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Performance Evaluation and Optimization Path of Industrial Land in Districts and Counties

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ABSTRACT: The inherent scarcity of land drives an inevitable shift in land resource utilization from "incremental expansion" to "stock optimization". Industrial land is the primary carrier of urban production functions and a key focus for optimizing stock space in districts and counties within the context of territorial spatial planning. Through a comprehensive review of relevant literature and practical experience, this study clarifies and extends the conceptual framework of the development potential of stock industrial land, providing a theoretical foundation for the revitalization of underutilized industrial land. It constructs an integrated framework for macro-scale performance assessment and micro-scale classification of inefficiency types of industrial land, offering categorized guidance for enhancing the quality and efficiency of the "three-level and five-category" industrial land system, and providing methodological references for district- and county-level redevelopment of stock underutilized industrial land as well as sustainable urban development decision-making in the new development stage. Furthermore, the study explores multi-scenario implementation paths and full life-cycle management mechanisms for the redevelopment of underutilized stock industrial land, providing support and assurance for the intensive and efficient utilization of construction land.

KEY WORDS: territorial spatial planning; stock industrial land; three levels and five categories; performance evaluation; optimization path

Introduction

Under the guidance of the concept of ecological civilization, territorial spatial planning in the new era actively addresses various conflicts among spatial resources, and fulfills the requirements of high-quality development through spatial development, protection, replacement, and renewal[1]. The scientific rationality of territorial spatial allocation, with land as the core resource element, is an important guarantee for improving the quality of China's economic development and promoting its sustainable growth [2]. The inherent scarcity of land dictates that, with the continuous rise of urbanization, the stock of unused land will steadily decline, while demand for land use will grow. Accordingly, the vast stock of urban space, as the most expansive "blue ocean" in territorial spatial planning, must inevitably be subject to potential tapping and urban renewal. As the reform of territorial spatial planning advances, the city construction model dominated by incremental planning is gradually being replaced by stock-oriented planning. "Strictly controlling increments and revitalizing stock" has become the core approach to achieving high-quality development. To improve the rationality of intensity in urban construction land development and utili-

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zation, attention must be paid to potential tapping in urban land use [3].

Industry is the driving force and foundation of urban development[4]. Industrial land, as an important carrier of urban production functions, is the key target for potential tapping in existing space. During the period of rapid urbanization, local governments sought development through investment promotion policies featuring low or even zero land prices. Consequently, the spatial structure of cities changed along with rapid land expansion. Meanwhile, shifts in industrial planning and environmental protection policies, coupled with the finite lifecycles of enterprises and the lack of effective exit mechanisms, led to a series of issues such as a high proportion of industrial land, inefficient utilization, and irrational spatial distribution [5, 6]. With the continuous advancement of new-type urbanization, promoting the redevelopment of underutilized industrial land within cities has become an inherent requirement for adapting to economic restructuring and optimizing the spatial development and protection pattern of national territory [7]. In current territorial spatial planning practices, it has been observed that cities of all scales—large, medium, and small—maintain a relatively high proportion of industrial land, which also demonstrates greater potential compared to other categories of land use. In recent years, relevant departments of the State Council have successively issued a series of policies and implementation guidelines related to industrial land, such as the "Overall Plan for Comprehensive Pilot Reform of Market-Oriented Factor Allocation" and the "Guidelines for the Implementation of Industrial Land Policies". All of these documents propose improving the efficiency of land factor allocation and addressing in depth the issue of output efficiency for stock industrial land [8]. How to create greater value from limited land resources has become an important direction of exploration for local governments to enhance spatial governance efficiency under the ongoing reform of territorial spatial planning [9].

Research on the evaluation and identification ofunderutilized industrial land and on optimized redevelopment pathways is of great significance for the systematic implementation of territorial spatial planning and for enhancing the efficiency of land resource allocation. Existing studies primarily concentrate on macro- and meso-level efficiency evaluations of construction land at provincial and municipal scales, with little refinement to the micro scale of industrial parcels, thereby limiting their ability to provide effective evidence for constructing rational and orderly pathways of stock industrial land optimization and renewal [10]. Meanwhile, domestic studies on the renewal of stock industrial land generally exhibit the characteristics of emphasizing conceptual frameworks over practical application and focusing on major cities while neglecting smaller towns, tending either toward theoretical construction or toward case studies in the central districts of first-tier metropolises [11]. Because they possess strong fiscal capacity, relatively mature policy mechanisms, and well-developed institutional foundations, large cities usually adopt government-led approaches such as repurchasing underutilized land for redevelopment as the main mode of urban renewal. However, such approaches provide limited direct guidance for ordinary small towns where financial resources are tight and supporting policies remain in exploratory stages. This study seeks to summarize and synthesize existing theoretical research and practical experience on underutilized industrial land redevelopment, aims to construct a performance evaluation and optimization framework for existing industrial land at the district and county level with broad applicability, thereby providing systematic operational guidance for ongoing industrial land renewal efforts across regions.

1 Local models of underutilized industrial land redevelopment

Since 2016, based on the implementation requirements and guiding principles of the former Ministry of Land and Resources' "Guiding Opinions on Deepening the Redevelopment of Inefficient Urban Land (Trial)", provinces and cities have proposed different implementation approaches forunderutilized industrial land redevelopment according to their respective industrial land-use characteristics. In practical applications, most provinces and cities adopt a similar approach to determine the redevelopment potential of underutilized industrial land in urban areas—namely, identifying and assessing potential sites based on the results of special investigations on underutilized urban land. This process involves conducting an inventory survey of existing construction land using data from the national land survey to obtain information on the quantity, distribution, and industrial types of underutilized urban land in the areas. The sites planned for redevelopment are then marked on remote sensing images and planning maps to establish a database of underutilized land. In terms of organizational modes for underutilized industrial land redevelopment, local practices vary slightly, but they can generally be categorized into three types: government-led redevelopment, redevelopment by original landowners, and redevelopment involving market participants (Table 1).

Table 1 Comparison of scope and modes of underutilized industrial land redevelopment at national and provincial levels

	Scope of Underutilized Industrial Land Redevelopment	Modes of Underutilized Industrial Land Redevelopment
Former Ministry of Land and Resources (2016)	(1) Industrial land used for prohibited or phased-out industries as specified in national industrial policies; (2) Land failing safety production or environmental protection requirements; (3) Land for "upgrading from secondary to tertiary industries"; (4) Areas with scattered layout and outdated facilities that are designated for reconstruction in plans	(1) Reconstruction and development by state-owned land use right holder; (2) Reconstruction and development of collective construction land in urban villages; (3) Land with structure to be optimized through industrial transformation and upgrading; (4) Concentrated, large-scale development; (5) Construction for strengthening public facilities and livelihood projects
Jiangsu Province (2016)	(1) Land not in line with industrial policy guidance, safety production, or environmental protection requirements; (2) Land with phased-out, redundant, or overcapacity industries; (3) Land with scattered layout and inefficient land use; (4) Land with irrational use or low output efficiency; (5) Land not meeting the conditions of state-owned construction land transfer contracts	(1) Government-led redevelopment; (2) Redevelopment by original landowners; (3) Redevelopment involving market participants; (4) Comprehensive renovation and improvement
Sichuan Province (2017)	(1) Land prohibited or to be phased out according to industrial policies and documents such as the "Catalogue for Guiding Industry Restructuring", the "Catalogue of Items for Which the Land Use Is Restricted", and the "Catalogue of Items for Which the Land Use Is Prohibited"; (2) Land identified by authorities as failing safety production or environmental standards; (3) Land for "upgrading from secondary to tertiary industries"; (4) Land with utilization intensity and input-output levels significantly below relevant standards or contractual agreements	(1) Government reclaims land use rights for redevelopment; (2) Redevelopment by original state-owned land use right holder in ways like self-development, joint ventures, equity participation, or transfer; (3) Market entities conduct concentrated, contiguous development: acquire adjacent plots through public procedures, then apply for concentrated redevelopment
Henan Province (2018)	(1) Industrial land used for prohibited or phased-out industries as specified in national industrial policies; (2) Land failing safety production or environmental protection requirements; (3) Land where buildings and structures pose serious safety hazards; (4) Land listed in municipal, county (district) industrial layout adjustment plans, pending relocation, or for "upgrading from secondary to tertiary industries"; (5) Land with low utilization intensity or land output rate	(1) Industrial upgrading and transformation to optimize land use structure; (2) Redevelopment involving original state-owned or collective land use right holders and other market entities; (3) Market entities acquiring adjacent plots for concentrated, contiguous development

(Continued)

	Scope of Underutilized Industrial Land Redevelopment	Modes of Underutilized Industrial Land Redevelopment
Tianjin Municipality (2020)	(1) Industrial land used for prohibited or phased-out industries as specified in national industrial policies; (2) Land failing safety production or environmental protection requirements; (3) Land for "upgrading from secondary to tertiary industries"; (4) Areas with scattered layout and outdated facilities that are designated for reconstruction in plans	(1) Government-led redevelopment: redevelopment according to current policies; (2) Market-led redevelopment: original land right holders redevelop independently or through investment cooperation, but their investment share must not be less than 51%
Shandong Province (2020)	(1) Industrial land used for prohibited or phased-out industries as specified in national industrial policies; (2) Land failing safety production or environmental protection requirements; (3) Land for "upgrading from secondary to tertiary industries"; (4) Areas with scattered layout and outdated facilities that are designated for reconstruction in plans; (5) Control indicators such as investment intensity, plot ratio, and land-based output intensity are significantly below local industry averages; (6) Land identified based on the list of "restricted development" enterprises according to the "per-mu output efficiency" performance evaluation reform	(1) Government reclaim land for redevelopment: plots planned for residential, urban infrastructure, or public facilities are reclaimed or purchased according to law; (2) Original land use right holder redevelop: through self-development, joint ventures, equity participation, or transfer; (3) Original rural collective economic organizations redevelop: urban village collective construction land may be redeveloped independently or with social investors; (4) Market entities redevelop: open bidding is conducted to determine market entities to acquire adjacent plots and implement concentrated, contiguous development
Zhejiang Province (2021)	(1) Land not conforming to planning purposes, or requiring implementation of "retreat from secondary, advance tertiary"; (2) Land failing safety production or environmental protection requirements; (3) Land classified as prohibited or phased-out at national and provincial levels; (4) Land with utilization intensity or input-output level significantly below construction land control standards; (5) Land occupied by outdated industries or struggling enterprises that needs to be vacated from use	(1) Government-led redevelopment; (2) Market entity redevelopment: acquire adjacent plots through transfer and apply for concentrated development; (3) Original land-use rights holder develops the land independently: a redevelopment plan shall be formulated, submitted for approval in accordance with procedures, and implemented upon approval. (4) Original collective economic organization develops independently or cooperatively

Although policy guidelines forunderutilized land redevelopment have been successively introduced at the provincial and municipal levels, the implementation of industrial land rectification and upgrading at the district and county level still faces a series of challenges. These mainly include: (1) identification of the scope of underutilized industrial land redevelopment is incomplete; (2) connotation of the redevelopment potential of stock industrial land is outdated; (3) An integrated implementation framework spanning from policy guidance to operational guidelines has yet to be established for the identification of underutilized land. Regional standards remain inconsistent, and the involvement of multiple departments renders data collection and survey work highly labor- and cost-intensive; (4) market entities show limited willingness to participate in the redevelopment or land exchange of certain plots due to financing difficulties and low expected economic returns; (5) high expectations of land value appreciation among original land use right holders result in substantial funding requirements for government land acquisition and reserve, potentially exceeding the fiscal capacity of local governments; (6) the relevant legal and policy framework remains incomplete, and there is limited exploration of localized safeguard mechanisms for implementation, including remediation, upgrading, and subsequent management [12].

2 Connotation of the redevelopment potential of stock Industrial land

Built-upunderutilized industrial land in urban areas constitutes the primary component of the redevelopment potential of stock industrial land. In 2015, the former Ministry of Land and Resources defined underutilized industrial land as "non-idle land whose current input-output intensity, floor area ratio, building density, industrial type, and production operation conditions do not meet industrial and urban development needs, yet still possess significant potential for adjustment and utilization." At present, there is still no universally accepted academic definition of the scientific connotation of underutilized industrial land. However, the concept is generally examined across multiple dimensions, including industrial orientation, external manifestation, output efficiency, utilization intensity, environmental protection and energy performance [13-15]. He Fang et al. proposed that the identification of underutilized industrial land should reflect the characteristics of comprehensive multi-departmental management, encompassing 6 categories: low efficiency due to idle or shutdown, low efficiency in development and utilization, low efficiency in input/output, low efficiency in industrial orientation, low efficiency in contract, low efficiency in functional allocation [16]. Based on the principle of land conservation, QU Zhongqiong summarized the connotation of underutilized industrial land into 3 aspects: low efficiency in land output, low utilization rate of industrial land, and insufficient function in social service [17]. Internationally, a similar concept to underutilized industrial land is the "brownfield". The two share four comparable characteristics: (1) In terms of physical form, they are previously developed lands that are currently idle, abandoned, or awaiting redevelopment; (2) In terms of economic performance, they have low productivity or fail to meet the requirements of regional dominant industries to be developed, with indicators such as total output value, profit, and tax revenue falling short of contractual obligations; (3) In terms of spatial efficiency, they feature disordered and underutilized layouts, with low indicators of land use intensity such as factory building density, floor area ratio, and fixed-asset investment; (4) In terms of environmental benefits, they are characterized by high energy consumption, high pollution, and high risk, and fail to meet relevant regulatory standards [18-20].

The incorporation of approved-but-unsupplied and idle land into the stock under the "increment-stock linkage" mechanism, together with the removal of legal barriers to the market entry of rural collective operational construction land, extended the spatial connotation of the potential exploitable in stock industrial land[21]. In 2018 the "Notice of the Ministry of Natural Resources on Improving the 'Increment-Stock' Linkage Mechanism for Construction Land" stipulated that approved-but-unsupplied and idle land should be included as stock indicators in calculations. Regions with large amounts of such land would see reduced allocations of new construction land, and subsequent annual quotas would be rewarded or reduced based on the completion of land disposal tasks. In the past, academic and planning circles often associated the redevelopment of underutilized land with "Three-Old Redevelopment" and "Urban Renewal" [22]. The discussion typically focused on the performance evaluation and low efficiency identification of already developed industrial land, while paid insufficient attention to unsupplied and undeveloped land. Furthermore, the *Notice of the Ministry of Natural Resources, the National Development and Reform Commission, and the Ministry of Agriculture and Rural Affairs on Ensuring and Regulating Land Use for the Integrated Development of Primary, Secondary, and Tertiary Industries in Rural Areas* issued in 2021 stipulated that large-scale and highly industrialized projects should be located in industrial parks, and sizable agricultural product processing projects should be concentrated within urban development boundaries. For a long period, the lack of adequate control over land outside urban development boundaries has led to scattered and underutilized development of rural collective operational construction land. Given the widespread overextension of construction land quotas, small towns must explore a more compact and efficient model for reconstructing urban-rural industrial spaces [23]. However, most national and provincial guidelines for investigating and redeveloping low-efficiency stock land focus primarily on urban areas, and little research is conducted for this in rural regions [24]. Consequently, many districts and counties still lack policy guidance for the redevelopment of low-efficiency collective industrial land in rural areas.

This study examines each stage of the full life cycle of industrial land and includes all non-high-quality industrial spaces throughout the processes of land approval, allocation, and construction within the scope of the redevelopment potential of existing industrial land. These spaces are classified into four major categories: approved but unsupplied industrial land, supplied but undeveloped industrial land, underutilized industrial land in urban areas, and underutilized industrial land in rural areas (Figure 1).

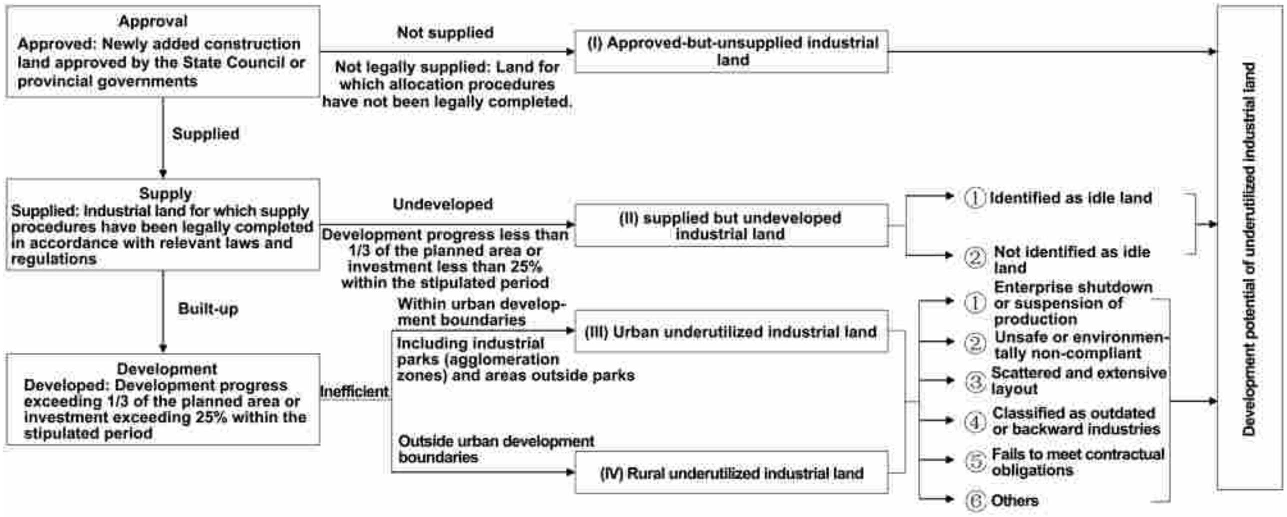
3 Evaluation and optimization pathway of industrial land use performance

3.1 Classification of industrial land by scale

There are objective differences in the utilization performance of stock industrial land across different scale levels. Higher-level industrial parks, being generally larger in area and benefiting from stricter entry thresholds, more complete supporting facilities and greater policy incentives, exhibit significantly higher land productivity than lower-level ones[25]. In order to propose targeted land-use renewal schemes from the perspective of overall territorial coordination and balance, it is necessary to conduct classified evaluations based on a macro-level assessment of the entire territory. Drawing on industrial land renewal practices in cities such as Shanghai and Suzhou, and based on the current scale distribution of industrial parks nationwide, the stock industrial land within districts and counties can be classified into a three-tier system comprising industrial bases, industrial communities, and industrial blocks (Figure 2). Industrial bases refer to large-scale industrial parks or clusters located within the jurisdiction of development zones or high-tech zones at the district or county level. The total land area generally exceeds 4 km^2. Industrial communities refer to industrial parks or clusters at the municipal level or above, that are situated outside industrial bases. Their area is typically greater than 1 km^2. Industrial blocks refer to smaller industrial parks below the municipal level, and other scattered industrial lands located outside industrial bases and industrial communities. Empirical evidence shows that in most regions, the output efficiency of industrial land is highest in industrial bases, followed by industrial communities, and lowest in industrial blocks. Under current resource constraints, the overarching principle is that industrial bases and communities within the urban development boundary should focus on prioritized development and optimization, whereas industrial blocks outside the boundary should focus on clearance, relocation, and improvement.

3.2 Macro-scale evaluation of industrial land use performance

A comprehensive evaluation is conducted at both the overall regional (macroscopic) level and the three-tier classification of industrial land use. The objective is to gain an intuitive understanding of the current efficiency of urban industrial land through a multidimensional factor profiling approach, identify the relative strengths and weaknesses of the industrial bases and communities, and thereby coordinate and balance the spatial layout of industrial land within districts and counties to more effectively guide the relocation and renewal of industrial sites. Based on existing theoretical research and planning practices related to industrial land evaluation methods[26-28], this study constructs an indicator system comprising five criterion dimensions: economic efficiency, land use intensity, accessibility and industry-friendliness, innovation and collaboration, and ecological efficiency (Table 2). Under each criterion, more than three representative indicators are selected. The number of "+" signs represent the relative importance of each indicator—the greater the number of "+" signs, the higher its weight in performance evaluation and the greater its priority in consideration. If it is necessary to assign specific weights to the indicators under each criterion and calculate a comprehensive performance score for a particular industrial base or community, methods such as the Delphi method, Analytic Hierarchy Process (AHP), or Entropy Weight Method can be adopted [29]. However, it should be noted that excessive dimensionality reduction or normalization may obscure important original attributes [30]. In many cases, qualitative judgments derived from multidimensional quantitative indicators may provide more intuitive and effective insights than the results of composite index calculations. Therefore, this study focuses primarily on the logic of macroscopic performance evaluation and the application of evaluation results within the system framework for industrial land optimization and renewal, while simplifying technical processes such as weight calculation as much as possible to better meet the practical needs of district- and county-level redevelopment of stock industrial land.



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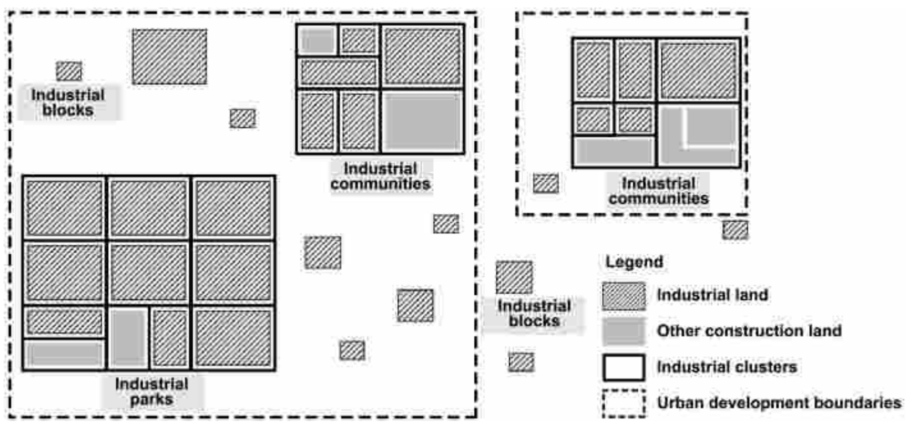

Figure 2 Classification ofndustrial and cale at istrict and ounty evel

3.3 Micro-scale identification of underutilized land use types by enterprises

Identifying and classifyingunderutilized land use by enterprises at the micro scale serves to establish a clear baseline, fully explore the redevelopment potential of the land, and facilitate phased, targeted management of different types of enterprises by relevant authorities. In current planning practice, the estimation of underutilized land use potential often relies directly on specialized survey and assessment data from administrative authorities. However, due to the involvement of multiple stakeholders, the lists of underutilized land submitted by local governments are usually limited in both number and scale. A scientifically sound, rational, and straightforward evaluation indicator system is the foundation for assessing the intensive utilization and high-quality development of industrial enterprises [31]. To avoid inaccuracies in specialized survey results and to enhance the relevance of evaluation outcomes, this study simplifies the composite scoring method used in previous underutilized land identification research into a single-factor integrated evaluation approach.

The identification of industrial enterprisesunderutilizing land ("inefficient enterprises" hereinafter) can be categorized into five fundamental dimensions: green, efficiency, quality, equity, and safety: (1) Industrial enterprises within ecological red-line zones should be gradually withdrawn or replaced. As Environmental Impact Assessments (EIAs) can predict environmental impacts through qualitative and quantitative analysis, enterprises encroaching on ecological red lines or failing to pass EIA acceptance are identified as inefficient enterprises in green dimension; (2) The operational efficiency of industrial enterprises significantly affects their future market expansion, their capacity to provide employment, and the overall development of local society. Output per unit of land serves as the fundamental metric for assessing how efficiently enterprises utilize resources; (3) The long-term high-quality development of enterprises is largely contingent upon the cultivation and support of local industrial policies. Industrial enterprises outside dominant sectors and with poor management performance, in their efforts to reduce fixed costs, often fail to make intensive and efficient use of land; (4) Tax revenue per unit of land directly reflects the capacity of industrial enterprises to assume social responsibilities and obligations, and also indirectly indicates the equity with which they utilize land resources for production and operation and bear the associated costs; (5) The purpose of a safety evaluation is to identify potential hazards, assess their severity and consequences, and propose effective control measures prior to establishing safety provisions. Accordingly, whether an enterprise has completed and passed the safety evaluation constitutes a key indicator in the safety dimension. Based on individual indicators enterprise data from various industrial parks, a five-layer recursive judgment logic is established to successively screen and classify enterprises into five categories: green-deficient, efficiency-deficient, quality-deficient, equity-deficient, and safety-alert enterprises. These classifications are then matched to corresponding underutilized industrial land (Figure 3). The specific classification criteria and judgment logic for inefficient enterprises can be adjusted according to local conditions and practical needs.

Table 2 Optional indicators for performance evaluation of stock industrial land at district and county level

Criterion	Optional Indicator	Unit	Effects	Importance
Economic Efficiency	Industrial land output value per unit area	CNY10,000/km^2	Positive	+ + + + +
	Industrial land tax revenue per unit area	CNY10,000/km^2	Positive	+ + + + +
	Proportion of above-scale industrial enterprises	%	Positive	+
	Other related indicators	...	...	...
Land Use Intensity	Comprehensive plot ratio of industrial land	%	Positive	+ + + +
	Fixed asset investment per unit area of industrial land	CNY10,000/km^2	Positive	+ + + +
	Idle land rate of industrial land	%	Negative	+ +
	Other related indicators	...	...	...
Accessibility and Suitability for Industry	Employment per unit area of industrial land	Persons/km^2	Positive	+ + + +
	POI density of public service facilities	Numbers per km^2	Positive	+
	Accessibility	-	Positive	+
	Other related indicators	...	...	...
Innovation and collaboration	Proportion of planned strategic emerging industries output	%	Positive	+ + +
	Proportion of high-tech enterprises	%	Positive	+ + +
	Spatial agglomeration of industrial enterprises	-	Positive	+ +
	Other related indicators	...	...	...
Eco-Efficiency	Electricity consumption per unit industrial output	10,000 kWh/10,000 RMB	Negative	+ +
	Water consumption per unit industrial output	10,000 tons/10,000 RMB	Negative	+ +
	Wastewater generated per unit industrial output	10,000 tons/10,000 RMB	Negative	+
	Solid waste generated per unit industrial output	10,000 tons/10,000 RMB	Negative	+
	Other related indicators	...	...	...

3.4 Framework for Industrial Land Optimization and Renewal

The management of industrial parks and industrial land primarily involves the Natural Resources Commission, the Economic and Information Technology Commission, the Development and Reform Commission, and the Commerce Commission. Although each department has distinct regulatory emphases, their authorities overlap. Thus, in the new round of optimization and renewal of stock industrial land, it is necessary to enhance integration and coordination to ensure smooth and controllable decision-making and implementation [32]. Given the shortage of new construction land quotas in many districts and counties, the unsustainability of the previous model of rapidly advancing development and demonstration zones, and the near absence of a policy foundation for stock land renewal, this study adopts a territory-wide perspective to coordinate industrial land layout and calculate renewal costs under multiple scenarios, and constructs a full-process, implementation-oriented framework for industrial land optimization and renewal (Figure 4). The specific pathways are as follows:

(1) Overall performance assessment atthe macro level: Based on data from the Third National Land Survey (the 3rd Survey), appropriate indicators are selected from five criterion dimensions to comprehensively evaluate the utilization performance of industrial land across the entire district or county. By benchmarking against other districts in the same city or the national level to form a macro strategic assessment. Then conduct classified evaluations of industrial land-use intensity across different scales to identify inefficient, wasteful, or poorly planned industrial parks as priority areas for renewal and optimization.

(2) Drawing on enterprise survey data provided by government departments such as the Economic and Information Technology Commission and the Development and Reform Commission, and taking into consideration of regional characteristics and data availability, this study identifiesthe types of inefficient enterprises. Through methods such as POI crawling, the list of inefficient enterprises is spatially matched with industrial park land-use survey data, thereby clarifying the enterprises requiring enhanced supervision or planned withdrawal, and providing direction for efficiency improvement and targeted guidance in subsequent industrial land renewal.

(3) Formulation of land renewal schemes: Based on the results of the macro-level performance assessment and micro-level inefficiency identification, and from the perspective of overall spatial optimization, three fundamental principles are established: maintaining total volume, promoting clustering, and enhancing quality. To develop and improve supporting policy mechanisms for industrial land renewal in a context-specific manner, explore multiple scenario-based renewal schemes, verify them against existing plans and the "three control lines," and complete cost-benefit accounting to evaluate the feasibility of implementation.

4 Design of the implementation mechanism for industrial land optimization and renewal

4.1 Categorized guidance for "three levels and five categories" of industrial land

Based on the three-level scale system of industrial land and the distribution characteristics of the five categories ofunderutilized land, multiple renewal and revitalization approaches are adopted to enhance quality and efficiency. (1) For underutilized industrial land within industrial bases and industrial communities, on-site renewal is prioritized. High-efficiency enterprises should be retained, and the supporting facilities within the parks should be gradually improved through micro-renovations. Emphasis should be placed on strengthening the supervision of approved but unused land and tapping into the potential of stock land indicators. The efficiency targets per unit of land for industrial bases should be higher than those for industrial communities. The transformation of "industry-to-industry" can be combined with "industry-to-commercial" and "industry-to-public" transformations, upgrade from secondary to tertiary industries to facilitate the industrial restructuring and the integration of industry and urban functions. (2) Industrial blocks within industrial clusters should prioritize industrial-to-industrial renewal, phasing out low-end industries while supporting and upgrading advanced ones, so as to promote industrial transformation and upgrading. The strategy is to advance the integration of industrial parks and the relocation of industries in an orderly way, or to abolish certain parks, gradually transferring industries into qualified industrial communities, thereby freeing up construction land quotas. The methods for improving the efficiency of land use by inefficient enterprises in industrial communities are generally the same with those used in industrial communities, but the land-use efficiency targets can be slightly lower. (3) Scattered rural industrial blocks should, in the near term, focus on comprehensive remediation, while in the medium to long term, depending on development needs, they should be adjusted into land reserve and development zones, thereby transforming their land-use function. Rural industrial land that encroaches on ecological protection zones or farmland protection zones must be prioritized for withdrawal, while industrial land in other areas should be gradually phased out in accordance with policy.

Among the five categories of low-efficiency enterprise land: (1) green-deficient enterprises located within permanent ecological protection zones must strictly comply with control requirements. Where rigid control elements cover more than 50% of the total land area, the enterprise land must be reclaimed and restored to green use; (2) for efficiency-deficient enterprises, the main strategy is partial renovation and selective demolition/reconstruction to support expansion and upgrading. Heavy industry enterprises should not simply increase land-use intensity, while light industry enterprises may selectively adopt multi-story industrial building models[33]; (3) for quality-deficient enterprises, guidance should be provided to utilize existing land and facilities or to eliminate outdated capacity to free space for technological upgrading; alternatively, the space may be reallocated to high-tech enterprises or large-scale industrial enterprises, thereby supporting the development of higher-quality firms; (4) for equity-deficient enterprises, emphasis should be placed on encouragement, guidance, and differentiated management. Enterprise classification results are to be applied more deeply, with differentiated urban land-use tax reductions or exemptions implemented according to the level of contribution to local public finance. Projects that significantly enhance tax revenue per unit of land are to be given priority in land allocation; (5) safety-alert enterprises are to be managed by establishing a standardized institutional environment and conducting safety evaluations in strict accordance with national or industry standards. Enterprises with safety risks shall be ordered to rectify or, if necessary, be compelled to exit.

4.2 Economic evaluation of multi-scenario industrial land renewal schemes

The spatial pattern of scattered industry is uneconomical and unsustainable, whereas a specialized and concentrated industrial geography is conducive to regional economic development and to strengthening regional competitiveness[34]. In practice, the single policy goal of "moving industry into parks" is insufficient for guiding the optimization and restructuring of industrial space. Furthermore, highly concentrated spatial patterns are difficult to implement in many districts and counties. Therefore, local governments must acknowledge the partial rationality of existing conditions and seek more realistic optimization strategies. Under the guiding principles of "maintaining total volume, promoting clustering, and enhancing quality", the possible coordinated optimization patterns for district- and county-level industrial land can be divided into three types: "large-scale concentration," "small-scale clustering," and "small clustering with moderate park integration" (Figure 5). Economic costs for each scenario can be calculated based on expected planning-period indicators, and the results can be combined with the local socioeconomic context to select the most appropriate scheme.

This study compares and evaluates the three industrial land renewal schemes to achieve a balance between short-term economic costs and long-term social development benefits. (1) "Large concentration" model: All industrial blocks outside the main industrial clusters are relocated and fully incorporated into industrial bases. This model entails extremely high short-term economic costs for land relocation. Currently, local district and county finances are often insufficient to support it, and issues such as insufficient development incentives for townships and rising unemployment may arise. (2) "Small clustering" model: Scattered rural industrial blocks are integrated by relocating them to nearby industrial bases or industrial communities within their corresponding towns or subdistricts. Multiple small parcels within the same industrial cluster are merged into larger blocks to achieve moderate clustering. This model, based on current conditions, involves only a small scale of land withdrawal and thus entails low economic and social costs. However, as the overall industrial spatial layout remains relatively dispersed, indicators such as output value per unit of land and tax revenue per unit of land are unlikely to meet planning expectations. (3) The "small clustering + moderate park" scheme involves relocating all small industrial blocks surrounding industrial bases and consolidating them into the base, while vacating certain scattered industrial blocks in towns and rural areas and incorporating them into nearby industrial communities. This model balances the advantages and disadvantages of the previous two schemes. Through a dynamic balance of land relocation and the addition of new land, it simultaneously considers planning feasibility and long-term development benefits, making it the preferred approach for most districts and counties.

