Analysis of Crowd Behaviour Intensity in Historic Urban Areas from the Perspective of Transportation Spatial Pattern: Case Study of Kunming, China

Yi Zhang , Jie Jiang

School of Geomatics and Urban Spatial Informatics, Beijing University of Civil Engineering and Architecture, Beijing, China – 1108160025008@stu.bucea.edu.cn, jiangjie@bucea.edu.cn

Keywords: Historic Urban Area, Transportation Spatial Pattern, Crowd Behaviour, Quantitative Approach

Abstract

Historic urban areas occupying an essential position in the context of urban heritage preservation and sustainable development for possessing unique regional characteristics. However, its complex crowd structure and behaviour formed in the course of history presents challenges to traditional urban space research methods. The study aims to propose an integrated approach of conventional research method and quantitative technique, focusing on double validation of spatial characteristics that impact crowd behaviour of historic urban areas. By focusing on historic spots with residential and functional land-use around, the study takes historic and cultural district in Kunming, China to conduct analysis of spatial patterns and road conditions. The findings demonstrate the connection between road conditions and individual choices, explaining the patterns of crowd activity in historic urban areas. The study provides an innovative methodological perspective for the research of historic urban areas, highlighting potential spatial conflict between indigenous residents and large numbers of tourists, which set forward the requirements for timely and adaptive scientific spatial planning for historic districts.

1. Introduction

The United Nation’s Sustainable Development Goals (SDGs) demonstrates a series of principles for urban spaces designing to follow, which emphasize the integration of inclusivity, safety, and sustainability (Chen et al., 2025) - especially of Goal 11.4 that focus on historical districts promotion, presenting connectivity of cities and communities. For historic districts in urban area, UNESCO provided a definition for which as a hub for cultural, social, and economic activities, as well as the representative of diverse and abundant expression of shared heritage (Duan, Lan and Jiang, 2022). Those statements provide a rational conceptual foundation for the protection of historic districts, also referred to the Athens Charter of 1943 that proposed the early concept of historic area, emphasizing that buildings and districts of historical significance required to be appropriately preserved instead of demolishing (Corbusier, 1943). To satisfy the sustainable protection of a complex system that encompass all the elements and human activities of urban areas, but also involving the tangible and intangible cultural heritage elements-which set historic urban areas apart from modern urban areas, it is essential to take advantages of digital and multidisciplinary approach, for the analysis and evaluation of multi-level big data (Zhao et al., 2024; Fu et al., 2025).

Space syntax theory, first introduced by Bill Hillier, focusing on the relationships between space physical and human behaviour, which has been widespread applicated in architecture and urban planning for the quantitative analysis of spatial structures on mathematical and graph level (Hillier, 1996; Yang, Jin and Fu, 2024). Based on the purpose to create an efficient, functional and attractive environments by revealing the pattern of human activity, space syntax theory is supportive on the evaluation of space correlation, street accessibility and spatial perception, playing a role in optimize space usage and motivate social interactions. Combined with the explanation of spatial configuration rules by space syntax model, Point of Interest (POI) data provides geospatial entities that abstracted as points, involving with information such as names, latitudes and coordinates, which could be used for the illustration of inherent social logic (Derya Arslan and Ergener, 2023; Hillier et al., 1993; Wang et al., 2021). By integrating the space syntax model and POI data analysis, a comprehensive understanding of the spatial patter that impact human activity modes within the specific area can be achieved, thereby propose precise data that support for the protection and renewal of historic district in urban area.

As a relatively mature technical method in urban planning research, the reliability and stability of space syntax theory and POI data analysis have been validated by scholars. The key research differences and gaps lie in the processed approach of input data in space syntax model, and the chose of the categories of POI data in combined analysis. The study converts vectorized maps data into a topology structure that readable by the space syntax model, focusing on the road hierarchy at the community and block scale, which is different from the traditional non-hierarchical processing method. Compared to traditional methods, the advantage of this study lies in its focus on road connectivity at the human scale, which better reflects an individual's understanding of the overall area in space. Benefit from the detailed space syntax analysis, categorized POI data can be combined for targeted interpretation. A historic district in Kunming city is included in the study, taking as an empirical case to demonstrate the validity of the analytical approach in the research of historic urban area.

