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Study on the Supply-Demand Matching and Layout Optimization of Urban Green Parks Based on Social Cognitive Theory

—Taking Yanta District of Xi'an as an Example

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ABSTRACT

This paper takes Yanta District of Xi'an as a case study to explore the supply-demand relationship and spatial layout optimization strategy of urban park green spaces. Through a combination of social analysis and spatial analysis, it investigates the usage characteristics and satisfaction of residents in Yanta District regarding urban park green spaces, analyzes the demand differences for park green spaces among different resident groups, and conducts an in-depth analysis of the service scope, vegetation coverage, and accessibility of park green spaces in Yanta District using multi-source data. The results show that there are problems such as unequal spatial distribution and poor overall accessibility of park green spaces in Yanta District. Based on this, this study introduces the concept of pocket parks, optimizes the site selection scheme of park green spaces using a location-allocation model, and verifies the rationality of the site selection through 3D elevation modeling. The study indicates that the optimized pocket park site selection can significantly improve the service level of park green spaces in the western green-deficient areas of Yanta District, enhance residents' happiness and satisfaction, and provide a scientific basis and practical guidance for the layout optimization of urban park green spaces.

KEYWORDS

Green spaces; Supply-demand matching; Social cognitive theory; Two-step floating catchment area method; Subjective perception

1. INTRODUCTION

With the acceleration of global urbanization, the density of urban populations has increasingly risen, with more than 55% of the world's population currently living in urban areas, and this proportion is expected to climb to 68% by 2050. This trend has not only brought about urban economic prosperity but also sparked public concern about the fairness and effectiveness of urban public facility services. As the main place for human activities, the perfection of a city's infrastructure is directly related to residents' quality of life and happiness [1]. The introduction of the Xi'an 14th Five-Year Plan for Public Service System Construction clearly sets the goal of strengthening the construction of the public service system, in which urban park green spaces, as important components of the urban ecosystem, play a vital role.

Urban park green spaces not only provide ecological shelter for urban residents but also carry multiple functions such as cultural, social, economic, and health functions [2, 3]. They are not only the "green lungs" in cities, helping to improve air quality and regulate the urban microclimate but also important

places for urban residents to engage in leisure and social interaction. In the fast-paced modern life, urban park green spaces have become ideal places for people to relieve stress, get close to nature, and enhance physical and mental health.

However, in the process of rapid urbanization, the construction and layout of urban park green spaces face many challenges. Traditional green space planning often pays too much attention to quantitative indicators such as green space rate and per capita green space area, while ignoring the heterogeneity and rationality of green space spatial distribution. This planning method has led to uneven utilization of green spaces, with some areas having an oversupply of green spaces while others suffering from a shortage. At the same time, park layout often lacks full consideration of the supply-demand relationship, resulting in a large mismatch between park supply and population demand [4]. This mismatch not only affects the use efficiency of urban park green spaces but also weakens their service function as urban public facilities.

To solve this problem more effectively, this paper re-examines the supply-demand relationship of urban park green spaces from a new theoretical perspective. In 1986, American psychologist Bandura first proposed the "social cognitive theory" in his book Social Cognitive Theory: The Social Basis of Thought and Action [5]. This theory deeply analyzes the formation and maintenance mechanism of human behavior from the perspective of the interaction among individuals, behavior, and the environment [6]. It believes that human behavior is not entirely driven by internal forces or shaped by external environmental stimuli but is the result of the continuous interaction among individuals, the environment, and behavior. This theory provides a new way of thinking for us to understand the supply-demand relationship of urban park green spaces [7, 8].

Within the framework of social cognitive theory, urban park green spaces are no longer static and isolated urban elements but are closely connected with urban residents, the urban environment, and residents' behavioral activities [9]. Urban residents, as users of urban park green spaces, their needs, preferences, and behavioral patterns directly affect the use efficiency and layout optimization of park green spaces. The urban environment, as the carrier of urban park green spaces, factors such as its spatial structure, traffic conditions, and socioeconomic status also have a profound impact on the supply-demand relationship of park green spaces. Therefore, from the perspective of the interaction among individuals, behavior, and the environment, we can comprehensively examine the supply-demand relationship of urban park green spaces.

