Research Paper

Measuring Visual Quality of Street Space Based on Deep Learning and Street View Picture :

Pilot in The Lilong Area in Shanghai

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Abstract

Built environment indicates of street space quality have been carried out in a profound influence on the image of city， human behavior and public health. A street that is considered as a fundamental element in urban studies. Of the 5 elements of the image of a city, i.e. landmarks, paths, nodes, districts and edges, suggested that the paths are the most dominant elements, the research of which would provide a basis for the clustering and organization of the meanings and associations of the other four elements and the city as a whole. Additionally, taking a quantitative measurement of the visual appearance of street space has proven to be challenging because visual information is inherently ambiguous and semantically impoverished. Recent developed image semantic segmentation techniques and Street View Picture dataset make it possible to eliminate the previous restrictions, Furthermore, bringing forward a research paradigm shift. Lilong, which typically represent for historical street space in Shanghai, are selected for empirical study .This paper attempts to measure subjective qualities of the Lilong environment comprehensively and objectively. By employing Street View Picture, pictorial information is the proxy for street physical appearance, which utilizes the image semantic segmentation techniques (The model used in this study is Deep lab V3 which can achieve a 85.7% pixelwise accuracy when classifying 150 categories of objects) to parse an street scene into scene elements, such as buildings, roads, pavement, trees, cars, pedestrians, and bicycles. Then, the elements corresponding to each street point in the two directions of spatial coordinate are summarized and the average value is calculated. The potential factors were calculated based on 3-dimensional composition calculation of greenery, openness, enclosure and motorization may serve as indicators for inferring. The outcomes were used to evaluate the street types, functionality, quality, time, status, and human activities of a street. The result indicates that visual quality of Lilongs are barely satisfactory, while some regeneration projects in the historical protection block is better. A lot of Lilongs are in shortage of visual green, relative more continuous but with low vertical diversity. In the most recent 6 years, less than 2.74 million square meters Lilongs are not regenerated which are mainly slow building renovation. A series of quantitative analyses demonstrates the ability and great potential of auto-calculation method useful for auditing street environments.

Keywords

Visual quality Quantitative evaluation Street View Picture Deep learning Lilong

1. Introduction

Street space is an important part of urban public space, the quality of street space affects the behavior of users, public health level, the shaping of urban culture. In its report "Streets as Public Spaces Promote Urban Prosperity", UN-Habitat states that streets have an important impact on the social productivity, quality of life and amenities of cities. The past several years have seen a rapid expansion of research on the health implications of street environment features such as aesthetics, traffic， physical disorder, social interaction, and pedestrian safety（Hoehner, C.M. et al,2005;Boehmer, T. K. et al ,2007; Middleton, J. 2018). Admittedly, good street environment can promote social interaction, form friendly neighborhoods, and also affect the healthy behavior of residents, improve the output of individual healthy behavior. Therefore, designing human-oriented street space has become one of the vital environmental improvement strategies for competitive cities. Many countries and regions have proposed street design guidelines to improve the environmental quality of the streets. In China, Shanghai has proposed street design guidelines. The widespread street policies and platforms indicate that people begin to pay more attention to the refined design based on the human-oriented scale.

In the past, the traditional measurement of street space quality adopted two-dimensional plane analysis or small-scale subjective research method, it is difficult to measure the level of urban three-dimensional street space quality on a large scale. With the development of image segmentation technology and street view acquisition technology, the research on street space has obtained a new method breakthrough. In this paper, in order to improve the quality of the street space environment, we introduce Baidu Street View pictures and machine learning techniques to quantitatively evaluate the indicators of street space environment. This paper selects the street view picture of Lilong area in Shanghai as research object, identifying the elements of the street environment and carrying out the evaluation of street space environment, which provides support for the transformation and quality improvement of the street during the urban renewal process.

