Article

Accessibility and Street Network Characteristics of Urban Public Facility Spaces: Equity Research on Parks in Fuzhou City Based on GIS and Space Syntax Model

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Abstract: Urban green spaces are conducive to people’s physical, mental, and social health; however, in many cases, these benefits are unevenly distributed in cities. This study explored the equity of urban green spaces in terms of accessibility and spatial morphology, specifically, (1) applied the geographic information system (GIS) accessibility index to the equity of parks in Fuzhou City; (2) discussed the accessibility of parks and the spatial morphological characteristics of streets from a space syntax analysis; (3) examined the correlation between the accessibility of parks in Fuzhou City and the spatial morphology of streets. The results provide a valuable reference for sustainable urban design and planning.

Keywords: spatial equity; accessibility; street network; urban parks; sustainability

1. Introduction

Sustainable development has been studied from environmental, economic, and social aspects. Numerous researches have defined the connotation of the three aspects and explored the ways to reach a balance among the three aspects. Although many measures and evaluation methods have been proposed on environmental protection and economic development, it is rather difficult to define the scope of social equity. Moreover, the research related to social sustainability is not as diversified as the research on the other two aspects [1].

Cities are spaces where most people live, thus, the tangible and quantifiable spatial characteristics of cities contribute to defining the connotation of social sustainability [2]. Urban public green spaces refer to public and service facilities, which are planned by the state and the government to provide convenient services and to maintain good living quality. The spatial structure formed by location and scale in an urban environment is a topic widely discussed in the field of urban planning. Similar to wealth and resources, how public green spaces are fairly distributed to various groups affect the operation of the entire society. Therefore, the spatial planning and strategy for making public green spaces should be oriented towards realizing the social sustainability of cities.

Urbanization has now become one of the global development agendas. The United Nations Sustainable Development Goals11 (SDG11) defined urbanization as the integration, protection, robustness, and sustainability of urban communities and human settlements. The United Nations expanded its SDG agencies to new urban management in 2016 [3], while the sustainability and
inclusiveness of cities depend on different standards, such as planning, fair spatial allocation, ecological services, urban management, green space quality, and socio-economic facilities. The social advantages provided by urban green spaces help to increase the personal satisfaction of urban residents \[4–6\]. It is widely recognized that human health is related to the measurement, quality, and equity of green spaces, and the environment requires that public places belonging to different social categories should be featured by sustainability and fair accessibility. Accessibility methods are available in planning documents and corporate verifiable records \[7–11\]. Accessibility is characterized by how the frame is used and transported, allowing the public to exercise or gain energy from the transport mode \[12,13\].

Street networks are regarded as the skeleton of cities, as they link the geographical units in the urban spaces. To a certain extent, the morphological structure of streets determines the connection breadth and strength of different functional areas in the urban environment, which affects the flow and operating efficiency of various resource elements and the urban spatial structure in cities \[14–18\]. There is a mutual promotional and restricting relationship between transportation networks and urban public facilities. Complex network methods have been deployed in many researches to evaluate the integrity and accessibility of street networks by analyzing their topological characteristics and spatial distribution \[19–23\]. Although some emerging researches have explored the relationship between street network characteristics and public facilities, most existing works focus on analyzing the accessibility of public facilities. Furthermore, few researches have addressed the street network of cities from a global perspective or studied whether the characteristics of urban morphological structures are related to the development of urban public facilities.

In the past, the political and ethnical reasons for unfair facility distribution were discussed \[24\]; however, urban morphology was rarely addressed due to the differences in access or convenience to public facilities in different areas, as generated by street and texture planning. In this regard, spatial equity is an important standpoint in spatial planning to analyze the configuration and structure of public facilities, as well as assess the distribution equity of public resources in spatial or territorial terms \[24\]. Spatial equity emphasizes the relationship between equity and location, and suggests that public services and resources should be made equally available to groups in different spaces. Spatial inequality implies unfair spatial separation or spatial proximity between residents and public facilities, and such separation or proximity is caused by the spatial morphology connected or blocked by the buildings and roads in the urban environment. Therefore, in addition to the configuration of public green spaces, the road networks also affect the convenience of residents to access public services as a bridge between different activities. Therefore, the analysis of spatial equity should regard the road network structure as the foundation of an urban environment system, which provides a fair starting point for different groups in different areas to access public services.