In recent years, scholars in human geography and urban sociology have conducted a large number of studies on the supply-demand relationship of urban park green spaces. Current research presents a trend of multi-disciplinary integration and new technology application [10, 11], using disciplines such as economics and ecology, as well as technologies such as big data and GIS for analysis [12], while taking into account both fairness and efficiency [13], and pursuing dynamic forward-looking, refined, and personalized research. However, there is a lack of research on residents' dynamic needs, segmentation, and behavioral psychology, as well as little attention to coordination with the surrounding areas [4, 14]. Therefore, this paper introduces the "social cognitive theory" to re-examine the supply-demand relationship of urban park green spaces from the perspective of the interaction among individuals (urban residents), behavior (residents' use of park green space behavior), and environment (urban environment), making up for the shortcomings in current research regarding residents and coordination with the surrounding areas.

Scholars at home and abroad have mainly focused their research on urban park green spaces on aspects such as availability [15], accessibility [16], health benefits [17], and social cohesion [18]. Among them, accessibility is one of the important indicators for measuring the supply-demand matching of park green spaces [19]. Domestic and foreign scholars have conducted a large number of studies on the spatial distribution characteristics [21] and influencing factors [24] of park green space accessibility using various methods such as buffer analysis [20], network analysis [21], and cost-distance weighting method [22]. In contrast, research on the supply-demand relationship of

urban park green spaces in China started relatively late but has made remarkable progress in recent years. In the past, domestic green space evaluation mainly focused on quantitative indicators such as the quantity and area of green spaces [25], while ignoring the application of indicators such as green space quality, spatial layout fairness, and service efficiency in green space evaluation [26-29]. Domestic scholars have begun to pay more attention to the supply-demand matching of urban park green spaces. They have comprehensively evaluated the supply level of park green spaces and the demand level of urban residents through building indicator systems and using coupling coordination models, and measured the supply-demand matching [30-32].

Therefore, in this paper, through social analysis methods, using questionnaire surveys and semi-structured interviews, we deeply analyze the usage characteristics, satisfaction, and subjective needs of residents in Yanta District regarding urban park green spaces. In spatial analysis, we use service area analysis based on road network data and the two-step floating catchment area method to accurately calculate the effective service scope of park green spaces, comprehensively considering the supply side, demand side, and transportation route conditions. Based on the concept of pocket parks, we use a location-allocation model and 3D elevation modeling technology to visually display the optimized pocket park site selection and the surrounding environment, further verifying the rationality and feasibility of the site selection scheme, and providing a scientific basis for measuring the accessibility of park green spaces.

2. DATA SOURCES AND RESEARCH METHODS

2.1. Overview of the Study Area

Yanta District is located in the southern part of the main urban area of Xi'an. As of 2023, the GDP of Yanta District is 311.894 billion yuan, and the permanent population at the end of 2022 is 2.1093 million. Yanta District is not only economically active and densely populated but also has a particularly prominent phenomenon of social stratification. The main social effect of urban park green spaces is to alleviate social injustice and improve residents' well-being. Therefore, taking Yanta District of Xi'an as a case study has a certain typical representative significance.