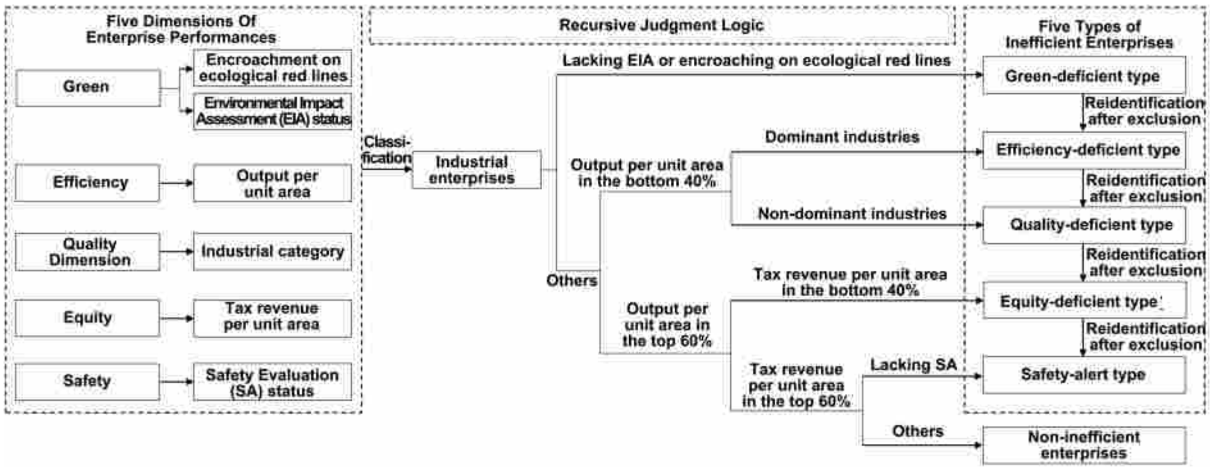

Figure 3 Recursive logic for identifying five categories of inefficient enterprises

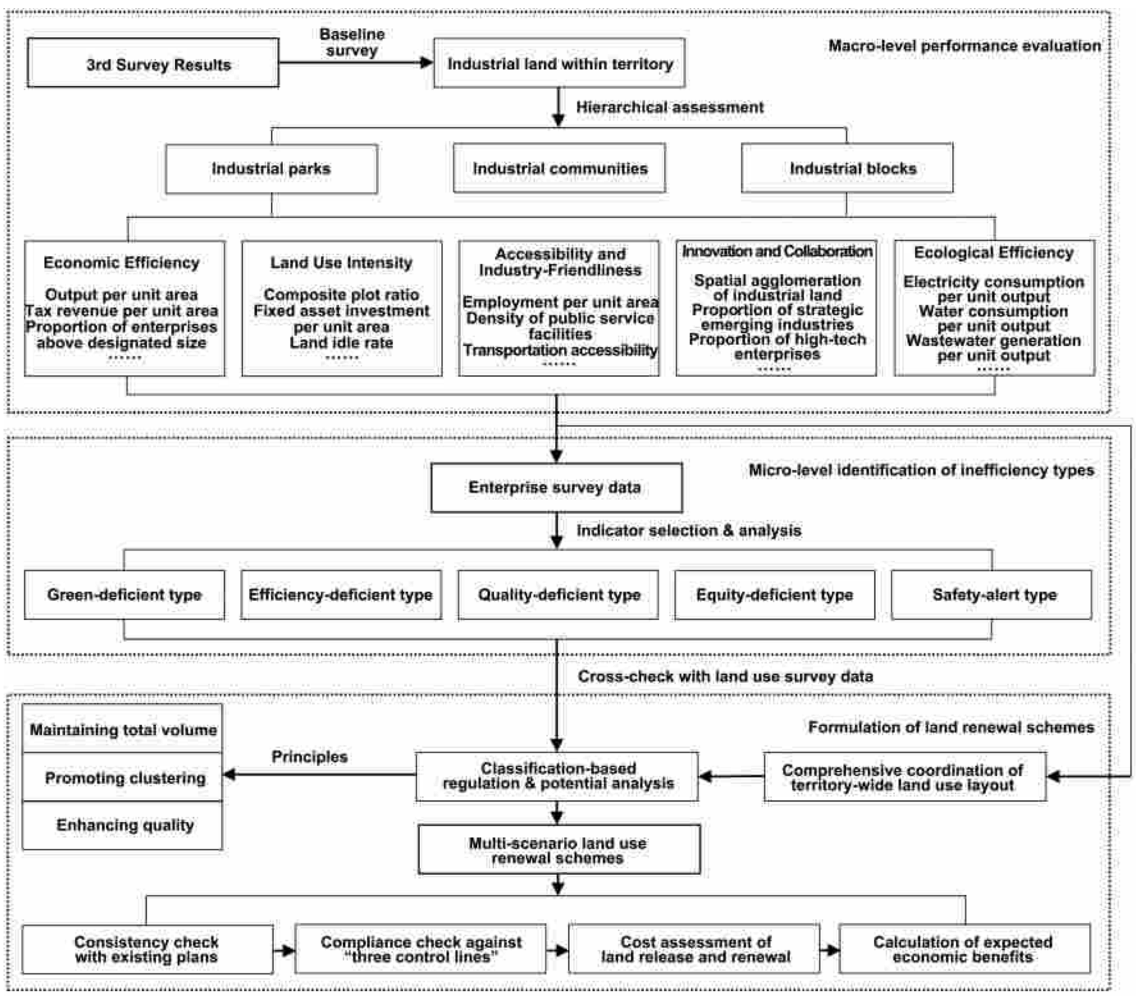

Figure 4 Framework for stock industrial land optimization and renewal in county level

4.3 Full lifecycle management mechanism for industrial land

Pre-supply management stage: The land-use approval process should be optimized, and strict entry thresholds for industrial land enforced. Clauses must be clarified regarding project construction, property self-holding requirements, performance bond supervision, and enterprise default responsibilities, with enterprises required to sign the corresponding performance agreement. The policy pilots flexible-term land transfers, considering market demand and the relatively short life cycle of industrial enterprises. Drawing on advanced regional practices, it sets an initial lease period, with renewal permitted if conditions are met upon expiry. In principle, the land-use term for general industrial projects should not exceed 20 years.

Post-supply supervision stage: A full life-cycle regulatory information platform should be developed, incorporating functions such as land transfer contract management, supervision of project commencement and completion, and evaluation of compliance with indicators like construction progress and achievement of production capacity. Strengthen continuous supervision and whole-process management by conducting annual project evaluations and addressing cases of non-compliance or default. The department responsible for introducing the project takes the lead in supervising whether enterprises fulfill their contractual obligations, and conducts an annual review and evaluation of project performance for the previous year. For projects that violate performance agreement commitments, the project introduction departments and the Natural Resources Bureau shall, according to the nature of the breach, propose measures such as requiring the payment of liquidated damages or reclaiming land-use rights and associated buildings.

Rights exit stage: Based on the results of performance evaluations, diversified methods of land withdrawal should be explored. While enterprise interests are fully considered, differentiated land revitalization policies should be explored, such as government buyback, land replacement or transfer, and transformation with capacity expansion. Enterprises revitalizing existing land stock may, based on project performance evaluation results, be reported to the district/county government, which will collectively decide the proportion of land value increment fees to be collected for capacity expansion. The compulsory withdrawal of project land-use rights shall be strengthened. For projects that fail to meet the performance indicators set forth in the land transfer contract, the transferee's breach of contract liability will be pursued in accordance with the contract, up to and including the recovery of land-use rights.

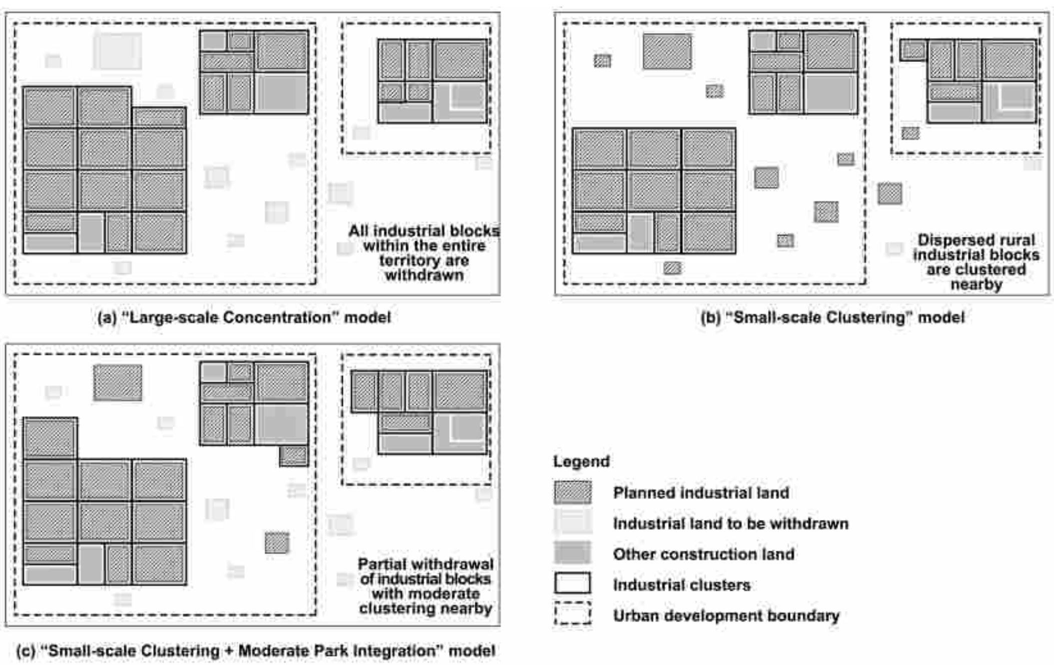

Figure 5 Three patterns for industrial land layout renewal

Conclusion

Revitalizing existing land resources, particularly through the optimization, redevelopment, and efficient utilization ofunderutilized industrial land, is an important means of coordinating and optimizing the national land development-protection pattern, promoting sustainable and high-quality economic development, and constitutes the inevitable choice for transformation in the new era. This study, drawing on local practical experience, expands the understanding of the exploitable potential of stock industrial land in the new era. It proposes an industrial land evaluation index system based on data from the Third National Land Survey and local enterprise surveys, enabling both macro-level performance assessment and micro-level identification of inefficiency characteristics of industrial land at the district and county levels. On this basis, multi-scenario industrial land renewal strategies are proposed, aiming to provide practical and operable references for widespread industrial land renewal at the district and county levels. It should be noted that although this study constructs a full-process system framework for optimizing and redeveloping stock industrial land by integrating macro- and micro-scale analyses, thus avoiding the fragmented limitations of previous studies that focus only on a single aspect or type of underutilized industrial land, there remains a lack of in-depth exploration into the operational mechanisms and dynamic evolution of stock industrial space, particularly the mechanisms generating underutilized land. Moreover, achieving quality enhancement, efficiency improvement, and long-term sustainable development of industrial land requires the integration of interdisciplinary theories and methods from urban and rural planning, economics, management, geography, and sociology, to facilitate the organic coordination of multiple objectives. These aspects need to be further supplemented and refined in future research.

Sources of Figures and Tables

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

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The Impact of Perceived Winter Riverside Environmental Characteristics on the Mental Health of Older Adults* : A Case Study of Harbin, China

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ABSTRACT: Urban riverside spaces serve as important venues for older adults to engage in outdoor activities and connect with nature, and the perceived characteristics of these environments exert a significant influence on their mental health. Compared with ordinary seasons, the winter climate in cold-region cities has distinctive effects on both older adults and waterfront spaces. The pathways of influence under this specific climatic background require further investigation. Using the wintertime Harbin section of the Songhua River as the study area, this research employs structural equation modeling (SEM) to empirically examine the impact of perceived winter riverside environments in cold regions on the mental health of older adults and to identify the mechanisms through which their different behavioral activities operate. The findings reveal that: (1) The environmental characteristics of winter riverside spaces in cold-region cities that influence the mental health of older adults consist mainly of four dimensions: social, landscape, comfort, and activity elements. (2) The pathways through which environmental perception affects mental health include both direct effects and indirect effects mediated by behavioral activities. Specifically, social and landscape elements exert direct effects on mental health and also indirect effects by influencing behavioral activities, whereas comfort and activity elements influence mental health only indirectly through behavioral activities. (3) Different behavioral activities undertaken by older adults in riverside spaces play mediating roles in the mechanism by which environmental perception affects mental health, with waterfront interactions exhibiting the strongest mediating effect. This study clarifies the mechanism through which environmental characteristics of winter riverside spaces influence the mental health of older adults, providing insights for enhancing and transforming winter riverside spaces in cold-region cities.

KEY WORDS: winter riverside space; older adults; mental health; cold-region cities; behavioral activities

Introduction

Against the backdrop of population aging, mental health issues among older adults have become an increasingly important public health concern—declines in mental health not only result in deteriorating physical and cognitive functioning but are also linked to higher morbidity and mortality risks [1]. *The Report on National Mental Health Development in China* (2019-2020) indicated that nearly one-third of older adults experience depressive symptoms [2], highlighting a concerning mental health situation that urgently requires effective interventions. Urban waterfront spaces serve as key venues for older a-

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dults' daily leisure activities, and their environmental characteristics are closely associated with the mental health of older adults [3]. Exploring this causal relationship is essential for improving urban waterfront environments, promoting healthy aging, and advancing the Healthy China initiative.

Waterfront spaces exert positive effects on residents' mental health, as reflected in their benefits for psychotherapy [4], emotional regulation [5], reduced depression scores [6], and enhanced subjective well-being [7]. Relevant studies have examined how individual attributes, the objective environment of waterfront spaces, and subjective environmental perceptions affect mental health. Existing studies confirm that residents' mental health is influenced by multiple individual attributes, including age, gender, income level, and physical health status [8]. The objective environment of waterfront spaces is mainly reflected in indicators such as the proportion of waterfront spaces within a certain distance [9], water body visibility [10], and accessibility [11]. An increase in the proportion of nearby waterfront spaces, greater water body visibility, and shorter distance between waterfront spaces and residences are all associated with a higher likelihood of better mental health among residents. Environmental perception refers to individuals' subjective feelings and psychological judgments about their surrounding environment and its changes, and it constitutes the psychological basis for environmental behavior [12]. Residents' environmental perceptions shape their behavioral activities and, in turn, exert positive or negative influences on their mental health. In recent years, scholars both in China and abroad have focused on examining how perceptions of the physical and social environments of residential areas influence residents' self-rated mental health. They have proposed that perceived attributes of the residential environment—such as aesthetic quality[13], walkability[14], and facility diversity[15]—exert significant positive effects on mental health. Similarly, favorable perceptions of social-environmental factors, including harmonious neighborhood relations and robust social capital, also contribute to residents' mental well-being[16]. Building on this foundation, some scholars have begun to focus on the relationship between subjective perceptions of waterfront spaces and human mental health. Qualitative studies have discussed the relationships between perceptions of elements such as waterfront spaces' safety [17], accessibility [18], and vitality [19] and mental health; quantitative analyses have verified that meeting perceptual preferences, such as appreciation of beautiful waterscapes [20] and well-designed walkways [21], facilitates activities in waterfront spaces and thereby helps prevent mental health problems. In addition, some studies have noted that residents' mental health is closely related to the duration [22] and intensity [23] of their activities in waterfront spaces.

Seasonal variations have a significant impact on residents' mental health, and changes in season are correlated with symptoms such as depression, mania, and anxiety [24]. The prevalence of winter depression reaches as high as 10% worldwide, with 70% of cases diagnosed as recurrent major depressive disorder [25]. It is particularly common in cold regions of North America, Northern Europe, and cold-region cities in China [26]. Researchers have mainly explained the mechanisms of seasonal effects on mental health from physiological and behavioral perspectives. From the physiological perspective, serotonin is believed to play a key role in regulating anxiety and depressive emotions. During winter, the brain's serotonin system becomes less active, making people more prone to negative and passive emotions, thereby increasing the incidence of mental disorders. From the behavioral perspective, low temperatures in winter reduce or even eliminate healthy activities among residents, which in turn negatively affects their mental health [27]. Meanwhile, seasonal changes also significantly affect the environmental quality of waterfront spaces: although winter snowfall in cold-region cities creates additional opportunities for ice- and snow-related recreational activities, the range of waterfront resources perceptible to urban residents is markedly reduced during winter [28]. Older adults—whose physical resilience and overall health tend to be comparatively lower—are particularly sensitive to these environmental changes. Consequently, their willingness, frequency, and duration of use of winter waterfront spaces are adversely affected, thereby increasing their vulnerability to mental health challenges.

Although studies on the relationship between waterfront spaces and residents' mental health have achieved some progress, several limitations remain: (1) Existing empirical studies mostly focus on the analysis of physical environmental characteristics, and pay little attention to the role of social environmental elements, so that a systematic set of environmental indicators has yet to be established; (2) In terms of study areas, most research focuses on coastal spaces, while inland riverside spaces remain underexplored; (3) Methodologically, most studies employ linear or logistic regression models to analyze correlations between riverside environments and residents' mental health, while exploration of the causal pathways through which waterfront environmental elements affect mental health is limited; (4) Research on the health benefits of waterfront spaces under specific climatic contexts remains insufficient. Based on the above, this study takes the winter riverside spaces along the Songhua River in Harbin as the research object, constructs a structural equation model (SEM) of perception of winter riverside environments, introduces older adults' behavioral activities in winter riverside spaces as mediating variables, and conducts a quantitative analysis of the variables affecting older adults' mental health in winter, as well as the mediating effects of different behavioral activities. This study aims to examine the mechanisms through which perceptions of winter riverside environments in cold-region cities affect the mental health of older adults, thereby providing a scientific basis for improving their mental well-being and for the planning and design of winter riverside environments in cold-region cities.

1 Research methodology

1.1 Model construction and research hypotheses

1.1.1 Construction of the indicator system

The environment that influences individual mental health includes both the social environment and the physical environment [29]. Drawing on existing domestic and international studies, this research integrates the waterfront environmental elements that influence older adults' mental health and classifies them based on the characteristics of winter riverside spaces in cold-region cities. It ultimately identifies the following four categories of environmental elements: social elements, landscape elements, comfort elements, and activity elements. In cold-climate regions, the social environment influencing older adults in winter is primarily shaped by social elements. Drawing on prior studies and preliminary interviews, four indicators were identified to define the social elements of winter riverside spaces: perceived liveliness of the site, sense of belonging, cultural identity, and retail presence in on-ice spaces. The physical environment, in contrast, is influenced by landscape, comfort, and activity elements. Specifically, a beautiful landscape environment greatly encourages residents to engage with nature and stimulates positive emotions [30]. Moreover, seasonal factors significantly affect urban color conditions [31]. Therefore, this study selects four indicators for landscape elements: on-ice landscape conditions, waterfront landscape conditions, near-water landscape conditions, and winter color conditions. A safe and easily accessible physical environment can promote residents' mental health [32]. On this basis, considering that outdoor activities in cold-region cities should not last long during winter, three indicators were selected as comfort elements, namely walking safety in winter, accessibility of the site in winter, and resting suitability of facilities in winter. Abundant and diverse activity spaces are the foundation for attracting people to engage in healthy activities [33]. Therefore, three indicators were selected as activity elements: diversity of activity spaces, water proximity of activity spaces, and adequacy of activity spaces.

Older adults' behavioral activities are closely related to their mental health[34]. Based on field observation records, 20 types of wintertime behavioral activities of older adults in the southern riverside spaces of the Songhua River were identified. Referring to the suggestions of Pasanen T. P. et al. [35], and considering the characteristics of older adults' activities in cold-region cities, these were categorized into 3 types and 9 forms: near-water exercise, waterfront interaction, and other leisure activities (Figure 1). Near-water exercises include walking, equipment-based exercises, and stretching, among other types. Waterfront interactions include in-water, on-ice, and waterside activities. Other leisure activities include individual, family, and social leisure activities.

Figure 1 Classification of older adults' behavioral activities in winter riverside spaces

1.1.2 Construction of the conceptual model

Based on the Active Living Ecological Model[36], this study incorporates winter climatic factors, selects three common types of winter activities of older adults—near-water exercise, waterfront interaction, and other leisure activities—as mediating variables, and takes older adults' mental health as the dependent variable to construct a theoretical framework of perception of winter riverside environments (Figure 2). The conceptual model posits that perceptions of the physical and social environmental elements of riverside spaces are directly or indirectly related to older adults' mental health. These environmental elements influence older adults' activities, thereby affecting their mental health. Therefore, older adults' activities serve as mediating variables in the relationship between the riverside space environment and their mental health. The model hypotheses are as follows:

H1: Perceptions of environmental elements in winter riverside spaces have a significant positive effect on older adults' behavioral activities;

H1a: Perceptions of social elements in winter riverside spaces have a significant positive effect on older adults' behavioralactivities;

H1b: Perceptions of landscapeelements in winter riverside spaces have a significant positive effect on older adults' behavioral activities;

H1c: Perceptions of comfort elements in winter riverside spaces have a significant positive effect on older adults' behavioral activities;

H1d: Perceptions of activity elements in winter riverside spaces have a significant positive effect on older adults' behavioral activities;

H2: Perceptions of environmental elements in winter riverside spaces have a significant direct positive effect on older adults' mental health;

H2a: Perceptions of social elements in winter riverside spaces have a significant direct positive effect on older adults' mental health;

H2b: Perceptions of landscape elements in winter riverside spaces have a significant direct positive effect on older adults' mental health;

H2c: Perceptions of comfort elements in winter riverside spaces have a significant direct positive effect on older adults' mental health;

H2d: Perceptions of activity elements in winter riverside spaces have a significant direct positive effect on older adults' mental health;

H3: Older adults' behavioral activities significantly mediate the relationship between perceptions of environmental elementsin winter riverside spaces and their mental health;

H4: The mediating effects of different types of behavioral activities in winter riverside spaces vary significantly.

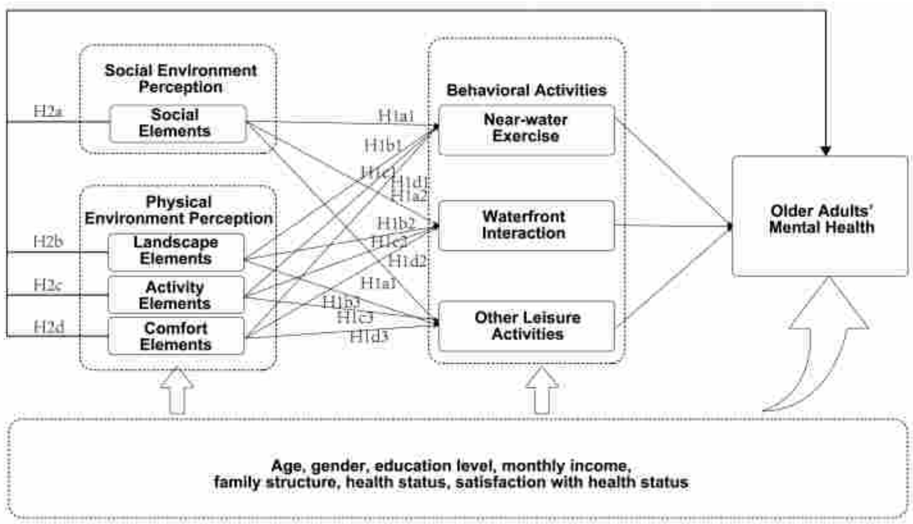

Figure 2 Hypothetical model

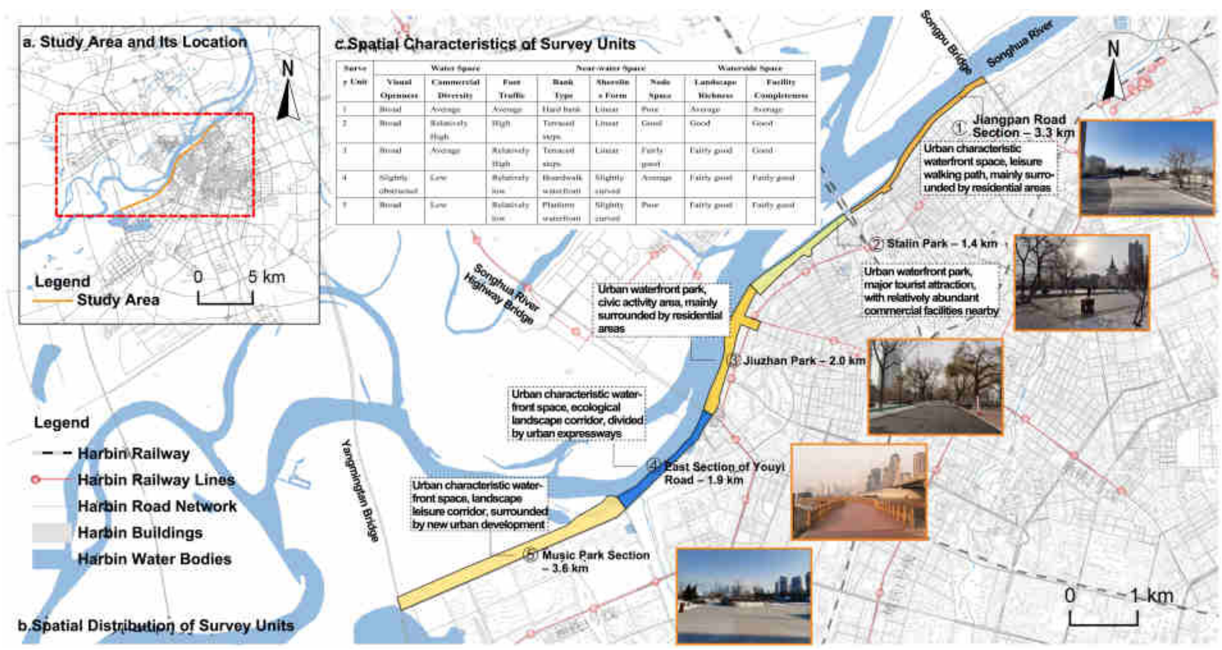

Figure 3 Study area and survey units

1.2 Questionnaire design and distribution

1.2.1 Area ofstudy

The site selected in this study is the southern riverside of the Songhua River in Harbin, stretching from Yangmingtan Bridge to Songpu Bridge. The Songhua River flows from the southwest to the northeast through Harbin's urban area. Its southern riverside, with attractive landscapes and abundant activity venues, serves as one of the most important leisure spaces to support the public life, social interaction, and recreational activities of local residents. As a typical cold-region city, Harbin has a harsh winter climate that has a profound impact on both the urban riverside landscape and the physical and mental health as well as activity choices of older adults. Consequently, riverside spaces face problems in planning, design, and management, such as monotonous design expression, insufficient expression of regional cultural elements, and limited site attractiveness.

In this study, the site was categorized based on the forms, facilities, and other environmental characteristics of winter riverside spaces, including on-ice, waterside, and near-water spaces, into five survey units: Songpu Bridge-Jingjie, Stalin Park, Jiuzhan Park, Gonglu Bridge-Shangjiang Road, and Music Park (Figure 3). These survey units include planar urban riverside parks, linear riverside walkways, and point-type riverside plazas, which collectively reflect the construction level of riverside spaces along the Songhua River and serve as representative examples among cold-climate city waterfronts.

1.2.2 Datasources

In November 2021, a pilot survey was conducted on the southern bank of the urban section of Harbin along the Songhua River, during which 42 valid questionnaires were collected. The questionnaire was subsequently optimized and adjusted based on the findings of this survey. Considering the particular characteristics of the winter climate in cold-climate cities, and incorporating factors such as the COVID-19 pandemic, weather, and temperature, the survey period was ultimately scheduled for mid-to-late December 2021. In each survey unit, 70 questionnaires were distributed using a convenience sampling method (encounter method), resulting in a total of 350 questionnaires across the five units. After collection and sorting, 25 questionnaires with missing or identical answers and 13 questionnaires indicating "serious illness" in health status were excluded, resulting in 312 valid questionnaires: 62 from Jiangpan Road, 63 from Stalin Park, 64 from Jiuzhan Park, 61 from the East of Youyi Road, and 62 from Music Park. The effective response rate was 89.14%. Analysis of the 312 questionnaire samples indicates that the gender ratio of respondents is nearly balanced at 1:1. The distributions of age, educational attainment, and income level approximate a normal distribution, suggesting that the sample data are highly representative.

1.2.3 Questionnaire design and variable measurement

The questionnaire used in this study consists of four sections: (1) basic personal information of older adults; (2) characteristics of older adults' behavioral activities in riverside spaces; (3) a mental health scale for older adults; and (4) a perception scale of the winter riverside environment. The first section covers demographic and health-related information such as gender, age, education level, monthly personal income, household composition, physical health status, and satisfaction with physical health. These individual characteristics that may influence health were included as control variables in this study. The second section investigates the behavioral characteristics of older adults in riverside spaces during winter and other seasons. The duration of older adults' near-water exercise, waterfront interaction, and other leisure activities in winter were selected as mediating variables. The third section investigates older adults' mental and emotional health over the past two weeks, which serves as the dependent variable in this study. The mental health scale for older adults is based on the "Warwick-Edinburgh Mental Well-being Scale" developed by Tennant et al [37]. The scale comprises 14 items that reflect three dimensions of mental well-being: positive emotions, positive psychological functioning, and satisfaction with interpersonal relationships. The total score ranges from 14 to 70, with higher scores indicating higher levels of positive mental health. The reliability and validity of the Chinese version have been effectively verified [38]. The fourth section serves as the core independent variable measurement for this study. A measurement scale for perception of riverside environment was developed by reviewing existing literature and related existing scales. This scale reflects subjective perception of the winter riverside environment through four characteristic dimensions: social, landscape, comfort, and activity elements. Respondents evaluated specific environmental elements according to their subjective impressions (see Table 1). Both scales in the questionnaire adopt the 5-point Likert scale.

1.3 Research and analysis methods

This study aims to empirically analyze the relationship between perceptions of the winter riverside environment and older adults' mental health. As indicated by the conceptual model presented earlier, the model contains multiple variables, including dependent variables, and includes certain environmental perception variables that are difficult to observe or measure directly. Conventional multiple regression analysis methods are inadequate for addressing the interrelationships among multiple variables across different dimensions. In contrast, the structural equation model (SEM), an advanced quantitative statistical method that integrates techniques such as Analysis of Variance (ANOVA), regression analysis, and path analysis, is capable of analyzing and handling complex multivariate relationships. It allows for the measurement of unobservable or hard-to-measure variables as latent variables and enables multiple mediation analyses. Therefore, this study adopts the structural equation modeling approach as the primary analytical method.

2 Data analysis

2.1 Descriptive statistics of the sample

Statistical analysis was conducted on the valid survey samples, with male respondents accounting for 50.64% and female respondents 49.36%. Most respondents were aged 66-70, with the majority having completedhigh school or technical secondary education, followed by those with junior high, college, university, or primary education. The majority reported a personal monthly income between 3,000 and 8,000 Yuan, and most of them lived with their spouses. In addition, the survey results indicate that the largest proportion of respondents classified themselves as "relatively healthy," and overall satisfaction with personal health was high, with 93.59% expressing neutral or positive satisfaction (see Table 2).

Table 1 Variable definitions and descriptive statistics

Category	Index	Variable definitions and measurement coding	Mean	Standard deviation
Individual Attributes	Gender	Female= 0; Male= 1	0.506	0.501
	Age	55—60= 1; 61—65= 2; 66—70= 3; 71—75= 4;> 75= 5	3.099	1.288
	Education level	Primary or below= 1; Junior high= 2; High school/technical= 3; College/undergraduate or above= 4	2.622	1.035
	Monthly personal income	< 3000= 1; 3000—5000= 2; 5000—8000= 3;> 8000= 4	2.365	1.028
	Household composition	Living alone= 1; Living with spouse= 2; Living with children= 3; Living with grandchildren= 4; Three-generation household= 5	2.712	1.303
	Health status	Very healthy= 1; Relatively healthy= 2; Average= 3; Relatively poor= 4	2.057	0.828
	Health satisfaction	Extremely satisfied= 1; Mostly satisfied= 2; Average= 3; Mostly dissatisfied= 4; Extremely dissatisfied= 5	1.913	0.923
Behavioral activities	Y1 Near-water Exercise	Average daily duration of near-water exercise in riverside spaces over the past week (1= < 0.5 h to 5= > 2 h)	3.430	0.929
	Y2 Waterfront interaction	Average daily duration of waterfront interaction in riverside spaces over the past week (1= < 0.5 h to 5= > 2 h)	3.300	0.966
	Y3 Other leisure activities	Average daily duration of other leisure activities in riverside spaces over the past week (1= < 0.5 h to 5= > 2 h)	3.390	1.070
Mental Health	Z1 Positive Emotion	I am optimistic about the future; I feel relaxed; I feel valuable; I am interested in new things; I feel energetic (1= Never to 5= Always, averaged across items)	4.032	0.956
	Z2 Positive psychological Functioning	I can handle problems well; My mind stays clear; I generally feel good about myself; I am confident; I can make decisions on my own (1= Never to 5= Always, averaged across items)	4.158	1.002
	Z3 Satisfaction with interpersonal relationships	I enjoy interacting with others; I feel close to others; I feel cared for; I feel happy (1= Never to 5= Always, averaged across items)	3.885	1.090

(Continued)

Category	Index		Variable definitions and measurement coding	Mean	Standard deviation
Subjective Perceived Environment	Social elements	X1 Sense of belonging	Many acquaintances in the space and harmonious interactions (1= Extremely dissatisfied to 5= Extremely satisfied)	3.545	1.024
		X2 Perceived liveliness of site	Busy and bustling with high pedestrian flow (1= Extremely dissatisfiedto 5= Extremely satisfied)	3.712	1.038
		X3 Cultural identity of site	Strong regional cultural characteristics (1= Extremely dissatisfied to 5= Extremely satisfied)	3.683	0.970
		X4 Retail presence in on-Ice spaces	Number and types of retail formats in the on-ice space (1= Extremely dissatisfied to 5= Extremely satisfied)	3.426	1.163
	Landscape elements	X5 Waterfront landscape conditions	Varied shoreline forms and ecologically friendly revetments (1= Extremely dissatisfied to 5= Extremely satisfied)	3.676	1.118
		X6 On-ice landscape conditions	Rich and attractive ice scenery (1= Extremely dissatisfied to 5= Extremely satisfied)	3.221	1.103
		X7 Near-water Landscape Conditions	Pleasant and rich near-water landscapes (1= Extremely dissatisfied to 5= Extremely satisfied)	3.131	1.157
		X8 Winter color conditions	Rich environmental colors (1= Extremely dissatisfied to 5= Extremely satisfied)	3.442	1.090
	Comfort elements	X9 Walking safety in winter	Anti-slip surface materials (1= Extremely dissatisfied to 5= Extremely satisfied)	3.599	0.946
		X10 Accessibility in winter	Convenient access to riverside spaces (1= Extremely dissatisfied to 5= Extremely satisfied)	3.587	0.930
		X11 Resting suitability in winter	Sufficient and comfortable indoor rest facilities (1= Extremely dissatisfied to 5= Extremely satisfied)	3.788	1.025
	Activity elements	X12 Variety of activity spaces	Various types of activity facilities (1= Extremely dissatisfied to 5= Extremely satisfied)	3.304	1.118
		X13 Water proximity of activity spaces	High degree of water accessibility (1= Extremely dissatisfied to 5= Extremely satisfied)	3.952	1.013
		X14 Adequacy of activity spaces	Appropriate area and sufficient facilities (1= Extremely dissatisfied to 5= Extremely satisfied)	3.516	1.209

The survey found that 62.82% of respondents engaged in riverside activities seven or more times per week during winter, of whom 18.36% visited twice daily. The majority of participants, at 78.52%, reported an average activity duration of 1 to 1.5 hours per session. In terms of activity types during the previous week, 80.77% of the older adults participated in near-water exercise, 47.44% engaged in waterfront interactions, and 21.47% took part in other leisure activities. Furthermore, the data analysis indicates that in winter, activity frequency declines compared with other seasons, activity types are significantly fewer, and activity duration is also reduced. Specifically, respondents' average activity frequency in other seasons was 13.8 times per week, compared with 7.14 times per week in winter. A total of 56.09% of respondents stated that activity types are more numerous in other seasons than in winter, while 59.61% reported that they visit riverside spaces more frequently in other seasons than in winter.

In this study, the average self-ratedmental health score among the respondents was 56.5. A total of 38.14% of them reached the threshold for high mental well-being (with 60 points designated as the recommended cutoff). Positive mental functioning had the highest mean score, followed by positive emotions, while satisfaction with interpersonal relationships scored the lowest. Interviews revealed that the older adults who regularly visited riverside spaces adapted better to changes in social roles, experienced less loneliness and anxiety, and exhibited better mental health.