Previous researches on the spatial equity of public facilities adopted accessibility as an indicator \[25,26\], as accessibility provides a relatively complete grasp of the availability and spatial location of facilities. Even in different methods, accessibility takes into consideration land use, transportation, time, and personal factors to different degrees. Regarding the development of the indicators, first, the simple measurements of the distance to the facilities were used to represent accessibility, and then, the cumulative opportunity method was used to assess the number of facilities accessible to each person or district within a certain range. Recently, the potential model, the facility scale, and the characteristics that the facility benefits, which gradually decline over distance, have been simultaneously considered. However, all previous researches divided the research area into many spatial units, and then, calculated the accessibility of each unit.

Therefore, this study analyzed whether residents have equal opportunity to access existing public facilities according to the texture of the urban road networks from the perspective of spatial equity. This study has two main contributions to the academic community. On one hand, from a methodological perspective, the proposed framework provides technical and methodological support for a better understanding of the relationship between urban facility construction and urban street

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structure. On the other hand, from an empirical perspective, the case study can guide decision-makers in sustainable urban development and urban space optimization.

2. Research Methodology

2.1. GIS

A geographic information system (GIS) can be used to enhance facility planning and management of public facility spaces. One of the applications discussed in this paper is the measurement of accessibility and distribution equity provided by the park system, which helps to identify low-accessible areas and groups. The system also provides suggestions for the best locations to design new facilities, thus, maximizing accessibility and equity. Accessibility provides a relatively complete grasp of the availability and spatial location of facilities. Even in different methods, accessibility takes into account land use, transportation, time, and personal factors to different degrees; therefore, accessibility has been widely adopted by researchers of spatial equity. The results of accessibility calculations were further analyzed in geographic space to reveal the areas with better and worse accessibility, and how the distribution of facilities is unfair to certain groups.

In reference to the theoretical basis, accessibility can be evaluated by three criteria: operability, interpretability, and dissemination, while the usefulness and limitations of different accessibility measurement methods can be judged according to the research topics. However, when using accessibility as an indicator, different methods should be considered to satisfy different situations and serve different purposes; in other words, there is no optimal accessibility indicator [27]. Instead, a most suitable measurement method should be identified to address the research purposes and criteria. In this study, the road network distance to the nearest facility was applied to measure accessibility, as it can clearly exhibit the aggregation error in accessibility measurement and has advantages in operability and interpretability. Moreover, its data requirements are not high, which makes it easier for researchers and planners to understand and assess the differences in accessibility in a more direct manner.

2.2. Interpretation of Spatial Inequality

The Lorenz curve and the Gini coefficient were originally used to explore the equity of income or wealth distribution. Income is positively related to wealth status. If the total income of n individuals in the area is x, under absolutely fair wealth distribution, when the income of n individuals is plotted as a histogram, the income of each individual is x/n. When the values are accumulated to plot the Lorenz curve, the x-axis is the cumulative percentage of the population, and the y-axis is the cumulative percentage of the income. As each individual uniformly obtains equal 1/n of the total income, the Lorenz curve is a 45° oblique line between (0, 0) and (1, 1), which is also regarded as an absolutely fair oblique line. If the wealth distribution is unfair, an area A will be generated between the Lorenz curve and the absolutely fair oblique line. The area below the curve is B and A + B is 0.5. The Gini coefficient is defined as A/(A + B). Under absolutely fair wealth distribution, A = 0 and the Gini Coefficient = 0. Under absolutely unfair wealth distribution, A = 0.5 and the Gini Coefficient = 1, where the Gini Coefficient = A/(A + B).

2.3. Space Syntax

The argument raised by space syntax is that the pattern of movement in a city is likely to be shaped to a large extent by the topology of its route network alone, irrespective of all other factors (e.g., distribution of land uses) [28], therefore, the network itself, and the analysis of its shape, is the focus of space syntax analysis and is an area that remains minimally explored [29]. Space syntax provides an alternative method of measuring street connectivity. Originated in the field of architecture and urban design, space syntax is generally used for characterizing and quantifying the spatial layout of buildings within urban spaces or enclosed spaces within streets based on topological methods [30,31]. Different from intersection density, space syntax focuses on the topological distance within the network,
which refers to the number of turns required to reach one location from another [32,33]. The calculation of space syntax has been explained in some researches [30,32,34,35]. In short, street integration is a key space syntax measure that shows the topological accessibility of one street segment to all other street segments within a defined area (i.e., a certain distance from the center of the street). A more highly integrated street segment means that it takes fewer curves to reach the street segment from other streets in the network. Figure 1a shows one street network, and Figure 1b shows the integration level (the red line represents higher integration).

