

Urban Street Space in Planning Transformation: Analyzing and Optimizing the Quality Differences between Subjective and Objective Perspectives—A Case Study of Xi'an

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Abstract

As the most common public spaces, urban streets are not only vital for daily activities but also a direct reflection of the quality of the urban environment and the inclusiveness of society. In the face of multiple challenges such as global climate change, resource crises, and social inequality, enhancing the spatial quality of urban streets has become crucial for improving environmental sustainability, social inclusiveness, and livability. However, most existing research focuses on either objective environmental features or subjective perceptions, often overlooking the systematic differences between these two aspects and their profound impact on spatial design and planning decisions. In the context of rapid urbanization, how to scientifically and quantitatively identify the differences between subjective and objective quality and develop targeted optimization strategies remains a critical issue that needs urgent attention.

In this study, an innovative spatial quality evaluation framework based on multi-label classification is proposed, integrating deep learning technology and semantic analysis methods. Using the MIT Place Pulse dataset, which includes 110,988 street view images, the Microsoft TrueSkill algorithm quantifies six subjective perception scores for streets, including safety, comfort, and richness. Additionally, using the Cityscapes dataset and the Mask2Former algorithm, the objective features of 28,662 streets in the central area of Xi 'an are semantically segmented, and eight landscape element indicators are extracted from four dimensions: safety, comfort, richness, and convenience. The study reveals that (1) the spatial quality of the main urban area of Xi 'an exhibits significant spatial heterogeneity and stratification in both subjective perception and objective physical environment dimensions, with higher scores in the core urban area compared to the peripheral areas. (2) There are significant differences in subjective and objective evaluations across different regions, with weak overall correlation between the two, and some administrative districts even showing statistically significant negative correlation. (3) Most streets exhibit inconsistencies between subjective and objective evaluations, particularly those where 'subjective is better than objective' and 'objective is better than subjective,' with a low proportion of streets achieving high consistency in both subjective and objective evaluations. Therefore, improving the quality of urban streets requires not only focusing on the construction of 'hard environments' but also emphasizing the coordinated optimization of subjective experience and social environment. Through quantitative analysis, this study reveals the key deviations and optimization paths of street space from subjective and objective perspectives, which provides practical basis and theoretical enlightenment for street planning and design under the background of rapid urbanization, and helps to build more inclusive and livable urban public space.

Key words: urban street quality, perceptual difference, deep learning

1. Introduction

As urbanization continues to deepen, street spaces, which are the most immediate public areas in residents' daily lives, have become a key indicator of a city's livability, sustainability, and social inclusiveness. Streets not only serve as transportation hubs but also function as multifaceted spaces that integrate social, cultural, and ecological elements. Their design and management significantly impact residents' quality of life and the city's image (Jacobs, 2012; Montgomery & John, 1998). In recent years, with the growing emphasis on a 'people-centered' approach, urban planning and design have increasingly recognized the importance of street spaces in enhancing urban vitality and social interaction (Yu, Zhang, & Zeng, 2019).

Although the measurement of street space quality has become a research hotspot, existing studies still face two main limitations: first, methods that focus primarily on physical environments overlook the importance of residents' subjective perceptions; second, perception studies based on questionnaires or expert ratings lack large-scale, efficient quantitative tools, making it difficult to adapt to rapidly changing urban environments (Tang & Long, 2019; M. Wang et al., 2022). Therefore, there is an urgent need to develop a street space evaluation framework that integrates both subjective and objective perspectives, combining scientific rigor with practical applicability, to reveal systematic differences across various dimensions and provide theoretical foundations and practical approaches for optimizing street design.

This study focuses on the main urban area of Xi 'an City as the empirical region, integrating deep learning and semantic segmentation technologies to develop a street space quality evaluation system that combines subjective and objective perspectives. On one hand, it extracts the physical environmental characteristics of streets using street view images and artificial intelligence algorithms; on the other hand, it quantifies residents'

perceptions of the safety, comfort, and richness of streets through a subjective perception model. By comparing the spatial distribution characteristics of the two types of evaluation results, this paper aims to reveal the discrepancies and coupling relationships between the subjective and objective perspectives of urban street spaces, and to propose targeted optimization suggestions, providing new ideas and practical references for the transformation and upgrading of urban street planning.

