

Article

Quantitative Evaluation on Street Vitality: A Case Study of Zhoujiadu Community in Shanghai

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Abstract: Streets functioning as important components of urban public space are not only the primary carriers of traffic but also essential spaces for individuals' daily activities, including recreation and communication. The paper highlights the social characteristics of streets by integrating them into one single index of vitality. The application of open recourse data combined with empirical research forms the foundation of a quantitative exploration on the street vitality of Zhoujiadu Community in Shanghai. Supported by the ideology of street urbanism, this paper defines the concept of "street vitality", and then constructs a quantitative evaluation index system. Afterwards, a multiple linear regression model is developed to explore the main influential factors of street vitality. This work evidences the relationship between the environment and citizens' activities and is beneficial to the potential improvement of street space quality and the enhancement of streets with higher vitality. Results from this work proved that the constituent factors of social function density, mixing degree of social functions, distance from the nearest subway station and green view have strong impacts on street vitality, among which the social function density and mixing degree of social functions are paramount.

Keywords: street vitality; environment; quantitative evaluation; index system



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1. Introduction

Streets play an intensely significant role in urban life. It is not only the main carrier of traffic and transportation, but also an urban open space promoting recreation, communication and interaction among citizens [1]. However, with the rapid development of urbanization and the expansion of urban scales, "car-oriented" concepts have been the mainstream in street and city design, resulting in the enhancement of traffic functions and dampening the social functions of streets. A host of urban problems arise such as traffic congestion, environmental pollution and noise interference [2]. How to effectively solve these problems, improve the quality of urban street space and build a livable city with stronger street vitality have dominated research in current urban renewal and development.

As early as the beginning of the 20th century, the discussion on the factors affecting the vitality of streets had already emerged. Some scholars agree that a vital street should have the following attributes of short length, high pedestrian density, mixed land use, buildings with diverse social functions, compact layout, small pedestrian scales and appropriate building densities, to name a few [3,4]. Other contemporary researchers introduce that the influential factors of street vitality may be inclusive of detailed texture, scalable humanity, mixed function and good street connectivity [5]. Gehl [6] also specifically analyzed the impact of mixed function, slow traffic and open space on street vitality through social research methods. Unfortunately, these studies are limited by the research conditions at that time and it is arduous to obtain data with strong temporal and spatial features, exceeding

amount and high precision. Therefore, most of the above viewpoints are discussed in a qualitative analysis and insufficiently verified by quantitative and in-time empirical data.

Since the quintessential research studies fall short in obtaining big data, few quantitative empirical research studies are indicative of the vitality of streets whereby a multitude of street elements are employed. Most of the proposed methods involve expert scoring, questionnaire surveys or field investigation. In quite a few representative studies, Systematic Pedestrian and Cycling Environmental Scan (SPACES) and Pedestrian Environment Data Scan (PEDS) methods have been applied to conduct field surveys concerning walking and cycling environments [7,8]. First-hand data were obtained from photographic records and manual investigations combined with expert scoring and weight assignment methods for quantitative research on the urban space construction, walkability and livability of environments [9]. The functions of two distinct types of streets in Cardiff, UK, were evaluated through the method of all-weather time-lapse videos [10]. In addition, scholars have utilized field investigations and observation methods to perform detailed field surveys on a set of urban living streets. They manually counted street data to analyze the impact of commercial space and interface characteristics on pedestrians' stay activities [11]. GPS data and spatial syntax were applied to study the relationship between street space and residents' behavior on an urban micro-scale [12]. These studies are time-consuming, arduous for obtaining data and have a heavy workload. In 2014, the University of Vermont published a research paper on urban planning based on spatial data and spatial analysis methods to measure the livability of street landscapes. It signified major progress in the field of urban and street design, as well as a milestone in the field of urban quantitative analysis [13].

With the advent of the new era of Internet technology, big data have become a hot spot for academic research and practical activities in various industries. The new data environment overcomes the limitations of traditional research. Scholars have performed a series of more refined scale quantitative studies on urban streets with new data and new technologies [14]. Some scholars took 37 high-walkability neighborhoods in New York as study cases and used street landscape pictures to evaluate the beauty of the neighborhood environment and some other physical space indicators [15]. Some scholars used multiple linear regression models to analyze the walking activity data of 9571 street survey locations and explore the relationship between different physical environments and street life (walking activities) in Seoul. The results show that the physical environmental facilities are important factors to improve the overall vitality of urban streets [16]. Some scholars applied large-scale travel demand survey data and a Normalized Difference Vegetation Index (NDVI) obtained from remote sensing infrared wave images combined with Special Design Network Analysis (SDNA), a space syntax software to establish a model to verify the correlation between pedestrian travel probability and street vegetation density or street connectivity [17]. Researchers used social network check-in data to display real-time urban population heat maps through nuclear density analysis [18]. Utilizing image segmentation technology to segment is utilized to extract the street elements of landscapes for vitality analysis [19]. These studies show that the data augmentation design triggered by the new data environment makes possible many studies that can hardly be completed by traditional methods. Furthermore, there is still much room for further research on the quantitative exploration of street vitality.

The rest of the work is outlined as follows. A literature review of street space vitality is presented in Section 2. The research methodology, area and applied data are introduced in Section 3 as well as the construction of the evaluation index system and quantitative analysis. Section 4 concludes the analysis results, followed by the discussion and limitations as provided in Section 5. Conclusions are given in Section 6.

2. Literature Review

Street vitality can be interpreted from two dimensions: street and vitality. Streets are distinct from roads in their concept and function. Roads mainly perform the traffic

function, while streets are more closely related to a citizen's life. Urban streets are regarded as public places for entertainment, communication and interaction and mainly emphasize the social function [20]. The concept of "vitality" has different definitions in the academic works of scholars. Some scholars argue that the activities between people, the interweaving process of living places as well as the diversity of urban life provide vitality to a city [3]. Some scholars agree that vitality refers to pedestrians and various activities on the street [5], and some scholars suggest that it is difficult to balance economic and social vitality in many cases. Fast traffic is the embodiment of economic vitality, while slow traffic means a vitalized city [6]. Mehta [21] proposes that a dynamic street is one in which a large number of people participate in a series of fixed or continuous activities, especially social activities. In China, some scholars suggest that street vitality is an external manifestation of social vitality in urban vitality, and its main manifestation is citizens' several walking-based activities on the street [22]. Long Y and Zhou Y [1] propose that the vitality of a street is mainly reflected in its social vitality, and the physical space environment of the street cannot form vitality but only provides a place for citizens' activities and has a certain impact on their activities. The core of street vitality is that people engage in various activities on the street and their activities have interactions that generate a sense of social belonging. Street vitality in this work is indicated by crowds of pedestrians in a street and is indicative of the extent to which the built environment of the street can attract people to walk and the extent to which citizens' social needs such as communication, shopping, walking and entertainment can be met.

