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Exploring urban street types and their impact on spatial people's aggregation in Nanjing

Mingyang LU[1], Ye ZHANG[2]

[1] Southeast University, China

[2] National University of Singapore, Singapore

Abstract

In the field of urban morphology, there is a lot of understanding of how cities have evolved over time by descriptive and deductive approach. Recently, some studies introduce more rigorous quantification method and link such types to their performance though developing and testing urban types, and a few convincing conclusions achieved in European cities. However, whether this is suitable for Chinese cities with different development processes and different political and cultural issues. This study uses the similar approach to get a better understanding of relationship between street configuration and people's aggregation in Nanjing--a typical Chinese mega-city.

There are two parts in this study. The first part is to generate urban types based on integration from space syntax and cluster analysis, because it has been proven to provide reliable and efficient. The second part is to test the types developed from first part. Density of surrounding block is obtained by measuring FSI and GSI, which it captures how spatial form structures people and things. People's aggregation in the space and time dimensions use telecom data for wide coverage. This study found that the types are robust based on cluster analysis. The types were able to explain the intensity of aggregation well and the trend of type is consistent with that of FSI and GSI.

Keyword: *Integration, aggregation, density, clustering, Nanjing*

Introduction

A better understanding of the relationship between urban form and built environment has been an important issue in urban morphology. In the classic urban morphology, street what is one of the important objects is considered to have a significant impact on people's daily life and urban vitality (Appleyard, Gerson, & Lintell, 1981; J. Jacobs, 2011). In the research method of urban morphology, classification is one of the important approaches. Conzen, Caniggia and other scholars describe and deduct the streets or blocks in the process of urban development though classification, and summarize the urban from patterns and the law of urban development. This kind of research method continues to this day, Moudon, Kropf and other scholars integrate the previous achievements, and promote the development of current urban morphology (Kropf, 2014; Moudon, 1997). However, under the background of the rapid expansion of the city, the huge and complex city information is difficult to be comprehensively and objectively processed through manual analysis. Therefore, quantitative research approach is introduced into urban research and has attracted more and more attention of urban morphology researchers in recent years.

In the quantification urban research, Space syntax is one of the pioneers, which has put forward the theoretical system of completion earlier (Bill Hillier, 1996). Since the 1980s, space syntax has proposed a

configurational approach to quantify the urban structure with indicators such as integration and choice through the line and segment model of road network, which has a good effect in the verification of human activities in cities (B Hillier, Penn, Hanson, Grajewski, & Xu, 1993). Since the new millennium, a variety of quantitative tools have developed, such as the discussion of urban density by FSI and GSI (Berghauser-Pont & Haupt, 2010), the discussion on functions of urban land use by MXI (van den Hoek, 2008) etc. At the same time, the integration of various quantitative methods is emerging by GIS, which enriches the urban quantitative research (Van den Hoek, 2008). A large amount of data brought by these approaches are mostly descriptions of urban in detail, however, it lacks of ways to condense them into practical conclusions. It IS difficult to understand and far away from urban practice.

To solve these problems, a rigorous quantitative approach--cluster analysis is worth trying in urban research. Clustering is a bottom-up algorithm, which reflects the overall structure through the characteristics of the data itself. In recent years, there are a lot of research findings based on clustering approach in urban morphology (Araldi & Fusco, 2019; Berghauser Pont et al., 2019; Gil J, 2012). Among them, the research of Pont (Berghauser Pont et al., 2019) has a great inspiration for this study. Pont pointed out: “a large pedestrian survey of three European metropolitan areas was conducted and used to test the performance of the urban types developed ... despite the number of people in each area, their distribution pattern is similar and related to street type ... urban rhythms are influenced primarily by building type and not by street type.” This paper has built preliminary standards for the cluster approach of urban morphology from the creation of the type to the verification. This paper focuses on several European cities, and the data of human activities come from walking behaviour in part of city. The universality of the conclusions needs to be further expanded.

This study based on the configuration develops the street clustering of Nanjing--a typical Chinese city, and verifies the effectiveness of the types. The data include urban street network, building, mobile signalling, which is from cooperation projects with the government. This research is divided into three parts. The first part is interpretation of data, the result including the street configuration, surrounding density and people’s aggregation, and then discuss the correlation between them. The second part is the clustering analysis based on the integration of street to develop the types. The third part is the validation of class depending on surrounding density and people’s aggregation.