Table 2 Basic information on the survey sample (N=312)

Basic Info	Category	Proportion/%
Gender	Male	50.64%
	Female	49.36%
Age	55—60	14.42%
	61—65	17.63%
	66—70	28.85%
	71—75	21.79%
	> 75	17.31%
Education level	Primary or below	17.31%
	Junior high	27.56%
	High school / technical secondary school	30.77%
	College / undergraduate or above	24.36%
Monthly personal income	< 3000 yuan	24.36%
	3,000—5,000 yuan	31.41%
	5,000—8,000 yuan	27.56%
	> 8,000 yuan	16.67%
Household composition	Living alone	14.42%
	Living with spouse	42.31%
	Living with children	18.59%
	Living with grandchildren	7.05%
	Three-generation household	17.63%
Health status	Excellent health	25.64%
	Good health	48.72%
	Fair health	19.87%
	Poor health	5.77%
	Severe illness	0%
Health satisfaction	Extremely satisfied	38.14%
	Mostly satisfied	40.06%
	Average	15.38%
	Mostly dissatisfied	5.13%
	Extremely dissatisfied	1.28%

2.2 Modeltesting

2.2.1 Reliability and validity analysis

Based on valid questionnaire data, SPSS 25.0 was used to conduct KMO and Bartlett's sphericity tests on all variables. The results show that the KMO value was 0.924 (reference> 0.7) and the significance value in Bartlett's test was $p < 0.001$ (reference< 0.05), indicating that the variables were suitable for factor analysis. Based on this, the measurement model was subjected to reliability and validity testing. Only one observed variable had a standardized coefficient slightly below 0.5, while all others exceeded 0.5, indicating that the measurement variables for each dimension effectively capture the latent traits of their respective dimension. The Cronbach's α coefficients for all dimensions were above 0.7, demonstrating that the questionnaire data possessed good reliability. The composite reliability (CR) values for all dimensions exceeded 0.7, suggesting that the observed variables of each latent construct had internal consistency. The average variance extracted (AVE) values for most dimensions were above 0.5, with a few approaching 0.5, indicating that the measurement model exhibited good convergent validity (see Table 3). Moreover, the square root of the AVE for each latent variable exceeded its correlation coefficients with other latent variables, confirming that the measurement model demonstrated discriminant validity among dimensions.

2.2.2 Model fit and path analysis

Using maximum likelihoodestimation, parameter estimation and goodness-of-fit testing were performed on the conceptual model. The fit indices are as follows (Table 4): $X^2/df = 2.759$, $SRMR = 0.065$, $RMSEA = 0.075$, $GFI = 0.872$, $AGFI = 0.827$, $IFI = 0.919$, $CFI = 0.918$, and $TLI = 0.899$. Generally, model similarity indices are considered acceptable when greater than 0.9, with values between 0.8 and 0.9 deemed tolerable; dissimilarity indices are considered acceptable when below 0.08. In this study, all model fit indices met the required criteria, indicating that the overall model demonstrates good goodness-of-fit. Path analysis results (Figure 4) show that hypotheses H2c (the perception of comfort elements has a significant direct positive effect on mental health) and H2d (the perception of activity elements has a significant direct positive effect on mental health) were not supported. H1a exhibited a significant negative effect, indicating that social elements reduced older adults' behavioral activities in winter, while all other hypotheses were supported.

2.2.3 Mediating effect testing

This study employed the Bootstrap method to examine the mediating role of behavioral activities between the perception of winter riverside environments in cold-region cities and the mental health of older adults. Following the recommendations of WEN Zhonglin et al. [39], 2,000

Bootstrap samples were set, and a 95% confidence level was used for iterative sampling. The results indicated that the mediating effect was partial. From the perception of winter riverside environmental elements to older adults' mental health, three paths exist: near-water exercise, waterfront interaction, and other leisure activities. Therefore, the three mediating variables were tested using the MacKinnon method to determine the significance of the paths. The analysis indicated that at a 95% confidence level, the *prodclin* confidence intervals did not include zero, confirming the significance of all three mediating paths. That is, older adults' behavioral activities in winter significantly mediated the effects on mental health, whereby perceptions of the winter riverside environment influenced mental health through near-water exercise, waterfront interaction, and other leisure activities.

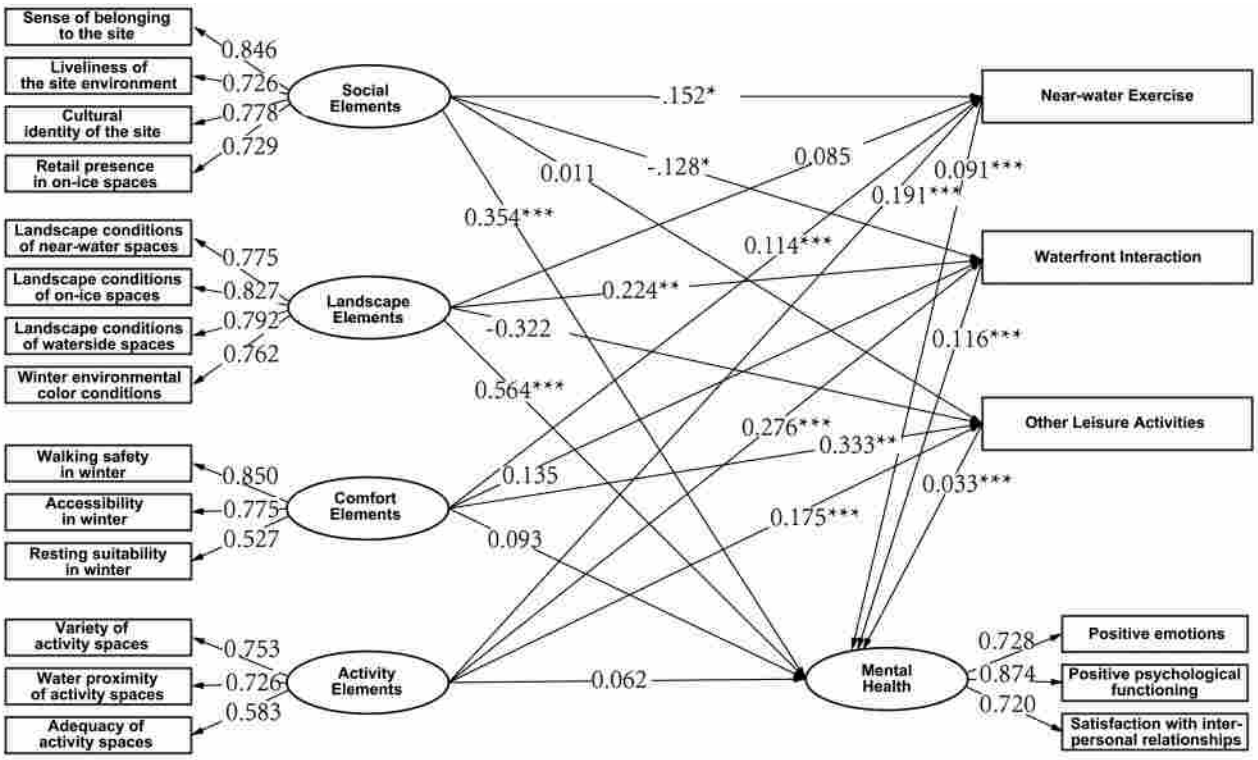

Figure 4 Standardized parameter estimates of winter riverside environmental perception affecting older adults' mental health

*** Note: * $p<0.01$; ** $p<0.05$; *** $p<0.001$.**

Table 3 Reliability and validity of scales

Latent Variables	Observed variables	Standardized coefficients	Cronbach's α	CR	AVE
Social elements	X1	0.723	0.849	0.854	0.594
	X2	0.802			
	X3	0.724			
	X4	0.828			
Landscape elements	X5	0.742	0.868	0.868	0.623
	X6	0.819			
	X7	0.827			
	X8	0.765			
Comfort elements	X9	0.465	0.734	0.762	0.531
	X10	0.801			
	X11	0.857			

(Continued)

Latent Variables	Observed variables	Standardized coefficients	Cronbach's α	CR	AVE
Activity elements	X12	0.584	0.721	0.733	0.481
	X13	0.775			
	X14	0.707			
Behavioral activities	Y1	0.724	0.765	0.772	0.533
	Y2	0.816			
	Y3	0.640			
Mental health	Z1	0.710	0.815	0.820	0.604
	Z2	0.868			
	Z3	0.745			

Table 4 Model fit indices

Fit indices	X^2/df	*SRMR*	*RMSEA*	*GFI*	*AGFI*	*IFI*	*CFI*	*TLI*
Reference values	< 3	< 0.080	< 0.080	> 0.90	> 0.90	> 0.90	> 0.90	> 0.90
Test values	2.759	0.065	0.075	0.872	0.827	0.919	0.918	0.899
Fit evaluation	Good	Good	Good	Approved	Approved	Good	Good	Approved

3 Influence mechanism of perception of winter riverside environment on older adults' mental health

3.1 Influence of perception of winter riverside environment on older adults' mental health

When individualfactors are taken into account, the perception of winter riverside environments in cold regions had a significant effect on older adults' mental health, with improvements in each variable exerting direct or indirect effects on mental health outcomes. Based on the total effect value on older adults' mental health, the influence magnitude follows: landscape elements (0.499)> social elements (0.304)> comfort elements (0.220)> activity elements (0.140). These constitute four key dimensions of winter riverside spaces.

3.1.1 Perception of social elements

The perception of social elements can affect mental health directly ($\beta = 0.354$, $p < 0.001$) or indirectly through influencing waterfront interaction ($\beta = -0.128$, $p < 0.01$) and near-water exercise ($\beta = -0.152$, $p < 0.01$). Interview analysis indicates that a sense of place-based spiritual belonging and cultural identification exert significant effects on the mental health of older adults. A high number of acquaintances and harmonious interactions, as key sources of place-based spiritual belonging, promote social engagement in other leisure activities, extend activity duration, facilitate participation in organized near-water exercise, reduce loneliness, and encourage joint participation in waterfront interaction, thereby enhancing positive emotions and satisfaction with interpersonal relationships. A strong regional cultural atmosphere enhances older adults' cultural identification with the site, thereby increasing the frequency of riverside activities and promoting positive mental health outcomes. Contrary to previous studies, the perception of social elements has a significant negative effect on the behavioral activities of older adults. This may be due to the lively atmosphere of the site and the retail presence in on-ice spaces. On the one hand, under the COVID-19 pandemic, a lively environment can trigger older adults' concerns about virus transmission, thereby limiting their activity choices; on the other hand, retail commerce in on-ice spaces may lead to mixed crowds, which affects the activity experience of the older adults and the achievement of their activity goals.

3.1.2 Perception of landscape elements

The perception of landscape elements can directly influence mental health ($\beta = 0.564$, $p < 0.001$) or indirectly through affecting older adults' waterfront interaction ($\beta = 0.224$, $p < 0.05$). Among the landscape elements, the path coefficients for "on-ice landscape conditions" and "near-water landscape conditions" were relatively high, indicating that older adults place greater importance on on-ice and near-water spaces among all riverside spaces in winter. Based on previous research, in cold-region cities during winter, the climate causes trees to wither and be covered by snow and ice, which greatly reduces landscape diversity. This in turn significantly lowers older adults' willingness to engage in outdoor activities, so their frequency and duration of going out in winter are much lower than in other seasons. This requires that, when planning and designing winter waterfront spaces, greater attention should be given to the landscape design of ice spaces and near-water spaces. Other factors, such as waterside landscape conditions and winter environmental color, also play important roles in attracting older adults to riverside activities and influencing mental health.

3.1.3 Perception of comfort elements

The perception of comfort elements exerts a significant positive influence on older adults' mental health via mediating effects. Specifically, comfort elements affectmental health by influencing older adults' near-water exercise ($\beta = 0.114$, $p < 0.001$) and other leisure activities ($\beta = 0.333$, $p < 0.001$). Among all observed variables, "walking safety in winter" had the highest path coefficient, indicating that safety is the most influential factor on older adults' activities and mental health in winter. Survey findings reveal that "resting suitability in winter" determines residents' duration of stay in riverside spaces. Respondents prefer to remain in areas with comfortable temperatures and indoor resting facilities. Meanwhile, "accessibility in winter" is another important factor influencing older adults' frequency of visits to riverside spaces.

3.1.4 Perception of activity elements

Perceived activity elements significantly and positively influence older adults' mental health, mediated by behavioral activity. Specifically, activity elements influence older adults' near-water exercise ($\beta = 0.191$, $p < 0.001$), waterfront interaction ($\beta = 0.276$, $p < 0.001$), and other leisure activities ($\beta = 0.175$, $p < 0.001$) in riverside spaces. Among the dimensions of activity elements, the factor "variety of activity spaces" had the largest path coefficient. Combined with interview analyses, the variety of fitness facilities and sports venues remains the most attractive factor for older adults, and can greatly promote near-water exercise, and thereby generate positive mental health effects. "Water proximity of activity spaces" is an important consideration for older adults engaging in waterfront interaction. Respondents prefer riverside spaces with higher proximity to water. "Adequacy of activity spaces" provides conditions for older adults to engage in other leisure activities in riverside spaces.

3.2 Analysis of the mediating effect of older adults' behavioral activities on mental health

Taking waterfront interaction as the mediating variable is the most effective pathway through which riverside environments generate mental health benefits. Near-water exercises are the second most effective, and other leisure activities have the least effect. The mediating effect analysis results are 0.114, 0.089, and 0.017 respectively (see Table 5). Across the pathways, the mediating effects of the three types of behavioral activities are relatively small but exhibit significant differences. Specifically, near-water exercises play a significant mediating effect in the relationship between social, comfort, and activity elements and mental health. This indicates that winter riverside spaces with favorable perceptions of these elements can promote older adults' participation in near-water exercise, thereby enhancing their mental health to some extent. Waterfront interaction significantly mediates the relationship between social, landscape, and activity elements and mental health. It suggests that winter riverside spaces with favorable perceptions of these elements can stimulate older adults' waterfront interaction, thereby alleviating negative emotions and benefiting mental health. Other leisure activities play a significant role in mediating the relationship between comfort and activity elements and mental health. This indicates that older adults' winter leisure activities are highly dependent on these elements. Well-designed winter riverside spaces with favorable conditions of these elements can stimulate older adults to engage in other leisure activities.

4 Conclusions and discussion

4.1 Conclusions

As indicated by the results presented above, some aspects of Hypotheses H1 and H2 were supported, while Hypotheses H3 and H4 were fully supported. Among them, H1a was not supported; the perception of social elements in riverside spaces in winter by older adults in cold-region cities exerts a significant negative impact on their behavioral activities. H2c and H2d were not significant, indicating that perceptions of comfort and activity elements do not have a significant direct effect on mental health. From the analysis, the following conclusions are drawn:

Table 5 Mediating effects of behavioral activities between perception of winter environmental elements and mental health (N=312)

Paths Tested	Total effect	Direct effect	Total indirect effect	Indirect effects		
				Near-water exercise	Waterfront interaction	Other leisure activities
Perception of social elements → mental health	0.303**	0.331**	-0.028*	-0.013**	-0.018**	0.003
Perception of landscape elements → mental health	0.499***	0.476**	0.023**	0.011	0.022**	-0.010
Perception of comfort elements → mental health	0.220*	0.055	0.165**	0.067*	0.082	0.016**
Perception of activity elements → mental health	0.140*	0.080	0.060**	0.024**	0.028**	0.008*
Perceptionof winter environmental elements → mental health	1.162***	0.942***	0.220***	0.089**	0.114**	0.017*

Note: *** $p < 0.001$, ** $p < 0.05$, * $p < 0.01$.

1) When individual characteristics are controlled, the perception of winter riverside environments in cold-region cities has a significant impact on older adults' mental health. Landscape, social, comfort, and activity elements all have significant positive effects, ranked in descending order of influence.

2) Perceptions of riverside spaces in winter affect older adults' mental health either directly or througha mediating effect. Specifically, perceptions of social and landscape elements can both exert direct and indirect effects through behavioral activities, whereas perceptions of comfort and activity elements influence mental health only indirectly, through their impact on behavioral activities. In addition, perceptions of riverside environments in winter have a significant direct effect on older adults' mental health.

3) The mediating effects of different types of older adults' behavioral activities between perceptions of the winter riverside environment and their mental health were confirmed. The mediating effect of waterfront interaction is the strongest, followed by near-water exercise, while other leisure activities exert the weakest effect.

4.2 Discussion

In summary, the following recommendations are proposed for the planning and design of waterfront spaces in cold-region cities in winter: 1) Enhance the attractiveness of near-water spaces for winter. First, fully consider safety by ensuring the site is level and has good anti-slip properties. Second, in terms of winter landscape, make reasonable use of color design to highlight seasonal landscape features and enhance the unique aesthetic experience of waterfront spaces in cold-region cities in winter. Finally, in terms of micro-level spatial layout, planners should fully consider the current conditions of the space and the winter activity preferences of older adults, and adapt to local circumstances to create different forms of activity spaces. Building warm pavilions, windbreaks, and other indoor rest facilities can create a relatively comfortable activity environment; (2) Improve the interactivity of winter waterside spaces. On the one hand, temporary railings and barrier-free facilities should be added to meet the needs of older adults of different ages and physical conditions for engaging with water, and use climate-friendly materials with gentle texture and low thermal conductivity to improve the age-friendliness of riverside spaces in winter. On the other hand, while safety is ensured, the forms of the shoreline should be diversified to create varied spaces for waterfront interaction; (3) Improve the accessibility of on-ice spaces in winter. At the city level, overall planning guidance for existing ice spaces should be strengthened to address the problem of too few reserved activity areas, which hinders on-ice activities. At the district level, functional zoning of on-ice spaces in winter should be improved to ensure that retail commerce brings vitality while avoiding interference with older adults' ice activities. (4) Coordinate on-ice, waterside, and near-water spaces. Achieve a value-oriented shift for riverside spaces in winter: through the coordinated design of these three spaces, shape the landscape characteristics of cold-region cities' riverside spaces, highlight the narrative of the overall landscape, and demonstrate the aesthetic value of riverside spaces. By incorporating ice-and-snow culture, planners can create a unique cultural atmosphere in cold-region riverside spaces, further strengthening older adults' local attachment and identity, and enhancing the cultural value of riverside spaces. Fully consider the spatial requirements of older adults' activities. Provide open spaces, diverse activity facilities, and organize regular events to enrich older adults' routines in winter and demonstrate the social value of riverside spaces. On this basis, health interventions for older adults can be achieved through riverside spaces.

Under the "Healthy China" initiative, it has become a consensus that environmental support can promote improvements in residents' health. This study investigated the pathways through which perceptions of waterfront environments in cold-region cities in winter affect the mental health of older adults. It identified the differential mediating effects of near-water exercise, waterfront interaction, and other leisure activities, and offers new insights for the optimization and enhancement of riverside spaces in cold-region cities in winter. Nevertheless, this study has several limitations. First, the survey area and sample size were limited, as only the Songhua River section in Harbin was examined in depth, so the conclusions may not fully represent riverside environments in cold-region cities and require further empirical validation. Second, the representativeness of the sample of older adults remains to be improved: although random encounter sampling was conducted across different survey units, the concentrated survey period led to some uncertainty in the final sample structure. Third, in terms of indicator selection, only the environmental elements subjectively perceived within the site were considered, while objective environment elements in the surrounding area that may affect older adults' behavior and mental health were not included. These issues should be addressed in future studies

Sources of Figures and Tables

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

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Spatial-temporal Differentiation and Influencing Mechanism of Accessibility of Park Green Spaces: A Case Study Based on Shenzhen City

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ABSTRACT: Park green space is an important part of the urban natural ecosystem and public service facilities. The accessibility index of park green space can characterize the difficulty of using park green space for residents. In addition, it is an important index that reflects the rational layout and fair use of park green spaces. With the rapid development of urbanization, the unrestrained expansion of construction land, and the continuously increasing demands of the population have led to a gradual imbalance between the supply and demand of park green spaces. In this study, the spatial-temporal differentiation characteristics of accessibility of multi-scale park green spaces in Shenzhen under multiple travel modes from 2013 to 2020 were analyzed using the Gaussian two-step floating catchment area (Ga2SFCA) method, which comprehensively considers both supply and demand. The influencing degree of each factor on the accessibility of park green space was studied with a geographical detector from the global scale, through which the dominant factors were screened. The spatial differentiation of the action intensity of each dominant factor on the local scale was investigated using the geographically weighted regression (GWR) model. Results showed that from 2013 to 2020:

1) Within the scope of construction land, the number and area of green parks in Shenzhen increased continuously. The number of community parks increased the greatest amount, and the area of comprehensive parks expanded the greatest amount. There was an imbalanced distribution pattern, which is characteristic of "more in the west and less in the east", "from the inner areas to the outer areas", and expansion from south to north. 2) The demand of residents for park green space was positively correlated with population density. The population density in the western region of Shenzhen was increasing gradually, and the population density in the eastern region was always low. The high-value area of green space demand extended gradually from the inner areas to the outer areas. 3) The accessibility of park green space generally presented a rising trend. The proportion of high-value residential areas was increasing gradually. The accessibility of the outside area became gradually higher than that of the inside area. The average accessibility of community parks achieved the highest growth rate, while the accessibility of comprehensive parks was basically stable. The standard deviation of special parks increased the most, and the spatial differentiation was intensified. 4) In 2013, the p-value of all influencing factors was 0, which passed the 0.01 significance test. In 2020, only the three factors of park area proportion, park entrance and exit density, and road density passed the 0.01 significance test, indicating that the spatial distribution of park accessibility from 2013 to 2020 was closely related to green space factors and road factors. The correlations of park accessibility with location, economy, and natural factors presented a downward trend with the development of science and economy. 5) According to the determination power (q-value) of the dominant factor, the q-values of the proportion of park area, park entrance and exit density, and road density all showed a downward trend on the dynamic level. The factors can be ranked road density > proportion of park area > park entrance and exit density in terms of action intensity. This revealed that road density was a dominant factor in park accessibility, with an explanatory power of as high as 10%, which was much larger than that of other factors. The park entrance and exit density and the proportion of park area were important factors for park accessibility. 6) The influences of different factors on the accessibil-

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ity index of park green space have significant spatial differences. Road density (X4) and proportion of park area (X1) had a greater impact in the eastern study area, while park entrance and exit density (X2) had a greater impact in the western study area. The research enriches perspectives on green space accessibility. The method of exploring the spatial-temporal differentiation characteristics and influencing mechanism of green space accessibility not only can be applied to the layout and planning of urban park green spaces, but also provides a reference to analyze other forms of geographical accessibility.

KEY WORDS: park green space; accessibility analysis; spatial-temporal evolution; gaussian two-step floating catchment area method; influencing mechanism

Introduction

The park green space is an essential part of the urban natural ecosystem and public service facilities. They not only have ecological functions, such as improving the urban environment [1] and reducing the risks of rain and flooding [2], but also social functions, including promoting public health [3] and enhancing real estate value [4]. The Central Committee of the Communist Party of China and the State Council proposed the concept of "Health for All" in the "*Healthy China* 2030" *Plan Outline*. Notably, in the post-pandemic era, the importance of urban green space in promoting public health has become increasingly prominent [3]. However, with the rapid development of urbanization, the disorderly expansion of urban construction land and the surge in population have led to a severe imbalance between supply and demand of urban park green spaces [5]. Furthermore, the current urban park green space assessment in China still primarily uses traditional quota indicators, such as per capita park green space area and green coverage rate, as the main standards, which are difficult to reflect the actual effectiveness of planning implementation and the rationality of spatial distribution [6]. The accessibility of park green spaces typically refers to the difficulty residents face in reaching a park, often due to obstacles such as distance and time. It is an important indicator for measuring the service capacity and spatial configuration of urban park green spaces [7].

A review of research by domestic and foreign scholars on the accessibility of park green spaces encompasses multiple disciplines, including landscape architecture, urban and rural planning, and geographic information. The research focus has gradually shifted from the early exploration of the relationship between physical activity and park accessibility [8] to emerging topics such as public health [9], environmental justice [10], and green space equity [8, 11, 12]. Public health focuses on the relationship between the accessibility of park green spaces and residents' physical health [13] and mental health [14]. Studies have found that the accessibility of park green spaces is directly proportional to the frequency of residents' contact with parks, so that better park accessibility can reduce the risk of physical and mental illnesses [13]. With research on environmental justice and the accessibility of park green spaces focusing on the perspective of "racial differences", many foreign scholars have found that wealthy white communities have higher accessibility of park green spaces and better park facilities than low-income people of color [15]. The study of green space equity has gone through three stages: quantitative equilibrium, spatial equity, and social equity. In the spatial equity stage, green space accessibility was introduced to measure the utilization efficiency and spatial allocation of green space resources [16]. In the social equity stage, the focus was on exploring the relationship between the accessibility of park green spaces and disadvantaged groups, as well as socioeconomic disparities [17, 18]. From the perspective of research time, most existing studies only explore the accessibility of park green spaces in a single year [19], and pay little attention to the dynamic configuration and influencing mechanism of parks in the process of urbanization; in terms of research scale, most studies are conducted at the city and district levels [20, 21], and the differences between subdistricts in the same city cannot be reflected.

There are currently many methods for measuring accessibility both domestically and internationally. For example, the buffer method [22] is simple for calculation, but does not consider the real road network; the network analysis method [23] is based on complete road network data, but requires high accuracy of the data; the gravity model [7] and the two-step floating catchment area method [21] cover more comprehensive factors and take into account the supply and demand relationship. The two-step floating catchment area method incorporates the concept of "spatial threshold" based on the gravity model, and has led to several improved models applicable to different research directions [24, 25]. It is considered the optimal model for measuring green space accessibility [26]. For example, Huang Jiuju et al. used the Gaussian two-step floating catchment area method with multi-radius to study the accessibility of park green spaces for different social groups in Shenzhen [27]; Yang Wenyue et al. combined the application of TIQS to construct a multi-mode two-step floating catchment area model and explored the differences in the accessibility of multi-scale park green spaces and its fairness under three travel modes—walking, public transport and private cars—in Guangzhou [28]; Ren Jiayi et al. used the improved Gaussian two-step floating catchment area method to study the accessibility of park green spaces under high-density urban walking conditions, taking Huangpu District of Shanghai as an example [19].

Previous studies on evaluating the accessibility of park green spaces have primarily employed standard classification methods in GIS, such as the natural breaks method and the quantile method, to assess the level of green space accessibility. The natural breaks method identifies data classification intervals and groups similar values to maximize the differences between classes; quantiles, on the other hand, require each class to contain an equal number of elements, which can be misleading. Therefore, using these classification methods to judge accessibility is biased. The actual meaning of the result calculated by the Gaussian two-step floating catchment area method is the generalized per capita park green space area considering distance decay, which can be compared with the per capita park green space area as the basis for evaluating accessibility levels and conducting horizontal comparisons among different spatial units within the region [21].

There are many methods for studying the influencing mechanism, such as the traditional regression model, the spatial econometric model, the geographic detector, the geographically weighted regression, etc. The geographic detector model focuses on the difference analysis of global-scale influencing factors [29], while the geographically weighted regression model can reflect the spatial heterogeneity of the effect of local-scale influencing factors [30]. Combining the two can make the study of the influencing mechanism more profound and comprehensive. Currently, these two methods are primarily used in studies on the evolution of ecosystem services [31], the characteristics of land use evolution [32], and the spatial distribution of traditional villages and towns [33], but are rarely applied in the field of park green space and accessibility studies. In addition, most studies on influencing factors of green space accessibility focus on green space and the population itself, without considering socio-economic factors. They often use single methods, such as qualitative descriptive analysis and correlation analysis, which cannot quantitatively determine the strength of the influencing factors and the spatial heterogeneity.

Therefore, this paper takes the spatial-temporal differentiation ofthe accessibility of park green spaces as its starting point, and uses Shenzhen, the city with the highest population density and fastest urbanization process in China, as the research object. It employs the Gaussian two-step floating catchment area method that comprehensively considers both supply and demand to analyze the accessibility of multi-scale park green spaces under multiple travel modes in 2013 and 2020. Furthermore, it constructs a composite index system of "green space-transportation-location-economy-nature" and integrates a geographic detector and a geographically weighted regression model to quantitatively express and spatially visualize the influencing mechanism of the spatial-temporal differentiation in the accessibility of park green spaces in Shenzhen. This study more clearly and comprehensively reveals the intensity and spatial differentiation patterns of various driving factors in the urbanization process. The research can provide decision-making suggestions for park policy formulation and green space system planning in similar cities, addressing the shortcomings of current studies that primarily focus on single time segments and travel modes.

1 Research subjects and data

1.1 Overview of the study area

Shenzhen is a national center for finance, science and technology, and innovation. It plays a pivotal role in the development of the Guangdong-Hong Kong-Macao Greater Bay Area, boasting the highest population density and urbanization rate in China. It administers 10 administrative districts and 76 subdistricts. In the early stages of its development, thecity was divided into inner and outer areas, covering a total of 1,997.47 km^2. During the process of urban development, the government places great importance on constructing an ecological environment. It has set forth several strategic goals, such as the "City of a Thousand Parks" and "Park City" initiatives. In 2019, the number of parks reached 1,090, and initial results have been achieved. Green space accessibility is an important indicator of the rationality of urban planning and construction, and it is of great significance for improving the quality of residents' lives and optimizing the allocation of green space resources.

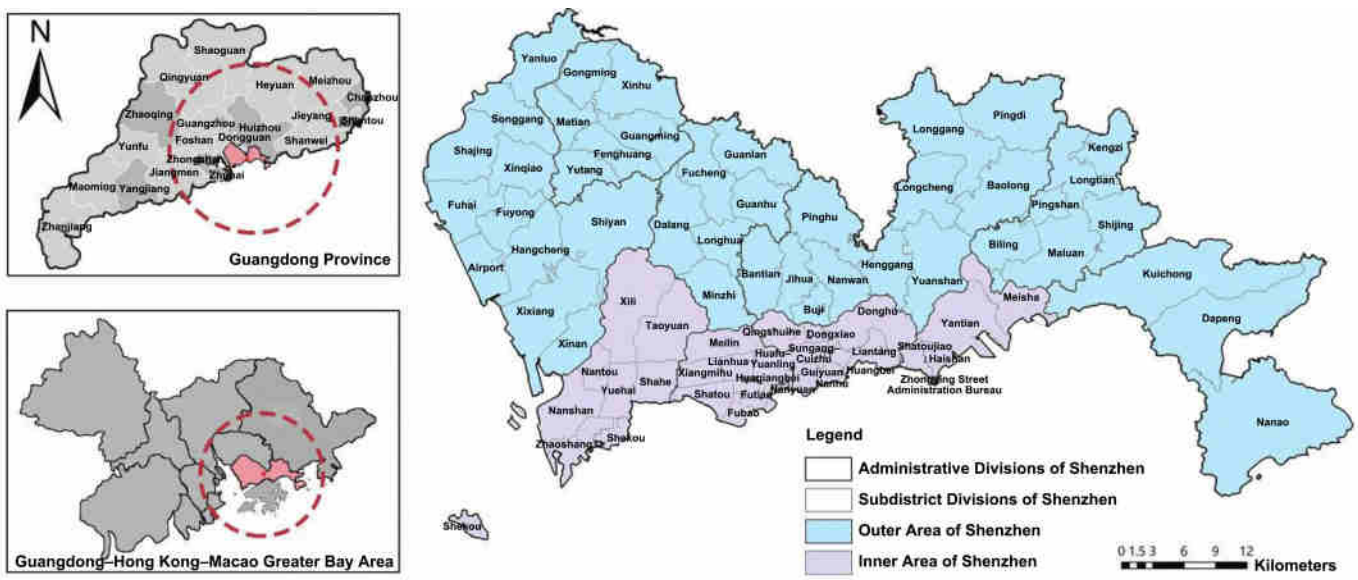


Figure 1 Study areas

1.2 Datasources and processing

In 2012, Shenzhenissued the *Shenzhen Urban Greening Development Plan Outline* (2012-2020), which set a working cycle from 2012 to 2020 and proposed new goals for future urban greening development. The first batch of park directory data was officially released in 2013. Therefore, this paper uses 2013 and 2020 as the research time frames. The park green space data are based on the *Shenzhen Park Directory* and the *Shenzhen Urban Planning Standards and Guidelines* (partially revised in 2019). Park green spaces within the scope of urban construction land are categorized into three types: comprehensive parks, specialized parks, and community parks. The entrances and exits of large parks, as well as the centroids of small parks, are extracted to establish a database of park green spaces. Administrative division data is sourced from the National Administrative Division Information Query Platform; the road network data is sourced from the OpenStreetmap website; data on residential communities, commercial service facilities, government facilities, and bus stops are crawled from Gaode Maps; DEM data comes from the Resources and Environmental Science Data Center of the Chinese Academy of Sciences; population and GDP data were downloaded from the Worldpop website and the Geographic Remote Sensing Ecological Network, respectively, and corrected according to the *Shenzhen Statistical Yearbook* to improve data accuracy.

2 Research framework and methodology

2.1 Research framework

Tomore accurately evaluate the actual construction effectiveness of park green spaces and achieve spatial equity in green space resources, this paper establishes a three-level research framework: spatial-temporal differentiation of supply and demand levels of park green spaces, spatial-temporal differentiation of accessibility, and exploration of the influencing mechanism of accessibility (Figure 2). The spatial-temporal differentiation analysis of supply and demand levels is conducted from both supply and demand perspectives, comparing the changes in the spatial layout, area, quantity, and population density of park green spaces in 2013 and 2020. The spatial-temporal differentiation of accessibility is analyzed using the Gaussian two-step floating catchment area method to calculate the accessibility of multi-scale park green spaces under multiple travel modes in 2013 and 2020, followed by a comparative analysis of its differentiation characteristics. The exploration of the influencing mechanism of accessibility first uses a geographic detector to analyze the relationship between the accessibility index and the factors of "green space-transportation-location-economy-nature", identifies effective influencing factors, and then uses a geographically weighted regression model to explore the spatial heterogeneity of the impact of each effective influencing factor on green space accessibility, aiming to provide differentiated strategies and methodological insights for future urban green space system planning.

