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# Optimizing Neighborhood Spatial Form for Sustainable and Resilient Urban Development through multisource approach

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**Abstract.** Urban areas face interconnected challenges such as urban sprawl, climate change, and social inequality, forming a complex web that requires comprehensive management strategies. Achieving sustainable and resilient urban development hinges on solutions that not only address local community needs but also identify root problems through participatory planning. Effective solutions blend vertical (local to regional) and horizontal (cross to sectoral) collaboration, offering promising perspectives for addressing these challenges. The paper reports a study combining field surveys with multi-source big data analysis to assess neighborhood spatial elements that influence resilience, with the aim to investigate the commonalities and conflicts in sustainable development and improve spatial form at the neighborhood scale. The study takes into account several aspects with qualitatively analyzed, including road networks, building layouts, and functional partition. Once the main features of each neighborhood are assessed, it is possible to address optimized solutions for increasing adaptability to social and environmental challenges. Optimization directions include improving road connectivity, redistributing public facilities, and promoting mixed-use zones. The findings offer actionable insights for urban planners and policymakers, providing strategies to better manage spatial resources and foster more resilient, sustainable urban environments.

## 1. INTRODUCTION

The evolution of contemporary cities involves several interrelated challenges, including increasing population pressure and density, the demand for additional resources and space, significant stress due to socio-economic factors, and the impacts of climate change [1]. With cities largely shaped by traditional and historical models and layouts [2], enhancing their livability while promoting sustainable development requires a clear understanding of their spatial organization and the related influencing factors. In this context, spatial optimization at the urban neighborhood level is a key strategy for achieving sustainable and resilient development in cities [3]. This is because the spatial organization of neighborhoods, as the fundamental units of the urban system, directly influences resource allocation, social interaction, and environmental quality [4]. The necessity of optimizing the spatial form of neighborhoods as a crucial approach to achieving sustainable and resilient development has been widely recognized [3,5]. An increasing number of studies have recognized the importance of capturing the complex and dynamic characteristics of urban space. Some scholars have further explored refined classifications of neighborhood types [6],



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demonstrating that these approaches can improve the accuracy of spatial analysis and provide valuable insights for urban reconstruction and regeneration [2].

This study constructs an assessment framework by integrating multi-source data and field research methods, and a case study is conducted to test its applicability and robustness. The main objectives include: (1) Constructing a neighborhood spatial form assessment framework to identify the impact of key factors such as road networks, building layouts, and functional partition on urban resilience development. (2) Revealing the commonalities and conflicts in spatial form optimization, by classifying and comparing different neighborhood types, analyzing their differences and synergies. (3) Proposing practice-oriented optimization strategies to provide actionable guidance for urban planners and policymakers, to enhance the resilience of cities to social and environmental challenges.

## 2. METHODOLOGY

### 2.1 Framework Development Process

This study develops a neighborhood spatial form assessment framework grounded in established urban spatial theories and empirical analysis results [7–9]. Three core modules: road networks [5], building form [10], and functional partition [9], which were selected - in the first step - due to their dynamic interactions and their direct role in shaping mobility patterns, land use efficiency, and socio-environmental interactions, making them critical for influencing on urban sustainability and resilience [11]. The data collection approach for all elements is multi-source, incorporating open data such as remote sensing imagery, POI (points of interest) data, and road network data. These are further supplemented with objective field measurements and subjective field assessments to ensure data accuracy and reliability. Step 2: In the data analysis stage, the study based on the ArcGIS platform [3] to conduct network analysis, spatial interpolation, buffer analysis, and other spatial analytical methods to calculate various indicators [11], and the dimensional effect is eliminated through Min-Max normalization (0-1 interval) to improve the comparability of the data. The quantitative results are visualized through radar charts. Next, the Ward.D method in hierarchical clustering analysis (HCA) is used to classify the results and identify the spatial form characteristics of different neighborhood types [9]. Step 3: Based on the clustering results, the core characteristics of various types of neighborhoods are summarized, and practice-oriented optimization strategies are proposed. Figure 1 describes in detail the indicator names and calculation formulas of each spatial form element.