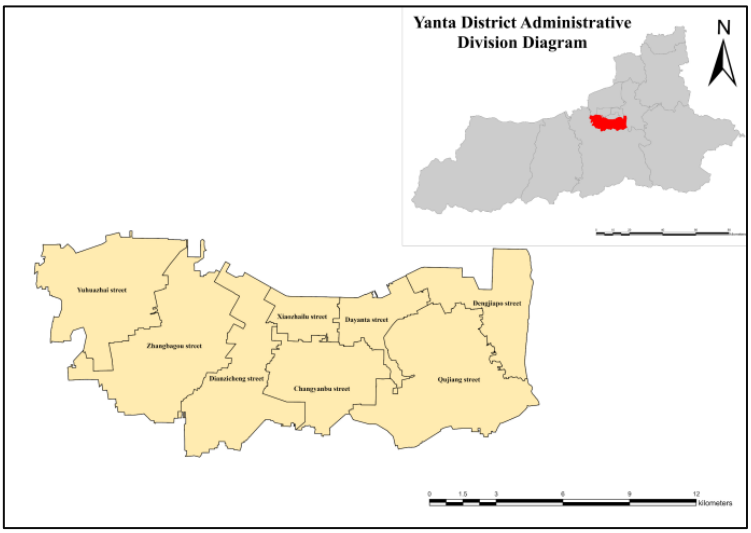

Figure 1. Overview of the study area

2.2. Data Sources

The social data used in this paper comes from on-the-spot investigations of Yannan Park, New Era Park, Tang City Wall Relic Park, and Qujiang Pool Relic Park in Yanta District. The vector data of administrative divisions and main roads come from the National Geographical Information Resource

Directory Service System. The remote sensing base map comes from the Landsat 8 remote sensing images of the Geospatial Data Cloud. The road network data comes from OpenStreetMap. The POI and AOI of park green spaces come from the Gaode Map API.

2.3. Research Methods

2.3.1. Social Analysis Method

This paper obtains the characteristics and satisfaction of residents in Xi'an Yanta District using urban park green spaces through questionnaire surveys, covering dimensions such as demographic characteristics, usage preference characteristics, and satisfaction scales. Among them, the satisfaction scale is the core part of the questionnaire. By quantifying indicators in various aspects such as venue facilities, ecological environment, and leisure and recreation functions (Table 1), it analyzes residents' subjective evaluations of the supply-demand matching relationship of urban green parks in Xi'an Yanta District. Through semi-structured interviews (Table 2), it deeply discusses citizens' views on park venue facilities, organizational management, leisure and recreation functions, ecological environment, and accessibility, reveals residents' overall feelings about park green spaces, and reflects satisfaction differences among different resident groups.

Table 1. Satisfaction scale for urban green parks

Dimension	Indicator	Source
Infrastructure	Quantity of Venue Facilities	[31-33]
	Types of Venue Facilities	
	Venue Facility Maintenance	
Management	Signage and Wayfinding System	[33,35]
	Safety and Emergency Response Level	
	Quality of Personnel Service	
Leisure Function	Richness of Leisure and Entertainment	[34,36,37]
	Educational Value	
	Aesthetic Value	
environment	Hygienic Conditions	[33,34,37]
	Greening Level	
	Biodiversity	
Accessibility	Parking Convenience	[35,36]
	Public Transport Accessibility	
	Walkability	

Table 2. Information attribute table of interviewed personnel

Number	Gender	Age	Occupation	Park Used and Needs
A1	Female	28	Bank Clerk	Yannan Park (camping with friends)
A2	Male	33	Company Staff	Yannan Park (evening walk after dinner)
A3	Female	19	Student	Yannan Park (weekend relaxation)
A4	Female	63	Retiree	Yannan Park (square dance group activities)
B1	Male	37	Advertising Company Staff	New Era Park (visiting the park with children)
B2	Female	33	Beauty Salon Professional	New Era Park (jogging for exercise)
C1	Male	18	Student	Tang City Wall Relic Park (weekend relaxation)
C2	Male	66	Retiree	Tang City Wall Relic Park (socializing with peers)
C3	Female	31	Stay-at-Home Mom	Tang City Wall Relic Park (visiting the park with children)
D1	Female	47	Self-Employed	Qujiangchi Relic Park (visiting the park with elderly family members)
D2	Male	35	Salesperson	Qujiangchi Relic Park (weekend night running)
D3	Male	45	Civil Servant	Qujiangchi Relic Park (visiting the park with children)

