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Spatial Intersection Analysis Based on the Choice of Streets, the Functionality Mixing Degree of Land Use and the Green Visibility Rate by Street Views—Taking the City Center in Shanghai as the Research Area

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Abstract: When carrying out urban renewal and related development projects, large-scale demolition and reconstruction in city centers inevitably present special challenges. Spatial quantitative analysis tools such as ArcGIS, Python, and depthMapX offer the opportunity to assess various urban development-related factors, including identifying which streets are most in need of renovation. In this paper, we employ space syntax analysis to design spatial intersections between low-choice streets and multipurpose land-use areas, as well as between high-choice streets and areas with low green visibility rates. Firstly, we use this approach to identify the low- and high-choice streets. Secondly, we use space information entropy to measure the degree of functionality mixing of land use, which is calculated based on POIs (Points of Interest) data. Thirdly, with the aid of semantic segmentation, this study uses street views to visualize the green visibility rates of specific regions. After intersecting spatially by ArcGIS, we are able to determine which areas should be given priority consideration for urban street renewal.

1. Introduction

Urban renewal is a complex process that has evolved from urbanization to reverse urbanization, and now to re-urbanization. However, it has become apparent that old city centers regularly lack sufficient infrastructure and municipal facilities [1]. Due to the impossibility of carrying out large-scale demolition and construction projects in these centers, spatial quantitative analysis tools can be used to identify which streets should be prioritized for improvement and optimization.

Regarding the spatial analysis method, space syntax was first proposed by Bill Hillier in the 1970s and demonstrated the relationship between street networks, human behavior, and the process of urban self-organization [2]. One key parameter in space syntax is the measure of *choice*, which can be applied to assess the probability of a street being traversed within a set distance in a particular area [3]. Street routes naturally have an uncertain quality as individuals can decide whether to traverse a street at any given time [4]. In other words, the *choice* is a useful measure for optimizing the organization of two-dimensional space, particularly with regard to routes. However, it is also important to consider socio-spatial characteristics when using the structuralism approach to achieve a more sensitive perspective [4].

To assess the interaction between daily social activities and space, we adopted the POIs (Points of Interest) capturing method proposed by Long to obtain data reflecting the distribution of land use [5]. To quantify the degree of functionality mixing of the land use in the study areas, we calculated the Shannon entropy, which measures the amount of information needed to accurately send or receive a message and is determined by the degree of uncertainty that the intended message contains [6]. We also applied the information entropy formula for multiple variables to calculate joint entropy [4]. By using spatial information entropy metrics, the functional mixing degree of land use could be quantified [7]. The spatial intersection of low-choice streets with areas of high functional mixing degrees allows for the identification of areas in need of optimization, which can then be clearly visualized on a map.

Urban street greenery, such as trees and shrubs, has been widely regarded as an essential component of the urban environment that enhances the aesthetic appeal of public spaces for pedestrians [8,9]. To quantify the visual quality of urban landscapes, the Green View Index (GVI) of streets has been developed as a key indicator [8,10,11]. By utilizing panoramic images from Baidu Street View and the open-source semantic segmentation dataset ADE20K from GitHub, a large number of street view images were accurately and efficiently segmented [11,12]. With the help of semantic segmentation, green visibility rates and street view image coordinates can be effectively quantified. Semantic segmentation is a deep learning algorithm that categorizes different parts of an image such as roads, sky, greenery, and buildings into certain colors [11,13]. Streets with low green visibility rates and high choice can then be spatially intersected using tools such as ArcGIS, Python, GeoPandas, and Matplotlib, among others.

2. Methodology

2.1 Research Area

This study focused on the central area of Shanghai, located within the outer ring road, and includes Huangpu District, Xuhui District, Changning District, Jingan District, and other nearby regions.