2. Research Methodology

2.1 Implementation framework

The study uses space syntax theory as technical foundation to conduct the analysis of street network in historic urban area, applying both axial and segment model for accurate results. POI data are obtained for kernel density analysis, which simulate spatial concentration of categorized facilities within the research district. A compared illustration is conducted based on the results of space syntax analysis and kernel density calculation, in order to accurately describe the relationship between the aggregation of different functions and street conditions. There are three steps consist the analysis framework: data collection, experimental analysis, and results analysis (Fig. 1).

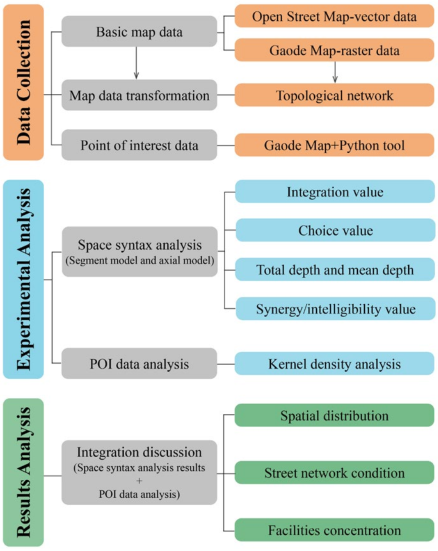

Figure 1. Analysis framework

1) Foundational data of the research includes vector street data and primary POI data within research districts. The vector street data are obtained from Open Street Map, and the accuracy of the map data is further validated using Gaode Map. The POI data are sourced by python tool from open data platform on Gaode Map, as well as related public information. The POI data are categorized into 6 types based on functional difference: historic spots, educational and cultural, commercial and residential, functional spaces (dinning services, shopping services, accommodation services).

2) Obtained vector map of the research area is validated with raster map in Gaode Map according to the specific research scale, then transformed into a geometric representation of spatial topological relationships to support subsequent calculations. During the processing, the core areas and surrounding major historical streets were extracted and preserved, for the establishment of the overall topological connections. Road hierarchy classification focuses on functional roads that serve historic urban areas, thus excluding non-public internal roads during the topological transformation stage. Data calculation for space syntax conducts in DepthmapX and kernel density analysis for POI data in ArcGIS.

3) Separation and combination approaches are employed in the results demonstration of space syntax calculation and POI data analysis, employing visibility graph for the comparison illustration to present evaluation of the spatial model. Based on analysis results, validation work is carried out with the actual situation of the road network.

2.2 Variables setting

Consider the built environment under practical spatial scales and urban contexts, the study incorporates the impact of actual terrain conditions on human activity, especially the undulating slopes around the Cuihu Lake area. Therefore, the research adjusts the topological transformation process with human movement, focusing on the detailed construction of segment model. Purpose of the comparison of the analysis of axial and segment model is to double validate the spatial rational of human activity. Besides, the integration of POI data analysis with space syntax approach aims to provide elucidation of urban spatial characteristics on microlevel.

Therefore, the study conducts evaluation of spatial properties including spatial distribution, accessibility and gathering points, focusing on attributes that influence individual's experience based on five levels of spatial parameters: integration value, choice value, synergy value/intelligibility value, total depth and mean depth, kernel density value. The elaboration of variables and formulas are as follows:

1) Integration value
The integration value describes the accessibility and convenience of historical districts surrounding environment, illustrating the degree of aggregation of one specific space with others in a street network. The formula as shown in the following:

$$INT_i = \frac{\mathrm{n}\left(\log_2\left(\frac{(\mathrm{n}+2)}{3}\right) - 1\right) + 1}{(\mathrm{n}-1)(\mathrm{MD_i}-1)}$$

2) Choice value
The choice value interprets the permeability of spatial units, a higher degree of choice means that the likelihood of the space being chosen increases. The formula as shown in the following:

$$Ch_i = \sum_{\mathrm{j}}\sum_{\mathrm{k}}\frac{\mathrm{d_{jk^{(i)}}}}{\mathrm{d_{jk}}}$$

3) Synergy value and intelligibility value
The synergy value is used to reflect the relationship between local and global integration within a spatial network, and the intelligibility value indicates the extent to which an individual understands the global system while visiting local space. Two values have the same formula but different variables. The formula as shown in the following:

$$R_S{}^2 = \frac{\left[\sum(\mathrm{INT_{il}} - \overline{\mathrm{INT_l}})(\mathrm{INT_{ig}} - \overline{\mathrm{INT_g}})\right]^2}{\sum(\mathrm{INT_{il}} - \overline{\mathrm{INT_l}})^2\sum(\mathrm{INT_{ig}} - \overline{\mathrm{INT_g}})^2}$$