![Street network](image)

**Figure 1.** Street network: (a) street network; (b) space syntax integration.

Path selection is also crucial for pedestrians [36]. The literature on pedestrian route choice behavior consistently reported that travel time/distance is the key determinant of route choice; this means that pedestrians choose the shortest path/time route between an origin and a destination. Even a more recent study in Cambridge, it was demonstrated that pedestrians choose a route that is shorter than the geographic information system (GIS) derived shortest path route by taking cut throughs and other paths not present in a typical road network used for a GIS-based analysis [37–41]. Directional distance (e.g., the number of directional changes required to reach a destination) is a commonly used indicator to represent street configuration in the space syntax literature [30,42–44]. The segment analysis in space syntax provides three analysis modes, which can comprehensively analyze the topology, angle and metric of the street network. The difference between these analysis modes lies in the definition of the number of “shortest paths”. The topological mode shortest path is the path with the fewest number of polyline breaks, or the path with the fewest number of other segments. The angular mode shortest path is the path with the smallest turn angle between two segments. The metric mode is that the shortest path is the shortest distance between two-line segments. In this study, the angular mode is selected, which is the most commonly used mode in line segment analysis [30].

### 2.4. Integrating GIS and Space Syntax

Different from most previous studies that employed GIS or space syntax, this study integrated GIS and space syntax to yield good data support. This approach can be used in similar or different studies, such as for the discussion of function and data. For example, a study on Xian-lin campus of Nanjing Normal University integrated GIS and space syntax to analyze the characteristics of the layout of the campus space and buildings [45]. In another study on Anhou Town’s new round of spatial development morphology, an implementation method of spatial morphology planning that integrated GIS and space syntax was used for quantitative analysis on syntactic variables of integration, integration core, and intelligibility [46]. To design a well-grounded system of roadside rest areas (RRA) for transit travelers and local inhabitants in Latvia and Lithuania, the space syntax method and GIS-based analysis were used to select places for the location of RRA on the Latvian–Lithuanian cross-border roads [47]. To understand how pedestrian movement is generated in relation to the
urban layouts and how to predict this movement in public spaces, GIS database, statistical methods, and space syntax were used and tested in the case of the municipality of Athens [48]. Space syntax quantitatively describes the spatial structure of cities from a cognitive perspective. GIS possesses excellent data analysis and efficient geographic modeling capabilities. A combination of space syntax and GIS could enhance the spatial analysis ability of GIS and deepen the quantitative research of space syntax on urban space structure.

A geographic information system (GIS) can provide a large number of opportunities for recreational service agencies to enhance the planning and management of their facilities. In this study, one such application was demonstrated for measuring the accessibility and distribution equity provided by the park system. As space syntax introduces the concept of network scale, by limiting the spatial distance or radius of network analysis, meaning only considering the topological connection between line segments within a certain range, the potential of street networks from both local and global scales was measured.

3. Research Design

3.1. Research Scope

As the provincial capital of Fujian Province, Fuzhou City is the political, economic, and cultural center of Fujian Province. It is also a seaside garden city that contains five districts and eight counties. As of 2018, the city managed six districts, six counties, and one host county-level city with a total area of 11,968 square kilometers. The research scope of this study includes four administrative districts in the center of Fuzhou City, Gulou District, Taijiang District, Jin’an District, and Cangshan District (Figure 2a). These four districts are developed similarly and have complete roads and other infrastructures. Specifically, Jin’an District is far from the city center with bending terrain, inconvenient traffic, and backward economic development. Therefore, the research area of the road network includes the third ring roads of Fuzhou City (Figure 2b).

![Figure 2. Research scope: (a) Gulou District, Cangshan District, Taijiang District, Jin’an District of Fuzhou City; (b) street network.](image-url)
3.2. Research Data

The basic data of the road network was obtained by OpenStreetMap and edited with ArcGIS to generate road segments. The coordinates of 3548 road segments were used as the starting points for calculating the respective requirements of public facilities. Through the API provided by Baidu Maps, the Baidu POI data were retrieved with parks and community committees as the keywords, and then imported into MS Excel. After data cleaning and coordinate correction, the latitudes and longitudes of parks and communities in Fuzhou City were acquired. Within the scope of the study, the coordinates of 120 parks and 412 community committees were obtained (Figure 3).

