Multi-Source Big Data-Driven Coupling Study of Spatial Quality and Vitality in Historic Districts: A Case Study of Nanqiang District, Kunming

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Abstract

With the increasing demand for urban renewal and cultural heritage preservation, the spatial quality and vitality of historic districts have become key issues in urban planning. This study takes the Nanqiang Historic District in Kunming as a case study and constructs a multi-source big data-driven analytical framework to explore the coupling between spatial quality and urban vitality. Utilizing POI data, streetscape imagery, and Baidu heatmaps, the study integrates GIS spatial analysis, semantic segmentation, and kernel density estimation to assess spatial quality in terms of functional types, environmental attributes, and design features. By incorporating temporal activity patterns and population types, it further examines vitality dynamics and spatial distributions. The study reveals the interaction mechanisms between spatial quality and vitality, and proposes optimization strategies including "spatial reconfiguration," "lifestyle empowerment," and "cultural continuity." The findings provide a scientific basis and practical guidance for the sustainable renewal and revitalization of historic urban spaces.

Keywords

Historic District, Spatial Quality, Urban Vitality, Multi-Source Big Data, Street Space Optimization.

1. Introduction

1.1. Research Background

As witnesses of urban history, historic districts carry the cultural heritage and memory of cities.[1] They represent the distinctive characteristics and charm of urban development and the cultural diversity of different regions. Protecting and rationally utilizing historic districts contribute to sustainable urban development by balancing heritage preservation with modern urban needs.

The application of big data technology offers new opportunities for urban and rural research and planning. In historic districts, big data provides detailed information about street spaces and their usage. By integrating streetscape imagery, social media data, and pedestrian activity records, planners can gain a clearer understanding of the current conditions of historic districts, enabling more informed spatial analysis and decision-making.

Nanqiang Historic District is one of the only two officially recognized historic and cultural streets in Kunming. Located in the city's central area, it preserves a unique combination of historic architecture and cultural-commercial atmosphere. These types of districts play a vital role in both urban development and cultural heritage protection. The integration of multi-source big data brings new possibilities for their planning, protection, and revitalization.

1.2. Literature Review

In the field of street space research, international studies tend to focus on urban design, environmental quality, public health, and pedestrian experiences, emphasizing empirical analysis and interdisciplinary approaches.[2-5] In contrast, domestic studies prioritize qualitative and quantitative analysis of various street types, concentrating on physical elements and theoretical frameworks rooted in local context and practice.[6-11] Overall, traditional methods and single-perspective approaches dominate current research, but there is a growing trend towards the integration of new methods and data technologies.

2. Research Framework and Methodology

2.1. Overview of the Study Area

This study selects the Nanqiang Historic and Cultural District in Kunming as the case study site. Located in the old city center, Nanqiang is a provincially designated historic cultural district and one of the few central urban areas preserving both historic architectural styles and vibrant cultural-commercial functions.

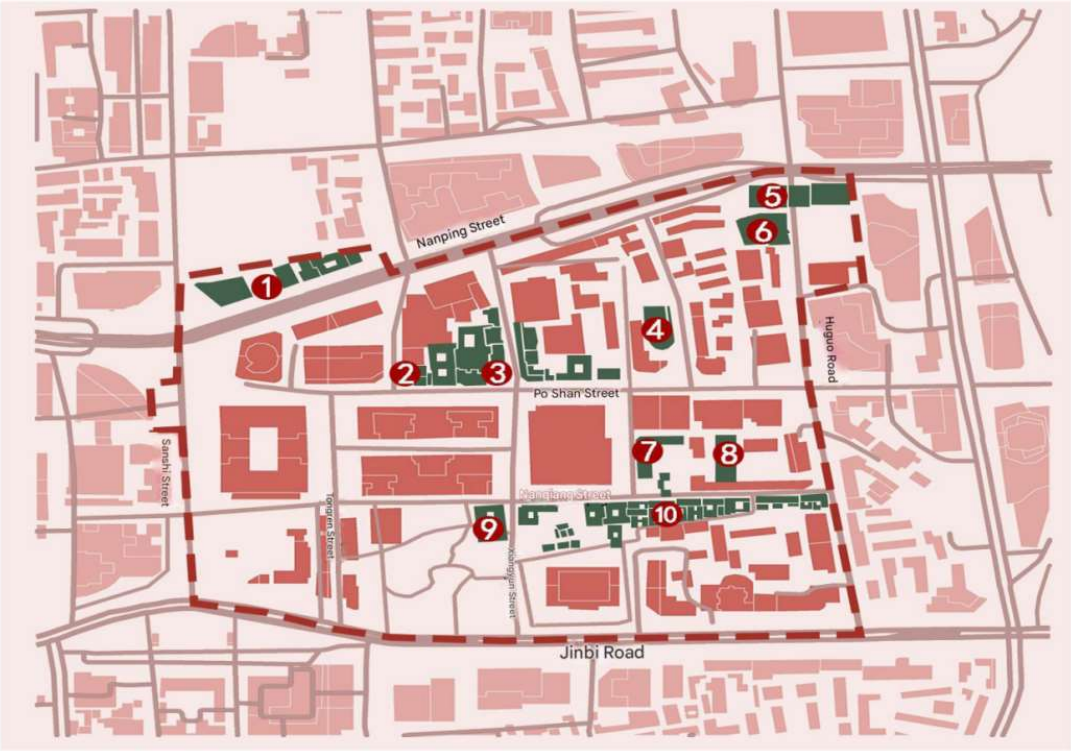


Figure 1. Location Map of Study Area

1.Modern and Contemporary Financial Architecture;.2.Baoshan Street;3.Flying Tiger Club;4.Nanping Cinema;5.Huguo Bridge;6.Former Site of Yunnan Mining Bank;7.Young Men's Christian Association;8.Kunming Branch of the Chinese Academy of Sciences;9.Renhe Xiang ;10.Nanqiang Street and Lane

2.2. Research Data and Method

This study adopts a multi-source big data analytical approach, combining semantic segmentation of streetscape images with GIS-based spatial analysis to investigate the spatial structure, street quality, and vitality characteristics of Nanqiang Historic District. A comprehensive street space database is constructed through the integration of various datasets. Baidu heatmaps are utilized to capture the spatiotemporal evolution of vitality patterns, aiming

to reveal the coupling mechanisms between spatial quality and vitality, and to provide scientific support for urban renewal strategies.