Methodology

Sample introduction and selection: Nanjing, located in the east of China, is a mega city in the lower reaches of the Yangtze River with a total urban population of 8.5 million. Nanjing is a famous ancient city with a history of 2460 years and 450 year of the capital history. In the past 100 years, the development of Nanjing has experienced four different periods, including: the period of feudal history before 1920s; the period of the capital of the Republic of China from 1920s to 1950; the period of socialist planned economy from 1950 to 1980; and the period of urban development after the reform and opening up after 1980. The large-scale

development of Hexi New, Xianlin and Jiangning new town are the reflections of the rapid expansion of Nanjing after 2000 (fig.1). Up to now, Hexi new town has the potential to become a city centre like the old town centre-- Xinjiekou. The spatial scope of this study is the old city as the centre, the Yangtze River and the ring expressway as the boundary, including the old city and Hexi New City (fig.1).

The unit consists of two parts: the centre line and its influence area. The centre line is a segment based on space syntax[1]. In the influence area, different from the traditional way of getting rectangular area by extending the street centre line to both sides (Vialard.A, 2013), this study uses Thiessen polygons as the geometric basis (Araldi & Fusco, 2019). The centre line of Thiessen polygon matches the segment, so polygon and segment are grouped into unit[2]. The purpose of using Thiessen polygon is to obtain the unit which can cover the urban and avoid the overlap between different units. The unite covered retreats 50m from the edge of the motorway to the block. If the depth of the block is less than 50m, all the polygon will be included.

Figure 1. Introduction to Nanjing City and unit results

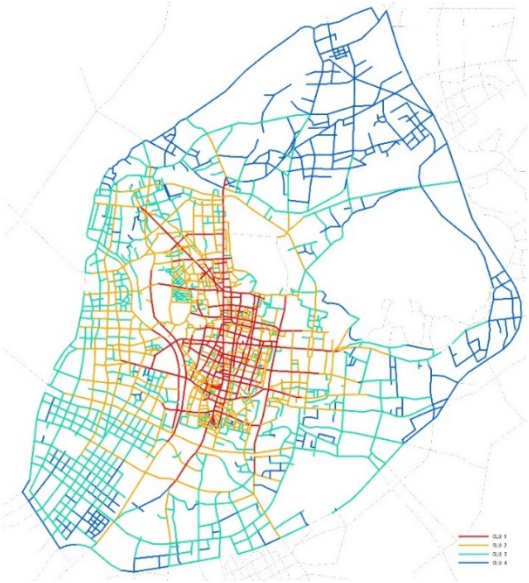

Figure 2. Clustering results based on integration

This study only focuses on the public accessible streets with mixed pedestrian and vehicle traffic, and streets like pedestrian roads in closed management area, greenways, commercial pedestrian streets, and expressways for vehicle only are not included. Besides, considering the geometric characteristics of Thiessen polygon, only the segment must be longer than 50m. A total of 3124 units met the requirements (fig.1).

**People`s aggregation:** In human activity, the telecom data from Nanjing Mobile Company is taken as the basis of people`s aggregation. The traditional way is to observe human activities in public through naked eye, and find the key elements according to the summary of researchers (Gehl, 1987). In recent years, with the progress of photography technology, we can record human activities more accurately. Some new methods

[1] The street between two intersections as a segment.
[2] In some segments, there will be a polygon corresponding to multiple segments. The longest segment is taken as the corresponding research.

are required to observe the flow of people on a large scale, and telecom data has become one of the breakthroughs. With the wide spread of mobile devices, telecom data with greater coverage and higher accuracy has attracted the attention of urban researchers (Noyman et al., 2019).

The telecom data collection time used in this study is from November 9 to 22, 2015, with a total of 1.65 billion pieces of effective information after cleaning. The market share of Nanjing Mobile Company is over 50% in mobile operators. In the aspect of data translation, the intensity of aggregation is quantified by the total number of telecom date in the unit at different time[3], and then the total number divided into 14 grades of decreasing strength. The intensity of aggregation in the unit can be reflected by the average grade of each time (fig.3). The rhythm of people can be reflected by the square difference of grades at each time (fig.4).