![Figure 3. Research data: (a) road segments; (b) parks; (c) community committees.](image)

3.3. Research Framework

In order to calculate the minimum distance from the park demand point to the park supply point, the Network Analyst extension tool in ArcGIS was used for analysis. Based on the actual road network, this study used spatial analysis tools to solve complex routing problems, including finding the best route, generating service areas, creating an OD cost matrix of starting points and end points, performing location-allocation of facilities, etc. To find the closest facility, the established road network can be used as the actual action path, and the event points (demand points) and facilities (supply points) can be set up to calculate the space resistance from the starting point to the nearest facility, which refers to the minimum road network distance in this study. When the information of event points and facilities is read in network analysis, the results of different scenarios can be obtained under different settings. First, this study identified the difference between the community-based and the road segment-based accessibility results. Second, the urban street morphology was investigated from the perspective of space syntax, and the global integration and local integration were calculated. Finally, the correlation between park accessibility and street spatial morphology in Fuzhou City was explored to provide a valuable reference for sustainable urban design and planning (Figure 4).
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Figure 4. Schematic for the research framework.

4. Accessibility Analysis

4.1. Accessibility Measurement

With the community-based and road segment-based accessibility calculations, through the road Network Analyst tool provided by ArcGIS, the information of the starting points (demand points) and end points (supply points) were imported, and the measurement method of the road network dataset and spatial impedance (actual road network distance) was set [49]. The analysis steps are as follows:

1. Import the road network data (.shp file) of communities and road segments collected through Baidu Maps POI into ArcMap, and create a new road network dataset.
2. Enter the starting points of the road network analysis (412 data units of communities, 3548 spatial data units of road segments).
3. Enter the end points of the road network analysis (120 data units of parks).
4. Perform “the closest facilities” in Network Analysis of ArcGIS to obtain the minimum road network distance between the starting points and the end points as the accessibility.

Figure 5 shows the preliminary results of the spatial distribution of the community-based and road segment-based accessibility results.

Hereunder, the road segment-based and the community-based accessibility results were analyzed by descriptive statistics. There are 412 spatial units calculated by the community-based accessibility results, and 3548 spatial units accessible by the road segment-based accessibility results. Figure 6 shows that the frequency distribution of the road segment-based and the community-based accessibility results are similar, both of which are right-skewed and exhibit obvious central tendency. Through statistical calculation (Table 1), the community-based skewness is 2.38, indicating that the mean is greater than the median, and that the accessibility of most spatial units is better than the overall mean. The road segment-based accessibility results skewness is 1.76, which is smaller than the community-based skewness, but has a similar right-skewed pattern. The community-based kurtosis index is 8.10, it shows a sharp peak, and its concentration trend is more significant than the result of 3.955 based on the midpoint of road segment-based accessibility.
4. Accessibility Analysis

4.1. Accessibility Measurement

To investigate spatial clustering, including the scattered or random distribution patterns, descriptive statistics were conducted (Table 1). The mean accessibility results show a right-skewed pattern, indicating that the majority of spatial units have better accessibility than the overall mean. The variation in accessibility is significant, as indicated by the standard deviation values.

In terms of community-based accessibility, to reach the nearest park facility requires walking 1218.71 m on average; however, in terms of the road segment-based accessibility, to reach the nearest park facility requires walking 897.27 m on average. The dispersion of the community-based accessibility results (1151.59) is also higher than that of the road segment-based accessibility results (735.85). Overall, the road segment-based accessibility results yield a more consistent and better outcome. Whether community-based accessibility results or road segment-based accessibility results, similar central tendencies are observed.
the difference in accessibility is truly reflected should be judged by exhibiting the district divisions in
the space.

4.2. Global Spatial Autocorrelation

In order to investigate spatial clustering, including the scattered or random distribution patterns
of the two results, the Spatial Statistics tool in ArcGIS was used to calculate Moran’s $I$ of global spatial
autocorrelation:

$$I = \frac{n}{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}(X_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

Based on point data, the spatial weight matrix was established with the square of the reciprocal
of the distance $\frac{1}{d_{ij}^2}$. Only the closer points are mutually affected by each other. The results
are shown in Table 2. The $P$ values are lower than 0.01, which is significant. Specifically, Moran’s $I$
of the community accessibility is 1.4175, and Moran’s $I$ of the road segment accessibility is 0.6172.
The random distribution is less likely to be applicable; instead, a more obvious clustering pattern is
demonstrated in the range of Fuzhou City. The results show the spatial positively-correlated mode,
in which accessibility is directly proportional to the spatial cluster. In addition, community accessibility
is more highly clustered than road segment accessibility.