Table 1. Research Data and Characteristics

Research Data	Data Characteristics and Applications
OSM Open Data	Obtain street data of Kunmingshang District, investigate geographical information, street layt, and building distribution information
POI Data	Understand functional facilities along the street, such as shops, cultural facilities, and public services, depict the functional characteristics and service layout of the street
Street View Data	Segmented analysis of street greenery, greeneing rate, and interface continuity through imagery language
Baidu Heatmap Data Field Survey Data	Understand the vitality characteristics of the street at different times and spaces, including population density and activity hotspots, such as observattion decks, green spaces, and small squares

2.3. Research Content

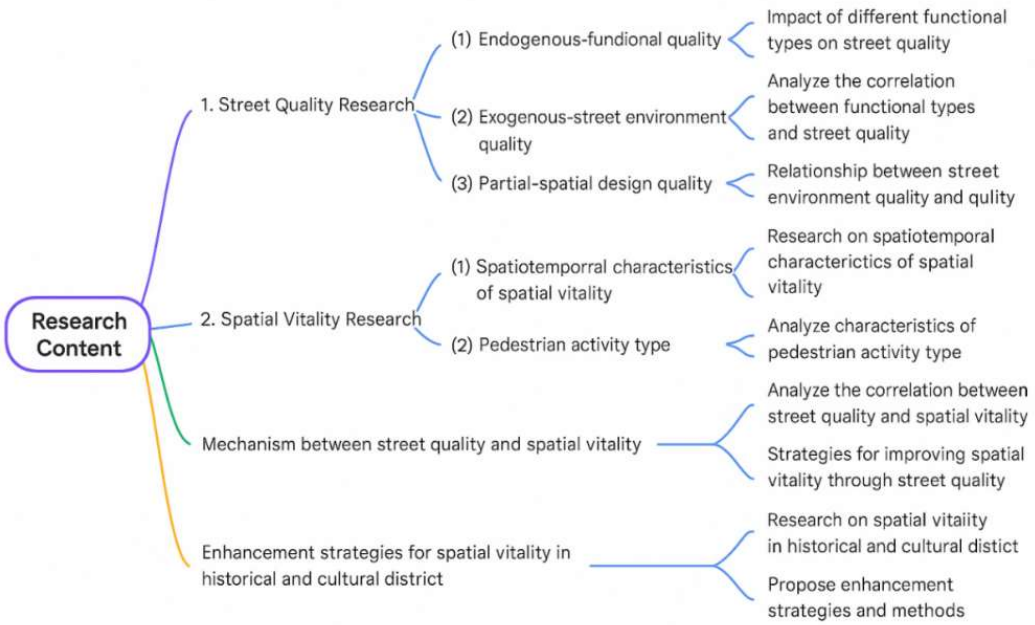


Figure 2. Structure of Research Content

This study systematically explores the relationship between street spatial quality and vitality from four perspectives: (1) analysis of spatial quality in terms of internal function, environmental perception, and localized design; (2) investigation of vitality features, focusing on temporal patterns and user behavior across different times and groups; (3) identification of the interaction mechanisms between spatial quality and vitality; and (4) proposal of spatial optimization strategies tailored to the characteristics of historic districts, aiming to provide theoretical and practical guidance for urban regeneration and heritage conservation.

3. Street Quality Assessment

3.1. Functional Typology Assessment

3.1.1. Street Function Type Analysis

Based on POI (Point of Interest) data, this study conducts classification and spatial distribution analysis of street function types. POI data from platforms such as Baidu Maps, Amap, and OpenStreetMap were collected and preprocessed. The POIs were categorized by type, and kernel density estimation and grid-based spatial analysis methods were used to calculate the density of each category at the street level. Clustering algorithms (e.g., K-means, DBSCAN) were applied to identify functional zones based on POI density features. These zones were then labeled using POI category data. The spatial boundaries and transitions between functional areas were also analyzed and visualized using GIS software such as ArcGIS and QGIS.