Figure 3. The intensity of aggregation: Mean result

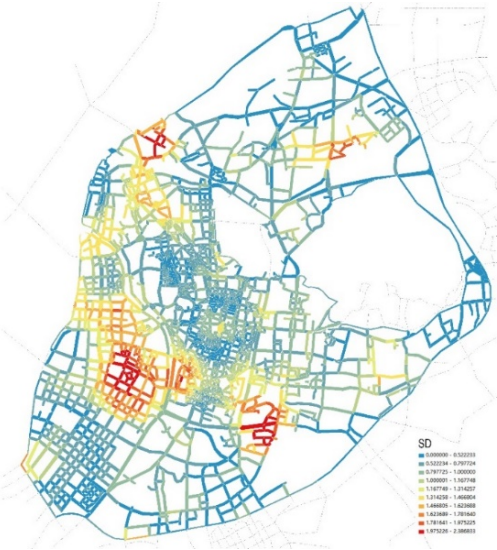

Figure 4. The rhythm of aggregation: SD result

Figure 5. Density of surrounding blocks: GSI result

Figure 6. Density of surrounding blocks: FSI result

[3] Time: 0:00am, 2:00am, 4:00am; 8:00am; 10:00am, 12:00am, 2:00pm, 4:00pm; 8:00pm; 10:00pm.

Density of surrounding blocks: The data of urban development and construction comes from Nanjing Planning Bureau. The urban map contains the building outline & height, block outline and road network. The map has been updated to December 2019 based on Baidu map and field investigation. According to Pont`s method (Berghauser-Pont & Haupt, 2010), FSI and GSI are used as quantitative indicators. FSI is used to describe the total built floor space in an area, while GSI describes the division between built and non-built land in an area. Besides, the plot area is replaced by the unit which is based on block area in the unit (road is not included). The FSI (fig.6) and GSI (fig.5) of unites are obtained through statistics in GIS.

Clustering of segment: This paper quantifies the street configuration based on spatial syntax. In space syntax, integration is the most classic way to describe street network configuration, which is a response to the topological depth of road space. It has been proved that it is closely related to human activities (Bill Hillier, 1996). Limited with people's perception, the cognition of the street is limited to a certain range, and space syntax simulates this situation by different radius. In Nanjing, it takes the radius from 500m to infinity. These indicators bring a large amount of data. The data from the integration is uniform, and the absolute value difference is not big, so the k-means clustering method is suitable. In the number of categories, it should consider both mathematical reliability and urban research. According to the characteristics of data (fig.9) and the experience (Berghauser Pont et al., 2019), this study takes four as the number of categories (fig.2).

Cluster testing: The validity of clustering should consider two aspects. Firstly, the mathematical characteristics should be obvious, which the types have obvious numerical distribution characteristics. Secondly, the types should have correspondence with other dimension data, which shows that has expansibility and universality. The cluster results can be understood as the performance of urban structure. Its correlation with other dimensions of urban performance shows that this structure is more representative, and whether the type is robust or not should be tested. It is divided into three steps: The first step is mathematical verification, which requires that data of street configuration have obvious characteristics in every cluster. In this study, by comparing the box-plot chart of each category in all radius. The second step is the people`s aggregation testing, which uses box-plot graph and scatter graph to discuss whether clusters are related to human activities. The third step is density of surrounding blocks testing with the same method of the second step.

Result and Discuss

Correlation analysis: It can be seen from table 1 that the street integration has a significant correlation with the intensity of aggregation FSI and GSI under each radius, and the order of correlation degree is intensity of aggregation > GSI > FSI. In the intensity of aggregation, the Pearson correlation coefficient is more than 0.4. Especially in the radius of 3000m and 5000m, the correlation coefficient is more than 0.8, showing a strong correlation. However, the correlation between street integration and rhythm is not strong. In the density of surrounding blocks, GSI has a strong correlation with integration because the correlation coefficient is almost

above 0.3 and when the radius is from 1500m to 5000m, the correlation coefficient is around 0.6. FSI and integration showed a moderate correlation, because although most of the correlation coefficients above 0.3, the maximum value at radius 3000m does not exceed 0.5. By observing maximum value, it is not difficult to find that the correlation is more significant at radius is around 3000m, which shows that 3000m is likely to be people's cognitive radius of the city based on space syntax.

Table 1. The Correlation results: the integration, people`s aggregation and the density of surrounding.