### 2.2 Definition of the Indicators and Mutual Interrelations

A well-connected road network (R1, R2) enhances accessibility, facilitating pedestrian and vehicular movement while fostering social and economic interactions (F1, F2). Conversely, low connectivity may be led to greater car dependency, increasing parking demand (R9) and influencing land use patterns (B1, B2). Then density of public transport stop (R3, R4) further shapes mobility choices, as neighborhoods with better transit coverage tend to reduce car reliance, fostering more sustainable and inclusive urban environments. Beyond connectivity, road dimensions (R5, R6, R7, R8) influence transportation modes; wider roads accommodate motorized vehicles but may reduce pedestrian friendliness, whereas narrower streets promote walking and cycling, enhancing public space utilization and supporting small-scale commercial activities (F6, F7, F8, F9). Additionally, spatial compactness (R10) plays a critical role in shaping urban dynamics. Compact neighborhoods encourage pedestrian interaction and efficient land use, while more open layouts provide flexibility for diverse spatial functions.

N <sup>o</sup>	Indicators	Reference	Formulas	Unit	Variables and Definitions
	<b>Road Network</b>				
R1	Number of Road Intersections	[5][8][9]	$R_1 = N_r$	(0-n)	$N_r$ : the number of road intersections.
R2	Road Network Density	[5][8][9]	$R_2 = R_i / S_i$	m <sup>2</sup> /km <sup>2</sup>	$R_i$ : the total length of the road center-line in each unit.
R3	Public Transport Stop Density	[3][9][11]	$R_3 = B_{tb} / S_i$	/km <sup>2</sup>	$S_i$ : the area of the i-th unit (i=1,2,3...n).
R4	Public Transport Stop Density in Buffer Zone	[2][3][9][11]	$R_4 = R_{3B}$	/km <sup>2</sup>	$B_{tb}$ : the number of bus stops b in the unit i (b=1,2,3...n).
R5	Average Width of Street-facing Roads	[5][8]	$R_5 = \sum_{n=1}^{SR} s r_n / SR$	m	$3B$ : the number of bus stops within the 500m buffer zone.
R6	Average Width of Internal Roads	[5][8]	$R_6 = \sum_{n=1}^{IR} i r_n / IR$	m	$s r_n$ : the width of a certain street road section.
R7	Average Width of Street-facing Walkways	[5][8]	$R_7 = \sum_{n=1}^{SW} s w_n / SW$	m	$SR$ : the total width of the street road.
R8	Average Width of Internal Walkways	[5][8]	$R_8 = \sum_{n=1}^{IW} i w_n / IW$	m	$i r_n$ : the width of a certain section of the internal road.
R9	Parking Availability in Buffer Zone	[2][3]	$R_{10} = 2\sqrt{\pi} * S_i / P_i$	(0-n)	$sw_n$ : the width of a certain part of the walkways along the street.
R10	Spatial Compactness	[5][8][11]	$B_1 = M / S_i$	(0-1)	$SW$ : the total width of the walkways along the street.
	<b>Building Layout</b>				
B1	Building Density	[4][8][9][10]	$B_2 = Q / S_i$	(0-1)	$i w_n$ : the width of a certain part of walkways along the internal road.
B2	Floor Area Ratio	[4][9][10]	$B_3 = \sum_{n=1}^{N} h_n / N_b$	(0-1)	$IW$ : the total width of the walkways along the internal road.
B3	Building Height	[4][10]	$B_4 = B_D / B_3$	m	$9B$ : the number of parking lots within the 500m buffer zone.
B4	Building Facade Width-Height Ratio	[4][8][10]	$B_5 = -\sum(b_i * \ln b_i)$	N/A	$P_i$ : the boundary perimeter of each unit.
B5	Building Age Diversity	[4][8][9]	$B_6 = (B_3 * B_L + B_L * B_W + B_3 * B_W) * 2 / B_3 * B_L * B_W$	N/A	$M$ : the average total base area of all buildings in each unit.
B6	Building Form Factor	[8][10]	$B_7 = 2 \ln(P_i / 4) / \ln S_i$	N/A	$Q$ : the total building area in unit n.
B7	Fractal Dimension	[8][10]	$F_1 = F_N / S_i$	/km <sup>2</sup>	$h$ : the height of each building in each unit.
	<b>Functional Partition</b>				
F1	Functional Density	[8][9]	$F_2 = -\sum_{u=1}^u [p_u / \sum_{u=1}^u p_u * \ln p_u]$	N/A	$N_b$ : the total number of buildings in each unit.
F2	Functional Mix	[8][9]	$F_3 = -\sum(\ln l_i)$	N/A	$B_D$ : the distance between buildings on both sides of the street.
F3	Landscape Diversity	[3][8][9]	$F_4 = F_{4N} / S_i$	/km <sup>2</sup>	$b_i$ : quantified by on-site assessment scoring, from 1-3.
F4	Cultural Facility Density	[2][3][7][8]	$F_5 = -\sum_{u=1}^u [p_u / \sum_{u=1}^u p_u]$	N/A	$B_L$ : the average length of the building.
F5	Cultural Facility Density in Buffer Zone	[2][3][7][8]	$F_6 = F_{4N} / S_i$	/km <sup>2</sup>	$B_W$ : the average width of the building.
F6	Residential Service Facility Density	[3][9]	$F_7 = F_{7N} / S_i$	/km <sup>2</sup>	$F_N$ : the number of points of interest (POI) in the unit.
F7	Business Service Facility Density	[3][9]	$F_8 = F_{8N} / S_i$	/km <sup>2</sup>	$u$ : the number of POI categories in the unit.
F8	Social Service Facility Density	[3][9]	$F_9 = F_{9N} / S_i$	/km <sup>2</sup>	$U$ : the total number of POI categories within the research scope.
F9	Food & Beverage Facility Density	[3][9]	$F_{10} = F_{10N} / S_i$	/km <sup>2</sup>	$p_u$ : the ratio of u to U.
F10	Residential Density	[3][9]	$F_{11} = F_{11N} / S_i$	/km <sup>2</sup>	$l_i$ : quantified by on-site assessment scoring, from 1-4.
F11	Shopping Facility Density	[3][9]		/km <sup>2</sup>	$4N$ : the number of cultural facilities in the neighborhood.
					$4B$ : the number of cultural facilities within the 500m buffer zone.
					$6N$ : the number of residential service facilities in the neighborhood.
					$7N$ : the number of business service facilities in the neighborhood.
					$8N$ : the number of social service facilities in the neighborhood.
					$9N$ : the number of food & beverage service facilities in the neighborhood.
					$10N$ : the number of people living in the neighborhood.