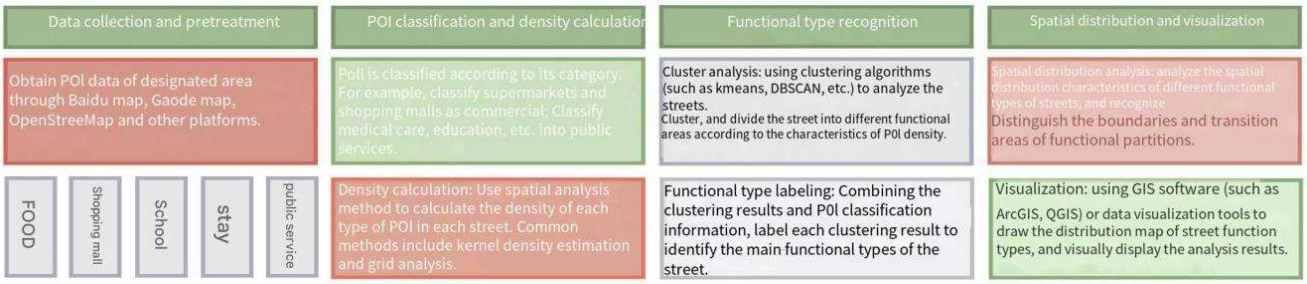


Figure 3. Data Collection and Preprocessing

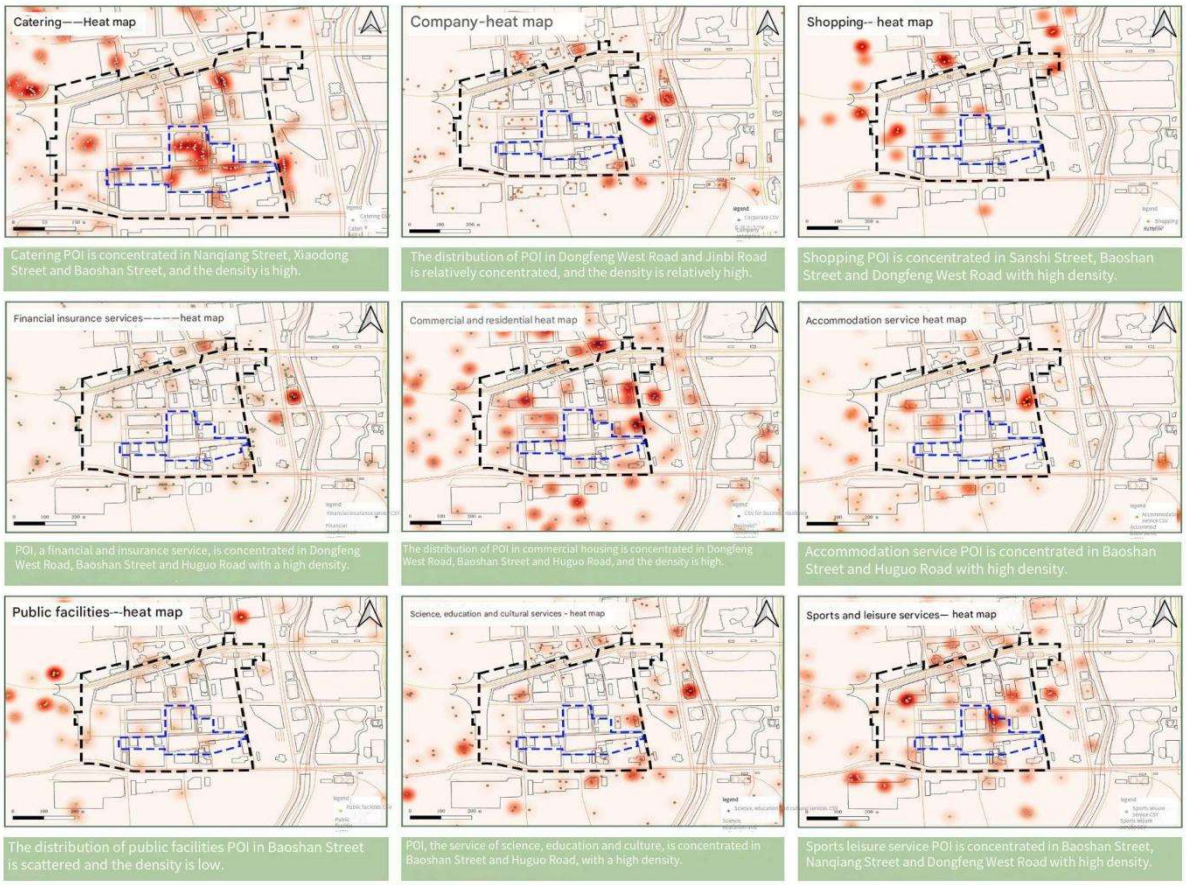
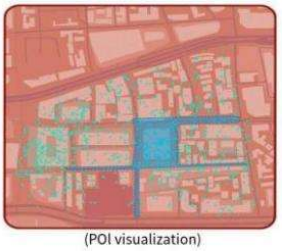


Figure 4. Street Function Type Distribution Map

The analysis reveals significant spatial clustering of various POI types. A heatmap analysis of thirteen POI categories-including dining, business, retail, finance, residential, lodging, public facilities, education and culture, sports and leisure, life services, healthcare, government and social organizations, tourist attractions, and transportation-shows that dining POIs are heavily concentrated in Nanqiang, Xiaodong, and Baoshan Streets. Financial and residential services cluster near Dongfeng West Road and Huguo Road. Retail and life services are also concentrated in Baoshan Street and Dongfeng West Road. Healthcare POIs are sparsely distributed. These results reflect spatial organization differences in urban street functionality.

3.1.2. Commercial Format Statistical Analysis

The study identifies a total of 1,106 valid POIs in the area, with an overall density of 0.837. The dominant categories are retail (35.6%) and dining (30%), indicating a strong commercial orientation. These are followed by leisure and life services (27.1% and 10.7%, respectively). Lodging and tourism-related POIs are less prominent, accounting for 3.4% and 0.27%. Visualizations and kernel density analysis further confirm that retail and dining POIs are densely clustered in the core district, forming a commerce-dominated spatial pattern.



(POI visualization)

Quantitative table of business indicators

Proportion of single format

	Catering gourmet	Shopping consumption	Hotel accommodation	scenic spot/tourist attraction	leisure and entertainment	Life service	Total	Business density
Distribution quantity	332	394	38	three	40	119	1106	0.837
Distribution proportion	thirty percent	35. 6%	3. 4%	0. 27%	27. 1%	10.7%		

Single format nuclear density analysis chart

(Food and beverage) (shopping consumption category) (Hotel accommodation) (leisure and entertainment) (life service category)

