancestors of Nuodeng Village were the indigenous forebears of the contemporary Bai people.

2) Shaxi Ancient Town was protected and renewed through "cultural return, lifestyle return, and subject return."

3) Develop a new district adjacent to the original village to extend the spatial pattern and texture of Shuhe Ancient Town while introducing enterprises to develop the tourism industry. The original village landscape and lifestyle were thereby preserved.

4) Use World Heritage protection to stimulate tourism, and use tourism development to support heritage conservation in Lijiang.

5) Revitalize the existing resources of Xizhou Ancient Town by leveraging its clusters of traditional dwellings. The renewal follows the development philosophy and operational model of "one courtyard, one product; one courtyard, one theme; one courtyard, one industry; and one courtyard, one distinct identity".

6) Protect and renew existing resources through "government regulation, enterprise funding, and villager participation" to achieve Heshun's "harmonious integration".

7) Adhere to the principle of "authenticity and integrity", and rely on the preservation of Chengzi Village's unique local traditional architectural features and overall settlement pattern to promote the revitalization of the village.

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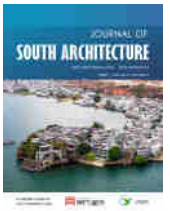

Exploring the Application of Quantitative Analysis Methods in Conzenian Urban Morphology: A Case Study of Traditional Urban Blocks in Guangzhou

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ABSTRACT: The delineation of morphological regions in Conzenian urban morphology has long been constrained by insufficient quantitative analysis. Therefore, its applicability in terms of scale, efficiency, and objectivity is limited. Focusing on the three constituent elements underlying morphological regions—plan type, building type, and land use—this study proposes corresponding quantitative analytical approaches for each element. Space syntax is primarily employed for the analysis of plan units, and different syntactic values and calculation methods are systematically compared and evaluated. *K*-means clustering combined with GIS technology is then applied for data integration and visualization. The proposed framework is empirically tested through a case study of representative traditional quarters in Guangzhou. The results demonstrate that the method can provide both data support and a customizable analytical framework for further urban morphological research. Nevertheless, the proposed technical approach still requires further refinement due to limitations associated with the research scope and methodology.

KEY WORDS: Conzenian urban morphology; quantification; GIS; space syntax; *K*-means clustering

Introduction

The Conzenian school is one of the major strands in Western urban morphology. Introduced into China in recent years, it has demonstrated substantial applicability in the study of Chinese urban development and historic conservation[1,2]. The core objective of the Conzenian approach is the delineation of morphological regions, which are formed through the integrated overlay of three constituent elements:Plan type, building type, and land or building use[1, 3-5]. However, for many years, this approach has relied heavily on subjective judgment and lacked sufficient quantitative analysis, which has, to some extent, undermined the objectivity and validity of the morphological regions it produces.

The development of contemporary information technologies and the interdisciplinary integration of research fields have promoted the rapid advancement of morphological analytical methods such as space syntax, while new statistical and computational techniques have increasingly been applied in urban studies[6]. Conzenian urban morphology should likewise actively incorporate these emerging technical approaches in order to improve

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both research capability and practical efficiency. Accordingly, this study aims to integrate space syntax, quantitative typological indicators, and urban big data within a GIS platform, and apply statistical methods to quantitatively refine the Conzenian approach to morphological region delineation.

1 Limitations of classical morphological approaches and recent quantitative explorations in both single-element analysis and integrative methods

In his 1960 plan analysis of the town of Alnwick, Conzen consciously attempted to quantify urban morphology. Focusing primarily on the single element of plan type, he conducted quantitative analyses of plot and building dimensions, quantities, and proportions. However, due to the technological limitations of the period, constraints in manual efficiency and computational tools restricted the work to descriptive statistical analysis within relatively small areas. Street systems and plan forms were described only in abstract terms. Furthermore, when it came to synthesizing multiple quantitative indicators and delineating units, there were no effective tools for quantitative integration, so plan units and morphological regions could only be derived inductively[3].

To date, the analysis of individual elements within the Conzenian school has incorporated more refined quantitative approaches.

Most improvements have concentrated on plan type. For example, HUANG Huiming[7], ZHENG Jianyi[8] et al. employed fractal dimensions to quantitatively describe the morphology of street systems and urban blocks. However, fractal dimensions can only calculate and represent the morphological characteristics of existing areas and cannot subdivide an entire study area into finer morphological units. Space syntax partially compensates for this limitation. The syntactic values generated through space syntax can effectively differentiate streets of varying hierarchical levels and structural roles within a study area, a capability that has gained broad recognition. Consequently, space syntax has become an important component of multi-factor integrated analytical tools such as UNA, Morpho, and Form Syntax[6]. Some researchers within the Conzenian school have also attempted to integrate space syntax into morphological studies, and demonstrated that syntactic values can assist in the delineation of plan units [9, 10]. Surprisingly, although earlier studies had already summarized improvements to space syntax methodology [11], they continued to employ relatively limited traditional approaches in both model construction and syntactic value calculation. Further comparison and critical examination therefore remain necessary.

Nevertheless, quantified morphological indicators have generally been used only as references for comparison and inductive synthesis, while the objectivity of the data itself has not been fully utilized due to the lack of effective quantitative integration methods. Drawing on other multi-factor integration studies, Form Syntax attempted to address the three constituent elements of plan type, building type, and function by establishing a quantitative framework and integrating them through a hierarchical evaluation process from individual categories to comprehensive assessment[6, 12]. Meanwhile, studies by Gil et al.[13] and ZHAO Yuwei[14] adopted data-mining approaches from the perspective of building typology to comprehensively evaluate indicators and perform spatial classification. However, both approaches used urban blocks as the basic unit of analysis and therefore could not achieve fine-grained delineation of morphological regions at the micro scale. By contrast, quantitative integration studies conducted at the building scale[15] paid insufficient attention to morphological-level elements, and resulted in fragmented outcomes that failed to form coherent morphological regions.

2 Construction of a morphological quantification model from the perspective of the Conzenian School

Using plots as the basic unit of analysis, representative quantitative indicators of the constituent elements of morphological regions can first be extracted and subsequently integrated and optimized through data-mining approaches. This strategy combines the strengths of classical morphological theory with those of recent methodological advances, and constitutes the fundamental approach to the quantitative delineation of morphological regions. Based on this framework, the present study constructs the following quantitative morphological analysis model.

2.1 Quantification of morphological elements

The first step involves extracting representative indicators for the three constituent elements of morphological regions and calculating them within a GIS platform. These indicators are then assigned to the morphological analysis unit—the property plot—thereby establishing a unified unit of analysis and forming an urban morphology database.

2.1.1 Plan type

Plan type is considered at three hierarchical levels: The street system, property plots, and building footprints [16]. In practical analysis, both these three levels themselves and the relationships among them constitute major challenges for quantitative analysis.

With respect to street systems, unlike the classical Conzenian approach, which classifies street patterns into abstract categories such as "gridiron" or "fishbone" forms, space syntax can objectively describe and quantify the morphology of streets or open spaces in a manner that approximates visual structure [17]. Moreover, plot sequences (i.e., the organizational relationships among property plots) can also be reflected in the calculated results when the street-network model is sufficiently refined, thereby enabling distinctions among different street hierarchies, spatial logics, and plot sequences.

The quantification of property plots and building footprints themselves depends primarily on their planar geometric characteristics, such as shape, size, and orientation. By contrast, no effective method currently exists for quantitatively measuring the relationship between plots and building footprints. Such relationships are therefore generally represented by using occupancy indicators such as building density.

2.1.2 Building type

In the Conzenian school, building type is typically considered in terms of structure, material, and number of floors. However, local classifications of building types often go beyond these attributes. Historic character, plan dimensions, function, and distinctive structural features may also become criteria for classification. In practice, this tends to appropriate elements belonging to other morphological dimensions, as plan type and functional characteristics are introduced into the category of building type, which results in conceptual ambiguity. Consequently, when extracting indicators for building type, independent building-type variables, such as structural system and number of floors, should be carefully distinguished and selected.

2.1.3 Land use or building function

This element already has relatively mature classification systems. The main area for improvement lies in the efficiency of large-scale data collection. The gradual development of open-source online data, particularly point-of-interest (POI) datasets, has provided an efficient means of obtaining such information.

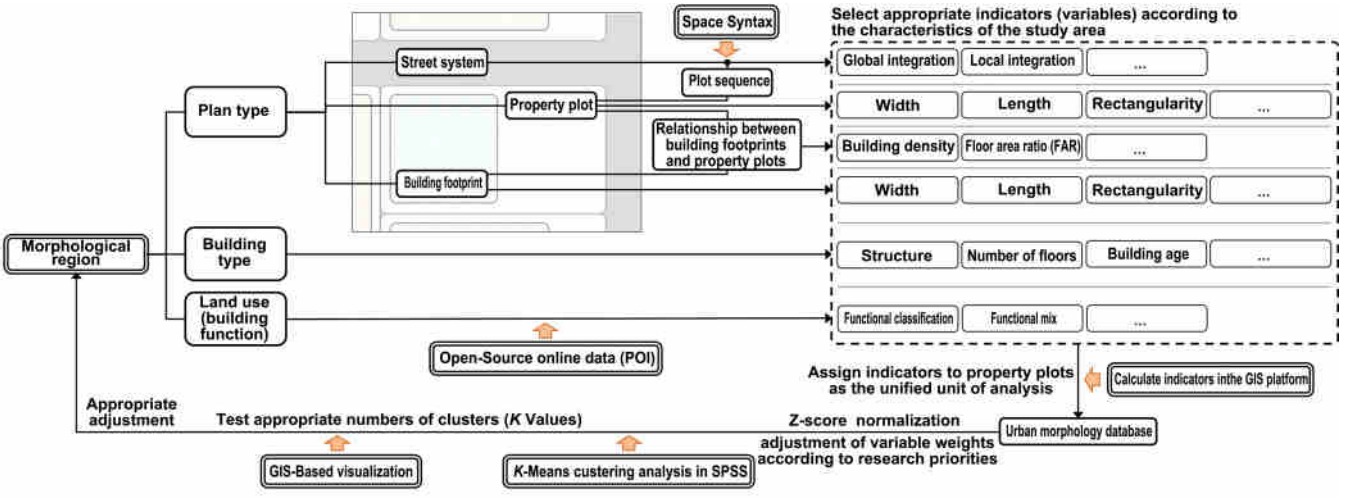

Figure 1 Schematic diagram of the quantitative research model for Conzenian urban morphology

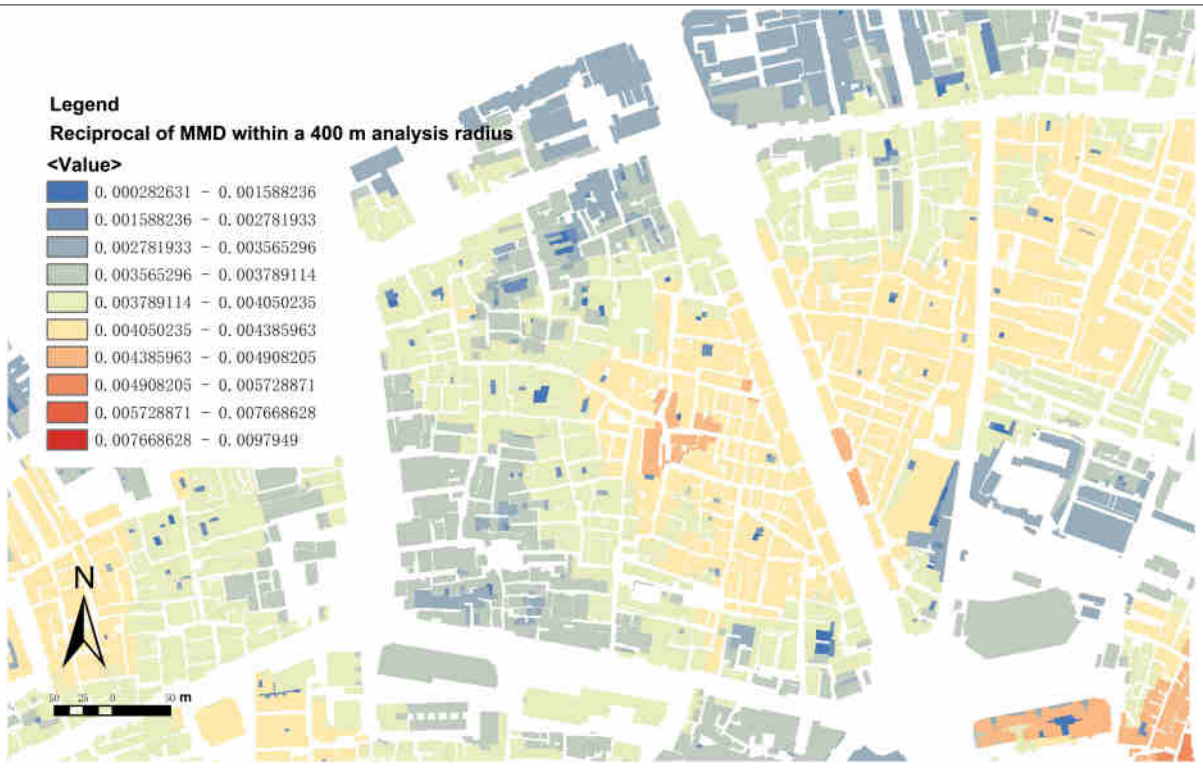

Figure 2 Metric integration fails to effectively distinguish differentiation in plan types (example area: Nanhua Donglu area, Guangzhou); syntactic values were assigned to buildings using the method described later

2.2 Integration of quantitative indicators

The second step involves the quantitative integration of multidimensional indicators (variables). *K*-means clustering analysis[1] in SPSS provides a suitable solution for this purpose. After indicators with different measurement scales are standardized using Z-score normalization[2], distances between cases can be calculated, and categories can be classified based on intrinsic data characteristics. Through GIS visualization and repeated adjustment of the *K* value (i.e., the number of clusters), morphological regions can be delineated and optimized. Categorical variables[3] such as structure, historic architectural character, and land use can be incorporated into clustering analysis after being hierarchically graded and ordinalized (Figure 1). Variables that cannot be ordinalized may instead be transformed into dummy variables[4] to represent categorical attributes.

3 Construction of an indicator system and calculation methods: A case study of traditional blocks in Guangzhou

Different study areas require indicator systems suited to their own characteristics. Indicators should therefore be selected according to local conditions and available data, prioritizing variables capable of clearly distinguishing different types and morphological forms within the study area. Owing to the constraints of the *K*-means clustering method, ordered and continuous variables should be selected whenever possible. The following sections take traditional blocks in Guangzhou as a case study to select and evaluate quantitative indicators. Notably, because urban morphological studies in China generally lack accurate large-scale property-plot data, and because traditional buildings in Guangzhou often exhibit a close correspondence between building footprints and property plots, buildings are used as the basic unit of analysis in this study.

3.1 Indicators for plan type

3.1.1 Street systems and plot sequences: Space Syntax

The theories and computational methods of space syntax have undergone continuous refinement. Nevertheless, the street-network models and calculation methods currently adopted by researchers within the Conzenian school still exhibit certain limitations.

Figure 3　Classification maps of global syntactic values of buildings in the Tongfu West Road area, top: integration; middle: choice; bottom: normalized choice, black areas indicate syntactic values of 0, syntactic values were assigned to buildings using the method described later

(1) Construction of Street-Network models: Axial analysis and segment analysis

In the study by SONG Mingxing et al.[10], the street-network model was constructed using axial analysis. Segment analysis, as an improvement derived from axial analysis, adopts more objective and accurate principles for street-network representation. When combined with analysis radius settings, it can effectively distinguish similar street-network configurations. It aligns more closely with conventional traffic-network analysis[11], and therefore corresponds more closely to the Conzenian emphasis on street-system structure.

(2) Weighting methods: Metric distance and angular change

Due to interactions among spaces of city blocks at different scales, it is necessary to measure syntactic values at both global and local scales and to consider them comprehensively[18]. Angular weighting has been demonstrated to more effectively capture subtle differences in urban spatial configurations[11], and there is now broad consensus on its value at a global scale. At the local scale, however, Li Xiaoxi et al. employed metric mean depth[5] (MMD) to account for metric characteristics of local space[9]. Yet Hillier et al. pointed out that MMD still contains numerous deficiencies[19] and is unsuitable for directly quantifying spatial structure. The authors also conducted tests in traditional urban blocks of Guangzhou, which showed that MMD with a large analysis radius failed to produce effective subdivision, whereas MMD with a small radius could distinguish only variations in street-network density while failing to clearly represent plot sequences (Figure 2). In fact, the analysis radius within the segment model already incorporates metric-distance considerations. Using angular-weighted segment models at both global and local scales can therefore more effectively distinguish different street structures and hierarchical levels.

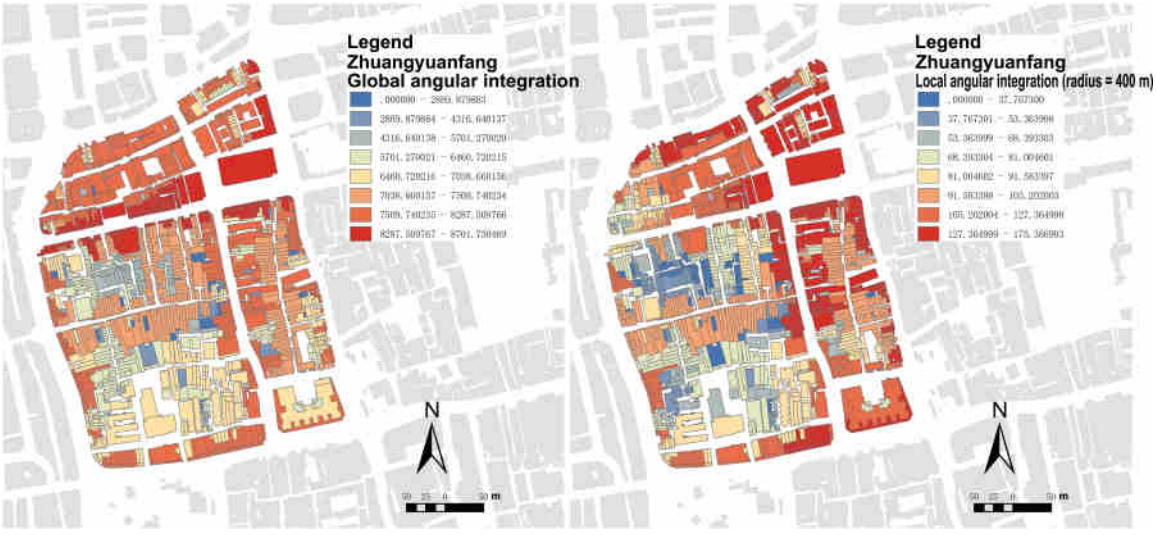

Figure 4 Global angular integration and local integration with a 400 m radius in Zhuangyuanfang Block (configurational values assigned to buildings using the method described later)

(3)Selection of specific syntactic values: Choice and integration

Space syntax produces a variety of syntactic values, among which integration and choice are most commonly used to describe the hierarchical structure of street space [9,10,12]. The present study compares the classification effects of integration and choice at the global scale (after syntactic values were assigned to buildings using the method introduced later in this paper) (Figure 3, upper and middle panels). The results indicate that both integration and choice can express accessibility and distinguish hierarchical differences among street segments. However, integration exhibits a more even data distribution, which is more suitable for clustering analysis. By contrast, the computational logic of choice causes all dead-end streets to receive a value of "0" regardless of street hierarchy, which makes it impossible for further differentiation even after standardization (Figure 3, lower panel).

Figure 5 Extent of the street-network model, extent of the historic urban area, and extent of the Zhuangyuanfang area (left); details of the street-network segment model (right)

Accordingly, this study employs segment analysis to construct the street-network model and adopts angular-weighted integration values at both global and local scales. For the local-scale analysis radius, the study refers to the research of Ref. [20] on the historic blocks along Beijing Road, Guangzhou. Given the similarity in regional context and spatial scale, a radius of 400 m is adopted, corresponding to the maximum distance of natural pedestrian activity. This radius both distinguishes local-scale analysis from global-scale analysis and satisfies the requirements for morphological identification in traditional blocks of Guangzhou (Figure 4).

Both the precision and spatial extent of the street-network model affect the accuracy of syntactic values. Existing quantitative explorations within the Conzenian school all exhibit insufficient street-network precision [9,10,12], which is one reason why plan-type delineation has failed to achieve fine-grained subdivision within urban blocks. Based on the 1:2,000 topographic map of Guangzhou from 2010, the present study constructed a detailed street network covering the entire historic urban area through field verification and updating. Following the empirical "30-minute rule" [21] (pp. 73-74), the study area was expanded to the range shown in Figure 5 (left). The resulting street-network model includes streets and alleys of all scales (Figure 5, right), and provides a foundation for the fine-grained subdivision of plan types at the levels of street systems and plot sequences.

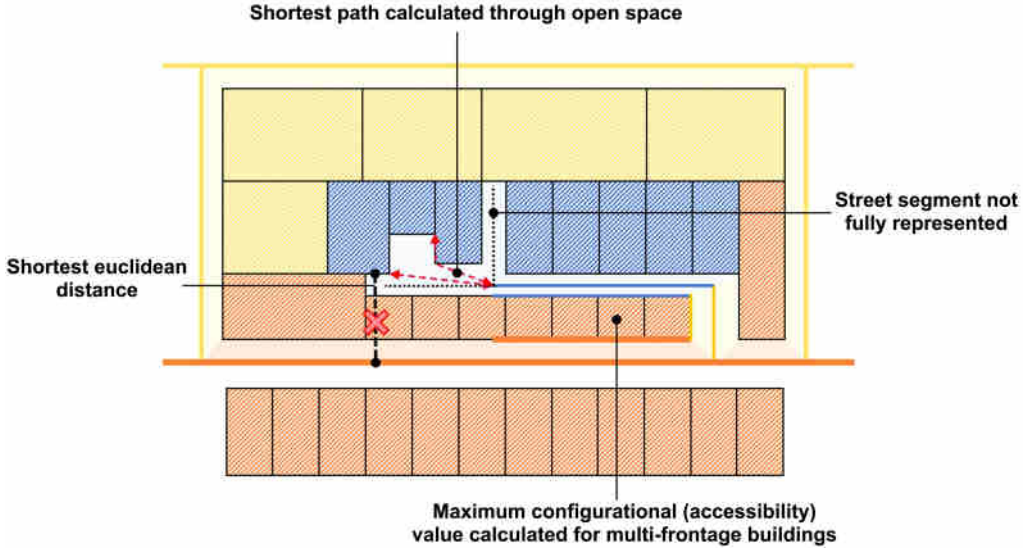

Figure 6 Schematic diagram of assigning syntactic values to buildings

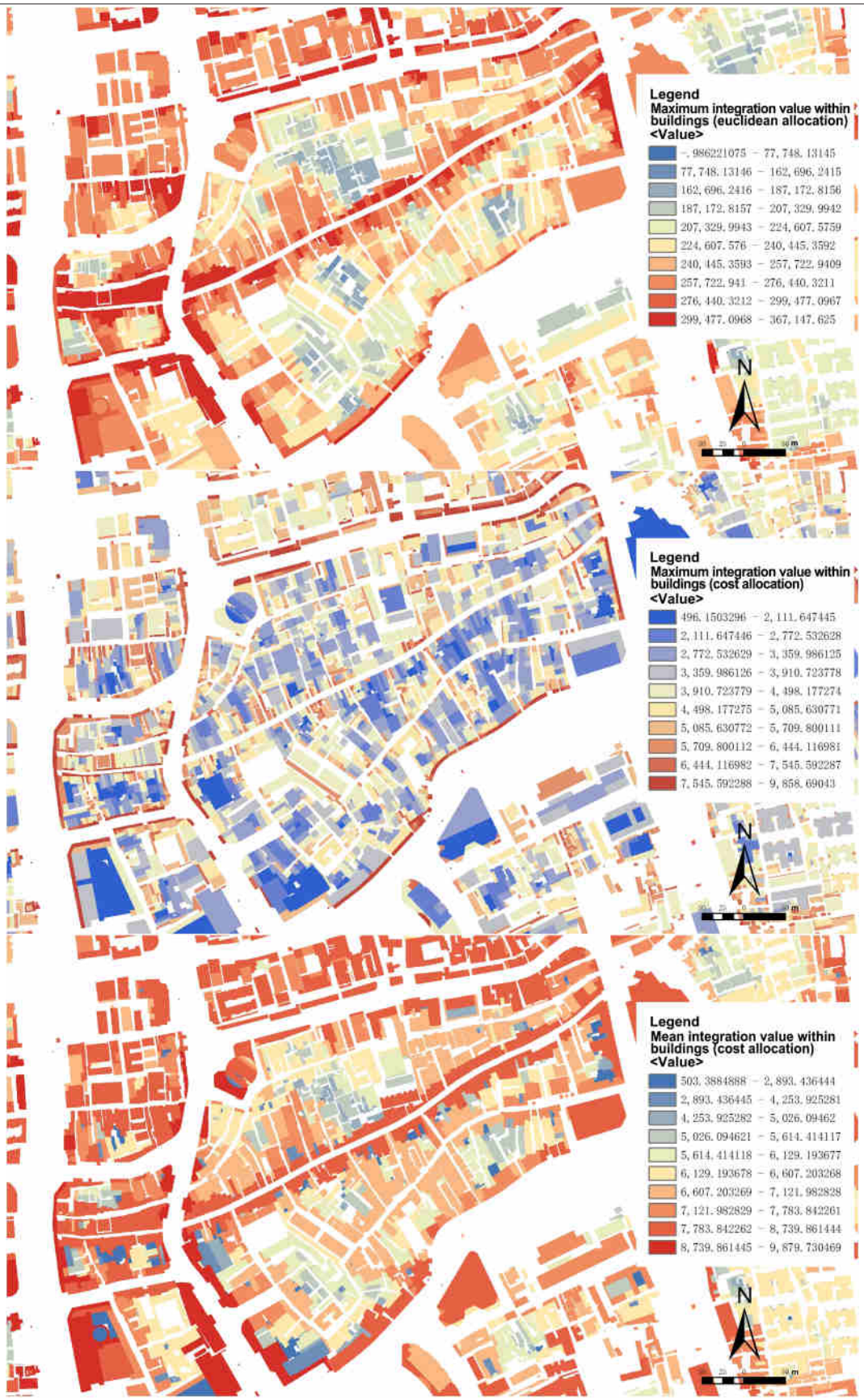

Figure 7 Assignment based on straight-line distance (top); average values extracted within buildings after assignment (middle); maximum values extracted within buildings after assignment (bottom)

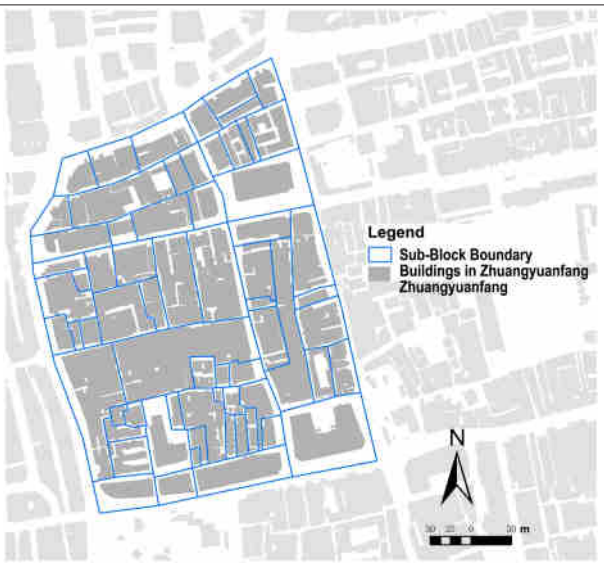

Figure 8 Delineation of "sub-blocks" in Zhuangyuanfang Block

After computation in DepthmapX, the results are generated in the form of line features; these must be assigned to buildings to establisha unified unit of analysis. If values are assigned based on straight-line distance, some buildings that are actually poorly accessible but happen to be close in straight-line distance to a main road will receive inappropriate values (Figure 6 and 7, upper panels). To address this issue, the present study proposes a method for assigning street-network syntactic values more reasonably to building elements: In GIS, different cost values are sequentially assigned to open spaces, gray spaces[6], and solid buildings. Syntactic values are then allocated across the entire study area through cost allocation, with distance decay incorporated, and the maximum value within each building is extracted.

This method compensates for spatial details not captured during segment drawing in space syntax analysis and enhances the representation of local metric spatial characteristics. Moreover, using the maximum syntactic value rather than the average value allows entrance patterns of plots to be reflected in syntactic values, thereby facilitating the identification of plot sequences (Figures 6 and 7, middle and lower panels). Buildings facing multiple streets often place their primary entrances on streets with higher accessibility.

3.1.2 Property plots and building footprints

Traditional blocks in Guangzhou are characterized by high density, low intensity, and relative homogeneity[22]. Buildings can therefore be grouped into "sub-blocks" (Figure 8), which are used to calculate building density and floor area ratio (Figure 9) in order to approximate the relationship between building footprints and property plots. This serves as a substitute method under conditions where property-plot data are unavailable. Likewise, because property plots and building footprints in these blocks almost completely overlap, the geometric properties of building footprints can approximately represent plot morphology. The selected indicators therefore include orientation[7], the length and width of the minimum bounding rectangle (MBR)[8] of the footprint, area-based rectangularity[9], and perimeter-based rectangularity[10].

3.2 Building type indicators

Buildings in traditional blocks of Guangzhou are predominantly characterized by deep and narrow "bamboo" forms[22]. Conventional building typologies are typically classified according to frontage width, depth, and function into categories such as "bamboo houses", "mingzi houses", and "Xiguan mansions" et al.[23]. However, this classification method overlaps with the other two elements in Conzenian urban morphology, namely plan type and land/building use. Therefore, when extracting quantitative indicators, indicators related to plan type and function should first be excluded in order to establish an independent classification system for building types and avoid repeated weighting during clustering analysis.

Accordingly, this study adopts conventional building-type indicators such as number of floors and structural type, together with indicators such as building age (from Ref. [9]) andstyle (from Ref. [23]), which reflect historical stratification and correspond to the consideration of morphological periods in Conzenian urban morphology. In addition, the indicator "Qilou building (i.e., an arcade building)" is introduced as a regionally distinctive architectural feature to facilitate the identification of clearly differentiated morphological regions.