At present, relevant studies on the vitality of street spaces mainly focus on four facets: the built environment of streets, the walkability index of streets, the quality of street spaces and the quantification of street vitality. Research on the built environment of streets mainly examines the built environment factors that affect citizens' choice of walking. As an example, in the study of Cauwenberg et al. [23], 60 elderly participants were invited to rate the degree of motivation to travel according to street panorama pictures, and the environmental factors that motivate the elderly to travel on foot were explored. The results found that environmental factors such as vegetation, benches and sidewalks have significant positive correlations with the walking traffic of the elderly, and a comfortable, safe and pleasant environment can attract the elderly to walk to the most extent. Rania et al. [24] conducted a longitudinal study on how different community environments affect citizens' walking behavior and analyzed the relationship between community walking ability and practical walking. The authors concluded that when people are exposed to a stronger walking ability community, their practical walking trips will increase. Other scholars selected five environmental attributes of residential density, intersection density, number of local destinations, sidewalk availability and public transportation accessibility and calculated their correlations with the Walk Score. The results showed that the intersection density and the number of local destinations are highly related [25]. Some scholars used exploratory factor analysis methods to analyze the impact of the built environment such as vehicle space, street interface enclosure, street environment and pedestrian space on pedestrian walking experience. The findings demonstrate that these four factors all have significant impacts on pedestrians' walking experience, and this experience is determined by the results of the comprehensive effect of the relevant street environment characteristics [26]. In addition, some scholars have taken residential areas as the objects of case studies. It was concluded that the environmental factors that have a greater impact on residents' walking travel within a 15-min living circle include branch road density, balanced distribution of intersections, diversity of facilities and good accessibility [27].

Research on the walkability index of streets highlights the Walk Score of the study area or the exploration of the relationship between Walk Score and walkability. Some scholars conducted research on the evaluation ability of the walkability index in several geographical locations and spatial scales of metropolitan areas in the United States, and they propose that there is a great correlation between the walkability index and the main indicators of community walkability [28]. Some scholars compared four different walking ability indices

on the same sample and examined the correlation between walking ability indices and family travel behavior by controlling factors such as individuals, families and travel characteristics. The results suggest that for non-work travel purposes, most walking ability indices are highly correlated with walking behavior, but the correlation is distinctive among individuals and families [29]. Other scholars examined 115 communities in Washington, DC, USA, using the mean deviation between the walkability and the city index to test whether the relationship between the two indices is consistent in communities with different income levels. It was suggested that the “pedestrian paradise” in high-income communities is more suitable for walking than that in low-income communities [30]. Wang De et al. [31] discuss the influence of the layout of community daily service facilities on pedestrian travel and argue that the frequency of use, diversity and the law of distance attenuation are the main factors affecting the walkability of the community. Zhou Y and Long Y [32] simplify the calculation method of Walk Score and add more street environmental impact factors to comprehensively evaluate the walkability of streets in districts of Chengdu. The results show that the residential streets have the highest walkability.

Studies on the quality of street spaces mainly evaluate factors affecting the quality of street space and screen the indices based on pedestrians. For instance, Banerjee [33] suggests that the evaluation of space quality should include two major elements: material and social. Material elements include characteristics such as type, scale, facility, and microclimate of the space while social factors include equality of rights, social tolerance and management level. Pikora et al. [7] established a quality evaluation system of street slow traffic space including five dimensions of function, safety, aesthetics, nature of land use and subjective evaluation. Some scholars measured the design quality of urban streets based on five physical characteristics of external representation, enclosure, human scale, transparency and complexity [34]. Some scholars analyzed the relationship between space quality and built environment according to the characteristics of walking activities in commercial streets and identified the factors that affect the quality of street space activities, such as street green space, high-quality building facade, block mode of narrow and dense road network, historical buildings and comfortable space scale [35]. Some researchers selected historical and cultural blocks as the main objects and combined them with street landscape maps to build an evaluation system from three dimensions of the material elements of street space, the perception elements and the connotation of historical and cultural blocks to evaluate the quality of street space [36].

The quantitative research of street vitality mainly focuses on case analysis to explore the influencing factors of street vitality. For example, Sung et al. [37] selected Seoul as the research object and constructed multilevel regression models with walking activity as the dependent variable. The results show that the overall walking activity in Seoul is related to six factors of built environment at the micro-level: land use mix, density, block size, building age, accessibility and border vacuums. Sugie et al. [38] chose three major commercial streets in Seoul to discuss their street-scale thermal environments and analyzed the thermal characteristics of various physical elements on urban streets using thermal imaging cameras. The results show that street trees are the most effective mitigation element for reducing surface temperatures, which can enhance the walking comfort of pedestrians. Xu et al. [39] selected streets built in nine different communities in old, main and new urban areas in Nanjing, China, and proposed a framework to assess street vitality considering different time dimensions and selected 10 subfactors under the factors of street form, street business and street accessibility for quantitative calculations. The authors conclude that in different time dimensions, street vitality in new urban areas is lower as compared with old and main urban areas. Khaled et al. [40] assessed the walking ability of two urban communities on the main islands of Abu Dhabi in the hot arid region. The survey results show that walking is a widely used form of non-motorized transportation for both leisure and utilitarian purposes among blue-collar employees working in the service and retail sectors. Moreover, many respondents said that the change of weather is the main reason for discomfort when walking. Some domestic scholars analyzed the constituent

elements of street vitality based on street urbanism. For instance, Long and Zhou [1] used mobile phone signaling data to conduct quantitative exploration on streets in Chengdu to analyze the relationship between the external representation and constituent factors of various types of street vitality. Furthermore, on the basis of Chengdu street research, Hao et al. [41] performed empirical research on street vitality in Beijing and added the spatial syntax index system to improve the interpretation of street vitality. Huang [20] established a quantitative evaluation system of street vitality and applied a quantitative study on Wuhan city. Through a multiple linear regression analysis, he explored the relationship between the external characteristics and constituent factors of street vitality. It is suggested that function density, function mixing degree and development intensity around the street significantly affect the formation of street vitality, and the factors of street spaces themselves, such as network density and street width, also affect their vitality.

Concluding the previous research on the vitality of street spaces, it evidences that a host of classic documents have laid the theoretical and empirical foundation in the research field. Relationships among the built environment, citizens' travel behavior and social life influences are investigated adequately. With the development of citizens' demand for better quality of life and the innovation of technology, the social function and quality of streets have significantly drawn much attention. In addition, under the new data environment of rich data sources and sufficient empirical cases, the shortcomings of traditional research methods are likely to be overcome. Related research on street vitality has gradually adopted the application of big data for quantitative analysis. Quantitative research methods are constantly innovating, whereby the quantitative analysis literature is also enriching.