4) Total depth and mean depth
Depth analysis is used for demonstrating the convenience of traveling around the entire research region starting from a specific street, presenting the number of turns that required to go through the entire area. Total depth is calculated by counting approach, and the formula of mean depth as shown in the following:

$$\text{Mean Depth}(a_1) = \frac{Total\,Depth(a_1)}{n}$$

5) Kernel density value
Kernel density analysis converts Point of Interest (POI) data into an intuitive visualization of hotspot areas, areas with higher kernel density indicate a greater number of functional points in a city. The formula as shown in the following:

$$F(x) = \frac{1}{\mathrm{nh}}\sum_{\mathrm{i=1}}^{\mathrm{n}}\mathrm{k}\left(\frac{\mathrm{x}-\mathrm{x_i}}{\mathrm{h}}\right)$$

2.3 Research area

The research established two typical historic districts in one region of Kunming city (Fig. 2) for comprehensive analysis, exploring the spatial characteristics of historical areas with different layouts.

As the central sightseeing spot in urban area of Kunming city, Cuihu Park owns water parts accounts for more than 60% of the entire planning region, which has been leveraged as an advantage to create attraction for diversities of tourist groups together with the surrounding cultural heritage. Therefore, the research includes certain areas around Cuihu Park into the research scope to enhance the support of the analysis results for the conclusions. According to government planning documents and field conditions, nine major historical streets around Cuihu Park are set as inclusion scope and main roads are used as boundary delineation for research area.

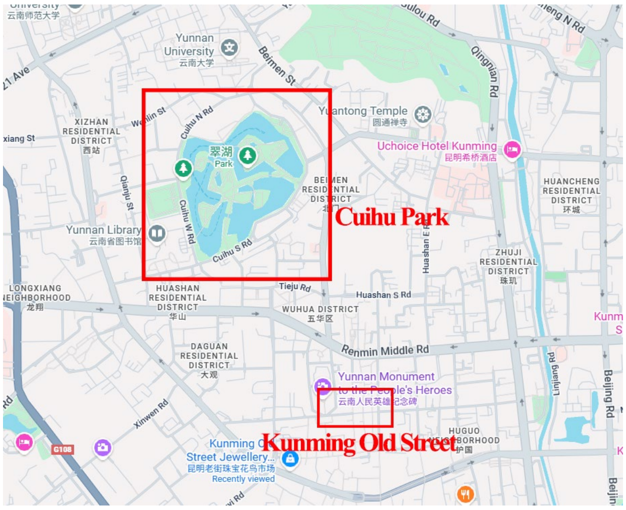

Figure 2. Two typical historic districts within the research area

Another historical core area included in the research – Kunming Old Street is within a 1 km walking distance south of Cuihu Park, which has the largest and the most preserved characteristics residential and commercial buildings area in Kunming city from the Qing Dynasty and the Republic of China period.

3. Experiments and Analysis

3.1 Data preprocessing

Data processing is based on the specific requirements of the experiments and research objectives, converting raster data into vector data and performing layered annotation of roads network and urban spaces. In order to prevent the model from defining road points cut off by the research boundary, the study set an 800m buffer zone to mitigate the edge effects of the peripheral streets within the research area. Meanwhile, hierarchical processing of vector data and the transformation of topological features are according to the research scale and environmental conditions, aiming to improve data accuracy and ensure the integrity of research results.

Regard historical spots as essential features in the research, the illustration of road hierarchy including four levels shows in Fig. 3: main roads, historic spots, functional roads and internal roads. Main roads are extracted to clarify junction and center nodes of road network within the research area, which serve as essential access points in the overall historic urban area. Historic spots level highlights core historic features defined as hot spots for tourism, coordinating with the texture of functional land-use formed around to become an iconic historical spatial narrative area. The study marks the hierarchy of internal roads separately for the reason of overlapping functions and semi-open space for specific crowds. Serving as campus, this area contains buildings are listed as cultural heritage sites, where only personnel with access permission can enter for visit or research.

