Exploring Associations between Street Networks and Cycling from the Perspective of Space Syntax: An Empirical Research of Yangpu District of Shanghai

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Abstract: Research on the correlation between physical activity such as walking and cycling and the built environment has received extensive attention. Based on how the built environment causes travel, most of the existing research focuses on spatial features such as land use, scale, density, and location on different geographic scales. The street networks is the largest and most obvious global space that affects the movement of residents. However, few studies pay attention to the influence of the structural characteristics of the street network on physical activity, thus ignoring how individuals are affected by the surrounding space elements in the process of movement. According to the theory of spatial syntax, the individual movement in the urban space network is caused by the space network itself under the same conditions, which means that the spatial configuration of the street network is a decisive factor for the movement pattern. Therefore, this paper, taking Yangpu District of Shanghai as an example, uses Mobike (a biking sharing service provider) location data to analyze the impact of urban spatial morphological characteristics on cycling. Firstly, the spatial network model of street space, which is based on the notion of a 'segment map is established by spatial syntax, and the variables such as connectivity, integration and depth are used to characterize the spatial topological features of networks. Then, the time-space characteristics of the distribution of residents' cycling activities are analyzed by using Mobike location data. Subsequently, a spearman correlation analysis was used to assess the correlation between cycling activity and street network morphological characteristic. Interestingly, this paper finds that the local morphological characteristics of the street network have more correlations with the use of bikes than the global features. The space syntax variable that is most strongly associated with bicycle use appears at a search radius of 700 meters.

Keywords: cycling; Mobike; space syntax; spatial networks analysis

Introduction

There is clear evidence that cycling has substantial benefits for both physical and mental health. Studies have shown that regular physical activity has substantial health benefits(Warburton and Bredin, 2006, Janssen and Leblanc, 2010). People who lack adequate physical activity are at higher risk of chronic diseases such as overweight, obesity, hyperlipidemia and hypertension (Katzmarzyk et al., 2009). Cycling, as a low-carbon, environmentally friendly way of travel, has received great attention in urban research and planning practices in various countries(Moudon et al., 2005a). Cycling activities are affected by many factors such as age, gender, natural and built environment, and there

are great differences in the habits of cycling in various countries(Wang et al., 2016, Stewart and Moudon, 2014). There is growing evidence that some characteristics of built environments are closely linked to the level of cycling activities. Among many factors in built environment, lower density housing, single land use, lack of health and recreational facilities, limited public transport systems and public open spaces usually act as the barriers to physical activities, including cycling(Giles-Corti and Donovan, 2002, Saelens et al., 2003, Sallis et al., 2012, Troped et al., 2011, Van et al., 2013).

Since 2016, bike sharing, featuring " on-demand" have begun to appear in the streets of some major cities in China. Compared with the traditional "pile-oriented" public bikes system, bike sharing can be more flexible and distributed in various angles in the city(Zhang and Mi, 2018). Although it brings certain difficulties to urban management, its flexible layout a provide great convenience to residents in cities. In some megacities such as Beijing and Shanghai, the number of sharing bikes has exceeded 3 million. Not only that, the popularity of bike sharing has also changed the daily traffic habits of residents. According to the White Paper on Bike Sharing and Urban Development released by Mobike in 2017, after the emergence of bike sharing, the proportion of urban cycling travel increased from 5.5% to 11.6%. Furthermore, 81% of bikes in Beijing are active around the bus station; 44% of bikes are active around the subway station. And these two figures are 90% and 51% in Shanghai, respectively. This shows that the emergence of bike sharing can not only effectively alleviate urban traffic congestion, but also change the traffic habits of urban residents. At the same time, under the background of bike sharing, residents' cycling activities will present new time and space characteristics. For this new cycling service provider in China, whether the relationship between cycling and built environment presents new features remains to be studied

Based on how the built environment causes travel, most of the existing research focuses on spatial features such as land use, scale, density, and location on different geographic scales. These researches are based on the assumption that space is the container of socio-economic activity and that the link between socio-economic activities results in movement. However, few studies pay attention to the influence of the structural characteristics of the street network on physical activity, thus ignoring how individuals are affected by the surrounding space elements in the process of movement. The quantitative description of urban spatial structure by space syntax theory makes it an important tool for urban planning and design decision-making. The theoretical basis of the "natural travel principle" is that the main factor shaping the urban user movement model is not the specific land use, but the spatial structure of the street network. Space syntax is a set of theories and techniques for measuring the spatial configuration of street networks. By focusing on street networks rather than buildings or parcels to describe the built environment, space syntax analysis considers spatial properties of physical space(Hillier et al., 1993). Therefore, this paper aims to use space syntax tool to identify the impacts of the relative characteristic of networks on cycling activities.