2. Literature review

2.1 Physical environment measurement method

In recent years, with the advancement of street view imagery and deep learning technologies, significant progress has been made in the objective measurement of street space quality. Researchers commonly use platforms like Google Street View, Baidu Street View, and Tencent Street View to obtain images of neighborhoods and employ deep convolutional neural networks (such as SegNet and DeepLab V3) for semantic segmentation, thereby quantifying physical elements such as green vegetation, openness, and interface transparency (Biljecki & Ito, 2021; Tang & Long, 2019). This automated image recognition and data analysis method has significantly improved measurement efficiency and has shown good accuracy and consistency in multiple empirical studies. Moreover, GIS and spatial network analysis remain crucial tools for assessing the physical characteristics of streets. By quantifying indicators such as building height, road width, street connectivity, and node density, researchers can construct accessibility models to analyze traffic efficiency and spatial organization (Harvey & Aultman-Hall, 2016). Building on this, the integration of multi-source data has become a new trend, including the integration of street view images, 3D building data, POIs, and LBS to establish systematic street quality assessment models (L. Zhang, Ye, Zeng, & Chiaradia, 2019). Data fusion not only enhances the expression ability of indicators, but also enables the dynamic capture of the spatio-temporal evolution characteristics of street space, which provides support for long-term monitoring and optimization.

2.2 Pedestrian subjective perception and multi-dimensional evaluation model

In contrast to the physical environment measurement, the subjective perception of street space has gained increasing attention. Traditional methods often rely on questionnaires and expert ratings, focusing on residents' psychological perceptions of safety, cleanliness, and human scale. However, sample representativeness and survey costs have become major bottlenecks for their widespread application (Du & Huang, 2022). In recent years, some studies have introduced social media text and sentiment analysis, using big data processing to capture residents' daily expressions of their preferences for the street environment. To integrate both subjective and objective perspectives, Wan et al. proposed the '5D+3S' model, which combines physical indicators such as design, density, diversity, accessibility, and transportation distance with perceptual dimensions like sociality, safety, and state, reflecting both the structural characteristics of street space and the complexity of human experience (Wan, Lu, & Sun, 2022). Technically, some studies have integrated street view image recognition and expert scoring to create semi-automated, multi-dimensional perception rating systems, enhancing the efficiency and reliability of data acquisition. Additionally, research on human-scale urban morphology emphasizes the profound impact of visual continuity, scale sense, and proportional relationships on perceptual experiences (Ye, Zeng, Shen, Zhang, & Lu, 2019). Du and Huang further empirically analyzed the relationship between leisure sports activities of the elderly and street quality, and found that green rate and sidewalk design had a significant positive effect on improving subjective satisfaction, which confirmed the value of environmental perception in the construction of healthy cities (Du & Huang, 2022).

3. Research areas and methods

3.1 Research area

This study focuses on the quality differences between subjective perceptions and objective environments in street spaces within the main urban area of Xi'an, a city in Northwest China. Xi'an is a key hub for regional economic, cultural, and technological development. In recent years, with the upgrading of urban functions, the implementation of the 'Belt and Road' initiative, and the deepening of the national central city construction, the city's space has rapidly expanded, with the built-up area surpassing 10,000 square kilometers and a permanent population exceeding 12 million. As the population and construction density continue to rise, the urban spatial

structure has shown a clear trend of concentric distribution and functional differentiation (Lin, Xiping, Junyi, Yongyong, & Zhiyuan, 2025).