2.2 Choice of Streets

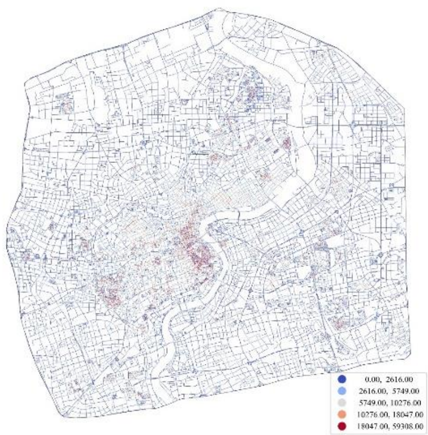

Figure 1: The Choice of Streets within 500m in Shanghai City Center

The road network data for the research area were downloaded from OpenStreetMap (OSM). Each street was divided into individual lines using AutoCAD and ArcGIS. The number of times each line was passed by the shortest route within a 500 m radius was calculated using depthMapX, which helped to determine the streets' choice values. Python and Matplotlib were then employed to classify the choices into categories via natural breaks. Figure 1 shows that streets with relatively high choices are primarily concentrated in the Huangpu and Xuhui Districts.

2.3 Functionality Mixing Degree of Land Use

2.3.1 POIs Data Capture

The original data set for this study included 808,657 POIs, which were obtained from the API interface of Gaode Map. The POIs were classified into 14 types: transportation facilities, recreational facilities, corporations, healthcare institutes, housing, tourist attractions, car services, convenience services, educational & cultural services, commercial services, sports & exercises, hotels, financial institutions, and restaurants. As such, POIs can reveal the current urban function distribution [7]. The data were then processed for analysis.

2.3.2 Spatial Information Entropy Visualization

Shannon entropy refers to a mathematical model proposed by Shannon that measures the uncertainty of random variables [6]. As shown below, X is a discrete variable with different n values [4,6]. To measure entropy, H, each unique state in a series of state events is summed, and the probability of that state is multiplied by the base-two logarithm. This figure is then subtracted from zero [4].

$$H(X) = -\sum_{i-l}^{n} p_i \log p_i \tag{1}$$

However, the challenge lies in how to quantitatively describe and mathematically analyze the diverse functions of urban structure and form. For this, we relied on Li's method, which judges the degree of functionality mixing of land use in the fractional dimension. To apply this method, the city center was partitioned into a 300 x 300 grid system as well as M x N grids based on the walking distance [7].

$$P_{ij} = \frac{A_{ij}}{A_k} \tag{2}$$

$$\mathrm{H_s} = -\sum_{i}^{M} \sum_{j}^{N} P_{ij} \times \log P_{ij} \tag{3}$$

Aij: the sum of one facility of POIs in row i, line j

Ak: the sum of 14 facilities of POIs in row i, line j

Figure 2: The Distribution of the Spatial Information Entropy in Shanghai City Center

Different types of POIs in each grid were counted, and the spatial information entropy was calculated and visualized on a map using Python and Matplotlib, among other tools (Figure 2). A higher *H* value signifies a greater degree of functionality mixing.

2.4 Green Visibility Rate

2.4.1 Street View Image Capture

To obtain street-view images of the study area, we drew on the GSV method developed by Aikoh [11]. This involved specifying the longitude and latitude of the points and using the Street View Static API in Baidu Maps to request images with the following specifications: size: 600 x 400; heading: 0, 90, 180, or 270; pitch: 20; fov: 90. In total, we captured images of 1756 coordinate points across the area. The heading was set to either 0, 90, 180, or 270 while images were captured, and they were then combined to create a 360-degree panoramic street view picture. This approach reduces distortion compared with capturing panoramic views directly (Figure 3).

2.4.2 Green Visibility Rate Visualization

To achieve semantic segmentation of each image, the ADE20K dataset by Zhou [12] was used for training, resulting in correctly segmented images and allowing for the calculation of metrics such as the green visibility rate and longitude and latitude coordinates (Figure 4). The data were then visualized on a map using various tools, including Python (Figure 5).