The whole spatial patter of the research area is categorized into tree types to illustrate the situation of accessibility (Fig. 4): public, semi-public and non-public. The purpose of the annotation work at this stage is to assist in the interpretation work of spatial connectivity and accessibility in subsequent spatial syntax calculations, and to verify the consistency between calculation results and real conditions. The study defines areas accessible to all people as public areas, including historical sites, commercial areas, and tourism services, which has an overlap of travel routes both for tourists and local residents. Semi-public areas have access restrictions for certain visitors due to crowd management or the requirements of seasonal exhibitions, which requires reservations or similar arrangements to access. Non-public spaces primarily including living areas for local residents, with functions limited to residential that require biometric identification for access.

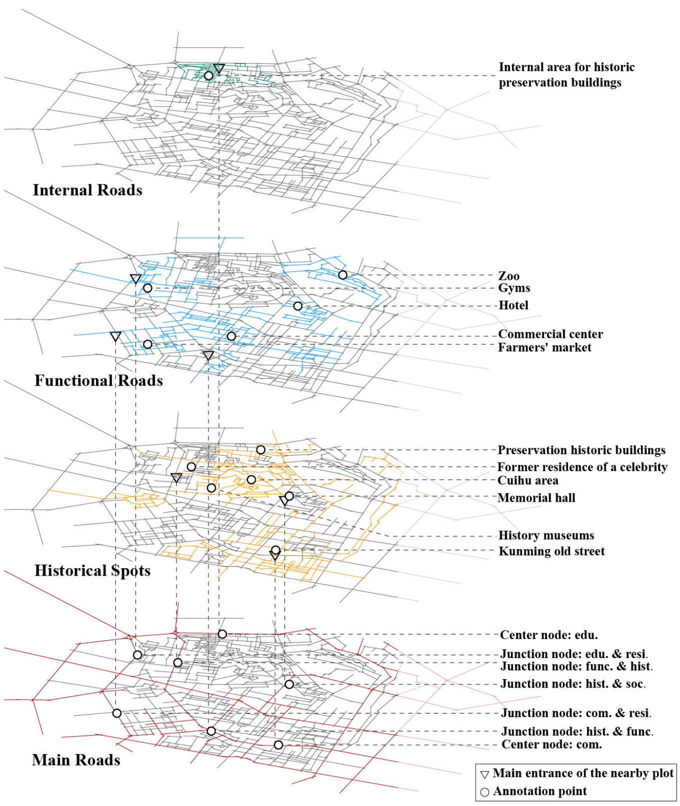

Figure 3. Four levels of road hierarchy: main roads, historic spots, functional roads and internal roads

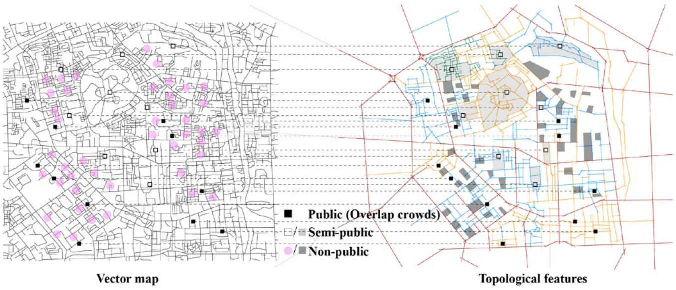

Figure 4. Accessibility illustration of road network: public, semi-public and non-public

3.2 A quantitative analysis-space syntax model

The study proposed to explore the characteristics of spatial distribution combined with street network in historic urban areas through space syntax model. Considering the explanatory ability of the space syntax model in analyzing individuals' perception of urban space under different travel modes, the study set an 800-meter walking radius as an analysis parameter to access local integration value, according to specific context of research area and human activities pattern. Colour coding is applied in space syntax analysis to indicate value levels, a red to blue bar correspond to higher value to lower value.

The analysis results of integration value, choice value, total depth and mean depth value are presenting in Fig. 5, which are analysed through segment model. Calculation result of overall integration shows a high correlation between road continuity length and accessibility, describing the pattern characteristics of high accessibility around main roads and a gradually decreasing trend toward the surrounding areas. In general, it is worth noticing that for streets with high integration values, the degree of choice will also be consistently presented relatively. The accessibility around and within the research historical district presenting as moderate in the whole street network, but the choice value does not show a positive correlation trend due to the abundance of narrow streets and the terrain's slope.

