Assessment of Urban Building Layout Based on Spatial Pattern Analysis Methods

TAO Yang, TANG Guoan[*], GE Shanshan, ZHU Shijie, DAI Xiangxi, ZHU Rui
Key Lab of Virtual Geographical Environment, Ministry of Education
Nanjing Normal University
Nanjing, China
E-mail: taoyanggis@163.com
[*]Corresponding Author: tangguoan@njnu.edu.cn

***Abstract*—Urban surface morphology characteristics mainly expressed by the shape of artificial building entities. Based on DLG data and field surveys, urban building entity model and point model of the vector-based surface model are constructed. In addition, from the view of exploratory spatial data analysis (ESDA) and spatial statistical analysis, a set of analysis and evaluation methods of the characteristics of urban layout are designed. As test areas, urban spatial distribution and pattern of the old city of Nanjing in China are analyzed. Experiment also showed that the surface model of the city based on the vector construction entities can better reflect the main patterns of urban surface characteristics and three-dimensional trend information on the characteristics of obvious benefit to deep analysis.**

Keywords- Urban Building Entity Models; Spatial Pattern Analysis; ESDA; Spatial Statistics; GIS

I. INTRODUCTION

Urban surface morphology characteristics mainly expressed by the shape of artificial building entities. At present, the research of urban three-dimensional models mainly concentrates on building the urban natural surface digital elevation model, obtaining three dimensional building and artificial entity model , dealing with the texture of natural and entity surface and building models such as street lights, trees and so on (Amnon Frenkel, et al. 2008; Batty M, et al. 1987; Carlo Ratti, et al. 2004; Zhu Q, et al. 2001). Human factor influences on the modality of urban surface which is mostly covered by artificial buildings compared with common terrain modeling. So spatial three dimensional structure and characteristic of artificial entity object are much more valuable for urban geo-science analysis and application. The application of traditional assessment methods of surface modality based on grid data is restricted from DEM modelling methods, scale matching and regional differences of different test areas. So how to assess the layout of urban buildings based on National fundamental geographical data and spatial pattern analysis methods is the key issue for city planning.

Based on vector modeling strategy and with the view of urban building entity model, a new urban digital elevation model is designed in part Ⅱ. Then a assessment system of urban layout based on urban building entity model, ESDA and spatial statistical analysis methods is designed. Finally, test areas experiment and results are shown in part Ⅲ.

II. METHOD

A. Urban DEM model based on vector modeling strategy

Human factor influences on the modality of urban surface which is mostly covered by artificial buildings compared with common terrain modeling. Urban DEM covered by artificial buildings, roads and plants as the main features. Traditional urban DEM based on grid data structure can express the gradual changed surface but not be good at describing break changed surface such as urban building entities. So a series of urban building entities' surface models based on vector modeling strategy are constructed as followes:

By means of building layer of big scale DLG data, the buildings' two-dimensional surface shape characteristic accurately been extracted. (Fig. 1A).

The DLG data does not gather the elevation information of construction entity. It only gives the floor number of the buildings in 1:500 scale DLG data. The urban DEM model mainly expresses the relative spatial relations and the shape characteristic between buildings. So the building elevation was estimated by means of building layer and the average height per floor. Three-dimensional urban DEM model is constructed by this elevation attribute (Fig. 1B).

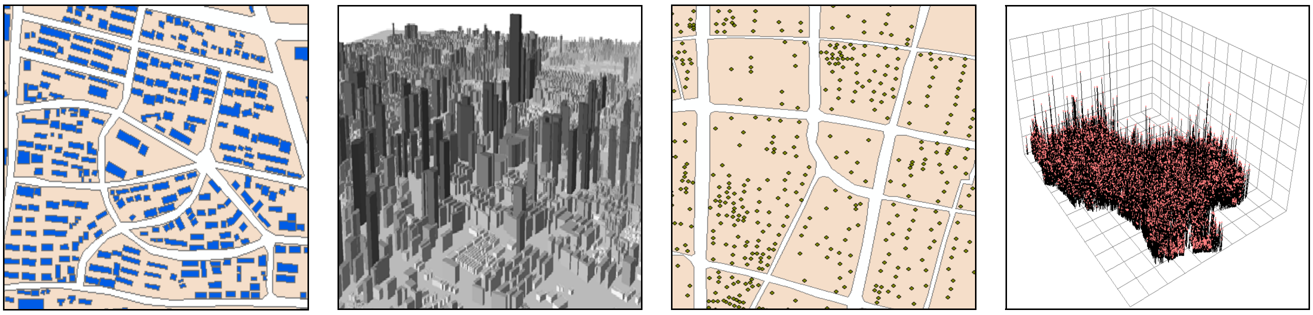
Urban DEM model based on building entity has some certain limitations on model maneuverability and compatibility with tradition spatial analysis algorithms. Therefore, point model based Urban DEM model is been constructed by means of calculate the areal coordinates of building entity (Fig. 1C and 1D). The formula of calculate the polygon areal coordinates (X, Y) as follows:

$$X = \frac{\sum_{i=1}^{n}(x_i + x_{i+1})\begin{bmatrix} x_i & x_{i+1} \\ y_i & y_{i+1} \end{bmatrix}}{3 * \sum_{i=1}^{n}\begin{bmatrix} x_i & x_{i+1} \\ y_i & y_{i+1} \end{bmatrix}}$$

$$Y = \frac{\sum_{i=1}^{n}(y_i + y_{i+1})\begin{bmatrix} x_i & x_{i+1} \\ y_i & y_{i+1} \end{bmatrix}}{3 * \sum_{i=1}^{n}\begin{bmatrix} x_i & x_{i+1} \\ y_i & y_{i+1} \end{bmatrix}} \quad (1)$$

Where, (x_i, y_i) is polygon various apexes, $x_{n+1} = x_1$, $y_{n+1} = y_1$.

DLG data shows building entity features by means of two-dimensional projection method. Actually, the shape of urban building is multiple and building roofs are seldom flat. This article temporarily neglects this factor in urban DEM modeling.



A. 2-D Polygon Model B. 3-D Modality Model C. 2-D Point Model D. 3-D Point Model

Figure 1. Urban Building Entity Models

B. Spatial characteristic analysis of Urban building based on ESDA and spatial pattern analysis methods

Exploratory spatial data analysis (ESDA) can explore the spatial distribution pattern and trend of spatial data and help for deeply data mining and geo-science analysis. A set of analysis and evaluation methods of the characteristics of urban layout are designed which contain the spatial trend analysis, the model of density estimation, central point and mean point models and indexes that measure spatial trend of cluster. The model of density estimation, central point and mean point models, indexes of spatial trend of cluster are shown as follows:

1) The model of density estimation

Density estimation is one of the common methods of spatial analysis. It represents the quantity of discrete objects in unit area. Therefore, density is an effective join between the discrete objects and continuum field conceptualization. This paper measures the density of urban building through using the model of simply point density estimation based on discrete data source and the model of kernel density estimation based on single variable normal kernel.

2) Central point and mean point model

Detecting central point and mean point is one of the mainly indexes of measuring the concentrated distribution trend of spatial discrete data. For facing different research objects, measuring models are different. The central point model faces to point cloud database. The model formula is shown as follows:

$$M = (\sum_{i=1}^{n} w_i x_i / \sum_{i=1}^{n} w_i, \sum_{i=1}^{n} w_i y_i / \sum_{i=1}^{n} w_i) \quad (2)$$

Where, w_i means the weight of point sets. It's calculated by the elevation data of the building point model.

We often concern a center point of Minimum Aggregate Travel (MAT) in test area. This issue could be calculated by iterative model as follows:

Let (x0, y0） mean the initial coordinate point.

$$x_{k+1} = (\sum_{i=1}^{n} w_i x_i / \sum_{i=1}^{n} d_{i,k}) / (\sum_{i=1}^{n} w_i / \sum_{i=1}^{n} d_{i,k})$$
$$y_{k+1} = (\sum_{i=1}^{n} w_i y_i / \sum_{i=1}^{n} d_{i,k}) / (\sum_{i=1}^{n} w_i / \sum_{i=1}^{n} d_{i,k}) \quad (3)$$

Where, di,j is the distance between No.i point to No.k best place which is evaluated.

3) Point pattern analysis

The core content of point pattern analysis is to show the discretization and aggregation degree of spatial point group data and the spatial autocorrelation degree of a pair of points. It is always by means of the distance statistic method to design the measuring indexes.