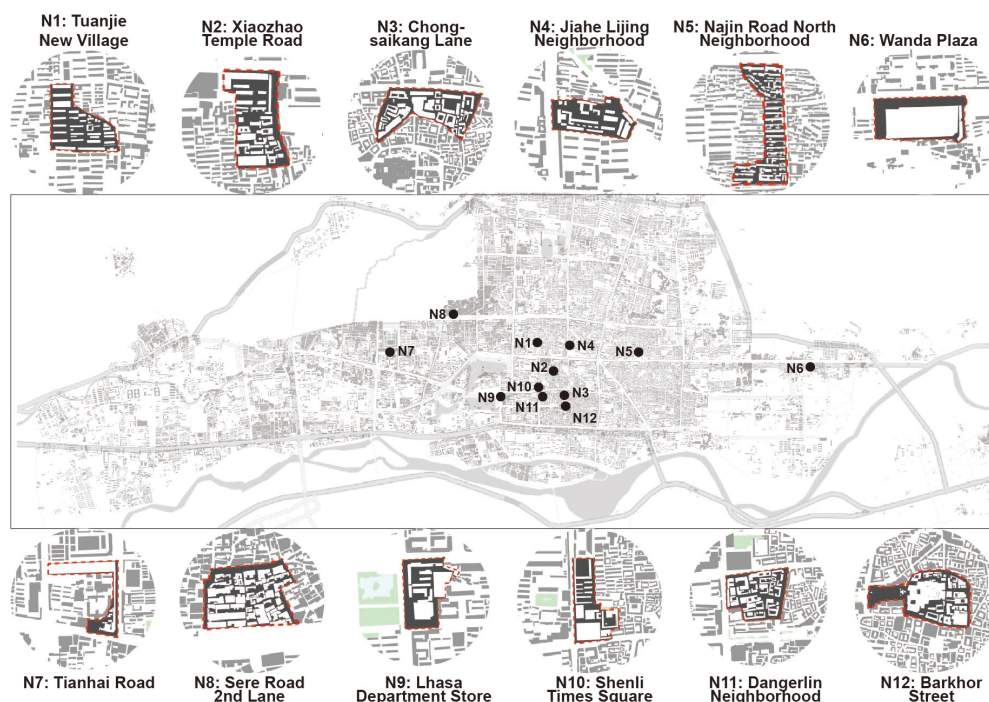
Figure 1. Indicator names and calculation formulas of each spatial form element.