2. Literature review

2.1. Visual quality of street space

"Space quality" usually refers to people's perception and experience of the space environment, which is highly correlated with the material spatial elements and service level of the built environment, and is an important index to measure street environment in urban design theory. There have been many classical studies on the quality of space. The pioneers, represented by Jacobs(1961) and Lefebvre(1962), reflecton on the functionally dominated modernist urban planning and design, and discuss the spatial characteristics of human-based scale and its social and economic effects. Young Gale(1971), William White(1980), Kevin Lynch(1984) discussed how the characteristics of urban space can better enhance the quality and vitality of the city. These studies have proven physical space and street form are the cornerstones of street activities.

The past several years have witnessed a considerable number of studies have measured the multisensory qualities of street space, including auditory quality (Easteal et al., 2014; Aletta et al., 2016; Herranz-Pascual et al.,2019) and the visual streetscape(Griew et al.,2013; Lun Liu et al.,2017; Jian Kang et al.,2018). In this paper, we concentrate on measuring the visual quality of street space. It objectively depends on physical components of street space. There are plenty of research discussing the spatial elements on street scale, such as greenery, enclosures, openness, connectivity, street wall continuity, density, accessibility, cross-sectional proportion, scale, tidiness and so on (Montgomery,1998; Sallis et al.,2003; Harvey et al.,2015).The spatial elements can bring better perception of visual perception and also play an important role in social interaction.

2.2. Methods for measuring visual quality of street space

Currently, there are many studies on street analysis and evaluation. Studies have been conducted to identify important factors in identifying important factors in the building environment that affect human mobility by assessing respondents' perceptions of the chosen building environment through different types of interviews or face-to-face questionnaires (Appleyard et al.,1972; Sallis et al.,1998). Ewing and Clemente (2013) made a quantitative evaluation of the five important factors of street perimeter, humanization scale, permeability, cleanliness and imagery by analyzing the respondents' ratings of street images. This kind of qualitative research is still instructive to the current research, but due to the lack of quantitative data and evaluation index in-depth study, it is not conducive to further assist the refined design practice and control.

The development of big data, artificial intelligence and other technologies can help solve the relatively vague and subjective evaluation of urban spatial quality in the past. With the widespread use of open data in urban spatial analysis, street view pictures are becoming an important complement to multi-source urban data. Google, Baidu, Tencent and other Street View image data can allow users to use 360-degree panoramic views to quickly access street space reality information, is suitable for street-scale research(Liu,2015). For example, Google Street view data has been used to the construction of urban three-dimensional models(TORII et al.,2009), the evaluation of street security(NAIK et al.,2014), and the quantitative analysis of street view green visibility(Yu Ye et al.,2018).

With the development of artificial intelligence, through machine learning algorithms in the computer field, using deep convolution neural network architecture to achieve the deep processing of accurate street view pictures, it has become possible to effectively identify various elements of street space. Image semantic segmentation-based models have developed rapidly in recent years, such as FCN networks, SegNet networks, DeepLab, PSPNet ,image recognition accuracy is getting higher and higher, and can be replaced to handle the complex built environments(YAMAGATA et al.,2017). The model used in this study, DeepLab V3 (Chen et al., 2017), can achieve a 85.7% pixelwise accuracy when classifying objects.

3. Method

3.1. Study area and data collection

3.1.1 Study area

Our research is conducted within lilong area in Shanghai central area， which has a history of more than one hundred years. According to official statistics, by the end of 2016, the lilong area covers 7 million m^2 , including Shikumen Lilong, and Guangli Lilong , Garden Lilong (Figure1). As the main residential building in modern Shanghai, lilong spatial layout coincides with the direction of the urban development of modern Shanghai, which reflects the microcosm of the modern Shanghai urban development, and has very important historical humanistic value and historical landscape value. However, with the development of the city, the Lilong area has appeared old houses and crowded living situation, and its facilities are not complete, which results in mismatch between Lilong and modern urban function. In this paper, the streets of the Lilong area are selected as the research object (Figure 2), we try to provide a strategy for the protection and renewal of the city's historical and cultural history through the study of the street quality of Lilong area.