In the process of urban spatial evolution, old urban areas, constrained by early planning, commonly face issues such as narrow streets, outdated facilities, and enclosed interfaces. In contrast, new urban areas boast higher standards and environmental advantages in street design, greenery configuration, and openness. This structural difference is not only evident in physical space but also profoundly influences residents' subjective experiences and daily behaviors. The growing gap between subjective and objective evaluations has gradually intensified the perception inequality and functional imbalance within cities. To gain a deeper understanding of the multidimensional aspects of street space quality and their optimization directions, this paper focuses on areas with high street density and frequent population activity in the main urban area. By integrating deep learning algorithms and semantic recognition technology, it quantitatively extracts environmental elements of streets and introduces a multi-label perception scoring system to explore the perceptual characteristics and optimization paths of street space at different scales. The aim is to provide theoretical support and practical references for enhancing urban spatial quality and traffic equity (W. Zhang, Chen, & Tian, 2025).

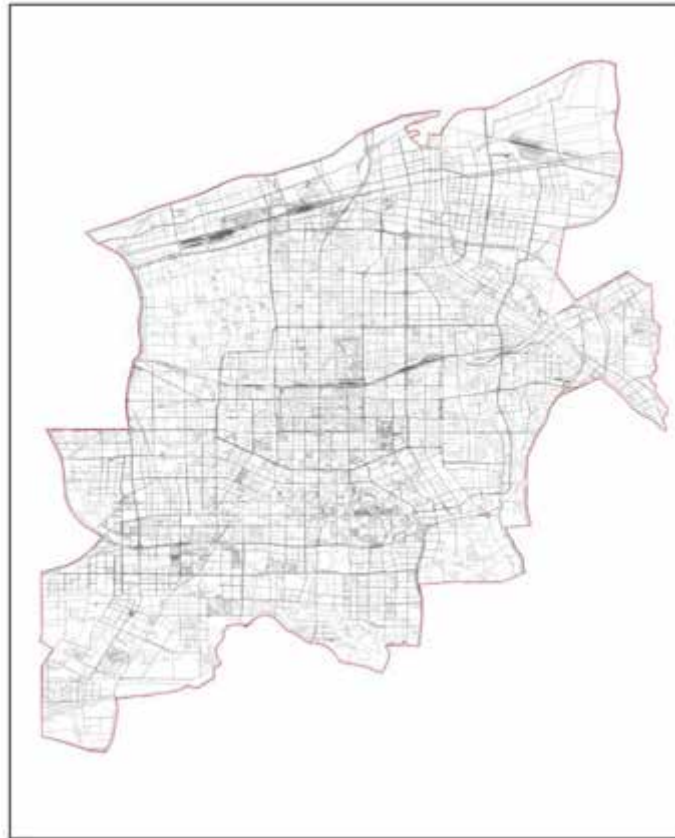


Figure 1. Scope of the study

3.2. Research methods

To support the quantitative assessment of street space quality and the systematic comparative analysis from both subjective and objective perspectives, this paper constructs a multi-source data system that includes built environment characteristics and perception evaluation information. The main data types include road network data, street view images, point of interest (POI) data, administrative division data, and subjective perception evaluation data. The sources, collection times, and processing procedures of each type of data are detailed in Table 1.

Regarding objective variables, the basic road data is sourced from OpenStreetMap (2021 edition). By extracting street centerlines, performing topological repairs, and manually correcting Gaode satellite images, the accuracy and usability of the road network structure are ensured. Street view images are collected from the Baidu Street View Open Platform, with sampling points set at intervals of 50 meters within the study area, resulting in a total of 289,664 images (1024×512 resolution). For sections with missing data, 360 Maps is used to supplement the data. Image processing employs a Mask2Former deep learning semantic segmentation model to extract key visual elements such as sky, greenery, and building interfaces, which form the basis for constructing a visual environment index system for street spaces (Li et al., 2022). POI data is obtained through the Baidu Map API, covering 18 categories of urban functional facilities, including dining, shopping, accommodation, education, and healthcare, to measure the functional mix and service accessibility of streets. Administrative boundary base map data is sourced from the National Basic Geographic Information Public Service Platform, uniformly projected into the WGS_1984 coordinate system using ArcGIS 10.7, ensuring spatial consistency and overlay compatibility across different data sources.