Let $d_{i,j}$ mean the distance from point No. i to the point No. j. Let min mean the nearest distance. The d_N means the average distance of sample points, and can expressed as follows:

$$d_N = \sum_{i=1}^{n} \frac{\min(d_{i,j})}{N} \quad (4)$$

Where, the average distance of random distributing scattered points (d_r) is expressed as follows:

$$d_r = \sqrt{A/N}/2 . \quad (5)$$

"A" means the area of the test areas. Then ANNI can be calculated as follows:

$$ANNI = \frac{d_N}{d_r} \qquad (6)$$

There are many indexes to show general spatial relation of geographical phenomena. Moran's I can more objectively reflect the spatial autocorrelation degree of features in the test area. It can make sure that a geographical phenomena has the trend of aggregation or decentralization. The formula is shown as follows:

$$I = \frac{\sum_i \sum_j w_{ij}(z_i - \bar{z})(z_j - \bar{z})}{p * \sum_j (z_i - \bar{z})^2} \qquad (7)$$

Where,

$$p = \sum_i \sum_j w_{ij} / n \qquad (8)$$

Moran's I reflects the general level of autocorrelation degree and aggregation degree. However, it is hard to reflect the local relation mode. Therefore, Getis-Ord General G statistical function is used to measure the spatial heterogeneity and search the hot-spot areas. Getis-Ord General G Index is mainly used to detect the aggregation degree of the discrete data's high value or low value. Getis-Ord General G can be calculated as follows:

$$G = \sum_i \sum_j w_{ij} z_i z_j / \sum_i \sum_j z_i z_j \qquad (9)$$

Where, $i \neq j$.

III. EXPERIMENT AND ANALYSIS

A. Test Area

Downtown of Nanjing is chosen as study Area, mainly including six administrative areas and some different function districts. The highly developed commercial districts in Nanjing, such as Xinjiekou are mainly composed of lot of tall and large building. The residential districts are comprised of with well organized apartment and densely houses built one or two decades ago, such as Ruijin Road. And commercial and residential mixed areas are chosen, such as Zhujiang Road and Gulou. All the function districts are foundation of this study and supply us rich information of urban area. The location of study site and part of its urban landscape are shown as Fig.2

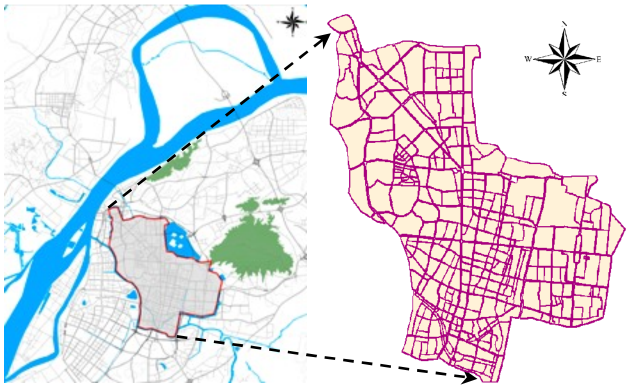


Figure 2. Schematic Diagram of Test Area

B. Experiment Data

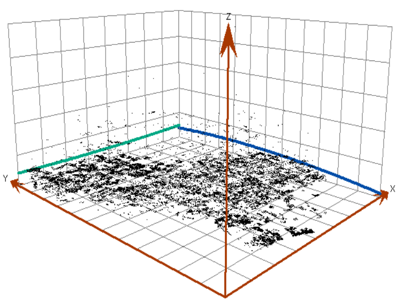
List below is test data that experiments have used:

1) *1:500 DLG data*
2) *1:10000 DEMs (5m resolution)*
3) *Administrative regions Map of Nanjing City*
4) *Annual economic statistic data of Nanjing City*

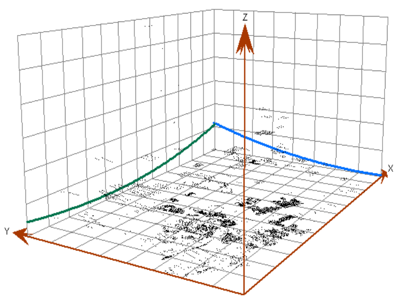
Firstly, construct the 2-D Urban DEM Model in virtue of extracting the architecture layer from Nanjing downtown 1:500DLG data, then estimate the architecture elevation based on its floor count and correct elevation in virtue of Nanjing downtown 5m resolution DEM data. Finally construct the point model based Urban DEM model in virtue of (1).