In terms of depth analysis, setting the walking radius as 800m is most favourable for individuals walking in the street network. Areas that can be easily covered by short walks are mainly concentrated around the historic core, which is not very different from the actual situation.

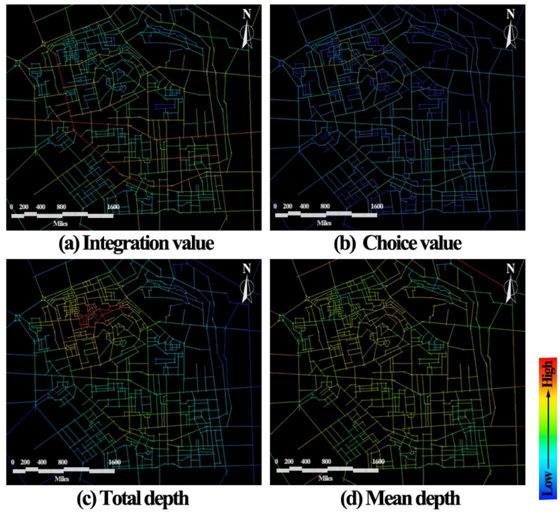

Figure 5. Space syntax analysis results by segment model: integration value, choice value, total depth, mean depth

Synergy and intelligibility analysis are conducted through integration calculation by axial model, for the parameter adjusting that match the scale of the research area. The results are shown in Fig. 6-7, presenting condition of global integration and local integration with topological radius set as 3. Calculation results are consistent with the actual environmental situations, and the synergy/intelligibility value of the entire region indicates high correlation (R>0.5) between global integration and local integration, which means individuals have relativity comprehensive understating of the whole area, providing a sense of direction when without map guidance.

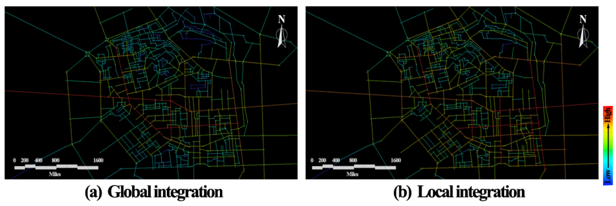

Figure 6. Space syntax analysis results by axial model: global integration, local integration

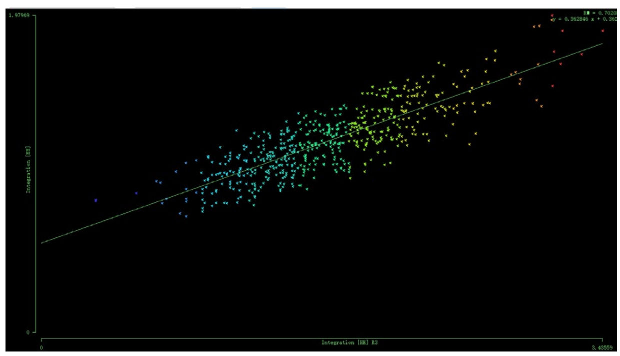

Figure 7. Space syntax analysis results by axial model: synergy value/intelligibility value

To explain the analysis results of the space syntax model in the context of actual environmental conditions, Fig. 8 compares the features in the road hierarchy with calculation results. In general, main roads has high traffic capacity no matter in global or local integration value calculation, and the accessibility rate show different trends around center and junction nodes, depending specifically on the type of functional block the individual enters.

The convenience, accessibility, and individual choice between historical spots areas and functional roads hierarchies appear relatively balanced in the spatial syntax results, while the accessibility of internal roads is lower. The area selected for the study can be defined as a small-scale road network, obvious guiding elements of functional zones and historical landmarks can effectively enhance individuals' perception of the overall environment, consistent with the results of spatial syntax analysis.