In the construction of subjective perception variables, the study incorporates the Place Pulse 2.0 dataset and its accompanying model developed by the Massachusetts Institute of Technology (MIT) Media Lab (MIT Media Lab). This model constructs a subjective evaluation framework covering six core dimensions: 'sense of security,' 'livability,' 'activity level,' 'wealth,' and 'sense of prosperity' through a paired comparison scoring mechanism. Using the Microsoft Trueskill algorithm, this paper ranks and normalizes image scores, and based on the model's output, it generates six categories of subjective perception scores for street images in Xi'an's main urban area, quantifying residents' emotional experiences and psychological perceptions of the street environment (Wang, Han, He, & Jung, 2022).

In the process of constructing the variable system, this paper integrates existing research findings and urban spatial quality theories to select eight key objective indicators from four dimensions: safety, comfort, richness, and convenience. Additionally, six subjective perception scores generated by the Place Pulse model are introduced, forming a multidimensional quantitative analysis framework for street space (see Table 2). Each indicator clearly defines its meaning, calculation method, and direction, comprehensively covering key factors such as spatial visual characteristics, traffic environment, functional diversity, and human scale. This provides a systematic and logical variable foundation for subsequent empirical analysis (L. Zhang et al., 2019).

Table 1 Multi-source, multi-scale data types, sources and processing

data name	data sources	acquisition time	data handling
Road network data	Open Street Map	December 2024	After the road centerline is simplified and extracted by manual, the topology is checked and verified with reference to the Gaode satellite image
Street View data	Baidu Open Street View Map platform	December 2024	The Baidu Street View API was invoked to collect 289,664 static panoramic images with a spacing of 50 m and a size of 1024 x 512 pixels. Then the Mask2Former semantic segmentation model was used to segment the street view images.
Interest Point (Point of Interest, POI) data	Baidu Map	December 2024	The geographic information interest point (POI) data was obtained from Baidu Map API. According to the research needs, 18 kinds of POI data such as food, hotel and shopping were obtained within the research scope and its surrounding area. The data contained industry categories, names, addresses, administrative areas and other information.
MIT Place Pulse Data set	MIT Media Lab Developed Place Pulse projects	December 2024	The Microsoft Trueskill algorithm was used to calculate the corresponding perception scores of six dimensions, and the model was trained to predict the scores of six perception dimensions on the streets in the central urban area of Xi'an.

Table 2 Subjective perception indicators and calculation methods

dimension	metric	computational method	weight	direction
safety	sense of security	The "safety" dimension score of street view images is evaluated based on Place Pulse model, and the weighted average of multi-angle image scores is obtained to obtain the perceived safety score of street segments.	0.1717	+
degree of comfort	Sense of oppression	The weighted calculation was carried out based on the negative score results of "livability" and "safety" dimensions of Place Pulse model, and the lower the value was, the stronger the depression was.	0.171741	-
	aesthetic feeling	The "aesthetics" dimension of Place Pulse model is used to score the perception, reflecting residents' subjective evaluation of the visual image of the street. The higher the score is, the stronger the aesthetic sense is.	0.1037	+
rich	Liveliness	The "activity" dimension of Place Pulse model is used to score the perception, which reflects residents' subjective evaluation on the visual image of the street. The higher the score, the higher the activity.	0.3285	+
	Boredom	The perception score of the "boredom" dimension of Place Pulse model reflects residents' subjective evaluation on the visual image of the street. The higher the score, the higher the boredom degree, which is a negative factor.	0.1194	-
convenience	A sense of affluence	Based on the "sense of wealth" dimension score of Place Pulse model, the building material, facade decoration complexity and high-end commercial POI density are taken as auxiliary factors for comprehensive calculation.	0.0759	+