C. Spatial trend analysis of urban buildings based on ESDA

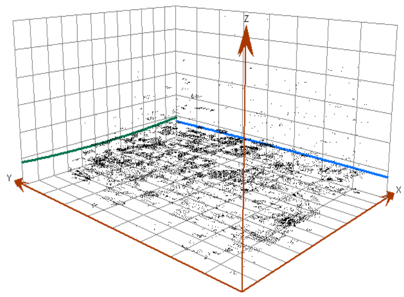
First of all, probe the distribution trend of the spatial data in every administrative region by means of ESDA analysis. The result is shown in Fig.3. The trend shows that the buildings in the north-south direction and east-west direction is well-distributed while in the direction of north to south, middle buildings are slight higher and both sides are lower, which is identical to the fact that the density of tall buildings in central is larger than sides. The basic trend of the three regions (B, C, D) is similar to the whole city's trend. Region A and E are located in the north and south part of the city respectively. The buildings there are decentralized and floors are mostly below 7 floors. Overall, it presents a pattern of quadratic parabola.



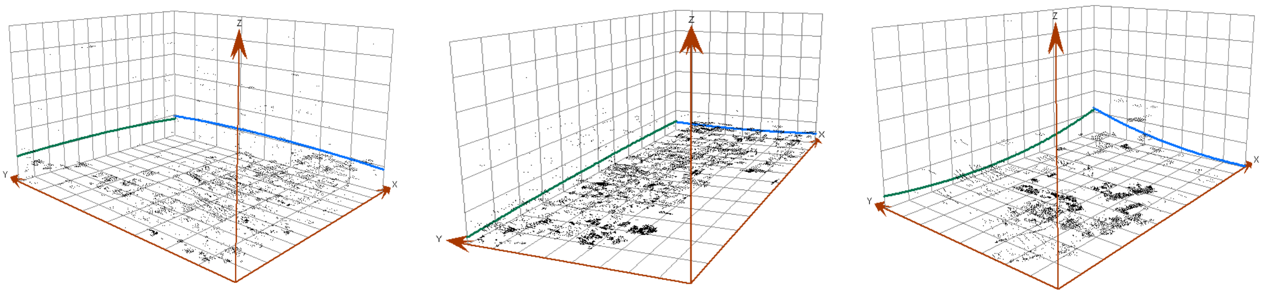
Nanjing City



Region A



Region B



Region C Region D Region E

Figure 3. Spatial Trend Analysis of Test Areas

D. Spaial Pattern Analysis based on central and mean model

It comes out the central point and mean point of buildings in each administrative region by (2) - (3). By calculating the average distance of the buildings in this area to the mean point, distance between the region and the central point was calculated, further a rationality evaluation of the buildings' layout was given out. The result shows in table I.

TABLE I. AVERAGE DISTANCE BETWEEN BUILDINGS AND CENTRAL (MEAN) POINT

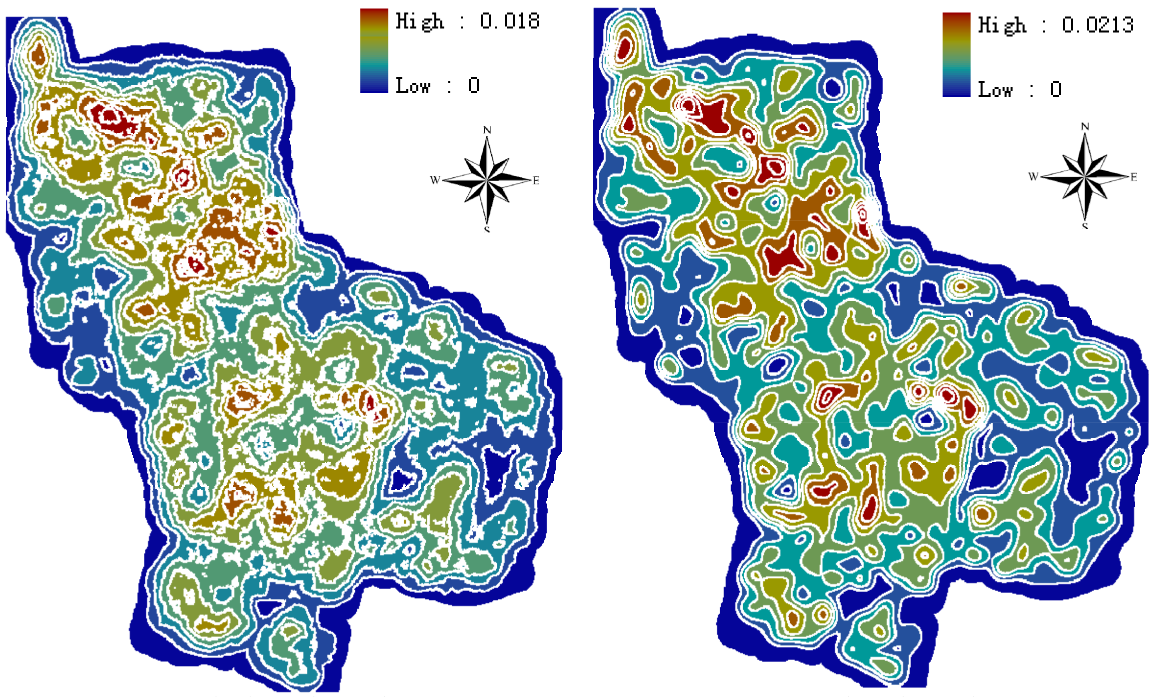
Test Area	**Point No.**	**Distance from CP[a]**	**Distance from MP[b]**	**□D**
Region A	4102	1625.39m	1706.56m	81.17m
Region B	9646	1748.57m	1753.52m	4.95m
Region C	3801	1403.48m	1409.54m	6.06m
Region D	6343	1745.46m	1759.13m	13.67m
Region E	4252	803.03m	807.98m	4.95m