Cycling and built environment

In the identification of built-in environmental factors for cycling activities, most researches are based on the "3D" theoretical model of traffic and environment, and the environmental variables are selected from the three dimensions of Density, Diversity and Design(Cervero and Kockelman, 1997, Cervero et al., 2009, Moudon et al., 2005b). The density dimension mainly includes population density: per acre, employment density, and employment accessibility. The diversity dimension mainly includes the number of land types used in each grid of hectares, the average entropy of various types of land, vertical mixing degree, and land development intensity: residential, commercial, office, etc. Business intensity, proximity to commercial retail. Design dimensions include street design, support for walking and cycling activities, and site design elements. Among them, street design elements include street type, connectivity, street width, speed limit, number of blocks, highways, street green coverage,

street lighting, etc. Supporting elements of walking and cycling activities include the proportion of sidewalks, signals, etc. Number of intersections, average length of street blocks, width of sidewalks, interval between street lights, slopes, length of acar lanes, stay and rest facilities, shelters, etc.; site design elements include commercial retail services The design of sexual and landscape fountains. In the subsequent research, according to the development level of different countries and regions and the behavior characteristics of residents, research has increased the distance from traffic stations and the accessibility of destinations on the basis of 3D(Lee and Moudon, 2006). Moudon added "R" on the basis of 3D, that is, the environmental characteristics of the travel path are equally important for walking or cycling. In addition, in another study, Moudon proposed a spatial element that influences physical activity in the environmental-behavior theory model, which she believes should be derived from the origins and destinations of the individuals' walking or cycling trips, and the surrounding areas of the travel path(Moudon and Lee, 2003). The primary spatial object that identifies the environmental impact factor. From this point on, urban streets have become the main target for identifying the impact factors of cycling activities. More and more research has begun to pay attention to the physical form of the road and the impact of the perceived environment on physical activity.

Spatial variables in urban models in existing studies are often measured by distance. This approach comes from the observation and assumption that economic and social forces shape matter and distance is a measure of economic costs. Another perspective in existing research is to build urban models through people's complex perceptions. The main spatial variables include safety, social environment, visual quality and maintenance, and perception of sports destinations or facilities. The presence of parks, sports facilities, trails and bikes lanes, the perception of the existence of walking obstacles, and the capture of walking support conditions in the neighborhood. And this perspective tends to be a partial vision to observe the urban space. Therefore, the urban modeling method in the urban planning field should focus on the overall and local level, the residents' perception of urban space during the travel process.

Previous studies for the measurement of built-in environmental characteristics within a spatial unit at a certain geographic scale. This type of research has a natural assumption that urban space acts as a container for the influencing factors of physical activity. However, urban forms are characterized by self-organization. The original research design ignored the influence of the structural features of urban form on physical activity. Therefore, the study aims to explain the initial application of this emerging travel mode through a quantitative model of urban morphology. Hillier pointed out that in fact people's movement in the urban street network is based on the minimum number of turns rather than the shortest distance, and is a city street network, rather than attraction points, shaping the travel activities in the network(Hillier et al., 1993).What is still unclear is whether the structural characteristics of this urban form still have an impact on bike sharing in China and what is the theoretical explanatory power.

Methodology framework

The case study and data

Taking Yangpu District of Shanghai as an example, this paper attempts to analyze the influence of topological features of street networks on the distribution of cycling activity based on spatial syntax theory by using the location data of bikes sharing on a rest day, trying to explore the applicability of space syntax theory to emerging bike sharing travel mode. As one of the first cities to share bikes and the largest number of bikes in Shanghai, residents have become more stable in terms of the number and habits of bike sharing. As an old industrial base in Shanghai, Yangpu District is transforming into a knowledge-based innovative city centered on colleges and universities. Wujiaochang is a sub-center

of Shanghai City. The research area is mature and rich in function types, and it is representative of the relationship between the spatial structure of the city and the distribution of cycling activities.