2.3.2. Spatial Analysis Method

Service area analysis: Existing studies mostly use GIS technology's buffer analysis and service area analysis to calculate the service scope of public green spaces. The buffer analysis can be realized with a small amount of data and has strong universality, but it has the defect of replacing the actual walking distance of residents with a straight-line distance. Service area analysis analyzes the effective service scope of public green spaces through the distribution of road network data, which is more detailed and in line with the actual situation. In this paper, the effective service scope of park green spaces in Yanta District is calculated according to the service radii corresponding to 5 minutes, 10 minutes, and 15 minutes of walking (500m, 800m, 1000m), respectively, to determine the spatial fairness of park green spaces in Yanta District.

Accessibility analysis: This paper mainly uses the two-step floating catchment area method to measure the accessibility of park green spaces.

First step, calculate the supply-demand ratio between residents and park green spaces.

$$R_{\mathrm{j}} = \frac{S_{\mathrm{j}}}{\sum_{k \in \{d_{kj} \le d_0\}} P_k} \tag{1}$$

Second step, calculate accessibility based on the obtained supply-demand ratio.

$$A_i = \sum_{j \in \{d_{kj} \le d_0\}} R_j = \sum_{j \in \{d_{kj} \le d_0\}} \frac{S_j}{\sum_{j \in \{d_{kj} \le d_0\}} P_k} \tag{2}$$

Location-allocation model: The location-allocation model can select the best layout location of facilities for specific needs based on the analysis of the locations of a series of demand points through

road network distance. The model can also set different facility addition and layout methods according to different needs. In this study, the concept of pocket parks is introduced. Based on minimizing the number of facilities and setting the impedance interruption to 15 minutes (i.e., the travel time from all residential communities to the nearest park green space does not exceed 15 minutes), the location-allocation model is used to optimize the site selection scheme of green parks to meet the needs of residents for urban park green spaces under the concept of a 15-minute living circle.

3D elevation modeling: For the pocket park site selection optimized by the location-allocation model, combined with the DEM raster data and residential building vector data with floor heights in the study area, 3D elevation modeling is carried out to visually display the optimization results of park green spaces and further confirm the feasibility and rationality of the pocket park site selection scheme.

3. EVALUATION OF RESIDENTS' SATISFACTION WITH URBAN GREEN PARKS

3.1. Satisfaction Evaluation

The survey results show that the overall average satisfaction score of residents in Yanta District using urban green parks is 3.86, which is at a moderately high level. In terms of each dimension, the satisfaction scores for ecological environment and leisure and recreation functions are relatively high, 4.23 and 4.17 respectively, indicating that residents are relatively satisfied with the park's ecological environment and the leisure and recreation activities provided. In contrast, the satisfaction score for organizational management is the lowest, only 3.43, indicating that there is much room for improvement in the park's organizational management. The satisfaction scores for venue facilities and traffic convenience are in between, 3.65 and 3.80 respectively, indicating that although these aspects have a certain foundation, they still need further optimization and improvement.

Through the comparison of overall satisfaction among parks, Yannan Park ranks first with 3.88

points, followed by Qujiang Pool Relic Park with 3.87 points, slightly higher than the total sample average (3.86 points). Tang City Wall Park and New Era Park rank behind with 3.83 points and 3.85 points respectively. Although slightly lower than the total sample average, their overall performance is still above average, indicating that there are certain differences in service management among different parks, but the overall level is relatively stable.

Specifically, in terms of venue facilities, the score of Yannan Park (3.48) in venue facilities is slightly lower than the total sample average (3.65), while the other three parks are relatively close to or slightly higher than the total sample level, indicating that Yannan Park may have problems such as facility aging or insufficient maintenance. In terms of organizational management, the scores of each park in organizational management are lower than the total sample average, and the differences are not significant, indicating that organizational management is a common shortcoming of each park and needs to be strengthened and improved together. In terms of leisure and recreation functions, Yannan Park and Tang City Wall Park have higher scores in leisure and recreation functions, reaching 4.27 and 4.21 respectively, slightly higher than the total sample average (4.17), indicating that these two parks perform well in providing leisure and recreation activities and can meet residents' needs. In terms of ecological environment, Yannan Park has the highest score (4.38) in ecological environment, significantly higher than the total sample average (4.23), reflecting that Yannan Park has achieved remarkable results in ecological environment protection and provided residents with a good ecological environment. In terms of traffic convenience, the scores of each park in traffic convenience are relatively close to the total sample average, with little difference, indicating that each park performs relatively stably in traffic convenience but still needs further optimization and improvement.