Figure 5. POI Data Statistics

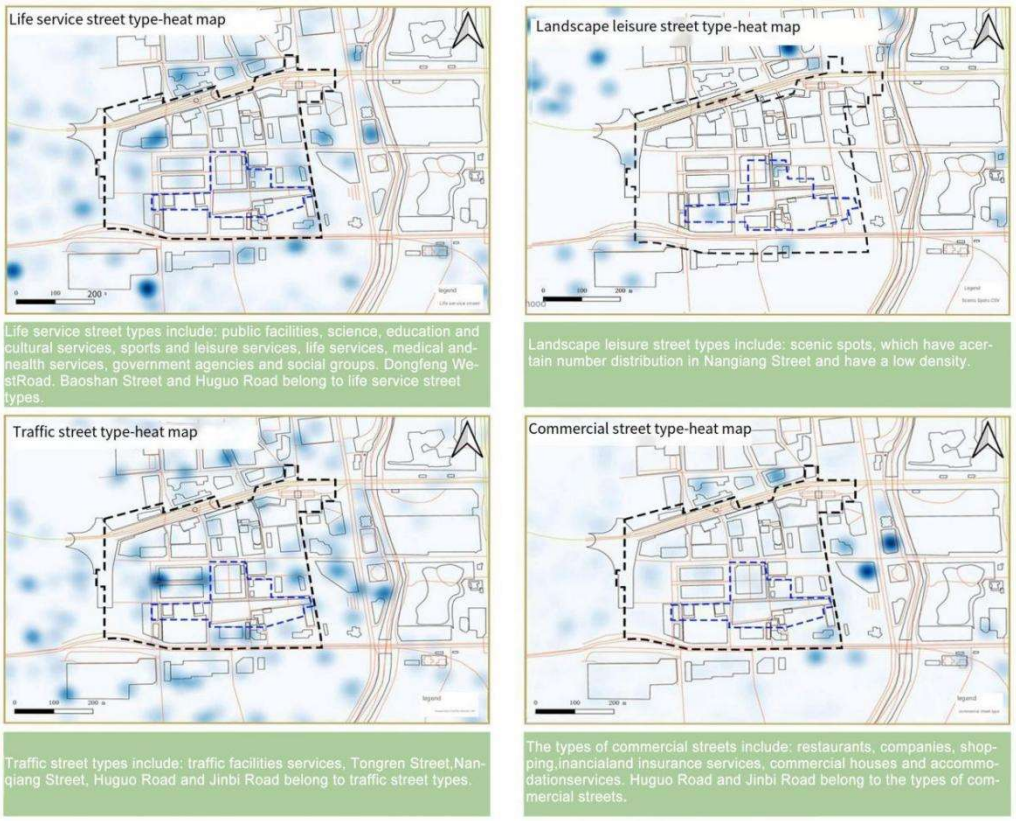


Figure 6. Street Function Type Heatmap

The heatmap identifies four primary functional street types: life service-oriented (e.g., Dongfeng West Road, Baoshan Street, Huguo Road), landscape and leisure-oriented (e.g., Nanqiang Street), transport-oriented (e.g., Tongren Street, Jinbi Road), and commercial-mixed (e.g., Huguo Road and Jinbi Road).

3.2. Environmental Quality of Streets

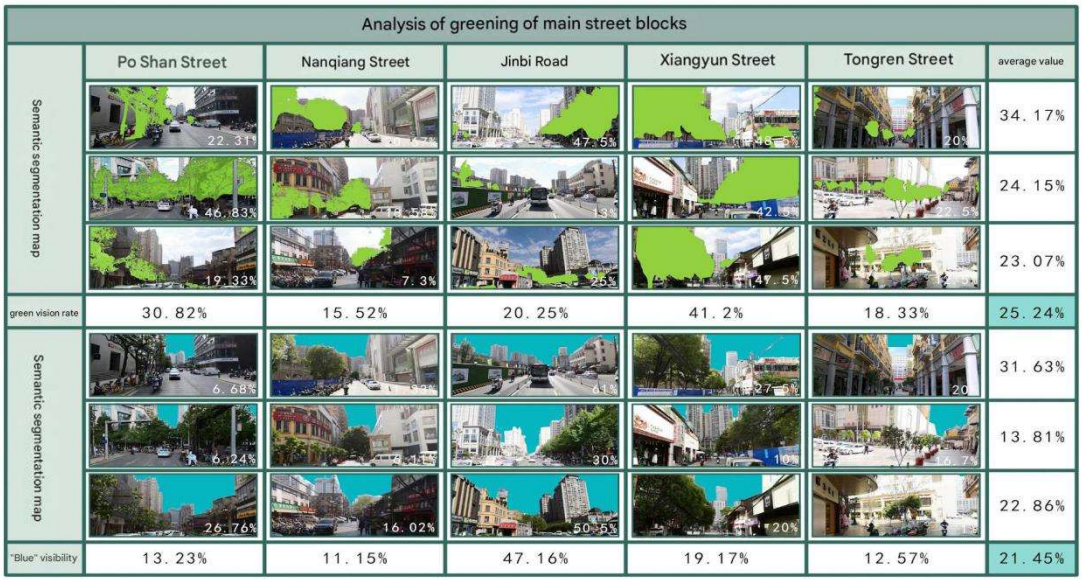


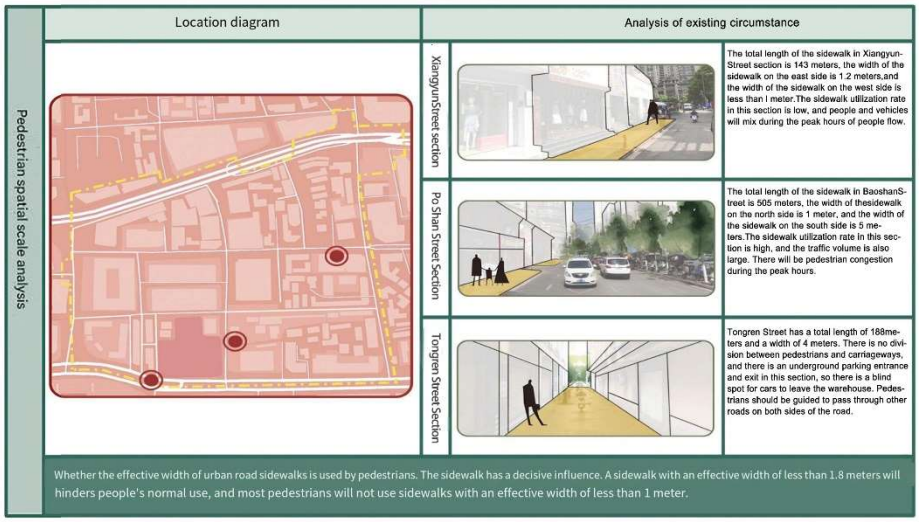
Figure 7. Environmental Quality Analysis Map