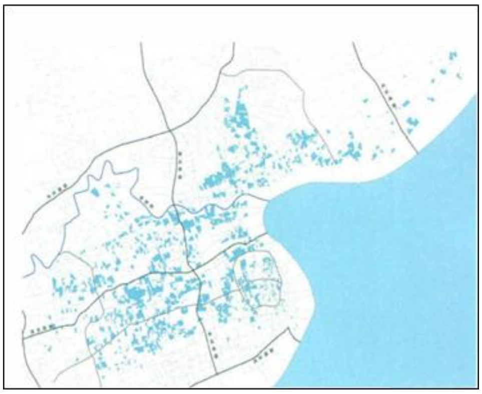


Figure 1 The distribution of Lilong area in Shnghai Source: Zhang Chenjie

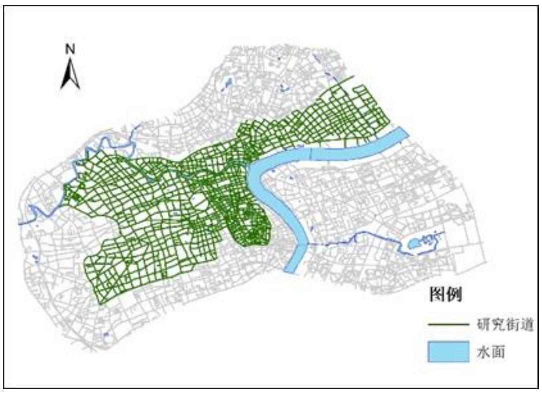


Figure 2 The distribution of street in Lilong area

3.1.2 Lilong

As the largest and most widely distributed building type in modern times, lilong has dismantled a considerable part in the transformation of the Old City, but in terms of the current stock, it is still an important part of the historical space of central Shanghai. Lilong is a combination of East and West architectural characteristics of the residential type, its layout takes the form of the early Western town-style housing, the building monolith plane and structure is born out of the traditional Chinese courtyard-style housing.The main types of lilong, mainly include old-style, new-style, park-style, apartment-style, and wide-style.(Figure3) At present, the core Lilong area of Shanghai's central city mainly includes: Laochengxiang area, Xiamen Road -Suzhou River area, Hengshan Road -Revival Road area, Changle Road- Changshu Road area, Huaihai Zhong road- Sinan Road area, West Nanjing Road- North Maoming Road area, Wuyi Road area, the southern part of Old North Station area, Shanyin Road -Dolun road area, and Tilanqiao area (Zhang,2012).(Figure4) In a nutshell, Lilong typically represent the fabric of historical streets and are of significant importance to Shanghai. From the perspective of historical value, there is an urgency for a technical recognition and interpretation of the characteristics of traditional street forms. The restoration, regeneration and transformation of Lilong spaces are key to historical protection in Shanghai, and need continuous scientific observation.