Cycling behavior is greatly affected by the weather, and poor weather conditions can result in a significant reduction in cycling travel(Wang et al., 2016). In addition, cycling behavior has obvious differences in the use of working days and rest days. In order to reduce the impact of weather and commuter traffic on the research results, the study selected the rest days with good weather conditions to analyze the characteristics of cycling behavior. The date is November 18, 2017.

The research data in this paper obtains the location data of the use of bike sharing in Yangpu District of Shanghai through crawlers, and the space vector data such as POI and road acquired through open source map. Among them, the bike sharing data is crawled through the network to obtain the unlocked bikes information available in the research area. The daily data covers 48 time-and-half-hour time points throughout the day, covering approximately 327,539 locations in November 18, 2017 (rest days) in Yangpu District, Shanghai, including: bikes ID, location information, time information, etc. . These data are based on the user's completely spontaneous riding behavior, which can more objectively reflect the space-time characteristics of the residents' cycling behavior.

Space syntax modeling based on the segment map

From the existing research, more urban travel activities are attributed to the results of being attracted by travel destinations and being perceived by distance. Space syntax theory holds that when people move linearly in the city, the land-use will tend to remain the same, but when you turn a corner and move from the front of the same plot to the back, you will enter another world. Hillier called this transition through two topological depths one of the historical mysteries of urban planning. Therefore, in the urban model of spatial syntax, the basic unit of the city is not a land, but a straight line. Thus, Hillier proposed the principle of “natural travel”, that is, when other factors are not considered, the distribution of traffic flow in the city is only related to the topological form of the street network. On this basis, he believes that it is not the store that attracts the crowd, but in the process of urban evolution and development, the choice of location of commercial land use will make full use of the advantages of people flow caused by the characteristics of pure space organization, thus making “natural movement” has a multiplier effect(Hillier et al., 1993).

The classical research tool of spatial syntax is the axial map. At the beginning of the spatial syntax applied to the spatial study of urban scale, the axis model dominates. However, as research continues to expand, the axial map gradually shows its limitations. Ratti pointed out that the axial modelling only considers the characteristics of the dual network, while ignoring the typical network features such as distance(Ratti, 2004). Since 2005, space syntax has developed a second-generation model: line segment angle model(Hillier and Iida, 2005, Turner, 2007). In addition to the topological relationship, the new model can accurately reflect the geometric properties of the street network (ie, the turning angle of the street segment), showing a more accurate description of the urban spatial structure. The basic element of the line segment model is the street segment between road intersections. It is essentially based on the improvement of the axial map.Reflecting the line segment angle map in addition to capturing the topological properties of the street network, it can also reflect the geometric relationship of the network, including Concepts in Euclidean geometry such as line angle, distance, etc. The improved integration value essentially reflects the minimum number of turns from one road to another within a certain radius.

In view of the extensive research that has proved the applicability of segment map to large-scale urban space research , this paper uses segment map as the network analysis model of space syntax.

(networks analysis models). Identify the spatial group effects that influence and shape sharing bikes and their importance. As a kind of analytical tool for quantitatively describing the topological features of urban spatial structure, spatial syntax reveals the complex relationship of urban spatial form through parameters such as connectivity, control, depth and integration. Its calculation method mainly inherits the centripetal analysis method in social network analysis. Connectivity primarily represents the number (k) of other spatial units in the network that are directly connected to spatial unit i.

Integration reflects the degree of agglomeration and dispersion of a certain space and other spaces in the city. If the integration of a point is higher, the other points within the analysis range are easier to reach. Its calculation formula is as follows：

$$\text{Integration} = \frac{D_k(k-2)}{2(\frac{\sum_{j=1,j\neq i}^{N} d_{ij}}{N-1} - 1)}$$

Where i, j represents a spatial unit, k is the number of other units in the network, and N is the total number of spatial units in the network. Depth is the reciprocal of the integration. Choice is used to measure the probability of traffic flow in space (Hillier, et al., 1987). All axes are linearly related to each other and must pass through other axes. The degree of selectivity can be measured as the number of passes. That is, the degree of selection can reflect the importance of the axis within the scope of analysis. Its calculation formula is as follows：

$$\text{Choice}_i = \frac{1}{(N-1)(N-2)} \sum_{j=1;k=1;j=k=1}^{N} \frac{n_{jk}(i)}{n_{jk}}$$