3. Methodology

3.1. Overview of Methodology

A flow chart of the methodology applied in this study is shown in Figure 1. In the first step, a community was selected as the research object based on the research assumptions. The second step was to collect data from open sources as the basis of the research such as road networks, Baidu heat maps, the attribution of points of interest (POIs) and Baidu panoramas. The third step was to construct the quantitative evaluation index system of street vitality from the two dimensions of external representation and constituent factors. The fourth step was to perform the quantitative analysis for each constituent factor based on its definition and calculation process. Finally, the Pearson correlation analysis and a multiple linear regression model were applied to (a) explore the degree of correlation between constituent factors and street vitality and (b) discuss the main influencing factors and their impacts on street vitality.

3.2. Research Area

In this work, Zhoujiadu Community in the southwestern Pudong New District of Shanghai (Figure 2) was selected as the objective area. Its total area covers 5.52 km². At the end of July 2017, the population reached 142,200 people, of which the registered population is 109,500 and the population density is about 25,000 per square kilometers. It ranks fourth in the population density rankings of Pudong New District blocks [42] and ranks fifty-third in population density of Shanghai Central District blocks. This street area is one of the earliest developed blocks in Pudong New District, with 76 residential communities of various types, of which 73% are old and worn-out blocks. Most of the old blocks in the city have grid road networks with relatively high road network density. In this work, a total of 23 streets were chosen (including 1 trunk road, 4 sub-trunk roads and 18 branch roads). These roads are divided at an intersection into 102 road sections and different road sections with the same street name are numbered (for example, Qihe Road is interrupted at the intersection to generate 5 road sections, named QH Road 1, 2, 3, 4 and 5).

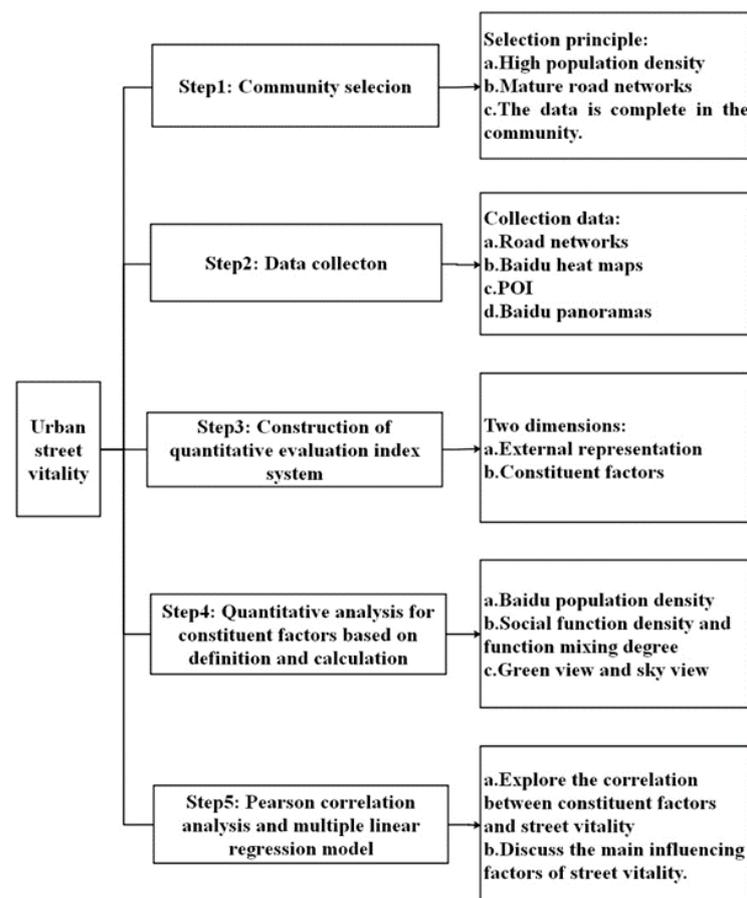


Figure 1. Flow chart of the methodology applied in this study.

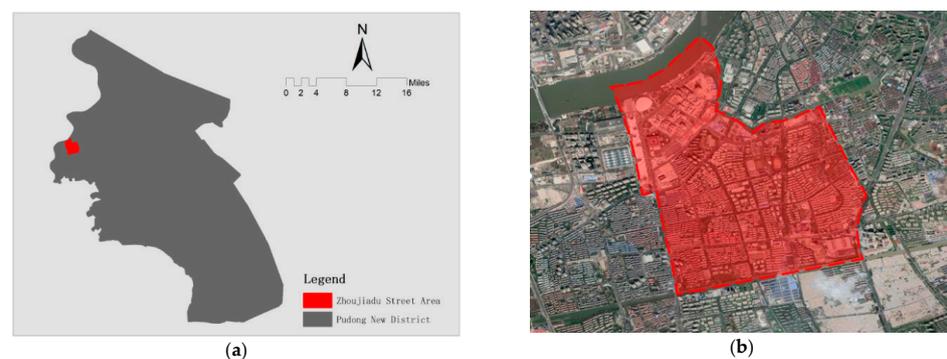


Figure 2. Diagram of research area location: (a) Location of the research area in Pudong New District; (b) scope of research area. The figures are generated in the Arcmap software.

3.3. Research Data

The research data mainly include road networks (trunk road, sub-trunk road and branch road), Baidu heat maps, points of interest (POIs) and Baidu panoramas. Data of road networks are the skeleton basis of quantitative analysis of streets. Data of Baidu heat maps are used to calculate the relative density of street population distribution and to imply the vitality of the street population. Data of POIs are composed of sets of POIs of various features generated to show the number and diversity of service facilities near the street. Data of Baidu panoramas are applied for semantic segmentation to quantify pedestrians' perception of the street environment.

3.3.1. Data of Road Networks

Road networks in the form of liner vector data were extracted from an open source of Open Street Map and transformed into shapefiles through QGIS to be dealt with in the geoinformation software ArcMap[®] 10.2. Since there are too many details of the original road networks and some existing topological errors, a cartographic generalization and topological processing were conducted for subsequent applications. After processing the original road networks of Zhoujiadu Community (Figure 3a), a more simplified and tidier road network was prepared, and the road grade is also marked (Figure 3b). Furthermore, buffer areas of distinct features were established along each road section according to the road grade (the buffer areas of trunk road, sub-trunk road and branch road are 50, 40 and 30 m, respectively).