3.3 Indicators for land use or building function

Data on land use and building function are generally obtained from two sources: (1) Land-use maps provided by planning and surveying departments or generated through

field investigation; and (2) datasets derived from the processing of open-source online data, such as Points of Interest (POI) from Amap. At large spatial scales, newly available open-source data can reflect the actual use of urban space more accurately than conventional planning land-use data and also provide more detailed classifications. However, errors remain when such data are applied at the micro scale[21] (p. 100). In traditional street-and-lane areas, functional data within the street network are often incomplete, and POI coordinates cannot be precisely matched to individual buildings, resulting in substantial deviations from actual functions (Figure 10). Therefore, given the limited reliability of functional data in traditional blocks of Guangzhou, building-function data should still primarily be obtained through planning and surveying departments or field investigation.

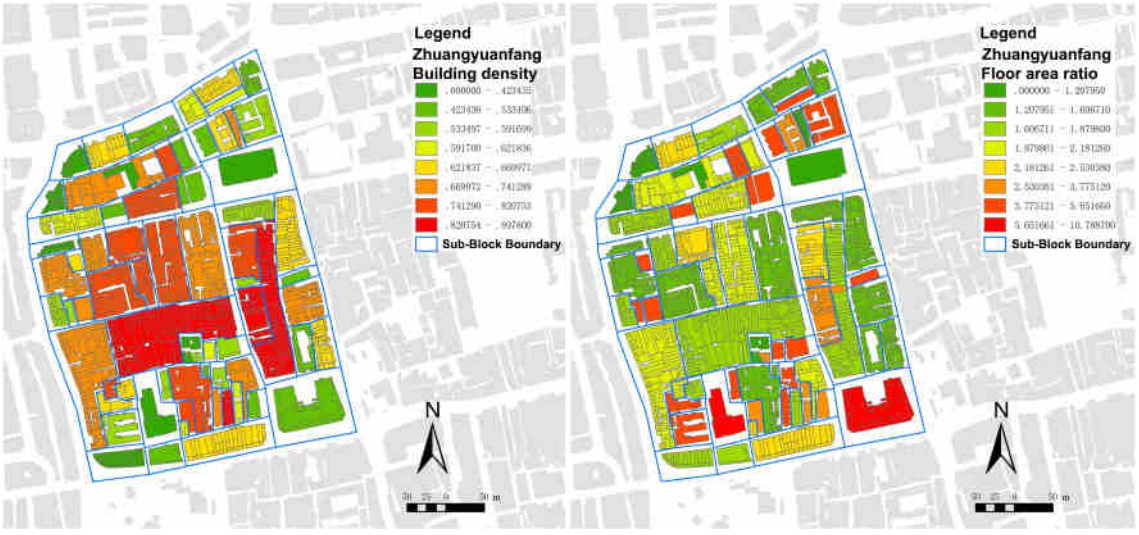

Figure 9 Building density (left) and floor area ratio (right) of Zhuangyuanfang based on "sub-blocks"

Figure 10 A map POI density in the Zhuangyuanfang district (left) and actual land use (right)

4 Empirical study and analytical demonstration of the traditional Zhuangyuanfang Block

The Zhuangyuanfang Block is located within the historic urban area of Guangzhou and is a well-known traditional commercial street. The surrounding area preserves a variety of historic commercial and residential spaces, and exhibits diversebuilding types and urban forms[24]. In particular, the prototype of traditional Guangzhou dwellings—the bamboo house—appears here in numerous variations[25]. In addition,

multiple academic studies and planning projects have conducted detailed investigations into the urban morphology and building typologies of this area[24-29]. Therefore, the Zhuangyuanfang Block constitutes an ideal case for validating and comparing methods of morphological quantification.

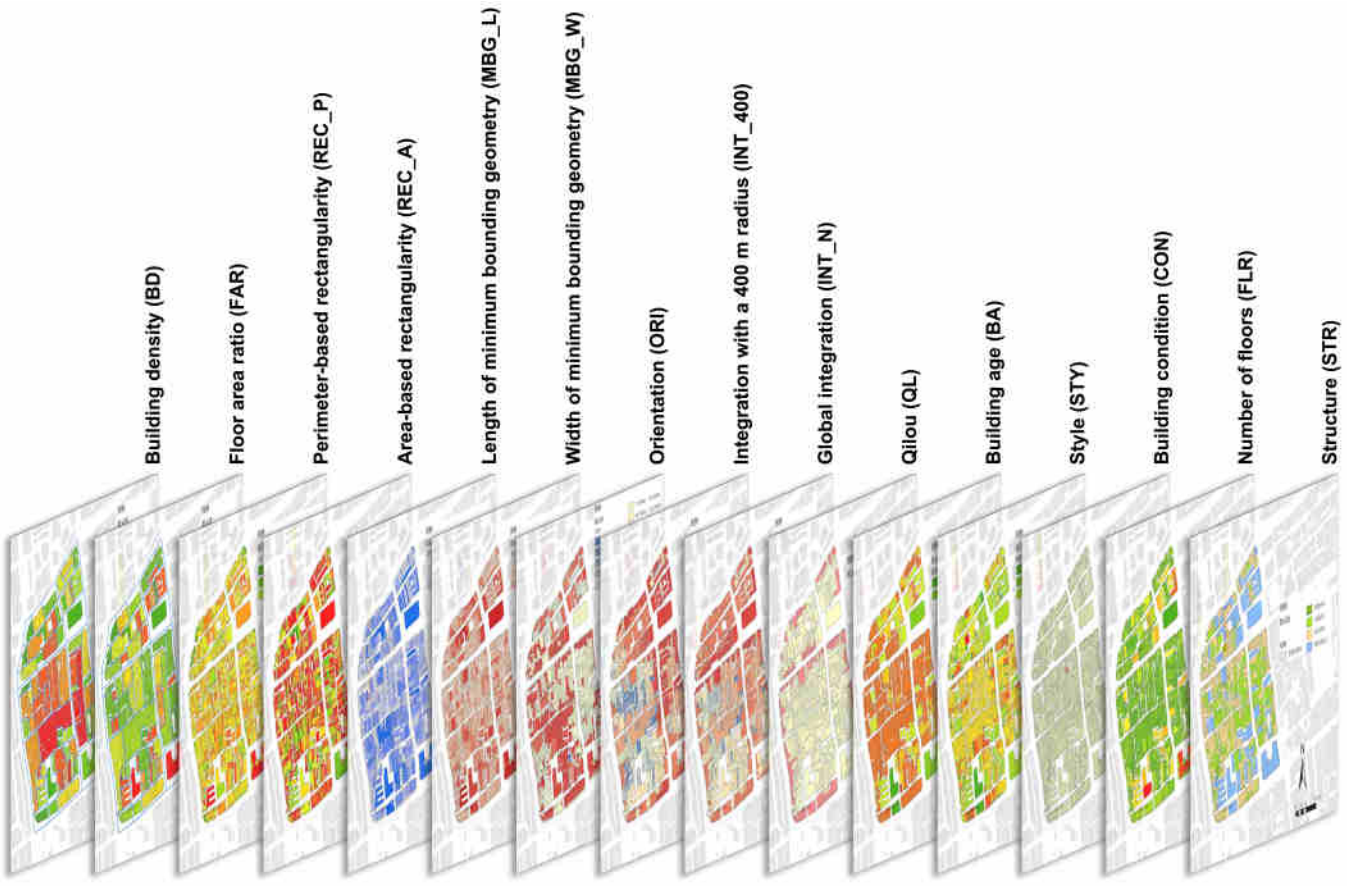

Figure 11 Overview visualization of quantitative indicators in Zhuangyuanfang Block

Table 1 Overview of Quantitative Indicators (Variables)

English name	Abbreviation	Unit	Remarks
Structure	STR	—	4 = Reinforced concrete frame structure 3 = Mixed structure (including brick + reinforced concrete) 2 = Brick-and-timber structure with two or more bays 1 = Single-bay brick-and-timber structure
Floors	FLR	—	
Building condition	CON	—	3 = Existing solid building 2 = Temporary sheds and ancillary structures 1 = Dilapidated building
Style	STY	—	7 = Cultural heritage building 6 = Historic building with certain historical or artistic value 5 = Historic building with relatively satisfying architectural character 4 = Historic building with ordinary architectural character 3 = Modern building compatible with the traditional character 2 = Modern building incompatible with the traditional character 1 = Building under construction or newly built 0 = No data

(Continued)

English name	Abbreviation	Unit	Remarks
Building age	BA	—	5 = Before 1955 4 = Before 1978 3 = Before 1989 2 = Before 1999 1 = Before 2010 0 = Before 2021
Qilou	QL	—	0 = not a Qilou 1 = Qilou or building with Qilou elements
Integration metric radius n by angular segment analysis	INT_N	—	See Section 3.1.1
Integration metric radius 400 by angular segment analysis	INT_400	—	See Section 3.1.1
Orientation	ORI	° (degree)	See Note 7
Minimum bounding geometry width of rectangle by area	MBG_W	m	Abbreviated as "W"
Minimum bounding geometry length of rectangle by area	MBG_L	M	Abbreviated as "L"
Rectangularity by area	REC_A	—	See Note 9
Rectangularity by perimeter	REC_P	—	See Note 10
Floor area ratio	FAR	—	Ratio of total floor area to total area of the "sub-block"
Building density	BD	—	Ratio of total building footprint area to total area of the "sub-block"

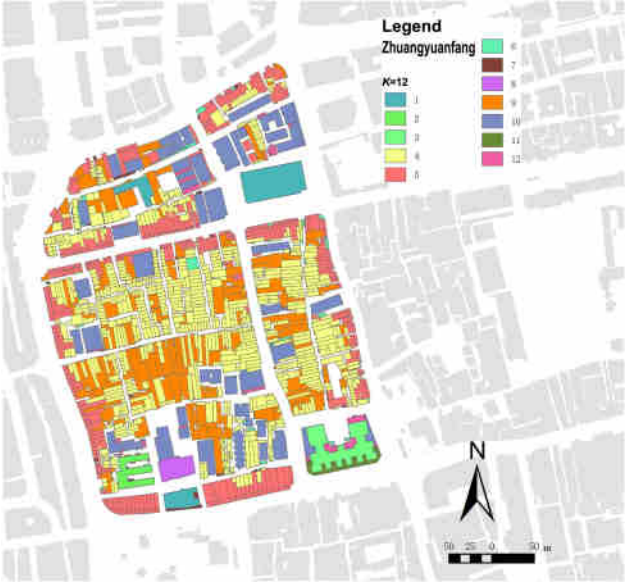

Figure 12 Clustering analysis of plan-type and building-type indicators at $K=12$

Following the indicator system established in the preceding sections, the indicators were organized as shown in Table 1 and visualized in Figure 11 to form an urban morphology database.

4.1 Clustering of plan types and building types

For study areas with relatively homogeneous functions, the delineation of morphological regions may place comparatively less emphasis on functional factors[4]. Moreover, spatial integration itself exhibits a relatively high correlation with the distribution of commercial activities [30], and can therefore partially represent the influence of function on morphology. Accordingly, this study first integrates indicators of plan type and building type.

K-means cluster analysis was conducted on the indicators in SPSS. After repeated testing, a value of $K=12$ produced relatively satisfactory visual classification results (Figure 12). After excluding anomalous cases, the resulting number of clusters was close to the number of building types previously identified by researchers in the Zhuangyuanfang Block [27], providing sufficient support for further superimposition with functional indicators in the delineation of morphological regions. The analytical results are as follows (all original data were standardized using Z-score normalization):

During the 25th iteration of the clustering analysis, the maximum absolute coordinate change among all cluster centers fell below 0.001, which indicates that the algorithm had converged. Meanwhile, the ANOVA results in

Table 2 show that, except for building condition (CON), all variables contributed to the clustering analysis, as indicated by their significance values (Sig.)[11]. Within the empirical study area, however, the value of building condition was almost uniformly "3" (solid buildings), making it incapable of producing meaningful differentiation. Consequently, this variable made no contribution to the clustering process and may be disregarded, while the clustering results themselves remain valid.

Table 3 presents the mean values of each variable at the final cluster centers. Values that are significantly distinct from those of other clusters are highlighted in bold.

By examining the clustering indicators, the principal characteristics of each cluster can be identified, thereby enabling the interpretation of morphological regions. Cluster 3 is distinguished by significant values for number of floors, length, width, and rectangularity, indicating a group of irregular medium- to high-rise buildings. Similarly, Cluster 10 represents low-rise buildings with relatively larger dimensions and more recent building age. Cluster 4, by contrast, has indicator values close to zero across most variables, representing the most common and morphologically typical bamboo houses within the study area.

Observation of the indicators also reveals the differentiation among clusters and helps explain the basis for morphological-region delineation. For example, Clusters 4 and 5 exhibit relatively similar mean values across most variables, but differ markedly in the indicators "Qilou building" and integration value. In practice, Qilou shophouses evolved from bamboo houses and are therefore similar in building footprint and structural characteristics; their principal distinctions lie in the presence of arcades and street frontage (i.e., accessibility). By comparison, Clusters 4 and 9 differ significantly in length, width, and area-based rectangularity, which indicate differences in frontage-depth proportions and footprint regularity, thereby distinguishing multi-bay traditional dwellings from irregularly shaped special bamboo houses.

4.2 Superimposition of land use / building function

After completing the clustering analysis of indicators related to plan type and building type, building function was further incorporated into the clustering analysis. Owing to space limitations, the detailed clustering report is omitted here, and only the visualized results are presented:

Table 2 ANOVA

	Cluster		Error		F	Sig.
	Mean Square	Degree of freedom	Mean Square	Degree of freedom		
STR	68.61	11	0.563	1,703	121.801	0.000
FLR	105.058	11	0.328	1,703	320.425	0.000
CON	155.818	11	0	1,703	—	—
STY	23.782	11	0.853	1703	27.885	0.000
BA	104.711	11	0.33	1703	317.195	0.000
QL	110.055	11	0.296	1,703	372.319	0.000
INT_N	42.956	11	0.729	1703	58.925	0.000
INT_400	42.696	11	0.731	1,703	58.434	0.000
ORI	3.672	11	0.983	1,703	3.737	0.000
MBG_W	101.784	11	0.349	1,703	291.632	0.000
MBG_L	66.519	11	0.577	1,703	115.325	0.000
REC_A	78.933	11	0.497	1,703	158.942	0.000
REC_P	100.203	11	0.359	1,703	278.939	0.000
FAR	95.439	11	0.39	1,703	244.717	0.000
BD	39.422	11	0.752	1,703	52.436	0.000

Table 3 Finalcluster centers

	Cluste											
	1	2	3	4	5	6	7	8	9	10	11	12
STR	1.71	1.71	1.71	−0.13	0.43	−2.72	−1.83	1.71	−0.02	1.66	1.71	0.70
FLR	0.30	3.08	11.98	−0.24	0.31	−1.26	−0.92	19.77	−0.15	2.90	0.85	0.17
CON	0.15	0.15	0.15	0.15	0.15	−6.47	0.15	0.15	0.15	0.15	0.15	0.15
STY	−1.24	−1.02	−1.02	0.11	0.14	−0.66	−1.30	−2.35	0.22	−1.02	−1.02	−1.41
BA	−2.60	−1.85	−2.97	0.28	0.25	−1.12	−3.51	−4.10	0.18	−1.63	−2.97	−2.10
QL	0.15	−0.60	−0.60	−0.60	1.29	−0.21	−0.40	−0.60	−0.41	−0.31	−0.60	−0.60
INT_N	0.84	−0.15	−0.12	−0.41	0.77	0.09	−0.36	−0.15	−0.20	0.36	0.84	−0.18
INT_400	1.32	−0.14	0.56	−0.43	0.72	0.17	−0.41	−0.35	−0.05	0.64	1.60	0.07
ORI	−0.98	−0.84	1.04	−0.11	0.16	−0.04	−0.15	1.04	0.17	0.27	−0.92	−0.20
MBG_W	7.67	9.23	13.96	−0.20	−0.17	−0.51	−0.86	6.09	1.14	2.62	3.89	−0.24
MBG_L	4.74	3.64	7.80	−0.12	−0.30	−0.26	−0.64	3.44	1.24	2.04	8.95	−0.12
REC_A	−1.86	−2.62	−3.45	0.28	0.25	−0.32	−0.11	−0.35	−2.20	−0.52	−5.51	−0.10
REC_P	0.60	20.27	21.49	−0.02	−0.10	−0.31	−0.49	−0.68	0.19	0.56	13.62	−0.09
FAR	−1.41	2.02	5.55	−0.16	−0.27	0.28	0.60	8.98	−0.18	2.26	5.55	4.29
BD	−3.17	−1.04	−1.95	0.40	−0.54	−0.42	−0.31	−2.28	0.36	−0.84	−1.95	−1.10

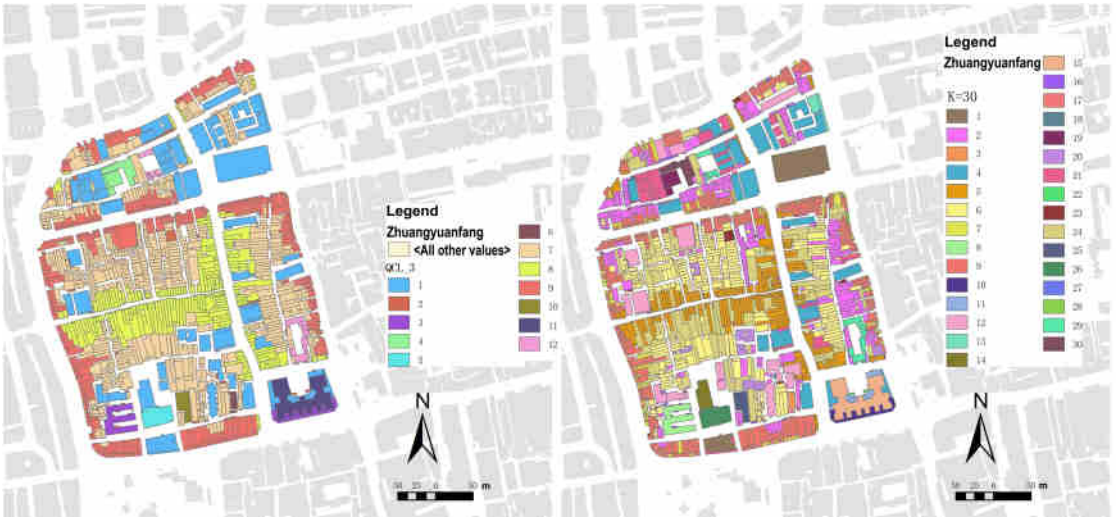

Figure 13 Morphological regions at $K=12$ (left) and $K=30$ (right)

As shown in Figure 13-15, because the present method lacks a historical evolutionary perspective and detailed investigation of plot sequences, there remains room for improvement in the subdivision of sub-regions within morphological regions. Nevertheless, comparison between Figures 14 and 15 clearly demonstrates that, after only minor operations of connection and infilling, the first-level regional delineation generated by the present method becomes almost identical to that produced by the classical approach. Overall, achieving the delineation shown in Figure 14 solely on the basis of current-condition data demonstrates that the method can provide reliable results both as a rapid analytical tool and as a foundation for more in-depth research.

Conclusion and Discussion

This study constructed a quantitative indicator system based on the constituent elements of morphological regions. The proposed method integrates the quantification

of plan types through space syntax, the calculation and visualization of graphical indicators using GIS technology, and integrative analysis through data-mining methods. It also attempts to identify land use and building function through urban big data. Using the Zhuangyuanfang Block in Guangzhou as a case study, the method produced results comparable to those obtained through the classical Conzenian approach. This demonstrates its feasibility at the micro scale. In addition, it provides a framework for interpreting analytical results and offers both data support and a customizable research pathway for further studies in urban morphology. The method may also contribute more objective results tomorphological regionalization in planning practice.

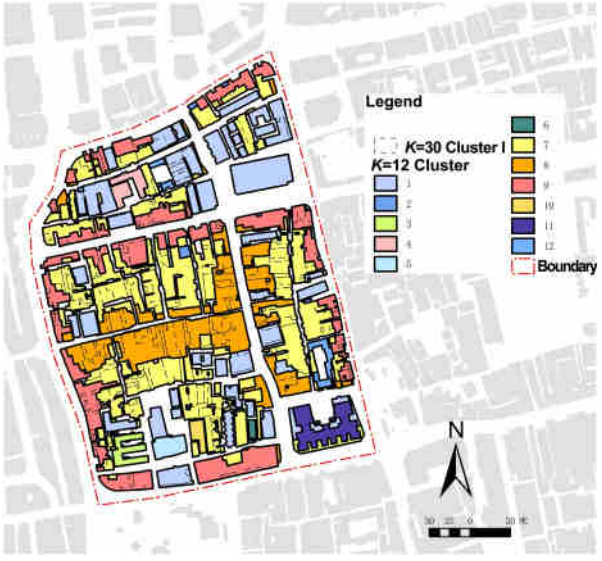

Figure 14 Superimposed map using $K=12$ for delineating major morphological regions and sub-regions, and $K=30$ for delineating the lowest-level units

Because open-source online data remain insufficiently accurate at the micro scale, their performance in functional quantification is limited. Therefore, in areas with diverse functions, more accurate functional data are required. However, in study areas with relatively homogeneous functions, such as residential blocks, the method can still achieve satisfactory regionalization results even when functional factors are excluded and only plan-type and building-type indicators are integrated[4] (Figure 12).

The quantitative method proposed in this study is based primarily on current data and lacks detailed consideration of historical evolution. As a result, differences emerge between the proposed method and the classical approach in the delineation of lower- and intermediate-level morphological regions. In addition, the selection of the *K* value remains relatively subjective, and relies on repeated experimentation and empirical judgment, which constitutes a limitation. At the same time, however, the *K* value can be flexibly adjusted according to research depth and analytical emphasis. For example, since the constituent elements of morphological regions differ in stability and exert varying degrees of influence on urban form[31], variable weights may be assigned prior to clustering according to the dominant characteristics of the study area. Likewise, if a study focuses on a particular element, the corresponding variable weights may be increased accordingly.

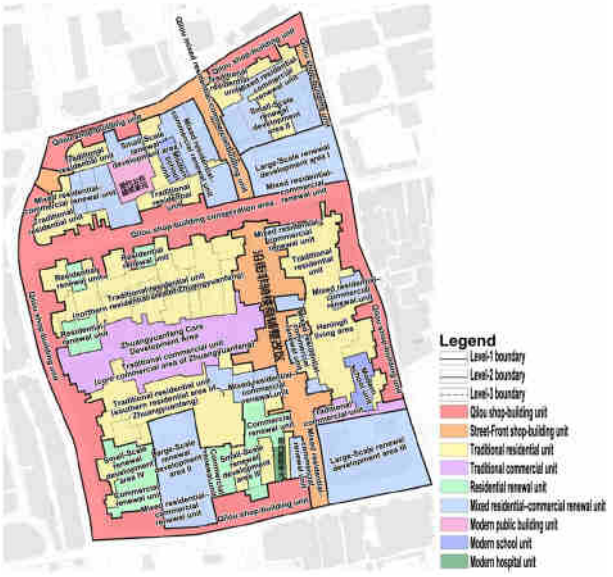

Figure 15 Morphological regions delineated by researchers using the classical morphological approach

Limited by the current scope of research in this field, there remains considerable room for improvement in both indicator selection and methods of integration. With the continuing development of information technology, artificial intelligence should also play a more important role in urban morphology research. Scholars have already applied machine learning and image recognition techniques to comprehensively evaluate street-space quality[32]. Similarly, it may be anticipated that, in future quantitative studies of urban morphology, indicators that are difficult to evaluate consistently—such as the relationship between building footprints and property plots, or architectural

character—could be uniformly identified and quantified through expert-trained artificial intelligence systems.

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Sources of Figures and Tables

Figures 10 (right) and 15 are adapted from Ref. [27].

All other figures and tables were produced by the authors.

Notes

1) *K*-means clustering, also known as the *K*-means clustering method, is a technique that rapidly classifies cases containing large volumes of data into *K* categories while minimizing the differences between the mean of each category and all objects within that category. It has the advantages of high computational efficiency and easily interpretable results, and also allows the number of categories and variable weights to be adjusted according to research needs.

2) Z-score normalization, also known as standard deviation normalization, standardizes data based on the mean and standard deviation of the original dataset. The processed data conform to a standard normal distribution with a mean of 0 and a standard deviation of 1.

3) A categorical variable is a variable used to describe categories of objects. Its values do not possess quantitative characteristics and serve only to distinguish categories.

4) Dummy variables, also referred to as nominal variables or indicator variables, generally take values of 0 or 1 and may be used to decompose and numerically represent the categories of categorical variables.

5) Metric integration, defined as the reciprocal of Mean Metric Depth (MMD), can effectively capture street segments with similar configurational characteristics and generate a "patchwork pattern," in which regions with similar numerical values display similar colors (see Ref. [33]). It reflects variations in block size and shape across different urban functional spaces (see Ref. [34]).

6) Gray space refers to transitional spaces between buildings and their surrounding environments, such as Qilou spaces and passageways, and also includes adjacent green spaces and semi-open areas.

7) Orientation refers to the clockwise angle of a building footprint measured from true north.

8) Minimum bounding rectangle refers to the minimum bounding geometry calculated in ArcGIS using the Minimum Bounding Geometry tool, with the calculation rule set to "by area".

9) Area-based rectangularity refers to the ratio between the area of a building footprint and the area of its minimum bounding rectangle. It measures the degree of similarity between the footprint and a regular rectangle. Its value range is (0,1].

10) Perimeter-based rectangularity refers to the ratio between the perimeter of a building footprint and the perimeter of its minimum bounding rectangle. It measures the degree to which the footprint approximates a rectangle or an orthogonally distorted rectangle, such as an "L"-shaped form.

11) In statistical analysis, variables with significance values (Sig.) below 0.05 are generally considered to make significant contributions to clustering, and the clustering results may therefore be retained.

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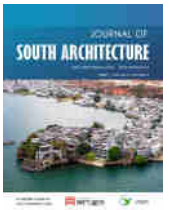

Public Perception of South China Historical Trails: A Case Study of Xijing Historical Trail

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ABSTRACT: The South China Historical Trails are being upgraded as a key aspect of new policies towards rural vitalization and targeted poverty alleviation. As an important example of linear cultural heritage, it is widely examined by local and international scholars. However, the effectiveness of their adaptive reuse is rarely evaluated due to the trails' extensive distribution, different construction contexts, and the diversity of users. In this study, the multiple benefits of adaptively reusing Xijing Historical Trail were investigated from the perspective of public perception through a case study based on the Ruyuan Section. A multiple linear regression model was applied. It is assumed that the public perception of the multiple benefits from the adaptive reuse of the South China Historical Trails would correspond with the planning objectives and expectations. Public perception was divided into three dimensions: Cultural inheritance, site usage, and economic promotion. A questionnaire survey based on a Likert scale was conducted at fixed places, supplemented by structured household questionnaire interviews in the village. A total of 230 questionnaires were collected. Results demonstrated that respondents' overall evaluation of the South China Historical Trails was positive, but they only had a vague understanding of specific functions such as cultural inheritance and economic promotion. There is a significant positive correlation between respondents' overall satisfaction and cognition of multiple benefits. According to further multiple linear regression model fitting, the regression equation between multiple benefit perception and overall satisfaction of respondents has explanatory power. As the linear heritage corridor and cultural path that carry special historical and cultural values, the South China Historical Trails are different from other recreational trails. However, this study found that site usage makes a greater contribution to improvement in respondents' satisfaction than cultural inheritance and economic promotion. To fully strengthen the cultural inheritance benefits of the South China Historical Trails, their functions of historical protection, cultural education, and recreation should be fully integrated to improve the site usage experience's comfort and interest. Meanwhile, it is necessary to explore effective ways of economic promotion in conditional and potential areas. In addition, the adaptive reuse of such heritage requires long-term, comprehensive, and multi-stakeholder participation and continuous investment. From this perspective, the adaptive reuse of the Ruyuan Section of Xijing Historical Trail as the South China Historical Trails is still in the early exploration stage. The full realization of its cultural, economic, and social benefits must be verified over a longer period. Based on this analysis, some specific improvement suggestions were proposed for the Ruyuan Section of Xijing Historical Trail: (1) Strengthen status maintenance, adopt an asset-light investment strategy, and optimize the historical trail network continuously. (2) Deepen historical exploration and show local characteristics by combining with the culture of the Yao Nationality. (3) Strengthen industrial planning, promote multiple participation, and perfect the relevant industrial chains. Moreover, some potential goals for the overall adaptive reuse of the South

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China Historical Trails were proposed: (1) Create activity-friendly designs and optimize the space by orienting to different activity preferences. (2) Implement low-cost, easy-maintenance, and inclusive strategies oriented towards sustainable long-term governance. (3) Explore historical connotations, highlight cultural heritage, and ensure sustained investment in fundamental research.

KEY WORDS: linear cultural heritage; cultural routes; South China Historical Trails; public attitude; public recognition; multiple benefits; improvement strategies

Introduction

Linear cultural heritage is one of the important concepts of international cultural heritage derived from cultural routes. It refers to the clusters of tangible and intangible cultural heritage in a linear or strip-shaped area with a special collection of cultural resources [1, 2]. It is integrated with a series of heritage protection concepts such as heritage corridors, historical routes, and cultural corridors in order to reflect the integrity and continuity of natural and human landscapes, reproduce the historical activities and migrations of humankind, as well as the exchange and interaction of material and cultural resources. It has important humanistic significance and multi-dimensional cultural connotation value [3, 4]. China's linear cultural heritage has distinct characteristics such as abundant resources, wide coverage, long history, huge span, long-lasting function, and strong vitality [5]. Represented by the Grand Canal, the Silk Road, and the Tea Horse Road, China's linear cultural heritage has become an important carrier for national ecological and cultural protection, leisure and recreation, aesthetic enlightenment, and education, for which extensive conservation work has been carried out [6－8].