Building density and scale (B1, B2) interact with the road network to define the spatial structure of a neighborhood. High-density areas tend to develop vertically, increasing floor area ratios and fostering mixed-use environments (F1, F2), whereas low-density areas offer more open space. The vertical profile of buildings (B3, B4) influences street vitality; taller buildings create enclosed street environments that support commercial activities, while lower structures contribute to a more human-scaled urban fabric. Form complexity (B5, B6, B7) further shapes neighborhood evolution. Irregular layouts, often found in historical centers, reflect organic growth patterns, characterized by winding alleys, irregular building distributions, and compact spatial arrangements. These features enhance cultural significance (F4, F5) and pedestrian experiences, fostering unique urban identities. In contrast, grid-like or planned spatial forms typically result from zoning policies aimed at optimizing land use efficiency.

The spatial distribution of functions (F1, F2) is crucial in shaping neighborhood resilience and inclusiveness. Mixed-use neighborhoods foster dynamic social interactions, and a well-balanced mix of residential, commercial, and public services (F6, F7, F8, F9, F10, F11) simulates economic activity while reducing reliance on long commutes, by minimizing travel time and energy consumption, thus supporting a more self-sufficient and sustainable urban model. Additionally, cultural facilities and green spaces (F3, F4, F5) further contribute to urban resilience. Green infrastructure mitigates climate-related risks, improving thermal comfort and stormwater management, meanwhile, cultural spaces strengthen community identity and enhance social cohesion. Their distribution often correlates with building density (B1, B2) and road accessibility (R1, R2), reinforcing their role as key urban anchors.

### 2.3 Case Study Description

For the case selection, some clear principles need to be established to ensure the representativeness and reliability of the analysis. These include prioritizing typological diversity



**Figure 2.** Geographical distribution and surrounding texture of 12 typical neighborhoods.

across neighborhoods and ensuring sufficient intra-neighborhood data availability to support comprehensive and comparable analysis.

This study selected Lhasa, China, as the pilot survey area, as exemplary of a spatial structure that has gradually adapted to the needs of modern urban life while retaining certain traditional functions, and undergoing spatial form adjustments [6]. 12 representative neighborhoods in Lhasa’s main urban area were selected as the research objects, where implement the assessment framework data collection is divided into two parts: online open data collection (3-9th, June 2021) and field survey (11-15th, June 2021), covering working days and rest days to ensure time-series integrity. The data collection period was free from extreme weather, special holidays, or large-scale events that affected the representativeness of the data. The research team consists of eight researchers in urban planning and architecture, including Han master’s students and Tibetan undergraduate students, ensuring a balance between professional perspectives and local cognition. Figure 2 illustrates the geographical distribution and surrounding texture of 12 typical neighborhoods.