<table>
<thead>
<tr>
<th>Table 2.</th>
<th>Moran’s $I$ index spatial autocorrelation analysis.</th>
</tr>
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<tbody>
<tr>
<td><strong>Community Accessibility</strong></td>
<td><strong>Road Segment Accessibility</strong></td>
</tr>
<tr>
<td>Moran’s $I$ index</td>
<td>1.4175</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.008642</td>
</tr>
<tr>
<td>Z Score</td>
<td>15.2751</td>
</tr>
<tr>
<td>$P$ value</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

Then, this study further examined the category of the accessibility cluster with the high/low
clustering analysis tools (high/low clustering (Getis-Ord General G)). The General G index is also an
inferential statistical method that uses limited data to estimate global characteristics. When the returned
$P$ value is small and statistically significant, the null hypothesis can be rejected. If the Z score is positive,
the observed General G index tends to be higher than the expected General G index, which indicates
that high attributes are clustered in the study area; if the Z score is negative, the observed General G
index tends to be lower than the expected General G index, which indicates that low attributes are
clustered in the study area.

The analysis results in Table 3 show that the Z score and $P$ value of the community accessibility
are 10.85 and 0.00, respectively, while the Z score and $P$ value of the road segment accessibility are
2.30 and 0.02, respectively, which are both significant. The results reveal a high accessibility cluster,
which means that the points with a short distance to parks are more concentrated. Specifically,
community accessibility has higher clusters than road segment accessibility, and the communities near
the park are more clustered.

<table>
<thead>
<tr>
<th>Table 3.</th>
<th>High/Low Clustering (Getis-Ord General G).</th>
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<tbody>
<tr>
<td><strong>Community Accessibility</strong></td>
<td><strong>Road Segment Accessibility</strong></td>
</tr>
<tr>
<td>General G</td>
<td>0.002884</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.000000</td>
</tr>
<tr>
<td>Z Score</td>
<td>10.856255</td>
</tr>
<tr>
<td>$P$ value</td>
<td>0.000000</td>
</tr>
</tbody>
</table>
4.3. Local Spatial Autocorrelation

While global spatial autocorrelation can be used to analyze the global spatial pattern of one characteristic attribute, this spatial pattern is not identical throughout the study area, which means that the space is heterogeneous. To describe how this characteristic attribute is distributed in space, the local differences of spatial autocorrelation in the study area should be discussed first. Therefore, in order to further understand the spatial distribution of accessibility, cluster and outlier analysis (Anselin Local Moran’s I) was used to perform local spatial autocorrelation analysis, and the results can be used to identify local differences in park accessibility from the perspective of spatial distribution. The high-high area means that the periphery of the highly-accessible spatial units also has low accessibility (high values represent low accessibility); conversely, the low-low area means that the periphery of the low-accessible spatial units also has high accessibility (low values represent high accessibility). The high-low and low-high areas are transitional areas; while a not significant area means that the local spatial autocorrelation is not significant, as shown in Figure 7.

![Cluster and outlier analysis](image1)

**Figure 7.** Cluster and outlier analysis: (a) community accessibility; (b) road segment accessibility.

The analysis results show that the overall trend of accessibility is similar. The low-low area is concentrated in the center, which includes the roads close to parks, and most of the high-high area is distributed in the south of the city district, while only a small part is in the east and north, which includes the roads far from parks and the areas with low accessibility. Although the overall trends of the two are similar, the road segment accessibility is more accurate and the location is more accurate; therefore, it is capable of capturing more accurate accessibility status. This study used hot spot analysis (Getis-Ord Gi*) to demonstrate a more prominent clustering effect, as shown in Figure 8.

4.4. Spatial Inequality Index

The Lorenz curve and Gini coefficient were originally used to explore the equity of income or wealth distribution; income is positively related to wealth status. Hereunder, the concepts of the Lorenz curve and the Gini coefficient were introduced to the accessibility results to show spatial inequality. The Lorenz curve, as plotted from the accumulated community-based and road segment-based accessibility results, is shown in Figure 9. The curvature of the community accessibility curve is higher than that of the road segment accessibility curve. The calculated spatial Gini coefficient (inequality index) of community accessibility is 0.7, and the calculated spatial inequality index of road segment accessibility is 0.29384, which implies that calculating accessibility by street segments can output a more fair result, while spatial units based on community accessibility produce less fair space.
The two are similar, the road segment accessibility is more accurate and the location is more accurate; therefore, it is capable of capturing more accurate accessibility status. This study used hot spot analysis includes the roads far from parks and the areas with low accessibility. Although the overall trends of distributed in the south of the city district, while only a small part is in the east and north, which (Getis-Ord Gi*) to demonstrate a more prominent clustering effect, as shown in Figure 8.