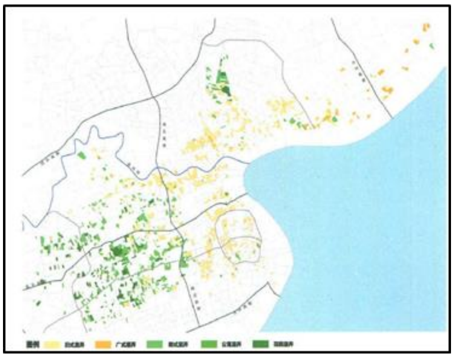


Figure 3 The distribution of different types of Lilong Source: Zhang Chenjie

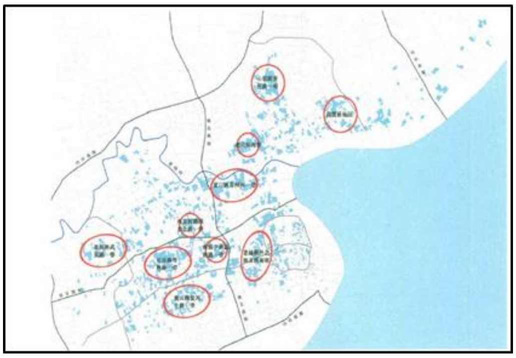


Figure 4 The spatial structure of the distribution Source: Zhang Chenjie

3.1.3 Street View Picture

This paper uses Baidu map street view picture data set to study the quality of street space. Street image data acquisition is obtained through API from Baidu Panorama static map service. The sampling point has an average spacing of 30m and generates the sampling position along the centerline of the road. Each sampling point has longitude and latitude parameters to facilitate the following scrawling process in GIS. In order to prevent the deformation of obtained Street View images, combined with the road centerline data obtained by OSM and the calculation of the sampling point based on the network topology before climbing the data by GIS, the Street View image is guaranteed to be parallel to the long axis direction of the street. And then, we input the angle of the horizontal and vertical direction and the sample point coordinate data to obtain street view picture by using Python and the request Key. (In our this research,: picture size: 1024 * 512; pitch: 0; heading: 0, 180 for two directional SVPs). The study obtained a total of 16,431 sampling points, 32862 street view pictures

3.1.3 Other data

The 2018 Point of interests data was crawled through the network including catering, shopping, and life services. The data format is point data of the shpefile in ArcGIS, which is used to calculate the functional diversity of the street.

3.2. Method

This study makes an objective evaluation of street features by machine learning to extract the characteristics of street scene pictures. A scene of deep full convolution neural network architecture segmentation technology analysis of images through semantic segmentation of picture pixels has been studied(Kendall et al.,2015). Using the Deep Lab V3 model, this paper uses the Deep Lab V3 model to semantically divide the street images of the Shanghai area, identifying 18 elements such as roads, sidewalks, buildings, walls, fences, columns, beacons, signs, vegetation, terrain, sky, pedestrians, bicycles, cars, trucks, trains, buses, motorcycles, etc(Figure5). Then, the elements corresponding to each street point in the two directions of spatial coordinate are summarized and the average value is calculated. The potential factors were calculated based on 3-dimensional composition calculation of greenery, openness, enclosure, motorization, walkability and functional diversity may serve as indicators for inferring. The outcomes were used to evaluate the street types, functionality, quality, time, status, and human activities of a street. The greenery is measured by the proportion of trees at the sampling point, the openness is measured by the sky ratio, the enclosure is taken by the sum of buildings, columns and trees, and the motorization is used as an indicator of the degree of mobility and the walkability is measured by pedestrian and pedestrian paving. Through the POI data, measure the street functional diversity in the 15m buffer zone of the street centreline.

Thus, several indicators (a temporary six in this research) have been formed to comprehensively evaluate the physical visual quality of street space, the values of which a_i are normalized to the values e_i based on the deviation standardization Eq.(1)

$$e_i = \frac{a_i - \min(a_i)}{\max(a_i) - \min(a_i)} \tag{1}$$

i = greenery, openness, enclosure, motorization, walkability, functional diversity and so on.

Following this, these six normalization values are summarized into one Index $Y_{quality}$ according to Eq. (2), below, which represents the overall physical visual quality of street space. The indicators are simplified into six and the coefficients of each are equally distributed for the convenience of discussion. Accurate coefficients still require further quantitative research based on large-sample surveying and theoretical literature reviews.

$$Y_{quality} = \sum_i \alpha_i e_i \tag{2}$$

α_i are the weighting coefficients, awaiting further detailed research for improvement.