The modeling method is to create the axis model by hand-drawing, transform the axis model into a line segment model by Depthmap software (version 10, UCL) and calculate the relevant space syntax variables. Then the segment map is imported into the arcgis and registered, and the attribute connection is used to connect the calculation result to the registered segment map. Cycling data analysis and visualization are done in ArcGIS (ver. 10.2) software. It should be pointed out that in order to avoid the "edge effect" in network analysis, it is necessary to set a buffer of a certain distance around the analysis area as the base area of drawing the segment map. Therefore, the study area of this study is Yangpu District, Shanghai. According to the speed of cycling activities and the actual urban space composition, base area is set up around Yangpu District, west to north-south elevated road, east to Huangpu River, north to outer ring highway. South to Yan'an elevated road.

Fig 1 the base area and the study area

Results

Since the acquired bike sharing data is the position information of the unlocked state, the bikes that have never been moved throughout the day, it is ensured that the counted bicycles have been used.. The activity of bike sharing in the study area is known by counting the number of bikes that have been moved throughout the day according to a 30-meter grid. As can be seen from Fig. 2, the use of bikes on the off day is still closely related to the subway station.

Fig 2 the distribution of the moved bikes

Secondly, the global and local space syntax parameters of the study area are calculated by Depthmap software, including integration, choice and depth. Among them, the local variables are calculated according to the cycling habits, and the local variables of the above three parameters are respectively calculated with the radius of 700, 1600, and 3500 meters. The results of the spatial syntax model of the study area are shown in Fig 3.

Fig 3 the results of integration, choice and depth in segment map modelling

Finally, the segment map in the Depthmap is imported into ArcGIS 10.2 and georeferenced. Then, in terms of line segments, count the number of moved bikes within 30 meters around the line segment. Spearman correlation analysis was performed in SPSS 22.Table 1 shows the spearman correlations between the global spatial syntax parameters and the use of moved bikes, important topological characteristic variables such as choice, integration, depth and connectivity pass the significance test ($p<0.0001$). However, although the level of significance is higher, the correlation coefficient is generally lower, and the highest correlation coefficient is 0.203(connectivity).

Table 1 Spearman correlations between the number of the moved bikes and the global space syntax parameters

	Global_choice	Global_integartion	Global_depth	Connectivity
R^2	.124**	.134**	-.134**	.203**
Sig.	.000	.000	.000	.000

Interesting findings are found in the correlation analysis of local spatial syntax variables and cycling volume from different scales, as shown in Table 2. When only the same variable is concerned, it will be found that the most relevant variable always appears on the 700m scale, and this total situation occurs simultaneously in these three set of variables. As the spatial scale becomes larger, the correlation coefficient decreases and the significance test is not passed at the 3500 m scale. Second, when compared with global variables, global integration and global choice are positively correlated with the number of bike sharing used, while these two variable show a negative correlation at with the number of bike sharing used 1600m and 700m scale. This change in the direction of correlation caused by the different scale does not appear in depth. The global spatial syntax variables represent the importance of spatial units in the overall spatial configuration. The local space syntax variable is related to how the residents perceive the local environment. It can be seen from the above analysis that the overall spatial structure of Yangpu District is related to the use of shared bicycles, and the influence is very limited. However, the spatial characteristics of the Yangpu District show few support for cycling activities. Comparing the two correlation analyses, it can be seen that the correlation coefficient of the local variable is generally higher than the global coefficient, and as the search radius continues to expand, the correlation coefficient begins to decrease.