Table 3 Objective environmental indicators and calculation methods

dimension	metric	computational method	weight	direction
safety	Vehicle interference	The degree of influence of motor vehicle traffic on pedestrian activity is measured by the number of vehicles in the unit.	0.0016	-
	Road surveillance	Assess the safety of a street, known as the "eyes on the street," by counting the number of surveillance facilities or pedestrians and shops on either side of the street.	0.1954	+
degree of comfort	Visibility over the sky	The proportion of the visible sky in the street space is calculated to reflect the degree of visual openness. The proportion of the sky in the total pixels is calculated through street view image analysis.	0.1809	+
	High viewership ratings	The proportion of green vegetation in the street view is calculated to reflect the greening degree of the street. The proportion of green pixels in the total pixels is calculated through street view image analysis.	0.0861	+
rich	Interface transparency	Measures the transparency of the facade of buildings on both sides of the street, i.e. the proportion of transparent or translucent parts (such as Windows, porches). Through street view image analysis, the proportion of transparent area to total facade area is calculated.	0.2945	+
	Interface richness	Evaluate the detail and diversity of the facade of buildings on both sides of the street. This can be measured by calculating the types and numbers of facade elements, such as decoration, material changes, etc.	0.0951	+

convenience	Walkable accessibility	Measures how easily pedestrians can get from a street to various facilities (such as stores, public transport stops). It is usually calculated by calculating the number and distance of various facilities within a certain range around the street, combined with the street connectivity index.	0.1449	+
	Function mix	The diversity of land use around the street is evaluated. The information entropy formula is usually used to calculate the proportion and distribution of different functions (such as residential, commercial, office, etc.) land use around the street.	0.0014	+

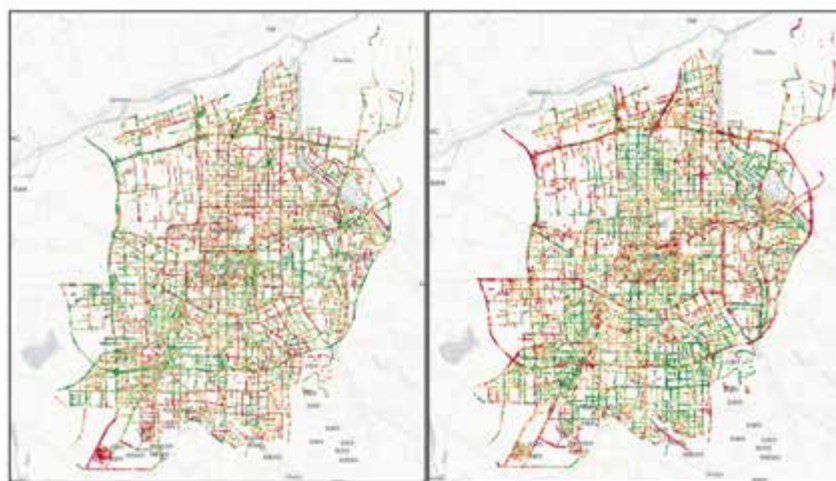
4. Results and analysis

4.1 Spatial distribution characteristics of comprehensive scores

To comprehensively reveal the overall distribution characteristics of the spatial quality of streets in Xi 'an's main urban area from both subjective and objective perspectives, this paper uses multi-source data and entropy value method weights to calculate the subjective and objective comprehensive scores for each street, and conducts spatial visualization analysis. As shown in Figure 2, the left figure (a) presents the subjective street quality measurement results, while the right figure (b) shows the objective street quality measurement results.

From the overall distribution pattern, both subjective and objective scores indicate that the main urban area of Xi 'an exhibits significant spatial heterogeneity and a layered structure. In the city's core areas, such as Beilin District, Lianhu District, and parts of Yanta District, streets generally score high. The high-score segments (primarily green) are concentrated in the city center, indicating that the core urban area offers high spatial quality in terms of both residents' perceptions and physical environment. In contrast, the outer areas of the city and some newly developed zones have generally lower street scores, with red and yellow sections being more densely distributed. This suggests that these areas need significant improvement in both residents' perceptions and physical environments.