As a core linear element of China's ancient regional transportation system, the historical trails bear witness to national integration and ethnic exchange, a memory of major historical events in China, and a spatial link containing regional "cultural genes," encompassing rich historical, social, economic, and cultural values. In order to implement the spirit of General Secretary Xi Jinping's important speeches on cultural confidence and "bringing the cultural heritage scattered across the vast land to life" and "preserving the roots of history", Guangdong Province has been carrying out the protection and utilization of the South China Historical Trails since 2016 [9]. Currently, the relevant research mainly consists of three parts: First, historical research and heritage status assessment, such as research on the historical and geographical contexts and the rise and fall of the South China Historical Trails [10, 11], the composition, cultural characteristics and value assessment of heritage along the route [12, 13], etc.; second, research on planning and design strategies and methods, such as restoration and construction techniques, thematic route design methods, signage and interpretation schemes, outdoor activity planning, etc. [14－16]; and third, research on activities undertaken along the route, such as a review of the construction effects of the "cultural and creative platform" based on professional volunteers and public participation [17], a survey of the "village revitalization through the road" effect perceived by villagers [18], and a study on tourism impressions based on multi-source data [19]. However, research on the planning, revitalization, and protection of the South China Historical Trails still shows a clear phenomenon of practice taking precedence over theory, resulting in limited ability of theoretical research to guide practical work and thus constraining the current construction of historical trails.

The fundamental purpose of adaptively reusing the South China Historical Trails is to provide the public with meaningful linear activity spaces. This meaninglies not only in leisure and use functions, but also in triggering users' emotions and resonance. Therefore, public attitudes are closely related to the prospects of heritage adaptive reuse [20]. It is necessary to further examine the attitudes and cognition of the public and explore the alignment between the expected goals of the action and the actual progress and effects, so as to provide a reference for future work. Public perception surveys primarily focus on respondents' perceptions of specific elements such as spaces, activities, or behaviors. These perceptions are in-

fluenced by a variety of complex factors, including personal behavioral preferences, post-use evaluations, public opinion guidance, and subjective value judgments. Currently, they are widely used in various fields such as tourism development, planning and construction, and public policy. For example, it has been used to investigate the perception of tourism impact among residents of tourist destinations in the context of tourism development [21]; it has been used to investigate the degree of support of residents along the route for planning behavior and the implementation effect of planning concepts in multi-level government governance in the context of planning and construction [22]; and it has been more widely used in public policy and health and hygiene in many complex issues such as public behavior [23], social issues [24], physical diseases [25], and policy formulation [26]. The main analytical methods used are structural equation modeling [27], Analytic Hierarchical Analysis [28], and importance-performance analysis [29]. Overall, public perception research focuses more on the attitudes, preferences, and needs of the public as the ultimate stakeholders in complex policies and behaviors. It is particularly important to point out that public perception surveys can provide an important lens for understanding the construction effectiveness of the South China Historical Trails, without being limited by the differences in context, quality, and resources between the routes. Against this backdrop, this paper, in conjunction with the expected goals of the plan, proposes multiple benefit evaluation factors for the adaptive reuse of the South China Historical Trails based on the multiple linear regression model analysis method commonly used in structural equation modeling. The first batch of demonstration sections is selected as examples to conduct an empirical survey on the public's perception of the multiple benefits of adaptive reuse.

1 Expected multiple benefits

1.1 Overall work implementation progress

Since the proposal of the South China Historical Trails, the rescue survey of historical sites and relics along the route has been carried out rapidly, becoming an important supporting basis for the formulation of relevant plans and their adaptive reuse. In 2017, the "Overall Plan for the Conservation of the South China Historical Trails in Guangdong Province" proposed a network of historical trails covering the entire province, encompassing 21 prefecture-level cities and 103 districts and counties, and connecting more than 1,160 cultural and natural development nodes. According to statistics from the Guangdong Provincial Department of Natural Resources, by the end of 2020, the repair and construction of 18 routes with a total length of 1,200 km, 588 nodes, and more than 1,500 supporting service facilities had been completed, and a large number of outdoor sports, tourism, and study tours had been carried out.

1.2 Planning objectives and expected multiple benefits

The overall plan for theconservation of the South China Historical Trails proposes to create linear cultural spaces that meet the needs of modern life for the public, inject new momentum into the development of underdeveloped towns and villages, promote economic development along the historical trails, and realize the overall vision of the revival of historical trail culture. It also specifies three concrete goals (Table 1): First, generating cultural inheritance benefits. Through the investigation, excavation, sorting, and dissemination of the rich historical and cultural resources and connotations along the routes, it aims to inherit excellent historical culture, enhance cultural confidence, and strengthen local attachment; second, delivering site usage benefits. By adaptively reusing the route network and nodes, it aims to create venues that meet the public's needs for leisure, cultural education, and the outdoor sports industry, thereby facilitating public use, providing historical and cultural education scenarios, and promoting the development of public health undertakings; and third, providing economic promotion benefits. Relying on the historical trail network to drive the development of related industries along the routes, it aims to achieve urban-rural interaction, rural revitalization, targeted poverty alleviation, and economic development.

Table 1 Expected benefits of the adaptive reuse plan for the South China Historical Trails

Expected benefits	Corresponding planning objectives	Specific content proposed by the planning objectives
Cultural inheritance benefits	A heritage path of Chinese civilization showcasing Lingnan's historical culture and regional features	Showcase the history, culture, and regional features of Lingnan, and inherit Chinese civilization: systematically organize and explore the post road culture with its traditional cultural connotations and geographical features, make the past serve the present, innovate and bring the cultural heritage scattered across the vast land of southern Guangdong, and make it a well-known cultural brand of Guangdong Province. At the same time, connect with surrounding provinces and cities as well as the national network of historical trails, laying the foundation for the application of national heritage routes and world cultural heritage status.
Site usage benefits	A healthy path promoting outdoor sports and rural tourism in Guangdong	Provide fitness venues and promote the development of outdoor sports and rural tourism in Guangdong: Responding to the national fitness plan, utilize the South China Historical Trails routes and their nodes to carry out various forms of outdoor sports, meet the growing leisure needs of the people across the province, and drive the development of the outdoor sports industry along the route.
Economic promotion benefits	An economic path promoting the interactive urban-rural economic development in eastern, western, and northern Guangdong, and achieving targeted poverty alleviation	Promote the interactive development of urban and rural economies in eastern, western and northern Guangdong and achieve targeted poverty alleviation along the route: Seizing the opportunities of national policies such as building characteristic towns, beautiful villages and targeted poverty alleviation, promote the construction of characteristic towns and villages and poverty-stricken villages along the historical trail, and promote the balanced development of the regional economy in impoverished areas of eastern, western and northern Guangdong and the whole province.

2 Public perception survey

2.1 Research scope

As one of the earliest, longest, and best-preserved historical trails in the South China Historical Trails Network, Xijing Historical Trail is one of the earliest routes to undergo restoration and adaptive reuse. It is also one of the earliest restored, most well-known, and most widely used historical trails among the South China Historical Trails. This study selected the Ruyuan Section of Xijing Historical Trail, which was among the first to be restored, as the research scope. It investigated the route characteristics and benefits perceived by users from three aspects of the South China Historical Trails: Cultural inheritance, site usage, and economic promotion (Figure 1).

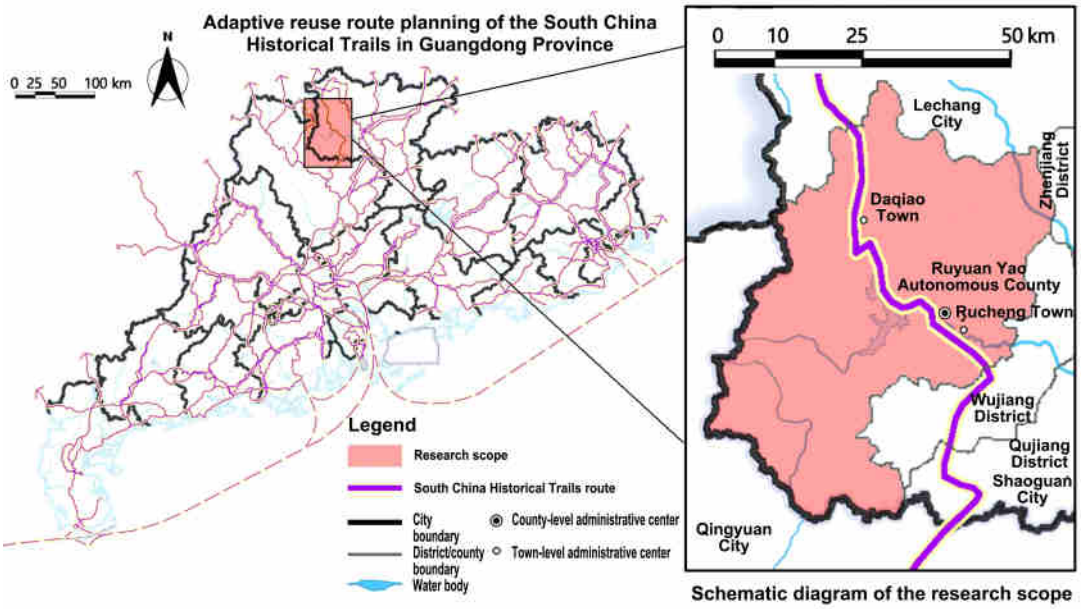

Figure 1 Research scope

Relying on the "Xijing Road" built in the second year of Jianwu in the Eastern Han Dynasty (26 AD) as the base, the Ruyuan Section was established through the restoration of the historical trail itself, the construction of connecting lines, and the restoration of heritage ruins and remains from 2016 to September 2020. It has formed a total length of 97.6 km, connecting 11 sections of the historical trail itself, 35 historical trail-related relics, 7 red cultural sites, and 10 natural resource landscapes, which cover 10 administrative villages and more than 110 natural villages within a 5 km radius along the route, forming a "colorful post-town trail". Relying on the South China Historical Trails, about 30 large-scale events have been held in this section, including professional sports events, folk activities, leisure tourism festivals, and historical trail study tour activities. Through these activities and capital diversion, comprehensive environmental improvement and the construction of a demonstration zone for the production and marketing of characteristic agricultural products have been vigorously promoted[30].

2.2 Data collection

This study primarily employed a method of distributing and collecting questionnaires at fixed locations, supplemented by structured household interviews, to collect data. The fixed locations included 6 public activity areas within 2 km of the built South China Historical Trails in Ruyuan County, namely the center of Ruyuan County, Ruyuan Characteristic Town, the center of Daqiao Town, and the Laling section, Shimen'ao section, and Wuliqiao section of the Ruyuan Section of Xijing Historical Trail. The door-to-door interview locations included four villages or communities along the historical trail, namely the center of Daqiao Town, Laofuwu Village, Daqiao Village, and Laowu Village (Figures 2 and 3). The selection of locations for questionnaire distribution and door-to-door interviews took into account the suggestions of the local historical trail management department, and combined the differentiated composition of urban residents, township residents, and rural residents concerned in the questionnaire, as well as the spatial proximity between popular historical trail routes and survey locations, so as to avoid situations where respondents lacked activity experience and cognitive basis regarding the historical trails.

Figure 2 Ruyuan section of Xijing Historical Trail (Daqiao Town section)

Figure 3 Ruyuan section of Xijing Historical Trail (Laling section)

A total of 230 questionnaires were distributed on-site during the three-day field survey, yielding 219 valid questionnaires, with an effective rate of 95.2%. Analysis of the respondents' basic information (Table 2) shows that the survey has universality and representativeness, and there is no serious bias towards any particular group.

Table 2 Summary of respondents' basic information

Item	Category	Proportion/%
Gender	Male	57.99
	Female	42.01
Age group	Under 18 years old	17.34
	18 – 25	15.07
	26 – 30	10.96
	31 – 40	21.92
	41 – 50	11.87
	51 – 60	12.79
	Above 60	10.05
Education	Primary school and below	9.59
	Junior high school	21.46
	High school/vocational school	29.22
	Junior college	21.46
	Bachelor's degree or above	18.27

(Continued)

Item	Category	Proportion/%
Born locally	Yes	48.86
	No	51.14
Long-term local resident	Yes	61.64
	No	38.36
Household registration type	Urban household registration	43.38
	Rural household registration	56.62
Hiking/m untaineering enthusiast	Yes	55.71
	No	44.29
Profession	Government agencies/public institutions/civil servants	10.50
	General staff/workers of companies/enterprises	22.84
	Professionals in the culture, education, and health sectors	1.37
	Self-employed/freelancer	13.24
	Farmers and rural migrant workers	10.50
	Student	23.74
	Unemployed or retired	10.96
	Other	6.85

2.3 Research methods and contents

At present, the evaluation of the effectiveness of linear landscape planning, including greenways, historical trails, and blueways, is often constrained by differences in spatial scale and usage frequency [31 - 33]. For example, historical trails are characterized by their wide spatial distribution, complex built and natural environmental elements along the route, and significant differences in the dominant functions and spatial quality of the linear landscapes themselves. Moreover, due to differences in the usage methods, purposes, and frequencies of the user groups, different groups of people will have significant inherent differences in their perception of linear landscapes across different regions and under different conditions, making it difficult to reflect the overall construction effectiveness of the historical trail. To address this issue, this study focuses on the perceptions of local residents along the Ruyuan Section of Xijing Historical Trail. By distributing questionnaires and conducting door-to-door interviews at multiple typical locations, it expands the diversity of respondents in terms of economic and social conditions, places of residence, activity preferences, and frequencies of historical trail use, thereby ensuring the representativeness of the survey.

In terms of the analytical model, a multiple linear regression modelwas adopted. It is assumed that residents' perception of the multiple benefits from the adaptive reuse of the South China Historical Trails and the planning goal expectations correspond to three dimensions: The perception of cultural inheritance benefits, the perception of site usage benefits, and the perception of economic promotion benefits. Consequently, the residents will thereby form an overall understanding and evaluation of the adaptive reuse work. This study first analyzes the planning objectives of the South China Historical Trails by combining relevant government documents. Then, it determines the factors influencing each dimension by combining specific sub-planning objectives. The Likert scale was used to measure the main factors of public perception, and calculations and tests were performed to achieve a detailed analysis of the cognition of multiple benefits from the adaptive reuse of the South China Historical Trails and public satisfaction. Among them, Likert scales have 4, 5, 6, and 11 levels. Generally, the more levels there are, the more refined the measurement [34]. Considering the respondents' experiences and information validity, this paper selected the 5-level scale and the 11-level scale for questionnaire design. The specific research steps were as follows:

(1) Understanding the public's overall satisfaction with the Ruyuan Section of Xijing Historical Trail. Since this perception is relatively abstract and emotional, an 11-point Likert scale was used to improve the quality of the data, with 0 to10 representing the degree from very dissatisfied to very satisfied.

(2) Understanding the public's cognition level regarding the benefits of the Ruyuan Section of Xijing Historical Trail in three aspects: Cultural inheritance, site usage, and economic promotion. Seventeen sub-item assumptions for the benefit dimensions were proposed (Table 3), using a 5-point Likert scale where 1 to 5 represent the public's strong disagreement, disagreement, neutrality, agreement, and strong agreement with the benefits, respectively.

Table 3 Assumptions of multiple benefits of the adaptive reuse of the South China Historical Trails

Benefit dimension		Sub-items of each benefit dimension	
x_1	Cultural inheritance	E1	Conducive to cultural preservation and development
		E2	Enabling the public to understand local culture better
		E3	Making the public proud of their local area
		E4	Making the public optimistic about the future development prospects of the historical trails
		E5	Making the public proactively visit here for activities again
		E6	Making the public recommend others to visit here for activities
x_2	Site usage	E7	The current state of construction making the public satisfied
		E8	The current state of maintenance making the public satisfied
		E9	The activity arrangements along the route making the public satisfied
		E10	The natural scenery viewed along the route making the public satisfied
		E11	The cultural landscapes viewed along the route making the public satisfied
		E12	The historical and cultural knowledge gained along the route making the public satisfied
		E13	The preservation status of historical relics along the route making the public satisfied
x_3	Economic promotion	E14	Bringing new job opportunities to the local area
		E15	Increasing local residents' income
		E16	Attracting more investment to the local area
		E17	Promoting local industrial development

(3) Analyzing the current public perception and satisfaction with the benefits achieved by the Ruyuan Section of Xijing Historical Trail through the obtained questionnaire survey data, and conducting confirmatory factor analysis (CFA) (validity verification). Constructing a multiple linear regression equation (Equation 1) to model the impact of the public perception of the site usage, cultural inheritance, and economic promotion benefits on their satisfaction regarding the adaptive reuse of the South China Historical Trails, and performing data fitting verification.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon \quad (1)$$

In the formula, y represents the overall public satisfaction; β_0 represents a constant; x_1 represents the perceived evaluation of cultural inheritance benefits; x_2 represents the perceived evaluation of site usage benefits; x_3 represents the perceived evaluation of economic promotion benefits; ε is the random error; and β_1, β_2, and β_3 represent the regression coefficients of x_1, x_2, and x_3, respectively.

Before fitting and verification, the overall satisfaction and benefit cognitions need to be normalized (Equation 2), and the range of values should be compressed to 0 – 1 to eliminate the analysis distortion caused by the different magnitudes of the variable values.

$$x_i = (x_{i0} - x_{imin})/(x_{imax} - x_{imin}) \quad (2)$$

In the formula: x_{i0} is the original value of each variable; x_{imax} is the maximum value of each variable, which is 11 for overall satisfaction and 5 for the benefits of the three dimensions; x_{imin} is the minimum value of each variable, which is 1.

2.4 Data reliability verification

Reliability analysis of the 17 benefit dimensions assumptions revealed that the data reliability was high and could be used for further processing (Table 4). Through validity analysis (confirmatory factor analysis, CFA), it was found that the dimensions had good discriminant validity, but items E4 and E13 needed to be removed (Table 5). After removal, the data were re-validated. The standard loading coefficients were greater than 0.7, the *P*-value indicated significance, and the MI index values were all less than 10. The total of 15 multiple benefit assumptions constructed across the three dimensions met the statistical data quality requirements and could be further analyzed.

3 Empirical findings

3.1 Public perception and satisfaction with the multiple benefits of the adaptive reuse of the Ruyuan Section of Xijing Historical Trail

(1) Overall satisfaction was high, with Promotors be-

ing the majority of evaluators

The survey on the public's overall satisfaction with the adaptive reuse of the Ruyuan Section of Xijing Historical Trail showed an average score of 8.43 and an NPS of 40.18%. The respondents were generally satisfied, with the majority being Promotors (Figure 4).

Table 4 Data reliability analysis

Benefit dimension		Dimension sub-items	Cronbach's α if item deleted	Cronbach's α coefficient
x_1	Cultural inheritance	E1	0.909	0.923
		E2	0.908	
		E3	0.909	
		E4	0.909	
		E5	0.909	
		E6	0.907	
x_2	Site usage	E7	0.945	0.949
		E8	0.942	
		E9	0.937	
		E10	0.940	
		E11	0.939	
		E12	0.940	
		E13	0.944	
x_3	Economic promotion	E14	0.896	0.907
		E15	0.872	
		E16	0.871	
		E17	0.88	

Table 5 Data validity analysis

Dimension sub-items	Factor loading coefficient analysis	MI index analysis		
	Standard load factor	Cultural inheritance	Site usage	Economic promotion
E1	0.814**	—	1.986	2.43
E2	0.806**	—	9.811	0.869
E3	0.814**	—	3.039	3.11
E4	0.819**	—	2.286	2.258
E5	0.824**	—	13.58	0.245
E6	0.822**	—	0.76	4.611
E7	0.795**	2.167	—	1.257
E8	0.818**	0.002	—	0.189
E9	0.890**	0.72	—	0.044
E10	0.880**	8.89	—	5.126
E11	0.893**	0.379	—	0.569
E12	0.884**	0.497	—	0.114
E13	0.818**	10.921	—	9.279
E14	0.757**	0.377	0.134	—
E15	0.817**	0.502	0.177	—
E16	0.903**	0.014	0.258	—
E17	0.888**	1.348	0.188	—

** $p< 0.01$. Note: The MI index test for items E4 and E13 yielded values greater than 10, so they were removed.

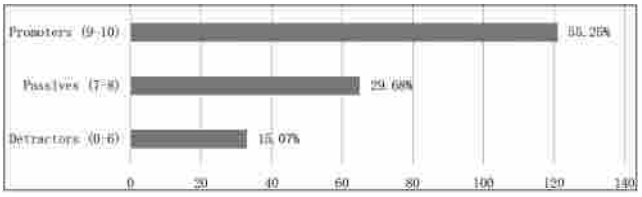

Figure 4 Distribution of overall satisfaction evaluation types

(2) The public rated the benefits of cultural inheritance the highest and the benefits of economic promotion the lowest

A detailed evaluation across three dimensions revealed that the public tends to approve of the multiple benefits of the adaptive reuse of the Ruyuan Section of Xijing Historical Trail, and their expectations for it are optimistic. The cultural inheritance dimension received the highest score, followed by site usage, while economic promotion received the lowest (Table 6). Regarding the economic benefits, it was found that the impact was not significant in terms of either overall industrial development or personal income increase. In particular, respondents held a neutral attitude toward the increase in personal income. In terms of site usage benefits, the evaluation of the site maintenance status and the arrangement of activities along the route was obviously lower than the mean value.

3.2 Linear regression analysis of multiple benefit perceptions and satisfaction

(1) The public multiple benefit perception and overall satisfaction scores are significantly correlated

After normalizing the data on overall satisfaction and multiple benefit perceptions, correlation analysis was per-

formed using SPSS software. The results showed a significant positive correlation among the fourvariables. That is, the higher the perception of a certain benefit dimension, the higher the perception of the other dimensions, and the higher the benefit perceptions, the higher the overall satisfaction rating, and vice versa (Table 7).

Table 6 Evaluation of the multiple benefits of adaptive reuse of the Ruyuan Section of Xijing Historical Trail

Benefit dimension		Sub-items of each benefit dimension		Perceived mean of	
				Sub-item score	Dimensional scores
x_1	Cultural inheritance	E1	Conducive to cultural preservation and development	4.35	4.26
		E2	Enabling the public to understand local culture better	4.26	
		E3	Making the public proud of their local area	4.31	
		E5	Making the public proactively visit here for activities again	4.24	
		E6	Making the public recommend others to visit here for activities	4.15	
x_2	Site usage	E7	The current state of construction making the public satisfied	4.09	4.11
		E8	The current state of maintenance making the public satisfied	4.01	
		E9	The activity arrangements along the route making the public satisfied	4.02	
		E10	The natural scenery viewed along the route making the public satisfied	4.15	
		E11	The cultural landscapes viewed along the route making the public satisfied	4.17	
		E12	The historical and cultural knowledge gained along the route making the public satisfied	4.21	
x_3	Economic promotion	E14	Bringing new job opportunities to the local area	3.86	3.93
		E15	Increasing local residents' income	3.87	
		E16	Attracting more investment to the local area	3.99	
		E17	Promoting local industrial development	4.01	

Table 7 Correlation analysis of multiple benefit perceptions and overall satisfaction evaluation

	Overall satisfaction evaluation	Economic promotion benefit perception	Site usage benefit perception	Cultural inheritance benefit perception
Overall satisfaction evaluation	1	—	—	—
Economic promotion benefit perception	0.359**	1	—	—
Site usage benefit perception	0.506**	0.481**	1	—
Cultural inheritance benefit perception	0.421**	0.628**	0.678**	1

** $p< 0.01$

(2) The regression equation holds true, but only the perception of the location usage dimension significantly affects the overall satisfaction score

Further linear regression analysis revealed that the regression equation for multiple benefit perceptions and overall satisfaction was explanatory, with an R-squared of 0.276. The model did not exhibit multicollinearity, meaning that the public perceptions of cultural inheritance benefits, site usage benefits, and economic promotion benefits could explain the 27.6% change in the public's overall satisfaction with the adaptive reuse of the South China Historical Trails. As an explanatory model, it showed a good fit (Table 8). Among them, the public perception of the benefits of site usage significantly affects overall satisfaction, while the perception of cultural inheritance benefits and economic promotion benefits has less obvious impacts. All three scores are positively correlated with overall satisfaction.

3.3 Survey results

(1) A total of 219 valid questionnaires were collected from the public along the Ruyuan Section of Xijing Historical Trail. The demographic composition was relatively even and met the requirements of the survey subjects. After the data quality inspection, sub-items E4 and E13 were removed. The reliability and validity were good, and the

data quality met the standards. This indicates that the public's multiple benefit perception of the adaptive reuse of the South China Historical Trails can be measured by establishing evaluation criteria from three aspects: Cultural inheritance, site usage, and economic promotion. These 15 measurement indicators can reflect the public perception of the adaptive reuse benefits in the above three dimensions to a certain extent.

Table 8 Linear regression fitting results

Model	Unstandardized coefficient		Standardized coefficient	t	Significance	VIF
	B	Standard error	Beta			
Constant	0.366	0.059	—	6.237	0.000**	—
Cultural inheritance benefit perception (x_1)	0.091	0.106	0.077	0.863	0.389	2.369
Site usage benefit perception (x_2)	0.413	0.083	0.396	4.991	0.000**	1.866
Economic promotion benefit perception (x_3)	0.117	0.073	0.121	1.608	0.109	1.668
R^2	0.276					
F	27.322**					
D-W value	1.973					
Dependent variable (y): overall satisfaction evaluation (Model fitting formula: $y = 0.366 + 0.091x_1 + 0.413x_2 + 0.117x_3$)						

** $p < 0.01$

(2) The survey results show that the public has a high overall satisfaction with the South China Historical Trails, represented by the Ruyuan Section of Xijing Historical Trail, and the respondents are mainly Promoters. In specific multiple benefit perception measurements, the overall public evaluation was relatively positive. However, the perception of economic benefits was weak, especially regarding the increase in personal income, where respondents tended to be neutral ("neither agreeing nor disagreeing"). In terms of site usage benefits, the perceived evaluation of the current state of site maintenance and the arrangement of activities along the route is low, which means that the level of understanding and satisfaction regarding the spatial quality and activity planning of the historical trail is also low.

(3) Correlation analysis revealed that the public perception of the benefits of cultural inheritance, site usage, and economic promotion is significantly positively correlated with their overall satisfaction with the adaptive reuse of the South China Historical Trails. That is, the higher the public scores on the three aspects, the higher their overall satisfaction with the South China Historical Trails, and vice versa.

(4) Through multiple linear regression fitting verification, the multiple linear regression equation of the multiple benefit perception factors affecting the satisfaction regarding the adaptive reuse of the South China Historical Trails was obtained. Based on the aforementioned survey results, although for the general public, the mean values of the perceived benefit evaluation ranked from highest to lowest as follows: Cultural inheritance, site usage, and economic promotion. In terms of the relationship between individual satisfaction and multiple benefit perception, the individual's perception of the benefits of site usage currently has the greatest impact on their satisfaction.

4 Conclusions and discussion

As a linear heritage corridor and cultural route carrying special historical and cultural value, the South China Historical Trails have historical and cultural value as their core characteristic that distinguishes them from other types of leisure trails. An empirical survey of the Ruyuan Section of Xijing Historical Trail showed that, among the three dimensions of cultural inheritance, site usage, and economic promotion, respondents had the highest perception ofcultural inheritance and the lowest perception of economic promotion. Statistical analysis further shows that, compared with cultural inheritance and economic promotion, site usage contributes the most to improving satisfac-

tion. That is, improving the quality of the site and the user experience will effectively enhance the public satisfaction with the adaptive reuse of the South China Historical Trails. To address this issue, we should fully integrate the historical preservation, cultural education, and leisure and recreation functions of historical trails, enhance the comfort and interest of the user experience, and explore effective ways to promote economic development in areas with suitable conditions and potential. It must be pointed out that the adaptive reuse of cultural routes is not something that can be accomplished overnight, but rather a long-term undertaking that requires comprehensive, multi-faceted, and sustained investment from various stakeholders. From this perspective, the adaptive reuse of the Ruyuan Section of Xijing Historical Trail and even the South China Historical Trails are still in the early exploratory stage, and the full realization of their cultural, economic, and social benefits requires a longer period of time to verify. In addition, the empirical evidence from the Ruyuan Section of Xijing Historical Trail further demonstrates the need for differentiated improvement of the local and universal characteristics of the South China Historical Trails.

4.1 Problems and optimization suggestions for the Ruyuan Section of Xijing Historical Trail

The Ruyuan Section of Xijing Historical Trail is highly representative among the South China Historical Trails, mainly due to its comprehensive planning and construction, rich historical and cultural resources, excellent historical relics, an active series of themed activities, and proactive government action. However, its adaptive reuse work still faces urgent pressure, mainly manifested in some design and operational issues that still need to be resolved. For example, some sections of the route are of low quality, with unclear signage and unknown routes; the use of the route for historical and cultural education relies too much on irregular activities and lacks regular operation; and the relatively low level of local economic development leads to high maintenance and management costs, and the investment in activity planning relies on special government funds while social participation is limited. These objective conditions directly affect its future sustainable development. Interviews with community management departments, residents, and hotel management in Daqiao Town revealed that, despite being an advanced area in the construction of the historical trail, it has not yet generated a large-scale tourism economy, and its interaction with surrounding hot spring resort hotels needs to be strengthened. In response to the above problems, this study proposes three specific suggestions.

First, we should strengthen the status maintenance, adopt a light-asset investment strategy, and continuously optimize the historical trail network. Considering the local financial situation and theobjective condition that Xijing Historical Trail is long and extends deep into the mountains, we should attach importance to its current state maintenance and conservation, and adopt a strategy of light asset investment, refined management, and micro-renovation to promote its sustainable development of adaptive reuse. For example, by reviewing the current construction status, we can conduct detailed designs for key nodes, optimize the existing network of the historical trail, enhance the continuity of the route, improve the signage system, and propose feasible low-cost maintenance solutions. On the other hand, it is necessary to fully integrate existing financial, material, and human resources. For example, we should vigorously integrate special funds such as rural living environment improvement funds, subsidies for traditional rural building renovation projects, and subsidies for ethnic minority infrastructure construction, and promote the integration of the historical trail network with the environmental improvement of towns and villages along the route; and widely attract and accept technical support from professional volunteer activities, targeted poverty alleviation work, etc.