3.2. Comparison of Satisfaction of Different Resident Groups Using Green Parks

To explore the impact of different variables on park users' satisfaction, this paper analyzes the satisfaction differences of different resident groups using green parks through ordered Logit-Probit regression analysis. The research results show that gender has a significant positive impact on venue facilities, ecological environment, and overall satisfaction; age has a significant negative impact on leisure and recreation functions; family structure has a significant impact on organizational management; occupation type has a significant impact on leisure and recreation functions, ecological environment, and overall satisfaction; housing type has a significant negative impact on all variables, indicating a high correlation between housing type and park users' satisfaction. In addition, travel purpose has a significant impact on leisure and recreation functions, ecological environment, and overall satisfaction; companionship situation has a significant impact on venue facilities, leisure and recreation functions, and ecological environment; travel mode has a significant impact on venue facilities, leisure and recreation functions, and ecological environment; usage frequency has a significant negative impact on organizational management, leisure and recreation functions, traffic convenience, and overall satisfaction; travel time to the park has a significant negative impact on venue facilities and overall satisfaction; park usage time has a significant negative impact on all variables (except leisure and recreation functions).

(1) As shown in Figure 3, male residents' satisfaction is generally higher than female residents', especially in terms of venue facilities, indicating that females are more sensitive to park green spaces, and the female-friendly construction of park green spaces needs to be improved; students' satisfaction is generally higher than that of various office workers, indicating that office workers have higher expectations for park green spaces and higher requirements for facility perfection, environmental hygiene, safety management, etc.

(2) Housing type has a significant negative impact on all investigated variables (venue facilities, organizational management, leisure and recreation functions, ecological environment, traffic convenience, overall satisfaction), indicating a high correlation between housing type and park users' satisfaction. Different housing types reflect social stratum differentiation to a certain extent, that is, the satisfaction of different stratum groups varies. Among them, the satisfaction of affordable housing (low-income groups) is relatively high, possibly because low-income groups have relatively low expectations for park green spaces and cherish and appreciate the opportunity to enjoy public green space resources for free, reflecting the good social effect of park green spaces (alleviating stratum differentiation and promoting social integration); unit system dormitories and commercial housing communities have lower values, and some unit system dormitories and commercial housing communities are located in urban peripheries or newly built areas, where park green space construction may be relatively lagging or insufficient, and residents face problems such as poor accessibility or inconvenient use.

(3) Residents with cultural and entertainment activities as their purpose have higher satisfaction, reflecting that park green spaces, as spatial carriers, provide ideal places for residents to carry out cultural and entertainment activities. In addition, residents with cultural and entertainment activities as their purpose pay more attention to the use value and functionality of park green spaces. When residents participate in cultural and entertainment activities in park green spaces, they not only enjoy the fun of the activities themselves but also feel the friendliness of neighborhood interaction and urban belonging. Residents with a usage frequency of once a day (high frequency) have lower satisfaction, indicating that users who use the park frequently have higher expectations in these aspects and are therefore more likely to be dissatisfied. Residents with a usage time of less than 1 hour (short time) have the most significant satisfaction differentiation, possibly related to the diversity of residents' needs, differences in green space quality and experience, and time use efficiency.