Using semantic segmentation techniques, the study assesses the greening rate and sky visibility along major street segments. The average green view index is 25.24%, and the blue sky view

index is 21.45%. Xiangyun Street shows the highest green view (41.2%), while Jinbi Road has the highest sky visibility (47.16%). Nanqiang Street shows lower overall ecological visual quality.

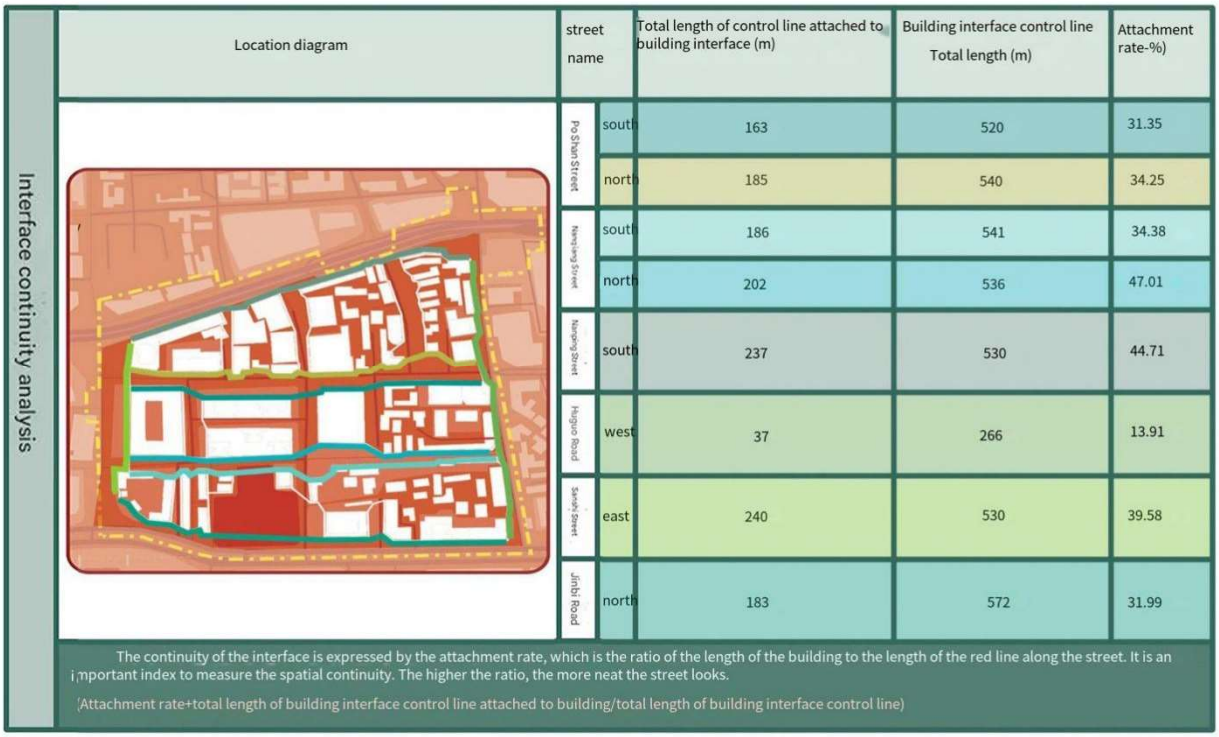
3.3. Spatial Design Quality

Table 2. Sidewalk Dimension Analysis



Pedestrian space and interface continuity are analyzed to assess the walkability of the street environment. Streets such as Xiangyun suffer from severely narrow sidewalks, affecting comfort and safety. Interface continuity analysis shows higher values on Huguo Road and East Sanshi Street (74.11% and 58.49%, respectively), indicating greater spatial guidance and vitality potential.