Second, we should deepen historical exploration, closely integrate it with Yao culture, and showcase local traditional characteristics. Ruyuan is a Yao Autonomous County. Theadaptive reuse of the South China Historical Trails must fully explore the historical value of the historical trail resources in the development of ethnic and local

culture, and further integrate them with local customs, culture, and history in the process of further construction, maintenance, and operation. For example, conducting in-depth historical research along the route, exploring local characteristic historical activities, folk customs and stories, folk specialties and skills, etc., so that the construction content and activity themes of the South China Historical Trails can be deeply connected with the history of surrounding ancient villages, the Yao ethnic folk culture along the route, and resources such as red culture. Tourism projects can be developed or promoted with historical stories, figures, and historical concepts as the center, and art projects that connect historical heritage with contemporary culture can be encouraged. Take the famous European cultural route "Destination Napoleon" as an example. This route spans 10 countries and 50 cities. Although people have different opinions about Napoleon along the way, his personal deeds and local history are still undeniably deeply connected. To this end, the route has developed an experiential project by revitalizing and interpreting Napoleon's deeds, using it as a historical landmark of the route, thus deeply exploring the historical and cultural value of the route itself.

Third, we should strengthen industrial planning, promote diversified participation, and improve related industrial chains. To further leverage theadaptive reuse of the Ruyuan Section of Xijing Historical Trail to drive rural revitalization and industrial development along the route, we should not limit ourselves to developing tourism projects based on the historical trail itself or a few cultural relic sites along the route. Instead, we should take into account all factors, including the ancient road itself, cultural relics sites along the route, surrounding ancient villages, agricultural resources, nature reserves, and national forest park resources, and make a full industrial plan to give full play to the advantages of integrating multiple resources. We should further strengthen cooperation between the government and enterprises, especially with local small and medium-sized enterprises, to promote local products while optimizing and improving the quality of the historical trail space. For example, Ruyuan County is rich in agricultural resources and has agricultural products that are recognized as part of the national-level rice-fish integrated farming demonstration zone. It can further improve agricultural experience-themed activities by combining them with historical trail study tours, adding content on agricultural production experience, agricultural knowledge education, certification, and sales of specialty agricultural products, and extending the industrial chain. Take the famous European cultural route "Via Francigena" as an example. This route spans four countries: the United Kingdom, France, Switzerland, and Italy. One section, the "Pilgrim's Belt", traces the connection between pilgrimage history and local traditional foods, and discovers that the area produces a large number of "pilgrim foods" that have a long shelf life, are easy to carry, and are suitable for long-distance travel. The management of the route conducts pilgrim food certification, connects local food production workshops, and makes them the industry's calling card for this section.

4.2 Implications for the adaptive reuse of the South China Historical Trails

Combined with the concurrent surveys on theadaptive reuse of the South China Historical Trails in Huizhou, Shanwei, Zhuhai, Zhongshan, and other places, it was found that the survey results of this study can also inspire the actual work of various cities, and provide a reference for improving the quality of space, highlighting social construction, showcasing historical culture, and strengthening event planning in the overall work.

First, we should develop activity-oriented design and optimize space qualityby orienting to different activity preferences. The survey found that users of the historical trail routes include not only residents of surrounding urban and rural communities, but also tourists and outdoor sports enthusiasts, and their needs are not the same. Therefore, it is necessary to fully respect the safety, accessibility, and comfort needs of residents in their daily lives, as well as the requirements of visitors for activities that are fun, challenging, and continuous. How to integrate the differentiated needs of ordinary residents, tourists, and outdoor

sports enthusiasts should be an important consideration in formulating strategies for improving spatial quality, and should also be the basis for decision-making in the planning of route themes.

Second, a low-cost, easy-to-maintain, and inclusive strategy oriented towards sustainable and normalized governance should be implemented. As linear landscapes, historical trails, like greenways and blueways, are characterized by their wide spatial distribution, significant differences in spatial location and accessibility, and complex built and natural environmental elements along their routes. In this regard, we should fully draw on the experience of greenway construction in Guangdong, and conduct detailed design and construction in accordance with local conditions and the frequency and preferences of the main activities, avoiding excessive standardization, artificial construction, and especially emphasizing the low cost, ease of maintenance, inclusiveness and expansion potential of the construction and maintenance of historical trails, so that the feasibility and sustainability of maintenance and management become the key determining factors in planning, design and implementation.

Third, we should explore historical connotations, highlight cultural inheritance, and ensure sustained investment in basic research. Upholding the historical and cultural significance of the South China Historical Trails, we will showcase historical stories and local characteristics through more experiential and immersive innovative methods, thereby enhancing the effectiveness of cultural inheritance. It is recommended that, on the one hand, we should further strengthen the construction and research of the basic theoretical system of the South China Historical Trails, enhance local archaeological capacity building and knowledge of historical and cultural heritage protection, and conduct thorough excavation, collation and interpretation of archaeological results through in-depth work such as excavation of historical artifacts, collection and sorting of documents, and verification of historical events. On the other hand, we should further strengthen the presentation of historical points of interest, enhance the reproduction of the historical connotation of southern Guangdong as an indispensable node connecting national, ethnic, and cultural identity, and conduct systematic research on the role and value of the South China Historical Trails as a means of connecting the Central Plains, linking southern Guangdong, and reaching the world.

Fourth, we will further strengthen the responsibilities and roles of government cultural and tourism departments in theadaptive reuse of historical trails. Compared to the housing and construction departments, whose main responsibility is construction, the cultural and tourism departments have a longer-term institutional foundation, richer social resources, and more professional technical reserves in the adaptive reuse of cultural heritage, and should become the key promoters of the adaptive reuse of the South China Historical Trails. Based on a comparison of the implementation and management of existing surveys in various regions, the cultural and tourism departments represented by Luofu Mountain Scenic Area are relatively well-developed in terms of cultural and historical resource excavation, project construction and management, signage system design, route maintenance and management, theme activity planning, financial fundraising, and long-term development planning. This is quite different from routes that rely on townships, streets, and housing and construction or natural resources departments for management. Of course, it must be pointed out that the adaptive reuse model that relies solely on government special funds and human resources has serious sustainable development problems. In the long run, the participation of social capital and the cultivation of local knowledge will always be the key driving force for the adaptive reuse of the South China Historical Trails.

Finally, since this paper is based on a questionnaire survey of a small group of people in a specific region, it has certain limitations in reflecting the overall construction of theadaptive reuse of the South China Historical Trails. Moreover, the overall work on the South China Historical Trails has only been carried out for about 5 years. It should be recognized that the multiple benefits

generated are phased and long-term, as well as the impact of other potential factors on public perception. Therefore, the adaptive reuse and improvement of the South China Historical Trails still need to be carried out in a longer and more continuous manner through operation, monitoring, and research.

Sources of Figures and Tables

Figures 1 and 4: Drawn by the author;

Figures 2 and 3: Photographed by the author;

Table 1: Compiled by the author based on the Overall Plan for the Protection and Utilization of the South China Historical Trails in Guangdong Province (Guangdong Construction Regulation [2017] No. 233);

Tables 2-8: Created by the author.

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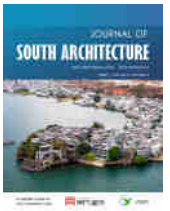

A Study on the Influencing Factors of the Cultural Image Perception in Subway Station Space: Taking the Subway Stations in the Historic Districts of Beijing as Examples

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ABSTRACT: In the new round of urbanization, subway construction has increasingly become the main axis of coordinated urban underground space development. As the engineering and technical problems are better solved, the construction and transformation of underground space turns to pay more attention to creating spatial "images" that satisfy psychological experiences, and to strengthen the "thematic" relationship between the above-ground and underground spaces. Based on the application of the theory of image creation in underground space and the coordination of urban public cultural construction, many cities have engaged in spatial practices using subways as cultural media carriers, prompting the gradual interpretation of the subway station space as a symbol for inheriting regional culture and displaying urban images. In the process of transforming the essence of subway station space design from "function" to "human-centricity", the expression of cultural images such as the city's regional characteristics, historical heritage, and place spirit has become the core issue in related practice and research. Although existing studies have conducted a certain degree of normative research on the environmental elements and design strategies that enhance the expression of cultural images in subway stations, they have ignored the empirical analysis of cultural image influencing factors measured from the perspective of the user's subjective perception. Therefore, this study draws upon a literature review and analysis to extract variable evaluation indicators that characterize the cultural image of subway station space and environmental design factors, aiming to investigate in depth how the environmental design of subway station space can effectively strengthen the cultural image perception of the surrounding area.

The study takes the typical historical and cultural subway stations adjacent to historical districts-Nanluoguxiang Station, Shichahai Station, Yonghegong Station, and Zhangzizhong Road Station as the research objects, while defining both the above-ground and underground parts of the subway station as the spatial research scope. It obtained the data of the users' perception and evaluation data of cultural images and related environmental elements, through 252 Likert scale questionnaires, and combined SPSS and AMOS software to systematically and quantitatively analyze the environmental design factors that affect the perception of cultural images in the subway station space and their degree of correlation, with a view to providing reasonable optimization strategies and development suggestions for relevant cultural practices on subway stations. The evaluation indicators of the questionnaire include two parts. One is the perception result of the cultural image of subway station space, including the cultural atmosphere, historical background, image taste, and regional characteristics as the evaluation indicators. Secondly, the environmental design factors affecting the perception of the cultural image of the subway station are classified into above-ground and underground spaces. The above-ground part involves 7 evaluation indicators, including spatial scale and outline, feature and style, detail elements, accessibility to tourist attractions, open space

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connection, landscape features, and entrance signage. Underground space involves 8 evaluation indicators, including the visual interface of subway station hall, platform area, auxiliary facilities, public art, signage system, thematic atmosphere, and spatial experience.

In order to determine the environmental design influencing factors of the cultural image perception of subway station space, and to find the internal structural relationship between the variables, the research first uses exploratory factor analysis (EFA) to divide the initial 15 environmental design indicators into reasonable dimensions, and thenthe structural validity test was carried out by confirmatory factor analysis (CFA), and the relationship model between the common factors of environmental design and the corresponding heading items was revised. Finally, in order to establish and verify the structural model of the perception of spatial cultural images in subway stations, the research employs structural equation model analysis (SEM), taking the result of perception of spatial cultural images in subway stations as the dependent variable and the common factor of the space environment design as the latent variable to verify the variables, including the influence relationships, the degrees of association and the regression path coefficients among them.

The research results show that: (1) In the evaluation of cultural image perception, the item expressing the historical heritage of the location has the highest score. In the horizontal comparison of the comprehensive evaluation of the cultural image of the 4 sample subway stations (Yonghegong Station > Nanluoguxiang Station > Shichahai Station > Zhangzizhong Road Station), the evaluation results are basically consistent with the current environmental status of the built spaces of each subway station; (2) based on the exploratory factor analysis results, the main dimensions of the space environmental design of the subway station are determined to be three aspects: Feature coordination, interface decoration, and service facilities. Based on the confirmatory factor analysis to optimize the measurement model and structural model, the correlation between environmental design factors and cultural image perception was analyzed. The three latent variables all have a significant positive impact on cultural image creation and have different degrees of influence. The degree of correlation is F1 feature coordination > F2 interface decoration > F3 service facilities, and the environmental design factors are significantly positively correlated. Therefore, if the overall design between the three can be coordinated, the cultural image expression of the subway station space can be effectively strengthened; (3) the demographic variable difference test shows that factors such as gender, age, education level, and occupational background have no obvious influence on the perception and evaluation of cultural images and environmental design factors of the interviewees, which proves that actively creating cultural images of subway station space universally applicable to all demographic groups; (4) based on the structural equation model verifing the causal relationship between environmental design factors affecting cultural image perception, the model fitting results are effective and credible. The regression path coefficients of the three latent variables of feature coordination, interface decoration, and service facilities are 0.40, 0.37, and 0.23, respectively. The correlation coefficients of the three latent variables have increased, indicating that the respondents' perception of the cultural image of the subway station space comes primarily from the recognition and judgment of the coordination of the characteristics of the historical district station area, followed by the decoration of the spatial interface in the subway station. Information transmission is affected to a certain extent by the quality characteristics of the spatial service facilities inside and outside the subway station. The more obvious the design intention of the subway station's spatial environment, the stronger the cultural image perception.

Finally, based on the results of quantitative analysis, the study puts forward the strategic suggestions and a design process for systematically-shaping the cultural image of subway station space from five aspects: Creating an integrated human-centric space environment, coordinating the surrounding features of subway stations, strengthening the construction of underground space scenes, improving the human-centric service facilities in the station area, and cooperating to build the overall cultural image of the city.

KEY WORDS: subway station space; cultural image; perception; environmental design; influencing factors

Introduction

With the ongoing process of urbanization, subway systems have become a major driver of coordinated underground urban development. The extension and expansion of subway station space plays a key role in the construction of the urban above-ground and underground public space system. It is not only crucial for improving land use and trafficconditions in old urban areas [1], but also plays a positive role in preserving regional cultural heritage and inheriting urban culture. Although engineering and technical problems have been largely solved, environmental psychological issues, such as how to eliminate the public's negative perceptions regarding the use of space and enhance their willingness to participate in activities, still constrain the optimal development of underground space [2]. In response, many studies have proposed using Lynch's theory of urban image as a strategy to improve the image of the underground space environment. According to Lynch, urban environments possess legibility, and their environmental image is a product of an individual's direct perception of the external environment and past ex-

perience memory [3]. Underground space also constitutes environmental order through a series of recognizable elements such as edges (interfaces), paths, landmarks, and districts, presenting its own place characteristics and emotional connotations [4,5]. It is this perceptible place attribute that highlights the "value and significance" of underground space and enhances the public's sense of identity [6]. Therefore, the new round of construction and renovation of underground space pays more attention to creating imageable spaces that satisfy psychological experiences and strengthening the "thematic" connection between above-ground and underground spaces [7].

Subway stations are not only nodes in the transportation network, but also places rooted in the urban area [8]. Based on the application of the theory of creating underground space images and the coordination of urban public culture construction, many cities have launched spatial practices using the subway as a cultural medium. Subway station space has gradually evolved into a symbolic gateway and iconic place for inheriting urban culture. As the design principles of subway station space shift from "function" to "human-centricity," the expression of cultural images such as urban regional characteristics, historical heritage, and the sense of place has become a core issue in related practices and research. The design of subway station space should not only meet functional requirements, but also enhance the identity of the place, highlight the regional image characteristics, and improve the cultural experience [9]. The cultural representation of subway station space should explore the historical and cultural elements around the station, echo the landmark buildings, translate above-ground geographic and cultural information into symbolic underground spatial elements in the form of symbols, create landmark references and memory points [10], and integrate underground and above-ground cultural resources by strengthening the spiritual connection between subway stations and ground information nodes, and helping users form a coherent understanding of the city [11]. The spatial cultural image of subway stations is generated in the process of users' overall perception of the subway station and its surrounding environment. The cultural image of subway station spaces is generated through users' overall perception of both the station and its surrounding environment. It conveys and expresses urban cultural meanings by extracting and abstracting characteristic environmental elements and by using the physical space of the subway station as an information carrier.

Existing literature has conducted some normative research on environmental factors and design strategies for enhancing the expression of cultural image in subway station space. Peng Di proposed that the physical structure of subway stations is the basis for generating thesense of place. The sense of identity and belonging of the station should be strengthened from the aspects of human-centric design, diversified experience, landscape integration, and cultural context assimilation [12]. Li Chongrui proposed that the creation of the cultural image of subway stations should take the cultural characteristics of the station area as the guiding thread. The interior space should use cultural elements to decorate the interface, strengthen the integrated design of auxiliary facilities, and the outdoor space should continue the regional cultural context and integrate the pedestrian sightseeing routes [13]. Based on the premise that the subway station area serves as a carrier of the urban landscape, Xu Xiaoxu extracted the elements of regional cultural expression from the three levels of urban area, station area transition, and underground space, and used the Analytic Hierarchy Process (AHP) method to summarize and analyze the element weights and propose design strategies [14]. However, existing research neglects empirical analysis of the influencing factors of cultural image measured from the user's subjective perception perspective, and is predominantly qualitative, lacking quantitative research. Therefore, this paper aims to conduct an in-depth study on how the environmental design of subway station space can effectively enhance the perception of the cultural image of the area. Four typical subway stations in the historical districts of Beijing are selected as research objects. By designing a questionnaire survey on cultural image and environmental elements, user perception evaluation data are collected. Combined with SPSS and AMOS software, a systematic quantitative analysis of environmental design factors that affect the cultural image perception of subway station space and their correlation is conducted, in order to provide reasonable optimization strategies and de-

velopment suggestions for related cultural practices in subway station areas.

1 Overview of the research sample

1.1 Classification of Beijing subway stations

Based on the dominant functions of land use around subway stations, subway stations in Beijing can be divided into four categories: Transportation hub type, public center type, residential type, and historical and cultural type [15]. The station area of historical and cultural stations mainly consists of historical districts, scenic spots, heritage conservation units, museums, exhibition halls, and other cultural facilities, and mainly serves tourism and leisure experiences. The study takes typical historical and cultural subway stations adjacent to historical districts as the research object.

1.2 Samplestation selection

The old city area in the center of Beijing, shaped like the Chinese character "凸" (convex), has the most concentrated cultural resources and is also a hotspot for the perception of regional cultural images. Beijing's relevant plans have successively designated 33 historical and cultural conservation areas in the old city area. Based on this, the Beijing Urban Master Plan (2016－2035) has identified 13 key areas with outstanding historical and cultural value as cultural essence zones. The study selected four subway stations—Nanluoguxiang, Shichahai, Yonghegong, and Zhangzizhong Road—as samples. These stations are concentrated in the cultural essence areas of Shichahai-Nanluoguxiang, Yonghegong-Guozijian, Zhangzizhong Road North-Xintaicang, and Zhangzizhong Road South-Dongsi Third to Eighth Streets in the northeast corner of the old city (Table 1 and Figure 1). Given that the area is a gateway space for tourism, the Beijing Municipal Commission of Planning and Natural Resources has carried out planning and renovation of key stations based on human-centric concepts since 2010. At present, the design practices of the four sample subway stations in terms of entrance and exit environment, station building, integrated interior decoration, and public art have received a lot of positive feedback (Figure 2).

Table 1 Location information of sample stations

Stations	Category	Line	Main adjacent historical districts	Main types of adjacent cultural facilities
1. Nanluoguxiang Station	Transfer station	Lines 6 and 8	Nanluoguxiang	Former residences of historical figures and religious temples
2. Shichahai Station	Ordinary station	Line 8	Shichahai	Scenic spots, former residences of historical figures, religious temples
3. Yonghegong Station	Transfer station	Lines 2 and 5	Yonghe Temple-Guozijian	Scenic spots, religious temples
4. Zhangzizhong Road Station	Ordinary station	Line 5	Zhangzizhong Road South, Zhangzizhong Road North	Former residences of historical figures

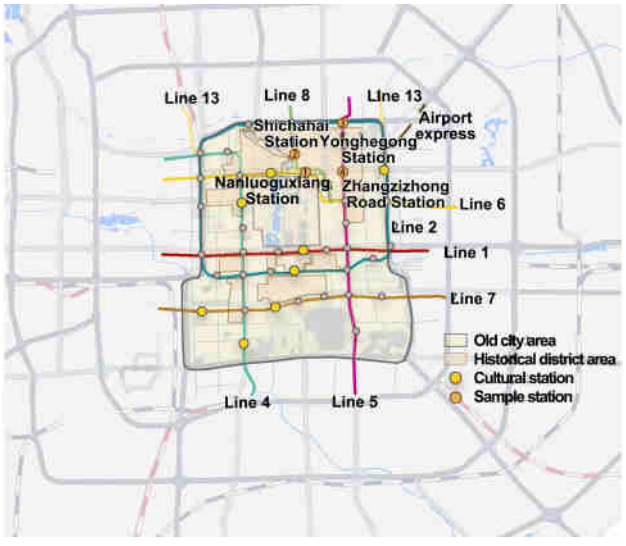


Figure 1 Location map of the sampled stations

1.3 Spatials cope

The research space includes both above-ground and underground areas. The above-ground portion refers to the area within a 100 m radius of station entrances and exits. During the construction and renovation of the subway station, this area can participate to a large extent in the environmental design of the public space around the station, including the coordinated renovation of buildings and streets, and the configuration of landscape facilities. The underground portion refers to the independent functional areas within the subway station. The focus of environmental design is on the main passenger gathering and distribution spaces, such as concourses, platforms, and transfer passages.

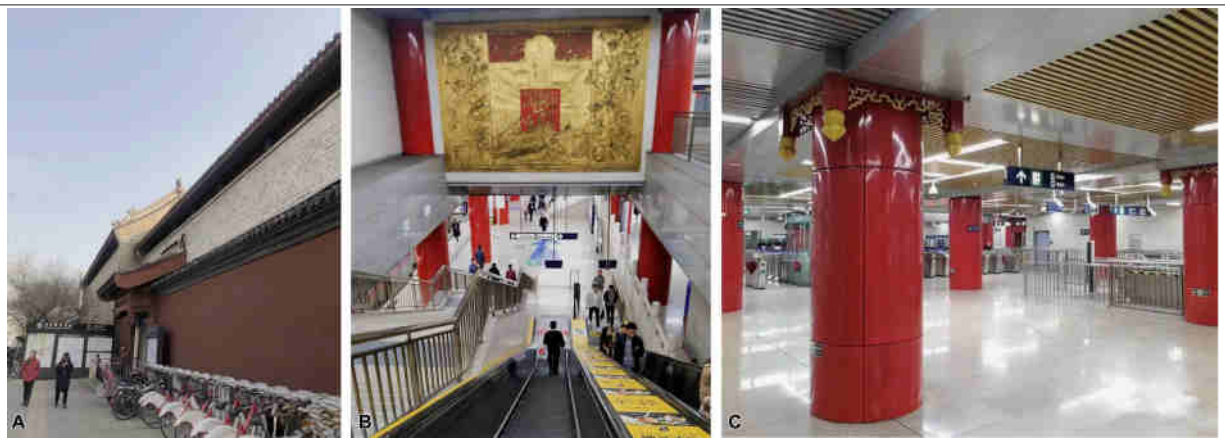


Figure 2 A, B, C: Current status of the indoor and outdoor environmental design at Yonghegong Subway Station

2 Research design

2.1 Indicator extraction and construction

In contrast to environmental implications, Lynch defined the material environment as an independent variable. The spatial cultural image of a subway station is a collection of comprehensive perceptions and experiences, and its creation and expression are subject to the allocation and control of the material elements of the subway station's spatial environment. Material elements are independent variables, while the cultural image perception is the dependent variable. After setting keywords on domestic and international academic platforms such as CNKI, the study retrieved and screened 50 relevant articles (2006 – 2019), and extracted evaluation indicators for characterizing variables based on literature review and analysis. The cultural image of subway station space is inherently abstract and difficult to observe directly. To balance the perception levels of cultural image in multiple dimensions, evaluation indicators are extracted from four aspects: Cultural atmosphere, historical background, image taste, and regional characteristics[10, 13, 14, 16, 17] for description (Table 2). The environmental design factors affecting the cultural image perception of subway stations are classified into unknown dimensions. Therefore, based on the physical structure of the subway station, it is classified into two parts: Above-ground (outdoor) space and underground (indoor) space. The above-ground space is directly related to the external environment (historical district), involving seven evaluation indicators: The scale and outline of connecting spaces, style, detail elements, accessibility to tourist attractions, open space connection, landscape features, and entrance signage [13, 14, 18, 19]. The underground space involves eight evaluation indicators: The visual interface of the subway station hall and platform area, auxiliary facilities, public art, signage system, scene theme, and spatial experience [10, 13, 14, 20 – 22] (Table 3).

Table 2 Evaluation indicators for cultural image perception

Evaluation objectives	Evaluation indicators	Document frequency
Overall perception	C1 Enhancing the cultural atmosphere	19
	C2 Showcasing historical heritage	35
	C3 Shaping image and taste	35
	C4 Reflecting regional characteristics	41

Table 3 Environmental design evaluation indicators related to the creation of cultural image

Evaluation objectives	Evaluation indicators	Document frequency
Above-ground space	S1 Scale and outline suitability	12
	S2 Style suitability	15
	S3 Detail elements suitability	13
	S4 Accessibility to tourist attractions	12
	S5 Open space connectivity	8
	S6 Landscape feature suitability	10
	S7 Entrance signage suitability	11
Underground space	S8 Public art suitability	11
	S9 Wall and column surface aesthetics	19
	S10 Ceiling surface aesthetics	16
	S11 Paving and enclosure aesthetics	15
	S12 Wayfinding system suitability	24
	S13 Seating, lighting, and other auxiliary facilities suitability	17
	S14 Thematic atmosphere fit	32
	S15 Cultural experience diversity	6

2.2 Questionnaire design and distribution

The questionnaire is divided into three parts. The first part is demographic statistics, including four questions: Gender, age, education level, and occupation. The second part is the evaluation of the overall perception of the cultural image of the subway station space, which includes 4 items, corresponding to the evaluation indicators in Table 2. The third part is the evaluation of the environmental design elements of the subway station's above-ground and underground spaces, which includes 15 items, corresponding to the evaluation indicators in Table 3. The second and third parts consist of scale items, using a 5-point Likert scale to differentiate the perceived level of the evaluation items. The perceived values correspond to 5—very good, 4—good, 3—average, 2—poor, and 1—very poor, respectively. To ensure the relevance and effectiveness of the data collection, all questionnaires were printed and distributed on-site at multiple entrances and exits of sample subway stations from December 12 to 15, 2019. A total of 70 questionnaires were collected at each station, and the number of valid questionnaires was as follows: 65 At Nanluoguxiang Station, 61 at Shichahai Station, 62 at Yongheggong Station, and 64 at Zhangzizhong Road Station, yielding a total of 252.

2.3 Research methods

This paper investigates the environmental design influencing factors of the cultural image perception in subway station space, explores the inherent structural relationships among variables, and establishes and validates a measurement model for the cultural image perception in subway station space. Although a spatial cultural image exists objectively, its abstract nature makes it impossible to observe directly. Using structural equation modeling allows us to describe the characteristics and relationships of latent variables through some observable variables. Before applying structural equation modeling, the selected latent variables, i.e., the factors influencing environmental design, must first be categorized. Here, exploratory factor analysis and confirmatory factor analysis are used.

2.3.1 Exploratory factor analysis (EFA)

Exploratory factor analysis is used to find structural relationships between multivariate observed variables to reduce data dimensionality. It identifies the potential structure of a scale by calculating the covariance matrix and estimating factor loadings. By using exploratory factor analysis on the initial 15 environmental design indicators, several closely related items can be condensed into a few core factors (F_1, F_2,$\cdots$,F_N).

2.3.2 Confirmatory factor analysis (CFA)

Confirmatory factor analysis is used to test whether the relationships between factors and measurement items conform to the hypothesized structure. After establishing a measurement model using exploratory factor analysis, the structural validity of the existing model is verified using AMOS software, which can further refine the relationship model between environmental design common factors and indicator items.

2.3.3 Structural equation modeling (SEM)

Structural equation modeling is used to process, evaluate, and adjust multivariate models, thereby confirming or falsifying research hypotheses[23]. Using the perception of cultural image in subway station space as the dependent variable and common factors of spatial environment design (F_1, F_2,$\cdots$,F_N) as latent variables, a structural equation model is established. This model can verify whether the spatial environment design of subway stations has a positive impact on the cultural image perception, and can also analyze the degree of correlation and regression path coefficients among the variables.

3 Results analysis

SPSS software was used to analyze the valid questionnaire results. The sample of this survey was balanced in gender, wide in age distribution, covered various occupational fields, and most ofthe respondents had received higher education, so it was highly representative (Figure 3). In the reliability test, the overall Cronbach's α value for the 252 questionnaires was 0.907, and the Cronbach's α values for the Cultural Image and Environmental Factors Evaluation Scale were 0.876 and 0.837, respectively. In addition, the Cronbach's α values for the questionnaires collected from the four sample subway stations ranged from 0.867 to 0.911. In summary, the reliability test results for each part

were all greater than 0.7, indicating that the collected questionnaire data had good internal consistency and could be further analyzed. Furthermore, it was reasonable to treat the four stations as a whole for the study.

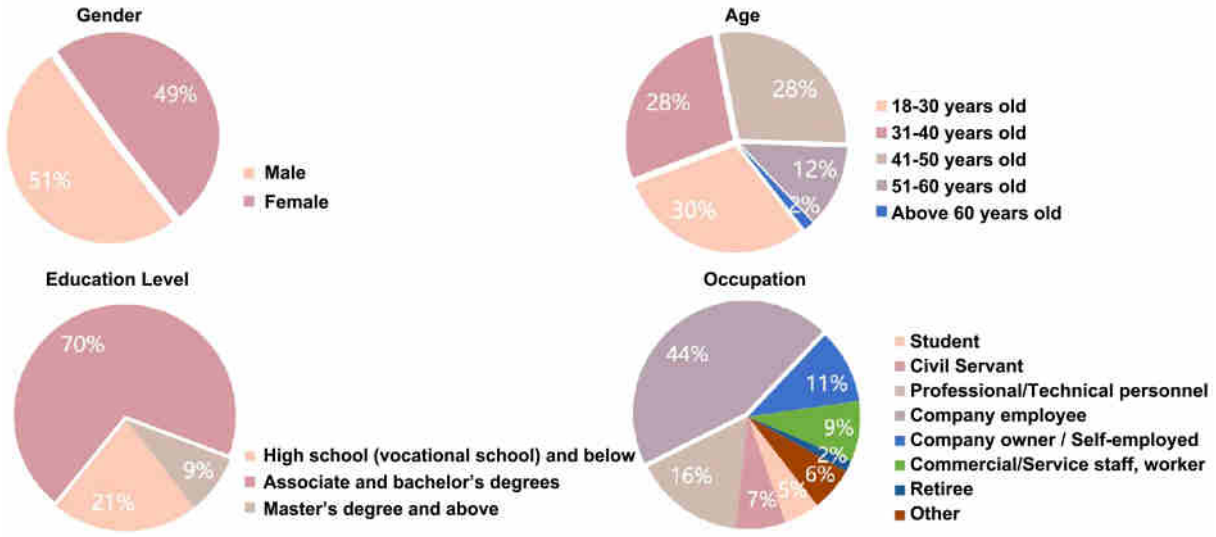


Figure 3 Demographic characteristics analysis of respondents

3.1 Analysis of the results of cultural image perception

The average score of the evaluation index for the perception of cultural image in subway stations was statistically analyzed, and the comprehensive score was 3.847, which proves that the sample subway station space is close to a good level in terms of cultural image creation. Among the four evaluation indicators, the item expressing the historical heritage of the area scored the highest, exceeding 4 points, while the other three items scored close to 4 points (Figure 4). In the horizontal comparison of the comprehensive evaluation of the cultural image of the four stations, Yonghegong Station > Nanluoguxiang Station > Shichahai Station > Zhangzizhong Road Station, with evaluation scores of 4.209, 4.069, 3.774, and 3.379, respectively. The evaluation results are basically consistent with the current environmental status of the existing spaces of each subway station.