Figure 3: The panorama street view image from Baidu Map

Figure 4: Image semantically segmented by the author

Figure 5: The Distribution of the Green Visibility Rate in Shanghai City Center

3. Results

3.1 Spatial intersection between the Low-Choice Streets and the High Functionality Mixing Degree Areas

Using ArcGIS, streets with a choice value less than 2616 were classified into the low-choice category. These were spatially intersected with areas showing high functionality mixing degrees, defined as regions with spatial information entropy values over 2.04. As stated earlier, higher entropy values indicate higher functional mixing degrees [5,7]. Figure 6 shows that areas in this category are mostly located in downtown Shanghai, particularly on the west side of the Huangpu River. Moreover, streets near the Huangpu and Xuhui Districts are mostly shorter than 300 m, indicating that while Shanghai's original central area remains important for its urban functions, its old networks are struggling to accommodate them.

Figure 6: Spatial intersection between the Low Choice of Streets and the High Functional Mixing Degree Areas

3.2 Spatial intersection between the High-Choice Streets and the Low Green Visibility Rate Areas

The second result of our study shows the spatial intersection between the high-choice streets and the low green visibility rate areas. Using the natural breaks method, we selected streets with a choice value greater than 18047 and intersected them with areas featuring green visibility rates below 0.06 (Figure 7). It is clear that these areas are primarily concentrated in Huangpu District, which is known for its narrow streets and heavy traffic.

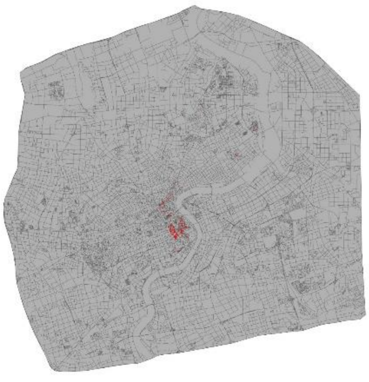

Figure 7: Spatial intersection between the High Choice of Streets and the Low Green Visibility Rate Areas

4. Discussion

Hansen [14] discovered the positive correlation between high accessibility and diversity of community activities, which is often the catalyst for land development. However, based on the spatial intersection between the low-choice streets and the high functionality mixing degree areas shown in Fig. 6, it is necessary to investigate what factors limit accessibility. Compared with analysis on an urban scale, it may be more reasonable to conduct an accessibility analysis on the architecture itself using the adjusted Gaussian 2SFCA (two-step floating catchment area) method, which emphasizes the relationship between demand and supply [14,15]. This approach can offer a finer spatial resolution, improving accessibility with increased precision.

Further, assessments of street environments encompass more than just green visibility. With the development of artificial intelligence tools, Zhang [10] and Tang [17] have proposed different processes to evaluate personal perceptions of streets on an urban scale. At present, however, the accuracy of machine training still lacks precision due to limited street view samples and current computer configurations. For this reason, environmental perception scores were not used as an evaluation index in this study. Nevertheless, future research will consider the perception of the street environment as an additional factor for evaluation.

5. Conclusion

Generally, areas targeted for urban renewal have been identified through qualitative analysis, and the advancement of computer technology has made it possible to perform quantitative analysis on even finer scales.

In this study, space syntax was used to analyze a current street network in two dimensions and assess people's preference for certain streets within 500 m areas using the parameter *choice* and tools including OSM, depthMapX, and ArcGIS. However, it is important to note that space syntax does not take into account street management, which can result in roads in enclosed neighborhoods being overlooked, potentially influencing the accuracy of the street choice analysis.

Additionally, the entire city center was divided into 300 x 300 grids and POIs were captured to identify the functional use of the land. Using spatial information entropy, each value related to the functionality mixing degree of land use was calculated and visualized in map form. By intersecting the low-choice streets (under 2615) with the high functionality mixing degree areas (those with an entropy value greater than 2.04), the study found that the streets with multiple functions but low preference from people are mainly located in the downtown area of Shanghai. Further investigation into these areas is needed to fully understand the reasons why people are unwilling to use these streets and whether they can handle a high degree of functionality mixing. Whether these areas should be targeted for improved street quality or whether certain functions should be relocated to other areas are both topics for future research to explore.

Finally, semantic segmentation techniques were used to calculate the green visibility rates of the street views, which were then visualized on the map. By spatially intersecting high-choice streets (those with choice values over 18015) with the low green visibility rate areas (values under 0.06), it became clear that streets in the original city center, specifically in Huangpu District, require the most urgent attention regarding improvements to their greenery.

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