As most of the park resources are concentrated in the downtown, most residential areas far from the rapid urban development, the population has expanded, and the downtown has been well developed. The southeast of Cangshan District cannot access any park within 400 m (Figure 10), which shows that, with mean road segment accessibility is 900m, most communities in the northeast of Jin'an District and the downtown still lack access to parks.

Spatial Inequality Index

5.1. Overview and Problems of Spatial Distribution of Parks

Based on the relationship between the travel modes and frequencies of the residents, as well as the accessibility results, is shown in Figure 9. The curvature of the community accessibility curve is higher compared with the road segment accessibility curve and the Gini coefficient were introduced to the accessibility results to show spatial inequality.

The Lorenz curve, as plotted from the accumulated community-based and road segment-based accessibility results, is shown in Figure 9. The curvature of the community accessibility curve is higher compared with the road segment accessibility curve. The calculated spatial Gini coefficient (inequality index) of community accessibility is 0.7, and the calculated spatial inequality index of road segment accessibility is more evenly distributed, and the park resources enjoyed by residents are also relatively even. The Lorenz curve and Gini coefficient indicate that road segment accessibility is closer to the absolutely fair line.

The spatial distribution of parks seeks to enable the most residents to reach a nearby park at a relatively small distance, and only a small number of residents have to travel long distances to access services. In the accessibility calculation, the distance of outliers and extremes to the nearest facility differs greatly from other spatial units, which includes the small number of residents who need to travel long distances to reach a park facility. Among the above park accessibility calculation and analysis from two different perspectives, the calculated road segment accessibility is better in terms of data, and the data is more concentrated. According to the overall spatial autocorrelation analysis, road segment accessibility is more evenly distributed, and the park resources enjoyed by residents are also relatively even. The Lorenz curve and Gini coefficient indicate that road segment accessibility is closer to the absolutely fair line.
5. Space Syntax: Spatial Structural Analysis of Streets and Parks

5.1. Overview and Problems of Spatial Distribution of Parks

Based on the relationship between the travel modes and frequencies of the residents, as well as the mean road segment accessibility, the service radiiuses of 400 and 900 m with optimal accessibility were set up. Buffer zones were applied in 120 parks in four administrative districts of Fuzhou City; most of the communities in Gulou District and Taijiang District are basically within 400 m of a certain park.

A small part of Cangshan District and Jin’an District can access a certain park within 400 m. If the mean road segment accessibility is 900 m, most communities in the northeast of Jin’an District and the southeast of Cangshan District cannot access any park within 400 m (Figure 10), which shows that, with rapid urban development, the population has expanded, and the downtown has been well developed. As most of the park resources are concentrated in the downtown, most residential areas far from the downtown still lack access to parks.

![Figure 10](image.png)

**Figure 10.** Analysis of buffer zones in Fuzhou City: (a) a park service radius of 300 m; (b) a park service radius of 900 m.

5.2. Intrinsic Connection between Spatial Structure of Streets and Space Syntax

The space syntax theory, as proposed by Hillier et al., regards a city as a complex and dynamic communication networks at different scales according to different traffic types. To correspond to the accessibility potential of streets on different urban scales can be measured by different network analysis radiuses; for example, a syntax calculation with a 400 m radius can reflect the mean road segment accessibility of 900 m, most communities in the northeast of Jin’nan District and the southeast of Cangshan District cannot access any park within 400 m (Figure 10), which shows that, with rapid urban development, the population has expanded, and the downtown has been well developed. As most of the park resources are concentrated in the downtown, most residential areas far from the downtown still lack access to parks.

According to space syntax, local spaces are different segments in the city, which are connected by a natural flow of people. The flow of people dominates the layout of urban spaces to a large extent and depends on the perception of the composition of urban spaces [50]. The characteristics of spatial layout and the harmony between different spaces are precisely produced by the interaction between the overall space and the flow of people. This symbiotic relationship between local and global spaces is the connection between different spatial levels of the city; however, this invisible logic is often neglected in existing planning researches.