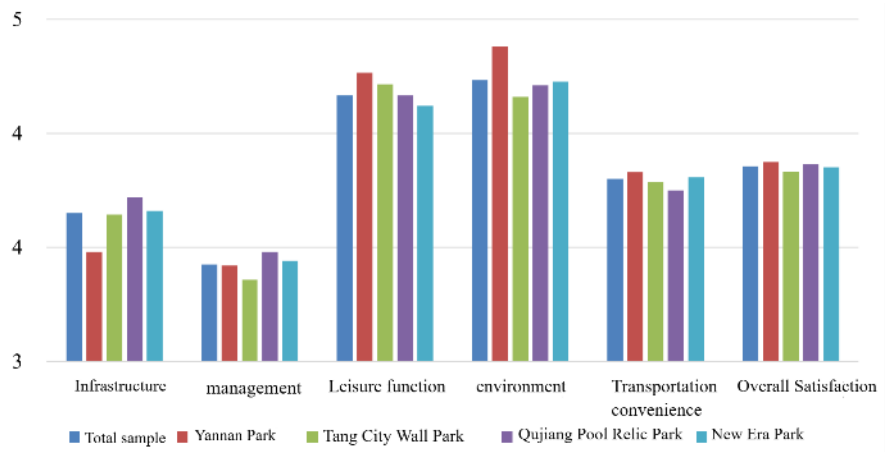

Figure 2. Comparison of Residents' Satisfaction with the Use of Parks

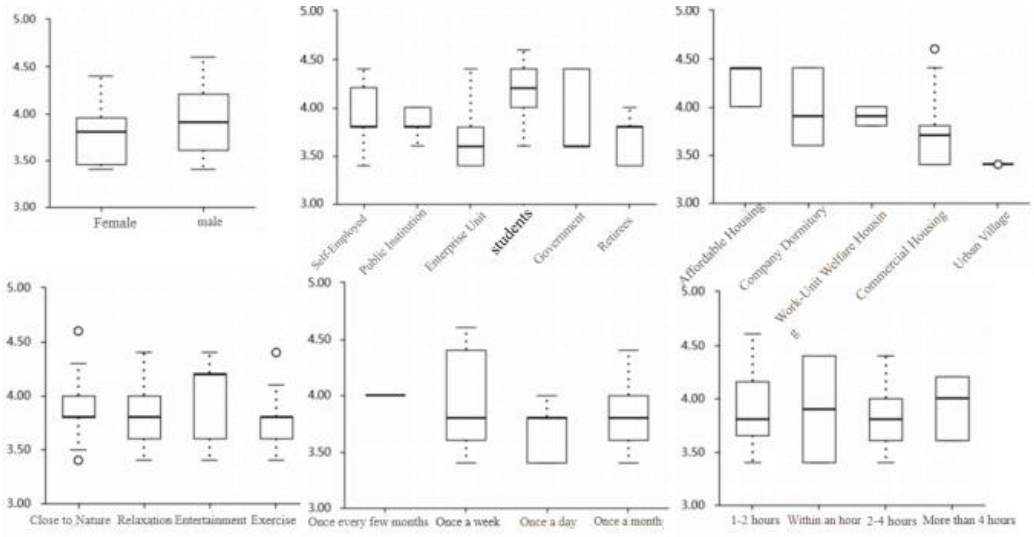

Figure 3. Comparison of satisfaction of residents with different attributes using green parks

4. SPATIAL LAYOUT OPTIMIZATION OF URBAN GREEN PARKS IN YANTA DISTRICT BASED ON MULTI-SOURCE DATA

Through the Green Space Service Scope analysis, Fraction of Vegetation Cover Analysis and Park Green Spaces analysis, this paper sets the location-allocation impedance to 15 minutes for analysis, ultimately obtaining two sets of location-allocation schemes. Based on the principle of minimizing the number of facilities, the second scheme was selected, identifying four allocated points as optimized site selection locations for pocket parks (Figure 4), with three points located in the western part of Yanta District and one point in the eastern part. The location-allocation pattern is basically consistent with the analysis results of vegetation coverage and green space distribution patterns, indicating that the situation of scarce green spaces in the western part of Yanta District can be improved and alleviated, confirming the rationality of the images.