Table 2 Spearman correlations between the number of the moved bikes and the local space syntax parameters

Choice_R700	Choice_R1600	Choice_R3500	Integration_R700	Integration_R1600	ntegration_R3500	Depth_R700	Depth_R1600	Depth_R3500

R^2	-.349**	-.126**	0.048	-.265**	-.122**	0.019	-.372**	-.193**	-.072*
Sig.	.000	.000	0.103	.000	.000	0.527	.000	.000	0.014

Unlike previous studies, the spatial syntax variables of this study did not show a strong correlation with shared bicycle use. There may be two reasons for this explanation. One is the existence of more access control street districts in Chinese cities. In Shanghai, shared bicycles are usually forbidden to enter the interior of residential areas and unit complexes. This is also why in the southern regions where road network density is high, the use of shared bicycles is very low. For further explanation of the less relevant correlation, the spatial structure of Yangpu District and the calculation result of segment map should be combined and analyzed. The result of spatial syntax also reflects the relationship between function and urban form. Fig. 4 shows the integration calculation results of the segment map in study area. It can be seen that, as Hillier said, the local road network encryption phenomenon brought by the integrated core appeared in the southern part of the region near the center of Shanghai. The inner center of Yangpu District is located at Wujiaochang area. As shown in the figure, the current commercial center and integration center are misplaced. In other words, the attractiveness of the Yangpu District Commercial Center has yet to be further enhanced. Secondly, through field research, it was found that non-motor vehicles were prohibited from entering the Wujiaochang area. In other words, due to the lack of support for the cycling activities in Wujiaochang, the high traffic is more from the subway station.. This is another potential reason why the relationship between integrated cores and shared bicycles is not strong. The results show that the overall explanatory power of networks features at the overall level is weaker than the local level. For integrated values, when the spatial scale of the analysis is large, it is positively correlated with the cycling activity. When the spatial scale is small, it is negatively correlated with the cycling activity and the depth value is always negatively correlated with the cycling activity regardless of the spatial scale. As is shown in Fig 4, the distribution of the high integration is more corelated to the subway station than local integration.

Fig 4 local integration distribution at 700 m, 1600 m, 3500 m radius

Discussion and conclusion

Based on the spatial syntax theory and model tools, this paper explores the influence of spatial fabric characteristics on the use of bike sharing in Yangpu District, Shanghai. This paper uses the location data of bikes among one day in weekend in Yangpu District of Shanghai, and analyzes the space-time characteristics of the bike sharing use on the rest day in Yangpu District by using ArcGIS and other

analysis tools, and the number of bike sharing and the parameters of space syntax at different scales. A spearman correlation analysis was performed. The study found that although there is a lack of strong correlation factors, integration, choice and depth in urban network analysis still shows a significant correlation effect with bikes use. Moreover, from the comparison of three different spatial scales, the correlation coefficient of choice is increasing as the spatial scale becomes larger. This shows that road density has a strong correlation with cycling activities at local scales. However, when the spatial scale is gradually increased, the correlation between the integrated value and the cycling activity begins to change positively and negatively. The larger the spatial scale, the stronger the positive correlation. Because the distribution of global integration values is more relevant in metro lines and site distribution. That is to say, compared with the "constant speed transportation system" of the traditional city, the actual "integrated nuclear" brought by the "differential transportation system" of the modern city is the shaper of the cycling, and is also the current resident's habits to use bike sharing. Yangpu District used to be an old industrial base in Shanghai. Compared with Jing'an and Huangpu, the neighborhood has a large scale and low road density. There are more "access control" communities and unit complexes. With the deepening of the transformation process of Yangpu District to the knowledge-innovated urban area, the road network encryption phenomenon of the local integrated core will appear in the future, and the correlation between urban spatial form and function will be further enhanced.

Compared with the existing research on the correlation between cycling and built environment, the urban model based on spatial syntax can simultaneously measure the influence of global and local spatial fabric features on cycling activities, and thus shape the spatial factor of cycling activities at different scales. The lack of trajectory data for cycling activity is the reason for the lack of explanatory power of the integrated value based on the minimum angle weighting. This research is not enough to answer the question of whether people move at the smallest or shortest distance.

Of course, there are many limitations in this study. For bike sharing data, since the python returns the location of the bikes every half hour, the bike sharing usage within half an hour will not be recognized, and it is difficult to eliminate the interference caused by human factors such as bikes company internal dispatch. Secondly, this paper only attempts to analyze the space syntax theory to explain this new way of cycling in China, and has not yet thoroughly analyzed the built-in environmental factors affecting cycling activities. So, in the background of bike sharing, is the space configuration still the shaper of the cycling activity? The answer to this question requires further research in the next step. In the follow-up study, other built-in environmental factors such as land use, spatial form, and road traffic conditions will be included as control variables, , so as to explore the causal link between cycling activity and the built environment more deeply and comprehensively.

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