The space syntax theory, as proposed by Hillier et al., regards a city as a complex and dynamic spatial configuration, and translates the spatial structure in reality into a quantifiable syntactic model. In the translation process, the spatial perception is translated into the organizational conceptualization, thus, completing the thinking jump of inferring the invisible from the visible. The core idea of space syntax is that the basic connection of urban spatial organization is the flow of people [50]. On one hand, urban structures affect the natural flow of people and traffic; on the other hand, the spatial perception and action of people largely determine the layout of urban spaces [51]. Syntactic analysis can predict...
the possible flow of people in each street by calculating the accessibility of the street network, thus, determining the relative convenience of the space. As space syntax is consistent with the concept of accessibility, it was applied in this paper to review the current layout of cultural facilities and select the highly-accessible areas. Then, combined with the park accessibility analysis by GIS, comprehensive layout recommendations and sustainable development trends were proposed.

Syntax summarizes the spatial system as an axial model, which corresponds to the linear flow of people in the city. Since public facilities have hierarchical attributes corresponding to the scope of services and functions, the natural flow of people thus generates hierarchical movement and communication networks at different scales according to different traffic types. To correspond to the accessibility analysis of park facilities in Fuzhou City, the segment model, as derived from the axial model, was adopted in this paper to expand the accessibility measurement from topological distance (number of turns between two axis) to angular distance (accumulated turning angle of the axis). In addition, the accessibility potential of streets on different urban scales can be measured by different network analysis radiuses; for example, a syntax calculation with a 400 m radius can reflect the accessibility of the space within a 5 min walk. As the mean road segment accessibility is 900, a syntax budget with a radius of 900 m can be used to calculate all the accessible objects in the space, as shown in Figure 11.

![Figure 11. Street integration: (a) global integration analysis; (b) 400 m integration analysis; (c) 900 m integration analysis.](image)

This study extracted the integration of a street where a park is located from global integration, 400m integration, and 900m integration as the accessibility attributes of the park. Specifically, the streets with an integration ranking in the top 20% form the foreground network, as defined by Professor Hillier, which constitute the main skeleton of the urban spaces. The streets with an integration ranking in the top 10% form the integration core that refer to the space with the best accessibility. The streets with an integration ranking in the bottom 80% form the background network where residents travel less efficiently. The quantitative results in Figure 12 show that, in the global integration calculation, 28% of the parks are located in the foreground network, 8% of which are included in the integration core. In the 400 m integration calculation, 17% of the parks are located in the foreground network, 7% of which are included in the integration core. In the 900 m integration calculation, 23% of the parks are located in the foreground network, 6% of which are included in the integration core. Both local and global integration calculations reveal particularly uneven park distribution. Most parks are distributed in low-accessible areas, while only a few parks are distributed in the main skeleton or integrated core.
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Figure 12. Park distribution integration.

This study subdivided the integration of the streets where the parks are located in the foreground network. According to the analysis of the three integration calculations, Gulou District has the most highly-accessible parks, followed by Taijiang District, Cangshan District, and Jin’an District, respectively. The top 20% of the streets based on road segment accessibility are similar to the results of the integration analysis. Gulou District has the most highly-accessible roads, which means there are more points close to parks (Table 4).

Table 4. Percentages of streets where the park is located with an integration ranking in the top 20%.

<table>
<thead>
<tr>
<th>Integration</th>
<th>Integration 900</th>
<th>Integration 400</th>
<th>Road Segment Accessibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulou District</td>
<td>4 10 5 13 5 7</td>
<td>120 329</td>
<td></td>
</tr>
<tr>
<td>Taijiang District</td>
<td>4 6 3 5 3 3</td>
<td>72 148</td>
<td></td>
</tr>
<tr>
<td>Cangshan District</td>
<td>0 4 0 2 0 4</td>
<td>55 130</td>
<td></td>
</tr>
<tr>
<td>Jin’an District</td>
<td>2 4 0 0 1 2</td>
<td>49 102</td>
<td></td>
</tr>
</tbody>
</table>