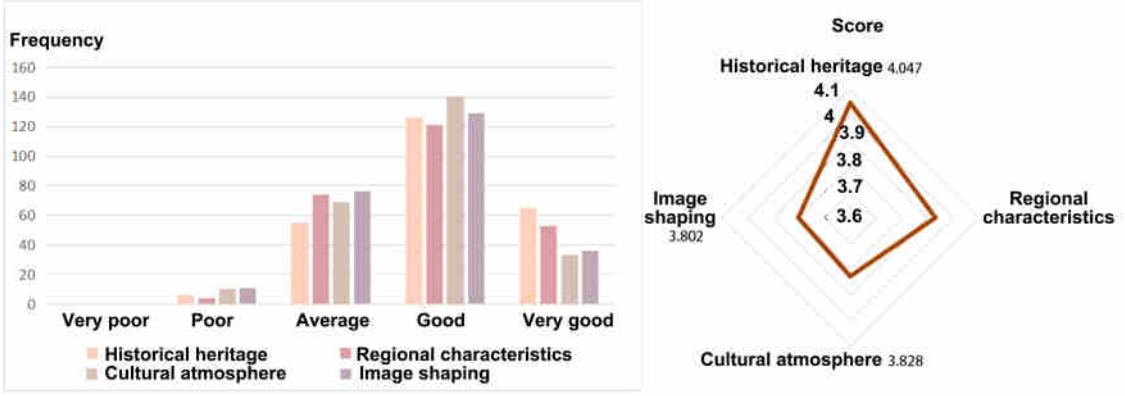


Figure 4 Evaluation results of cultural image perception

3.2 Exploratory factor analysis of environmental design evaluation elements

First, we examined whether the environmental design evaluation factor scale was suitable for factor analysis. The results showed that the KMO value was 0.871 (> 0.6); the significancep-value of Bartlett's test of sphericity was 0.000 (< 0.01), indicating that the 15 items initially selected were suitable for establishing a factor model. Common factors were extracted using principal component analysis and varimax rotation. A factor loading value greater than 0.5 was set as the extraction criterion. The results showed that only the loading value of evaluation item S15 (cultur-

al experience) did not meet the criterion, so it was deleted. The component matrix of the remaining 14 evaluation items after rotation showed 3 principal component factors, with a cumulative variance contribution rate of 63.900% (> 60%), which explained most of the information of the initial variables. Based on the content of the items involved in the three principal component factors, they are named as follows: Feature coordination common factor, interface decoration common factor, and service facility common factor (Table 4).

Table 4 Exploratory factor analysis of environmental design evaluation elements

	Common factor F_1: Feature coordination	Common factor F_2: Interface decoration	Common factor F_3: Service facilities
Cumulative contribution rate of variance	25.554%	45.104%	63.900%
Eigenvalues	3.833	2.933	2.819
Variance explained	25.554%	19.550%	18.796%
Cronbach's α value	0.888	0.855	0.844
Observed variables (Factor loading)	S2 style 0.873	S8 Public art 0.812	S13 Auxiliary facilities 0.771
	S1 Scale profile 0.854	S9 Wall and column surface 0.811	S6 Landscape feature 0.767
	S14 Theme atmosphere 0.853	S10 Ceiling surface 0.784	S12 Wayfinding system 0.738
	S3 Detail elements 0.829	S11 Paving and enclosure surface 0.780	S7 Entrance signage 0.684
	S4 Accessibility to tourist attractions 0.672	—	S5 Open space 0.550
Average rating	4.064	3.904	3.394

The common factor offeature coordination explains 25.554% of the total variance. The order of variance contribution rate is as follows: Style suitability > scale and outline suitability > (underground) thematic atmosphere fit > detail element suitability > accessibility to tourist attractions. The content mainly refers to the coordination and integration of subway station space and historical district features.

The common factor of interface decoration explains 19.550% of the total variance. The order of variance contribution rate is as follows: Public art suitability> wall and column surface aesthetics > ceiling surface aesthetics> paving and maintenance surface aesthetics. The content mainly refers to the visual interface of the subway station's underground space and the decorative and aesthetic aspects of public art.

The common factor of service facilities explained 18.796% of the total variance. The order of variance contribution rate was as follows:Suitability of auxiliary facilities such as seats and lighting > suitability of landscape features > suitability of (underground) signage system > suitability of (above ground) entrance signage > connectivity of open space. The content mainly refers to the auxiliary improvement and human-centric design of service facilities in the above-ground and underground spaces of subway stations.

Based on the dimensional division of evaluation elements for subway station spatial environment design, the average values of the evaluation results of the items covered by each common factor were calculated. The factor forfeature coordination was 4.064, the factor for interface decoration was 3.904, and the factor for auxiliary facilities was 3.394.

3.3 Confirmatory factor analysis of environmental design evaluation elements

Confirmatory factor analysis was conducted using Amos software to analyze the dimensional composition of environmental design evaluation elements. The measurement model constructed by the observed variables and their corresponding latent variables shows that there is a moderate positive correlation among the three latent variables: Feature coordination, interface decoration, and service facilities. Except for factor S5 (open space), whose loading is less than 0.5, the loadings of the other factors are between 0.51 and 0.93, which are within the acceptable and ideal range. After items that did not meet the criteria were removed and the model was optimized, the composite reliability of each dimension was greater than 0.8 (Table 5), indicating that the model had good structural validity and that all fitting coefficients reached acceptable and ideal levels.

Table 5 Confirmatory factor analysis of environmental design evaluation elements

Path	Factor loading	Averag evariance extracted (AVE)	Composite reliability (CR)
S3← F_1	0.846	0.704	0.921
S4← F_1	0.591		
S14← F_1	0.861		
S2← F_1	0.931		
S1←F_1	0.920		
S10← F_2	0.707	0.673	0.911
S11←F_2	0.706		
S9← F_2	0.869		
S8←F_2	0.875		
S7←F_3	0.511	0.508	0.800
S12←F_3	0.679		
S13←F_3	0.817		
S6←F_3	0.802		

3.4 Tests for differences in demographic variables

Independent samples t-tests were used to compare the differences in evaluations of the overall perception of cultural image and the 3 dimensions of environmental design among respondents of different genders. The *p*-values of all test variables were greater than 0.05 (Table 6), indicating that there were no significant differences in perception evaluations between men and women. One-way ANOVA was used to compare the differences in the evaluations of respondents of different ages, education levels, and occupations in the three dimensions of overall perception of cultural image and environmental design. The *p*-values of each part were all greater than 0.05 (Table 6), which was not statistically significant. This indicates that different ages, education, and occupational backgrounds have no significant impact on the perceived evaluation of cultural image and environmental design factors. This demonstrates that creating a cultural image through subway station spatial environment design has universal applicability to various groups of people.

Table 6 Results of tests for differences in demographic variables

	Gender		Age		Education level		Occupation	
	t-value	p-value	*F*-value	p-value	*F*-value	p-value	*F*-value	p-value
F_1 Feature coordination	0.015	0.988	1.198	0.311	0.592	0.554	0.375	0.916
F_2 Interface decoration	0.426	0.670	0.199	0.963	1.984	0.140	1.144	0.336
F_3 Service facilities	1.776	0.077	0.421	0.834	0.850	0.429	0.524	0.816
Cultural image	0.402	0.688	0.742	0.593	1.833	0.162	0.837	0.557

3.5 Correlation analysis of environmental design factors and cultural image perception

SPSS correlation analysis results (Table 7) show that all three principal component factors in the spatial environment design dimension of the subway station are significantly positively correlated with cultural image perception ($P < 0.01$), with the correlation degree as follows: F_1 feature coordination > F_2 interface decoration > F_3 service facilities, proving that environmental design factors have a positive impact on cultural image perception. Meanwhile, all environmental design factors are significantly positively correlated, indicating that the latent variables are not independent or exclusive material factors, but have a certain degree of interdependence and promotion, which also shows that spatial environmental perception is systematic.

Table 7 Correlation analysis of environmental design factors and cultural image perception

	F_1 Feature coordination	F_2 Interface decoration	F_3 Service facilities	Cultural image
F_1 Feature coordination	1	—	—	—
F_2 Interface decoration	0.488**	1	—	—
F_3 Service facilities	0.489**	0.337**	1	—
Cultural image	0.642**	0.593**	0.460**	1

** $P < 0.01$

3.6 Regression analysis of factors influencing cultural image perception

The causal relationship between the spatial environment design factors of subway stations and the cultural image perception was verified and analyzed using Amos structural equation modeling. The overall goodness-of-fit index was used to test the fit between the hypothetical model and the sample data. The model fit results (Table 8) show that the absolute goodness-of-fit indices GFI, AGFI (> 0.8), and RMSEA (< 0.1) meet the acceptable standards, CMIN/DF and SRMR meet the ideal standards, and the relative goodness-of-fit index also meets the standards, ensuring the validity and credibility of the research results.

Table 8 Fit coefficients and discrimination criteria for structural equation modeling

	CMIN/DF	GFI	AGFI	CFI	NFI	RMSEA	SRMR
Observed values	2.932	0.860	0.811	0.920	0.884	0.088	0.0523
Judgment criteria	< 3 Ideal	> 0.8 Acceptable	> 0.8 Acceptable	> 0.9 Ideal	> 0.9 Ideal	< 0.1 Acceptable	< 0.08 Ideal

The model results show (Figure 5): (1) The three latent variables, namely, feature coordination, interface decoration, and service facilities, which are the main dimensions of subway station space environment design, all have a significant positive impact on the creation of cultural image. Their regression path coefficients are 0.40, 0.37, and 0.23, respectively. Among them, feature coordination and interface decoration are significant at the 0.01 level, and service facilities are significant at the 0.05 level. This indicates that the respondents' perception of the cultural image of subway station space is based on the recognition and judgment of the coordination of the features of the historical district station area, followed by the information transmission of the interface decoration in the subway station space, and is also affected to a certain extent by the quality characteristics of the service facilities inside and outside the subway station space. The more obvious the intention of the environmental design, the stronger the perception of the cultural image of the subway station space; (2) in the structural equation model, the correlation coefficients of the three latent variables of feature coordination, interface decoration and service facilities have increased, and the observed variables reflecting the theme fit of the space (S14 thematic atmosphere fit, S8 public art suitability) have a high load, indicating that the various environmental design elements complement each other at the level of image perception, and should be integrated comprehensive through material media; (3) in the cultural image evaluation, the respondents have a clear and positive perception of historical heritage and regional culture, which indirectly confirms the correctness and necessity of using the subway station space as a gateway to the city for regional image marketing.

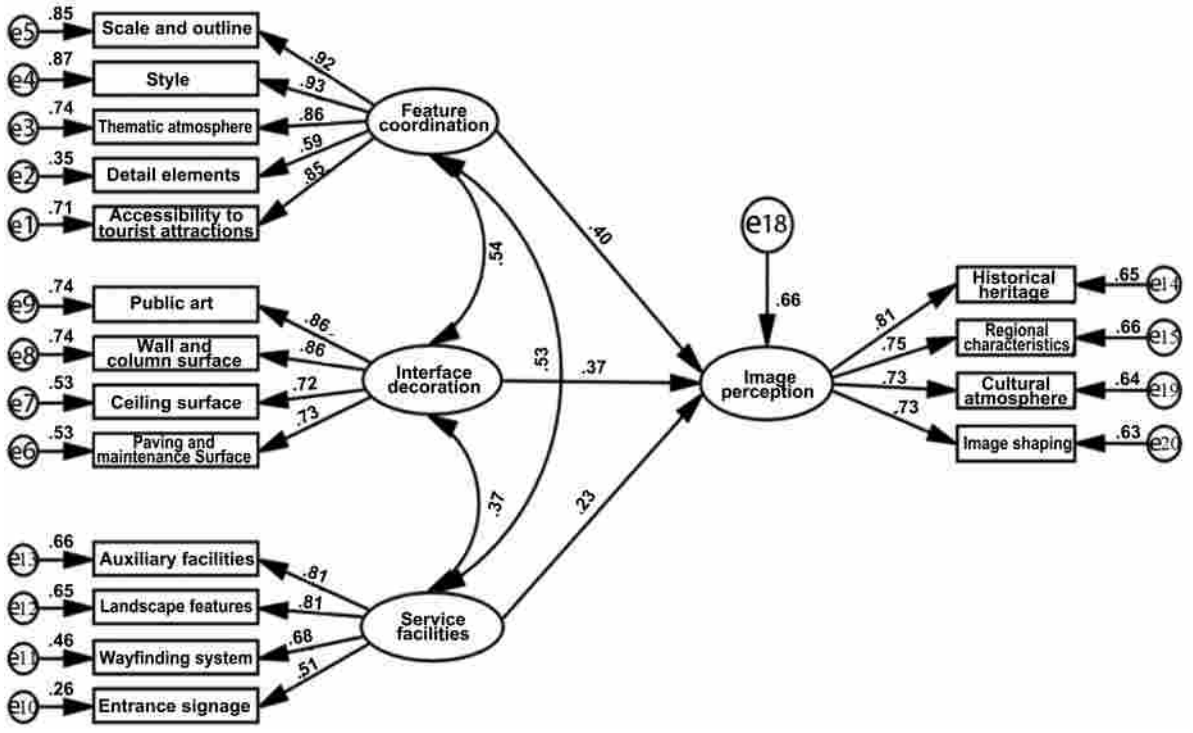
4 Strategy recommendations

Based on the results of quantitative analysis, the study proposes strategies and design processes for systematically creating the spatial cultural image of subway stations (Figure 6).

4.1 Creating an integrated human-centric spatial environment

The study concluded that environmental design factors influencing the cultural image perception in subway stations can be categorized into three aspects: Feature coordination, interface decoration, and service facilities. Coordinating these three aspects will have a multiplier effect. However, preliminary research revealed that while subway culture practices have become widespread in many Chinese cities, they largely remain at the level of interior decoration design, exhibiting problems of similarity in form and limited dimensionality. Therefore, it is recommended that subway stations in key urban areas actively expand the construction dimensions of cultural image, taking into account both the subway station area space and underground space, shifting from two-dimensional to three-dimensional and from planar to stereoscopic. Furthermore, they should carry out integrated environmental design from three aspects: Feature coordination, scene creation, and human-centric facilities. This involves mobilizing multiple disciplines such as urban design, architectural design, and landscape design to participate in relevant prac-

tices, and coordinating various environmental elements to carry out a three-dimensional and comprehensive overall expression, so as to comprehensively enhance the cultural narrative effectiveness of subway station media spaces.



F gure 5 Structural Equation Model of the relationship between Subway Station Spatial Environment Design and Cultural Image Perception

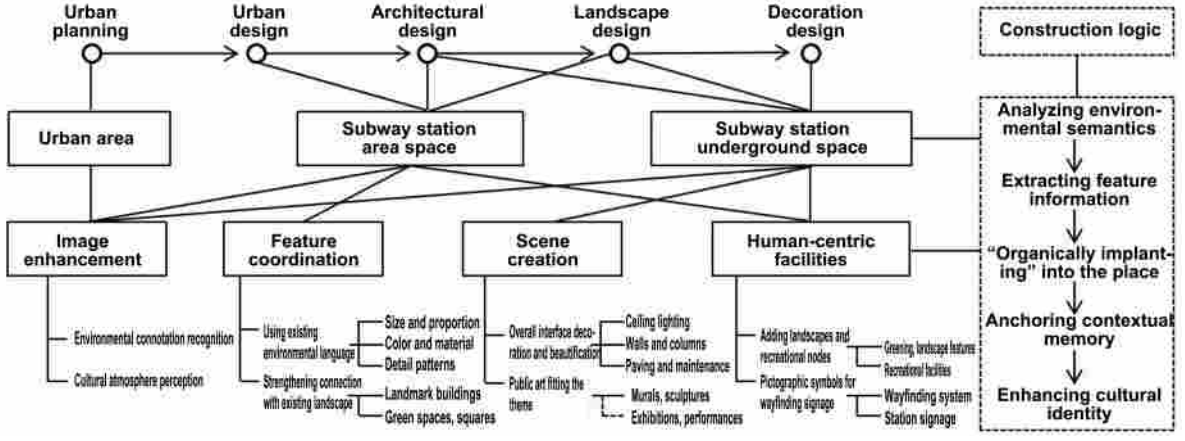


Figure 6 Design process for creating cultural images in subway station space

4.2 Coordinate the landscape features around the subway station

Feature coordination is the primary influencing factor in controlling the expression of cultural images in subway station space. The public's perception of the cultural image of subway station space is also related to their overall interpretation of the existing environment. Therefore, the design of subway station space should follow the semantic background of the surrounding environment, organically integrate into the existing site through the mining, refinement, and reorganization of characteristic information, and maintain and coordinate the authenticity and integrity of the station area's features. First, in the urban design and architectural design of the subway station entrance and exit areas, the conservation principle of "restoring the old as it was" can be appropriately adopted. The "old" historical environment can be used as the design script, and attention should be paid to the control of elements such as color and

material, height and proportion, and decorative patterns. This will ensure that the style, scale, outline, and detailed decoration maintain visual continuity with the surrounding blocks of the station area and organically continue the existing environmental context. For example, the design of Nanluoguxiang Station of the subway adopted a scheme based on the concept of "darning" (urban weaving). In the architectural and street design of the subway station entrances and exits, the traditional architectural language of the historical district was abstracted and integrated at a macro spatial scale. The sense of invasion of traffic nodes was eliminated through the isomorphic integration of environmental elements, and the historical spatial texture of the old city was restored to a certain extent (Figure 7). Secondly, the design should appropriately strengthen the connection and transition between the subway station entrances and exits and the historical districts, buildings, and other landmark landscapes. The place characteristics of the subway station are further enhanced through the "bundled" design of the two. For example, Yonghegong Subway Station has set up multiple entrances and exits that smoothly connect to the Yonghegong temple buildings, Yonghegong-Guozijian Creative Park, and the ring park, which not only improves the accessibility of the surrounding cultural space but also enhances people's perception of the station area.

Figure 7 A, B, and C: Entrance/Exit and interior space design of Nanluoguxiang Subway Station

4.3 Enhance the creation of underground space scenes

In addition to fulfilling functional requirements, the underground space of a station should also effectively connect the above-ground and underground environments, and maintain the spatiotemporal unity of thesense of place by depicting and continuing the characteristics of the above-ground place. The creation of scenes in underground spaces includes two parts: Public art and surface decoration. The former focuses on establishing the theme and conveying the "meaning" by introducing public artworks such as murals and sculptures that echo the historical districts, landmarks, and station names of the subway station areas, directly narrating the "theme" of the above-ground place. For example, there is a mural depicting the Shichahai scene in Shichahai Station and a sculpture of Zhangzizhong at Zhangzizhong Road Station. The latter focuses on expressing the "meaning" through imagery by extracting visual symbols that reflect the surrounding environment to decorate the continuous spatial interface and reproduce the above-ground scene. For example, Shichahai and Nanluoguxiang Subway Stations extract traditional architectural vocabulary such as sloping roofs, gray brick walls, and wooden rafters to decorate the ceilings, beams, columns, and walls of the stations, echoing the formal characteristics of the historical districts (Figures 7C and 8). Yonghegong Station uses golden murals, red columns, and white marble steps as elements for overall decoration to highlight the theme of religious sites (Figures 2B and 2C). The combination of public art and spatial interfaces that fit the theme of the site creates "anchor points" for the memory of the site through "scenes," which helps to strengthen people's positioning of the ground environment and form a clear spatial cognition. However, the current art practices in China's subway stations are one-dimensional and generally lack interactive cultural projects with public participation. It is hoped that temporary art activities such as exhibitions and performances can be introduced in the future to further enrich the cultural experience of subway spaces.

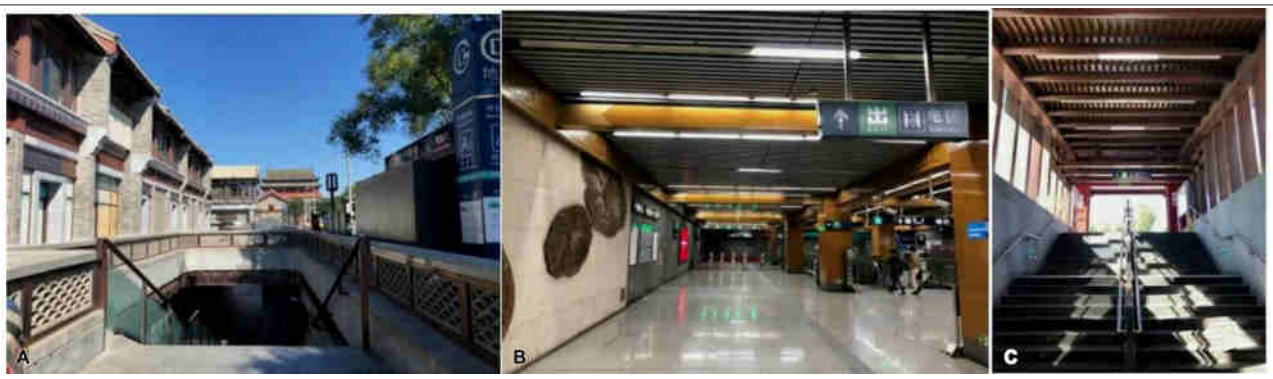


Figure 8 A, B, C: Entrance and exit design and internal space of Shichahai Subway Station

4.4 Improve the station's human-centric service facilities

Service facilities play a subtle guiding role in the gathering and movement of people, and are an invisible clue that organically connects above-ground and underground spaces. Improving the human-centric design of service facilities can further enhance the cultural image of subway station space. For landscape and recreational facilities, the leisure landscape can be transformed by adding green vegetation, sculptures, seats, and other facilities, providing places for people to stay and interact, and optimizing the recreational experience of urban nodes. At the same time, innovative design language can be used to transform the traditional form of service facilities and integrate them into the station's integrated design. For example, the Beijing Forest Park Station embeds the lighting system into the "tree branch" grid of the roof to create a continuous and unified "forest" image (Figure 9). For signage and wayfinding facilities, symbolic design can be used to represent the cultural connotation of the station area. Important buildings, landscapes, or historical events that are coupled with the subway station space can be used as pictographic objects to reconstruct the abstract cultural identity of the subway station. For example, the Xi'an Metro uses the "Xi'an City Wall" as a symbolic element for the overall identity. The identity of each station also provides a symbolic interpretation of the cultural landmarks adjacent to the station area. For example, Houweizhai station uses the ancient village gate and soldiers' armor as symbols, and Yuxiangmen uses the ancient city traffic channels and auspicious clouds as design elements (Figure 10).

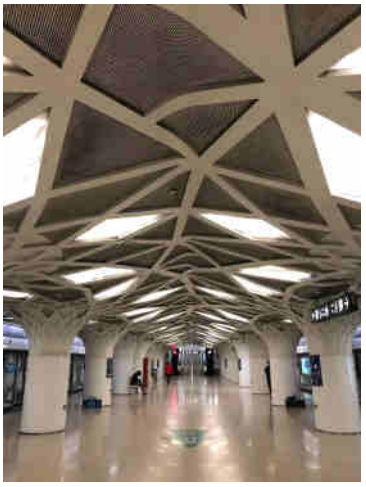


Figure 9 Lighting facilities at Forest Park subway station

Figure 10 Signage design for the Xi'an subway system and some stations

4.5 Shaping the overall cultural image of the city

The creation of a pleasant environment in subway stations can effectively enhance people's perception of regional cultural images and has a universal cultural media

function for all types of people in the city. If a cultural network can be woven around subway lines, it will comprehensively enhance the city's image, activate urban memory, highlight urban characteristics, increase local identity, and innovate the development path of the "last mile" of public cultural services. Therefore, future urban development and construction should consider strengthening the integration of rail transit planning and cultural space planning in the top-level design stage, so that more subway stations and geographical and cultural nodes can achieve a mutual feedback relationship, and realize the cultural catalyst effect of the city on a large scale by means of the "point-axis" linkage mechanism of the subway network [24].

Conclusion

In the new round of urban expansion and construction, the competition for comprehensive urban strength is increasingly focused on the contest of cultural soft power. Cultural constructionusing subways as a medium has opened up a new direction for urban cultural development. Subway station space, which is coupled with geographical and cultural nodes, has evolved into a "second space" for inheriting and showcasing regional culture. The popularization of the "human-centric turn" in subway station space design has prompted related research to focus on how to effectively create and express the essence of profound regional culture. Based on a literature review, this study selected 15 evaluation indicators for subway station spatial environment design related to the creation of cultural image, and 4 evaluation indicators for cultural image perception. Taking four typical historical and cultural subway stations adjacent to historical districts in Beijing as research objects, and using the results of 252 questionnaires as data, the study explored and analyzed the environmental design factors and dimensions that influence users' perception of the cultural image of subway station space, as well as the influence relationships between variables. Furthermore, it proposed countermeasures and suggestions for improving subway station environmental design, aiming to provide a basis and reference for the optimized development of subway cultural practices. However, the evaluation system and methods proposed in this study also have certain limitations. Further research plans should improve these shortcomings to make the research conclusions more objective and reasonable.

Sources of Figures and Tables

Figures 1 – 9: Photographs and drawings by the author;

Figure10: Compiled from online sources: https:// www.logonews.cn/xian-metrostation-sign.html; http: // www.logozhan.com/3870.html;

Tables 1-8: Drawn by the author.

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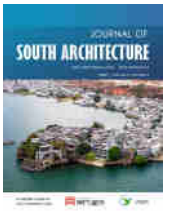

Exploration of the Renovation of Old Residential Districts in Historic Urban Areas of Guangzhou under the Concept of Complete Community

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ABSTRACT: Currently, the renovation of old residential districts is a pivotal initiative in China to improve the quality of people's lives and stimulate economic growth. Based on Wu Liangyong's concept of Complete Community, this study explored methods to reconstruct old residential districts in historic urban areas of Guangzhou into "complete communities" in order to meet the increasing demands of residents and the requirements of refined community management. This study aimed to provide a new model for the renovation of old residential districts that can be easily promoted and applied in other areas. Firstly, two renovation principles for old residential districts in historic urban areas were proposed: 1) to formulate renovation schemes according to local practical situations by respecting differences among different types of old residential districts; 2) to preserve and inherit residential cultural characteristics of local regions with respect to historical relics and the cultural network of old residential districts. Additionally, corresponding renovation strategies concerning the facilities, spaces, and governance of old residential districts were proposed. With respect to facility renovation, key attention was paid to the marketization of public services, and it was suggested that community social enterprises be built to supplement the public services of old residential districts. It was recommended that community culture be highlighted and community images be built by guiding upgrades of cultural and business facilities. Secondly, attention was paid to the protection of cultural context and texture in public space renovation, with vitality added to public spaces in communities using catalytic elements. Thirdly, regarding the governance of old residential districts, it was proposed to encourage different subjects to participate in community renovation, increase channels for residents to access information about its progress and ways to participate, and promote public participation throughout the renovation period. It was also suggested that social groups be formed to act as a third party, independent from community stakeholders, to balance the interests of multiple parties and guarantee the implementation of the renovation process. Attention should be paid to cultural development in the community, thereby fostering residents' sense of community belonging. Fourthly, the renovation modes of old residential districts were analyzed according to the positions of different subjects in the renovation process, such as the government, enterprises, residents, different aspects of society, etc. To ensure the effective implementation of the renovation schemes, old residential districts in historic urban areas should adopt a renovation mode involving the collaborative participation of multiple subjects. Finally, an evaluation index system for the renovation of old residential districts was established, which included two construction dimensions: Material space (hardware) and community governance & service (software), five level-2 factors, and 16 level-3 factors. A case study based on communities in the Old Nanhai County Community in Liurong Subdistrict was carried out to analyze renovation conditions, and some optimization suggestions were proposed. The research results provide some points of reference for the renovation of old residential districts in historic urban areas.

KEY WORDS: old residential district; complete community; historic urban area; renovation strategy; renovation mode

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Introduction

Since the reform and opening up, China has experienced a rapid urbanization process. In particular, in the mid-to-late 1980s, with the rapid development of the real estate industry, almost all old residential districts in large and medium-sized cities began to enter the stage of renovation and upgrading [1]. According to statistics, there are nearly 160,000 old residential districts nationwide, involving more than 42 million households and a building area of about 4 billion m^2 [2]. The CPC Central Committee and the State Council have successively issued a series of important documents on the renovation of old urban communities. In December 2019, the Central Economic Work Conference deployed the pilot work of the renovation of old residential districts nationwide [3]. On July 10, 2020, the *Guiding Opinions on Comprehensively Promoting the Renovation of Old Urban Communities* clarified the overall requirements, basic principles, and tasks for the renovation of old districts, established an implementation mechanism, improved supporting policies, and strengthened organizational guarantees [4]. It also proposed to promote the construction of complete residential communities and issued the *Standards for the Construction of Complete Residential Communities (Trial)* and the *Guidelines for the Construction of Complete Residential Communities* in August of the same year [5]. In March 2021, the *Outline of the 14th Five-Year Plan for National Economic and Social Development and the Long-Range Objectives Through the Year 2035 of the People's Republic of China* put forward the important task of accelerating urban renewal, which aims to transform and upgrade the functions of existing built-up stock areas such as old residential districts, old factory areas, old blocks and urban villages [6].