Table 3. Interface Continuity Analysis



4. Spatial Vitality Study

4.1. Temporal Characteristics of Street Vitality

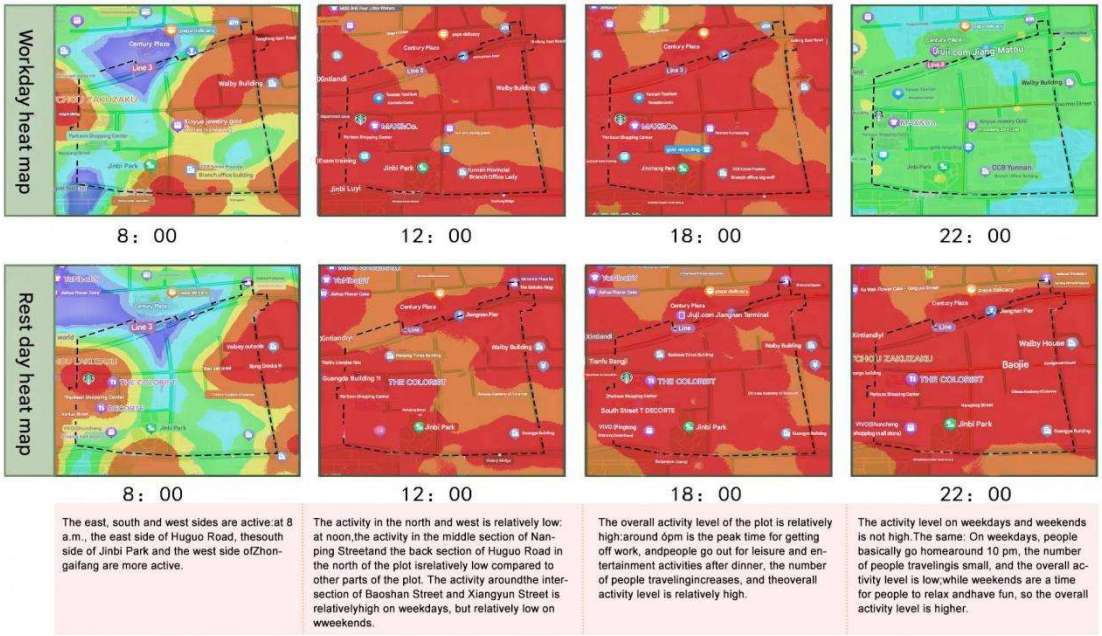


Figure 8. Heatmap Comparison by Time Period

Baidu heatmap comparisons reveal differences in pedestrian activity between weekdays and weekends. Activity peaks at noon and 6 p.m. on weekdays, with a sharp drop after 10 p.m. On weekends, activity remains relatively stable at 8 a.m. and 10 p.m., indicating greater flexibility and extended mobility times. Spatially, Huguo Road, Jinbi Park, and Zhongaifang emerge as high-activity zones due to strong functional support and public attraction.

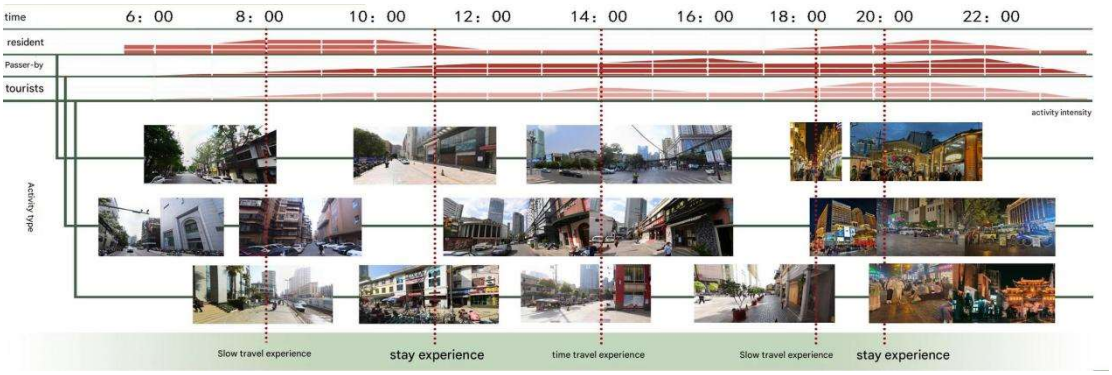


Figure 9. Activity Types by Time and User Group

The study analyzes the intensity of activity across three user types-residents, passersby, and tourists-at different times of day. Residents are most active in the early morning and evening, while tourists dominate the midday and evening periods. Passersby are more evenly distributed. Three primary spatial experiences are identified: walking, lingering, and transiting, with patterns varying by time and user type.

4.2. Spatial Expression of Street Vitality

Four dimensions of spatial support are analyzed: accessibility to public and transport facilities, layout of parks and plazas, and continuity of historical context. Areas with high facility density exhibit strong spatial attraction. Historical buildings form unique cultural paths, and optimized

green space distribution enhances vitality and user experience, reflecting the integration of function and culture.

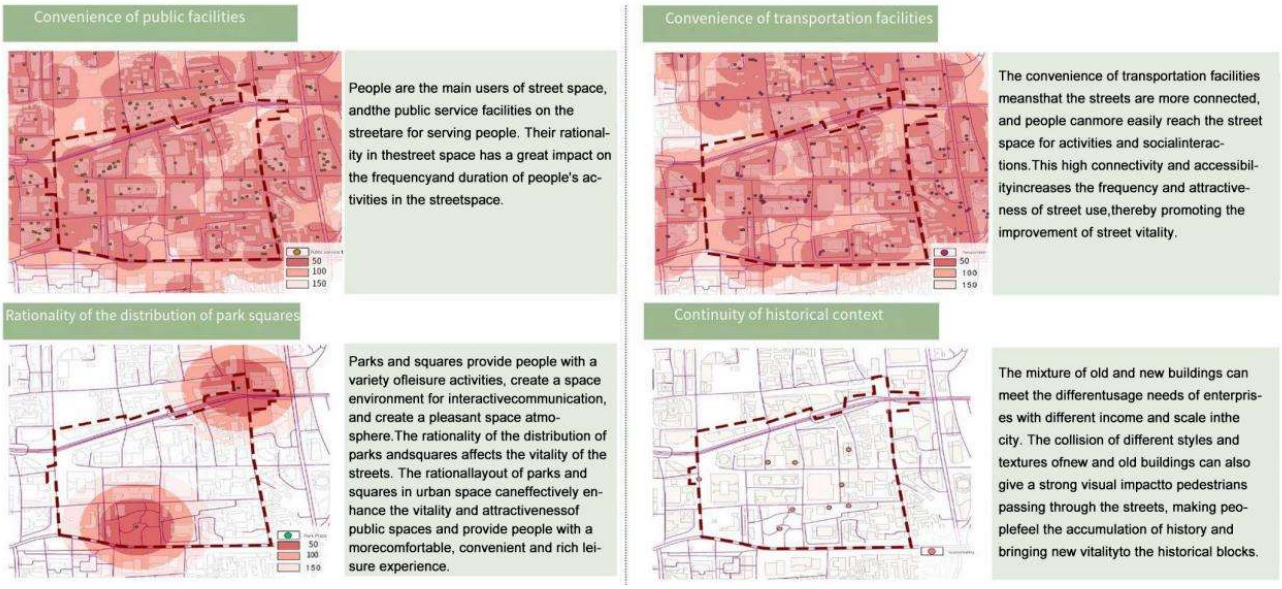


Figure 10. Public Space Experience Analysis

Activity frequency and time distribution are further analyzed across street and architectural space types. Nanchang Street and Nanqiang Street (commercial and transport-oriented) show high usage around 6 p.m. Plazas and commercial buildings also have high frequency and prolonged evening use.