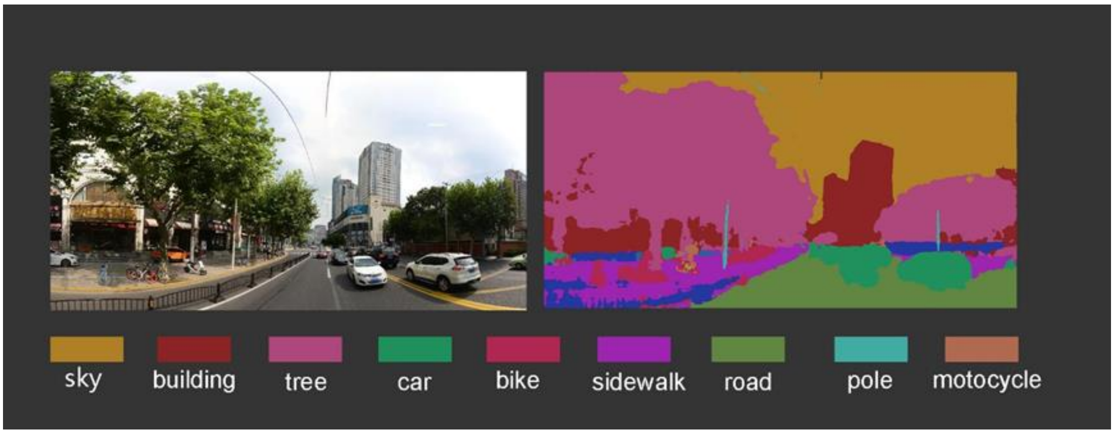


Figure 5 A segmentation demo by Deeplab V3

4. Results

4.1. Identify different street types

This study makes an objective evaluation of street features by machine learning to extract the characteristics of street scene pictures. Calculate the elements of 32,862 images in the study area and determine the main road types in the study area based on the proportion of the various elements. Figure 6 shows the seven most common dimensions of street features in each road type, namely buildings, roads, skies, sidewalks, cars, trees, and walls. For each dimension, the length of the axis represents the average ratio of each feature within the horizontal perspective. For example, green streets generally 50% green rate, 30% of buildings. In different historical periods, the elements of the streets are quite different, and the streets in the old Shikumen area are mainly based on buildings and higher degree of openness, and the green rate is low. There are some areas that have been updated through the city, with buildings accounting for 40% of the view and about 26% of motorways, and these streets have higher traffic. The garden is more green and the enclosure is high.

The semantic division of the features of the street shows that the various scene features of the street will change due to the change of different road levels, so we can identify different types of roads by identifying the proportion of various elements in the street. With the continuous construction and development of the city, the function and role of Lilong area's streets will change with the changes of urban heterogeneity and urban renewal. Lilong is a gathering area of the history and architecture of the central city of Shanghai. Different time span and different construction types show its unique style of urban style. Updates and protections also need to be treated according to their characteristics .From this point of view, according to the results of the above analysis, according to the composition of the design elements of the street to determine the real function and function of the street, and further the renewal and protection of the streets in Lilong area put forward a more scientific and clear update strategy.