As a city with a thousand-year history and culture, Guangzhou took the lead nationwide in carrying out the transformation and redevelopment of existing land due to the influence of building lifespan and land economic lifespan. From the "Three Olds" renovation in 2009 to the "Urban Renewal" campaign in 2015 and the micro-renovation of old residential districts in 2016, Guangzhou completed the renovation of 799 old residential districts by the end of 2022, with a total renovation area of 45.24 million square meters, involving 620,000 households and 1.986 million people [7]. The renovation of old residential districts in Guangzhou mainly focuses on improving facilities and enhancing the living environment, but has not yet established systematic requirements for community culture and governance. Therefore, the key challenge lies in transforming these communities into Complete Communities integrating both hardware and software dimensions[1)]. Exploring a paradigm for the construction of complete residential communities is a topic worth discussing in Guangzhou, a pioneer in the micro-renovation of old residential communities nationwide.

1 Principles for the renovation of old residential districts in historic urban areas

1.1 Respect differences and adapt to local conditions

The problems of old residential districts in historic urban areas are diverse. As participants, promoters, and beneficiaries of the renovation, the residents also have different needs. Therefore, the design and construction standards for the renovation of old residential districts should not be uniformly applied. Before renovation, a detailed survey of residents' needs should be conducted in the community to understand the community culture and respect the differences between different types of old residential districts, and thus propose tailored renovation plans.

1.2 Respect history and preserve authenticity

In the renovation of old residential districts in historic urban areas, it is necessary to respect history, maintain the original residential functions, protect the social network gradually established by residents in long-term community life, inherit and develop the regional characteristics of residential culture, so as to preserve the authenticity of local life, revitalize community vitality, and make the community an organic unit of the city[8].

2 Strategies for the renovation of old residential districts in historic urban areas

2.1 Facility upgrade strategy-introducing the market and activating latent spatial potential

In modern society, the marketization of public serv-

ices has become a development trend of government social service supply in China and internationally[9]. The historic urban areas have relatively complete public service facilities, which is an achievement of Guangzhou's efforts to address the shortcomings in public service facilities. It also relies on the economic foundation of the old city as the original urban center. Therefore, the development direction of public service facilities in such communities should be more targeted. Taking commercial service facilities as an example, in historic urban areas, many old residential districts with street and alley layouts are located in historic and cultural blocks, and their surrounding cultural and commercial resources are rich. Therefore, in the renovation of old residential districts, the upgrading of cultural and commercial service facilities should be strategically guided. On the premise of ensuring the authenticity of community life, introducing boutique businesses that are in line with the community culture will help shape the community image and improve the quality of community commercial service facilities. Taking elderly care services as an example, the large elderly population in historic urban areas makes providing public services for home-based elderly care an issue that cannot be ignored in the renovation of old residential districts. Therefore, allowing and encouraging community-based elderly care service facilities to explore marketization on the basis of meeting the needs of universal services can alleviate the pressure of government subsidies to a certain extent and is conducive to the sustainable development of elderly-friendly public services. The marketization and professionalization of community-based elderly care services can bring about professional services, which in turn lead to service and consumption upgrades, enabling communities to better provide elderly care services to cities and create additional employment opportunities. The government, communities, and third-party market companies working together, with the government acting as a safety net, third-party companies providing services, and communities conducting oversight, ensure the marketization of public services in old residential districts and promote a virtuous cycle (Table 1).

Table 1 Comparison of third-party community service provision by non-governmental organizations

	Nonprofit social organizations [10]	Social enterprises [11]	Commercial enterprises
Nature	Purely for public welfare	Combining public welfare and commercial interests	For commercial interests
Target	Create social value	Create social and economic value	Economic value
Purpose	Driven by social responsibility	Market operations that prioritize achieving social benefits	Market-driven
Profit allocation/ surplus revenue usage	Used for public welfare	Reinvesting in economic activities aimed at social benefits and giving back to the community	For thebenefit of shareholders and business owners

2.2 Strategies for spatial renovation-cultural continuity and functional enhancement

2.2.1 Preserve the spatial texture and provide a comfortable space for interaction

Given the limited existing space in historic urban areas, the renovation of old residential districts mainly focuses on small-scale, gradual micro-renovations. The first step is to improve the quality and functionality of idle public spaces in the community, such as community entrances, small squares, and small parks, to tap the potential of the spaces and improve the community environment and residents' lives. For the spatial renovation of old residential districts with street and alley layouts, since streets and alleys are important places for people to move around, gather and interact, and the residential districts often contain a large number of traditional style blocks and historical buildings, it is necessary to pay attention to the protection and inheritance of traditional culture, and adopt spatial stitching methods to restore the spatial texture of the blocks, so as to ensure the historical authenticity, life authenticity and morphological integrity of the community. For the public spaces of parallel-layout old residential districts, focus should be placed on revitalizing inefficient spaces in the community, enhancing the recognizability and continuity of public spaces, and paying attention to the installation of small-scale furniture in public spaces during the renovation process, such as adding flower beds, steps and other informal seating elements, as well as interesting urban furniture, to create comfortable settings for pause, interaction, and spontaneous social exchange in public spaces.

2.2.2 Utilizing catalytic elements to enhance the vitality of community spaces

The public spaces of old residential districts in historic urban areas, as the accumulation and microcosm of urban development, have unique historical and humanistic characteristics. Therefore, in addition to meeting the residential functions of residents, the traditional streets, courtyards, and individual buildings in the community often also serve cultural, tourism, and commercial functions. According to the "Urban Catalyst Theory", a catalyst can be a material form, a specific space, or a non-material form, such as cultural elements like history and folklore. Suitable catalytic elements can be selected and implanted through urban design methods [12] so that they can interact with the surrounding environment, inject vitality into public spaces, and thus promote regional sustainable development. Catalyst elements can be either modern elements that differ from the original residential area, engaging in dialogue and collision with tradition to create new cultural symbols, or elements that are integrated into the original residential area while preserving its features, implanting or upgrading business models to generate catalytic effects with commercial and cultural characteristics.

2.2.3 Strengthen resilience and enhance risk resistance capabilities

In the renovation of public spaces in old residential districts, resilience building should be strengthened to enhance spatial continuity, openness, and functional diversity. A three-in-one resilient public space of "point-line-plane" should be formed in the community, supplemented by public service facilities and fitness equipment, to create a healthy and resilient community for residents. "Points" refer to the cleanup and revitalization of small street corner spaces and inter-building green spaces in the community, transforming them into small plazas, green spaces, and pocket parks. Combined with the construction of sponge cities, these serve as basic units of resilient spaces, providing residents with a place to rest and socialize, and can also be flexibly transformed into fitness spaces, information display areas, or gathering areas between houses and street corners for emergency epidemic prevention and disaster relief. "Lines" refer to the road spaces in the community, such as streets, alleys, and small paths between houses, which are linear public spaces with pedestrian flow guidance. Through clear and smooth linear public spaces, the "point" public spaces in the community are connected, guiding people to more spacious and open "plane" public areas, such as public roads and large squares. Through the resilient construction of old residential district spaces, the overall risk resistance capacity of the residential district is improved.

2.3 Governance strategies-multi-party collaboration and emotional connection

The difficulty in reconstructing old residential districts lies not only in the allocation of material space resources but also in the conflicting interests and demands of various stakeholders. This is especially true for old residential districts in historic urban areas, which bear witness to the city's history and civilization and contain many historical and cultural relics and buildings. Therefore, the people concerned about the renovation include not only the residents of the community, but also experts, scholars, public welfare organizations, and volunteers from all walks of life. Therefore, in the renovation of old residential districts in historic urban areas, in addition to residents, government, developers, and planners, it is necessary to add independent third parties such as experts, scholars, teaching and research personnel, non-profit public welfare organizations, etc., but with relevant experience and ability, and establish third-party organizations [13]. During the renovation process, through coordination and supervision, reasonable demands can be put forward, the rights and interests of multiple parties can be balanced, and the coordination and resource allocation of the renovation process can be facilitated.

At different stages of the transformation, relevant information channels should be increased to enhance public participation (Table 2). For example, during the pre-renovation research stage, a detailed questionnaire survey and interviews should be conducted to understand residents' needs, and resident forums should be organized; during the renovation plan development process, residents should be organized to hold plan seminars to discuss and vote on important decisions such as renovation content, community governance model, and pro-

ject funding; during the renovation implementation process, residents' feedback on the implementation site should be collected, and forums should be organized between residents and the implementation team to address problems and needs encountered during implementation; in the post-renovation management phase, resident representatives can be organized to join the community management team for joint management.

Furthermore, communities are encouraged to establish social organizations based on shared traditional cultural backgrounds, occupational ties, or common interests and hobbies among neighbors. These community social organizations can take the lead in organizing activities and promoting relevant culture. This not only enriches the cultural connotation of the community but also enhances community cohesion and residents' sense of belonging, ultimately realizing a model of multi-stakeholder co-governance, co-construction, and sharing.

Table 2 Overview of information channels and public participation methods at each stage of the renovation

Stage	Participation content	Participation methods	Community information channels	Information
Pre-renovation survey	Residents' needs survey before renovation	Answering questionnaires, participating in interviews, and attending resident forums	Community bulletin boards, property management WeChat groups, community official accounts, community broadcast announcements, and door-to-door surveys	Demand questionnaire, renovation project approval status
Renovation scheme formulation	Scheme design, scheme revision, schemepublicity, and fundraising	Providing schemes, providing funding, and supervising	Participating in seminars, related websites, community bulletin boards, property management WeChat groups, community official accounts, community broadcast announcements, and newspapers	Renovation project, renovation area, investment funds, renovation timeline, renovation design team, channels for participating in the renovation design, and public notice documents related to the renovation
Implementation of the renovation scheme	Construction of various schemes	Participating in supervision, implementation, and resident forums	Community bulletin boards, property management WeChat groups, community official accounts, community broadcast announcements, construction sites, and online broadcasts	Renovation project, renovation area, renovation duration, renovation implementation team, and participation methods in the renovation implementation
Post-renovation management	Property management and operation funding	Joining the management team as a resident representative andproviding funding	Community bulletin board, community property management WeChat group, community official account, community broadcast announcements	Management content, management team, channels for participation in management, and public disclosure of community management funds

3 Implementation modes for the renovation of old residential districts in historic urban areas

The renovation of old residential districts involves different entities such as the government, enterprises, residents, and other civic stakeholders. Based on the different implementing entities and their respective roles in the implementation process, the main implementation modes for the renovation of old residential districts include:The government-led mode; the government-guided, enterprise-implemented mode; the government-led, resident-participating mode; the government-guided, resident-led mode [14]; and the multi-stakeholder joint implementation mode (see Table 3 for details). Different implementation modes will inevitably yield different outcomes. To ensure the effective implementation of the renovation schemes, old residential districts in historic urban areas should adopt a multi-stakeholder joint implementation mode.

4 A case study of the renovation of old residential districts in historic urban areas: The Old Nanhai County Community in Liurong Subdistrict

4.1 Community overview

The Old Nanhai County Community (hereinafter referred to as the Old Nanhai Community) is located within the core protected area of the historic cultural block centered on the Temple of the Five Immortals, Huaisheng Mosque, and the Temple of the Six Banyan Trees. It was

named after the former Nanhai County yamen site dating to the Ming and Qing dynasties (Figure 1). The community has a total land area of approximately 4.28 ha, with 359 residential buildings, approximately 1,840 households, and 5,155 residents. The community has many historical and cultural relics, including one historical building and 72 traditional architectural traces from the Republican era. The community contains the best-preserved early Republican era buildings and is a typical representative of modern collective housing in Guangzhou and a community with the "Quintessential Guangzhou" characteristics [15]. The existing buildings in the central area within the renovation area are mainly Western-style or Sino-Western hybrid buildings from the 1920s, mostly 2 to 4 stories high, including the former site of Ta Kung Pao newspaper and the former residence of Chen Jitang, the "King of the South" (a powerful warlord in the People's Republic of China era) of the People s Republic of China. The community is surrounded by numerous Buddhist temple ruins, including the Temple of the Six Banyan Trees and Guangxiao Temple to the north, and the Huaisheng Mosque to the south. The community is bordered by the 500 m-long arcade street of Zhongshan Sixth Road to the south. Within walking distance are cultural attractions such as the General's Mansion Ruins, People's Park, and the former site of the Guangzhou Commune. Heading east along Zhongshan Sixth Road leads to the Beijing Road Cultural Tourism Area.

Table 3 Overview of different types of renovation modes for old residential districts

Mode	Main content	Advantages	Disadvantages
government-led mode	The government is the main investor and builder	—	The government is under great financial pressure and cannot sustain the implementation of subsequent projects as originally planned
Government-guided, enterprise-implemented mode	The government initiates the project, signs a land transfer contract with a company, and the company organizes the relocation of residents and project construction. The completed houses are used for resident resettlement and sale or commercial operations	It could alleviate the pressure on government funding	It is prone to problems such asloss of authenticity, poor residential continuity, and over-commercialization
Government-led, resident-participating mode	The government bears the primary responsibility, while residents offer suggestions or participate in the implementation of the renovation project as decision-makers and collaborators	It could reduce conflicts and meet needs	The funding sources are relatively limited, incurring high communication costs
Government-guided, resident-led mode	The government constructs infrastructure and other external resources, while residents renovate their residential buildings and the community's public environment themselves	The renovation is small in scale, short in duration, and flexible in approach	It could easily lead to technical problems related to renovation, as well as issues affecting public interests and historical character
Multi-stakeholder joint implementation mode	It integrates the efforts of the government, the market entities, society, and residents	It could avoid problems such as unsustainable funding or over-commercialization	The renovation projectposes high requirements for the leading and technical support parties, and requires specific suitability for the targeted community

4.2 Main renovation contents

4.2.1 Material space (Hardware)

(1) Infrastructure and public services

In terms of infrastructure improvement, the Old Nanhai Community carried out the renovation of the "three lines" (power, telecommunications, and broadcasting cables) and the integration of the "four lines" (telecommunications, broadcasting, etc. aerial cables), installed lighting facilities, standardized the setting of garbage collection points, installed a community video surveillance system, and added express delivery lockers. The community also renovated the underground pipe network to improve the water supply, drainage, and sewage system, achieving the separation of stormwater and sewage systems. Simultaneously, community roads and damaged walkways between buildings were repaired, with paving styles, colors, and materials modified to better match the cultural atmosphere of the historical district.

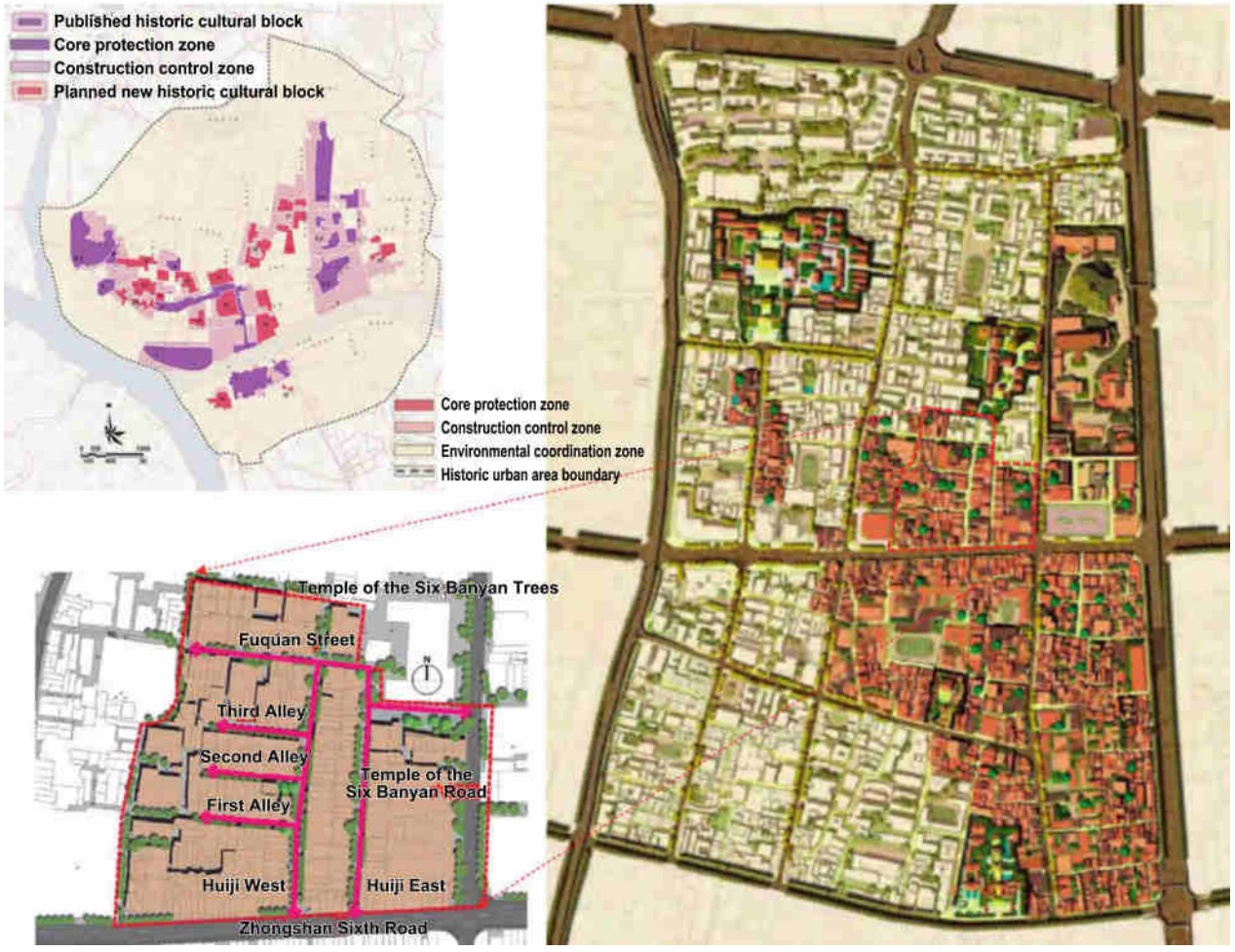

Figure 1 Location map of the Old Nanhai Community

After addressing these livelihood shortcomings, the community delved into the cultural heritage of historical buildings, such as the former site of the Ta Kung Pao newspaper. These historical buildings were revitalized and utilized to highlight the community's cultural atmosphere and reshape the spatial ambiance of the streets and alleys. Serving as a spatial catalyst, the Ta Kung Pao site facilitated the introduction of commercial services such as cafes, convenience stores, and bars (Figures 2 and 3). This integration of historical architecture with modern, experience-oriented commerce successfully promoted the improvement of business quality.

In addition, the Old Nanhai Community has taken into account the needs of the elderly in improving public service facilities. There are grassroots housekeeping service stations in the community, mainly targeting home care for the elderly, housekeeping services, and maternal and infant services. At the same time, there is a canteen in the community that provides three meals a day for the elderly in the community, providing facilities and channels for catering, health, and door-to-door home care services for the elderly in the community. Market-oriented services and smart platforms have been introduced to assist in the monitoring and management of the elderly in the community.

(2) Public space

The renovation of streets and squares aims to improve the quality of the space. The renovation included refurbishing the Huiji West entrance space, Liurong Street Cultural Square, and Ta Kung Pao Square, repainting and renovating the community archway, and repairing the landscape wall. Meanwhile, stone tables and chairs, rest benches, and rest pavilions were added to the central activity square, the space in front of the shops along the street was renovated, public furniture was added, and elderly-friendly barrier-free facilities were built in the public space.

Figure 2 Public service facilities in the Old Nanhai Community

Figure 3 Introduction of market-oriented public service facilities

Figure 4 Schematic diagram of greening renovation

The green landscape was transformed, and the bonsai were reorganized, adopting the strategy of "preservation, trimming, thinning, and enhancement". Based on residents' opinions and the actual lighting conditions, trees with large diameter at breast height and good growth were retained in the site; trees overgrown or disorganized branches that seriously affected residents' travel and life were tidied up; trees with serious pests and diseases that endangered residents' safety, small diameter at breast height and poor growth were thinned out and removed; finally, group-style greening and local movable flower boxes were added to the public space (Figure 4).

In terms of architectural space renovation, the project includes refurbishing the facade, repairing and installing intercom systems for building entrances, painting corridors, repairing stair treads and handrails, repairing fire-fighting equipment and building safety facilities, repairing and installing corridor lighting, and restoring the Historic Feature Building (Figure 5).

Figure 5 Elderly-friendly public space renovation

4.2.2 Community governance and services (software)

(1) Management mechanism and digital management construction

The community explored community self-governance models and maximized the coordinating role of grassroots organizations. With the community Party organization at its core, a community deliberation platform is formed with the broad participation of resident representatives, building leaders, representatives from local units, and social organizations. Standardized rules for consultation and deliberation are established, and renovation-related matters are included in the scope of consultation and deliberation. Through equal, rational, and peaceful consultation, the community's conditions and opinions are fully reflected and understood, and community issues are jointly resolved through consultation.

As a demonstration project for the construction of 5G smart communities, the Old Nanhai Community mainly includes intelligent pedestrian access, intelligent security, and intelligent management. At the same time, a smart community service platform (Figure 6) has been built in the community, which can monitor key areas, key personnel, unrecognized individuals, population density, fire lane obstruction, and littering in the community, and display the information on the smart platform and issue alarms. The community also monitors the health status of elderly people living alone in real time by equipping them with smart bracelets, and issues timely warnings when abnormalities are detected.

(2) Public participation

Before the community renovation, a "co-creation" workshop was established as a project discussion platform, a collaboration platform, recruitment posters were issued, residents' needs were proactively understood, social forces were actively guided, and diverse participation in community renovation and construction was promoted. A working mechanism for the joint participation of the government, the market, residents, and designers in community renovation was established. During the renovation process, on-site coordination meetings were held to strengthen project safety and quality management, and to jointly discuss, build, and govern the project; the responsibilities and division of labor of each unit and department were clarified to form a working synergy, jointly solve problems, and coordinate the implementation of the project; complaint and reporting channels were opened to maximize the role of social supervision and promote the

implementation of the renovation work; and community residents and university teachers and students were attracted to participate in the community renovation through participatory design (Figure 7).

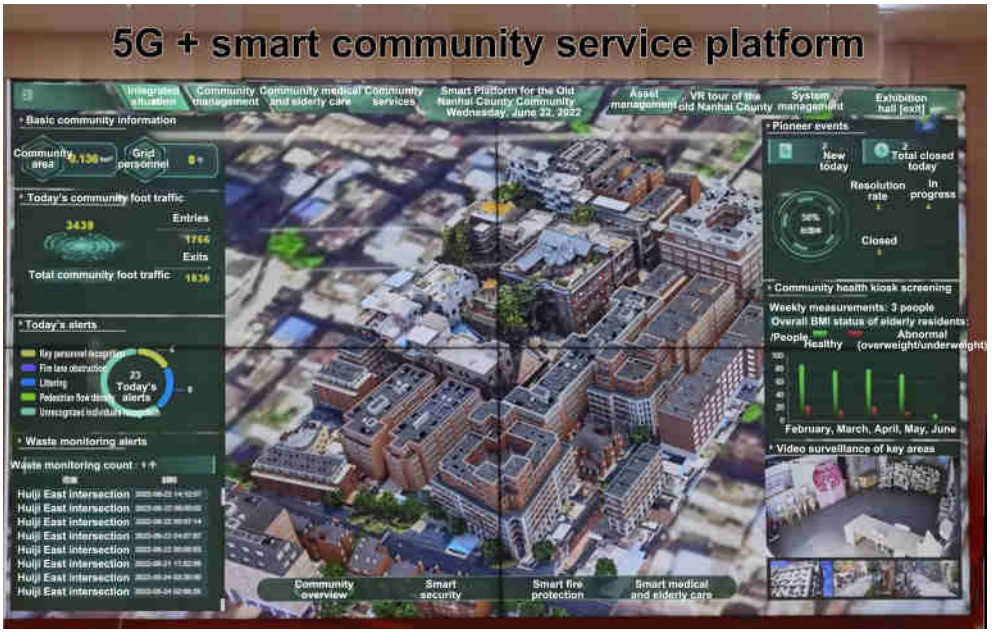

Figure 6 Smart platform construction

Figure 7 Multi-stakeholder participation in the community design phase

In the daily management of the renovated community, a homeowner self-governance model is adopted. The community's management mode, regulations, and homeowner deliberation rules are all confirmed through joint consultation by the residents, and then basic management is carried out by the community street office to jointly maintain the

results of the renovation. Establish and improve the mechanism for raising special maintenance funds in communities, with residents making supplementary or renewed contributions to support construction and renovation, guiding specialized enterprises to fulfill their social responsibilities, implementing subsequent maintenance and management of pipeline facilities and equipment, and promoting the participation of social forces in management.

Based on history and culture, carry out community activities and cultural promotion. The Old Nanhai Community carries out a variety of community activities, mainly promoting the community's history and culture, popularizing scientific knowledge, and carrying out activities for specific groups such as the elderly and children. Community activities help strengthen the relationship between the community residents' committee and residents, as well as among the residents themselves. Residents showed good participation and positive feedback regarding these activities.

(3) Community culture and community sentiment

The renovation of Old Nanhai Community focus on exploring and revitalizing historical heritage to improve the quality of life for residents. To highlight the overall design concept of "one brand per street" and "one characteristic per community", the historical building of "Ta Kung Pao Former Site" in the community is revitalized and utilized according to the principle of "restoring the old as it was" to create a community mural historical and cultural wall, highlighting the community's cultural atmosphere and reshaping the place atmosphere of the street. It also guides residents to participate in the beautification of electrical boxes and mailboxes with graffiti, highlighting the characteristics of art being close to residents' lives and improving community services.

Relying on its own history and culture, the community uses the space of historical buildings as a carrier to set up a Party building education and cultural station, which displays and promotes the community's historical evolution and cultural construction. Educational films are also shown regularly to enrich the spiritual and cultural life of community residents. In the square space in front of the former site of Ta Kung Pao Square, the community's cultural history is publicized and displayed, so that residents can become familiar with the community's history and culture and increase their sense of community belonging and identity. Targeting the elderly and children in the community, community activities are carried out in conjunction with public spaces, including safety education for children, free health checkups for the elderly, and festive activities during holidays, creating new collective memories for community residents (Figure 8).

Figure 8 Community activities promote collective memory among residents

4.3 Analysis of the indicator system

To gain a more objective understanding of the renovation situation, this paper establishes an indicator system for the renovation of old residential districts from both the hardware and software aspects of the community. The system consists of material space and community governance and services as level-1 factors, 5 level-2 factors, and 16 level-3 factors. A group composed of experts in related fields, staff of relevant departments, front-line designers, community managers, and resident representatives was invited to score the importance of the factors. The weight of each factor in the indicator system was determined using the analytic hierarchy process (AHP)[2] (Table 4), and a method for evaluating the indicator factors was proposed.

Table 4 Weighting of indicator factors for the renovation of old residential districts

	Level-1 factor (Criterion Level)	Level-2 Factor (Criterion layer)	Level-3 factor	
A1: An indicator system for the renovation of old residential districts based on the "Complete Community" concept	B1 Hardware: Community material space (0.7679)	C1 Public service facilities (0.0956)	D1	Basic public service facilities (0.0660)
			D2	Market-based public service facilities (0.0296)
		C2 Municipal supporting facilities (0.4781)	D3	Water, electricity, gas, heating, telecommunications networks, and sanitation facilities (0.2234)
			D4	Transportation facilities (0.0653)
			D5	Security facilities (0.1606)
			D6	Smart facilities (0.0288)
		C3 Publicspace (0.1942)	D7	Streets and squares (0.0281)
			D8	Green landscape (0.0242)
			D9	Epidemic and disaster prevention space (0.0532)
			D10	Architectural space (0.0887)
	B2 Software: Community governance and services (0.2321)	C4 Community governance (0.1653)	D11	Community management mechanism completeness (0.0164)
			D12	The level of digital management construction in the community (0.0094)
			D13	Public participation level (0.0459)
			D14	Residents' satisfaction with community services (0.0936)
		C5 Community economy and culture (0.0668)	D15	Community economy (0.0231)
			D16	Community culture (0.0437)

The weighted scores of each factor in the indicator system were statistically analyzed, and the improvement of the factor was described by classifying the scores according to the ratio of the scores to the full score of the factor. It can be seen that the overall condition of the community hardware construction in the Old Nanhai Community is relatively good. This indicates that the renovation of the common parts of the building and the public areas of the community has significantly improved the living environment of the old district, and the residents are relatively satisfied with the hardware renovation. The specific factor scores and levels are shown in Table 5.

4.4 Suggestions for improvement and optimization

At present, the government is still the main source of funding for the renovation of the Old Nanhai Community. Based on the idea of reconstructing old residential districts in Guangzhou in a contiguous manner, the Old Nanhai County Community, as a typical example in the area, should have a radiating effect on the surrounding old residential areas. Its relatively complete public service facilities, especially elderly-friendly services such as the elderly canteen, can be opened to the surrounding residentsat staggered times. This approach can help the surrounding old residential areas that are undergoing renovation to improve their living environment to a certain extent during the transition period between construction and completion.

In shaping public spaces, utilizing public spaces to build community epidemic prevention and disaster prevention systems, and enhancing community resilience are also important aspects of public space construction. In the micro-renovation of plazas and green spaces, the construction of sponge cities should be combined to make them basic units of resilient spaces, so that they can not only serve as a place for residents to rest and socialize, but also be flexibly transformed into fitness spaces, information display areas, or emergency epidemic prevention and disaster relief gathering areas between houses and street corners.

In addition, as a demonstration project for the construction of 5G smart communities, although a smart community service platform has been built in the community, it has failed to fully utilize the platform's function of providing community services and achieving community gov-

ernance by integrating resources. As a result, community residents are not very willing to use smart devices to obtain corresponding services. Going forward, efforts should be made to strengthen the construction of smart infrastructure to match this, improve the terminal equipment and methods for sensing and monitoring, as well as the functions for collecting related data and information, and expand the promotion of smart services.