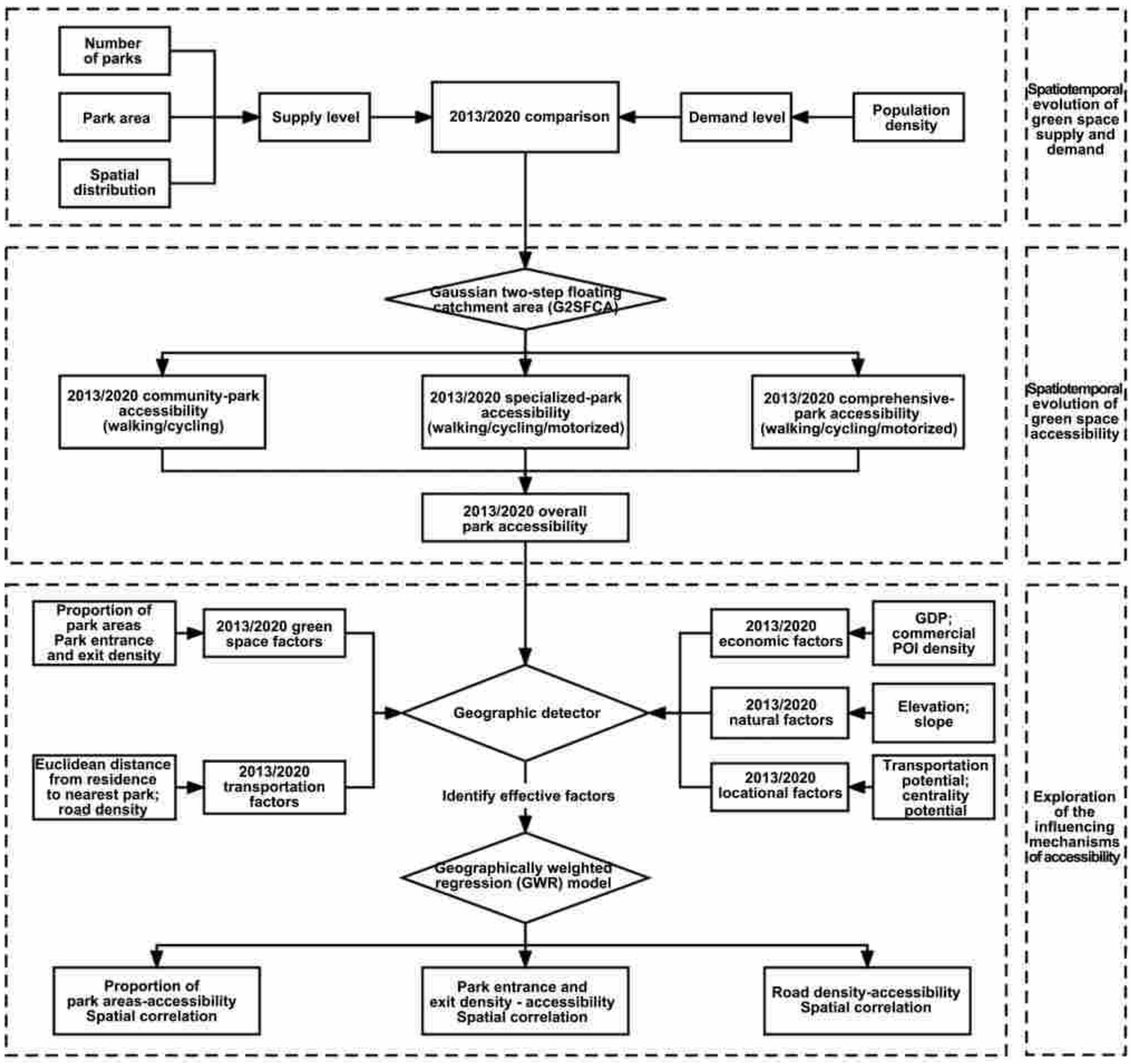


Figure 2 Research Framework

2.2 Gaussian two-step floating catchment area method

The traditional two-step floating catchment area methodadopts a “binary” decay function, meaning that areas within the search radius are completely reachable, while areas outside the radius are entirely inaccessible. This does not reflect the actual travel characteristics of residents. Therefore, this paper employs a Gaussian function, which better reflects the actual travel patterns of residents, to enhance the two-step floating catchment area method. It then explores the accessibility of multi-scale park green spaces under multiple travel modes, thereby improving the reliability and accuracy of the research results. The specific steps are as follows:

Step 1:Use the park entrance or exit as supply point j, and establish a search domain based on the research threshold $d0$ for park green spaces at different levels under multiple travel modes (Tables 1 and 2). Calculate the total population of all demand points k within the search domain of each supply point j, apply a Gaussian function for decay, and calculate the service capacity Rj of each supply point j.

$$Rj = \frac{Sj}{\sum k \in \{djk \leqslant d0\} G(djk,d0)Dk} \quad (1)$$

$$G(djk) = \frac{e^{-1/2 \cdot (djk/d0)2}}{1 - e^{-1/2}} (djk < d0) \quad (2)$$

In the formula:Dk is the population (persons) at each demand point k, djk is the distance cost between supply point j and demand point k, $G(djk)$ is the Gaussian decay of the distance cost, and Sj is the supply capacity of supply point j, expressed in park area (m^2).

Table 1 Threshold settings for research on park green spaces at all levels

Mode of travel and speed	Comprehensive parks	Specialized parks	Community parks
Walking at 5km/h	30min	20min	15min
Cycling at 15km/h	20min	15min	10min
Motor vehicles (speed limits based on road grade)	15min	10min	—

Table 2 Speed assignments for roads at all levels

Road grade	Highway	Expressway	Main road	Secondary roads	Branch road
Road speed	80km/h	60km/h	40km/h	30km/h	20km/h

Step 2:Establish a search domain with the residential area as the demand point k and the $d0$ threshold. Find all the park green space supply points j within the search domain and summarize their supply-demand ratio R_j. Use a Gaussian function to decay the ratio and calculate the accessibility index Ai of the residential area k.

$$Aj = G_{(dkj,d0)} * R_j \quad (3)$$

In the formula, $G(dkj)$ is the distance cost after Gaussian decay, and R_j is the sum of the service capabilities of all supply points within the search threshold.

Step 3: Since the accessibility calculated by the Gaussian two-step floating catchment area method represents the generalized per capita green space area, this paper uses the method of “whether the ratio of the accessibility of park green spaces to per capita park green space area is greater than 1” to evaluate the accessibility level and carry out horizontal comparison of different units in the region. Areas with a value greater than 1 are considered to have relatively high accessibility, and areas with a value less than 1 are considered to have relatively low accessibility[21].

2.3 Geographic detector

The geographic detector is a new tool proposed by Wang Jinfeng et al.[29] for exploring driving factors and spatial differentiation. It mainly uses the q value to measure the magnitude of the driving factor's determination power. Its formula is:

$$q_x = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \quad (4)$$

Where q_x is the determination power of the influencing factor x on the accessibility of park green spaces, and its value range is [0, 1], h= 1, 2, ..., L is the number of strata of the driving factor; N_h and N represent the number of samples in the region of stratum h and the number of samples in the whole city, respectively; σ_h^2 and σ^2 are the variances of the dependent variables of stratum h and the whole city, respectively.

2.4 Geographically weighted regression

Geographically weighted regression (GWR) is a geostatistical method developed based on the traditional ordinary least squares (OLS) model, in which spatial characteristics are incorporated into the model through distance-based weighting. It isparticularly effective for evaluating the spatial heterogeneity of influencing factors [34]. The calculation formula is as follows:

$$y_i = \beta_0(u_i,v_j) + \sum_{j=1}^{k}\beta_j(u_i,v_i)\chi_{ij} + \varepsilon_i \tag{5}$$

Where y_i represents the accessibility of park green spaces on the i-th subdistrict, (u_i, v_i) represents the spatial geographic coordinates of the i-th subdistrict, β0 represents the fixed-effect intercept of (u_i, v_i), X_{ij} represents the j-th influencing factor of accessibility of the i-th subdistrict (j= 1, 2, ..., K), β_j represents the regression coefficient of X_{ij}, and ε_i represents the random error.

3 Results and analysis

3.1 Spatial-temporal comparison of green space supply levels

In terms of spatial layout (Figure 3), the park green space exhibits an uneven distribution pattern with the characteristics of "more in the west and less in the east", "from the inner areas to the outer areas", and expansion from south to north. In terms of the number of parks (Figure 4), the number of parks in Shenzhen increased from 655 in 2013 to 1,169 in 2020, a relative increase of 78.47%, with community parks showing the most significant increase. In terms of park area (Figure 5), the park area in Shenzhen increased from 55.76 km^2 in 2013 to 84.42 km^2 in 2020, representing a relative increase of 51.40%. Comprehensive parks accounted for the most significant proportion of the area. Shenzhen's core development areas are primarily located in the earlier-developedinner areas, such as Futian District, Nanshan District, and Luohu District. These areas serve as hubs for urban functions, including residence, commerce, and administration. The eastern areas, having been developed later, have fewer park green spaces. With the implementation of integrated development between the inner and outer areas of the Shenzhen Special Economic Zone, infrastructure construction in the outer areas has accelerated, and park green spaces have continued to expand. Among them, community parks—characterized by their wide distribution and small size—primarily serve neighborhood residents, resulting in a substantial increase in their numbers. In contrast, comprehensive parks feature larger service coverage and greater scale, thus showing a more significant increase in total area.

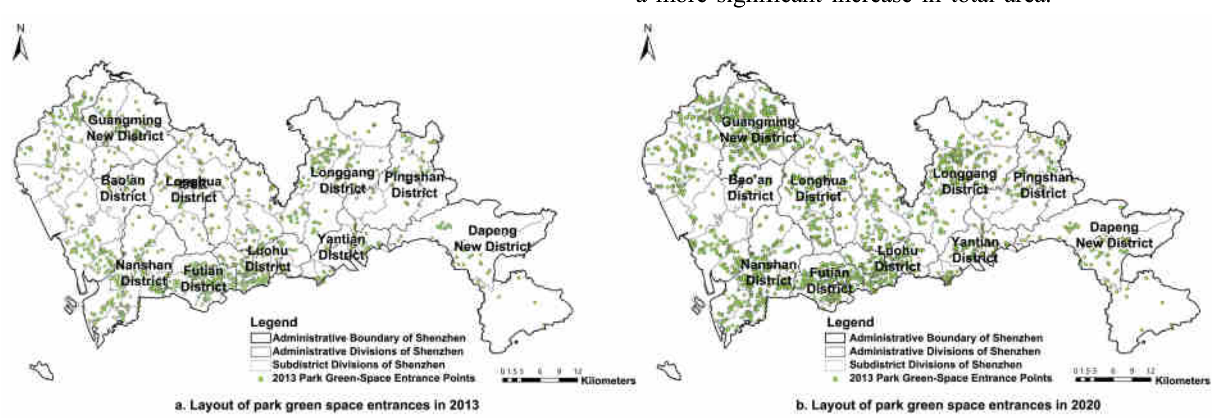


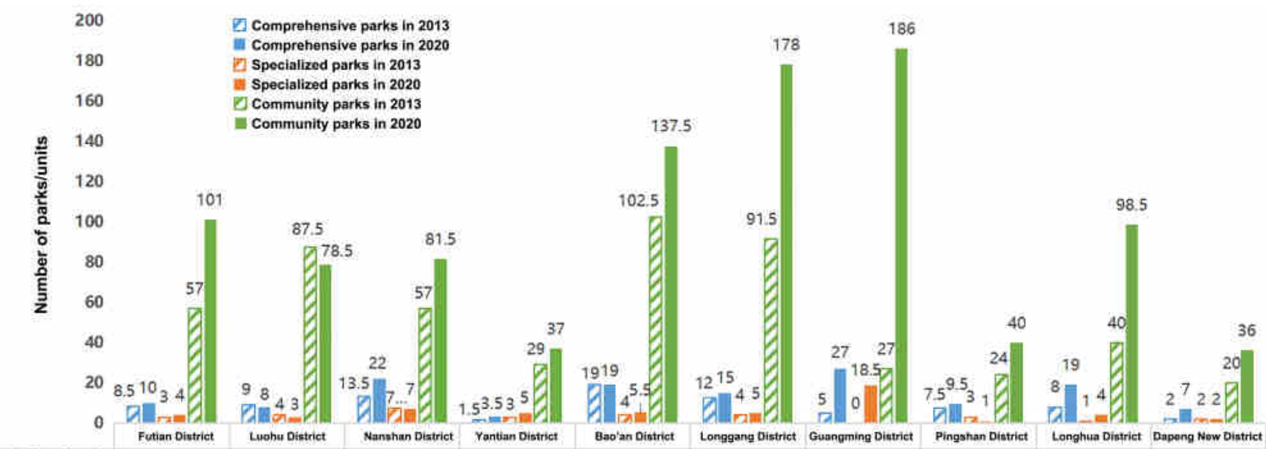
Figure 3 Layout of park green space entrances in 2013 and 2020

3.2 Spatial-temporal comparison of green space demand levels

The demand for park green spaces among residents is positively correlated with population density. From 2013 to 2020, the population of Shenzhen increased by approximately 3.4 million. By calculating the ratio of population to area in each subdistrict, a population density distribution map of Shenzhen was obtained. As shown in Figure 6, from 2013 to 2020, the acceleration of urbanization led to the gradual development of outer areas, with high population density extending from inner to outer areas. Futian, Luohu, and Nanshan are the core development areas of Shenzhen, with high population density and high demand. The population density in Bao'an District, Longhua District, and Guangming District in the west has gradually increased, and the demand level has risen accordingly. The development and construction of Yantian District, Longgang District in the east, and Dapeng District were slower, with lower population density and lower demand.

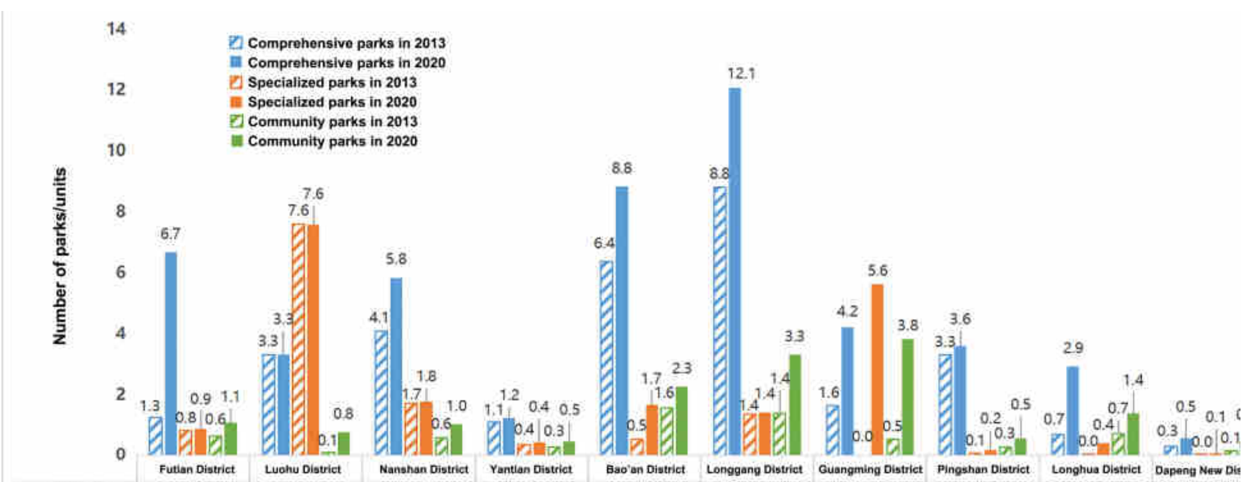
3.3 Spatial-temporal differentiation characteristics of the accessibility of park green spaces

This paper takes the spatial-temporal differentiation of the accessibility of park green spaces as its starting point and uses the Gaussian two-step floating catchment area method, which comprehensively considers both supply and demand, to analyze the accessibility of multi-scale park green spaces in Shenzhen under multipletravel modes in 2013 and 2020. High-value areas and low-value areas are divided by whether the ratio of the accessibility of park green spaces to per capita park green space area is greater than 1. Furthermore, the accessibility values are classified into four levels—low, relatively low, relatively high, and high—using the geometric interval classification method.



	Futian District	Luohu District	Nanshan District	Yantian District	Bao'an District	Longgang District	Guangming District	Pingshan District	Longhua District	Dapeng New District
Total number of parks in 2013	69.5	99.5	79	33.5	124.5	108.5	32	35.5	49	24
Total number of parks in 2020	115	89.5	110.5	45.5	162	198	231.5	50.5	121.5	45
Increment	45.5	-10	31.5	12	37.5	89.5	199.5	15	72.5	21

Figure 4 Comparison of the number of parks in 2013 and 2020



	Futian District	Luohu District	Nanshan District	Yantian District	Bao'an District	Longgang District	Guangming District	Pingshan District	Longhua District	Dapeng New Dis
Total area of parks in 2013	8.17	11.66	6.58	1.72	8.45	11.54	2.14	3.63	1.40	0.48
Total area of parks in 2020	8.58	11.92	8.60	2.12	12.72	16.77	13.63	4.30	4.70	1.08
Increment	0.41	0.26	2.02	0.40	4.27	5.23	11.49	0.67	3.30	0.61

Figure 5 Comparison of park areas in 2013 and 2020

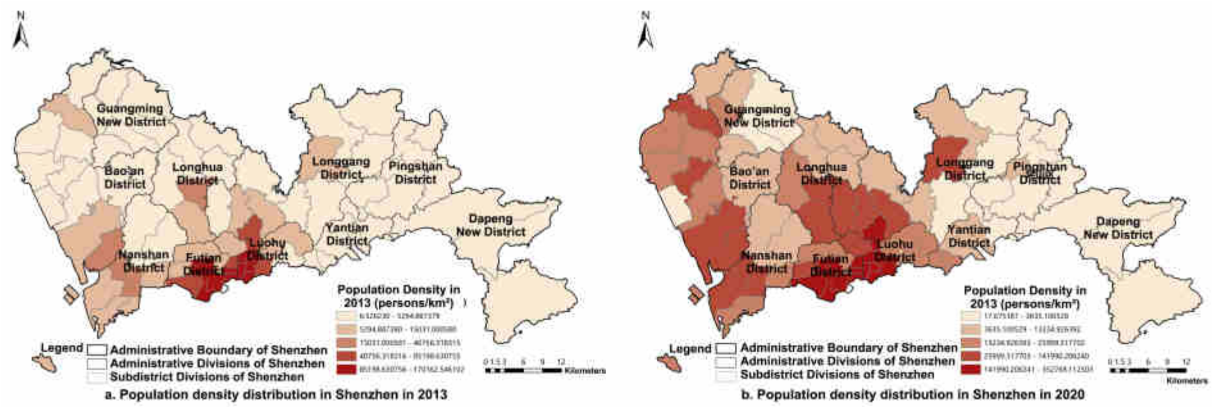


Figure 6 Population density distribution in Shenzhen in 2013 and 2020

Overall, from 2013 to 2020, the accessibility of park green spaces in Shenzhen showed an upward trend. The proportion of communities with high accessibility gradually increased. The average accessibility of community parks saw the most significant increase. The accessibility of comprehensive parks remained relatively stable. Specialized parks saw the most significant increase in standard deviation and a greater degree of spatial differentiation. Over the past decade, Shenzhen has prioritized park construction as a crucial aspect of enhancing the city's overall competitiveness and sustainable development capabilities. Park construction has entered a period of rapid development, with overall accessibility improvements relying on the implementation of multiple green space strategies such as "City of a Thousand Parks" and "Park City."

From the perspective of the spatial-temporal differentiation of accessibility, the accessibility of community parks has improved the most, which is most significant in Guangming District. The main reason is that in recent years, Guangming District has served as a typical model for Shenzhen's efforts to build an ecologically civilized city. Itrecorded the most significant increase in parks and is located in the outer areas, where population demand is relatively low. The oversupply has led to a significant improvement in the accessibility of community parks. The accessibility level of comprehensive parks is basically stable. The high accessibility value areas exhibit a trend of migration from inner areas to outer areas. This is because the development level of the inner areas is high, resulting in a continuous increase in population density. However, the inner areas have long entered the stage of stock development, and the available land resources for green space construction are limited. On the other hand, outer areas are in the stage of development and construction, with low population demand and a strong supply capacity for green spaces, which gradually improves accessibility. Accessibility of specialized parks, however, has slightly decreased, and spatial differentiation has become more pronounced. The main reason is that 72.5% of the newly added specialized parks are concentrated in Guangming District. The rapid increase in supply capacity has led to a significant improvement in accessibility, resulting in a significant uneven spatial distribution of accessibility throughout the city (Figures 7-12).

3.4 Exploring the influencing mechanism of the accessibility of park green spaces

3.4.1 Identification of influencing factors based on geographic detectors

The accessibility of park green spaces isinfluenced by a variety of factors. This paper selects 10 influencing factors, categorized into five categories, as independent variables, and the comprehensive accessibility index as the dependent variable (Table 3). The effect of each influencing factor on the changes in the accessibility of park green spaces in 2013 and 2020 is analyzed using a geographic detector.

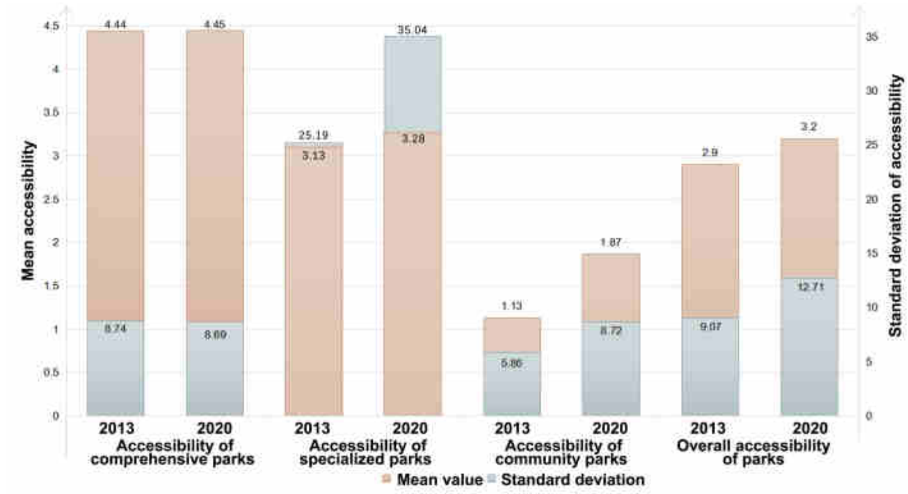


Figure 7 Accessibility coefficients of different types of parks in 2013 and 2020

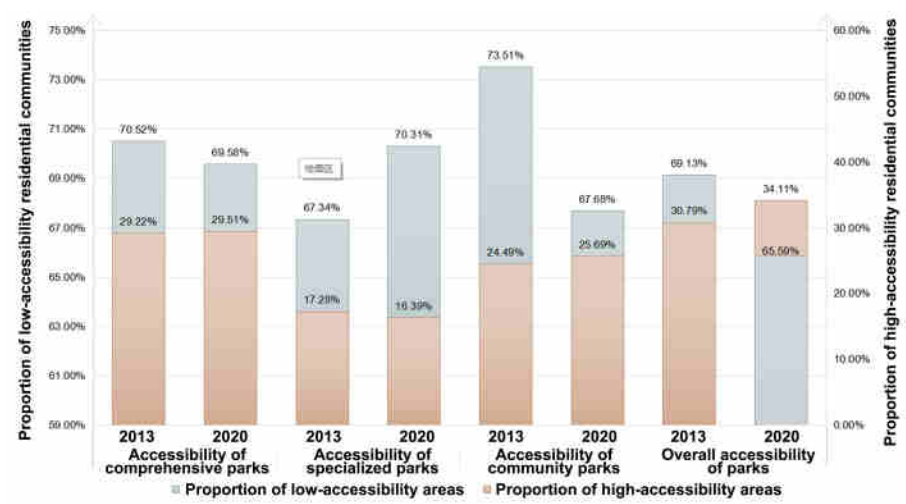


Figure 8 Spatial-temporal comparison of changes in the accessibility of multi-scale park green spaces in Shenzhen

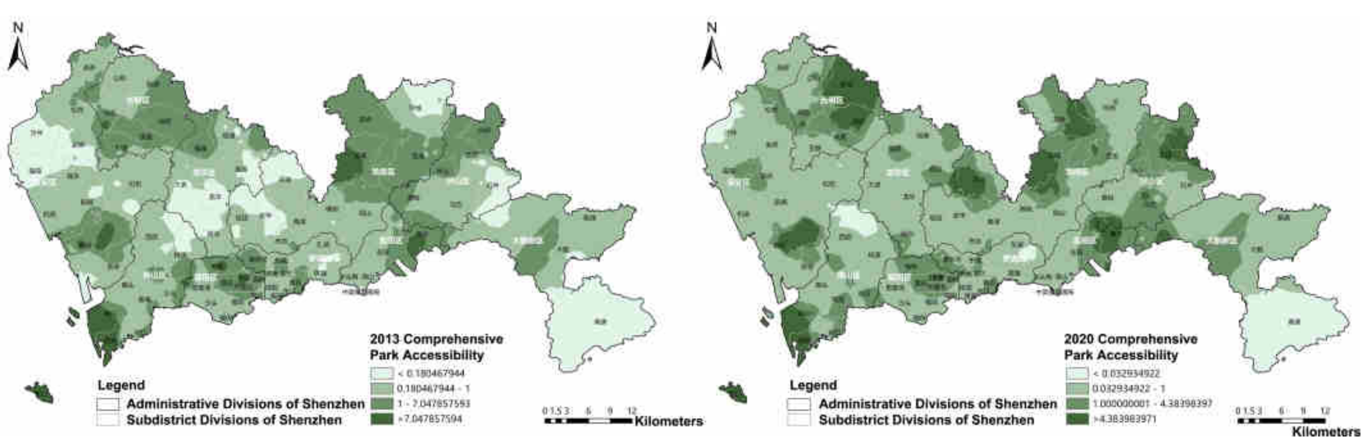


Figure 9 Accessibility of comprehensive parks in 2013 and 2020

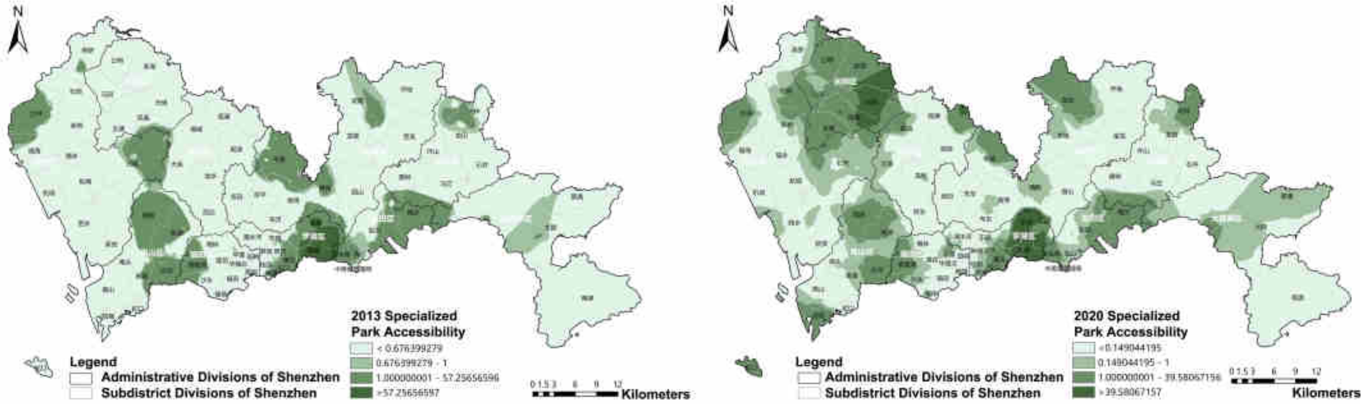


Figure 10 Accessibility of specialized parks in 2013 and 2020

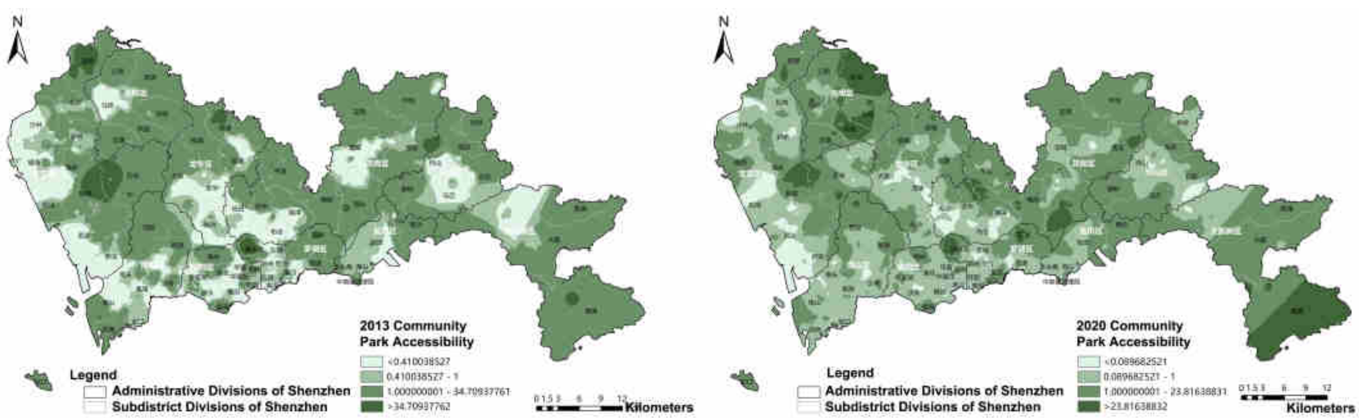


Figure 11 Accessibility of community parks in 2013 and 2020

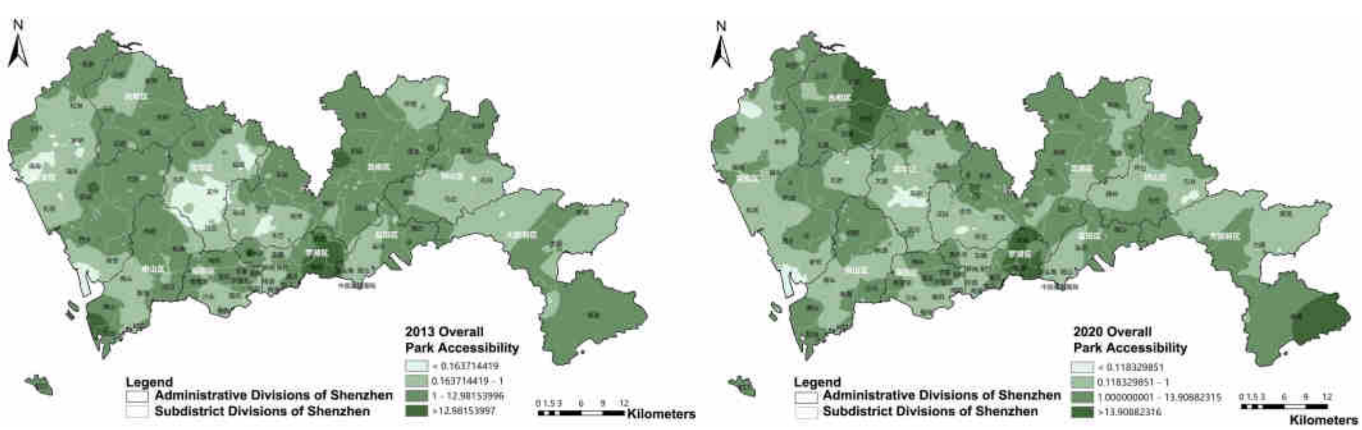


Figure 12 Overall accessibility of parks in 2013 and 2020

The results of the accessibility influencing factor q-value detection (Table 4) show that in 2013, all influencing factors had p-values of 0 and passed the 0.01 significance test. However, in 2020, only the three influencing factors X1, X2, and X4 passed the 0.01 significance test. This indicates that between 2013 and 2020, the spatial distribution of park accessibility was more strongly and structurally associated with green-space and road-related factors. The reason for this is that with the integrated development of the urban economy and the progress of science and technology, the economy and commerce of each district have become the focus of development. The gap in commercial service facilities, technical difficulties, and the cost of development and construction have gradually decreased, resulting in a continuous decline in the correlation between location factors, economic factors, and natural factors, and park accessibility. Further investigation into the significant influencing factors, as indicated by the *q* values, revealed that, at the dynamic level, the *q* values of X1, X2, and X4 all showed a decreasing trend. The ranking of their *q*-values of determination power was X4 (0.10275) > X1 (0.0536) > X2 (0.0472), indicating that X4 is the dominant factor in park accessibility, with an explanatory power of over 10%, far exceeding that of other factors. X2 and X1, on the other hand, are important factors in park accessibility. The primary reason is that roads are a crucial infrastructure for urban development. Areas with higher road density have relatively higher levels of urban development and construction, more complete park green space facilities, and more convenient travel routes that significantly improve residents' access to park green spaces. Therefore, road density has the strongest determination power. In addition, the accessibility of park green spaces is inseparable from their construction. The larger the area of a park or green space, the more entrances and exits it will have, as well as the wider its service area, thus improving its accessibility.

Table 3 Accessibility Influencing Factor Index System

Category	Influencing factors	Influencing factor	Code	Classification
Influencing factor (X)	Green space factors	Proportion of park area	X1	6
		Park entrance and exit density	X2	6
	Traffic factors	Straight-line distance from the residence to the nearest park	X3	6
		Road density	X4	6
	Location factors	Traffic Location	X5	6
		Central potential	X6	6
	Economic factors	GDP	X7	6
		Commercial POI density	X8	6
	Natural factors	Elevation	X9	6
		Slope	X10	6
Dependent variable (Y)	Accessibility	Comprehensive Accessibility Index	Y	6

Table 4 Results of the accessibility influencing factor q-value detection

Influencing factors	2013		2020		2013-2017	
	Determination power q	Significance level p	Determination power q	Significance level p	Determination power q	Average value
X1	0.0755	0.0000	0.0317	0.0038	- 0.0438	0.0536
X2	0.0578	0.0000	0.0366	0.0031	- 0.0212	0.0472
X3	0.0974	0.0000	0.0098	0.4737	—	—
X4	0.1585	0.0000	0.0470	0.0000	- 0.1115	0.10275
X5	0.1702	0.0000	0.0012	0.9972	—	—
X6	0.1874	0.0000	0.0128	0.8128	—	—
X7	0.1472	0.0000	0.0394	0.1849	—	—
X8	0.0598	0.0000	0.0484	0.2456	—	—
X9	0.0876	0.0000	0.0224	0.0918	—	—
X10	0.0618	0.0000	0.0040	0.9490	—	—

Table 5 Regression model indicator system

Indicator Name	Indicator code
Overall accessibility index	Y
Proportion of park area	X1
Park entrance and exit density	X2
Road density	X4

3.4.2 Spatial heterogeneity analysis of influencing factors based on GWR

Geographic detector models primarily focus on analyzing factors that influence spatial differentiation at the global scale, while neglecting the spatial differentiation of these factors' effects at the local scale. Therefore, after testing with the geographic detector model, this paper selected three effective factors—proportion of park area(X1), park entrance and exit density (X2), and road density (X4)—as explanatory variables, and constructed a regression model index system with the accessibility index in 2020 as the explained variable (Table 5).

OLS regression was performed on the accessibility index and each of the dominant factors. The results showed that the residual fit did not follow a normal distribution. To improve the fit, the GWR model was subsequently introduced. First, we used Geoda 1.14 to analyze the spatial autocorrelation of the overall accessibility index of parks in Shenzhen in 2020. The results showed that Moran's I was 0.823753, which passed the Z-test for significance ($p < 0.05$), indicating significant spatial autocorrelation in the accessibility index in 2020. Then, the influencing factor data were standardized, and geographically weighted regression analysis was performed using GWR4 to further explore the spatial differentiation of the influencing factor effects. The results (Table 6) show that the fitted R^2 increased from 0.172066 to 0.403038, and the AICc value decreased from −61.379260 to −73.339113, with a difference of 11.959853. These results indicate that the GWR model provided a significantly better fit and more accurate spatial representation than the OLS model.