### 3. RESULTS

Figure 3 shows the visualization results of 12 selected neighborhoods after the quantitative calculation of assessment, enabling easy comparison of different neighborhoods' spatial patterns. Each radar chart represents the spatial characteristics of an individual neighborhood, covering three dimensions: road network (red), building layout (gray), and functional partition (green). The chart axes correspond to specific indicators (R1–R10, B1–B7, F1–F11), with values reflecting their

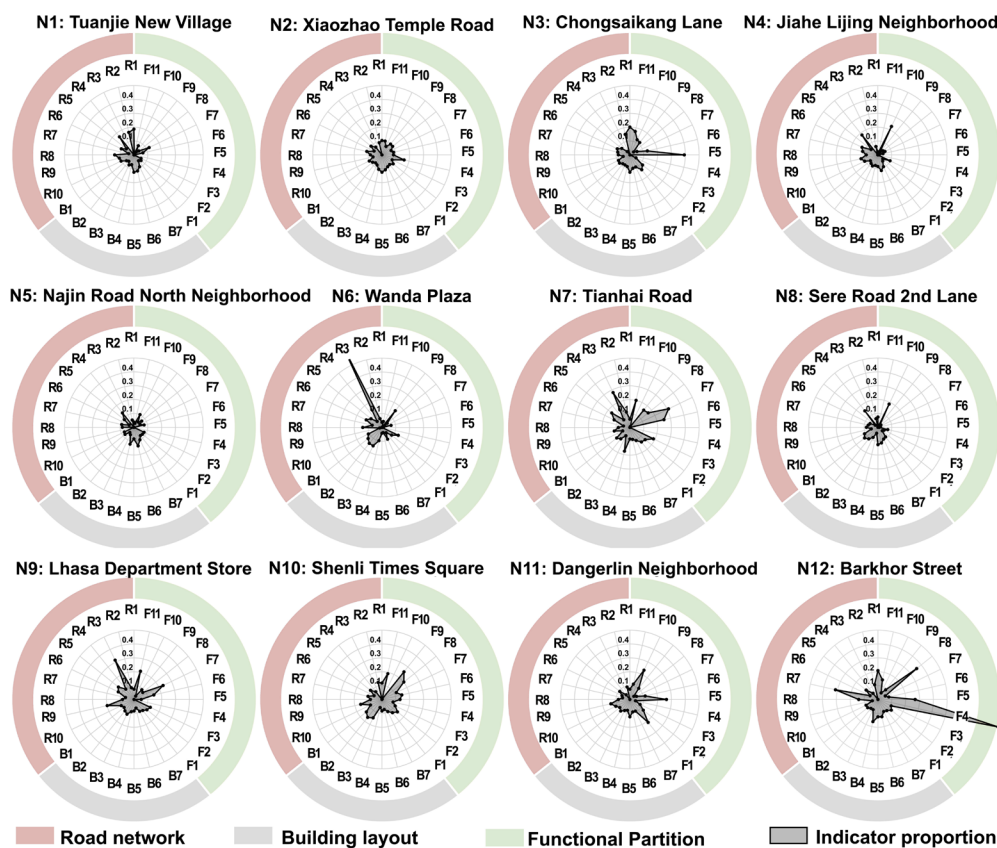


Figure 3. Visualization results of spatial form assessment.

proportional contribution to the neighborhood’s spatial composition. Figure 4 illustrates the hierarchical clustering results. Each row corresponds to a specific indicator, while each column represents a neighborhood. The numerical values indicate the quantitative result of each indicator in this neighborhood (not standardized), with higher values signifying stronger characteristics. The color intensity of the cells reflects these proportions, with darker shades of green representing higher values and lighter shades indicating lower values. The dendrogram beneath the table illustrates the clustering process, the analysis shows that these neighborhoods can be summarized into four categories. According to the overall characteristics of these four types of spaces, they are named as follows: modern commercial neighborhoods, modern residential neighborhoods, mixed-function neighborhoods, and traditional historical neighborhoods. A difference in road networks, building forms, and functional partitions is as follows:

Modern commercial neighborhood are characterized by high-density development, vehicle orientation, and concentrated commercial functions. Service facilities are highly concentrated; for example, Wanda Plaza has a catering facility density of 19.67 and a shopping facility density of 9.33, far exceeding other neighborhoods, indicating high-intensity commercial activity and strong attraction. High-rise buildings and high-volume ratios are the prominent features, such as Shenli Times Square, with a floor area ratio of 2.68, exemplifying a vertical development model. The height of buildings is mostly around 20m, which makes the space utilization rate high, but may lead to a certain sense of space oppression. Roads are wide with few intersections, benefiting cars but reducing walkability. Public transport is abundant, but parking is limited, which may lead to congestion. Cultural elements are scarce, reflecting a focus on modern commercial growth over traditional cultural gathering spaces.

Modern residential neighborhood are mainly characterized by low-density development, residential function-dominated, and motor vehicle-oriented. The building density is low, for example, the building density of Jiahe Lijing Neighborhood has a building density of only 0.32, with building height generally ranging from 8 to 12m. Functions are singular, and commercial facilities

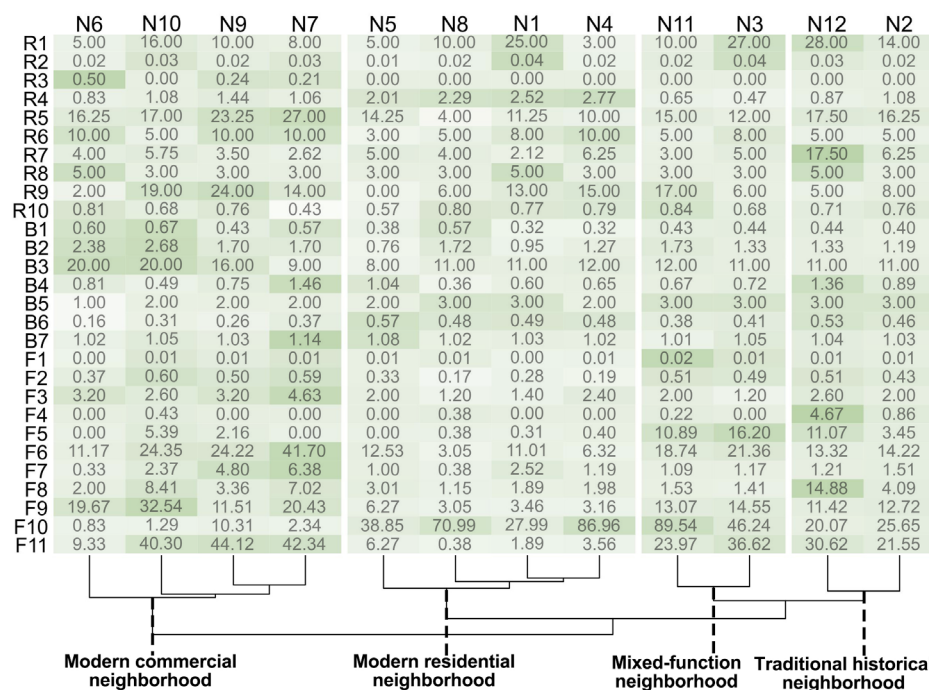


Figure 4. Hierarchical cluster analysis results.

are minimal, indicating a primarily residential focus. The parking convenience is high, and sufficient parking facilities are typically incorporated into the neighborhood's design. However, the pedestrian environment is constrained, featuring narrow sidewalks, such as the sidewalk width of Tuanjie New Village is only 2.12m, leading to a poor walking experience. The landscape environment is well-developed, with a landscape diversity index between 2.0 to 2.4, creating a more comfortable living atmosphere.