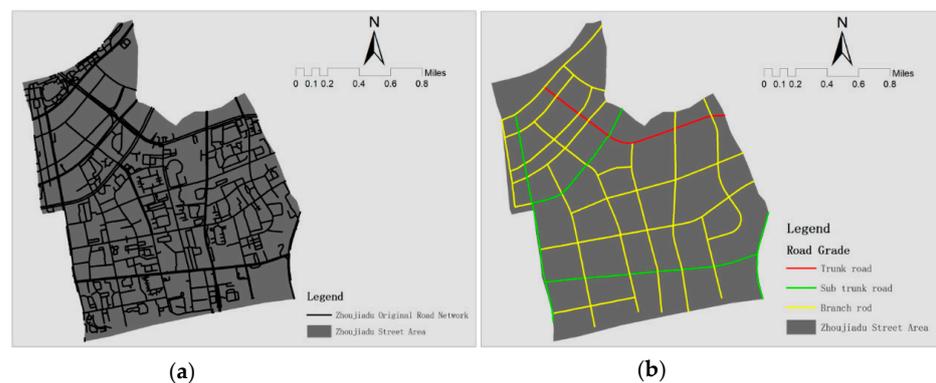


Figure 3. Simplified road network data: (a) Original road network. (b) Simplified road network. The figures are generated in the Arcmap software.

3.3.2. Data of Baidu Heat Maps

Baidu heat maps presenting the heat data of a working day and a weekend in Shanghai in November 2020 were obtained through the Application Programming Interface of Baidu Huiyan. The time interval was set as 1 h and the time slice information with regard to the heat population data corresponding to a certain time point from 7:00 to 23:00 was collected as the indicative data for the external representation of the vitality of pedestrians in the street. A buffer area of 50 m on both sides of the street in the study area was used as a mask to extract adjacent information of the heat data (Figure 4).

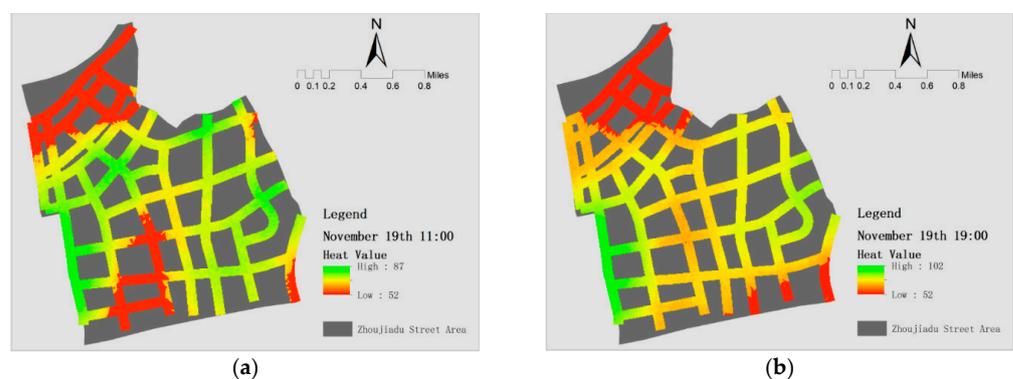


Figure 4. Heat data extract by mask result: (a) November 19th 11:00 heat value; (b) November 19th 19:00 heat value. The figures are generated in the Arcmap software.

3.3.3. Data of Point-of-Interest (POI)

Data of POIs were collected through the interaction of Application Programming Interfaces with one of China's strongest online searching engines. Firstly, through screening and classification, the POIs were divided into 12 categories and 67 sub-categories (Table 1).

Then, the toolboxes embedded in ArcMap were used to generate 1065 POIs under study. Their spatial distributions are illustrated in Figure 5.

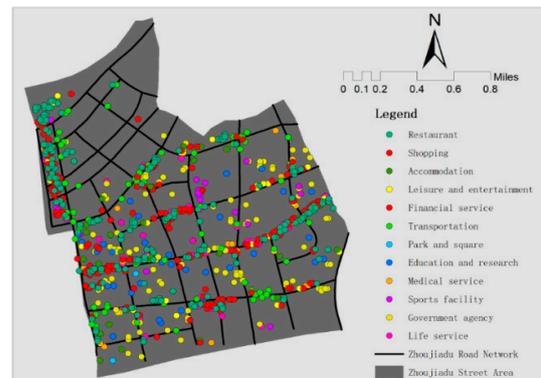


Figure 5. Spatial distribution of Points-of-Interest (POI). The figure is generated in the Arcmap software.

3.3.4. Data of Baidu Panoramas

Baidu panoramas were gained through a key (AK) by creating a Baidu Map application on the Baidu Maps open platform at a specified URL. Relevant parameters were set as follows. The width range of Baidu panorama was (101,024), the height range was (10,512) and the horizontal direction (*fov*) range was (10,360) whereby the entire panorama was displayed when *fov* = 360. Based on the simplified road networks, picture sampling points were generated every 50 m, and the picture parameters were set to width = 1024, height=512 and *fov* = 360. The picture resolution rate was set to 1024 × 512 to obtain the clearest picture and ensure that the subsequent semantic segmentation processing results were more accurate. The horizontal direction range was set to 360 to fully interpret the pedestrians' perception of the street environment from any direction on a street. The programming language of Python[®] was applied in this study, mainly to complete the batch extracting of Baidu panoramas. A total number of 925 pictures were generated in the research area. Figure 6 shows two Baidu panoramas of the Changli Road 1. It is illustrated that there are many facilities and service points along the road, herein the real space environment of the streets is thoroughly captured and clearly substantiated.

3.4. Index System Construction and Quantification

3.4.1. Index System Construction

Primary users of streets are pedestrians, whereby they are provided with street space for activities and services of street functions. Street vitality is indicated by the vitality of pedestrians in the street space, determining to what extent the built environment of the street can attract people to walk there and to what extent citizens' social needs such as communication, shopping, walking and entertainment can be met. Therefore, the analysis of street vitality in this work is executed from two dimensions of external representation and constituent factors.

Table 1. Data of point of interest (POI) classification.

Serial Number	Facility Sort	Facility Subdivided	Quantity of Facility Subdivided	Quantity of POI
1	Restaurant	Hotel, restaurant, coffee shop, milk tea shop, dessert shop, fast food restaurant, deli	7	279
2	Shopping	Market, supermarket, convenience store, franchise house, clothing shop, vegetable market, agricultural fruit and vegetable	7	236
3	Accommodation	Guesthouse, hotel, hostel, apartment, holiday house	5	38
4	Leisure and entertainment	Bar, karaoke, foot therapy, scouring bath, chessboard room, Internet bar, cinema, teahouse, game room, spa shop	10	46
5	Financial service	Bank, ATM, investment and financing	3	42
6	Transportation	Bus station, motor station, subway entrance and exit, railway station	4	72
7	Park and square	Park, square	2	8
8	Education and research	Kindergarten, primary school, high school, university, early education center, senior high school, library	7	35
9	Medical service	Hospital, pharmacy, clinic, community health centers and health service stations	5	27
10	Sports facility	Fitness, swimming, yoga, badminton, taekwondo, basketball, martial art	7	38
11	Government agency	Government agency, community service center, community activity center	3	163
12	Life service	Haircut, manicure, repair service, post office, laundry, photo studio, housekeeping	7	81



Figure 6. Original Baidu panorama. The figures are generated from Baidu Street View.