Table 6 Comparison of OLS and GWR model fitting results

Model	AICc	R^2	Adjust R^2
OLS	- 61.379260	0.172066	0.137569
GWR	- 73.339113	0.403038	0.307432

The regression coefficients fitted by the GWR model (Figure 13) show that road density(X4) has the most significant influence and variability on the accessibility index (regression coefficients range from −0.963989 to −0.097715), exhibiting a spatial characteristic of being higher in the east and lower in the west. This is due to the obvious east-west polarization of development in Shenzhen, with the eastern Longgang and Pingshan districts lagging behind in development and having less developed road systems than the west. As a key factor in accessibility, road density has a significantly greater impact on accessibility improvement in the east than in the west. Park entrance and exit density (X2, with regression coefficients ranging from −0.252221 to 1.386147) exhibits a decreasing regression coefficient from west to east. The positiveeffects are concentrated in the western Guangming, Bao'an, Longhua, and Nanshan districts of Shenzhen, where there are many parks and a high density of entrances. The negative impact is mainly concentrated in the eastern Pingshan and Dapeng districts, where the supply of green space resources is relatively poor. Proportion of park area (X1) showed the smallest spatial variation (regression coefficients ranged from -0.074609 to 0.251136), with a predominantly positive effect. Only six subdistricts in Guangming District and Bao'an District showed a negative impact. The distribution of regression coefficients revealed significant spatial zonation. Due to the larger area of the eastern administrative district, but with less green space compared to the western district, the influencing effect in the eastern region is markedly stronger than that in the western region.

4 Conclusions and outlook

As an important public resource in the city, park green spaces serve as vital spaces for residents' daily leisure activities, possessing ecological and cultural functions. Their accessibility has a profound impact on the quality of life for residents. In 2012, Shenzhen released the *Shenzhen Urban Greening Development Plan Outline* (2012-2020), which set a working cycle from 2012 to 2020 and proposed new goals for the future development of urban greening in Shenzhen. The first batch of park directory data was officially released in 2013. Therefore, this paper takes 2013 and 2020 as the research time frames, uses the Gaussian two-step floating catchment area method to explore the spatial-temporal differentiation characteristics of the accessibility of park green spaces in Shenzhen, and uses a geographic detector and a geographically weighted regression model to examine the influence level of different factors on the accessibility of park green spaces and its spatial heterogeneity characteristics. The main conclusions are as follows: 1) Within the scope of construction land, the number and area of park green spaces in Shenzhen have continued to grow, and spatially they show the characteristics of "more in the west and less in the east", "from the inner areas to the outer areas", and expansion from south to north. 2) Between 2013 and 2020, the accessibility of park green spaces in Shenzhen showed an overall upward trend. The accessibility of outer areas gradually surpassed that of inner areas. Among the different park types, community parks exhibited the most significant increase in mean accessibility, while specialized parks demonstrated the most substantial spatial variation in accessibility, and the accessibility level of comprehensive parks remained relatively stable. 3) Road density, park entrance and exit density, and proportion of park area are the main influencing factors. In contrast, the correlations between location, economic, and natural factors and accessibility have weakened over time, owing to the integrated development of the urban economy and technological progress. 4) Different factors exhibit significant spatial heterogeneity in their effects on the accessibility index. Road density(X4) and proportion of park area(X1) have a greater impact in the eastern part of the study area, while park entrance and exit density(X2) has a greater impact in the western part of the study area.

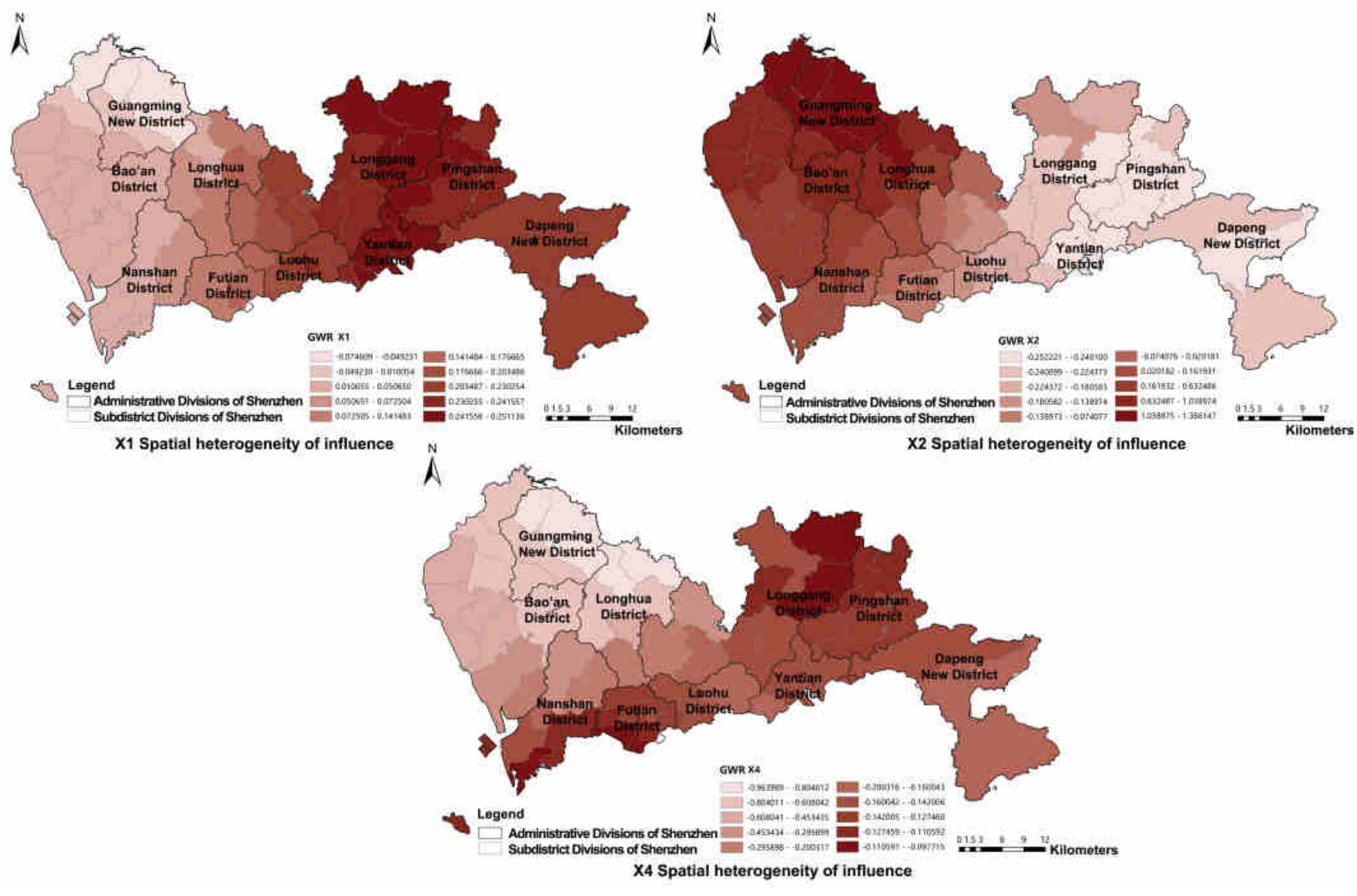


Figure 13 Spatial heterogeneous distribution of the effects of effective factors

Against the backdrop of rapid urbanization, the inequality of social, economic, and ecological benefits caused by differences in accessibility of park green spaces has attracted the attention of many scholars[35-37]. However, there remains a lack of in-depth research on the dynamic characteristics and the influencing mechanism of the accessibility of park green spaces. This study quantitatively expresses and spatially analyzes the spatial-temporal differentiation characteristics and driving factors of the accessibility of various park green spaces in Shenzhen, summarizes their distribution characteristics and development patterns, and provides a reasonable explanation for the mechanism of their spatial-temporal differentiation from multiple perspectives. This can provide differentiated and targeted suggestions for the planning and construction of Shenzhen's green space system. Furthermore, the research framework and conclusions of this paper have specific reference and guiding significance for the overall assessment, optimal allocation, and spatial equity of other similar urban park green spaces. The methodology can also provide useful reference for the accessibility analysis of other geographical phenomena.

However, this study also has certain limitations due to factors such as data collection. Because accurate population data are difficult to obtain, this paper utilizes WorldPop population density raster data, which may result in discrepancies between the population of residential areas and the actual population. Although district-level corrections were made using data from theSeventh National Population Census, differences in the demand level at the residential-community scale remain. Secondly, both the 2013 and 2020 park directories contain a small number of records with missing information on the area of parks or classification, as well as ambiguous location data. Such data deviations may affect the estimation of green-space supply and, consequently, the results of accessibility analysis. In addition, this study does not fully account for subjective factors among different population groups or the intrinsic attractiveness of parks, both of which may influence accessibility. Future research could further evaluate park attractiveness through questionnaire surveys and satisfaction scoring, and improve the accuracy of the analysis by refining park datasets and enriching the indicator system of influencing factors.

Source of Figures and Tables

All figures and tables in this article were drawn by the author

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"Seeing the City from a Meter Height": Evaluation of Enjoyment of Comprehensive Parks from a Child-Friendly Perspective

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ABSTRACT: A green space for children's outdoor activities is an important measurement indicator for building a child-friendly city. The construction of child-friendly cities in China has gradually shifted from theoretical research to practical exploration. As an important public space for urban children to have contact with nature and engage in outdoor activities, comprehensive parks should give special consideration to the needs of children. Children's behavioral psychology is closely related to enjoyment in the activity space. Studying the relationship between children's activities and enjoyment of parks from the perspective of behavioral psychology corresponds with the child-friendly city construction principle of "seeing the city from a meter height". This evaluation and analysis of enjoyment in comprehensive parks is expected to provide a useful reference for the design optimization of child-friendly comprehensive parks.

Based on determined behavioral and psychological characteristics of preschool children, the factors influencing enjoyment in comprehensive parks are divided into three types according to the behaviors and psychology of preschool children, including the perceptual type, sports type, and social type. Based on relevant studies, 29 representative sample sites were chosen in the Pengpu Four Seasons Park in Shanghai for field survey using the Public Space & Public Life (PSPL) survey method, behavior mapping, questionnaire survey, Analytical Hierarchy Process (AHP), and other methods.

To screen evaluation factors that influence enjoyment of comprehensive parks, an evaluation model for enjoyment of comprehensive parks was constructed. Enjoyment of comprehensive parks was evaluated from five dimensions, including space, facilities, plant configuration, waterscape design, and landscape culture. Differences in enjoyment among the same type of sample sites were analyzed and problems in enjoyment of comprehensive parks were explored. Finally, the corresponding optimization suggestions were proposed to solve shortcomings—such as the landscape and space sites not being novel enough, the science popularization of natural education needing to be improved, and the existence of single interaction modes— aiming to enrich landscape design strategies of comprehensive parks from the perspective of children.

Based on the status and enjoyment evaluation of comprehensive parks, some optimization suggestions were proposed in combination with children's behavioral and psychological needs. Based on the results of a field survey and interviews with parents, the basic principle of children participating in construction under the premise and guarantee of their safety was proposed. It is suggested that children's ideas be incorporated throughout the construction of parks. To better meet the behavioral and psychological needs of children, some specific suggestions to optimize the enjoyment of comprehensive parks were proposed according to the results of evaluating landscape elements in different dimensions. For example, the space site should meet the needs of activities, facilities should cooperate with natural elements, and landscape design should promote perceptual interaction. This study has some innovations: for example, typical sample sites were screened and classified to realize the modularization and visualization of space studies. Furthermore, based on existing studies, the degree of naturalness of materials was introduced into the enjoyment evaluation system of

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comprehensive parks, which supplements existing studies. However, this study still has some limitations. It is difficult to get rid of subjective factors in surveys of the activity preferences of children. Furthermore, only one park was chosen as the research object, but commonalities and differences in parks in different regions have not been explored deeply. This will be discussed in the next stage.

KEY WORDS: comprehensive parks; preschool children; behavioral psychology; enjoyment; evaluation

By the end of 2021, China had a child population of 263 million, accounting for 18.6% of thenational population[1)]. In October 2021, the National Development and Reform Commission, together with 22 other ministries and commissions, issued the *Guidelines on Promoting the Construction of Child-Friendly Cities*, which further proposed to formulate construction standards for various child-friendly spaces and facilities in cities to effectively guarantee children's rights to survival, development, protection, and participation[2)].

The construction of a child-friendly city in Shanghai has begun. In 2021, the Shanghai Municipal People's Government issued the *14th Five-Year Plan for the Development of Women and Children in Shanghai*, which pointed out the need to attach importance to environmental optimization and create child-friendly communities[3)]. In 2022, the *Implementation Plan for the Construction of a Child-Friendly City in Shanghai* was issued, proposing 20 specific construction tasks in 5 aspects to build a child-friendly city and promoting the concept of "seeing the city from a meter height" to be integrated into the entire process of urban development[4)].

Creating green spaces that meet the needs of children's outdoor activities is a key indicator of a child-friendly city [1]. The design of urban parks is often based on the perspective of adults, neglecting the behavioral and psychological needs of children, resulting in a lack of appeal to children [2]. Therefore, from the perspective of children's behavioral psychology, it is urgent to explore enjoyable activity spaces in comprehensive parks that meet the needs of contemporary children and provide children with friendly spaces for perception, movement, and socialization [3].

Existing research on children's activity-oriented outdoor spaces mainly focuses on children's usage preferences [4], the safety of the space, and its naturalness. In terms of spatial elements, the main focus is on plant landscape configuration, children's activity facilities, ground paving, and color schemes [5]. Research methods for outdoor activity spaces from a child's perspective are also being improved: Existing studies have combined questionnaire surveys with other methods to explore the influencing factors of children's environmental perception [6], including using methods such as content recognition, photo projection, and behavioral annotation [7]. The relationship between preschool children's behavioral psychology and space site design has received special attention. The research findings cover various spatial types at different scales, including community parks, comprehensive parks, and children's parks. From the perspectives of children's perception and needs [8], scholars explore the interactive behaviors of preschool children with the space sites, including their safety [9], playability [10], enjoyment [11], and social interaction [12].

Research on the enjoyment of space sites mainly focuses on design methodology [13], with less systematic analysis and post-use evaluation. Through the analysis of children's play spaces and play behaviors, scholars explore the factors that affect the enjoyment from perspectives such as natural factors, the introduction of the spirit of exploration, terrain shaping, and sensory engagement [10], and propose design strategies focusing on space, facilities, and terrains [14]. Evaluation-oriented studies select evaluation factors related to activity space, play facilities, plant configuration, hardscape, and landscape culture to systematically analyze the space site's enjoyment and conduct post-use evaluation, and propose corresponding countermeasures.

In summary, existing research mainly focuses on the activity preferences of preschool children and the design approaches for enhancing the enjoyment of outdoor spaces, while post-use evaluation still needs further in-depth exploration. Therefore, by comprehensively utilizing methods such as the PSPL survey method, behavior mapping, questionnaire survey, and Analytical Hierarchy Process (AHP), this study evaluates and analyzes enjoyment of space sites in a comprehensive park from the perspective of the behavioral psychology of preschool children, taking Shanghai Pengpu Four Seasons Park as an example, from five dimensions: space, facilities, plant configuration, waterscape design, and landscape culture. The aim is to provide useful insights for optimizing the design of child-friendly comprehensive parks.

1 Research subjects and methods

1.1 Researchsubjects

Preschool children are children aged 3 to 6 years who have not yet reached the age of school enrollment [15]. Infants and toddlers are too young, leading to excessive reliance on their parents for outdoor activities. School-aged children, burdened by academic workloads, lack time for play outside of school. As a result, preschool children constitute the primary child user group in comprehensive parks.

Enjoyment is a landscape feature that uses various methods to attract children's attention and generate strong interest in participation [16]. A play space characterized by enjoyment is often full of tension and fun, attracting users' attention and fostering activities in the space [8].

Taking into account the functions and facilities of the parks, a preliminary screening was conducted on 144 comprehensive parks within the outer ring road of Shanghai, and six comprehensive parks with clearly defined children's activity areas were selected (Figure 1). Pengpu Four Seasons Park, situated in Jing'an District, Shanghai, features four themed gardens dedicated to spring, summer, autumn, and winter (Figure 2). The park covers an area of 9.1 hm^2, with a children's activity area of 0.18 hm^2. It is the largest park in a residential area in the central urban area of Shanghai[5]. The park has a complete spatial composition, a natural layout, a large daily user base, and a high utilization rate, making it suitable for evaluating the park's enjoyment factor.

Figure 1 Distribution of comprehensive parks with clearly defined children's activity areas within the outer ring road of Shanghai

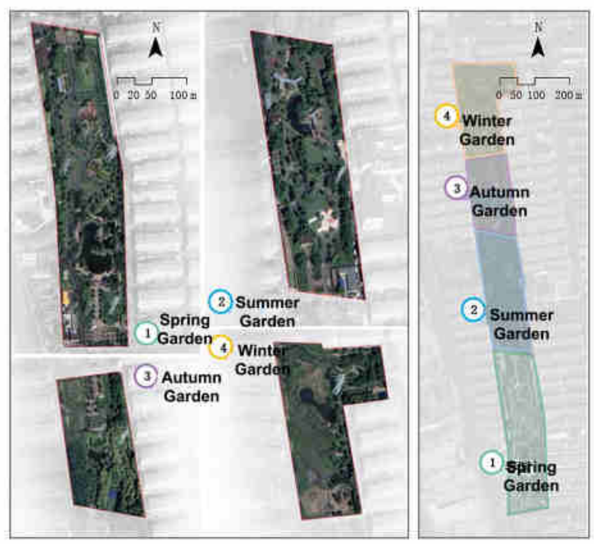

Figure 2 Plan view of Pengpu Four Seasons Park

1.2 Research methods

1.2.1 Questionnaire survey

(1) Questionnaire content. The questionnaires were distributed over four weekends in September 2022, with a total of 200 copies distributed. A total of 196 questionnaires were collected, with a response rate of 98%; 190 questionnaires were valid, with an effective rate of 95%. The question is divided into three parts and is distributed to children aged 3-6 and their accompanying parents. The questionnaire consists of three parts. Part 1 is a preference selection question, which includes children's preferred outdoor play space types, activity formats, and activity

types, as well as their desired improvements to the park to enhance play experience. The results of the preference survey are combined with observational records of children's behavior. Part 2 is a rating scale, which evaluates three qualitative factors of the overall park's appeal: the facility color aesthetics (C4), the comfort of landscape features (C7), and site theme storytelling (C13). A Likert scale is used, and to help children better understand, the importance is converted into a level of liking, using five levels: very dislike, dislike, neutral, like, and very like. Part 3collects basic information about the survey participants, including the frequency and duration of children's visits to the park, as well as the relationship between the accompanying parents and children.

(2) Reliability test. The reliability of the scale and data was primarily assessed using Cronbach's α as the main testing method. Analysis showed that the overall Cronbach's α value of the scale was 0.930. Among them, the α value of the facility color aesthetics C4 was 0.865, the α value of the comfort of landscape features C7 was 0.933, and the α value of the site theme storytelling C13 was 0.941, indicating that the questionnaire has good overall reliability.

1.2.2 PSPL survey method

The PSPL (public space & public life survey) method focuses on people and their activities in public spaces. It consists of three parts: public space analysis, public space life survey, and summary and recommendations. Four main methods complement each other: map marking, on-site counting, field investigation, and interview [17]. Considering the large number of child tourists during holidays, and to facilitate the survey, the time was selected from four weekends in September 2022, totaling eight days. Three time periods with the largest number of child tourists were selected: morning (10:00-12:00 am), afternoon (14:00-16:00 pm), and early evening (16:00-18:00 pm). On the one hand, the survey on children's activities served as an important basis for the preliminary designation of 29 activity sites and the selection of evaluation factors. Activity preferences were investigated using behavior mapping, with records taken every half hour and each observation lasting 10 minutes. Record the children's activities (such as running, jumping, kicking a ball, taking photos, etc.) and the distribution of the number of children within 10 minutes; on the other hand, conduct a spatial environment survey as a data source for later evaluation. Based on satellite maps, we conducted on-site surveys of the current status of 29 activity sites, including site layout, facilities (play equipment, rest seats, supporting service facilities, etc.), and spatial characteristics (size, paving patterns, terrain variation, plant enclosure, etc.). Based on the survey results, the characteristics of each activity site were statistically analyzed. At the same time, random interviews were conducted with accompanying parents to understand their attitudes toward enjoying comprehensive parks and the perceived influencing factors (such as facilities and environmental conditions). These interviews supplemented the survey, providing substantial data support and a solid descriptive foundation for children's evaluation of the enjoyment of comprehensive parks.

1.2.3 Cat's Eye Quadrant mini program

Based on image recognition technology, the location is located, photos are taken, and indicators are calculated within the program[18]. Using the WeChat mini-program "Cat's Eye Quadrant", photos of 29 sample sites were taken and uploaded to mark the activity space locations accurately. The mini program automatically calculated the visible green index of each node, which corresponded to the uploaded on-site photos [19].

1.2.4 Correspondence analysis

Using SPSS software, based on the decomposition and contribution of chi-square statistics, an interactive contingency table was constructed for the types of enjoyment activities and environmental factors, and a two-dimensional correspondence diagram was generated in the form of points to intuitively reveal the correspondence between the three enjoyment activities and the five environmental factors [20].

2 Determination of evaluation factors of enjoyment based on the behavioral psychology of preschool children

2.1 Behavioral and psychological characteristics of preschool children

Psychologist Jean Piaget's theory of cognitive development refers to the preschool stage as the "intuitive operational stage". Children at this stage exhibit a certain degree of independent activity and thinking ability, and their emotions and cognitive development progress rapidly [21]. This is mainly reflected in the development of cognition, emotion, sociality, and personality (Table 1).

Table 1 Behavioral and psychological characteristics of preschool children

Cognitive development	Utilize various senses to better form concrete image perception.
Emotional development	Generate emotional responses and store them in memory. In this process, the most immediate emotions that arise are curiosity and a sense of mystery.
Social development	Behavioral activities and social interactions, among which peer interaction is a very common social activity for preschool children.
Personality development	Children develop emotions and personalities through activities, which prevents them from becoming withdrawn.

2.2 Types of enjoyment activities

Play is an integral part of children's development. Rubin developed the Play Observation Scale (POS) to describe game levels: social play behavior and cognitive play behavior, where social play behavior emphasizes collective participation and cognitive play behavior emphasizes construction and exploration [22]. The enjoyment activities for preschool children in comprehensive parks are conducted in the form of games. Based on Rubin's Play Observation Scale and combined with field research, the activities are supplemented with physical play behaviors, emphasizing physical training. Finally, the enjoyment activities that children engage in at the park were screened and summarized (Figure 3) and categorized into three types: movement-based, perception-based, and social.

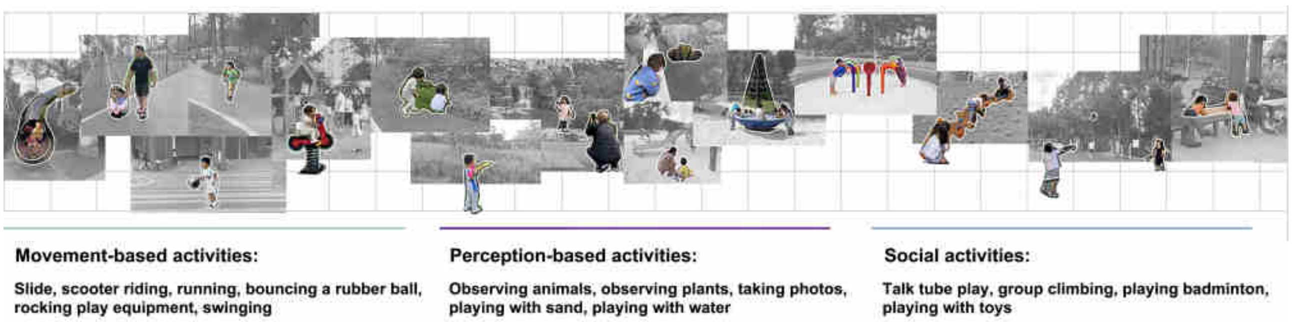

Figure 3 Types of enjoyment activities

2.3 Types of enjoyment elements in comprehensive parks

Based on the behavioral and psychological characteristics and activity types of preschool children, we analyzed the environmental factors that influence the occurrence of enjoyment activities, established a connection between enjoyment activities and space sites, and classified the enjoyment elements of comprehensive parks into perception-based, movement-based, and social types (Table 2).

Table 2 Types of enjoyment elements in comprehensive parks

Perception-based enjoyment elements	Including perceptual activities in both natural and artificial environments, as well as artificially designed facilities that trigger children's senses.
Movement-based enjoyment elements	Facilities or sites that meet the needs of movements can encourage children to participate in sports and improve their physical fitness.
Social enjoyment elements	Environmental factors that promote parent-child interaction or peer interaction, including space sites and activity facilities.

2.4 Evaluation factors of enjoyment of comprehensive parks

Based on preliminary literature screening, questionnaire statistics, and field research, the environmental factors affecting the enjoyment of comprehensive parks are ultimately categorized into 14 evaluation factors across five dimensions: space, facilities, plant configuration, waterscape design, and landscape culture (Figure 4).

3 Construction of an evaluation system of enjoyment

3.1 Classification ofactivity sites

Based on spatial characteristics, the activity sites for preschool children in the park are classified into different types (entrance, park path, plaza, children's activity area, fitness area, pavilion, etc.). Based on the road network, the zones were numbered, and the types of sites in each zone were counted, totaling seven categories and 29 activity sites (Figure 5).

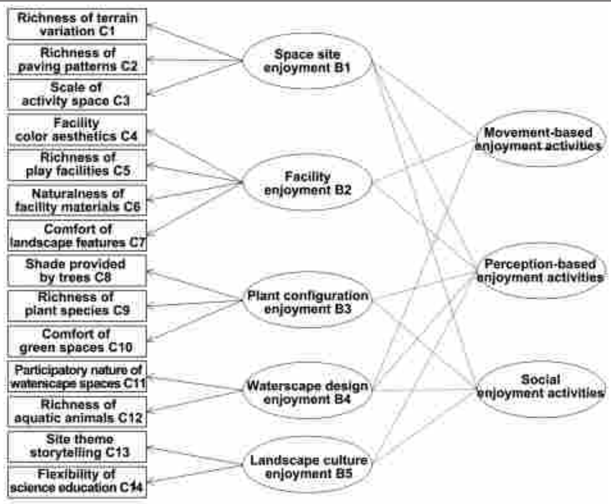

Figure 4 Evaluation factors of enjoyment

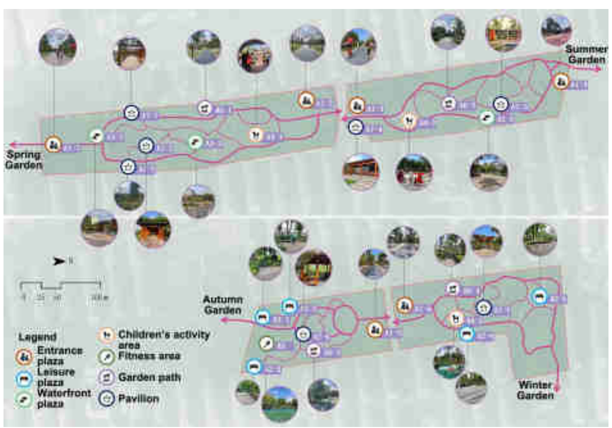

Figure 5 Plan distribution of activity sites in the comprehensive park

3.2 Evaluation model construction

3.2.1 Single-factor assignment criteria

It is divided into three layers: the target layer, the criterion layer, and the factor layer. The target layer is the evaluation of enjoyment of comprehensive parks based on preschool children's behavioral psychology. The criterion layer comprises five design dimensions that impact the enjoyment of comprehensive parks. The factor layer refers to 14 evaluation factors that affect enjoyment from different dimensions. The environmental factors affecting the enjoyment of comprehensive parks are divided into 14 evaluation factors from five dimensions: space, facilities, plant configuration, waterscape spaces, and landscape culture. The three qualitative evaluation factors include: the facility color aesthetics (C4), the comfort of landscape features (C7), and the site theme storytelling (C13). For qualitative evaluation factors, a Likert scale scoring method was used to assign values, with values of 5, 4, 3, 2, and 1 points assigned from highest to lowest. The 11 quantitative evaluation factors include: richness of terrain variation (C1), richness of paving patterns (C2), scale of activity spaces (C3), richness of play facilities (C5), naturalness of facility materials (C6), shade provided by trees (C8), richness of plant species (C9), comfort of green spaces (C10), participatory nature of waterscape spaces (C11), richness of aquatic animals (C12), and flexibility of science education (C14). For quantitative evaluation factors, their scores are mapped to 1-5 points according to specific data standards (Table 3).

3.2.2 Construction of comprehensiveevaluation models

Ten experts, scholars, and children's space designers were invited to fill out a judgment matrix. Each factor was compared pairwise using a scale of 1 to 9 to quantify the relative importance of the two factors. Use the YAAHP software to calculate the weight scores. After obtaining the weight results, CR= CI/RI is used to perform a consistency test on the weights of each criterion layer and factor layer to ensure logical consistency and model validity (CI < 0.1). The final ranking weights of index factors for evaluating the enjoyment of comprehensive parks, based on the behavioral psychology of preschool children, were determined (Table 4).

Based on the weights of the factors at each level determined above, the comprehensive evaluation model for the enjoyment of comprehensive parks is as follows:

$$B = \sum_{i=1}^{n} a_i r_i$$

In the formula: B is the comprehensive evaluation value of the enjoyment of comprehensive parks; B is the weight of the evaluation factors; r_i is the rating score of the evaluation factor.

3.2.3 Classification of enjoyment levels

Based on the evaluation scores, the enjoyment level of comprehensive parks is divided into four levels: Level I (Excellent), Level II (Good), Level III (Average), and Level IV (Poor) (Table 5), which reflects how well comprehensive parks meet the enjoyment needs of preschool children.

Table 3 Definition of evaluation factors

Target layer	Criterion layer	Factor layer	Meaning and scoring criteria of the factor layer
Evaluation system of enjoyment of comprehensive parks based on preschool children's behavioral psychology A	Space site enjoyment B1	Richness of terrain variation C1	Terrain variations (including hills and sunken spaces). 1= Basically flat; 2= 1 change; 3= 2 changes; 4= 3 changes;5= There are 4 or more changes [27].
		Richness of paving patterns C2	1= No variation in paving; 2= 2 variations in paving; 3= 3 variations in paving; 4= 4 variations in paving; 5= 5 or more variations in paving [27].
		Scale of activity spaces C3	The number of people allowed to participate in activities simultaneously within the plaza space. 1= For1 person only; 2= Provides space for 2 people; 3= Provides space for 4 people or two small groups; 4= Provides space for 6 people or 4 small groups; 5= Can provide activity space for 8 or more people or 4 or more groups [23].
	Facility enjoyment B2	Facility color aesthetics C4	The pleasant and comfortable feeling brought by the color of the facility's exterior. 1= Disharmonious colors; 2= Dull colors; 3= Mediocre colors; 4= Rich colors; 5= Bright, cheerful, and comfortable colors[27].
		Richness of play facilities C5	The following types of facilities are included: swinging, climbing, rotating, sliding, suspended, crawling, walking/running, and jumping. 1= 1 type; 2= 2-3 types; 3= 4-5 types; 4= 6-7 types; 5= 8 types or more[23].
		Naturalness of facility materials C6	The quantity and distribution of natural materials (wood, fruit, branches/bark/leaves, wood chips, grass, stone, water, sand, moss, soil, etc.) used. 1= Present in some areas or not present in any area, using 0-1 methods; 2= Present in some areas, using 2 methods; 3= Present in all areas, using 1-2 methods; 4= Present in all game areas, using 3-4 methods; 5= Present in all areas, using 5 or more methods [23].
	Plant configuration enjoyment B3	Comfort of landscape features C7	The novelty and aesthetic appeal of the landscape features. 1= Landscape features are dilapidated and have disharmonious colors; 2= Landscape features are monotonous and damaged, with relatively disharmonious colors and relatively poor materials; 3= Landscape features are of average appearance, color, and materials; 4= Landscape features are relatively interesting, have relatively beautiful colors, and use relatively novel materials; 5= Landscape features are interesting, have beautiful colors, and use novel materials [27].
		Shade provided by trees C8	The shades provided by tree canopies, and their scale and the extent of shaded coverage 1= None; 2 = Yes, but located on the edge of the site; 3= Yes, but it surrounds the entire edge area of the site; 4= distributed in some areas inside the site; 5= distributedin the whole area inside the site [23].
		Richness of plant species C9	Measured by the diversity index. The number of species in a site of aspecific size is defined as the diversity index. The higher the index, the better the richness. $R = (S-1)/\ln N$ (S: number of species; N: total number of trees), scored from 1 to 5 based on the diversity index.[24].
	Waterscape design enjoyment B4	Comfort of green spaces C10	The level of comfort brought about by the greening effect. The Cat's Eye Quadrant mini-program calculatesthe visible green index. The higher the percentage (x) of green in the field of vision, the higher the score. When $x < 5\%$, 1 point is awarded; when $5\% \leqslant x < 15\%$, 2 points; when $15\% \leqslant x < 25\%$, 3 points; when $25\% \leqslant x < 15\%$, 4 points; when $x > 35\%$, 5 points [19].
		Participatory nature of waterscape spaces C11	Participate in (touchable) water activities. 1= No water body; 2= Water body present, but no water activities allowed; 3= Water body present, water activitiespermitted on the shore (e.g., watching fountains and swans); 4= Water body present, water activities allowed (e.g., fishing, catching tadpoles); 5= With a body of water, one can flexibly and freely participate in and carry out water-related activities [25].
		Richness of aquatic animals C12	Animal species that can be observed/contacted in the water. 1= None; 2= Observable/Contact with 1 type; 3= Observable/Contact with 2 types; 4= Observable/Contact with 3 types; 5= Can contact/observe 4 or more types [23].
	Landscape culture enjoyment B5	Site theme storytelling C13	The concept story is combined with landscape expression methods, making it the guiding principle of the design. 1= No theme story; 2= Theme story, but incomplete; 3= Has a complete theme story; 4= Has a complete theme story that is integrated with the function of the venue; 5= Has a complete theme story that is both educational and entertaining [26].
		Flexibility of science education C14	Popular science education activities take many forms and are rich and interesting in content (including plant information boards, regular flower shows, tree planting in parks, and sculpture information boards). 1= None; 2= There is 1 type; 3= There are 2-3 types, but not complete; 4= There are 2-3 types, and relatively complete; 5= There are 4 or more types [26].