Table 5 Comparison of weighted scores of case communities

Level-1 factor	Level-2 Factor	Level-3 factor		Old Nanhai Community Weighted score	Percentage/%	Score level
B1 Hardware: community material space	C1 Public service facilities	D1	Basic public service facilities	4.75	67.8	Good
		D2	Market-oriented public service facilities	2.25	75.1	Fairly Good
	C2 Municipal supporting facilities	D3	Water, electricity, gas, heat and telecommunications facilities	15.77	71.7	Fairly Good
		D4	Transportation facilities	4.53	64.7	Fairly Good
		D5	Security facilities	11.79	73.7	Fairly Good
		D6	Smart facilities	1.92	63.9	Good
	C3 Publicspace	D7	Streets and squares	2.06	68.8	Good
		D8	Green landscape	1.81	90.3	Excellent
		D9	Epidemic prevention and disaster relief space	3.64	72.8	Fairly Good
		D10	Architectural space	6.12	68.0	Good
	Hardware score			54.64	70.1	Fairly Good
B2 Software: community governance and services	C4 Community Governance	D11	Completeness of management mechanism	1.31	65.6	Good
		D12	Digital management of communities	0.79	79.0	Fairly Good
		D13	Public participation	3.20	64.1	Good
		D14	Residents' satisfaction with community services	6.87	76.3	Fairly Good
	C5 Community economy and culture	D15	Community economy	1.85	92.4	Excellent
		D16	Community culture	3.04	76.0	Fairly Good
	Software score			17.07	74.2	Fairly Good
Total score (out of 100)				71.70	71.7	Fairly Good

Conclusions

This paper first highlights the importance of reconstructing old residential districts in historic urban areas for preserving the urban cultural context and promoting urban development. Accordingly, it establishes the renovation principles of adapting to local conditions while respecting history and preserving authenticity. Subsequently, specific strategies are proposed for the renovation of material spaces (both facilities and public spaces) and the enhancement of community governance and services.

First, regarding facility renovation, focus should be placed on the marketization of public services by encouraging the establishment of community social enterprises to supplement public offerings. Furthermore, community culture and image should be highlighted by guiding the upgrading of cultural and commercial facilities. To address the shortage of space for new facility construction, it is advocated to explore the functional compatibility of existing facilities, promoting their utilization in staggered time periods and composite spaces.

Second, in the renovation of public spaces, priority must be given to the protection of the cultural context and urban fabric, utilizing catalytic elements to inject vitality into community public spaces.

Third, for community governance, it is essential to

facilitate multi-stakeholder participation. This involves expanding information channels and participation pathways to promote continuous public involvement throughout the entire renovation cycle. Moreover, the formation of independent social groups acting as third-party organizations is highly encouraged; this approach helps navigate complex stakeholder dynamics, coordinates diverse interests, and ensure effective implementation of renovation plans. Additionally, significant attention must be paid to cultural construction to foster a strong sense of community belonging among residents.

Furthermore, based on a comparative analysis of common renovation modes, the paper concludes that a multi-stakeholder joint implementation mode is the most suitable approach for old residential districts in historic urban areas.

Finally, using the Old Nanhai Community in Liurong Subdistrict as a case study, anindicator system was established. By analyzing the renovation outcomes from both material space (hardware) and community governance and services (software) dimensions, targeted suggestions for further improvement and optimization were formulated.

Sources of Figures and Tables

Figure 1: Redrawn by the author based on available materials;

Figures 4, 5, and 7: Provided by Guangzhou Urban Renewal Planning Institute;

Figure 8: Provided by the former Nanhai Community Residents' Committee;

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

Notes

1) The concept of "Complete Community" was first proposed by Wu Liangyong at the 2010 Shanghai World Expo. He believes that the community is the most basic living place for people, and its planning and construction should start from the vital interests of residents. It includes not only the shaping of the material space of housing, but also many other factors such as services, security, education, and transportation. The construction of a Complete Community, which includes both hardware and software, is a systematic social project.

2) The Analytic Hierarchy Process (AHP) is a systematic and hierarchical analysis method that combines qualitative and quantitative approaches, proposed by the famous American operations researcher Thomas L. Saaty. This method can quantify the relevant experience of multiple decision-makers, and is suitable for situations with complex target structures and a lack of data. It is a simple, flexible, and practical multi-criteria decision-making method.

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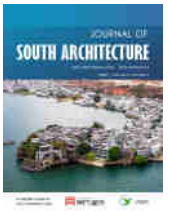

Assessment of Urban Public Green Space Services from the Perspective of the 15-Minute Living Circle

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ABSTRACT: With socioeconomic development and rising living standards, urban public services have gradually shifted from a focus on quantitative provision to a greater emphasis on service quality and refinement. However, pronounced supply-demand mismatches, outdated evaluation approaches, and insufficient quantitative precision undermine the validity of urban public green space assessments and the practicality of improvement strategies. Existing evaluation methods tend to measure service performance at a regional scale, whereas public services are primarily accessed within residents' daily activity spaces. As a result, current assessment frameworks often fail to precisely evaluate the actual service effectiveness of public green spaces. Using Tianhe District, Guangzhou, as a case study, this research develops a demand-oriented framework for evaluating urban public green space services from the perspective of the 15-minute living circle. By integrating multiple datasets and analytical methods, the study conducts a multi-indicator, multi-level assessment of urban public green space services and proposes targeted optimization strategies for different types of urban spaces.

KEY WORDS: 15-minute living circle; urban public services; public green space service assessment; evaluation framework; optimization strategies

Introduction

Urban public green spaces constitute an important form of public service provision and serve as the spatial setting for recreation and leisure activities. They not only perform important urban functions but also exert a significant influence on residents' quality of life and lifestyles. Traditionally, assessments of urban public green space services have focused on the rational allocation of land resources at the regional scale. From the perspective of individual residents, however, whether urban public green spaces are used in daily life depends largely on factors such as the quantity, accessibility, and convenience of green spaces in the vicinity of their homes. When viewed from the perspective of daily service provision, significant problems emerge in the quantity of public green spaces, the equity of their spatial distribution, and the spatial dis-

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parities revealed by different evaluation indicators.

Against the policy backdrop and broader trend of shifting urban public services from an emphasis on absolute quantity to one on service quality and refinement, existing evaluation perspectives and technical approaches are no longer adequate for service-oriented and fine-grained assessment objectives. Adopting a people-oriented perspective, this study takes the 15-minute living circle as the spatial scope of residents' daily activities and seeks to develop a demand-oriented assessment framework for urban green space services. By integrating multiple datasets and analytical methods, the study explores the service effectiveness of urban public green spaces.

1 Literatu rereview

1.1 Assessment of urban public green space services

When emphasis is placed on social performance, urban public green spaces can be regarded as a form of urban public service, and their evaluation has been approached from diverse perspectives.

SUN Defang et al. argued that international studies have primarily focused on accessibility assessment, whereas Chinese studies have emphasized spatial layout and planning standards [1]. SUN Yi et al. suggested that international studies mainly concentrate on three aspects: the impacts of public service provision on residents' health, the equity and accessibility of facility distribution, and the evaluation of service performance and resident satisfaction; in contrast, domestic studies have focused more on standards, site selection and spatial layout, facility provision, and satisfaction assessment [2]. ZHAN Dongsheng further observed that international studies mainly address the location, accessibility, equity, and socioeconomic benefits of public services, while Chinese research places greater emphasis on facility allocation, accessibility, spatial patterns, social differentiation, residents' needs, and satisfaction [3]. Research on urban public services has continued to evolve both domestically and internationally, and differences in analytical perspectives remain evident. Overall, however, facility allocation, accessibility, equity, and satisfaction constitute core concerns shared by scholars in both contexts.

In terms of evaluation methods, relatively mature assessment frameworks were gradually established around the year 2000 [4]. During the subsequent decade, numerous scholars expanded these frameworks by introducing additional indicators from different perspectives, focusing primarily on quantity and efficiency [5,6], accessibility [7-9], equity [10-13], and supply-demand relationships [14,15]. Increasing attention has been paid to the social value of green spaces, while the degree of alignment between services and residents' individual needs has become an important concern. As a result, evaluation frameworks and indicators have shown clear trends toward greater systematization, quantification, refinement, and stronger people-centered orientation.

1.2 The living circle concept: Value orientation and delineation methods

Research on living circles is generally grounded in the perspective of residents' daily needs, with particular attention given to issues such as daily life, employment, public service provision, the scale and structure of public spaces, accessibility, spatial organization, and implementation guidelines [16-18]. Some scholars have also examined the feasibility and practical implementation of planning approaches based on the living-circle concept, as well as challenges that may arise during implementation [19, 20]. These studies suggest that, whether viewed from the perspectives of residents' needs, community governance, or planning institutions, a community living circle is fundamentally people-centered and aims to improve residents' quality of life.

With regard to methods for delineating living circles, many studies employ data sources such as GPS trajectories, points of interest (POIs), and mobile phone signaling data to define living circles based on residents' daily activity ranges and spatiotemporal behavioral patterns. In addition, a number of Chinese cities, including Shanghai, Guangzhou, and Ningbo, have incorporated the living-circle concept into planning practice and carried out related planning initiatives [21-25].

2 Assessment of urban public green space services from the perspective of the 15-minute living circle

The 15-minute living circle refers to the spatial area surrounding residents' homes within which daily needs can be met through activities such as work, education, rec-

reation, healthcare, and social interaction [26]. The concept emphasizes the creation of an integrated community environment at the neighborhood scale [27].

The demand-oriented logic inherent in the living-circle perspective—characterized by a people-centered approach and the overarching objective of improving residents' quality of life—together with the application of multi-source data and advanced analytical methods, provides a feasible framework for enhancing the assessment of urban public green space services. Compared with conventional assessment approaches based primarily on land-use perspectives, an evaluation framework grounded in the 15-minute living circle can achieve improvements in three respects: orientation toward residents' everyday behavioral needs, the selection and classification of indicators, and the refinement of indicator calculation methods.

2.1 Indicato rselection

A review of the literature reveals that many scholars have proposed new indicators for assessing urban public green space services or refined the calculation methods of existing indicators. Commonly used indicators include green space area, per capita green space area, and the number of green spaces to reflect the quantity and scale of urban green resources; green coverage ratio, service coverage ratio, and overlap ratio to evaluate service efficiency; travel time along the shortest path, minimum travel cost, path resistance, and average distance to assess accessibility; the Gini coefficient, location entropy, and shareindicator to measure spatial equity and distributional balance; and supply-demand ratio, level of service access, and the coefficient of variation of spatial patterns to evaluate the balance between the supply and demand of green space services.

Although the specific calculation methods of these indicators vary somewhat across studies, their underlying evaluation objectives are broadly consistent. Moreover, while some indicators differ in terminology, their substantive meanings are highly similar. Through comparison, consolidation, and screening of the literature, the most frequently used indicators were identified as green coverage ratio, service coverage ratio, green space area, per capita green space area, equity, shortest path, road-network density, number of green spaces, supply-demand ratio, service overlap ratio, and mix.

Drawing upon the *Planning Guidance of Community-life Circle* (*Draft for Consultation*), an industry standard issued by the People's Republic of China in October 2020 [28] (hereafter referred to as the *Living Circle Guidelines*), the indicators were categorized into four dimensions and evaluated accordingly: Scale, efficiency, accessibility, and quality (Table 1).

Table 1 Evaluation indicator framework for urban public green space services from the perspective of the 15-minute living circle

Dimension	Secondary indicator	Indicator No.	Correlation with service level
Scale	Effective green space area within the 15-minute living circle	A1	Positive
	Effective green space ratio within the 15-minute living circle	A2	Positive
	Effective green space service coverage within the 15-minute living circle	A3	Positive
Efficiency	Per capita effective green space area within the 15-minute living circle	B1	Positive
	Green space shape indicator	B2	Positive
	Green space service overlap ratio	B3	Positive
Spatial accessibility	Road-network density	C1	Positive
	Minimum proximity distance	C2	Negative
	Comprehensive accessibility	C3	Positive
Quality	Green space equity	D1	Positive
	Urban functional mix	D2	Positive

The first four indicators are adapted from the *Evaluation Standard for Urban Landscaping and Greening* GB/T 50563-2010 (hereafter referred to as the 2010 *Evaluation Standard*), with their calculation methods revised and optimized to suit the

analytical perspective adopted in this study. The remaining seven indicators were derived from the literature review and supplement the framework with high-frequency indicators directly associated with residents' daily service needs.

2.2 Data sources

The evaluation indicators are primarily calculated based on datasets including administrative boundaries, residentialcompounds, green spaces, population distribution, transportation networks, and points of interest (POIs) related to urban public services (Table 2).

Table 2 Data categories and sources

Data category	Primary data source	Data content
Administrative divisions	Tianditu Cloud Platform of Spatiotemporal Information	Boundaries of subdistricts and communities
Residential compounds	Baidu Map Open Platform	Boundaries of residential compounds[1)]
Urban public green spaces	Baidu Map Open Platform	Boundaries of urban public green spaces
Population	"Number of households" data from real-estate websites	Population of each community[2)]
Road network	OpenStreetMap	Road network
Urban public service POIs	Baidu Map Open Platform	Eight categories: Fresh produce markets, dining services, supermarkets and department stores, shopping malls, healthcare services, bank branches, postal services, and government institutions

2.3 Evaluation objectives

Following the "Living Circle Guidelines", the evaluation indicators are classified into four dimensions: scale, efficiency, accessibility, and quality. Scale reflects the level of green space provision; efficiency reflects the service capacity of green spaces; accessibility measures the time and distance costs incurred by residents in accessing green spaces; and quality reflects the equity of green space distribution and the convenience of accessing green space services (Table 3).

Table 3 Assessment framework for urban public green space services from the perspective of the 15-minute living circle

Dimension	Indicator	Objective
Scale	Effective green space area within the 15-minute living circle	Evaluate the area of green spaces effectively serving residents' daily activities
	Effective green space ratio within the 15-minute living circle	Evaluate the proportion of area covered by effective green spaces
	Effective green space service coverage ratio within the 15-minute living circle	Evaluate the proportion of residential compounds covered by effective green space services within the 15-minute living circle
Efficiency	Per capita effective green space area within the 15-minute living circle	Evaluate the amount of effective green space available per resident for daily use
	Green space shape indicator	Evaluate the complexity of green-space boundaries
	Green space service overlap ratio	Evaluate the diversity of green-space choices available to residents within their daily activity range
Spatial accessibility	Road-network density	Evaluate the likelihood of residents reaching green spaces
	Minimum proximity distance	Evaluate the minimum travel cost required to reacha green spaces
	Comprehensive accessibility	Evaluate the overall accessibility
Quality	Green space equity	Evaluate the equity between population distribution and green-space provision
	Urban functional mix	Evaluate the degree of mix of green spaces and other public service facilities

3 Empirical assessment of urban public green space services in Tianhe District, Guangzhou

The evaluation indicators were calculated at three spatial levels—region, subdistrict, and community. Results at the regional level can be used to compare performance against planning standards and findings from comparable studies, thereby revealing the relative strengths and weaknesses of individual indicators. Given that evaluation out-

comes should ultimately inform the optimization of the built environment within specific administrative units, further analysis of spatial differentiation was conducted at both the subdistrict and community levels.

3.1 Region-level assessment

Residentialcompounds were used as the basic analysis units. Based on the existing road network, a walking distance of 1,000 m (approximately a 15-minute walk), was defined as the service area for daily life. Urban public green spaces located within this range were regarded as effective green spaces within the 15-minute living circle (Figure 1).

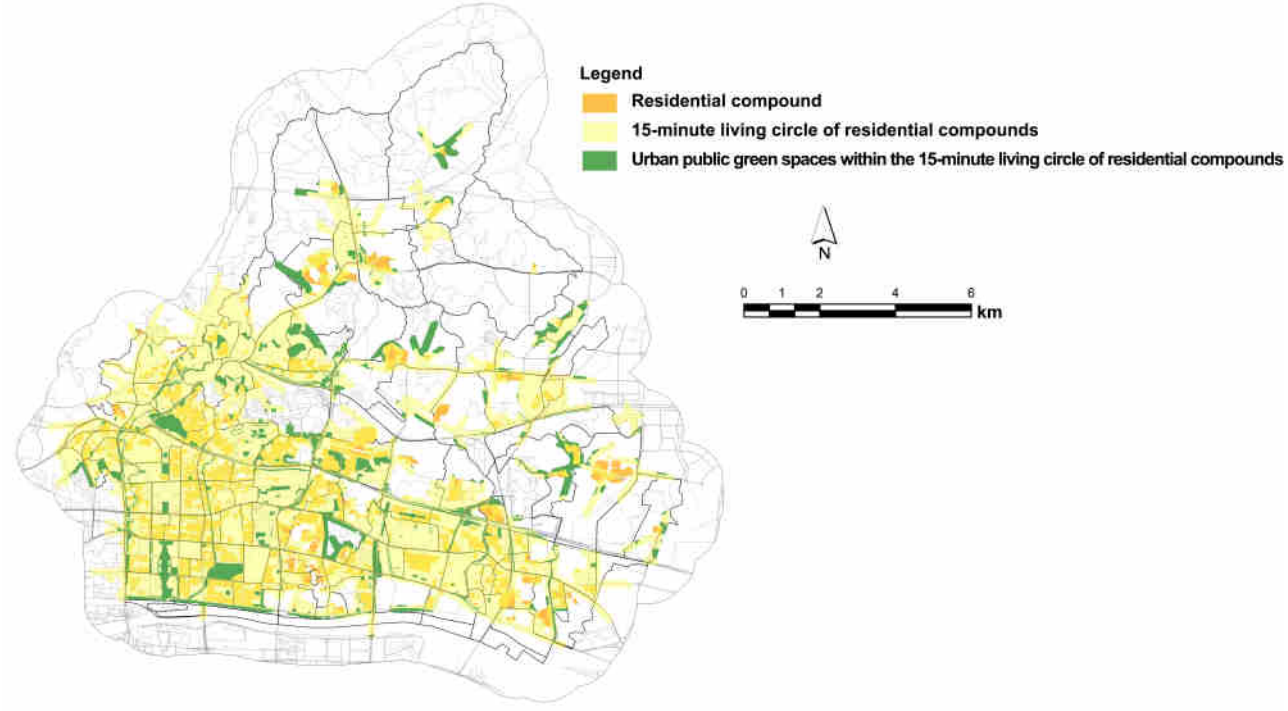

Figure 1 Urban public green spaces within the 15-minute living circles of residential compounds

3.1.1 Assessment results for scale indicators

(1) Effective green space area within the 15-minute living circle

A total of 47.5 km^2 of urban public green space is located within Tianhe District and its surrounding 1,000 m buffer zone. However, only 10.0 km^2 of this green space is capable of providing daily services to residential compounds within the district. Although the remaining green spaces make substantial contributions in ecological and economic terms, their effectiveness in serving residents' daily activities is limited because of their long distance from residential areas.

(2) Effective green space ratio within the 15-minute living circle

The effective green space ratio within the 15-minute living circle of Tianhe District is only 11.94%, substantially lower than the green space ratio of 25.9% calculated according to the "2010 Evaluation Standard".

(3) Effective green space service coverage ratio within the 15-minute living circle

Residential compounds located within a 15-minute walking distance from urban public green spaces along the existing road network were considered to be covered by green space services at this travel threshold (Figure 2). The effective service coverage ratio reaches 90.6%, which essentially meets the target of 90% coverage within a 15-minute walking distance proposed in the "Guangzhou Master Plan (2017 – 2035)". This result indicates that, in terms of scale, the current provision of urban public green space services in Tianhe District adequately covers residents' daily needs.

3.1.2 Assessment results for efficiency indicators

(1) Per capita green space area within the 15-minute living circle

The per capita green space area within the 15-minute

living circle of Tianhe District is 5.8 m^2, considerably lower than the 25.28 m^2 calculated according to the "2010 Evaluation Standard". This suggests that the provision of urban public green space for residents' daily needs remains insufficient.

(2) Shape indicator

Within Tianhe District and its 1,000 m buffer zone, the total perimeter length of green spaces capable of providing services within the 15-minute living circle is 33.6 km, yielding a shape indicator of 26.6.

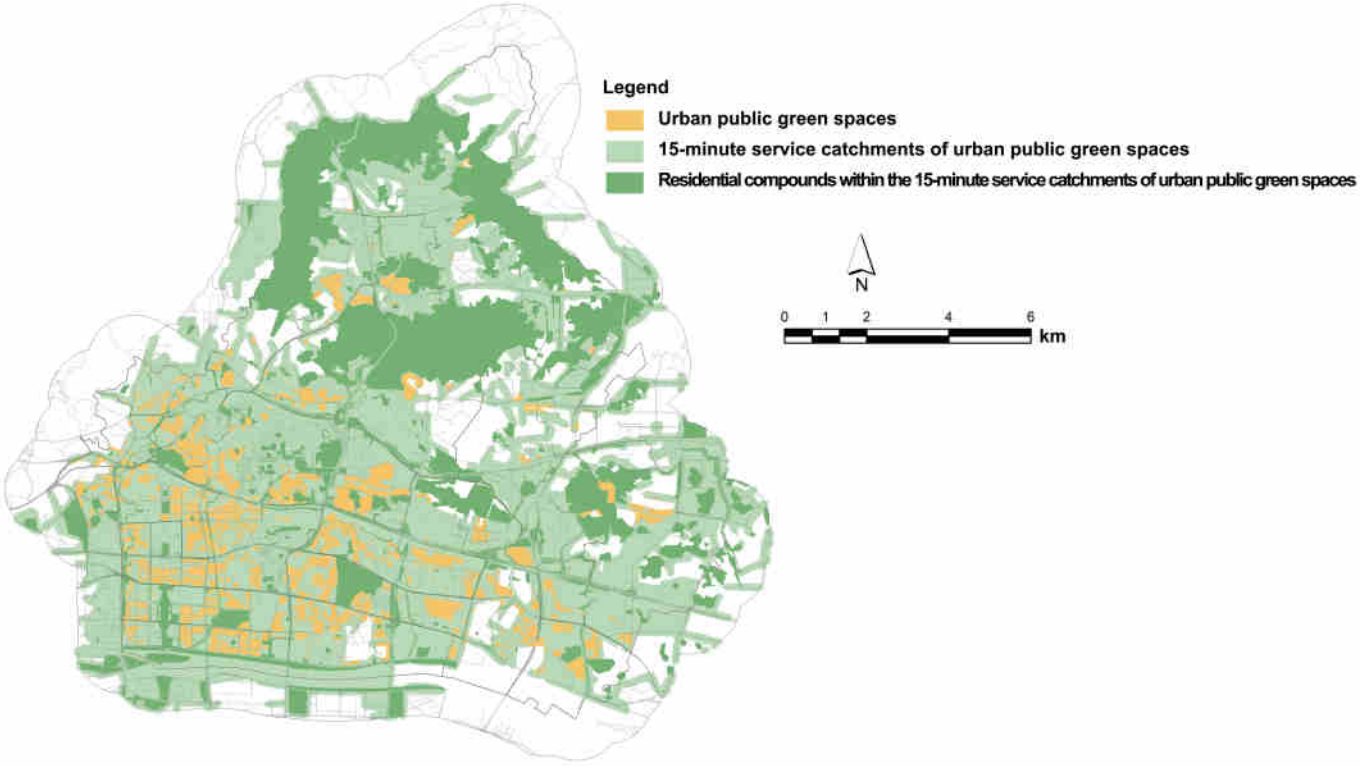

Figure 2 Residential compounds within the 15-minute service catchments of urban public green spaces

(3) Service overlap ratio

The service overlap ratio of urban public green spaces across Tianhe District is approximately 51.11%. In other words, about half of the residential land area is covered by the service areas of two or more green spaces. Residential land served by at least two green spaces is covered an average of 3.5 times.

3.1.3 Assessment results for accessibility indicators

(1) Road network density

According to the 2020 *Monitoring Report on Road Network Density in Major Chinese Cities*, the road network density of Tianhe District is 7.0 km/km^2[29].

(2) Minimum proximity distance

The average minimum distance betweena residential compound and the nearest urban public green space (Minimum Proximity Distance) is 695.7 m, approximately equivalent to a 10-minute walk. A total of 805 residential compounds are located within 1,000 m of their nearest urban public green space, accounting for 78.2% of all residential compounds.

(3) Comprehensive accessibility

At the regional level, comprehensive accessibility between urban public green spaces and residentialcompounds was measured using origin-destination (OD) cost matrix analysis. Taking urban public green spaces as origins and residential compounds as destinations, a cost matrix was generated using an impedance threshold of 1,000 m. The results indicate that the southwestern part of Tianhe District offers residents a greater range of choice opportunities for green spaces.

3.1.4 Assessment results for quality indicators

(1) Green space equity

Significant disparities exist in residents' access to urban public green space services across Tianhe District. Among residents with relatively low levels of access, 20% of the population receives only 1.5% of total Public green

space services, whereas the same proportion of the population with relatively high levels of access receives 60.7% of such resources (Table 4).

Based on the cumulative proportion of urban public green space services enjoyed by different proportions of the resident population, the Gini coefficient (G) was calculated. For comparison, reported Gini coefficients are 0.292 for Gongshu District in Hangzhou [30], 0.431 for the area within Wuhan's Third Ring Road [31], 0.246 for Nanshan District in Shenzhen [32], and 0.392 for Ba'nan District in Chongqing [15]. The calculated Gini coefficient for urban public green space services in Tianhe District is 0.5549, indicating a relatively high degree of inequity in service provision.

(2) Urban functional mix

To evaluate the degree of urban functional mix at the district level, Tianhe District was divided into a 500 m × 500 m grid, and a functional-mix indicator was calculated for each grid cell (Figure 3). The results reveal a pronounced concentration of functional diversity toward the southwestern part of the district.

3.2 Subdistrict- and community-level assessment

The regional level results provide an overview of the overall condition of urban public green space services in Tianhe District. To further examine spatial differentiation among the indicators, all indicators were calculated separately at the subdistrict and community levels. The results were classified into five categories: High, relatively high, moderate, relatively low, and low.

Table 4 Cumulative proportions of urban public green space services by population group

Cumulative proportion of permanent residents/%	Cumulative proportion of urban public green space/%
0	0
10	0.3
20	1.5
30	4.6
40	9.3
50	14.4
60	21.2
70	29.1
80	39.3
90	52.8
100	100

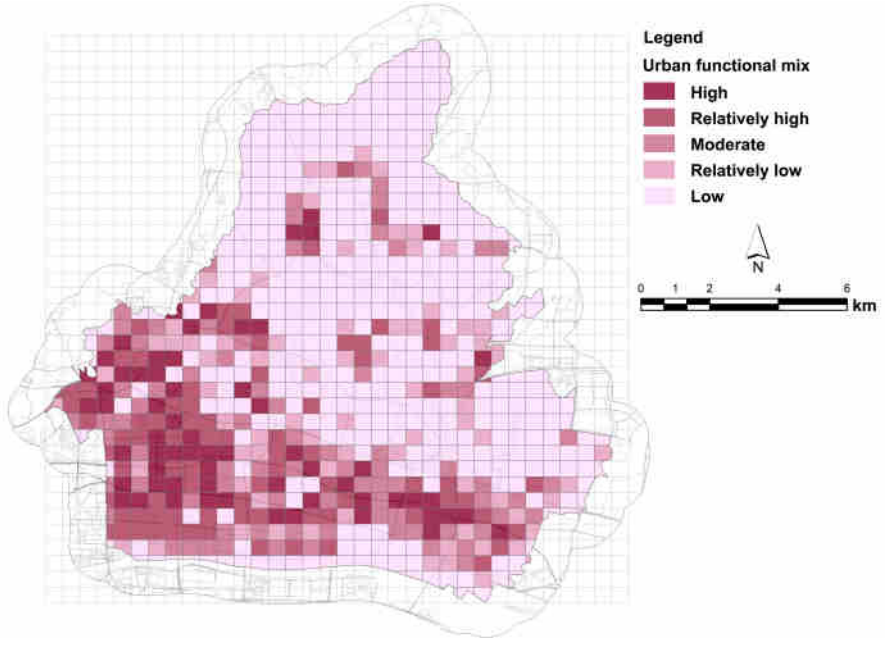

Figure 3 Distribution of functional mix across the area

In quantitative studies, the definition of "community" varies considerably. Some studies examining community living circles at the subdistrict level have effectively treated residential compounds as communities [33], whereas studies conducted at the regional level have often regarded subdistricts themselves as communities [34,35]. Field in-

vestigations further revealed that many residential compounds in Guangzhou have already displayed maps of 15-minute living circles, in which the term "community" corresponds to cadastral communities. This definition offers a higher level of spatial precision than the subdistrict and more closely approximates the spatial extent of a living circle than individual residential compounds.

3.2.1 Single-indicator assessment

(1)Assessment results for scale indicators

The scale dimension comprises three indicators: Effective green space area, effective green space ratio, and effective green space service coverage ratio within the 15-minute living circle. Effective green space area refers to the area of green spaces capable of serving residents' daily activities; effective green space ratio denotes the proportion of urban public green space within the area covered by the living circle; and green space service coverage ratio represents the proportion of residential compounds that can access green space services. These indicators focus primarily on the effectiveness of green spaces in meeting residents' daily needs and reflect the level of green space provision and service within the 15-minute living circle (Figure 4).