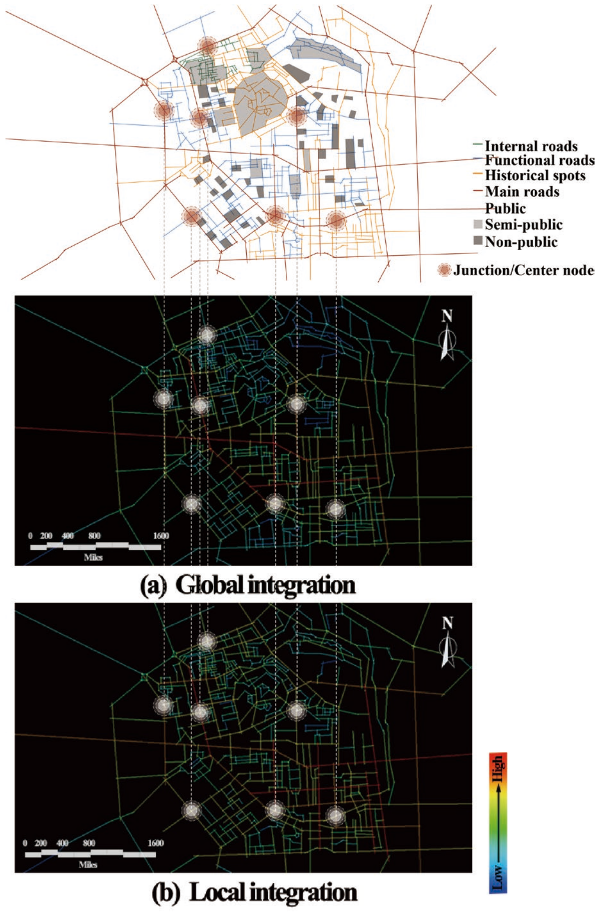

Figure 8. Comparison of road features with calculation results

3.3 POI data analysis

The categorized POI data analysis results are shown in Fig. 9, and overall fairly consistent with the reality situation. The distribution of scenic spots and commercial clusters is highly correlated with the development status of the historical core areas in the city, following the inherent characteristics of the two historical regions. Other functions show a pattern of spreading outward from the historical areas to the surrounding regions.

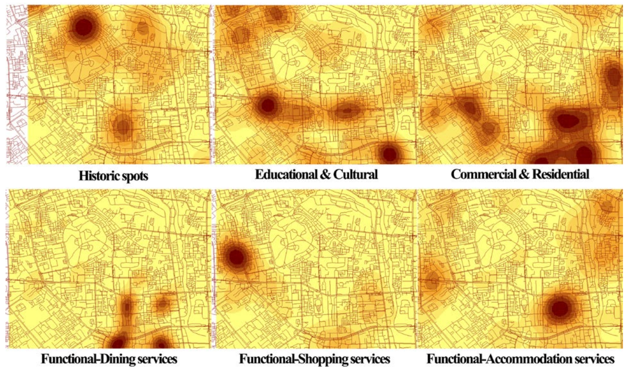

Figure 9. Kernel density of POI analysis results: historic spots, educational and cultural, commercial and residential, functional spaces (dinning services, shopping services, accommodation services)

3.4 Comprehensive illustration of space syntax results and POI data analysis

Combining the analysis of space syntax and POI data analysis, it could be seen that there is an extent positive correlation between accessibility and functional clusters. For the southern part where the living functions are concentrated, higher degree of choice value and lower street network depth compared to northern area. The northern area, as the historical core where scenic spots are concentrated, has nearby educational functions that mainly developed based on its historical background, and the nearby shopping centres have also become symbols of local life characteristics to attract tourists.

Through the combined analysis and integration illustration of syntax models and POI data calculation, the study validates two layers of logic on the perspective of spatial structure. The road network in historic urban areas overall shows a clear spatial separation between the tourism service layer and the residential layer. Although residential and tourist areas appear intertwined on raster maps, local distinctions are still evident through the previous labelling work of roads by public hierarchy. In the results of spatial syntax analysis, accessibility shows a gradual decrease from public to non-public areas, indicating a decline in individual choice between the tourism layer (public or semi-public areas) and the residential layer (non-public areas). Major roads with high global integration concentrate over 80% of tourism-related commercial POIs (dining, services, and retail), while secondary streets with high local integration gather local life service POIs (convenience stores, markets), forming a typical pattern of hierarchical classification that shows a stepwise functional openness.

In core protection zones, the predictive of spatial syntax model on POI distribution is significantly weakened, especially within the 200-500m buffer zone around key cultural heritage buildings, presenting a “high accessibility – low commercialization” phenomenon. The results demonstrates that the relevant protection policies effectively inhibit the complete penetration of market logic, but it cannot be guaranteed whether this phenomenon will lead to functional decline in some blocks or neighborhoods.