Table 4 Weights in the evaluation system of enjoyment in comprehensive parks

Target layer	Criterion layer	Criterion layer weights	Factor layer	Factor layer weights	Factor layer normalization Weighting
Evaluation System of Enjoymentof Comprehensive Parks based on the behavioral psychology of preschool children A	Space site enjoyment B1	0.4706	Richness of terrain variation C1	0.2583	0.1216
			Richness of paving patterns C2	0.1047	0.0493
			Scale of activity spaces C3	0.6370	0.2998
	Facility enjoyment B2	0.2999	Facility color aesthetics C4	0.2331	0.0699
			Richness of play facilities C5	0.0846	0.0254
			Naturalness of facility materials C6	0.0773	0.0232
			Comfort of landscape features C7	0.6050	0.1814
	Plant configuration enjoyment B3	0.0901	Shade provided by trees C8	0.6491	0.0065
			Richness of plant species C9	0.0719	0.0585
			Comfort of green spaces C10	0.2790	0.0251
	Waterscape design enjoyment B4	0.0901	Participatory nature of waterscape spaces C11	0.8333	0.0751
			Richness of aquatic animals C12	0.1667	0.0150
	Landscape culture enjoyment B5	0.0492	Site theme storytelling C13	0.2500	0.0123
			Flexibility of science education C14	0.7500	0.0369

Table 5 Standards for classifying the enjoyment level of comprehensive parks

Score	4.0< Y≤5.0	3.0< Y≤4.0	2.5< Y≤3.0	1.0≤Y≤2.5
Enjoyment level	Level I (Excellent)	Grade II (Good)	Level III (Average)	Grade IV (Poor)

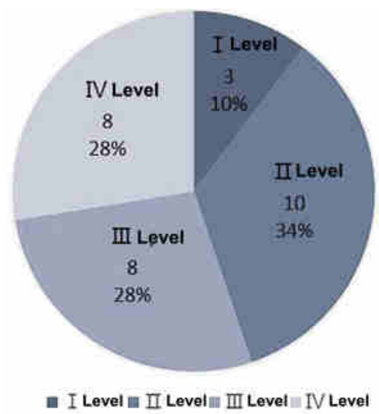

Figure 6 Distribution of the number of activity sites at different levels of enjoyment

4 Analysis of the enjoyment of space sites

4.1 Comparative analysis of overall levels of enjoyment evaluation

The evaluation scores show that there are three sites with an overall enjoyment rating of Level I, accounting for 10%; 10 sites with a rating of Level II, accounting for 34%; and eight venues with a rating of Level III and Level IV, each accounting for 28% (Figure 6). The average enjoyment score for the 29 activity venues was 3.0440, indicating that the overall enjoyment level of the activity venues in the park was relatively good. The highest score was 4.5658, and the lowest score was 2.3638 (Figure 7), indicating significant differences in enjoyment levels among different activity sites.

4.2 Comparison of the enjoyment levels of different types of activity sites

The analysis and evaluation results show that the children's activity area scored the highest at 4.5225, followed by the fitness area, waterfront plaza, pavilion, entrance plaza, and leisure plaza in descending order. The garden path scored the lowest at 2.4652 (Figure 7). All three children's activity areas scored highly, featuring ample space, comfortable greenery, and varied terrain; the tailor-made theme park stories were well-matched with thesites and facilities. Among the six entrance plazas, A1-3, A1-5, and A1-6, which scored higher, were more open and suitable for activities, while A1-1, A1-2, and A1-4, which scored lower, were smaller and lacked activity space and facilities. The seven pavilions showed significant differences in scores; A7-1, A7-2, and A7-3 were adjacent to the water, offering expansive views and high levels of greenery comfort; A7-4, A7-5, A7-6, and A7-7 were hidden deep in the woods, with smaller spaces and simpler facilities. The three waterfront plazas also showed significant differences in scores. The areas are relatively large. A3-1 is quite large, with ornamental animals such as swans and goldfish in the water. A3-3 has a wide view, pleasant greenery, and a fountain. Although A3-2 has comfortable greenery, the space is small and lacks interactive water features. A5 is the only fitness area in the park and scores highly. It is open, surrounded by trees, and has new and complete supporting facilities, meeting the needs of ball games. The five leisure plazas all scored low. These areas are generally small in scale, mostly with rest seats, lacking activity space, and lacking variation in paving and terrain. The four garden paths all scored low. They have high comfort and protection, but are narrow and lack variation, have a monotonous visual experience, and lack space to accommodate activities.

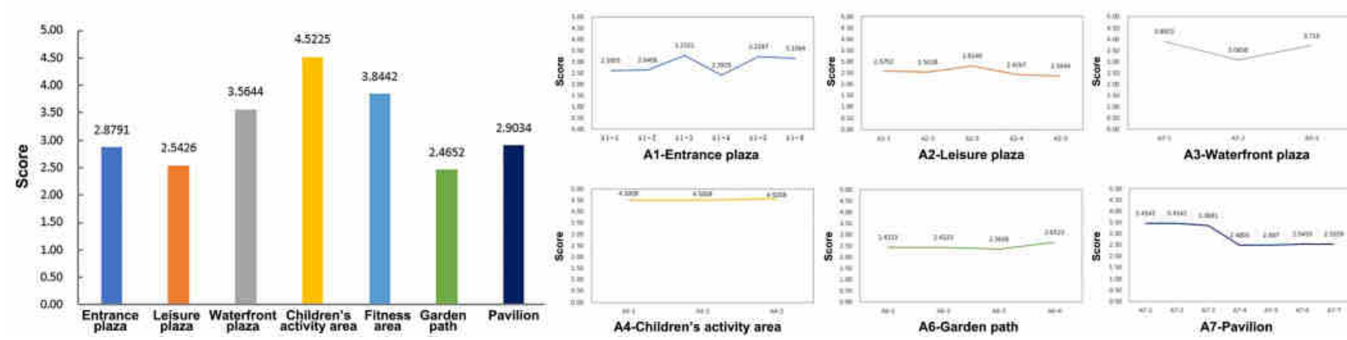

Figure 7 Comparison of the enjoyment levels of different types of activity sites

4.3 Correspondence analysis between types of enjoyment activities and influencing factors

A correspondence analysis was conducted between three types of enjoyment activities for preschool children and five environmental factors in Pengpu Four Seasons Park. The chi-square value was 38.346, and the significance level was sig= 0.000 ($P < 0.01$ indicates an extremely significant difference). This indicates that the types of enjoyment activities and environmental factors are not completely independent and have a certain correlation.

Overall, different types of enjoyment activities show different correspondences with the environment (Figure 8). The correspondence between different types of enjoyment activities and facilities is relatively small. The preference for these environmental factors among the three types of enjoyment activities is ranked as follows: movement-based > social > perception-based. Movement-based enjoyment activities are closer to spatial factors, meaning they tend to favor spatial factors and have a higher demand for spatial scale and richness. Perception-based enjoyment activities are closer to two environmental factors: plant configuration and landscape culture, meaning they are more dependent on plant configuration and landscape culture. Social enjoyment activities are closer to waterscape factors, meaning they have a strong preference for water features. Interactive and nature-friendly water features are more conducive to social-based recreational activities.

4.4 Comparative analysis of the enjoyment levels of single-factor activity sites

The comparison of single-factor enjoyment scores for different types of activity sites (Figure 9) shows that C4, C7, C8, and C10 all scored relatively high in different sites; C1 and C13 scored relatively high in the children's activity area, while the other six types of spaces did not show much difference; C2, C3, C5, C6, C9, C11, and C12 showed significant differences in scores in different sites; and C14 scored relatively low in all different sites. This indicates that different space types vary significantly in terms of the appeal of the space sites, facilities, plant configuration, waterscape design, and landscape culture. The children's activity area and fitness area performed well in terms of space, facilities, and plants; the entrance plaza scored highly in terms of space and facilities; the waterfront plaza performed excellently in terms of water features and plants; the garden paths, leisure plazas, and pavilions showed similar scoring trends, performing well in terms of plants, but exhibiting shortcomings in terms of space and facilities.

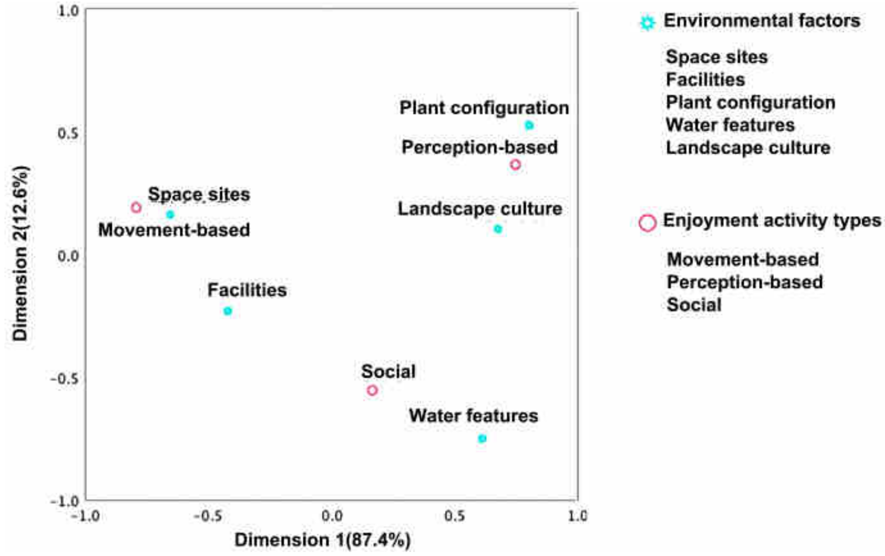

Figure 8 Correspondence analysis between types of enjoyment activities and environmental factors

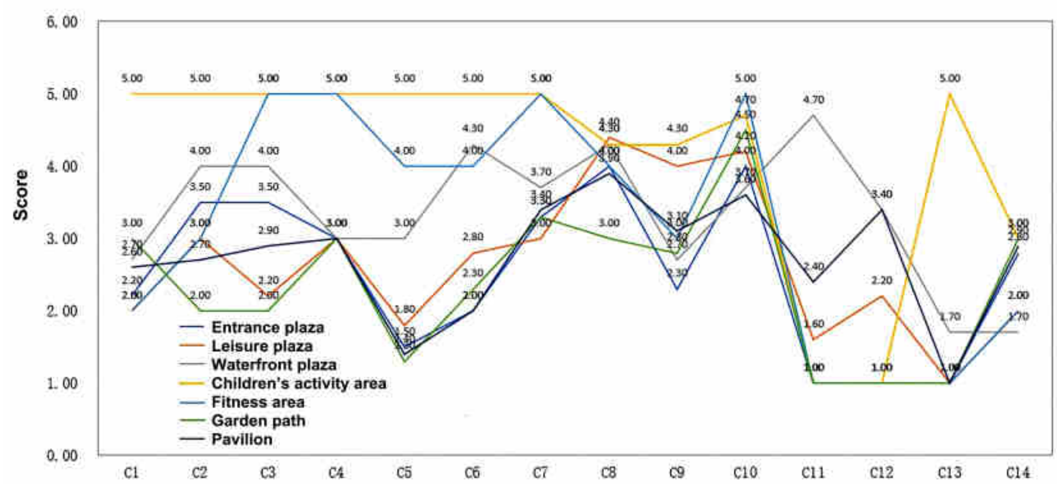

Figure 9 Comparison of single-factor enjoyment scores for different types of activity sites

Based on the comparison of single-factor enjoyment scores (Figure 10), the enjoyment of Pengpu Four Seasons Park exhibits the following characteristics: In terms of space, the paving patterns are diverse, the space is ample, and the terrain variation is average; in terms of facilities and small features, the colors are beautiful, the landscape is comfortable, the degree of differentiation is small, and the richness and naturalness are average; in terms of plant configuration, the plant species are abundant, and the greenery is comfortable; in terms of waterscape design, it is concentrated on the central water surface, which is relatively small compared to the entire park, and there is insufficient interaction with the water; in terms of landscape culture, popular science education on natural and humanistic knowledge is widely distributed, while site theme storytelling is only fully reflected in the children's activity area.

5 Basic principles and design strategies for enhancing enjoyment

5.1 Basic principles

5.1.1 Security principle

Safety is the prerequisite and guarantee for enjoyment. Through word frequency analysis of interviews with parents, we learned about their emphasis on park safety. On the one hand, children are vulnerable to risks and are easily harmed; on the other hand, with the post-pandemic era, the public's awareness of public health and safety has increased. Therefore, design and guidance should be strengthened, and spaces such as garden paths and waterfronts should be rationally laid out. Facilities should be designed with safety and sturdiness as the basic standard, and daily disinfection during use should be taken into consideration.

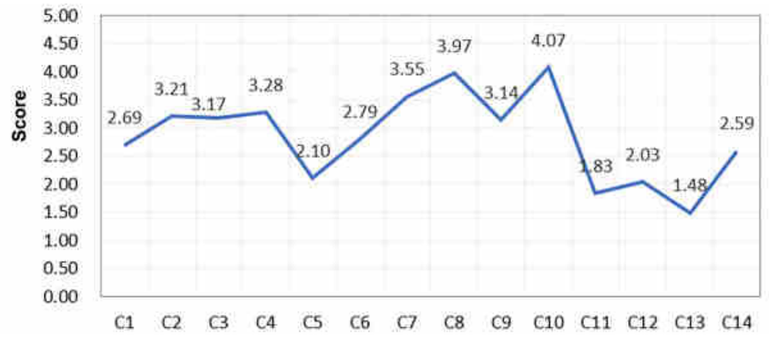

Figure 10 Comparison of single-factor enjoyment scores

5.1.2 The principle of children's participation in co-creation

Children's ideas should be incorporated into the entire process of park construction. Research has found that children's expectations of a space are often replaced by the adult perspectives of guardians and designers, resulting in park spaces becoming passive "cramming" spaces. From design and construction to operation, we should encourage and guide children to participate in expressing their needs and making joint decisions, understand their true demands from their perspective, and protect their right to participate.

5.2 Design strategies

5.2.1 The space sites meet the needs of the activities.

Based on the behavioral and psychological characteristics of preschool children, the following aspects should be considered to optimize the enjoyment of the space. Firstly, design friendly spaces that foster companionship. Preschool children often ignore their surroundings during activities, exhibiting a form of "egocentrism," which also means they require the presence of guardians. Therefore, parents become another major user group, and the design should consider a space that is friendly to accompanying children. Secondly, provide spaces for individual performances. The personalities of preschool children develop rapidly, and they often have a strong desire to express themselves. By designing a "small stage" suitable for performance, we can encourage them to showcase their talents and promote their personal growth and development. Thirdly, optimize the space for interaction with peers. The social development of preschool children is mediated by behavioral activities and social interactions. The design should take into account the number of players and the scale of activities, and encourage children to participate in different types of games with different numbers of players (Figure 11).

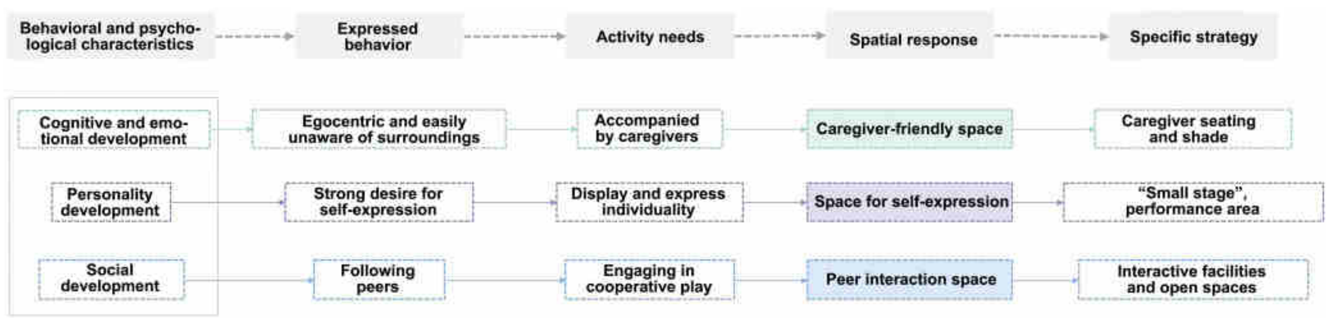

Figure 11 Spatial optimization strategy based on behavioral and psychological characteristics

5.2.2 Facility features integrate natural elements

Comprehensive parks are vital places for children to connect with nature and learn about the natural world. Materials such as flowing water, gravel, plants, wood, and stones will add natural interest to the play area. In the design, natural elements are incorporated to simulate natural surroundings, thereby blurring the boundary between natural and artificial environments, and allowing children to connect with nature (Figure 12). This approach encourages them to engage with the natural environment in a fun and engaging way, guiding them to explore and understand the natural world.

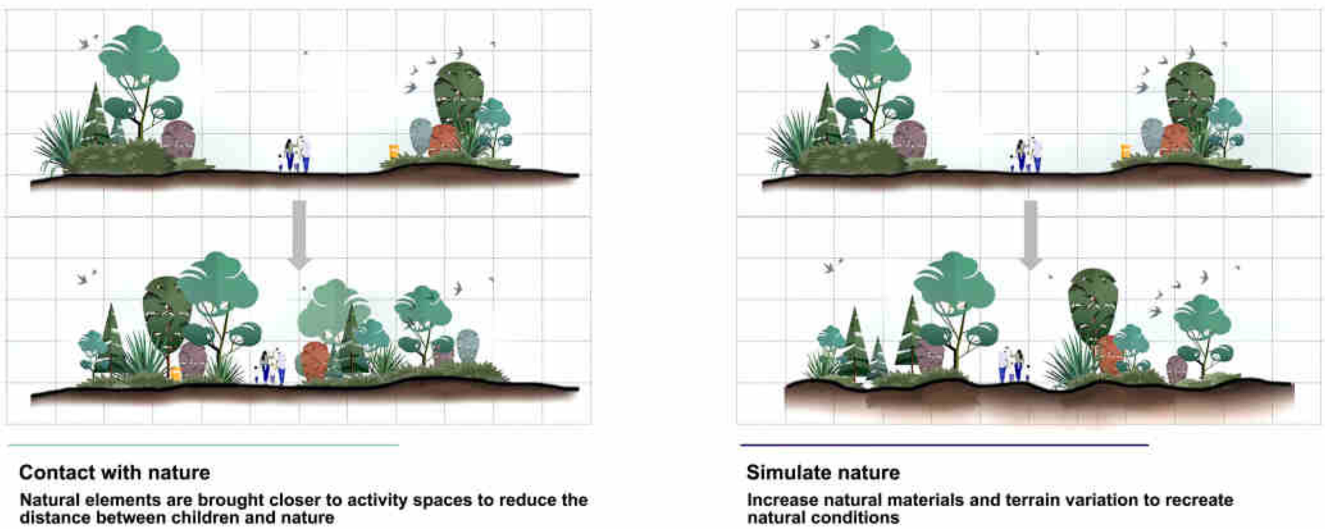

Figure 12 Naturalness Optimization Strategy

5.2.3 Waterscape design promotes perceptual interaction

Preschool children enjoy water-interaction spaces that provide enjoyment and opportunities for social play. Diverse water-related activities, aquatic organisms, and the varied forms and dynamics of water features can satisfy children's curiosity. Watching animals near the water or playing in shallow water are both ways that children enjoy interacting with water. While ensuring safety, we should actively provide children with suitable watergames and interactive spaces through environmental landscapes and facilities.

6 Conclusion anddiscussion

6.1 Conclusion

The construction of child-friendly cities in China has gradually shifted from theoretical research to practical exploration. As important public spaces for urban children to have contact with nature and engage in outdoor activities, comprehensive parks should give special consideration to the needs of children.

Based on the behavioral and psychological characteristics of preschool children, this study conducted field investigations on 29 sample sites in Pengpu Four Seasons Park, analyzing children's activity preferences and the environmental factors influencing park enjoyment. From a behavioral psychology perspective, park enjoyment and enjoyment-related activities were corresponded and categorized into three types—movement-based, perception-based, and social enjoyment activities—and the relationships between enjoyment activities and environmental factors were further examined. From five dimensions—space, facilities, plant configuration, waterscape design, and landscape culture—an evaluation model for enjoyment in comprehensive parks was established using the Analytic Hierarchy Process (AHP). Multiple data collection and processing methods, including the Public Space & Public Life (PSPL) survey and the "Cat Eye Quadrant" mini-program, were applied to assess the enjoyment within the sample spaces. Finally, targeted optimization strategies are proposed to address insufficient spatial interaction, limited richness of landscape features and facilities, and inadequate natural science education. The suggestions emphasize respecting children's behavioral psychology, encouraging child participation in spatial creation, and enhancing the naturalness and safety of the space sites, providing a valuable reference for child-friendly urban park planning and design.

6.2 Discussion

Children's activity needs and preferences in comprehensive parks are precisely a reflection of their behavioral psychology. Studying the relationship between children's activities and park enjoyment from a behavioral psychology perspective is more in line with the principle of building child-friendly cities that allows people to "see the city from a meter height," and it is also an advantage that distinguishes it from other studies. Preschool children are curious and tend to follow the crowd, making them easily attracted to their surroundings. This leads to children's activities in parks not being limited to a specific space, with no fixed activity area and relatively random movement routes. The study aims to explore the relationship between park enjoyment and children's activities; therefore, the functional differences between various sites within the park were not considered in this evaluation model.

Drawing on existing research, typical sample sites were selected and categorized to visualize spatial research. The conclusions regarding space sites, facilities, plant configuration, and landscape culture that affect the appeal of comprehensive parks are largely consistent with existing research, thus confirming the scientific validity of the study. Meanwhile, based on existing research, this study introduces the naturalness of materials into the evaluation system for comprehensive parks, supplementing existing research on the topic.

The limitations of this study lie in the subjective nature of investigating children's activity preferences, which is difficult to avoid completely. In addition, only one park was selected as the research subject, and the commonalities and differences among parks in different regions were not explored in depth. This aspect will be further addressed in the next stage of research.

Source of Figures and Tables

Figure 2: Redrawn by the author based on existing maps;
Figures 6-10: Drawn by the author based on the analysis results;
Figures 1, 3-5, 11-12, and Tables 1-5: Drawn or photographed by the author.

Notes

1)Data are sourced from the Statistical Communiqué of the People's Republic of China on the 2021 National Economic and Social Development. (http://www.gov.cn/xinwen/2022-02/28/content_5676015.htm)
2) http://www.gov.cn/zhengce/zhengceku/2021-10/21/content_5643976.htm.
3) https://fgw.sh.gov.cn/sswghgy_zxghwb/20210716/264e9863ef354fe68ad18e244bca8b67.html.
4) https://www.nwccw.gov.cn/2022-09/19/content_305678.htm.
5) https://m.gmw.cn/baijia/2020-09/29/1301619430.html.

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Genetic Information Coding and Mapping of Traditional Settlement Landscapes in Northern Shaanxi

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ABSTRACT: Traditional settlements represent typical rural landscapes that have emerged from specific historical and cultural backgrounds. They are also important spatial carriers for the transmission of regional cultural heritage. As the historical source of traditional Chinese culture, traditional settlements exhibit stable and harmonious development, with unique features. The Loess Plateau in China nurtures the unique cave dwelling culture of northern Shaanxi. It is characterised by distinct architectural features such as traditional cave dwellings. However, the cave settlements in northern Shaanxi, which exhibit Chinese culture, face a habitat crisis due to rapid urbanisation. Based on the kernel density distribution of traditional settlements in Shaanxi Province, one of the core distribution zones centred at Suide County and Mizhi County appear in the Southeast region of Yulin City and the eastern region of Yan'an City. It is a major distribution zone involving cave settlements and their characteristic landscapes. Settlements mainly extend along river valleys and gullies, accompanied by water and soil loss as well as harsh ecological environment. However, it is marked by a severe shortage of construction land and narrow space for development. Over the years, the hills and gullies of the Loess Plateau in northern Shaanxi constrained the development of settlements in the region. Therefore, the traditional settlements in the Loess hills and gullies of northern Shaanxi were selected for further investigation. Landscape genetics and construction mapping were studied by combining with local settlement status. Appropriate protection and inheritance mechanisms of traditional settlements in Shaanxi Province were analysed.

Based on the theory of landscape genetics, 46 national traditional settlements in northern Shaanxi were selected. First, the typology of traditional settlement was used to establish landscape gene information codes in northern Shaanxi. The numerical codes of "Shaanxi E-M1/2- XXXX" were acquired using the combination of "area code + gene category code + Class-1 element + Class-2 element + Class-3 element + landscape gene element". Second, further analysis revealed that the traditional settlements in northern Shaanxi were mainly based on family inheritance and small-scale peasant economy, and depicted in terms of location layout, clansman and residential buildings. Hence, the genetic pedigree of traditional settlements in the region can be built by combining internal and external environmental elements, information associated with traditional residential and subjective public buildings as well as landscape genes with similar cultural significance, that is, the "A+ B+ C+ D" mode. Third, this study presents the material landscape map of cave settlements in northern Shaanxi symbolically and provides a two- and three-dimensional graphical expression of landscape elements including site selection pattern, spatial layout, street layout and architectural form of cave settlements in northern Shaanxi. The abstract symbols have been extracted based on morphological features and cultural connotation of elements, and abstract internal connotations based on graphical expression. Finally, a landscape gene map of 15 typical settlements in northern Shaanxi was built by combining with landscape gene code structure and extraction of landscape gene prototype.

Based on the results of landscape genetic analysis of traditional settlements in northern Shaanxi, this study explored the landscape gene code and established a landscape gene map. Results have practical implications for sustainable development of different types of traditional settlement and

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ecological restoration of traditional dwellings. Although the landscape genetic map of traditional settlements provides a practical basis for their historical and cultural transmission, genetic "mutations" and functional transformations within the settlements as well as new demands of local residents for modern living space after development over a long period have been identified. The hierarchy of regional characteristics and the delineation of settlement zones in the landscapes provides further direction for subsequent research. The findings provide a comprehensive insight into the natural and human characteristics of traditional settlements in a particular landscape and the construction of a regional landscape map eventually. This system provides a layer-by-layer analysis of specific areas using a set of maps. The hierarchical regional map corresponds to large areas, sub-areas, sub-sub-areas and even individual settlements in the traditional landscape systems. It not only facilitates a comprehensive, scientific and accurate understanding and representation of the unique characteristics of traditional settlement landscapes from a macroscopic to a microscopic perspective, but also enhances the analysis of traditional settlement landscapes in China.

KEY WORDS: northern Shaanxi; traditional settlement; landscape gene; genetic code; mapping

Introduction

As the historical source of the traditional culture of the Chinese nation, traditional settlements have maintained a stable and harmonious state of development, preserving their unique features.In China, the Loess Plateau has nurtured the unique cave-dwelling culture of northern Shaanxi. Traditional cave dwellings are the most distinctive architectural type on the Loess Plateau. However, amid rapid urbanization, the cave-dwelling settlements in northern Shaanxi, which embody Chinese culture, are facing a habitat crisis. Therefore, how to scientifically and effectively tap into the landscape genes of traditional settlements and ensure their inheritance and continuation has always been an essential topic of research at home and abroad.

Foreign scholars' research on traditional settlements has shifted from the development of settlement resources to the restoration and protection of settlement cultural landscapes [1]. The research content focuses on the inherent cultural genes of landscape features and has been applied to the study of specific spatial areas [2]. Domestic research results on the genetic information coding and mapping of traditional settlement landscapes are becoming increasingly abundant. From the perspective of specific research content, they can be divided into two levels: material and non-material. At the level of material landscape gene research, Liu Peilin, Hu Zui, and other scholars first divided the landscape system of traditional settlements from a national perspective, and further analyzed the practical significance of the genome mapping of traditional settlement landscapes [3]. Existing studies have conducted in-depth research on material landscape elements such as settlement environmental factors [4] and architectural factors [5], used field research [6], GIS spatial analysis [7], and other research methods, and combined interdisciplinary theories such as typology and geography to construct a traditional settlement landscape genome map [8]. At the level of non-material landscape gene research, traditional culture is the core element rooted in traditional settlements, and the customs, dialects, clans, and belief features [9] within the settlements are essential components of the settlement landscape features.

In summary, scholars at home and abroad generally agree that traditional settlement landscape genes share features with biological genes, both of which exhibit stable inheritance and individual variation. They have successively researched landscape gene identification and extraction, map construction, and the regional division of traditional settlements. However, current research on the internal structure among various elements of landscape genes is not systematic enough. In view of this, this study took 46 national traditional settlements in Yulin and Yan'an in northern Shaanxi as the research objects, took the theory of landscape genetics as the research perspective, and the landscape genetic information coding as the framework, combined with the results of the construction of landscape gene prototypes and landscape gene maps, to clarify the relationship between the various elements of traditional settlement landscapes in northern Shaanxi and provide new paths for its protection and development [10].

1 Areas in this research and data sources

1.1 Overview of the areas in this research

Administratively, northern Shaanxi includes Yulin City and Yan'an City, as well as 21 county-level regions, accounting for approximately 39% of the total area of Shaanxi Province. Except for Jingbian County, Dingbian County, Hengshan District of Yulin City on the southern edge of the Mu Us Desert, and Luochuan County on the border of the Loess Plateau, the remaining 17 counties are all located in theloess gully landform area. The total area is 43,578 km^2, accounting for 22.2% of the province's total area, and comprises 230 townships and 5,570 administrative villages.

Based onthe kernel density distribution of traditional settlements in Shaanxi Province (Figure 1), a core distribution zone centred at Suide County and Mizhi County appear in the Southeast region of Yulin City and the eastern region of Yan'an City. It is a major distribution zone of cave settlements and a typical region of cave settlement landscapes. The development of these settlements primarily extends along river valleys and gullies, areas that are simultaneously characterized by severe water and soil loss. The ecological environment is harsh, marked by a severe shortage of construction land and narrow space for development [11]. Over the years, the unique loess hilly and gully landform in northern Shaanxi has become the most significant impediment to settlement development in the region. Therefore, this paper selects traditional settlements in the loess hilly and gully area of northern Shaanxi as the research objects, conducts relevant research on landscape genetic information coding and mapping based on the current status of local settlements, and explores the direction of protecting and inheriting traditional settlements in this area.

1.2 Data source

The research samples in this paper mainly come from the 46 existing national traditional settlements in northern Shaanxi (Figure 2). These settlements have well-preserved historical features, which more completely reflect the production and living styles of the settlement residents and the regional spatial features; or they have unique spatial layouts and rich traditional residential buildings, whichpossess high protection and research value. This is of universal significance for the study of traditional settlements in northern Shaanxi [12]. These settlements have been successively included in the list of traditional villages, and their research value has been recognized. The historical and cultural customs of the villages are relatively complete, making it easier to conduct research.

The primary data sources of this study include literature materials and field surveys. The literature materials include Shaanxi Provincial Chronicles, traditional village atlases, traditional village planning texts, traditional village-related survey registration forms, and other research results related to Shaanxi's traditional settlements. In addition, the basic data for the northern Shaanxi region are sourced from the National Geomatics Center and the Geospatial Data Cloud. Remote sensing image data and contour terrain data are collected using software such as Google Earth, 91 satellite images, and Global Mapper. Thegraphs are drawn collaboratively using software such as AutoCAD, Photoshop, and Arc GIS.

2 Basis and process of constructing traditional settlement landscape gene maps

2.1 Traditional settlement landscape gene identification indicator system

Identifying the landscape genes of traditional settlements involves examining their essential features at the micro level. The article adopts the feature deconstruction extraction method proposed by Hu Zui [13], which divides the landscape of traditional settlements into two categories: material landscape genes (including environmental and architectural features) and non-material landscape genes (including custom, clan, dialect, and belief features), which are then further divided into six categories including 17 indicators (Figure 3).

2.2 Genetic information encoding of traditional settlement landscapes

To obtain a map of the traditional settlement landscape genes in a specific area, it is necessary to sort and encode the identified landscape genes, which involves arranging them in a logical order and constructing a landscape gene information coding structure. In the process of encoding landscape genes, the article applied typological principles and adopted coding techniques based on the*Chinese Library Classification* and the *Classification and Codes for Fundamental Geographic Information Feature*, and used the N-level coding theory to encode the landscape genetic information of traditional settlements in northern Shaanxi [14].