a. CP: Central Point; b. MP: Mean Point.

The result shows that the distance between the buildings and the central or mean point (maybe commerce center or potential commerce center) in the region is within 2 kilometers. Specifically, Region E locates in the old city zone and its buildings are centralized relatively, the area of this research region is small, so the average distance is even smaller.

E. Spaial Pattern Analysis based on Density Estimation

Buildings' density in the region reflects the degree of buildings' aggregation, which reveals the trend of population aggregation to a large extent. Simple density estimation (Fig.4A) and kernel density estimation based on Kernel function (Fig.4B) were used in experiments. These two density estimation methods have difference in dealing with the border of different density distribution case, but they all reflect the spatial - aggregation trend that buildings in the old city zone of Nanjing is centralized to the main business center and spread radialized.



A. Simple Density Graph B. Kernel Density Graph

Figure 4. Density Estimation Maps of Old City of Nanjing

F. Trend analysis of urban buildings' spatial aggregation

According to the the nearest distance model and overall auto-correlation model, explores the degree of aggregation and spatial autocorrelation of buildings' distribution in each administrative district The result shows as follows:

TABLE II. SPATIAL AGGREGATION STATISTICS OF UBRAN BUILDINGS

Test Area:	ANNI			Getis - Ord General G			Moran's I			
	ANNI	Z (std.)	Conclusion	G	Z (std.)	Conclusion	I	Z (std.)	E (I)	Conclusion
Region A	0.62	-46.19	Clustered	0	-7.94	Low	0.13	157.05	-0.0002	Cluster
Region B	1	0.12	Random	0	-5.74	Low	0.04	105.93	-0.0001	Cluster
Region C	0.7	-35.68	Clustered	0	2.86	High	0.04	42.33	-0.0003	Cluster
Region D	0.88	-18.24	Clustered	0	-13.4	Low	0.09	155.31	-0.0002	Cluster
Region E	0.7	-37.69	Clustered	0	-18.99	Low	0.10	162.87	-0.0002	Cluster

The distribution of Region B reflects the characteristics of random distributions through the ANNI. The region belongs to the old part of Nanjing and contains Nanjing's economic, political and cultural center. It shows a uniform distribution when so many old buildings remains. While, on the other hand, another four regions shows a general trend to the concentrate distribution as it has a close association with its purpose.

Spatial autocorrelation Indexes give out characteristics about the degree of spatial aggregation of the buildings. From the Moran's I, the five regions of the buildings show a weak positive correlation. That is to say, high buildings and low buildings are separated from each other and at the same time, they are relative concentrate. Indicators from the Getis-Ord General, in addition to C outside, all showed a trend of low accumulation, and the Region C, a high-value accumulation, which is the distribution of local buildings compare with.

IV. CONCLUSION

By means of spatial pattern analysis and based on vector model of urban building entities, a set of analysis and evaluation methods of the characteristics of urban layout are designed from the view of exploratory spatial data analysis and spatial statistical analysis. Based on the example of Nanjing's five-old-major administrative districts, it is obvious that this method is conducive to the development of urban land use to help reveal the hidden factor in the unreasonable and is the guidance to get better urban planning, when this method is from the view of spatial statistical distribution of urban buildings in the macro-evaluation.

ACKNOWLEDGEMENT

Thanks for financial support provided by National Natural Science Founation of China（Grant Nos. 40671148 and 40801148）and Cultivate Project of Excellent Ph.D Thesis of Nanjing Normal University. We also thanks to Dr. LUO M. L. and Dr. WANG C. for their constructive advices.

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