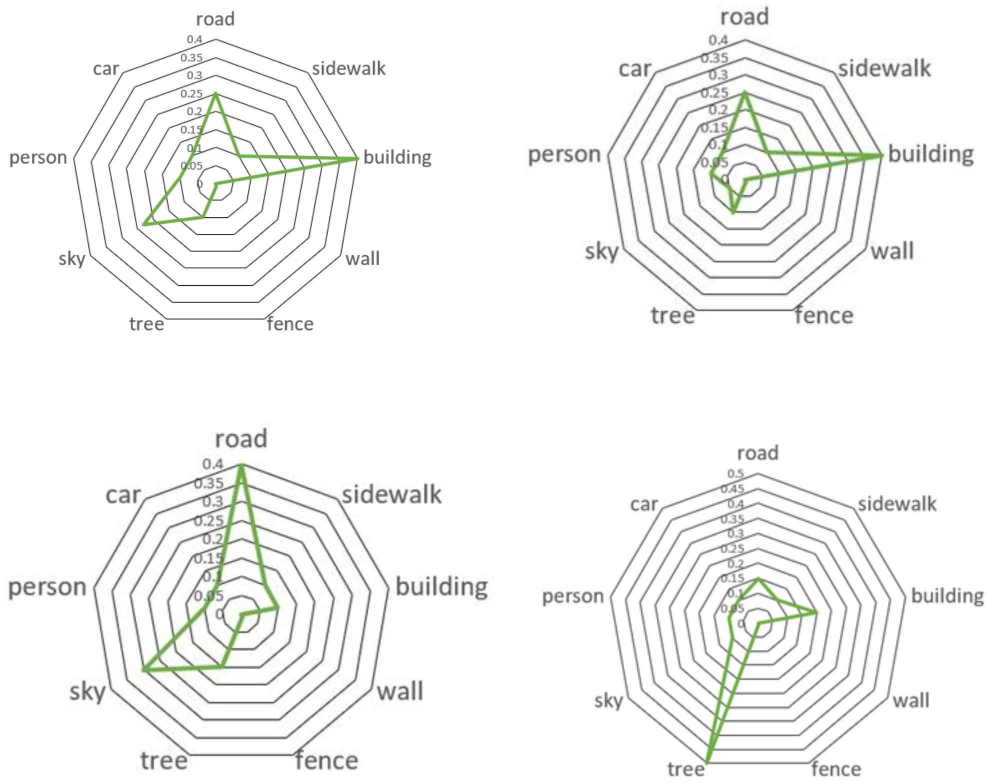


Figure 6 Percentage of different types of street elements

4.2. Spatial distribution of street features

After identifying the proportion of various elements of the street, the evaluation index of street quality is summarized. The average green viewing rate on streets in the Lilong area was 23.4%, which is nearly 5 percentage points higher than the average green viewing rate of 19.8% in Beijing Hutong(Tang et al.,2018) which typically represent for historical street space in Beijing.The average openness of streets was 22.8%, the average enclosure was 56.1 % and the average degree of mobility was 12.8%. The spatial distribution of greening in the study area was uneven, and the degree of greening was quite different in different construction periods. The street scale in Lilong area is more suitable for human-based scale, and the incidence of automobileises is much higher than that of bicycles. The walking conditions are suitable for walking activities.

4.2.1 The spatial distribution characteristics of street greenery

Due to the influence of urban construction in the historical period, the degree of greenery of the streets is obviously different. The old town area is the early old-style construction area, its greenery degree is the lowest in the Lilong area, the average street greenery rate of 13.2%, far below the greenery level of the whole study area. Though it is a relatively complete area of Shanghai's old city texture, but its level of greenery landscape needs to be greatly improved. Huaihai Zhong road -Sinan Road area, Changle Road Changshu Road area, Hengshan Road - Revival Road, West Nanjing Road- North Maoming Road area is a new style of Lilong, garden and apartment gathering distribution area, its greenery degree is better, some areas of green view as high as 60%. In Xiamen Road, Suzhou River area, the south of the old North Station the southern part of Old North Station area and Tilanqiao area and other areas are wide-style distribution area, have low level of greenery.

4.2.2 The spatial distribution characteristics of street openness

Contrary to the spatial distribution characteristics of street green vision rate, the higher areas of street opening are the Laochengxiang area, Suzhou Road area, the southern part of the Old North Station and Tilanqiao area. The area with lower street opening is Huaihai Middle Road- Sinan Road, Changle Road, Changshu Road, Hengshan Road, Fuxing Middle Road. Although the height of the building is not high, the street is green and the street is directly blocked by trees because of the small scale of the street. The degree of opening is lower, and the street green vision is higher.

4.2.3 The spatial distribution characteristics of street enclosure

The street enclosure characteristics of the street are generally better, and a higher enclosure can form different levels of space. The areas with relatively high degree of street interface are the Laochengxiang area, the Huainhai Middle Road- Sinan Road, the Changle Road- Changshu Road area, and the Hengshan Road- Revival Middle Road area. These areas have dense urban textures, and the ratio of the height of the buildings on both sides of the streets is high. It can reflect the characteristics of the old Shanghai city. The area of the the southern part of the old North Station and the Tilanqiao area is relatively low.