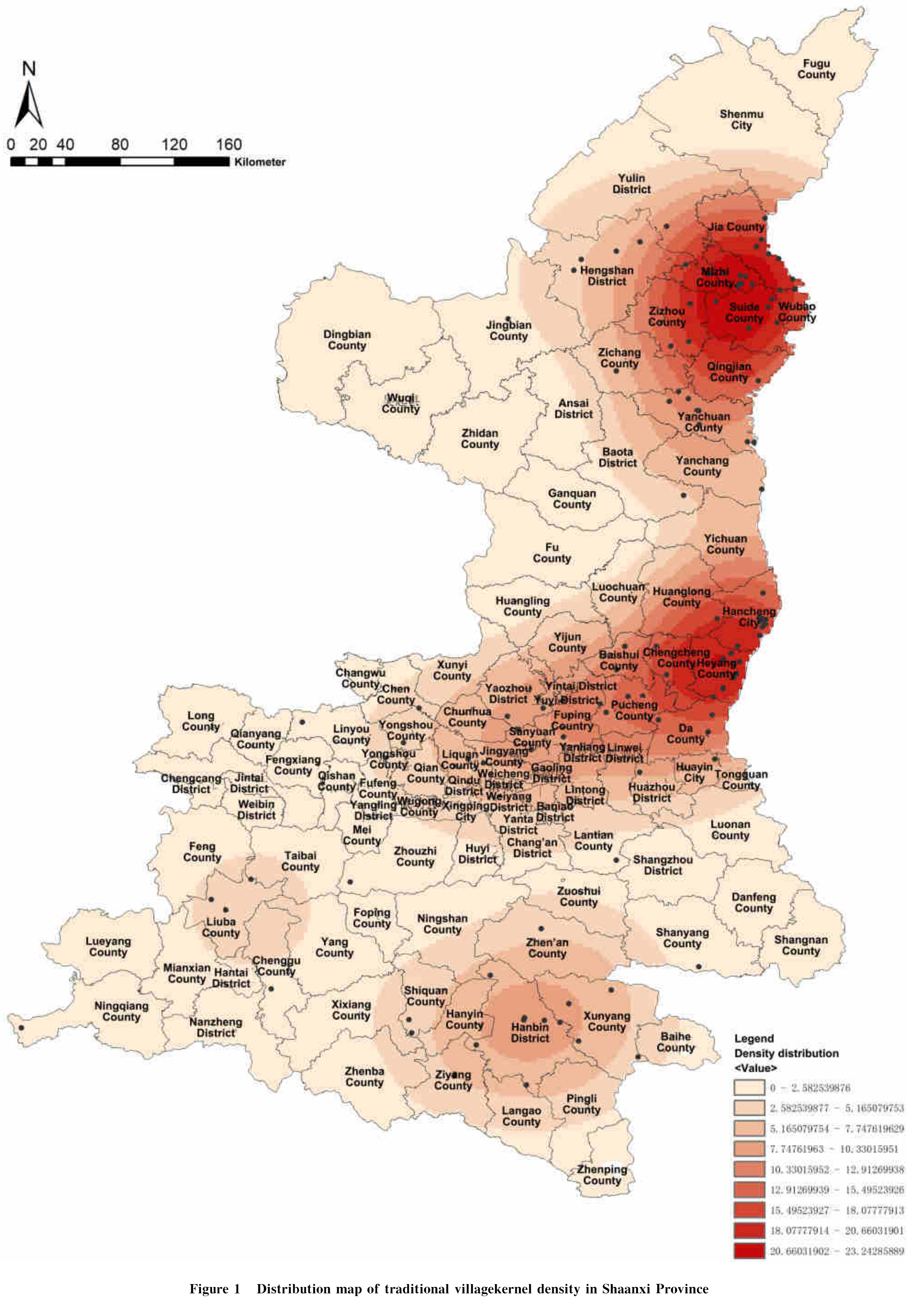


Figure 1 Distribution map of traditional villagekernel density in Shaanxi Province

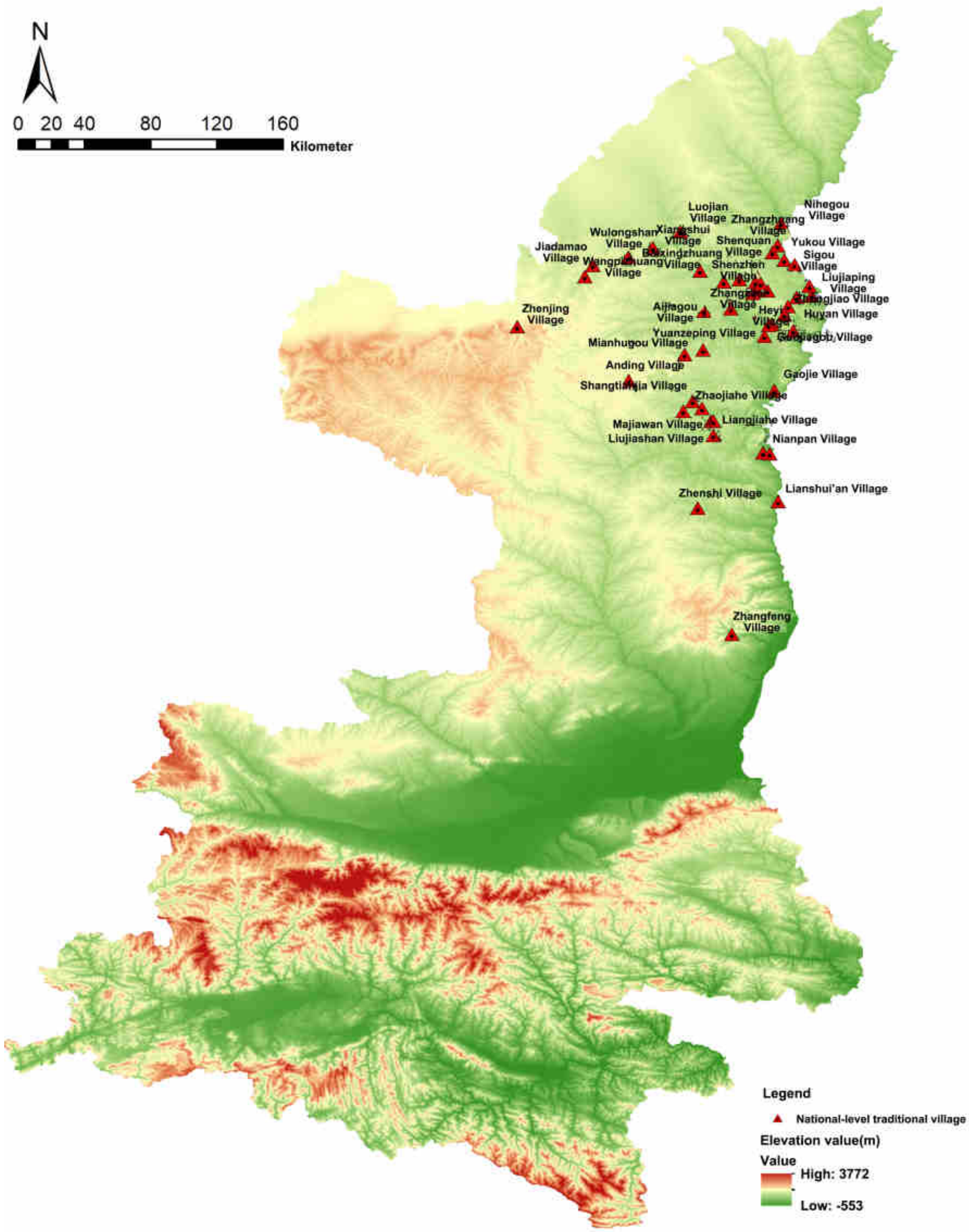


Figure 2 Spatial distribution of national-level traditional villages in northern Shaanxi

Taking northern Shaanxi as an example, the coding structure of landscape genes is divided into "area code + category code + feature code":①Area code: Northern Shaanxi is set to Shaanxi-E, where Shaanxi represents the Shaanxi region and E represents North; ②Category code: According to the "Meme" proposed by Dawkins, M is used to describe landscape genes, and according to the landscape gene identification index system, it is divided into M1 (material landscape genes) and M2 (non-material landscape genes); ③Feature code: The subordinate relationship of the landscape genes of cave settlements in northern Shaanxi is divided into four levels: " class-1 element, class-2 element, class-3 element, and landscape gene element". Each level is represented by a single digit and encoded using Arabic numerals (Figure 4). Through landscape coding, not only can the encoded traditional settlement landscape genes be identified, but also the classification and affinity between numerous landscape genes can be accurately determined.

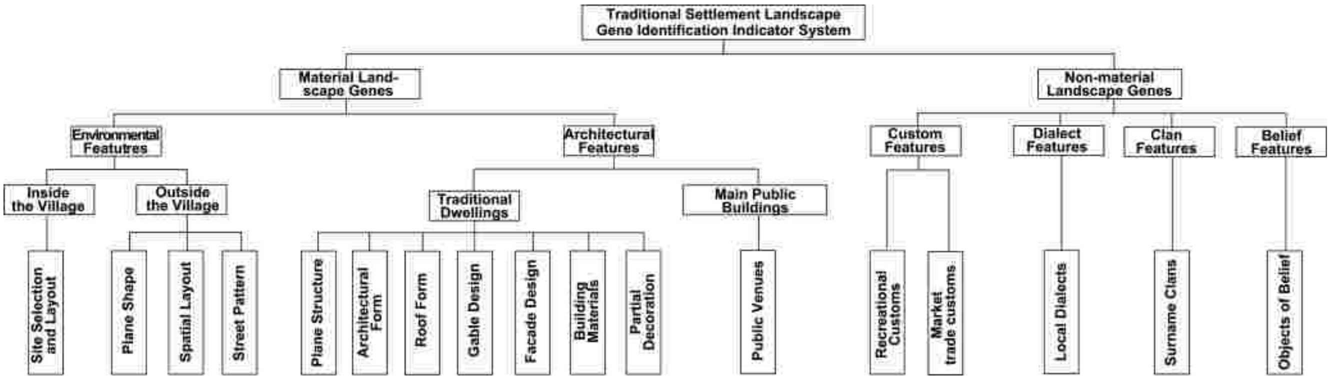


Figure 3 Traditional settlement landscape gene identification indicator system

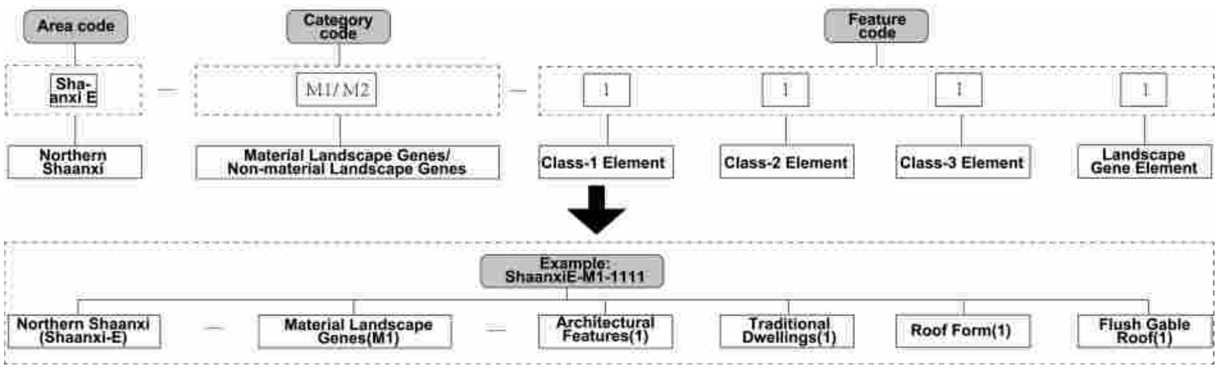


Figure 4 Genetic information encoding of traditional settlement landscapes

2.3 Construction of traditional settlement landscape gene maps

The construction of landscape gene maps involves using graphic language to comprehensively express and analyze the research object across temporal and spatial dimensions, thereby interpreting, classifying, and identifying it by disassembling and refining graphics or patterns [15]. The application paths of the mapping construction method mainly include landscape gene feature identification, landscape gene coding structure, and landscape map screening and reconstruction. The construction of traditional settlement landscape gene maps employs methods of abstraction, conceptualization, and typification. This method employs graphic language to explore, organize, classify, select, extract, and reorganize the fundamental features of traditional settlement landscapes, and then to interpret and express these features.

3 Genetic information coding structure of traditional settlement landscapes in northern Shaanxi

3.1 Genetic information coding of traditional settlement landscapes in northern Shaanxi

Through literature and field investigations, the traditional settlement typology is used to construct the genetic information coding of traditional settlement landscapes in northern Shaanxi. The specific structure of the digital code is "Shaanxi E-M1/2-XXXX" (Figure 5), which follows the format of "area code + gene category code + class-1 element + class-2 element + class-3 element + landscape gene element." According to the landscape genetic information coding structure diagram of traditional settlements in northern Shaanxi, its landscape genes are divided into two major categories: material landscape genes (M1) and non-material landscape genes (M2).

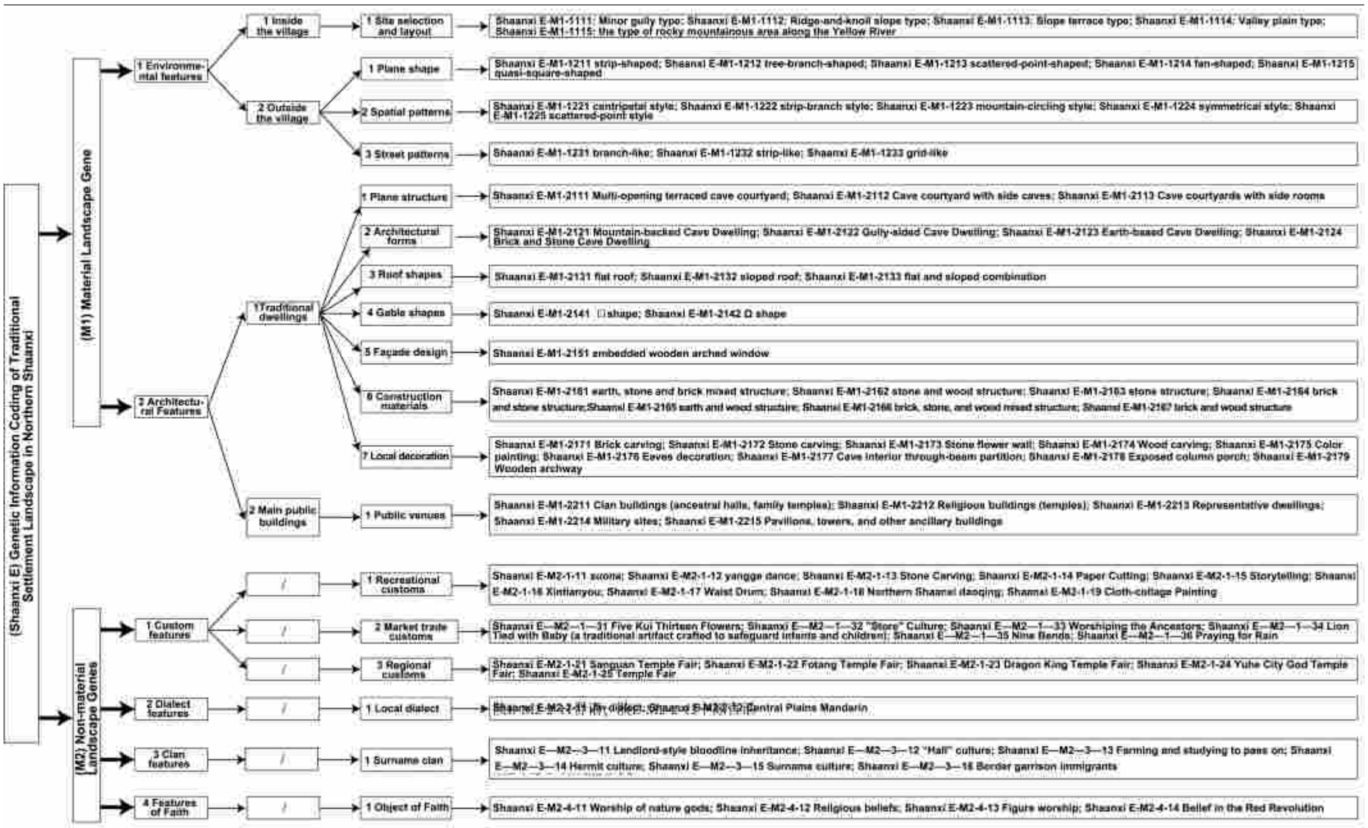


Figure 5 Genetic information coding of traditional settlement landscapes in northern Shaanxi

Among these, material landscape genes are divided into two categories: environmental and architectural features. (1) In terms of environmental features, cave settlements in northern Shaanxi are mainly located in the hilly and gully areas of the Loess Plateau and the rocky mountainous areas along the Yellow River. The plane forms of the settlements are mainly strip-shaped, tree-branch-shaped, scattered-point-shaped, fan-shaped, and quasi-square-shaped. The street patterns are mainly tree-shaped, strip-shaped, andgrid-shaped. (2) In terms of architectural features, ① traditional dwellings are mainly divided into seven categories based on their plane structures, building forms, roof and gable shapes, façade design, local decoration, and building materials. ② Main public buildings are primarily divided into five types: clan and religious buildings, representative dwellings, military sites, pavilions, towers, and other ancillary buildings.

The non-material traditional settlement landscape genes in northern Shaanxi are categorized into four distinct features: custom, clan, dialect, and belief features. (1) In terms of custom features, ① entertainment customs include *suona* (traditional Chinese trumpet), *yangge* dance, stone carving, paper-cutting, storytelling, *Xintianyou* folk songs, waist drum performances, Northern Shannxi *daoqing* (a local ballad form), and cloth-collage painting. ② Market trade customs are mainly temple fairs, including the Sanguan Temple Fair, the Fotang Temple Fair, the Dragon King Temple Fair, and the Yuhe City God Temple Fair. (2) Dialect features include the Jin dialect and Central Plains Mandarin. (3) Clan features are divided into landlord-style blood inheritance, "hall" culture, and surname culture. (4) Belief features are divided into nature god worship, religious belief, historical figure worship, and red revolutionary belief according to different belief objects.

3.2 Generation of the genetic pedigree of traditional settlement landscapes in northern Shaanxi

Through the previous analysis of the landscape genes of traditional settlements in northern Shaanxi and the construction of the landscape genetic information coding structure, it can be concluded that most of the traditional settlements in northern Shaanxi are based on family inheritance and small-scale peasant economy, which is reflected in the location layout, clan, and residential architecture. Therefore, by combining the internal and external environmental genes of the settlement, the genes of traditional dwellings and main public buildings, and the landscape genes with the same cultural significance, we can construct the traditional settlement landscape genetic pedigree in the region, namely the "A+ B+ C+ D" mode (Figure 6).

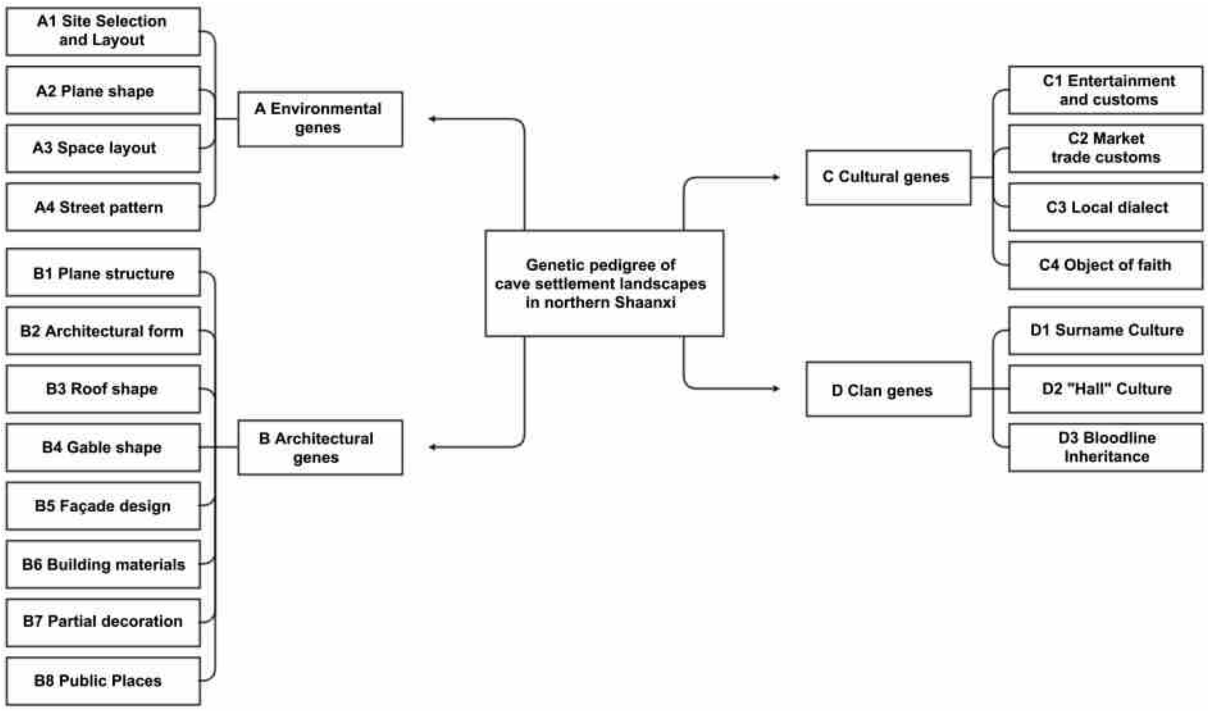


Figure 6 Genetic pedigree of traditional settlement landscapes in northern Shaanxi

4 Genetic prototype extraction and mapping of traditional settlement landscapes in northern Shaanxi

4.1 Genetic prototype extraction of traditional settlement landscapes in northern Shaanxi

The extraction of landscape gene prototype is the process of abstractly extracting and restoring the layout and architectural forms of traditional settlements, including their internal structure and formation principles, mainly achieved through methods such as graphic extraction, element extraction, and meaning extraction [13]. Because the existence and development of material landscapes have their own laws and clear representational forms, and non-material cultural landscapes are "living" landscapes that are transferred and flow based on human consciousness, and have collided and integrated with the cultures of various regions many times in the course of historical development, expressing human activity forms and spiritual and cultural emotions, this article mainly attempts to symbolically express the material landscape gene map of cave settlements in northern Shaanxi. The landscape elements of the cave settlements in northern Shaanxi, including site selection patterns, spatial layouts, street patterns, and architectural forms, are visually represented through two-dimensional and three-dimensional graphics. Abstract symbols are extracted based on the morphological features and cultural connotations of each element, and their inherent meanings are abstracted through graphical expression [16].

4.1.1 Prototype extraction of environmental genesfrom traditional settlements in northern Shaanxi

Combined with landscape gene identification results, the graph extraction method was used to derive prototypes for site selection, pattern, plane form, spatial pattern, and street pattern in traditional settlements of northern Shaanxi (Figure 7).

(1) The location and pattern of traditional settlements in northern Shaanxi can be divided into five types: minor gully type, ridge-and-knoll slope type, slope terrace type, river valley plain type, and the type of rocky mountainous area along the Yellow River. ① Among them, influenced by the topography, the minor gully type settlements are the

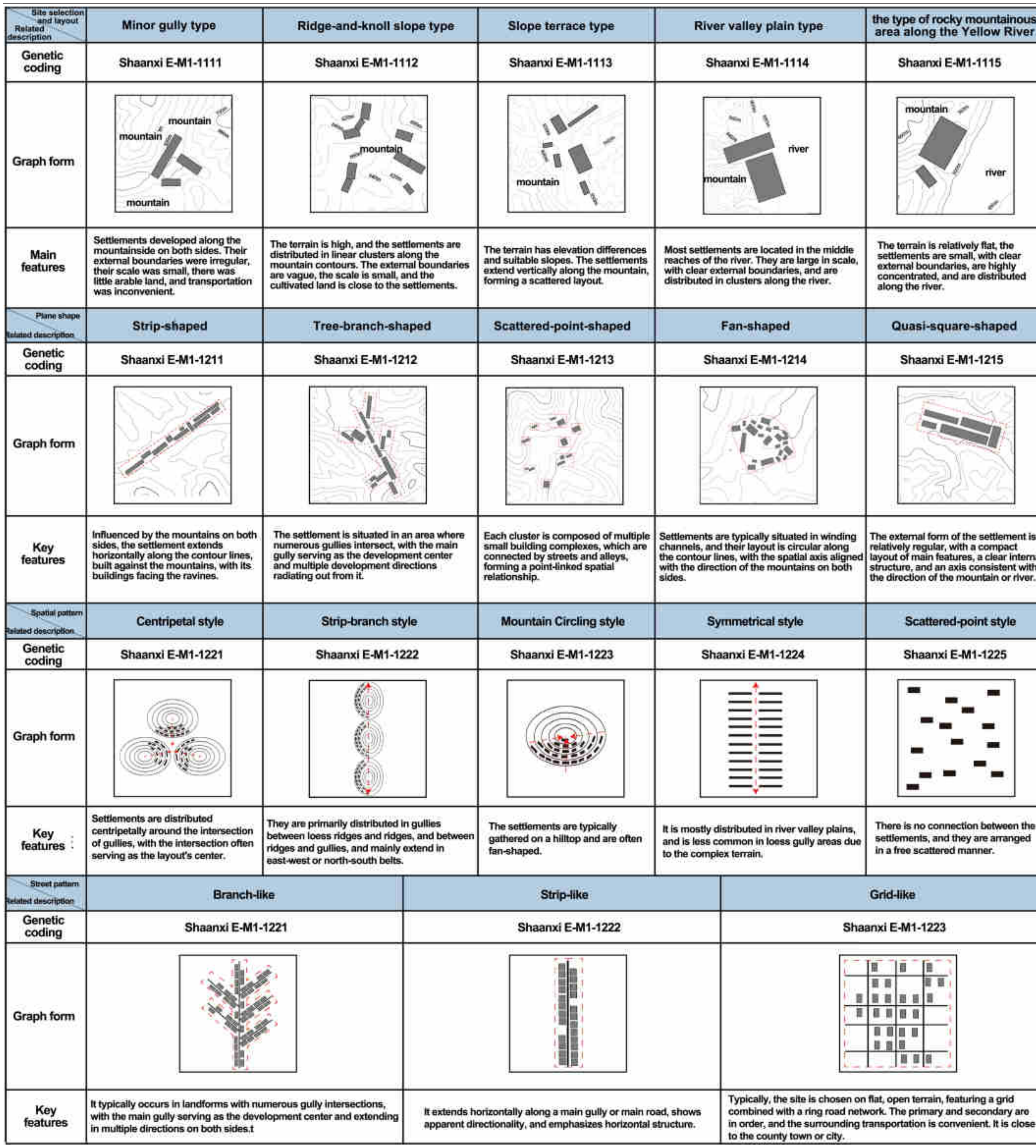


Figure 7　Environmental gene prototype of the traditional settlements in northern Shaanxi

most numerous. They develop along the mountain lines on both sides. The external boundaries of the settlements are irregular, the scale is small, there is little cultivated land, and transportation is inconvenient, as seen in Aijiagou Village and Changjiagou Village. ② Ridge-and-knoll slope type settlements are distributed in higher areas. The settlements are distributed in linear clusters along the contours of the mountain. The external boundaries are vague, the scale is small, and the cultivated land is located near settlements, such as Liangjiajia Village and Huling Village. ③Slope terrace type settlements are distributed in areas with large elevation differences and suitable slopes. The settlements extend vertically along the mountain, forming a scattered layout, as seen in Yuanzeping Village and Gaojie Village. ④River valley plain type settlements are mostly distributed in the middle reaches of rivers. They are large in scale, with clear external boundaries, and are distributed in clusters along the river, such as Zhangzhai Village and Nihegou Village. ⑤The rocky mountainous settlements along the Yellow River have relatively flat terrain, small settlement scale, clear external boundaries, and a high concentration, distributed along the river, such as Liujiaping Village and Mutouyu Village.

(2) The plane forms of traditional settlements in northern Shaanxi are strip-shaped, tree-branch-shaped, scattered-point-shaped, fan-shaped, and quasi-square-shaped.① Strip-shaped settlements are primarily based on the surrounding water systems and transportation, with streets and alleys used as extension units of traditional dwellings, thus presenting a linear extension trend. Influenced by the mountains on both sides, settlements extend horizontally along the contour lines, built against the mountains, with buildings facing the gullies, such as Zhongjiao Village and Zhangfeng Village. ② Tree-branch-shaped settlements are located in a terrain where multiple gullies intersect, with the main gully as the development center and multiple development directions extending around it. In the time of primitive society, the settlements were located in deep gullies. Due to the obstruction of roads and transportation, they could avoid war and reproduce in a relatively comfortable environment. For example: Heyi Village, Taozhen Village. ③ Scattered-point-shaped settlements are usually located at the top of ridge-and-knoll slopes. The settlement morphology consists of several clusters connected by a network of streets and alleys. There is no obvious center for the development of residential architecture. Terraces are typically cultivated on the surrounding ridges and knolls to increase the area of arable land, reflecting the ecological thinking of the primitive residents. Each cluster is composed of multiple small building groups, connected by streets and alleys, forming a point-linked spatial relationship, as in Heiyita Village and Liujiashan Village. ④ Fan-shaped settlements are usually located in winding gully channels. The settlement layout is circular along the contour lines, with the spatial axis aligned with the direction of the mountain or river, as seen in Jiadamao Village and Zhenjiawan Village. ⑤The quasi-square-shaped settlements have a relatively regular external shape, a compact layout, a clear internal structure, and a spatial axis that is consistent with the direction of the mountains on both sides, such as Anding Village and Luoyan Village.

(3) The spatial pattern of traditional settlements in northern Shaanxi presents five types of forms: centripetal style, strip-branch style, mountain-circling style, symmetrical style, and scattered-point style. The spatial pattern of settlements shows a clear correspondence with their plane forms. Settlements with strip-shaped plane forms usually present a strip-branch style pattern, while settlements with tree-branch-shaped plane forms mostly have a centripetal style spatial pattern.① Settlements with a centripetal style pattern are often distributed centripetally along intersecting gullies, with the intersection often being the center of the layout, such as Liujiamao Village and Yuejiacha Village. ② Settlements with a strip-branch style pattern are mostly distributed in gully channels between loess ridges and ridges, and between ridges and gullies, and mainly develop in an east-west or north-south belt, such as Nianpan Village and Zhaojiahe Village. ③ Mountain-circling style settlements are usually clustered on a hilltop and are usually fan-shaped, such as Liangshui'an Village and Jiadamao Village.④ Settlements with symmetrical style layout are mostly distributed in river valley plains. They are less common in loess gully areas due to the complex terrain, such as Mutouyu Village. ⑤ Settlements with a scattered-point style layout are usually unrelated to each other and present a free scattered layout, such as Huling Village and Heiyita Village.

(4) The street patterns of traditional settlements in northern Shaanxi present three forms: branch-like, strip-like, and grid-like.① The branch-like pattern usually appears in landforms with many gullies intersecting. This pattern is most common in traditional settlements in northern Shaanxi. It develops from the main gully as the center and extends in multiple directions on both sides, such as Mianhugou Village and Baixingzhuang Village. ② The

strip-like pattern often appears in settlements located in tributary gullies or slope terraces. When the mountains on both sides are steep and the slope is limited, making it difficult to build residential houses vertically, the settlement will expand parallel to the contour lines. In this case, the streets and alleys connecting the settlements will develop in a strip-like form, extending horizontally along a main gully or main road. This has a clear directionality and emphasizes a horizontal structure, as seen in Yuejiacha Village and Shapingshang Village. ③The grid-like pattern is typically situated in flat and open terrain, primarily distributed within river valley plains and settlements with minimal elevation difference and relatively level ground. The pattern within such settlements is usually regular and orthogonal. However, in areas with slight topographic variations, the village street network adopts a more freely intersecting form. A hierarchical order is maintained between the grid and ring road systems, with the grid pattern dominant and the ring roads secondary. Surrounding transportation is convenient and close to county towns or cities, such as Zhenziwan Village and Zhenjing Village.

4.1.2 Prototype extraction of architectural genesfrom traditional settlements in northern Shaanxi

Combined with the identification results of landscape genes, the element extraction method was used to extract prototypes of traditional dwellings and main public buildings in traditional settlements in northern Shaanxi (Figure 8).

(1) The plane structures of traditional residential buildings in northern Shaanxi are of three different forms: multi-opening terraced cave courtyards, cave courtyards with side caves, and cave courtyards with side rooms.① Multi-opening terraced cave courtyards are the most common in cave settlements of northern Shaanxi, and there are also a small number of landlords' manors, such as the Dang family manor in Heyi Village, which use this courtyard model. ②The cave courtyard with side caves is the most typical model of cave dwellings in northern Shaanxi. The courtyard is oriented south-to-north, with a cave dwelling serving as the main room, often featuring five openings. Four hidden caves are symmetrically distributed on either side of the main cave, and six side caves are distributed on the east and west sides. The courtyard's interior follows the ethical and functional layout of "main cave as the most important, side rooms as the second, and miscellaneous rooms as the auxiliary", which provides good privacy and functionality. Examples include Ma's Manor in Yangjiagou Village, Jiang's Manor in Liujiamao Village, and Chang's Manor in Gaomiaoshan Village. ③Cave courtyards with side rooms are mainly distributed in the northern part of the Weibei area. They are only found in Zhangfeng Village in northern Shaanxi. The settlement features a coexistence of both the cave courtyards with side rooms and the narrow courtyards typical in the Guanzhong area, demonstrating distinct transitional and divergent characteristics.

(2) Traditional dwellings in northern Shaanxi are mainly cave dwellings. From the perspective of architectural form, they are divided into mountain-backed cave dwellings and independent cave dwellings. Among them, mountain-backed cave dwellings are further divided into mountain-backed and gully-sided cave dwellings based on their architectural form. ① The mountain-backed cave dwelling is against the cliff, with an open plain in front. The layout is significantly influenced by the terrain and is often parallel to the contour lines, featuring a curved or broken line layout. ②The gully-sided cave dwellings are cave dwellings dug inward on the cliffs on either side of the gully. This type of cave dwelling typically features a complex and varied layout. Because it is located near the gully, it can effectively shield against wind and sand, thereby regulating the regional microclimate. Its ecological environment is good, making it an ideal place to live. ③ Independent cave dwellings are divided into brick and stone cave dwellings and earth-based cave dwellings. Since the Wuding River Basin is rich in stone and quarrying is convenient, residents use local materials—soil, stone, and wood—to construct cave buildings that are closely integrated with nature.

4.2 Genetic mapping of typical settlement landscapes in northern Shaanxi

The landscape gene map of traditional settlements is a comprehensive expression of their landscape genes, including architecture, layout, and culture. It can clearly present the landscape genes of the settlements, including lay-

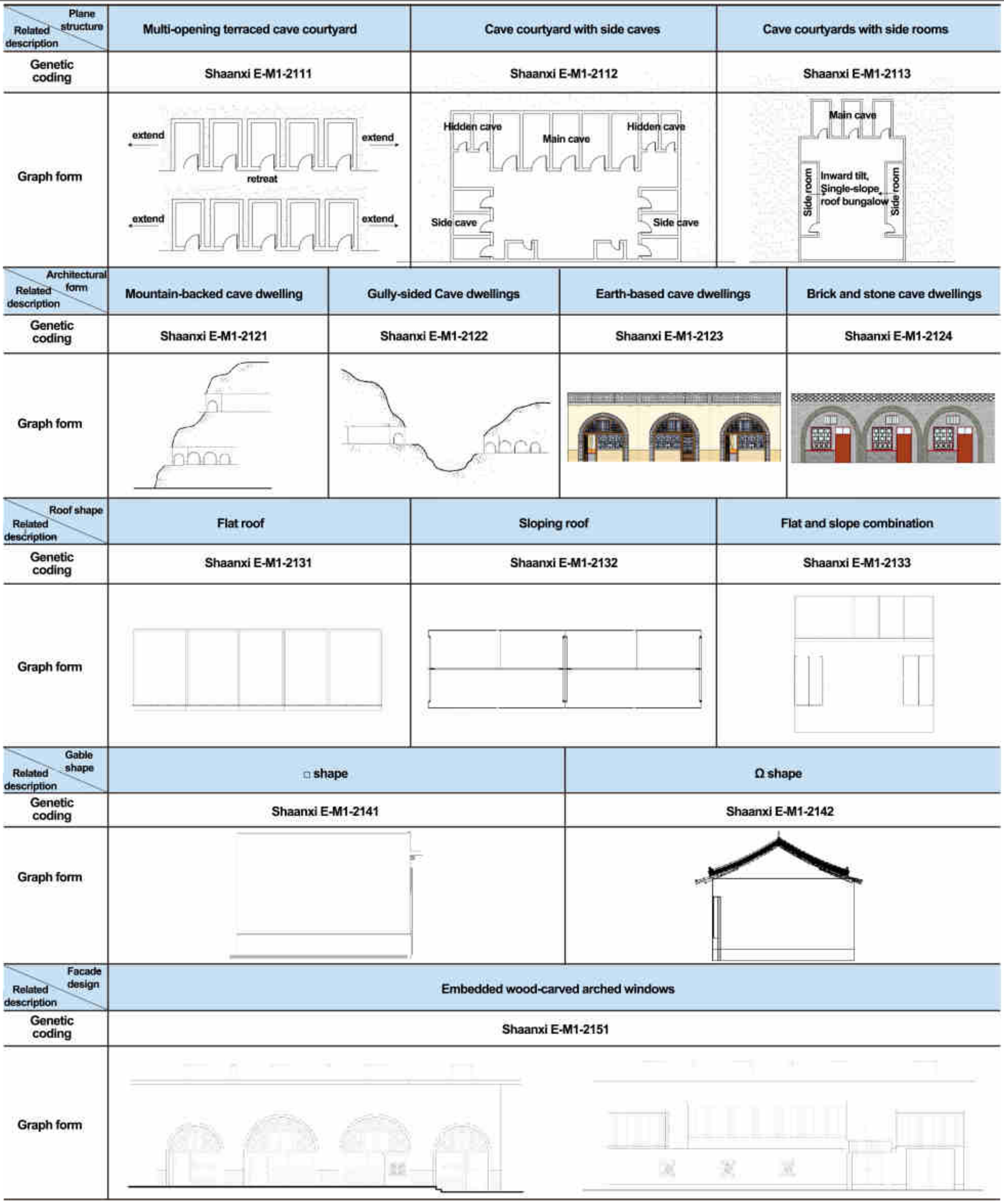
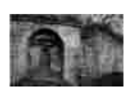
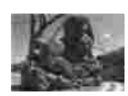


Figure 8 Architectural gene prototype of the traditional settlements in northern Shaanxi

out, architecture, beliefs, and folk customs, and explain the inherent laws of the traditional settlement landscape genes. It also reflects the logic and orderliness of the settlement landscape genes. Combining the traditional settlement landscape gene coding structure in northern Shaanxi and the landscape gene prototype extraction results, this article constructed a landscape gene map of 15 typical settlement cases in northern Shaanxi (Table 1).