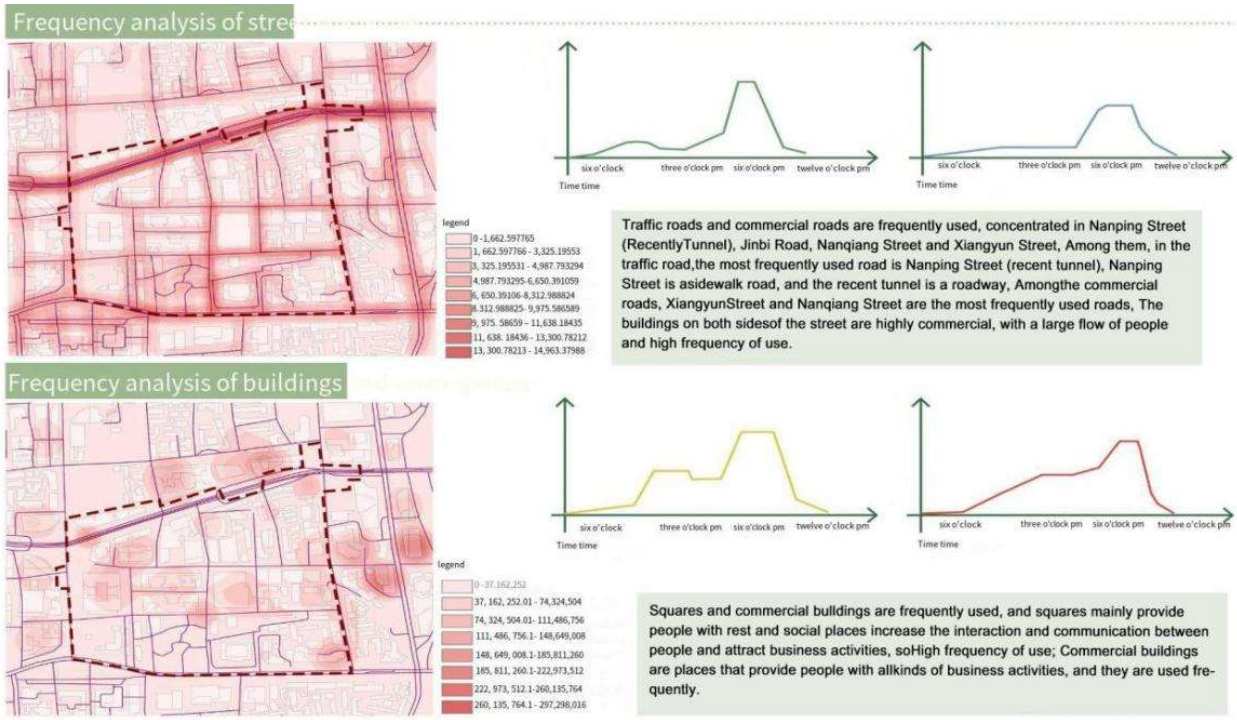


Figure 11. Public Space Usage Frequency Analysis

5. Rategies for Enhancing Spatial Vitality in Historic Districts

5.1. Strategies for Improving Street Quality and Vitality

Figure 12. Street Space Quality Transformation Strategies

Five street space transformation strategies are proposed: "spatial reconfiguration," "lifestyle empowerment," "cultural embedding," "visual expression," and "heritage continuity." Implementation paths are tailored to street types. For example, Baoshan Street (life service-oriented) should enhance pedestrian access and amenities; Nanqiang Street (commercial) should focus on storefront redesign and tenant mix; Xiangyun Street (leisure) should improve visual identity through cultural and aesthetic enhancements; and Jinbi Road (transport) should prioritize accessibility and digital infrastructure. Emphasis is placed on multifunctional public space and cultural scene creation, improving accessibility, sociability, and cultural identity.

5.2. Strategies for Enhancing Historic District Layout

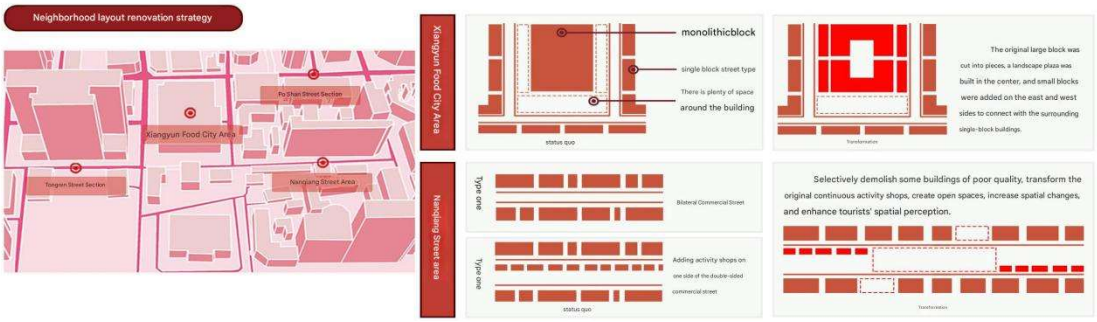


Figure 13. Layout Optimization Strategies for Historic Districts

Specific spatial transformation strategies are proposed for Xiangyun Food District and Nanqiang Street. For Xiangyun, the introduction of smaller buildings, central plazas, and spatial subdivision improves openness and connectivity. For Nanqiang, selective demolition, recreational nodes, and street activation improve spatial perception and visitor experience.