6. Conclusions and Discussion

6.1. Conclusions

From a methodological perspective as GIS has more comprehensive spatial data management and geographic analysis capabilities, the metric distance analysis of GIS and the topological analysis of space syntax were integrated in this study to construct the spatial geographic information of cultural facilities, Depthmap information of the street network in Fuzhou City, and a database. First, GIS was used to establish network data and analyze the accessibility indicators. The space syntax was then adopted to superimpose the urban street network analysis model with park points. Next, spatial analysis was performed on the current park layout. The conclusions of this study are proposed in the following sections (Figure 13).
In the study of park equity, in order to yield better accessibility calculation results from the GIS, accessibility was calculated based on both urban communities and road segments. Since the community-based accessibility calculation method assumes that all the community individuals have the same accessibility as the community center, it ignores the spatial differences within the spatial unit, and thus, cannot detect subtle differences in the community. Therefore, a more accurate road segment was adopted as the spatial unit. Later, spatial autocorrelation analysis, the Lorenz curve, and Gini coefficient analysis revealed relatively unfair park accessibility in Fuzhou City, as shown in Figure 12. The hot spot analysis of the road segment accessibility showed that high accessibility is concentrated in the cold spot areas, which indicates that most of the residents in Gulou District and Taijiang District can access park resources at only a small distance. Most of the residents in Jin’an District and Cangshan District have poor accessibility to parks, especially the residents in the east of Jin’an District and the south of Cangshan District.

In this paper, the integration of space syntax was used to describe the spatial characteristics of parks and streets. The integration reflects how physically close a space is to all other spaces, which refers to its potential as a destination; a more integrated road has higher accessibility. From the analysis of the global integration results, most of the parks are located on streets with low integration. High integration is more consistent with the GIS accessibility analysis result. The parks located on highly-integrated streets are collectively distributed in the center of the map, as well as on most streets in Gulou District and Taijiang District. The accessibility of most streets in the north of Jin’an District, and the north and south of Cangshan District is low, which is an important reason for unfair resources.

The results of this study show that when the streets where the parks are located are more integrated, the accessibility to the parks is also higher; the two also prove the unfair distribution of green space resources in parks of Fuzhou City. From the perspective of space syntax integration, the rankings of global integration, 400 m integration, and 900 m integration are Gulou District, Taijiang District, Cangshan District, and Jin’an District. For the GIS network analysis, the top 20% of streets in the road segment accessibility rankings is in the same order. Gulou District has the most highly-integrated streets, followed by Taijiang District, Cangshan District, and Jin’an District, respectively.
6.2. Discussion

(1) This paper provides a new perspective for optimizing the spatial layout of urban public facilities in terms of equity and accessibility. The research method integrated GIS and the space syntax theory, and is universally applicable to other cities and regions. In the future, with urban renewal and cultural development, public cultural facilities will play a more important role in enhancing the humanistic value of a city. Fuzhou City is rich in park resources and has a good structural order of street space; however it is unevenly distributed, as most of the resources are concentrated in the old downtown. Future development can refer to the 400 m and 900 m integration measures, as proposed in this study, and adopt a multi-center clustering development structure, which can focus on the construction of areas with low urban spatial accessibility to maximize the utilization of park facilities. In addition, the layout of parks and public facilities should consider both homogeneity and efficiency optimization, while the key spaces with structural advantages should be constructed to maximize efficiency and equity.

(2) The spatial inequality in this study emphasizes the difference in proximity and convenience of different areas to public services due to street network planning and public facility allocation. Therefore, the road segments were regarded as spatial units, and their distance to the facilities through the actual road network was calculated. However, as the density of road segments does not equal the density of the actual population, it is possible that one road segment carrying 500 residents and another road segment carrying 5000 individuals are considered equally important. In addition, the facility size, the service level, and the use of surrounding land lead to different urban park benefits. Future studies may consider the above factors according to their research motivations and purposes, and reflect them in the research design.

(3) The accessibility of road networks plays a vital role in affecting sustainable urban development, while the spatial equity of public facility layout, such as parks, is directly related to the quality of the living environment of residents on different streets. In particular, accessibility has a profound influence on the use frequency of public facilities, such as parks, by low-income groups, the elderly, children, and the disabled in the urban areas. At present, the rationality of the spatial distribution pattern of parks is examined by determining the service radius of parks according to the park levels in China, which refers to achieving full coverage of park services through planning. The main indicators include the number of parks, park area per resident, and spatial layout homogeneity. Quantitative research of resident demands and spatial equity of park layout is still insufficient. However, many researches abroad have shown that, on many streets with high social demands, despite high park accessibility, the residents are reluctant to use the parks [52], which is due to the park quality, such as comfort, safety, quality, and artistic value. As this problem involves the discrepancy between resident demands and behaviors, further questionnaire surveys and analysis are needed to accurately grasp the resident demands and behaviors, which is also a top priority for the author to explore in the future.

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