The external representation of street vitality is evaluated by the relative density of the population on the street. We apply Baidu heat maps to analyze the population agglomeration of street space, herein Baidu heat population density is employed as the external representation of street vitality. Constituent factors of street vitality were firstly proposed by Long Y [14], including the peripheral and internal factors of the street. For the peripheral factors of the street, we extract the Euclidean distance of the street's middle point from the subway station and the density of bus stations in the street buffer area, locations referring to the Euclidean distance of the street's middle point from the center of city and large commercial complexes, social function density, social function mixing degree, the nature of surrounding plots under the current urban land classification and the development intensity of the surrounding plots, defined as the average plot ratio in the street buffer area. For the internal factors of the street, we apply the street texture indicative of intersection density and its own physical characteristics including street length/width/grade/speed limit/greening on both sides of the road. Based on the above considerations and on the premise of data availability, the following eight indicators are finally determined from the index pools of peripheral and internal factors (Figure 7).

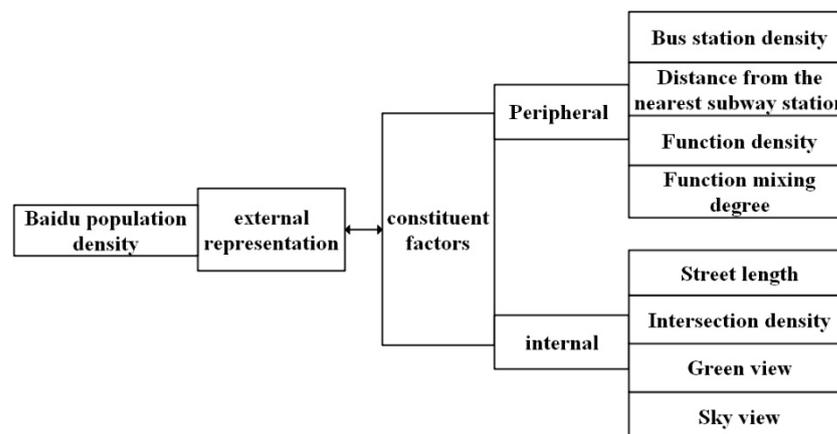


Figure 7. The index system.

3.4.2. Index System Quantification

In the index system, the bus station density, the distance from the nearest subway station, the street length and the intersection density possess clear definitions and are also quantified by ArcMap. However, the concepts of other indicators are relatively abstract; they are defined and measured in this section.

Baidu Population Density

In order to minimize the impact of daily necessary activities (such as commuting to work or school) on the spatial distribution of Baidu population density, we took the time slots from 10:00 to 11:00 a.m., 14:00 to 16:00 p.m. and 19:00 to 23:00 p.m. on weekends from Baidu heat map data to measure the population density related to the crowd vitality of the street. The processing steps of Baidu heat map data are shown in Figure 8. After processing the heat map data at different time points, the average heat value at all time points was calculated using Equation (1) as Baidu population density. The higher the heat value, the greater of the street's relative population density and vitality. Since the collected data of heat maps cannot completely be indicative of the real population data and for the reason of

further visualization, we divided the Baidu population density into 7 levels and 3 categories, whereby Levels 6–7 are for high-vitality streets, Levels 4–5 are for medium-vitality streets and Levels 1–3 are for low-vitality streets.

$$\bar{H} = \sum H_i / m \quad (1)$$

where \bar{H} is the average heat value, H_i is the heat value of the street at a certain time point and m represents the number of time slots.

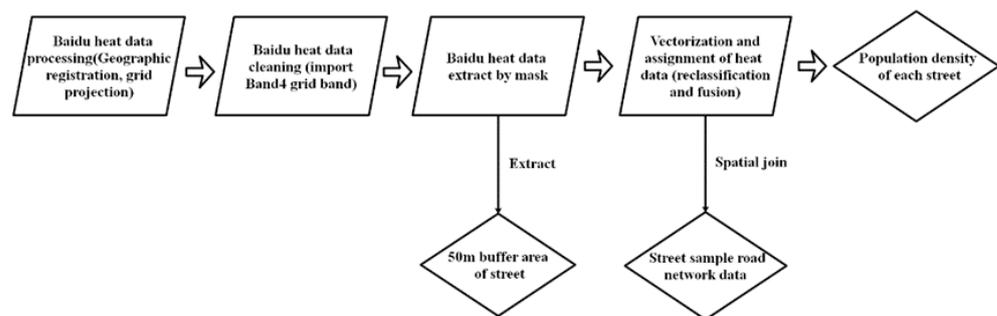


Figure 8. Baidu heat data processing process.

The Social Function Density

The social function density is the ratio of the number of POIs of various facilities within different buffer areas of the street to the length of the street, as depicted in Equation (2). In order to ensure the number of POIs not affected by the street length, the number of different types of POIs is normalized. The higher the function density, the more service points can provide daily facilities around the street, and herein, it is more beneficial to attract citizens to walk in streets.

$$G1Density = POI_num / road_length \quad (2)$$

where $G1Density$ is the function density of the street, POI_num is the total POIs within the buffer area of the street and $road_length$ represents the length of the street.

The Social Function Mixing Degree

The social function mixing degree is calculated as the POI mixing degree within different buffer areas of the street with the application of information entropy, as depicted in Equation (3). The higher the mixing degree, the more types of facilities are in the street providing services that meet the needs of people for various travel purposes.

$$G2Density = - \sum_{i=1}^n (p_i \times \ln p_i), (i = 1, \dots, n) \quad (3)$$

where $G2Density$ is the social function mixing degree of the street, n is the number of categories of POIs of the street and p_i represents the proportion of a certain type of POI to the total number of POIs of the street. The number of various types of POIs is then normalized.

Green View

Green view is different from the greening rate of the common concept. It refers to the proportion of vegetation in the street landscape observed by pedestrians, and consequently, its value affects citizens' judgment on the comfort degree of the street space environment. Through programming using the language of Python, we collected Baidu panoramas in batch. Then, semantic segmentation was performed to distinguish the proportion of people, cars, road, vegetation, sky and other elements in the whole panorama. As shown in Figure 9, the upper part of the figure is the original Baidu panorama, and the lower part of the figure illustrates the processed result of semantic segmentation. It was measured from

the processed panorama that the proportion of vegetation and sky elements in the picture is 0.37 and 0.48, respectively. Finally, the segmentation results were statistically analyzed, and the proportion of vegetation to all elements was connected and matched to the road networks using the toolboxes of ArcMap.