It is worth noting that while the overall trends in subjective and objective distribution are consistent, there are still some differences. For instance, some newly developed peripheral areas have seen improvements in physical space indicators, such as wider roads and better pedestrian accessibility, but the subjective perception scores have not improved accordingly, indicating that residents' subjective experiences of the street environment still need further enhancement. Moreover, some older areas, despite less favorable objective indicators, have relatively higher subjective scores due to their strong historical and cultural atmosphere or community sense of belonging, reflecting the complex spatial characteristics of perceptions and evaluations of street quality from both subjective and objective perspectives.



a. Subjective street quality measurement results b. Objective street quality measurement results

Figure 2 Measurement results of street quality

4.2 Analysis of differences among different administrative regions

To systematically reveal the differences in street spatial quality among different administrative districts in Xi'an's main urban area, this paper combines the results of both subjective and objective comprehensive scoring (see Table 4). Subjectively, Chang'an District, Lianhu District, Beilin District, and Weiyang District stand out, with average scores of 0.4282, 0.4249, 0.4237, and 0.4249, respectively, significantly higher than those of Xincheng District, Baqiao District, and Yanta District. This trend suggests that core urban areas and regions with mature public service facilities and earlier development better meet residents' subjective expectations for safety, aesthetics, and vitality. For instance, Chang'an District has actively promoted ecological livability and the creation of cultural streets in recent years, significantly enhancing residents' sense of belonging and satisfaction. In contrast, Xincheng District and Baqiao District have lower subjective evaluations, indicating that some emerging areas still face challenges in improving public space quality and have not yet effectively met residents' demands for a high-quality street environment. Notably, the standard deviation of subjective scores across districts is concentrated between 0.03 and 0.04, suggesting that there is still some variation in quality within each district, particularly in Xincheng District and Baqiao District, where internal spatial differences are greater than in core urban areas like Beilin.

From the perspective of objective comprehensive scores, Beilin District, Chang'an District, and Yanta District rank at the top, with average scores of 0.1294, 0.1295, and 0.1274, respectively, higher than peripheral areas such as Xincheng District, Weiyang District, and Baqiao District. These districts excel in physical dimensions like green coverage, street transparency, and pedestrian accessibility, reflecting significant achievements in urban governance and the enhancement of public space environments. Additionally, the standard deviation analysis indicates that the internal fluctuations in the objective scores of Beilin District and Chang'an District are relatively small, suggesting a balanced physical quality of their streets. In contrast, Xincheng District and Baqiao District exhibit higher score dispersion, indicating significant internal differences in spatial development. Some areas still face issues such as strong motor vehicle interference and closed interfaces, requiring urgent intervention and improvement.

Further comparison of the comprehensive scores of subjective and objective indicators reveals a certain degree of synergy and discrepancy between residents' perceptions and the physical environment in different districts. For instance, Beilin District and Chang'an District have highly aligned subjective and objective scores, indicating that improvements in the physical environment can effectively enhance residents' spatial satisfaction, making these areas typical examples of successful urban space governance. In contrast, Yanta District shows a situation where objective evaluations lead but subjective experiences are weak, suggesting that merely improving the physical environment is insufficient to significantly enhance residents' sense of gain and happiness. Additional improvements are needed in human-centric aspects and social interaction. Meanwhile, Xincheng District and Baqiao District have low scores in both subjective and objective indicators, indicating that they need to improve in both spatial quality construction and residents' perception.