4.2.4 The spatial distribution characteristics of street motorization and walkability

The degree of motorization in the study area increases with the level of the road network, and the degree of motorization is higher. The average car's appearance rate is 8.2% higher than the bicycle's appearance rate of 1.2%. It shows that the way of traveling in Shanghai is still characterized by car. The street scale of the Lilong area is relatively small, giving people a better sense of space and being more suitable for walking. With the process of urban renewal, the development of the city in the past focused on the development of traffic-oriented transportation. The Lilong area is also the main way to consider the car dealership, Ignore the way to walk. In the Laochengxiang area, Tilanqiao area ,the street sidewalks are relatively small and poorly walked. The renewal and construction of the future should focus on people's feelings and need to create a systematic walking space.

4.2.4 The characteristics of street functional diversity

The diversity of street functions in the study area increases with the level of the road network, and the degree of diversity becomes higher. There are differences in the diversity of streets in the Lilong area in different historical periods. The areas with low levels of street function diversity include the Laochengxiang area, the Tilanqiao area, and the Changshu Road-Changle Road area. The areas with high degree of street functional diversity include the Suzhou Road-Xiamen Road area, Huaihai Middle Road- Sinan Road, the Hengshan Road-Revival Middle Road area. With the development of the city, the function of some areas can not adapt to the mode of modern urban development. The development of its single function has led to the reduction of urban vitality. In the process of urban renewal, it is necessary to inject a variety of functions to arouse the original Vitality.

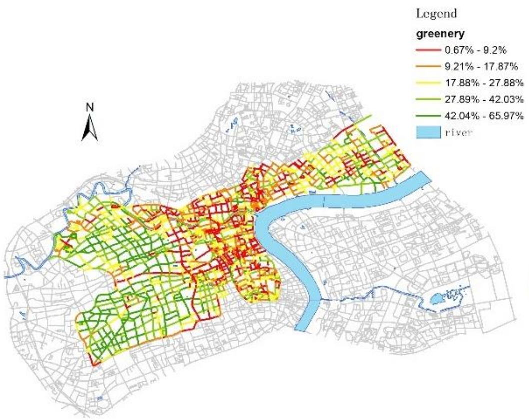


Figure 7 Greenery

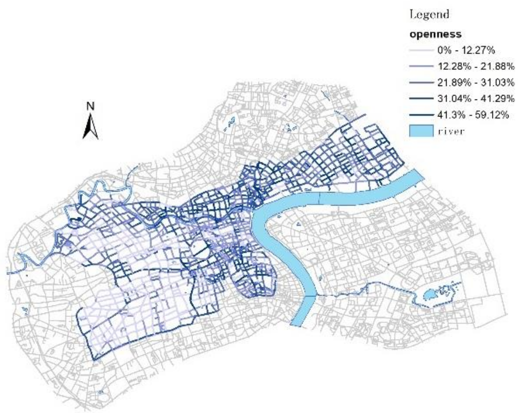


Figure 8 Openness

Figure 8 Enclosure

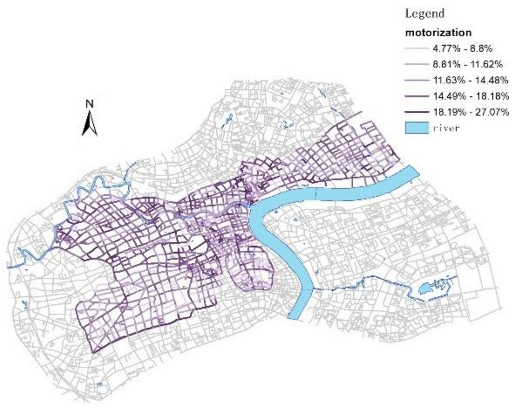
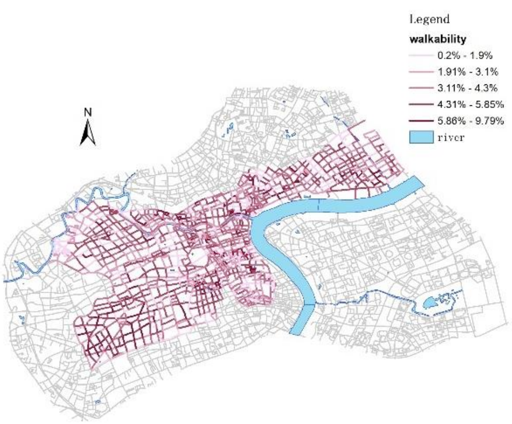