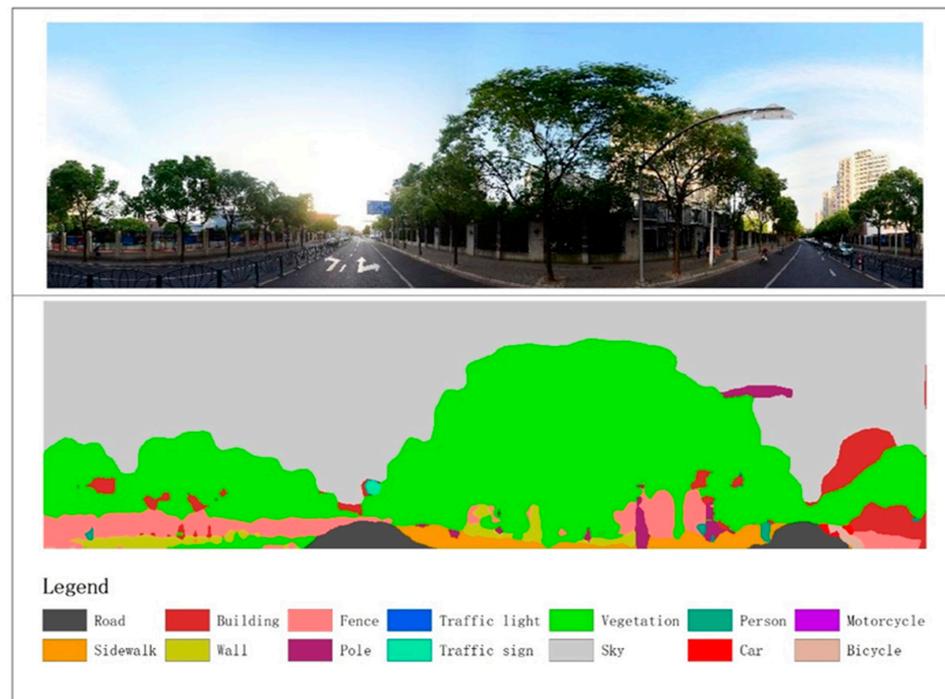


Figure 9. Baidu panorama and semantic segmentation result. The figure is generated from Baidu Street View and programmed in Python.

Sky View

The sky view refers to the proportion of the sky area that pedestrians can see from a certain point on the street. The data acquisition and quantification methodologies were the same as for the green view. The final calculation was the proportion of the sky element in the Baidu panorama. The quantitative results were also connected to the road networks through ArcMap.

4. Results

4.1. Spatial Distribution Law

Since the research area we selected is a small-scale block, and to better describe the detailed information of its spatial distribution, we established the geometric center point of Zhoujiadu Community. The quantitative results of each index are connected and matched to the road network in the research area for vivid spatial visualization.

4.1.1. Baidu Population Density

The Baidu population density of the streets is grouped into three levels by natural breaks (Figure 10). It can be observed from the figure that some streets in the west and southeast of the geometric center point present high vitality. The amount of medium-vitality streets is distributed in the largest area range around the geometric center point in all directions. Low-vitality streets are mainly distributed in the periphery of the research area. In addition, it is illustrated that the streets with high vitality during the selected time slots are Shangnan Road 4 in the west of the geometric center point and East Changli Road 4 in the southeast. There are many subway stations near Shangnan Road 4 (such as the Zhonghua Art Palace and Yaohua Road subway station), resulting in the high traffic accessibility and the enormous flow of pedestrians. Moreover, there are also many POIs

on both sides of East Changli Road 4 that possess potential attractions, leading to people visiting these facilities on foot.

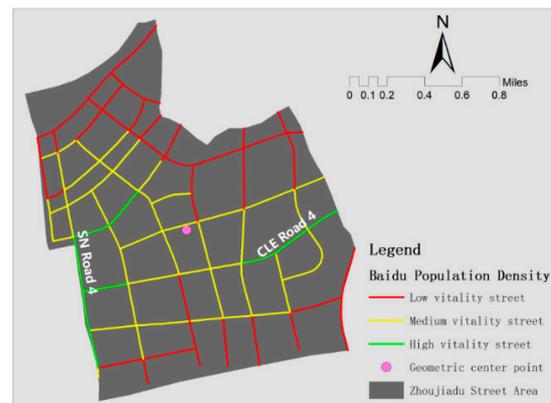


Figure 10. Spatial distribution of Baidu population density. CLE Road 4 is the abbreviation for East Changli Road 4 in the text. The figure is generated in the Arcmap software.

4.1.2. Social Function Density and Function Mixing Degree

The social function density and function mixing degree of the streets are clustered into five hierarchical levels by natural breaks (Figures 11 and 12). From the two figures, it is shown that the spatial distribution patterns are intensively distinct. Starting from the geometric center point, the overall distribution of social function density in the area shows that streets in the northern region present lower values than of those in the southern region. Streets in the central region have a higher social function density than those in the peripheral region. Among the streets in the central region, Qihe Road 2 near the geometric center point, Chengshan Road 3 in the south and East Changli Road 4 in the southeast have the highest values of social function density. The reasons are that on both sides of these streets, there are many shops on the ground floor with a large number of other facilities evenly distributed. Compared with the social function density, scores of the social function mixing degree are higher in general and are more concentratedly distributed. Streets with the lowest social function mixing degree are primarily distributed in the northwest of the geometric center point while the streets with the highest values of social function mixing degree are mainly spread in the north and southeast of the geometric center point. Among the streets with high values of social function mixing degree, South Pudong Road 3 in the north of the geometric center point and Yunlian Road 3 and East Changli Road 4 in the southeast have the greatest social function mix. Along both sides of these streets are situated large residential areas with relatively complete and comprehensive living supporting facilities, covering a variety of functions such as finance, accommodation, restaurant, medical treatment, life service and shopping.



Figure 11. Spatial distribution of function density. QH Road 2 is the abbreviation for Qihe Road 2 in the text. The figure is generated in the Arcmap software.



Figure 12. Spatial distribution of function mixing degree. PDS Road 3 is the abbreviation for South Pudong Road 3 in the text. The figure is generated in the Arcmap software.

4.1.3. Green View and Sky View

The green view and sky view of the streets are similarly grouped into five levels by natural breaks (Figures 13 and 14). From the spatial distribution shown in these two figures, streets with a high green view have a lower sky view in general. It is explained that streets with a high green view are generally planted with more roadside trees, which might obstruct pedestrians' view of the sky and thus reduce the proportion of the visible sky. Streets with the lowest sky view are mainly distributed in the southwest of the geometric center point, and the streets with the highest sky view are Shangnan Road 4 in the west of the geometric center, Chengshan Road 5 in the southeast and West Gaoke Road 4 in the northeast. These streets are basically the trunk and sub-trunk roads in the study area. Both types of roads have high road grades, wide road transections and a large spacing between roadside trees on both sides of the street, resulting in a large visible proportion of the sky. The streets with the highest green view are Changli Road 2 and Dezhou Road 2 in the southwest of the geometric center point. Furthermore, since these streets are close to primary and middle schools, senior apartments and Manqu Park, it is reasonable to expect that the street greening environment is sufficiently planned and executed.