	GSI		FSI		MEAN		SD	
	PCCs	Sig.	PCCs	Sig.	PCCs	Sig.	PCCs	Sig.
500m	0.018	0.307	0.026	0.140	0.024	0.170	-0.032	0.066
800m	0.379**	0.000	0.278**	0.000	0.424**	0.000	-0.081**	0.000
1000m	0.544**	0.000	0.404**	0.000	0.633**	0.000	-0.087**	0.000
1500m	0.608**	0.000	0.473**	0.000	0.756**	0.000	-0.059**	0.001
2000m	0.608**	0.000	0.488**	0.000	0.788**	0.000	-0.049**	0.005
3000m	0.596**	0.000	0.491**	0.000	0.813**	0.000	-0.039*	0.028
5000m	0.590**	0.000	0.466**	0.000	0.824**	0.000	0.026	0.140
7000m	0.561**	0.000	0.428**	0.000	0.799**	0.000	0.080**	0.000
10000m	0.507**	0.000	0.377**	0.000	0.747**	0.000	0.112**	0.000
15000m	0.386**	0.000	0.319**	0.000	0.616**	0.000	0.070**	0.000
20000m	0.312**	0.000	0.286**	0.000	0.527**	0.000	0.011	0.526
30000m	0.264**	0.000	0.263**	0.000	0.476**	0.000	-0.001	0.957
∞	0.250**	0.000	0.259**	0.000	0.461**	0.000	-0.006	0.722
GSI	1	-	0.585**	0.000	0.645**	0.000	0.083**	0.000
FSI	-	-	1	-	0.492**	0.000	-0.046**	0.009
Mean	-	-	-	-	1	-	0.284**	0.000

**. significant correlation at 0.01 level (bilateral). *. significant correlation at 0.5 level (bilateral).

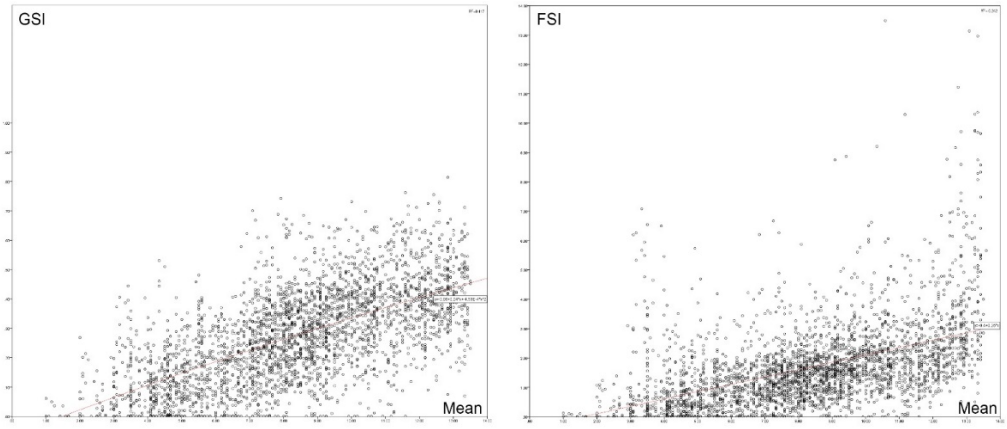

Figure 7. Left: scatter graph and fitting line of Mean & GSI; Right: scatter graph and fitting line of Mean & FSI

In addition, the relationship between people`s aggregation and density of surrounding blocks is also worthy of discussion because these four indicators are significantly correlated each other. The correlation coefficient between GSI and intensity of aggregation is 0.645, which is significantly higher than FSI. The cost of GSI is smaller than FSI under the premise of enhancing the same intensity of aggregation. According to the fitting line (fig.7), the effect of increasing GSI by 0.1 is the same as that of increasing FSI by 0.6. In Nanjing, it reflected in the difference between Xinjiekou and Hexi CBD. Both of them are generally recognized as Nanjing city centre. However, Xinjiekou with higher GSI has full-time vitality, while Hexi CBD with high-rise and low-density is lack of night vitality, and the tidal effect of people flow is very obvious (fig.4).

Cluster analysis: According to the clustering results, characteristics of each type are obvious. Integration of four clusters increases orderly under different radius. The median line does not cross, and there is almost no overlap between the first and third quartiles (fig.8). In Nanjing (fig.2), cluster 1 is located in centre, mainly including the main streets in the old city; cluster 2 mainly includes most of other streets in the old city, as well as the main streets in centre of Hexi; cluster 3 includes most of the streets in Hexi, the streets near the old city and some the branch streets in the old city; cluster 4 is located in the periphery of the city, with huge road network scale. Four clusters of distribution can well show the street configuration of Nanjing: Taking Xinjiekou as the centre, the degree of integration decreases outward.