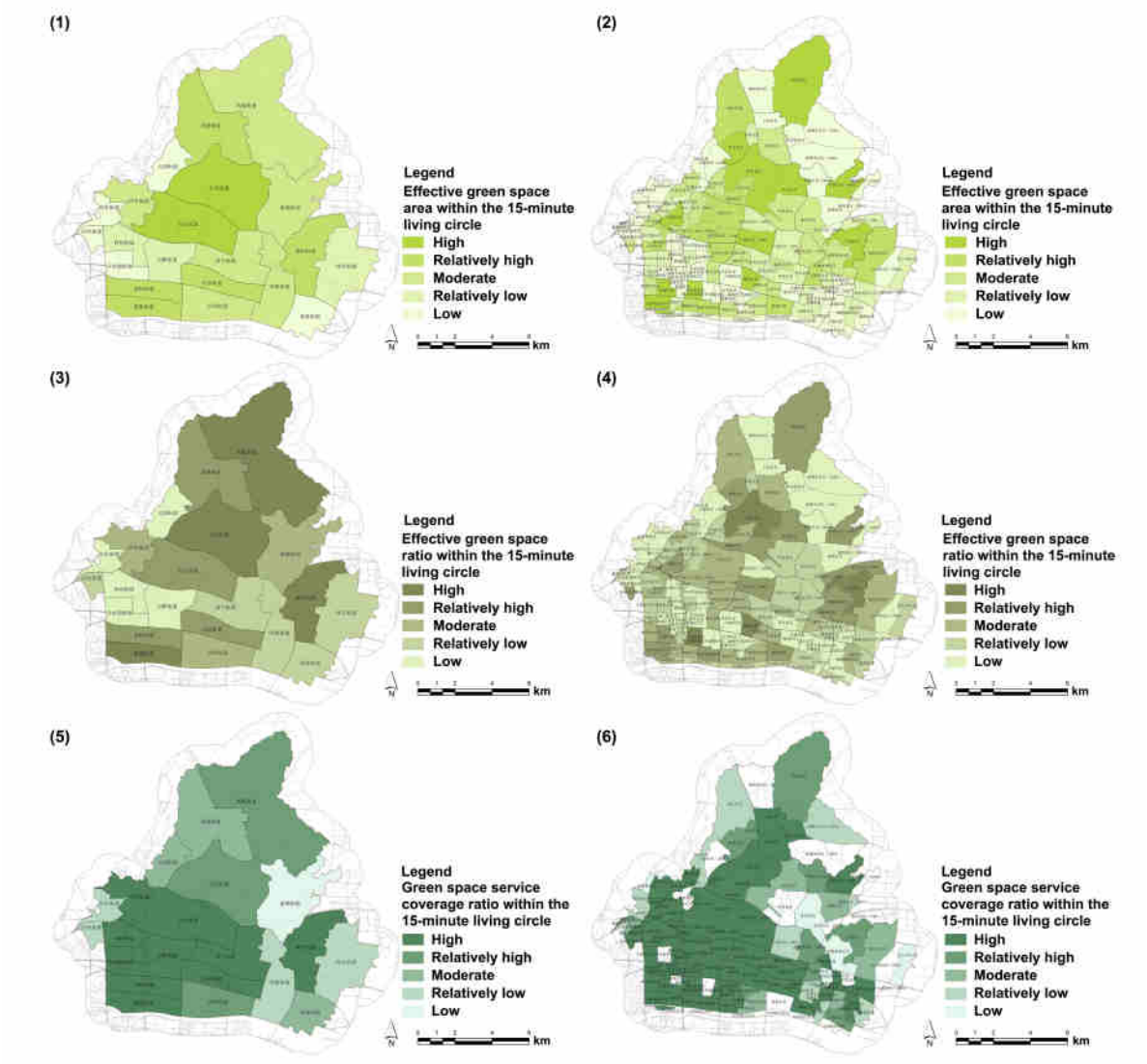

Figure 4 Assessment results for scale indicators ((1) Effective green space area within the 15-minute living circle (subdistrict level); (2) Effective green space area within the 15-minute living circle (community level); (3)Green space ratio within the 15-minute living circle (subdistrict level); (4) Green space ratio within the 15-minute living circle (community level); (5) Green space service coverage ratio within the 15-minute living circle (subdistrict level); (6) Green space service coverage ratio within the 15-minute living circle (community level))

(2)Assessment results for efficiency indicators

The efficiency dimension includes three indicators: Per capita green space area, shape indicator, and service overlap ratio within the 15-minute living circle. Per capita green space area represents the amount of green space available for residents' daily use; the shape indicator is used to evaluate the influence of boundary complexity on the service capacity of urban public green spaces of equivalent size; the service overlap ratio measures whether residents have access to multiple green space options within their daily activity range. Together, these indicators reflect the efficiency with which green spaces satisfy residents' everyday needs (Figure 5).

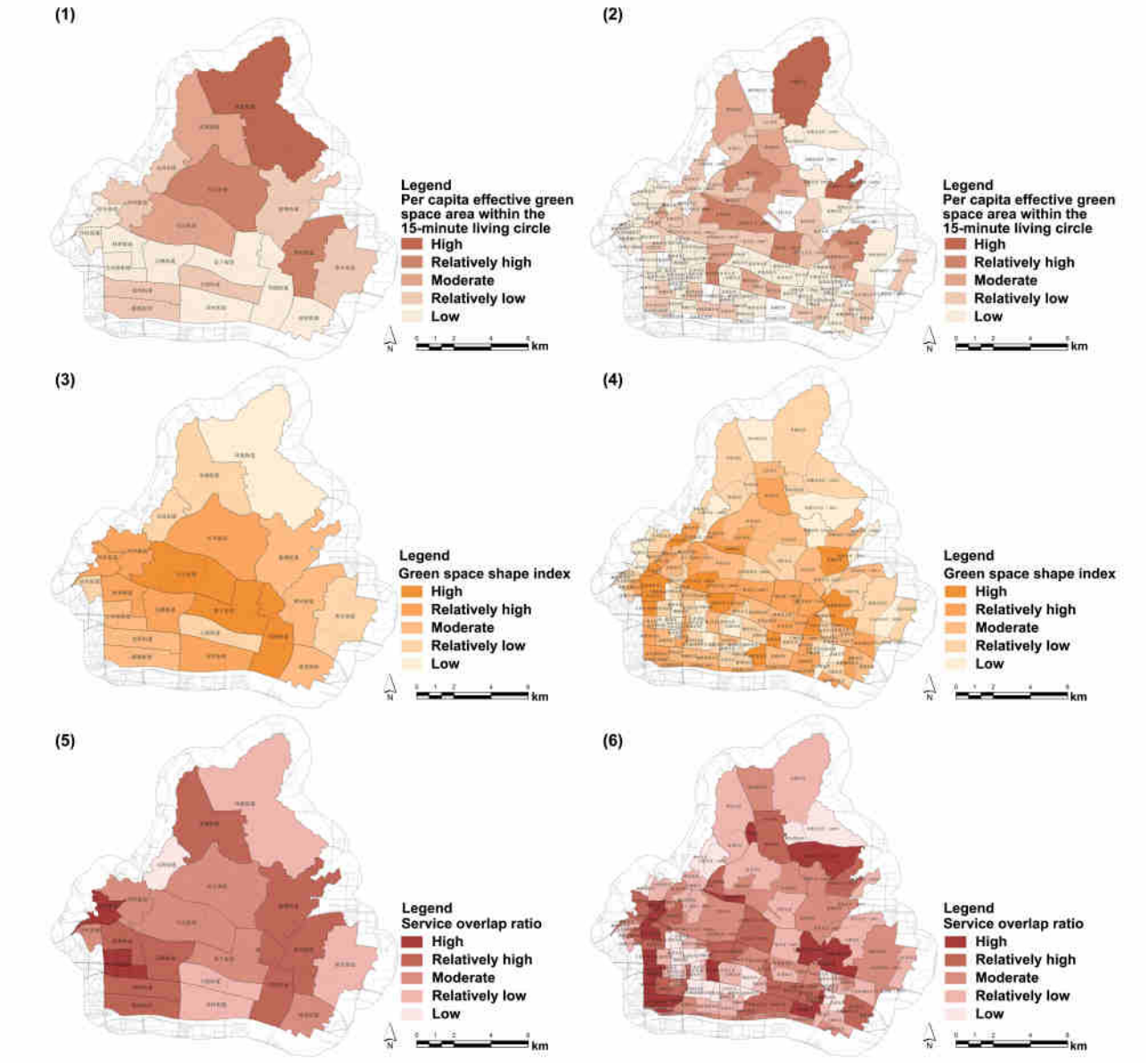

Figure 5 Assessment results for efficiency indicators((1) Per capita effective green space area within the 15-minute living circle (subdistrict level); (2) Per capita effective green space area within the 15-minute living circle (community level); (3) Shape indicator of effective green spaces within the 15-minute living circle (subdistrict level); (4) Shapeindicator of effective green spaces within the 15-minute living circle (community level); (5) Service overlap ratio of effective green spaces within the 15-minute living circle (subdistrict level); (6) Service overlap ratio of effective green spaces within the 15-minute living circle (community level))

(3)Assessment results for accessibility indicators

The accessibility dimension consists of road network density, minimum proximity distance, and comprehensive accessibility. Road network density reflects the ease with which residents can reach green spaces. Minimum proximity distance represents the minimum travel cost required to access the nearest

green space; comprehensive accessibility was measured at both the subdistrict and community levels using the Gaussian two-step floating catchment area (G2SFCA) method to assess green space accessibility within the 15-minute living circle. Collectively, these indicators reflect the ease with which residents can access and use green spaces in their daily lives (Figure 6).

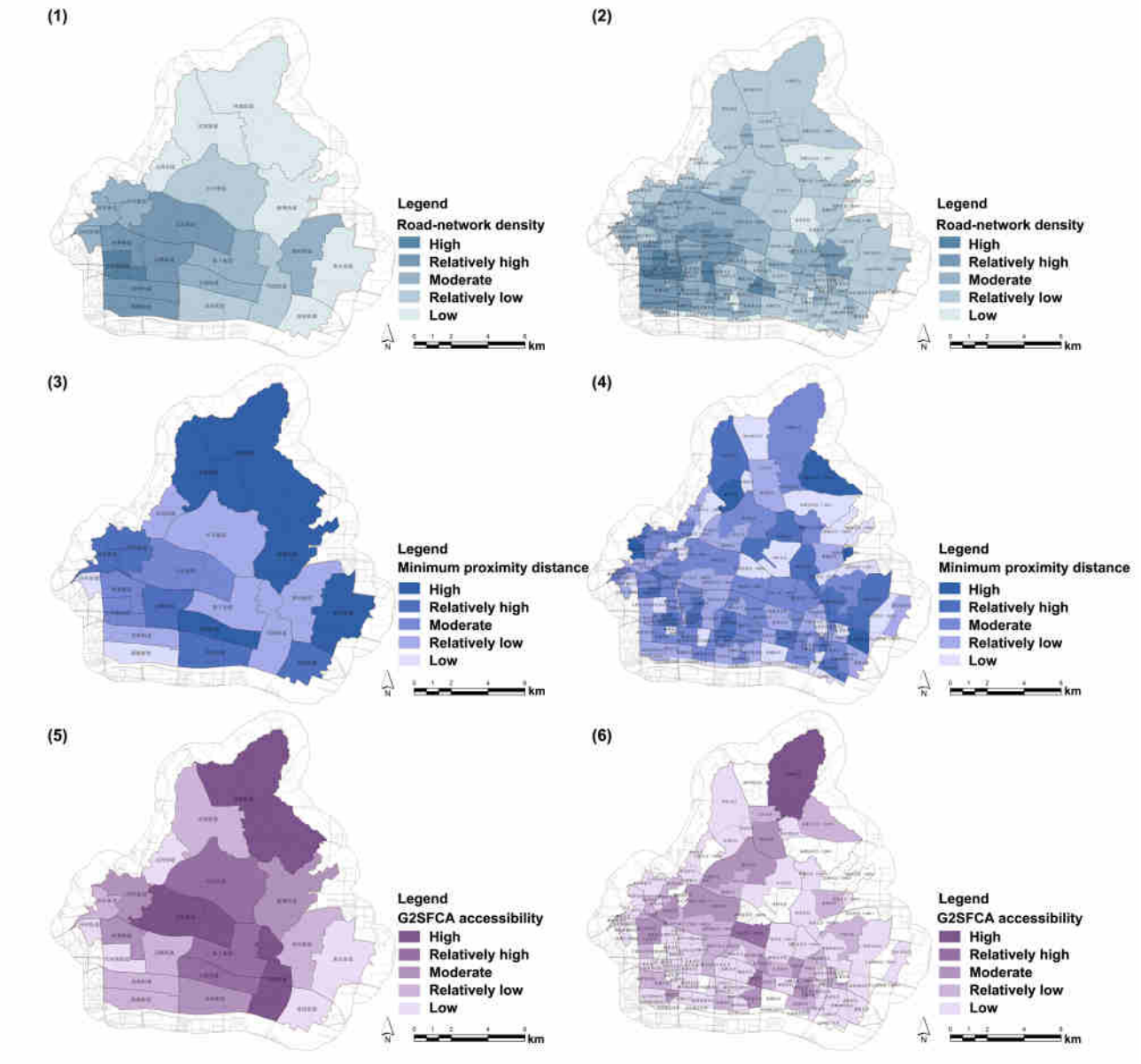

Figure 6 Assessment results for accessibility indicators((1) Distribution of road network density (subdistrict level); (2) Distribution of road network density (community level); (3) Meanminimum proximity distance from residential compounds to the nearest green space[3] (subdistrict level); (4) Mean minimum proximity distance from residential compounds to the nearest green space[3] (community level); (5) Comprehensive accessibility (G2SFCA, subdistrict level); (6) Comprehensive accessibility (G2SFCA, community level))

(4)Assessment results for quality indicators

The quality dimension comprises two indicators: Green space equity and functional mix, which represent the attributes of equity and convenience, respectively. Equity refers to the degree to which urban residents enjoy equitable access to public green spaces. At the overall scale, it is measured in terms of distributional evenness, whereas at the community scale it is measured through service availability. Convenience refers to the ease with which residents can access other types of public service facilities while enjoying public green space services, and is measured using the degree of functional mix surrounding urban public green spaces (Figure 7).

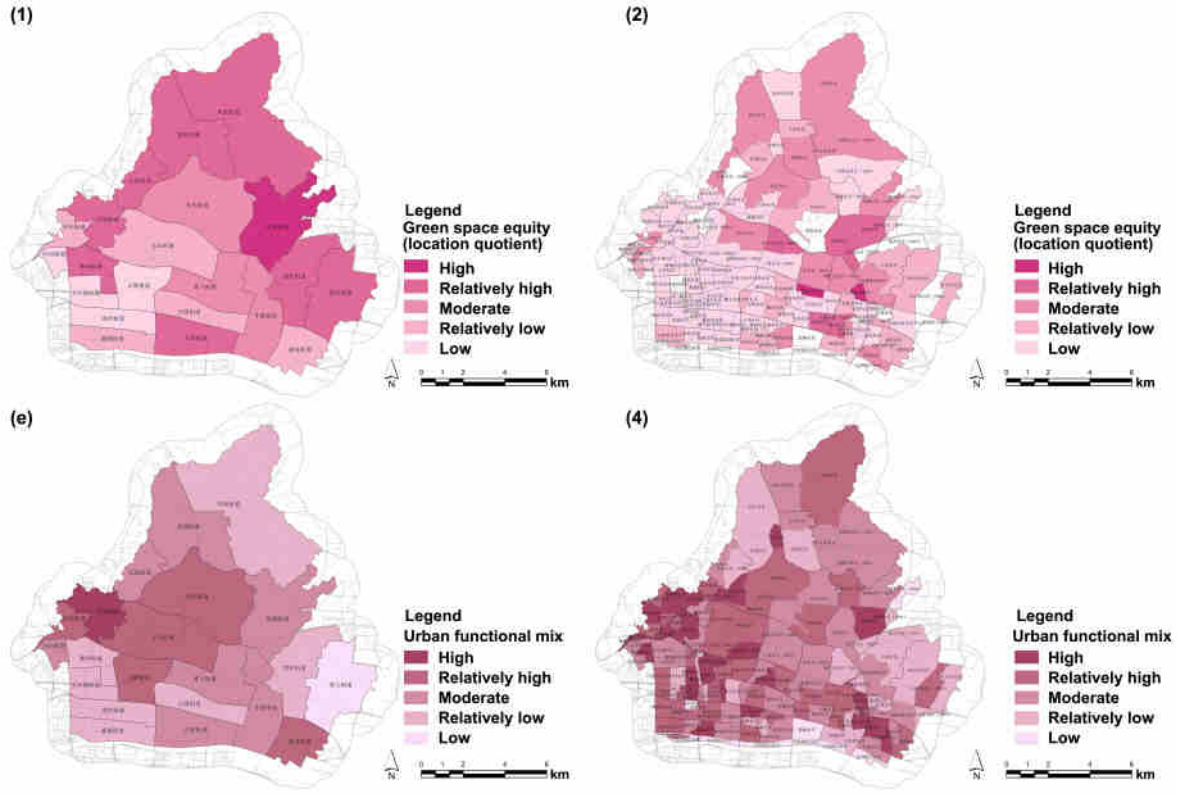

Figure 7 Assessment results for quality indicators((1) Green space equity (by location entropy, subdistrict level); (2) Green space equity (by location entropy, community level); (3) Distribution of urban functional mix (subdistrict level); (4) Distribution of urban functional mix (community level))

3.2.2 Selection of the weighting method

(1) Indicator correlations

Because the indicators may contain overlapping information and mutual influences, bivariate correlation analysis was conducted to examine the relationships among indicators and to identify an appropriate weighting method.

At the significance level of $p < 0.05$, several indicators exhibited notable correlations. Effective green space area within the 15-minute living circle showed a strong positive correlation with green space ratio. Effective green space service coverage ratio also displayed moderate positive correlations with per capita green space area and comprehensive accessibility. Effective green space service coverage ratio exhibited a moderate positive correlation with road network density. Service overlap ratio likewise showed a moderate positive correlation with road network density. Per capita green space area was moderately positively correlated with comprehensive accessibility, and effective green space area also exhibited a moderate positive correlation with comprehensive accessibility.

(2) Weight adjustment

The independence-weighting method provides a more objective approach for assigning weights to indicator systems exhibiting multicollinearity. Given a set of indicators X_1, X_2, ⋯, X_n, a larger multiple correlation coefficient between indicator X_k and the remaining indicators indicates stronger collinearity and greater redundancy of information. Accordingly, a lower weight should be assigned to that indicator.

Indicator weights at both the subdistrict and community levels were determined using theindependence-weighting coefficient method and subsequently adjusted to obtain the final weights (Table 5).

3.2.3 Comprehensive assessment by subdistrict and community

Using the adjusted weights, scores for scale, efficiency, accessibility, quality, and overall performance of urban public green space services were calculated for each subdistrict (Figure 8) and community (Figure 9).

Table 5 Adjusted indicator weights

A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2
0.0508	0.0508	0.0639	0.0884	0.0766	0.0874	0.0811	0.1185	0.0869	0.2132	0.0825

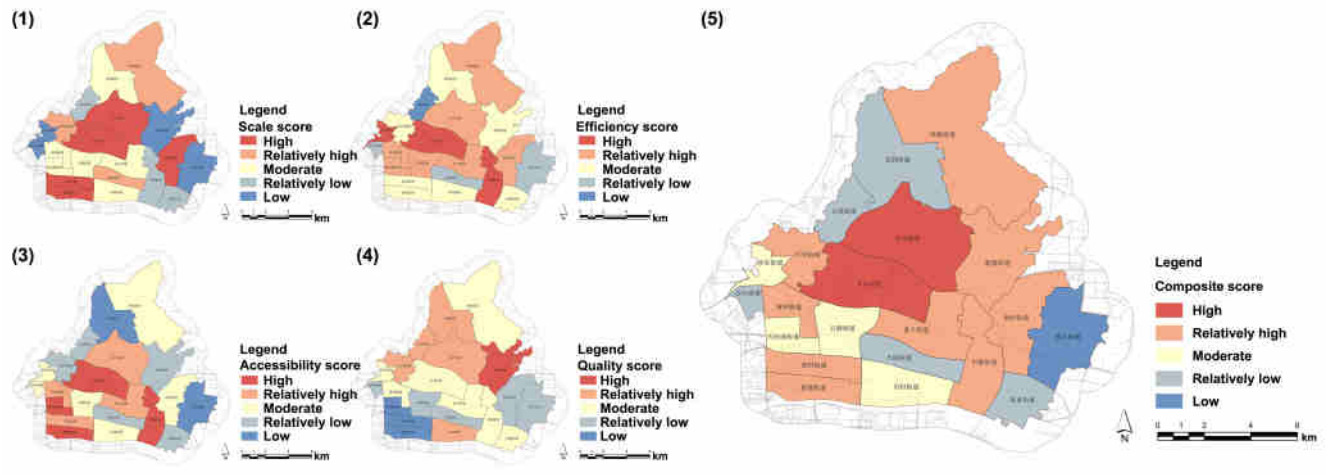

Figure 8 Classification of urban public green space service levels and overall composite scores by subdistrict

((1) Scale score; (2) Efficiency score; (3) Accessibility score; (4) Quality score; (5) Composite score)

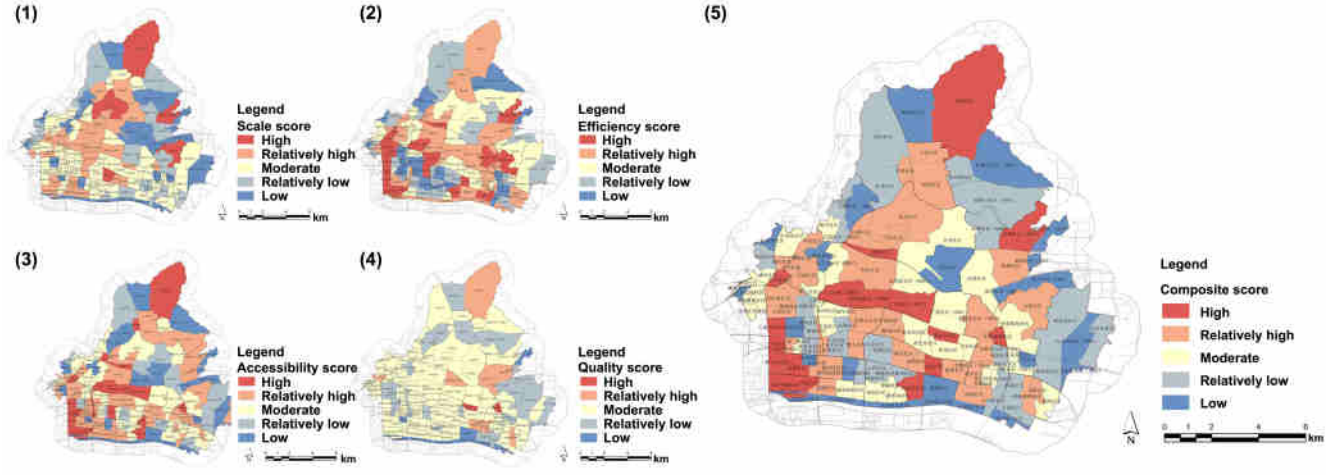

Figure 9 Classification of urban public green space service levels and overall composite scores by community

((1) Scale score; (2) Efficiency score; (3) Accessibility score; (4) Quality score; (5) Composite score)

With respect to scale, relatively high levels of green space provision were observed in Wushan Subdistrict and Keyi Community in Changxing Subdistrict in central Tianhe District; Xiancun and Liede subdistricts in the southwest; Daguan Community in Huangcun Subdistrict in the east; and Fenghuang Community in the north. In central Tianhe, this performance is largely attributable to public green spaces associated with the South China Botanical Garden, Huolu Mountain Forest Park, and the open campuses of South China University of Technology and South China Agricultural University. In the southwest, major contributors include large public squares and green spaces such as Huacheng Square and Zhujiang Park. In eastern Huangcun subdistrict, green spaces surrounding Grand World Scenic Park play an important role, while in the north the influence of Fenghuang Mountain Forest Park is particularly significant. In terms of efficiency, relatively high performance was observed in Wushan Subdistrict in central Tianhe District, Shadong Subdistrict in the west, and the Huasui Road area. Wushan benefits from both an

abundant supply and an even distribution of green spaces. Although Shadong possesses comparatively limited green space resources within its own boundaries, its proximity to Guangzhou Zoo, Luhu Park, and Baiyun Mountain enables residents to enjoy a relatively high level of green space services. Regarding accessibility, higher scores were concentrated in areas characterized either by dense road networks or exceptionally abundant green space resources, such as the Zhujiang New Town area in the southwest and the surrounding area in the university districts in Wushan. For quality, Xintang Subdistrict achieved relatively high scores owing to its balanced distribution of green spaces and the relatively even provision of other urban services.

Overall, the areas surrounding Wushan in central Tianhe District, Huacheng Square in the southwest, and Fenghuang Mountain Forest Park in the north exhibit relatively high levels of urban public green space services. In contrast, the Yuangang-Longdong area in the northwest and the Zhuji-Qianjin area in the east perform relatively poorly in terms of service provision.

3.3 Optimization strategies for urban public green space services

Low service effectiveness and uneven spatial distribution remain the principal challenges facing urban public green spaces in Tianhe District. Guided by residents' daily needs and the principles of optimizing existing resources, open sharing, and balanced coordination, this study proposes targeted strategies addressing different dimensions of service deficiencies, together with recommendations for the three stages of planning, design and construction, and governance. The aim is to provide references for improving the effectiveness of urban public green spaces in serving everyday life.

3.3.1 Optimization strategies

(1) Optimize spatial layouts in areas with adequate scale but low efficiency. Such areas typically possess abundant green space resources while also accommodating relatively large populations. Given their high level of urban development and limited opportunities for large-scale green space expansion, improvements may be achieved through increasing overall greenery and optimizing spatial distribution. Potential measures include expanding vertical greening and rooftop greening, as well as supplementing existing large green spaces with smaller, more dispersed green areas.

(2) Improve resource utilization in areas with adequate scale but poor accessibility. These areas are commonly located outside urban centers, where green space resources are abundant but population densities are relatively low. Although substantial green resources exist, they often fail to effectively serve residents' daily needs. Building upon existing road networks, complete, accessible, and safe pedestrian systems can be developed. Measures such as improved wayfinding, upgraded pedestrian crossing facilities, and encouraging public buildings to open internal circulation routes can help reduce travel time and enhance accessibility.

(3) Unlock the potential of existing urban spaces in areas with low efficiency but good accessibility. This situation is commonly found in highly urbanized central districts, where green space resources are insufficient and opportunities for expansion are extremely limited. Existing buildings and sites may be used more intensively to accommodate diverse public service facilities. In addition, micro-scale regeneration of underutilized spaces can be undertaken. Neglected urban spaces—such as street corners, riverbanks, and areas beneath elevated roads—can be revitalized through interventions including opening visual and physical connections to greenery, introducing landscape elements, expanding green infrastructure, and incorporating pocket green spaces to improve the scenery, functions and service facilities. Such measures can alleviate shortages of public green space, create small-scale recreational environments for residents, improve the overall urban environment, and stimulate urban vitality.

(4) Enhance green space service quality in areas with good accessibility but relatively low quality. These areas are often located around the core zones of highly developed urban centers. Although accessibility is generally high, their overall service quality remains lower than that of surrounding areas. The provision of complementary urban public services within or adjacent to green spaces can increase functional diversity, improve supporting public service facilities, and enhance environmental quality.

(5) Promote interdistrict connectivity in areas with low accessibility but high quality. Such areas typically possess well-developed internal services but maintain weak connections with surrounding districts, so that they showed a degree of spatial isolation. Strengthening transportation connectivity with adjacent areas and promoting the sharing of public service facilities are therefore recommended.

3.3.2 Recommendations

(1) Rational spatial allocation during the planning stage. An effective assessment of existing public service provision constitutes an essential prerequisite for planning. This study explores an approach for applying the living-circle concept to the evaluation of public green spaces in built-up areas. The assessment results can inform future planning processes. Furthermore, planning units should be delineated from a living-circle perspective to promote the balanced and coordinated provision of public service facilities.

(2) Refined improvement during the design and construction stage. Following the principles of balance and coordination, diversified public service facilities should be arranged through intensive land-use strategies to promote compact mixed-use development. At the same time, pedestrian accessibility should be enhanced through improvements to high-density road networks and walking systems. Green spaces that currently perform poorly—such as abandoned pocket squares, roadside green strips, and spaces beneath elevated roads—should be redesigned and transformed into active public spaces. Public participation in the design and construction process should be encouraged to better understand residents' needs and strengthen their sense of involvement. Sustainability, durability, and ease of maintenance should also be fully considered in the construction of green spaces and public plazas.

(3) Orderly sharing during the governance stage. One of the major constraints on public accessibility arises from issues related to long-term management and maintenance. Therefore, the concept of "Urban Entrepreneurialism" should be introduced to promote the shared use of green spaces located within residential compounds, university campuses, industrial parks, and other non-public or semi-public environments. Public participation should also be emphasized in the operation and maintenance of public green spaces. Public facilities should be encouraged to provide public access through internal passageways, thereby improving the continuity of pedestrian networks. Efforts should also be made to enhance the quality of street frontages and the comfort of pedestrian environments. In addition, vibrant and diverse systems of urban "gray spaces" can be created by utilizing elevated ground-floor spaces (pilotis), entrance areas, and similar transitional spaces.

Conclusion

To address the limitations of existing evaluation approaches, this study proposes an assessment framework for urban public green space services from the perspective of the 15-minute living circle. The framework aims to provide a comprehensive evaluation of green space service effectiveness based on residents' daily needs. Through the development and empirical application of a systematic, scientifically grounded, and operational evaluation method, three principal conclusions are drawn:

(1) Evaluation standards that have long emphasized the quantity of green spaces produce results that increasingly diverge from contemporary service demands and are no longer compatible with people-oriented urban development objectives. Compared with the traditional perspective dominated by land-resource allocation, a perspective grounded in residents' daily needs better reflects actual patterns of service use and represents a shift in planning logic from a focus on resources to a focus on people.

(2) Based on the literature review and the "Living Circle Guidelines", urban public green space services can be evaluated from four dimensions: scale, efficiency, accessibility, and quality. Scale is primarily influenced by the quantity of green space both within and around the area concerned. Efficiency is mainly affected by the amount and spatial distribution of green spaces. Accessibility depends largely on green space amount and road-network density. Quality is determined principally by the equity of green space distribution and the balance of other urban services.

(3) Through dimension-specific assessment, differen-

tiated improvement strategies can be formulated according to local deficiencies. Areas with adequate scale but low efficiency should prioritize layout optimization; areas with adequate scale but poor accessibility should improve resource utilization; areas with low efficiency but good accessibility should focus on unlocking the potential of existing spaces; areas with good accessibility but low quality should prioritize improvements in service quality; and areas with low accessibility but high quality should strengthen integration and coordination with surrounding districts.

Sources of Figures and Tables

All figures and tables in this paper were prepared by the authors.

Notes

1) Includes residential compounds, villas, and mixed residential-commercial developments, but excludes urban villages. Data are current as of the end of 2020.

2) Owing to the limited timeliness and insufficient spatial resolution of the Sixth National Population Census data, population data were derived from the "number of households" information for individual residential compounds obtained from real-estate websites (including residential compounds, villas, and mixed residential-commercial developments; data are current as of the end of 2020). Using this method, the estimated permanent resident population of Tianhe District was 1.663 million, compared with 1.747 million reported in the "Tianhe Yearbook 2019". The overall error is within 5%, indicating a relatively high level of reliability.

3) As the minimum proximity distance is a negative indicator, darker colors indicate greater distances to the nearest green space and therefore poorer performance for this indicator.

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