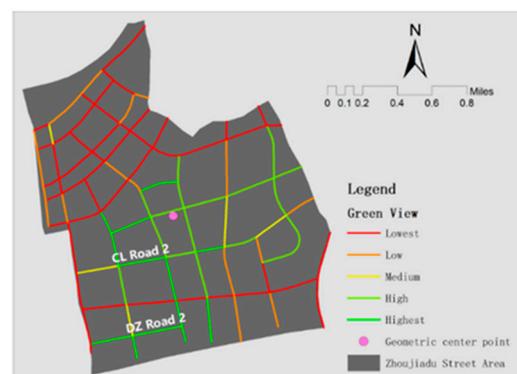


Figure 13. Spatial distribution of green view. CL Road 2 is the abbreviation for Changli Road 2 in the text. The figure is generated in the Arcmap software.



Figure 14. Spatial distribution of sky view. GKW Road 4 is the abbreviation for West Gaoke Road 4 in the text. The figure is generated in the Arcmap software.

4.2. Analysis of Influencing Factors of Street Vitality

In order to understand the impacts of various factors on street vitality, the external representation and constituent factors of street vitality were analyzed by multiple linear regression using the SPSS software. The dependent variable was determined as the Baidu population density (pop_i) of street (i), and the independent variables were bus density (bus_{den}), distance from the nearest subway station (sub_{dis}), function density (fun_{den}), function mixing degree (fun_{mix}), street length (str_{len}), intersection density (int_{den}), green view (gre_{vie}) and sky view (sky_{vie}). The processing steps of the multiple linear regression analysis are depicted as follows: (1) firstly, a correlation analysis of the external representation and constituent factors of street vitality was performed whereby some factors failing to pass the significance test ($p > 0.05$) were eliminated; (2) Secondly, the multiple linear regression model was constructed and analyzed; (3) Thirdly, the multiple linear regression model was tested through F -test and t -test.

According to the correlation analysis results of street vitality (Table 2), the Sig. value of street length and sky view is greater than 0.05, failing to pass the significance test. The two variables were thus eliminated. The other six factors were all correlated with street vitality, among which the function density and function mixing degree present a high positive correlation, the distance from the nearest subway station has a moderate negative correlation and the bus station density, intersection density and green view are weakly positively correlated. Here, a multiple linear regression model is constructed, as shown in Equation (4).

$$pop_i = \beta_0 + \beta_1 \times bus_{den} + \beta_2 \times sub_{dis} + \beta_3 \times fun_{den} + \beta_4 \times fun_{mix} + \beta_5 \times int_{den} + \beta_6 \times gre_{vie} \quad (4)$$

Table 2. Correlation analysis results of street vitality.

Index	Pearson(r)	Sig. (P)	Degree of Correlation
Function density	0.538 **	0.000	High correlation
Function mixing degree	0.512 **	0.000	High correlation
Street length	0.026	0.801	/
Bus station density	0.209 *	0.043	Low correlation
Intersection density	0.210 *	0.042	Low correlation
Distance from the nearest subway station	−0.315 **	0.002	Moderate correlation
Green view	0.221 *	0.032	Low correlation
Sky view	0.122	0.240	/

Note: ** at 0.01 level (two-tailed), * at 0.05 level (two-tailed), the correlation is significant.

By applying the model in Equation (4), the SPSS software was implemented to import data for multiple linear regression analysis. The final results are presented in Tables 3–5. It can be concluded from Table 3 that the judgment coefficient R of the model is 74.7%,

indicating that the change in street vitality is primarily determined by the change of each constituent factor. The R -squared and adjusted R -squared coefficients of the model are 0.558 and 0.517, respectively. It is explained that the fitting degree is at the middle level but within the acceptable range and the model is effectively established. The DW -test value is 2.010, which is close to 2. Therefore, it is suggested that there is no intercorrelation between variables with their independent residuals. To sum up, the model is well and effectively designed.

Table 3. Summary result of model.

Model	R	R Squared	Adjusted R Squared	Standard Error of the Estimate	DW
1	0.747	0.558	0.517	0.99135	2.010

Predictors: (constant), sky view, bus station density, intersection density, function density, distance from the nearest subway station, function mixing degree. Dependent variable: Baidu population density.

Table 4. ANOVA test result.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	85.828	6	14.305	14.555	0.000
	Residual	85.501	87	0.983	-	-
	Total	171.330	93	-	-	-

Dependent variable: Baidu population density. Predictors: (constant), sky view, bus station density, intersection density, function density, distance from the nearest subway station, function mixing degree.

Table 5. Regression coefficient results.

Model	Unstandardized Coefficients		Standardized Coefficient Beta	t	Sig.	
	B	Standard Error				
1	(Constant)	1.404	0.714	-	1.966	0.052
	Function density	0.042	0.016	0.363	2.700	0.008
	Function mixing degree	0.732	0.294	0.357	2.490	0.015
	Bus station density	0.121	0.094	0.110	1.289	0.201
	Intersection density	0.054	0.027	0.193	1.995	0.076
	Distance from the nearest subway station	-0.001	0.001	-0.291	-2.063	0.042
	Green view	2.150	0.901	0.202	2.387	0.019

Dependent variable: Baidu population density.

Next, the significance test (F -test) was performed for the multiple linear regression model. The F -test was developed to determine whether the overall independent variables have a significant impact on the dependent variable in general. As illustrated in Table 4, the value of F is 14.555 and the Sig. value is less than 0.05, indicating that the independent variables have a great influence on the dependent variable and the whole linear relationship is significant.

Finally, the significance test (t -test) was conducted to examine the regression coefficients in the multiple linear regression model. A t -test is utilized to verify whether each independent variable itself has a significant impact on the dependent variable. When the absolute value of t is large and the significance level is less than 0.05, the regression coefficient passes the significance test. Table 5 shows that the absolute values of t of the six constituent factors of street vitality, i.e. function density, function mixing degree, bus station density, intersection density, distance from the nearest subway station and green view are 2.700, 2.490, 1.289, 1.995, 2.063 and 2.387 respectively, and the significance levels are 0.008, 0.015, 0.201, 0.076, 0.042 and 0.019, respectively. Therefore, the regression coefficients of bus station density and intersection density in street vitality are not significant (failed the t -test), while the regression coefficients of the rest factors are significant (passed the t -test).

To sum up, there are four main factors affecting the street vitality. According to the standardized coefficient (Table 5), the influence degree of each factor on the street vitality

in descending order is as follows: social function density, social function mixing degree, distance from the nearest subway station and green view. It is concluded that streets with high vitality generally have the following characteristics:

1. A large number of facilities and service points are distributed in the adjacent area of the street, their types are distinctive and functions are comprehensive, and herein, citizens' daily needs are met and they are more encouraged to walk in the streets.
2. If the street is close to subway stations, it implies the provision of greater traffic convenience; therefore, people will prefer to walk and take public transport for various daily activities.
3. If the street presents a high green view, it possesses a better walking environment quality and attracts people with its comfortable walking experience. Compared with the streets with a low green view, people are more willing to walk on greener streets.