Table 1 Construction of the landscape gene map of typical settlements in northern Shaanxi

		Heyi Village	Aijiagou Village	Changjiagou Village	Guojiagou Village	Huyan Village	Liangjia Village	Zhongjiao Village
Building genes	Plane structure	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2112 Cave courtyard with side caves	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2112 Cave courtyard with side caves	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2112 Cave courtyard with side caves	Shaanxi E-M1-2112 Cave courtyard with side caves
	Architectural form	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2123 Earth-based cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2123 Earth-based cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2123 Earth-based cave dwellings	Shaanxi E-M1-2122 Gully-sided cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings
	Roof shape							
	Gable shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 Ω shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape Shaanxi E-M1-2142 Ω shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape
	Facade design							
	Building materials	Shaanxi E-M1-2161 Earth-stone-brick mixed structure	Shaanxi E-M1-2161 Earth-stone-brick mixed structure	Shaanxi E-M1-2162 Stone-wood structure	Shaanxi E-M1-2162 Stone-wood structure	Shaanxi E-M1-2163 Stone structure	Shaanxi E-M1-2164 Brick-stone structure	Shaanxi E-M1-2165 Earth-wood structures
	Local decoration							
	public space	Shaanxi E-M1-2213 Representative dwellings (Dang Family Manor)	Shaanxi E-M1-2212 Religious buildings (Guandi Temple, Zhenwu Patriarch Temple)	Shaanxi E-M1-2212 Religious buildings (Monkey King Temple, Dragon King Temple, Buddhist Temple)	Shaanxi E-M1-2212 Religious buildings (Qingliang Temple, Sanguan Temple)	Shaanxi E-M1-2212 Religious buildings (Temple of the God of Wealth)	Shaanxi E-M1-2211 Clan building (ancestral hall) Shaanxi E-M1-2212 Religious buildings (ancestral temples, Dragon King Temple	Shaanxi E-M1-2214 Militaryruins (ancient road ruins)

(Continued)

		Heyi Village	Aijiagou Village	Changjiagou Village	Guojiagou Village	Huyan Village	Liangjia Village	Zhongjiao Village
Cultural genes	Recreational customs	Shaanxi E-M2-1-11*suona* Shaanxi E-M2-1-12 yangge dance Shaanxi E-M2-1-13 stone carving	Shaanxi E-M2-1-12yangge dance (water-moving boat)	Shaanxi E-M2-1-12yangge dance Shaanxi E-M2-1-13 Stone Sculpture	Shaanxi E-M2-1-12yangge Shaanxi E-M2-1-14 Paper Cutting Shaanxi E-M2-1-15 Storytelling	Shaanxi E-M2-1-11suona Shaanxi E-M2-1-12 yangge dance	Shaanxi E-M2-1-13 stone carving	Shaanxi E-M2-1-11S*uona* Shaanxi E-M2-1-12 yangge dance
	Regional customs	/	Shaanxi E-M2-1-31 Five Kui Thirteen Flowers (Wedding Customs)	/	/	Shaanxi E-M2-1-32 "Store" culture	Shaanxi E-M2-1-33 Worship the ancestors	Shaanxi E-M2-1-34 Lion Tied with Baby (traditional artifacts crafted to safeguard infants and children)
	Object of Faith	Shaanxi E-M2-4-12 Religious beliefs (Buddhism)	Shaanxi E-M2-4-12 Religious beliefs (Buddhism, Taoism	Shaanxi E-M2-4-13 Character Worship (Legend of Chang Yuchun's Descendants)	Shaanxi E-M2-4-11 Nature Worship (Legend of the Hongtong Big Locust Tree Immigrants)	Shaanxi E-M2-4-13 Character worship (the legend of " Li Guang shooting a tiger")	/	/
clan genes		Shaanxi E-M2-3-11 Landlord-style bloodline inheritance	Shaanxi E-M2-3-13 Farming and studyingto pass on	Shaanxi E-M2-3-14 Hermit Culture		/	Shaanxi E-M2-3-15 Surname Culture (Ma Family)	Shaanxi E-M2-3-13 Farming and studying to pass on
Building genes	Plane structure	Shaanxi E-M1-2111 Cave courtyard with side caves	Shaanxi E-M1-2112 Cave courtyard with side caves	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2112 Cave courtyard with side caves
	Architectural form	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2123 Earth-based cave dwellings Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2122 Gully-sided cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings
	Roof shape							
	Gable shape	Shaanxi E-M1-2141 ☐ shape	Shaanxi E-M1-2141 ☐ shape Shaanxi E-M1-2142 Ω shape	Shaanxi E-M1-2141 ☐ shape	Shaanxi E-M1-2141 ☐ shape	Shaanxi E-M1-2141 ☐ shape	Shaanxi E-M1-2141 ☐ shape	Shaanxi E-M1-2141 ☐ shape Shaanxi E-M1-2142 Ω shape

(Continued)

		Heyi Village	Aijiagou Village	Changjiagou Village	Guojiagou Village	Huyan Village	Liangjia Village	Zhongjiao Village
Building genes	Facade design							
	Architecture Materials	Shaanxi E-M1-2166 Brick, stone, and wood mixed structure	Shaanxi E-M1-2166 Brick, stone, and wood mixed structure	Shaanxi E-M1-2164 Brick and stone structure	Shaanxi E-M1-2167 Brick and wood structure	Shaanxi E-M1-2164 Brick and stone structure	Shaanxi E-M1-2166 Brick, stone, and wood mixed structure	Shaanxi E-M1-2166 Brick, stone, and wood mixed structure
	Local decoration							
	Public space	Shaanxi E-M1-2212 Religious building (Ma's Ancestral Hall), Shaanxi E-M1-2213 Representative dwellings (Chairman Mao's former residence)	Shaanxi E-M1-2212 Religious buildings (Buddhist temples, Laoye temples) Shaanxi E-M1-2213 Representative dwellings (Chang Family Manor) Shaanxi E-M1-2215 Pavilions, towers, and other ancillary buildings (theater)	Shaanxi E-M1-2212 Religious buildings (Buddha temples, Guangong temples, Mawang temples)	Shaanxi E-M1-2212 Religious building (Niangniang Temple), Shaanxi E-M1-2213 Representative dwellings (Guo Hongtao's former residence) Shaanxi E-M1-2214 Military Site (Former Site of the CPC Midong County Committee)	Shaanxi E-M1-2212 Religious buildings (Temple of Zhenwu Emperor) Shaanxi E-M1-2213 Representative dwellings (Ma Mingfang's former residence)	Shaanxi E-M1-2212 Religious buildings (Mawangye Temple, Sangong Palace) Shaanxi E-M1-2213 Representative dwellings (Bai's stone cliff cave dwelling)	Shaanxi E-M1-2212 Religious buildings (Dragon King Temple, Fajia Temple) Shaanxi E-M1-2213 Representative dwellings (Jiang's Manor)
Cultural genes	Entertainment customs	Shaanxi E-M2-1-11 *suona* Shaanxi E-M2-1-14 Paper Cutting	Shaanxi E-M2-1-14 Paper Cutting	Shaanxi E-M2-1-12 *yangge dance*	Shaanxi E-M2-1-12 *yangge dance*	Shaanxi E-M2-1-12 *yangge dance*	/	Shaanxi E-M2-1-12 *yangge dance*
	Regional customs	Shaanxi E-M2-1-35 Nine Bends Shaanxi E-M2-1-36 Pray for rain	Shaanxi E-M2-1-36 Pray for rain	/	/	/	/	/
	Object of Faith	Shaanxi E-M2-4-12 Religious belief (Buddhism) Shaanxi E-M2-4-14 Red Revolutionary Belief	Shaanxi E-M2-4-12 Religious beliefs (Buddhism)	Shaanxi E-M2-4-13 Character Worship (Li Dingming's "Streamlining Administration" Theory)	Shaanxi E-M2-4-12 Religious beliefs (Buddhism)	Shaanxi E-M2-4-11 Worship of Nature Gods (Legend of the Hongtong Big Locust Tree Immigrants)	Shaanxi E-M2-4-11 Worship of nature gods (*feng-shui* prosperity theory)	Shaanxi E-M2-4-13 Character Worship (The Legend of Jiang Yaozu's Rise to Wealth)

(Continued)

		Heyi Village	Aijiagou Village	Changjiagou Village	Guojiagou Village	Huyan Village	Liangjia Village	Zhongjiao Village
clan genes		Shaanxi E-M2-3-13 Farming and studyingto pass on Shaanxi E-M2-3-12 " Hall " Culture Shaanxi E-M2-3-15 Surname Culture (Ma Family)	Shaanxi E-M2-3-11 Landlord-style bloodline inheritance	Shaanxi E-M2-3-11 Landlord Bloodline Inheritance (Bloodline of the "the Sixth of Old Li Clan")	Shaanxi E-M2-3-15 Surname Culture (Guo Family Revolutionary Tradition)	Shaanxi E-M2-3-16 Border Guard Immigrants	Shaanxi E-M2-3-13 Farming and studying to pass on	Shaanxi E-M2-3-11 Landlord bloodline inheritance

5 Conclusion and discussion

5.1 Conclusion

(1) The genetic information coding structure of traditional settlement landscapes in northern Shaanxi has been initially formed. By adopting the structural mode of "area code+ gene category code＋class-1 element＋class-2 element＋class-3 element＋landscape gene element", and analyzing the settlement landscape genes, the main characteristics and internal composition laws of the settlement can be clarified, thereby realizing the recognition of the overall and regional landscape features.

(2) Extract and analyze thegenetic prototypes of traditional settlement landscapes in northern Shaanxi. The prototypes of the material landscape environmental genes, and architectural genes in northern Shaanxi were extracted using graphic extraction and element extraction methods, respectively, and it was concluded that the minor gully type settlements and multi-opening terraced cave settlements are the main cave types and courtyard patterns in northern Shaanxi.

(3) Construct a landscape gene map of typical cave settlements in northern Shaanxi. Fifteen typical settlements were selected, and a landscape map was constructed using graphical expression. The obtained landscape gene map can serve as an important data and information source for traditional settlement protection planning, providing theoretical support for the restoration of the historical memory of traditional settlement landscapes in northern Shaanxi, the establishment of regional identity, and landscape protection planning.

5.2 Discussion

(1) Based on the results of landscape genetic analysis of traditional settlements in northern Shaanxi, this study explored the landscape gene code and established a landscape gene map. Results have practical implications for the sustainable development of different types of traditional settlements and the ecological restoration of traditional dwellings. Although the landscape genetic map of traditional settlements provides a practical basis for their historical and cultural transmission, genetic "mutations" and functional transformations within the settlements, as well as new demands from local residents for modern living space after long-term development, have been identified.

(2) The hierarchy of regional characteristics and the delineation of settlement zones in the landscapes provide further direction for subsequent research. The findings offer comprehensive insight into the natural and human characteristics of traditional settlements in a particular landscape and, eventually, into the construction of a regional landscape map. This system provides a layer-by-layer analysis of specific areas using a set of maps. The hierarchical regional map corresponds to large areas, subareas, sub-sub-areas and even individual settlements in the traditional landscape systems. It not only facilitates a comprehensive, scientific, and accurate understanding and representation of the unique characteristics of traditional settlement landscapes from a macroscopic to a microscopic perspective, but also enhances the analysis of traditional settlement landscapes in China.

Sources of Figures and Tables

All figures and tables in this article are drawn by the author.

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Re-adaptaion of a Functional Hospital Heritage from Sociological Perspective: Case Study of Dhaka Medical College, Bangladesh

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ABSTRACT: Historic buildings provide tangible reminders of the illustrious history of Bangladesh. These have significant emotional worth in addition to their architectural, artistic, historic, and iconic significance. They are a part of country's tradition and serve as emblems of its cultural identity. In order to maintain cultural history for a civic society that cherishes its past and cares for future generations, architectural heritage preservation is crucial in any urban context. Located in the heart of Bangladesh, the old Dhaka region is home to the Dhaka Medical College (DMC), a priceless piece of cultural history. The historical core of the city is a prime option for architectural and urban area conservation due to the exceptional quality of the spaces and the concentration of numerous historic buildings. This research looks for a way to revitalise the hospital without changing its original purpose or architectural design. Since the authority recently threatened to demolish the heritage building due to the so-called development of multi-storey solutions, which ultimately led to the haphazard trend of rapid urbanisation, the conservation plan or policy may be developed for adaptive reuse of the structure. In Bangladesh's challenging circumstances, the research's potential findings could help the relevant authorities adopt fair and appropriate practices for successful conservation, drawing inspiration from successful case studies overseas for coordinating various efforts to achieve the desired goal. The study may attempt to offer some recommendations and suggestions for combining the resources available for long-term, sustainable cultural heritage management.

KEY WORDS: Dhaka; Bangladesh; hospital heritage; re-adaption; sociology

1 Research problem identification

Article No. 61 of the Archaeology Department stated that, to protect any historical building along with other surroundings in old Dhaka, authority can enact regulations [1]. The Antiquities Ordinance of 1976 (as modified) and Article 24 of the Bangladesh's Constitution offer legal backing for the preservation of DMC for future generations. The national archaeological record lists it as a site. Additionally, there are requirements for managing and conserving historic buildings in the most recent gazette of the Building Construction Rule 2007 [2]. In this study, DMC (Figure 1) is taken as subject as it shows some threats, the boundary walls of promises are taken over by the restaurants, and the parking area is encroaching on its

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garden. The distinct architectural style and aesthetics are ruined by the name of modernisation and unsuitable installations. For example, a huge iron net was added in an ugly way to control the mass entry in the year 2002, and air conditioning units are present in every window. Also, External façade installation for air conditioning of doctors' and nurses' chambers was introduced as a new addition, which ruined the historic facades of the building, although the building is naturally ventilated. And more importantly, the heritage building is in great threat; several times the building was put up for debate to be demolished, and a multi-story modern hospital should be erected on the site instead, which ignited protest among the heritage lovers.

Figure 1 Main entrance captures the symmetric façade of DMC

There are lots of good examples around the world of how to fit modern installations over historic buildings. Experts need to be concerned about these historical value facts to conserve such a 'unique witness' still standing from the glorious history. For that, some socio-cultural study needs to be synchronised in heritage studies to identify the root psyche of Bangladesh's society: Why do Bangladeshis want to demolish their heritage and not properly understand the value? And what are the underlying causes that come from sociocultural factors and forces? These causes and consequences need to be identified first. Otherwise, no heritages can be protected in the future unless public awareness of protective attitudes is developed, included, and practiced in the mainstream perception of that society.

2 Research aim and objectives

(1) To identify the heritage value and significance of the DMC hospital from the literature review.

(2) The second goal is to find suitable conservation scopes for the DMC hospital, according to western standards coming from foreign case studies.

(3) To identify root causes for the existing lack of public awareness and interest in heritage conservation from the base of western sociological scholarship.

(4) To recommend and suggest possible measurements and policies for logistic and financial supports from the authorities and stakeholders that fit from Bangladesh's context, after appropriate analysis of the research findings (Chart 1).

3 Methodology

Refer to Chart 1.

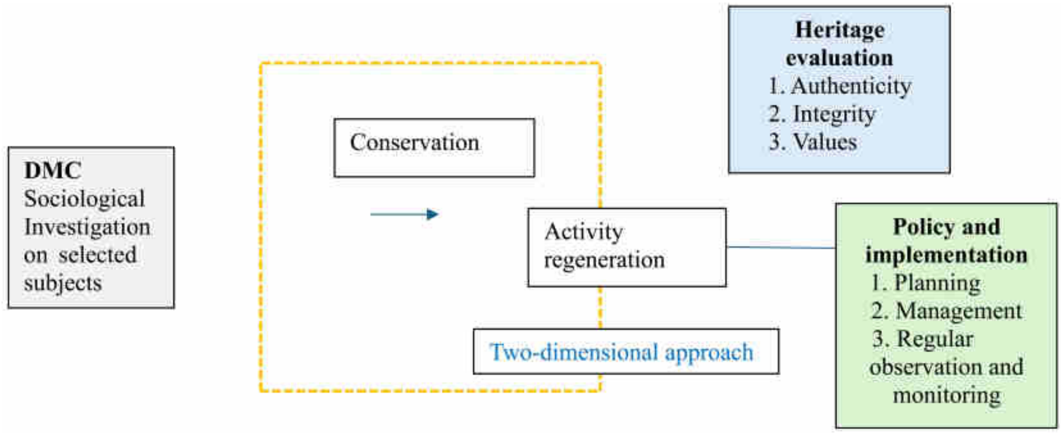

Chart 1 Methodology of research

4 Significance of the research

Architecturally, Dhaka Medical College shows the late British colonial architectural characteristics: a compound 'Zaminder Bunglow' type building with three entries. This is only one of a few late British colonial public buildings in Dhaka city, where the rest are either dilapidated or extinct today. Also, around DMC, heritage lovers will find many other colonial buildings like Curzon Hall, the High Court Building, and Bangabhaban (Presidential Palace), which has stood for 100 years, holding the contextual, urban, and architectural development history of Dhaka city as the capital of Eastern Bengal province from the British reign, which could be better explained through a heritage trail[3]. This building is the birthplace of the language movement. The dormitories, once known as 20 tin shed barracks (today's site for Shaheed Minar, commemorating the language movement), were the heartbeat of the Bengali Language Movement, as political protesters used to gather here and organise processions for demonstration. Because it was close to the Parliament of East Pakistan, which temporarily took its seat at Jagannath Hall of Dhaka University during the early days of East Pakistan legislation. On February 21, 1952, students decided to defy Section 144 at 4:00 pm from the historic mango tree called Aam-tola (present-day Emergency Gate; the tree is no longer there, Figure 2). The police fired at the procession, resulting in the deaths of many protesters, while only a few names like Salam, Barkat, Rafique, Jabbar, and Shafiur are known today. After sunset on February 21st, at the site of the deaths, the students of Dhaka Medical College decided to build a monument using bricks, gravel, and cement reserved for the construction of the hospital to erect the first-ever language martyr monument. The site was developed to its recent form much later by painter Hamidur Rahman and sculptor Novera Ahmed [4]. Today, this great incident was declared as International Mother Language Day by UNESCO in 1999, celebrated all over the world. Also, this building played a significant role in getting an independent country, Bangladesh [5].

Figure 2 Amtola in front of DMC in 1952, the mango tree is not existing today

5 Background

Dhaka Medical College Hospital goes with 4 types of functional reshuffle and adapts for all the purposes without any major changes in its plan and elevation. First, it was constructed as the Secretariat Building for the newly formed province of East Bengal and Assam in 1904. It was designed by British architect James Ransome (1865- 1944) in 1909 (Figure 3). The building also hosted the University of Dhaka in 1921. One part was the university's medical centre; another was the student dormitory, which again shifted as the university's arts faculty. In 1939, the university council requested the British government to establish a separate medical college. It was postponed because "American Base Hospital" was running during World War II[6]. After the war, the British government wanted to establish 3 modern medical colleges in Madras, Karachi, and Dhaka. Civil surgeon of Dhaka, Dr. Major W. J. Virjin, and local leaders launched a committee for the suggested medical college. Finally, in 1946 a one hundred-bed hospital was established as Dhaka Medical College and Hospital, where class started on 10th July [5].

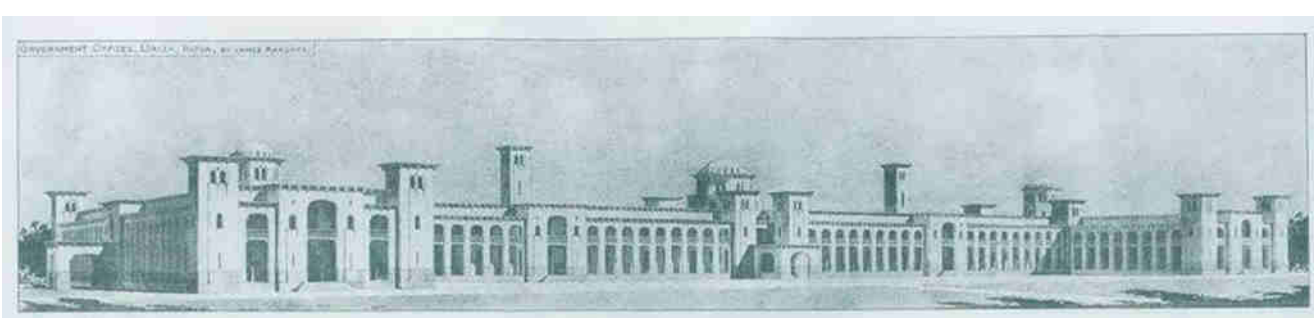

Figure 3 Dhaka Medical College image at British Weekly Magazine, 'The Builder': January edition in 1909

Adaptive reuse of the individual heritage buildings as well as any historic area is always referred solution in third world context[7] and DMC shows great potentials. Surprisingly, the building doesn't have any sleeping period within its four-stage transformation. The table below depicted its adaptation patterns, minor changes, and four phases chronologically (Table 1):

Table 1 Functional evaluation of the premise

Year	Purpose	Type
1904	Govt's public secretariat building	Administrative
1921	University of dhaka	Educational
1933	American base hospital military (World War I)	Public health
1946	DMCH	Public health

6 Architectural features of DMC

DMC is a wonderful and unique landmark in old Dhaka as well as one of the largest colonial public buildings. The building shows prominent local ornamentations with colonial features: dome, portico, porch, kiosk, parapet, series of columns, high raised plinth, oblong plan, series of courtyards, and symmetric elevation. This building is naturally ventilated as an internal courtyard, like the compounds of colonial landlord's houses, locally known as Zaminderbari,[8] is placed on its two flanks. Its high-raised plinth and symmetric elevation are other important features. The architectural style of DMC could be classified as quasi-Saracenic (Figure 4). Its huge dome at the centre is mainly inspired by the Mughal feature, but it is also recurrently used in many colonial public buildings to show power and prestige. While a portico is truly a European element to give a grand look at the symmetric building façade and defined entry to make it more monumental. Thereby, a new hybrid style emerged known as the Indo-British or the late colonial style [9]. It's echoed in three gateways; the main entrance echoed the central building block as the main entry. Another two are located on the right and left sides of the main building to assist the central one; these are smaller in size. The construction of the building entirely depends on the load-bearing wall. The main hospital quarter wall has a thickness of 20 inches on the ground floor and 10 inches on the upper floor, bonded with shurki (chips) and lime mortar. Limestone was sealed in the central structure to support the dome's structural stability. Brick chips mixed with mortar were used to construct the projective eaves and cornices (Figure 5). The horizontal elements were 6 inches, and diagonal buttresses were 8 inches in thickness. The bull's trench kiln of Hooghly produced typical colonial burnt clay bricks (22.8 × 10.7 × 6.9 cm). Burmese teak wood (*Tectona grandis*) was used for all the wooden frames and door and window friezes of the building. The longitudinal teak logs were placed over a frame. Beneath it and in between two frames, red brick chips mixed with the mortar were cast as a floor [4].

Figure 4 Architectural features from British colonial trend are dominant in interior

7 Case studies of successful hospital heritage conservation practices in Western context

7.1 The Cook County Hospital, Illinois, USA

Cook County Hospital is a historic Chicago landmark, has been revitalised as part of a $ 1 billion redevelopment plan. The building, completed in 1914, was once the heart of the Illinois Medical District healthcare community and was threatened with demolition. World-famous architecture firm Architects: Skidmore, Owings & Merrill (SOM), along with its local partners, has preserved, restored, and adapted the building to meet the changing needs of the neighbourhood. The revitalised historic hospital building includes a new hotel, food hall, medical offices, and community spaces. The renovation aims to restore the building to its former glory, including the development of the first blood bank in the United States and its role in the field of medicine. The renovation has earned the project a 2020 Landmarks Illinois Richard H. Driehaus Foundation Preservation Award for Adaptive Reuse (Figure 6)[10].

Figure 5 Architectural details on fenestrations, dome and light well features

7.2 Bathurst's old hospital, NSW, Australia

Bathurst's first hospital, one of Bathurst's historic landmarks, was initially a convict settlement built in the 1820s. Renamed Bathurst District Hospital in 1842, it faced issues like dampness and termites, and the new hospital was completed in 1880. An architect from Sydney, Mr. Boles, had his plans accepted in 1878. The new hospital was completed in 1880, costing £12,000. Bathurst District Hospital was listed on the New South Wales State Heritage Register of Australia on 2 April 1999. The late Victorian hospital complex, in the second empire style, features a two-storey administrative area, an operating theatre block, and octagonal operating theatres. It is constructed of brick with a hipped iron roof and moulded string courses, decorated with timber posts and cast-iron balustrades. Bathurst Hospital is still operational and provides essential healthcare services to the community, while the hospital is undergoing a significant redevelopment project, that will start from 2025 (Figure 7)[11].

8 Findings and analysis

Those who are keen to replace heritage buildings with modern buildings need to know that there are some better inherent and designed advantages of the heritage buildings compared to contemporary and designed ones, even though some of the contemporary buildings lack these facilities. Let's consider some architectural factors of the DMC complex for explaining its viability, which is still contextual and worthy of heritage preservation.

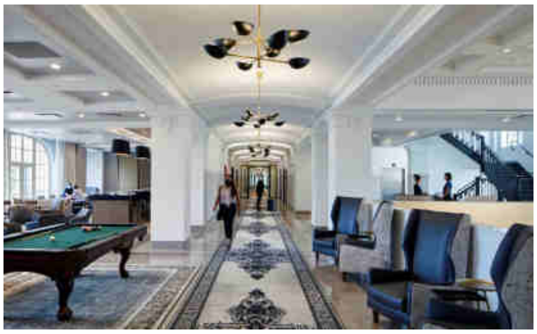

Figure 6 The Cook County Hospital, Illinois, USA. SOM renovated the hospital in 2020

Figure 7 Bathurst's old hospital, NSW, Australia

8.1 Landscape

A natural acoustic barrier in front of the premise is offered by the garden, which is working like a perfect buffer zone for a heritage. Moreover, larger trees provide shadows against the sun, while the hedges are acting like effective thresholds for sound and view control. Also, the huge grassland in the front is a perfect rainwater percolation area for recharging groundwater in a congested city like Dhaka.

8.2 Functional arrangement

It's posing an E-shaped footprint; such an oblong plan of the hospital building is very effective for the functional purpose and medical facilities of any hospital building. The main block has another five blocks like wings and a series of rooms with double-loaded corridors connected to all the surrounding verandas at its peripheries, which is a good example of accessibility from any corner. Additionally, at the adjacent point of two building blocks, every corridor has placed a staircase. Services were put at the end of the corridors, which are grouped together.

8.3 Energy efficiency

The building is also very energy efficient, as it was built in a time when the electricity supply and demand were not as high as in today's context. Such energy efficiency is achieved by optimising the natural sources: the ventilators, light wells, and eaves. As these colonial architectural details are present in the building facade and interior ornamentations, no artificial light is required during the daytime and load-shedding period of electricity. Heavy construction of the brick wall also added some heat insulation quality, and ventilators over doorframes help to keep the interior cool on hot summer days. The same thick walls help to trap the heat during the winter, while it's cool on the outside.

8.4 Climate-responsive design

Traditionally, DPC (damp-proofing course) is used in the foundation to provide effective protection against capillary action of groundwater, to prevent dampness, which is a great threat for the lifespan of any building, especially heritage brick-walled buildings like this. And to worsen the scenario, drifting rain can cause damage over years, which tends to accumulate in the footings of brick walls' steeped foundations. In addition to DPC, projected eaves are installed over each fenestration for rain protection. This provided not only a majestic character of late British colonial architecture of Bengal but also protected its facade from the decay in inner walls, while Bangladesh's monsoon period is very long, nearly 6 months, and even its dry winter season could be regarded as humid compared to other parts of the world. So, from which angle is this heritage building treated inferior compared to other newly constructed contemporary and so-called well-designed buildings?

9 Discussion: a sociological perspective

Sociologists study the social, economic, and political consequences of any conflict, inequalities, and environmental vulnerabilities, and the sociology of destruction terms it as 'destructive creation,' and the topic of this research surely falls under it. The "sociology of destruction" broadly explores how societal structures, institutions, and human actions lead to negative impacts, both on the environment and on human well-being. This study examines the social causes and consequences of built environment degradation, which is heritage destruction in this case, and the role of power dynamics, conflict, and inequality in inducing destructive processes. Politics itself shapes power dynamics, power structures, ideology, and economic interests in fuelling conflicts. Also, how new technologies or social structures can have unintended negative consequences, sociologists try to identify these factors as well [12]. For this case study of DMC, it is meticulously observed that the impact of past social movements, like the Language Movement of 1952, is still stimulating the aware psyche of the local communities, despite having threats coming from displacement, poverty, and urban spatial contestations. This study will try to challenge those destructive processes and promote more sustainable practices for 'architectural conservation' using two sociological tools like "right to the city," from Lefebvre, and "symbolic capital" from Bourdieu.

DMC has reflected a role of being a national emblem apart from its structural viewpoint. The entity was relevant in the Bengali Language Movement and is commemorated worldwide on International Mother Language Day. The demographic and social composition of the area surrounding DMC consists of working-class inhabitants whose financial activities are intricately linked to the vicinity of the hospital to a large extent. It can be observed that the street vendors and informal workers frequently operate in and around hospital premises with limited alternatives for their livelihood. Their utilisation of public space exemplifies famous modern social thoughts from the Lefebvrian approach of the "right to the city," which vouched for the idea of marginalised communities establishing their presence despite official regulations[13], frequently complicating hierarchical conservation initiatives, which is related to the present findings of this research.

The hospital's central geographical location renders it to be important as well as susceptible from different perspectives. It is evident that Old Dhaka experiences frequent flooding and congestion, with those who rely heavily on DMC being the most impacted by these natural hazards. Engineered for natural ventilation and climate resilience, the structure provides insights for contemporary urban planning. Besides, DMC possesses significant emotional significance, and from an environmental psychology perspective, locations such as this foster a sense of stability and collective memory for a nation. From a social psychological viewpoint, it is not merely a hospital; it is a site where generations have undergone significant life events for numerous individuals in Dhaka. To sum up, referencing Bourdieu's concept of symbolic capital[14], DMC's intrinsic value transcends its economic significance in many aspects. Its legacy as a centre of medical education and anti-colonial resistance imparts a greater social and geopolitical significance. Preservation necessitates more than mere architectural planning, as it demands inclusive, community-oriented initiatives that harmonise heritage with practical requirements.

This article has examined the potential for the re-adaptation of Dhaka Medical College Hospital (DMC), a location of substantial historical and cultural importance, to address modern healthcare and urban requirements while preserving its heritage value. It emphasises the equilibrium between maintaining identity and facilitating functional transformation in a swiftly evolving urban environment. A detailed analysis of how a structure can embody the conflicts among development, identity, and social equity is worth investigation from a sociological perspective. Socioeconomic discussions regarding its future emphasise the strain on land in rapidly expanding, low-income urban areas, as the paper developed an argument that in Old Dhaka, the increasing demand for contemporary healthcare conflicts with efforts to conserve cultural heritage sites. The concerned authorities frequently emphasise immediate economic gains, whereas heritage advocates contend for enduring social and cultural significance, which underscores a broader power dynamic where wealthy developers often overshadow the perspectives of marginalised communities.

10 Challenges

(1) The boundary walls are taken over by the vendors, stalls, pharmacies, and restaurants due to illegal encroachment.

(2) The parking area is encroaching on the garden; the rainwater-soaked area is turning into brown fields day by day.

(3) The maintainable and distinct architectural styles and features have been ruined over the years in the name of unnecessary modernisation. Especially the façade of the heritage building is losing its original appeal due to the installation of massive air conditioning equipment. Such unsuitable installations create disturbances to its original aesthetics. The case studies of this research should be followed for DMC conservation as an effective strategy; a central air-cooling system could be installed instead.

11 Suggestions and recommendations

(1) Authority must need to enlist the building as protected heritage and prepare a list of heritage buildings to be conserved in Dhaka city. To prepare this list, the city authority may consult with the Archaeological Department, the Institute of Architects Bangladesh (IAB), the Dhaka City Corporation (DCC), the Rajdhani Unnayan Committee (Rajuk), and university teachers, historians, and heritage experts based on the historic, scenic, scientific, social, and spiritual qualities of the heritage buildings [15]. This should be published as a gazette, and the list could be demonstrated for general discussion in the public sphere.

(2) The Archaeological Department, under the supervision of the Ministry of Culture, has to list special scenic, historic, scientific, social, spiritual, or naturally remarkable areas of Dhaka city as urban conservation sites to develop a heritage trail connecting all the heritage buildings and elements in a route. After preparing the list of heritage buildings, the authority has to notify the concerned owners of the buildings, provide subsidies to protect heritage, and bear the cost of conservation.

(3) For any change, extension, addition, or destruction of these buildings, one has to obtain written permission from the Rajdhani Unnayan Committee (Rajuk). The ultimate authority could be the Dhaka City Corporation (DCC), which can permit (fully or partially) applications to change, extend, adjoin, reuse (adaptively), or refurbish the enlisted heritage buildings. They can impose reasonable conditions for any alteration and bring charges against any vandalism also. Such permission from the authority will be

valid for up to 3 (three) years, and the owners need to renew it immediately.

(4) If any person/institute does some illegal change, extension, joining, vandalization, or destruction of the enlisted heritage buildings, the authority will order the occupier or owner to impede the tasks. If it seems that there is a lack of superintending of the listed buildings, the authority can entirely acquire the enlisted heritage buildings forever. Authority will take steps to upgrade and conserve the heritage buildings and urban areas from time to time. Law enforcement should be strict, and punishment should be executed immediately to create awareness in the public.

(5) Regular design competitions among architects and conservation specialists could be arranged to bring the best possible solutions for each of the heritage cases.

Conclusion

One fundamental idea can be used to encapsulate the entire conservation and management plan proposed in this study: different stakeholders should acknowledge the necessity of DMC conservation and management. The present study, which may enable the authorities to come under the Government of Bangladesh Umbrella as a common platform, focuses on mutually derived solutions of complementary authorities from Bangladesh's context for the adaptive reuse of the DMC buildings as well as the old Dhaka urban area. Public awareness should also be raised by experts (such as architects, urban planners, academics, engineers, archaeologists, historians, etc.), civic organisations, environmentalists, media, company owners, etc. In summary, this study recommends a cooperative strategy for managing DMC Hospital's cultural heritage, which is crucial given that the hospital still continues to serve its purpose and is recognised as the top public health care provider for the general public in Bangladesh. In order to achieve posterity in a challenging and difficult environment, this heritage could serve as a paradigm-shifting example of functional preservation in a third-world background like Bangladesh for an inventive conservation and management approach.

Sources of Figures and Tables

Figure1: Ar. Alamin Abu Ashraf Dolon, 2019

Figure 2: https://mm-gold.azureedge.net/new_site/muktomona/bengali_heritage/bangla_language_movement.html

Figure 3: Rare photos of Bangladesh

Figure 4: Ar. Alamin Abu Ashraf Dolon, 2019

Figure 5: Ar. Alamin Abu Ashraf Dolon, 2019

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Figure 7: Heritage NSW.au.

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