Figure 9 Motoriazation



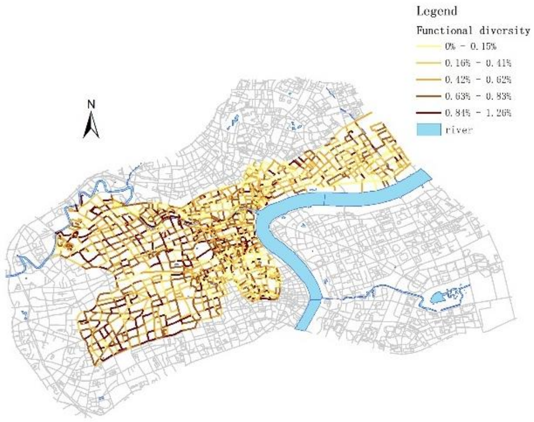


Figure 10 Walkability **Figure 11 Functional diversity**

4.3. Visual quality of Lilong

Figure 12 shows the final six-aspect physical visual quality of Lilong index result. The average physical quality index score is 2.35. From the calculation results, We can see that the areas with high street quality and quality scores include Hengshan Road- Revival Middle Road area, Huaihai Zhong road-Sinan Road area, Changle Road- Changshu Road area, and West Nanjing Road - North Maoming Road area. The areas with low street quality scores include Laochengxiang area, Suzhou Road -Xiamen Road area, the southern part of Old North Station area, and Tilanqiao area.

It can be concluded that Lilong on the south side have better skeletons than those on the north, especially Lilong in the historical protection areas. The reason for this phenomenon may be the management factors in the historical period. The blocks with higher scores are mainly distributed in the French Concession, the management is unified and perfect, and the lower scores in the public concessions are not well managed. It is not difficult to observe that some regeneration projects take full consideration of the historical forms , keeping the original architectural features, while some partially change in spatial scale due to the need for modern transportation. In addition, with the continuous development of the city, the street texture of the Lilong area has been affected by motorization, and these areas have a high degree of openness. It can be seen from the various visual space elements that high-quality streets tend to have high greenness, diversity and spatial envelopment (ie, inverse contrast of sky visibility), while street greening can enhance the shelter of the street and strengthen the space. It also reduces the visibility of the sky. It can be seen that in the street renewal and renovation of the case area, improving the street green rate, strengthening the space enclosure and diversity should be the main strategies to improve the space quality.

Figure 12 Physical Visual quality of Lilong Index

5. Conclusion

This paper examines the application of space quality evaluation in street urban design environment assessment for the Lilong area in the central area of Shanghai. The empirical research on Lilong shows that although the central city of Shanghai is famous for its culture, history and architectural layout, the quality of the street environment cannot meet the needs of current urban development and needs to be improved. A lot of Lilongs are in shortage of visual green, relative more continuous but with low vertical diversity. In addition, due to the low levels of street function diversity single function ,it has led to the reduction of urban vitality In the most recent 6 years, less than 2.74 million square meters Lilongs are not regenerated which are mainly slow building renovation The current urban design concept lacks the concept of refinement, the difference in street space is small, lack of recognizability and regional characteristics, and the safety, convenience, comfort and visual pleasure of slow-moving activists are not considered enough. The objective elements of this paper quantitatively measure the green visibility, openness, enclosure, motorization and walkability of the street. The research shows that the spatial distribution of greenery in the study area is uneven. The greening degree of the different types of construction in different areas is different. The construction scale of Lilong area is small, so the spatial opening degree and interface enclosing degree are suitable. In addition, many traditional styles and features are challenged by rapid urbanization. The development of vehicle-oriented traffic ignores people's feelings, and future development should focus on meeting the diversity needs of people.

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