5. Discussion

Urban streets are the public open space of the city, performing their social function of transportation to the traditional extent, and also provide space for citizens' daily leisure, fitness and social activities such as communication and information exchange in communities. The vitality of streets indicates the vitality of a community and also has close relationships and strong implications with city sustainability indices such as walkability, healthy lifestyle and living happiness, etc. Street vitality in this work is indicated by pedestrian crowds in the streets and is indicative of the extent to which the built environment of a street can attract people to walk there and to what extent citizens' social needs such as communication, shopping, walking and entertainment can be met. The improvement of street vitality is crucial to promoting healthier public lifestyles, creating sustainable communities, improving closer social communications and accelerating social development.

Research on street vitality has been conducted by many scholars and the relationship among street vitality and built environment and street users (pedestrians) has been constantly explored. The results in many studies show that street vitality is related to functional diversity, traffic accessibility, road connectivity, street texture and related characteristics of the street itself (length/width/grade/speed limit and greening conditions on both sides of the road). It is suggested that the pedestrian density in a street should be increased through reasonable layout of land use function within the block, division of street scale and design of building interfaces on both sides of the street so as to realize the improvement of street vitality [3]. Limited by the research conditions at that time, most of these studies are based on qualitative analysis and lack quantitative data validation. Nowadays, more precise data on the micro-level of the city are accessible, so the quantitative analysis of street vitality is no longer limited by the difficulty of data acquisition, and scholars have begun to perform more in-depth quantitative exploration on street vitality. It is concluded that the overall walking activity is related to six factors of built environment at the micro-level: land use mix, density, block size, building age, accessibility and border vacuums [37]. It is discussed that the main factors affecting the vitality of the streets include the distance from the subway entrance or commercial center, function density, function mixing degree, development intensity and road network density [1,20]. Crucial elements from these studies constitute the draft version of the index system in this paper. Their independency and contributions are interpreted afterwards.

This paper selected some streets of Zhoujiadu Community in Shanghai and constructed a quantitative evaluation index system of street vitality from the two dimensions of external representation and constituent factors. Pearson correlation coefficients were used to explore the degree of correlation between constituent factors and street vitality, and a multiple linear regression model was established to discuss the main influencing factors of street vitality. The results from this work propose that the constituent factors of function density, function mixing degree, distance from the nearest subway station and green view all have impacts on street vitality.

First, a higher degree of function density and function mixing degree enhance the vitality of streets. If the number of facilities and service points along a street is large, their types are diverse and functions are comprehensive, the street can meet most people's daily needs. Therefore, properly increasing the number and diversity of POIs along streets not only raise the attractiveness to pedestrians but also invites people with different travel purposes, increasing pedestrian crowds in the street as a result. Take Changli Road 2 and East Changli Road 4 for example (Figure 15)—they are typical commercial streets with abundant facilities (covering catering, commerce, shopping, medical treatment, entertainment, transportation and education services). The crowd vitality of the streets is high. Conversely, the number of POIs on both sides of Liuhe Road (Figure 15) is small, its daily service function is poor and its overall street vitality is also slightly inferior.



Figure 15. Live-action pictures of some streets. Note: The figures are generated From Baidu Street View.

Secondly, highly efficient and convenient public transportation accessibility is an important indicator for street vitality. If the distance between a street and a subway station or bus station is short and, thus, the degree of transportation convenience is high, people would prefer walking and taking public transport for daily activities. In this study, there are more subway stations near Shangnan Road 4 and Shangnan Road 3, resulting in the better public transportation convenience of these streets. It is more possible for nearby residents to choose to walk for daily activities and commuting. Setting more public transport stations along streets tends to create higher street vitality.

Last but not least, a good street walking environment will increase the frequency of street use of pedestrians and naturally enhance the vitality of the street. The quality of the walking environment mainly depends on the degree of green plants on both sides of the streets. Streets with a high green view often have better walking environment quality and are more likely to provide people with a comfortable travel experience. Take the examples in Figure 15. Changli Road 2 not only has a large number of facilities but also has a high greening rate on both sides, which effectively improves the walking environment. Dezhou Road 1, adjacent to a primary school and health service centers, injects more efforts into the

construction of a green environment, resulting in a strong attraction of pedestrians, while in the case of Bailianjing Road 1 leading to the industrial wharf, and there are basically no roadside trees planted on both sides, the walking environment is poor for people. South Yanggao Road 1 is a sub-trunk road with a width of 50 m and eight two-way lanes. It is a major traffic road, and the daily traffic is dominated by vehicles. The green view on both sides of the street is low, and it is relatively less attractive for people to walk.

6. Conclusions

Under the new data environment, this work aimed to perform quantitative explorations of street vitality with the application of open data of maps of road networks, POIs, Baidu heat maps and Baidu panoramas as well as the adoption of the geoinformation software of ArcMap[®] 10.2 and the programming language Python[®]. The basic study unit was a small-scale urban public street area. From the theoretical perspective, we derived arguments from the basic framework of street urbanism and then constructed a quantitative evaluation index system for measuring street vitality. Afterwards, we established a multiple linear regression model to examine the main influencing factors of street vitality, so as to provide supports for the improvement of street space quality and the development of higher vitality streets. The empirical results of the Zhoujiadu Community in Shanghai evidence that the indices of social function density, social function mixing degree, distance from the nearest subway station and green view all have strong impacts on street vitality. Among them, the social function density and function mixing degree have the most significant influences. From the practical perspective, the research results from this work are beneficial in encouraging slow traffic in urban regions, improving the quality of urban streets and guiding the construction of livable cities with stronger street vitality. Compared with the arduous work of changing the physical embedded features of streets, it might be more realistic to enhance the vitality of streets by improving the social function density and social function mixing degree of the streets. A host of facilities with various types and services provided can attract people for more walking opportunities, enhance the walking friendliness of the built environment and elevate the vitality of the crowd in the street. Appropriately strengthening the planning of basic public transportation infrastructure in the context of street design can enhance the convenience for people to walk to public transportation stations. Planting more roadside trees on both sides of the broad street can create a more beautiful and comfortable walking space for people.

The overall framework of the methodology and analysis process can be replicated and applied in other communities with proper adjustments of details. The actual built environment and inherent facilities of each community are distinct, whereby possible addition to or deletion of the current constituent factors so as to obtain the evaluation index system may be performed. The methodology framework and the results presented in this work can provide some significant implications on street vitality and healthy community lives. Meaningful insights from this work can also be provided for current urban construction and regeneration and urban sustainability development.

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