Table 4 Statistical table of subjective and objective comprehensive scores of each administrative region

canton	Subjective mean	Subjective standard deviation	Objective mean	Objective standard deviation
new city zone	0.4170	0.0360	0.1380	0.0323
Weiyang District	0.4249	0.0394	0.1348	0.0321
Baqiao District	0.4202	0.0366	0.1349	0.0342
Beilin District	0.4237	0.0335	0.1294	0.0287
Lianhu District	0.4249	0.0386	0.1364	0.0335
Chang'an District	0.4282	0.0386	0.1295	0.0288
Yanta District	0.4188	0.0337	0.1274	0.0292

4.3 Subjective and objective coupling and deviation analysis

According to the results of the correlation analysis (see Table 5), there is a weak negative correlation between the subjective and objective comprehensive scores of street spatial quality in the main urban districts of Xi 'an City. Except for Beilin District, the Pearson correlation coefficients for the other districts are all negative and highly statistically significant ($p < 0.001$). Notably, the negative correlation is most pronounced in Weiyang District (-0.290), Xincheng District (-0.220), and Baqiao District (-0.205), with an average correlation coefficient of -0.196 across all districts. This indicates that improvements in the physical environment of streets have not consistently led to an increase in residents' subjective perceptions, suggesting that the subjective and objective evaluation systems exhibit a certain degree of independence in spatial dimensions, and even show a clear divergence trend in some areas.

To further clarify the structure of the discrepancy between subjective and objective evaluations, this paper constructs four coupling types based on subjective and objective scores (see Table 6). The 'subjective superior to objective' type (high-low) has the highest proportion at 29.56%; followed by the 'highly consistent' type (low-low) and the 'objective superior to subjective' type (low-high), with proportions of 27.76% and 25.87%, respectively; only 16.81% of the streets achieve a 'highly consistent' type (high-high). This indicates that less than 20% of the street spaces have seen simultaneous improvements in both subjective perception and objective quality, while most streets exhibit varying degrees of discrepancy between subjective and objective evaluations.

The above results indicate that in the process of enhancing the quality of street space in Xi 'an's main urban area, residents' perceptions have not fully aligned with the objective improvements. In areas with a strong sense of community or historical and cultural ambiance, despite relatively weaker physical environment indicators, residents' subjective evaluations are more positive, showing a 'high-low' type deviation. Conversely, in newly developed or renovated areas, although the physical environment has significantly improved, residents' subjective satisfaction has not significantly increased, resulting in a 'low-high' type deviation. This phenomenon suggests that urban spatial governance should not solely rely on the improvement of 'hard environment' indicators but should also focus on the collaborative shaping of 'soft environment' factors, such as residents' emotions, social

interactions, and cultural belonging.

In summary, the interplay between subjective and objective evaluations reveals the intricate mechanisms behind enhancing spatial quality, underscoring the importance of a people-centered approach to governance that focuses on perception. Future strategies for optimizing urban street spaces should focus on a two-way feedback mechanism that integrates 'physical improvements' with 'perceptual responses,' aiming to enhance both functional rationality and emotional experiences, thereby promoting a dual improvement in high-quality public spaces and urban well-being.

Table 5 shows the correlation coefficient and significant p value of subjective and objective comprehensive scores

canton	Pearson correlation	Significant p values
Beilin District	0.025	0.094
Lianhu District	-0.157	<0.001
new city zone	-0.22	<0.001
Weiyang District	-0.29	<0.001
Yanta District	-0.187	<0.001
Chang'an District	-0.143	<0.001
Baqiao District	-0.205	<0.001
The average of the region	-0.196	<0.001

Table 6 Statistical table of subjective and objective comprehensive score deviation types

Type of bias	sample number	percentage
Subjective superiority over objective (high-low)	19351	29.56%
High consistency (Low-Low)	18173	27.76%
Objective superiority over subjective type (low-high)	16938	25.87%
High consistency (4-5)	11003	16.81%

5. Conclusion

This paper focuses on the main urban area of Xi'an City, utilizing multi-source spatial data and deep learning algorithms to develop a street spatial quality evaluation system that integrates subjective perception with objective built environment. It conducts a systematic analysis of the urban street environment from dimensions such as spatial layout, regional differences, and the coupling relationship between subjective and objective perceptions. The main conclusions are as follows:

From an overall spatial perspective, the street space quality in Xi 'an's main urban area exhibits significant spatial heterogeneity and stratification in both subjective and objective dimensions. The core urban areas, such as Beilin District, Lianhu District, and Chang 'an District, stand out with high scores in both subjective and objective evaluations, characterized by a dense concentration of high-quality streets that highlight the spatial advantages of historical urban areas and well-developed public service zones. In contrast, the scores for the city's periphery and some newly developed areas are relatively low, indicating room for improvement in street environment optimization and resident satisfaction.