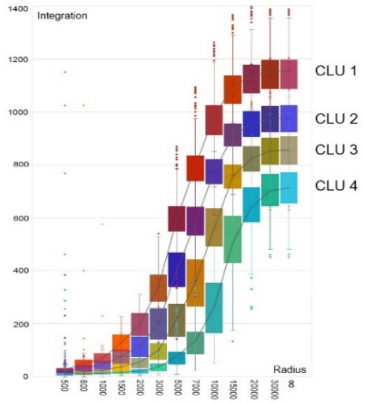

Figure 8. box-plot of types based on integration

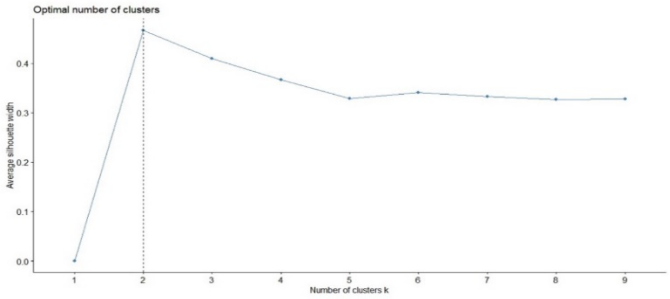

Figure 9. Clustering effect: larger silhouette width, better clustering

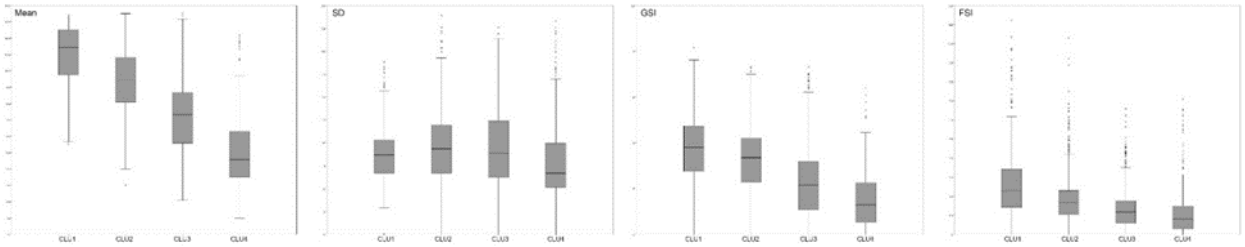

Figure 10. left 1: intensity box-plot; left 2: rhythm box-plot; right 2: GSI box-plot; right 1: FSI box-plot.

In the people`s aggregation, according to box-plot graph (fig.10 left 1), there is a correspondence between types and intensity of aggregation. The higher integration, the higher intensity in different type. However, there are obvious overlaps in the quartile range of integration between different types, which indicates that this is not a strong correspondence. There is no correspondence between types and rhythm of aggregation (fig.10 left 2). The human activities of the four types basically correspond to its street configuration and it also conforms to people's life experience in Nanjing. In the density of surrounding, the situation of FSI and GSI is similar to intensity of aggregation, but the correspondence is not as good as intensity (fig.10 right 1&2). The correspondence between GSI and types is slightly better than FSI. In summary, the correspondence between types and another two-dimensional data is similar to the previous correlation analysis. Combined with the graphs (fig.2,3,5,6), it can be seen that the index decreasing from centre to edge is general. Compared with density of surrounding blocks, intensity of aggregation is more corresponding to street types

based on integration clustering. This is consistent with some of Pont`s conclusion:" ... street types explain how this intensity is distributed within those areas ... their distribution pattern is similar and related to street type (Berghauser Pont et al., 2019)."

Conclusions

Through the correlation analysis, we can see that the integration of street units is positively related to people's aggregation and the density of surrounding. Moreover, the three results point to Xinjiekou as the only centre of Nanjing. Although Hexi centre has the potential to become a centre, its density of road network and the floor area are slightly insufficient, which makes it difficult to keep 24-hour vitality. Compared with the old the new city of Nanjing, the gap is in GSI rather than FSI. This shows that in big Chinese cities, urban vitality needs more support from density on the ground rather than blindly pursue height.

Through the cluster analysis, we can see that the types are robust based on street configuration. The types were able to explain the intensity of aggregation well and the trend of type is consistent with that of FSI and GSI. This also proves that part of Pont's conclusion is also right in Chinese cities: the spatial distribution of types has stronger correspondence with the intensity of people's aggregation.

Acknowledgements

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