4. Discussion and Future Work

As a city with inherent geographical advantages, Kunming continues to present a rising trend in the choice of tourist destinations. Original functions of the historic urban areas are

https://doi.org/10.5194/isprs-archives-XLIX-B4-2026-331-2026 |

primarily driven by the needs of local residents, and that's lead to the topic about the spatial pressure brought by the seasonal influx of large numbers of non-local people, which is worth further exploration.

The research proposes three potential categories related to spatial conflicts in historical urban areas for future research. The first identifiable category is the over-matched area, which can be analyzed by capturing the streets with the highest tourism flow load, calculating their percentage of the total road network length, and examining the concentration of residential functions to assess existing safety hazards and conflicts in pedestrian movement. The second category is developable areas. These areas have good accessibility but insufficient POI density, which may be due to complex property rights or policy factors, causing challenges for further planning. The third category is forefront areas with eroded functions. The study found that some original residential areas host both local residential life and tourism-related commercial POIs. This phenomenon can provide a research approach related to critical thresholds, suggesting that if the proportion of tourism commercial POIs in local residential neighborhoods exceeds a certain value, the community network may be at risk of displacement.

5. Conclusion

In the discussion of balancing the development and preservation of historic urban areas, the historic district of Kunming, China, is a typical example of this challenge, which continuously to seek approaches to retain its cultural heritage while adapting to extremely high tourist traffic demands. The study addresses the challenge by exploring methodologies for sustainable development under the context of high pedestrian traffic in tourist season, by the analysis of road hierarchy and spatial distribution. Three components are structured in the study. Firstly, classification of road network and spatial categories conducted in data processing stage. Secondly, the research evaluates spatial characteristics through space syntax model and kernel density calculation of POI data. Finally, spatial attributes are illustrated through the integration analysis.

The study utilizes space syntax as theoretical foundation to calculate the spatial distribution characteristics and street network condition of Kunming historic urban areas, effectively identifying features that influence human activity. Experimental results demonstrate that data processing and POI classification at the block scale are essential approaches during the analysis stage, which can explain the road conditions in historic urban areas more precisely compared to other literatures. Integrated quantitative analysis methods present in the research provide a research perspective for the preservation of urban heritage in sustainable level, elaborating the essential status of data-driven approaches in the issue addressing of complex challenges under urban context.

References

Chen, J., Li, P., Lei, Y., Zhang, Y., Lai, C., Chen, B. et al. (2025). Leveraging augmented reality for historic streetscape regeneration decision-making: A big and small data approach with social media and stakeholder participation integration. Cites, 166, 106214. https://doi.org/10.1016/j.cities.2025.106214

Corbusier, L. (1943). La Charte d'Athènes. Paris: La Librairie Plon.

Derya Arslan, H. and Ergener, H. (2023). Comparative analysis of shopping malls with different plans by using space syntax method. Ain Shams Eng J, 14(9): 102063. https://doi.org/10.1016/j.asej.2022.102063

Duan, J., Lan, W. and Jiang, Y. (2022). An evaluation approach to spatial identity in historic urban areas from a humanistic perspective. Front. Archit. Res. 11, 806-814.

Fu, J., Tang, Y., Zeng, Y., Feng, L. and Wu, Z. (2025). Sustainable Historic Districts: Vitality Analysis and Optimization Based on Space Syntax. Buildings, 15, 657. https://doi.org/10.3390/buildings15050657

Hillier, B. (1996). Space is the Machine: A Configurational Theory of Architecture. Cambridge University Press: Cambridge, UK.

Hillier, B., Penn, A., Hanson, J., Grajewski, T. and Xu, J. (1993). Natural movement: or, configuration and attraction in urban pedestrian movement. Environ. Plann. B: Urban Anal. City Sci. 20(1), 29-66. Doi: 10.1068/b200029.

Wang, M., Yang, J., Hsu W-L, Zhang, C. and Liu, H-L (2021). Service facilities in heritage tourism: identification and planning based on space syntax. Information, 12(12), 504. https://doi.org/10.3390/info12120504

Yang, L., Jin, Q. and Fu, F. (2024). Research on Urban Street Network Structure Based on Spatial Syntax and POI Data. Sustainability, 16, 1757.

Zhao, P., Md Ali, Z., Nik Hashim, N.H., Ahamd, Y. and Wang, H. (2024). Evaluating social sustainability of urban regeneration in historic urban areas in China: The case of Xi'an. J. Environ. Manag. 370, 122520.