5.3. Integrated Spatial Vitality Enhancement Strategies

A holistic strategy is proposed to enhance spatial vitality through multifunctional space creation and diverse user needs. Key nodes integrate cultural flash events, science exhibits, smart fitness, and farmers' markets. Spaces for all ages and uses are embedded, including light installations, exercise zones, elder care services, chess areas, and reading lounges. Weekend markets and mobile amenities add flexibility. This approach follows the path of "node activation-functional overlay-perceptual enhancement," transitioning streets from transit spaces to vibrant public realms with interaction, relaxation, and cultural engagement.

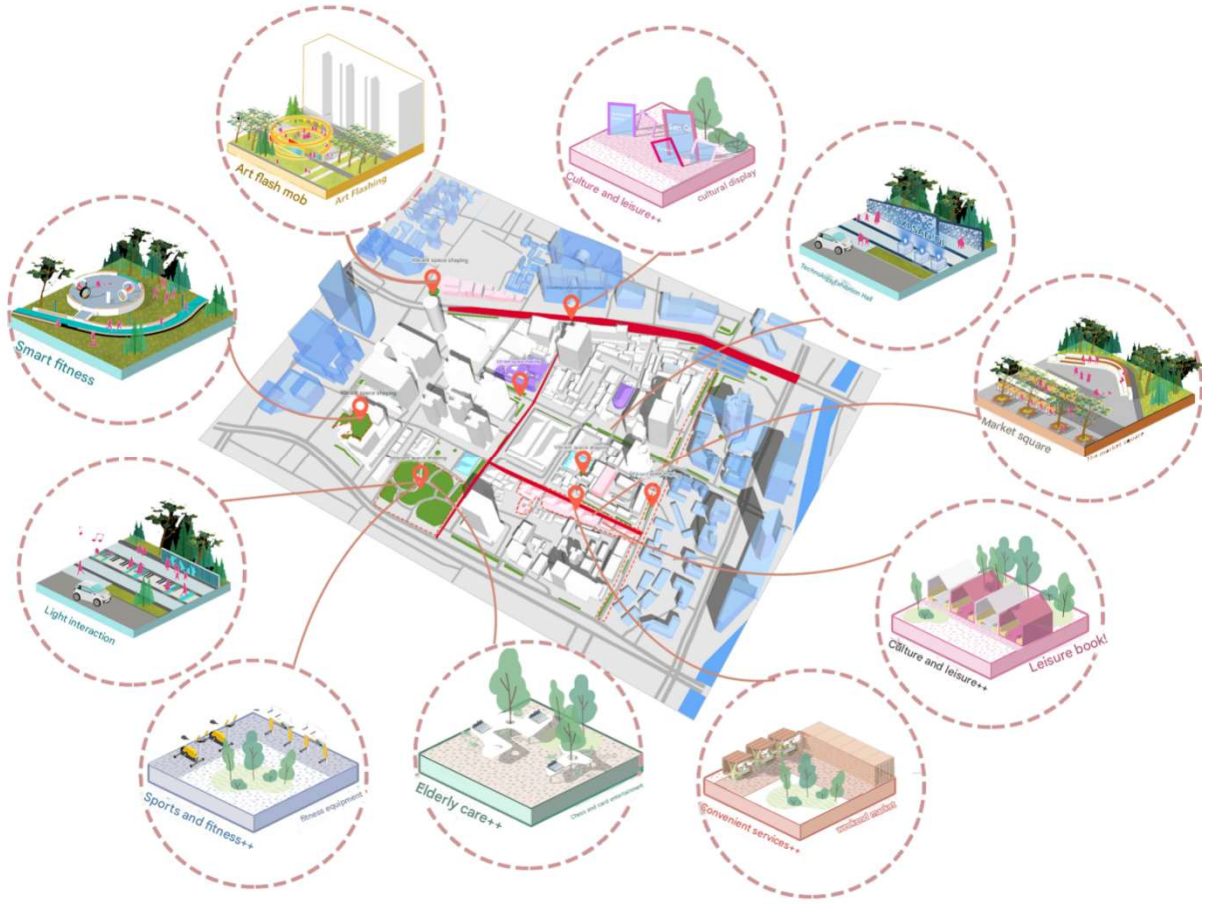


Figure 14. Spatial Vitality Strategy Framework

A multi-stakeholder coordination model is also introduced, involving government, residents, tourists, and businesses. Government ensures policy, renovation, and service provision. Residents benefit from improved living and social interaction spaces. Tourists enjoy optimized leisure and cultural routes. Businesses contribute through façade and tenant upgrades. Spatially, emphasis is placed on green systems, slow traffic networks, node activation, and scene building-ultimately forming a people-centered, functionally mixed, and livable environment for historic street revitalization.

Figure 15. Systematic Spatial Quality Improvement Strategy

6. Conclusion

This study constructs a coupling analysis framework for street spatial quality and vitality based on multi-source big data, using Kunming's Nanqiang Historic District as a case. Four main street types were identified: life service, commercial, leisure, and transport-oriented, with varying characteristics in green view, interface continuity, and pedestrian scale. Temporal vitality distribution reveals strong coupling between high-quality space and active use.

Based on these findings, five optimization strategies were proposed-spatial reconfiguration, lifestyle empowerment, cultural embedding, visual expression, and heritage continuity-with customized interventions for different street types. For instance, improving access and facilities on Baoshan Street, upgrading storefronts on Nanqiang Street, and opening alley networks in Xiangyun District. A methodology of "node activation, user perception, and functional overlay" is emphasized to transition from transit-oriented space to multifunctional, culturally vibrant public space, integrating heritage protection with contemporary urban vitality.

Acknowledgments

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