Mixed-function neighborhood combine high-density compact spaces, diverse functions, and coexisting commercial and residential areas. The building density is high, maximizing space use. For example, the Danjielin Neighborhood has a building density of 0.43 and spatial compactness of 0.84, indicating closely packed structures. Functional integration is strong; for instance, Danjielin's Neighborhood's functional density is 0.02, and the functional mix is 0.51, indicating that the neighborhood not only contains many residential spaces but also has commercial activity places, forming a strong integration feature. The neighborhood road network is dense and accessible. Chongsaikang Lane has 27 intersections, and Danjielin Neighborhood has 10. The streets and lanes inside the neighborhood are intertwined, which is suitable for walking activities. However, parking resources are limited. Also, cultural facilities are limited, and the historical ambiance is weaker than in traditional historical neighborhood.

Traditional historical neighborhood emphasize a rich cultural atmosphere and pedestrian-oriented movement. The density of cultural facilities is extremely high; for instance, Barkhor Street is 4.67, reflecting the importance of the neighborhood in the protection of traditional culture and historical heritage. The pedestrian network is well-developed and highly accessible. The streets and alleys are densely populated; for example, Barkhor Street has 28 intersections, representing a typical small-scale pedestrian street model. The building façade width-to-height ratio is 1.36, and the heights are relatively low (11 m), reinforcing the traditional enclosure with a distinct historical style. The functions are highly mixed, commercial, residential, and cultural activities are highly integrated, with Barkhor Street's functional mixing degree at 0.51, creating a strong spatial appeal. However, the streets are narrow, restricting motor vehicle traffic and parking, which further reinforces the pedestrian-oriented travel mode of the neighborhood.

#### **4. Discussion and Conclusion**

The interplay among these elements suggests that urban resilience is best achieved through coordinated, adaptive interventions rather than isolated modifications, where changes in one module should be accompanied by corresponding adjustments in the others. Firstly, strengthening road network connectivity enhances urban resilience. Modern commercial and mixed-function neighborhoods require increased intersection density and pedestrian-oriented pathways to improve walkability, reduce car dependency, and mitigate emissions. In contrast, traditional historical and modern residential neighborhoods, often characterized by fragmented layouts, benefit from a hierarchical street system that improves mobility while maintaining spatial integrity. Transit-oriented development (TOD) ensures seamless integration of walking, cycling, and public transit, minimizing disruption to existing urban forms. Secondly, optimizing the building layout improves spatial adaptability. Effective building layouts need to balance spatial efficiency and environmental quality. High-density neighborhoods like modern commercial neighborhood and mixed-function neighborhood require compact design that avoids overcrowding while incorporating human-scale design and cultural spaces. Conversely, low-density neighborhoods, like modern residential neighborhood, often face underutilization, which can be addressed by integrating commercial, residential, and public spaces within building

clusters. In traditional historical neighborhood, where enclosed spatial forms dominate, the focus lies on preserving heritage while enabling adaptive reuse. Dynamic and adaptable functional partitioning reduces urban fragmentation and fosters inclusive communities. Thirdly, the modern commercial neighborhood with few residential areas tends to become inactive after business hours, while the modern residential neighborhood shows the opposite pattern. Therefore, promoting a balanced mix of commercial, residential, and leisure functions helps reduce commuting distances and improve daily convenience. Multi-functional public spaces strengthen social cohesion and improve resilience to external shocks such as climate events. Across all neighborhood types, green infrastructure, such as permeable pavements and tree-lined streets, contributes to climate adaptability and is commonly integrated to enhance environmental performance.

This study adopts a structured, classification, and data-driven approach, based on multi-source data analysis and field research, to develop a spatial form assessment framework at the neighborhood scale. The findings reveal distinct spatial characteristics across different neighborhood types and demonstrate the potential of a structured assessment approach in optimizing spatial configurations. The proposed framework has good portability and adaptability, while it is worth noting that when applied in other cities, it still needs to be moderately adjusted according to local socio-cultural background and climatic conditions. For example, in the case cities selected for this study, the assessment of cultural facilities focuses more on traditional elements of Tibetan Buddhism, such as temples, pagodas, and prayer flags; while in some European cities, more attention is usually paid to other cultural, religious or social elements of urban fabric. In addition, for subsequent research, it is recommended to expand the case comparison database to further improve the adaptability and accuracy of the assessment framework.

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