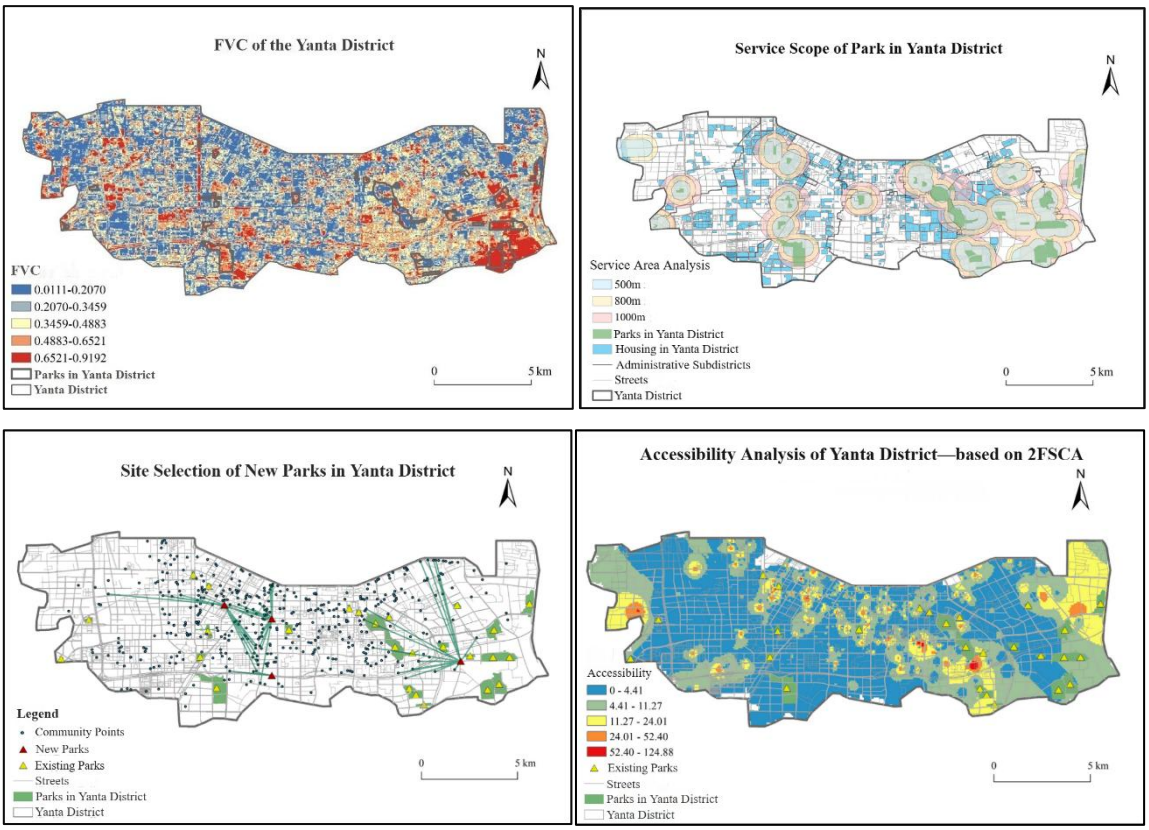

Figure 4. The process of the site selection

To verify the rationality of the site selection location for green parks, the location-allocation result image data and building vector data with floor heights were imported into ArcGIS Pro to conduct 3D modeling of the surrounding environment of the pocket park site selection, resulting in the following images:

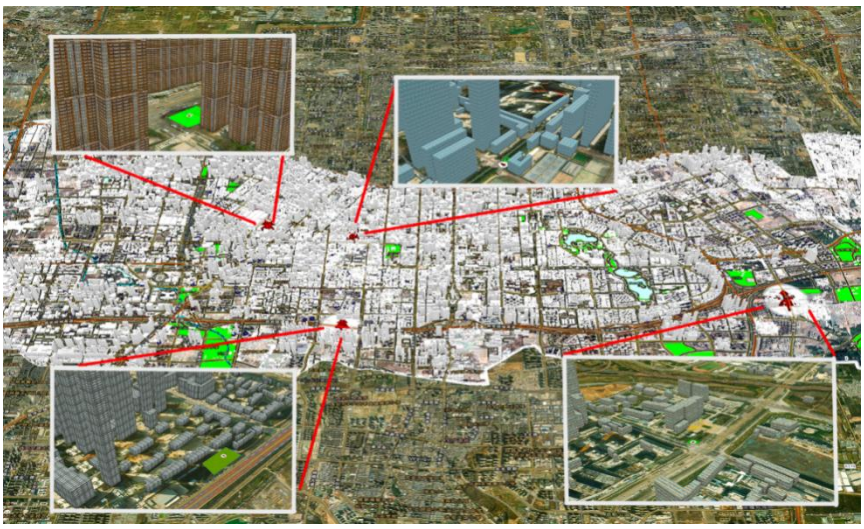

Figure 5. Surrounding environment and overall pattern of optimized pocket park site selection in Yanta District

The images reveals that the selected locations for pocket parks are all located along roads or at road intersections, with a large number of residential communities nearby, capable of filling the demand for park green spaces among surrounding residents. In addition, constructing pocket parks at these sites can maximize efficient land use, not only continuing to perform the original sidewalk functions but also enhancing the happiness of surrounding residents by adding leisure and recreation functions. Therefore, the pocket park site selection is feasible and reasonable.

5. CONCLUSIONS

This study innovatively integrates social analysis and spatial analysis methods, focusing on urban green parks in Yanta District, Xi'an, to deeply explore residents' satisfaction and analyze multiple dimensions of park construction from this perspective. Through rigorous empirical research, it systematically combs the hierarchical relationships of satisfaction across different dimensions and the performance differences of various park construction types in meeting residents' needs. Specifically, at the social analysis level, it uses questionnaire surveys, interviews, and other means to collect residents' feedback, accurately quantifying residents' satisfaction evaluations regarding the park's ecological environment, leisure and recreation functions, traffic convenience, venue facilities, and organizational management, and clarifying the importance ranking of each dimension as: ecological environment ≥ leisure and recreation function > traffic convenience > venue facilities > organizational management. This achievement provides a key basis for balancing park construction priorities, highlighting the core position of ecological and recreational functions in residents' experiences.

At the same time, with the powerful integration of multi-source big data and Geographic Information System (GIS), it reveals the layout panorama of park green spaces in Yanta District from a spatial perspective. Multi-source big data includes satellite imagery, urban planning data, etc., which are deeply mined and visualized through GIS technology to accurately display the spatial distribution characteristics of green spaces. The results show that the overall green space pattern in Yanta District presents an unbalanced trend of "dense in the east, sparse in the west," with specific administrative streets showing high-value agglomeration, reflecting the internal relationship between regional development and green space resource allocation, providing a precise target for subsequent targeted improvements. Further comparison between park green spaces relying on tourist attractions and urban ordinary functional park green spaces shows that the former significantly outperforms the latter in comprehensive attractiveness and service quality, indicating the optimization direction for urban ordinary functional park green spaces, namely strengthening humanized design to meet residents' daily recreational needs.

Integrating the above achievements and closely combining the development plan of Yanta District, Xi'an, with residents' actual needs, this study ingeniously proposes an optimization scheme for the spatial layout of park green spaces, innovatively introducing the concept of pocket parks to reshape the urban green space ecology and improve residents' quality of life. With their compact size and community-centric characteristics, pocket parks can minimize the spatial distance between urban residents' homes and park green spaces, significantly improving the spatial distribution balance and fairness of park green spaces in Yanta District, allowing residents to enjoy rest and entertainment venues within walking distance and comprehensively meeting urban residents' diverse needs for leisure, recreation, and sightseeing. This provides a brand-new vitality and a highly practical reference model for future urban green space planning and refined management.

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