(2) There are significant differences between different administrative regions. Chang 'an District, Lianhu District, Beilin District, and Weiyang District have performed well in overall subjective comprehensive scores, indicating that these areas have not only improved their spatial environment but also better met residents' psychological expectations for street safety, vitality, and aesthetics. In contrast, Xincheng District, Baqiao District, and parts of Yanta District have performed poorly in both subjective and objective scores and internal balance, suggesting they still face the dual challenges of spatial quality differentiation and insufficient resident perception.

(3) The overall relationship between the subjective and objective evaluation systems is weakly negatively correlated. Pearson Correlation analysis indicates that in most areas, the correlation between subjective and objective scores is low, and in some areas, there is even a significant negative correlation. This suggests that improvements in physical space do not directly enhance residents' subjective satisfaction. Subjective perceptions are significantly influenced by cultural background, social relationships, and individual experiences, indicating a high degree of independence and complex coupling between subjective and objective evaluations.

From the analysis of subjective and objective bias types, only 16.81% of the street samples achieved 'high-high consistency,' while nearly 60% of the streets exhibited inconsistencies between subjective and objective evaluations. Among these, the 'subjective superiority over objective (high-low)' and 'objective superiority over subjective (low-high)' types were more prevalent, reflecting residents' reliance on soft elements such as cultural environment and community belonging, as well as the disconnect between physical environmental improvements and psychological perceptions. In particular, in some newly developed areas, even with significant improvements in the physical environment, residents' subjective sense of gain remains lagging, highlighting a gap between 'hard environment' and 'soft experience' in current urban spatial governance.

6. Discussion

This study integrates deep learning technology with multi-source spatial data to systematically reveal the spatial distribution patterns, regional differences, and coupling deviation characteristics of urban street spatial quality in both subjective perception and objective environment dimensions. The findings indicate that while the continuous optimization of the physical environment forms the foundation for enhancing urban spatial quality, the transformation of the 'hard environment' alone is insufficient to fully meet the increasingly diverse and personalized subjective needs of residents. Many street samples exhibit a mismatch between subjective and objective evaluations, highlighting that 'soft environment' elements such as social and cultural atmosphere, community belonging, and public participation play a crucial role in influencing residents' sense of gain and spatial identity. This finding underscores the need for urban spatial governance to shift from a single functional physical perspective to a human-centered approach that integrates perceptual experiences, promoting a systematic transformation of urban renewal from 'object-oriented' to 'people-oriented'. In future urban renewal and spatial optimization processes, it is essential to focus on the coordinated regulation of differences between regions and within areas, driving the dual improvement of the physical environment of streets and the enhancement of residents' subjective experiences, gradually achieving the goal of constructing high-quality, balanced urban public spaces.

However, this study still has certain limitations. Firstly, while the Place Pulse model has improved the efficiency of measuring subjective evaluations, its predictive outcomes are limited by factors such as image acquisition methods, algorithm training biases, and cultural context differences, making it difficult to fully represent

individual perceptions in real-world scenarios. Secondly, the study uses Xi 'an's main urban area as a case for empirical analysis, and its conclusions need further validation and expansion across different city types and social structures.

Future research can expand in two directions: first, by integrating field surveys and online questionnaires with other sources of subjective data to enhance the authenticity and representativeness of the model in perception evaluation; second, by incorporating time-series street view images and dynamic perception data to conduct a longitudinal analysis of urban spatial quality, exploring the temporal evolution mechanisms and influencing factors of both subjective and objective evaluations. This will help develop more precise and actionable strategies for urban spatial optimization, providing a solid theoretical foundation and practical approach to creating fair, efficient, and livable urban public spaces.

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