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Parcel direction: Definition, computational approach and measuring urban form*

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Abstract: The parcel direction, as a spatial index to evaluate the urban form in the parcel scale, is currently paid less attention in the urban morphology domain. In the paper we brought forward the term of the parcel direction and its definition as to analyze the urban form quantitatively. The approach for calculating the parcel direction was as well investigated, together with the empirical study of the urban form of Detailed Planning of the Beijing Central Metropolitan Area. We calculated the parcel direction of the historical urban form of Beijing in 1949, followed with the comparison of the historical and planned forms using the proposed parcel direction index. The demonstrated conclusions are as followed: (1) The urban form in terms of the parcel direction, can be divided into four types, including normal, slanting, mixed and ecological types. (2) The parcel direction index is not correlated with the perimeter, area, or compactness indictors of the parcel. (3) The parcel direction is explicitly spatial heterogeneous, and the probability density function of the parcel direction within the entire study area varies from that of local parts. Therefore, the probability density function of the parcel direction can be adopted to examine the urban form. (4) The parcel direction can be utilized to evaluate to what extent the planned form inherits the historical form via comparing the parcel direction index of the two forms.

Key words: urban morphology; spatial metrics; planning evaluation; spatial heterogeneity; Beijing

1 Introduction

The parcel direction (PD) can be introduced as a novel index for the urban morphology analysis in the parcel scale since the urban form can be spatial explicitly compared through the analysis of spatial differentiation of the index. Via comparing the direction variation of the present parcels and planned parcels, the influence of urban planning on the urban form can be identified quantitatively. PD is the geometric analysis for geographical space from the geography perspective. The urban form is the integration of elements in the geographical space, including the shape of the entire build-up space, road network, and landscape. The parcel, as the basic component of block, is the container of various urban infrastructures, such as buildings, green lands, municipal infrastructures, and public services. Since it has traffic connection with the road network, the parcel has close relationship with both of the block and road network. Meanwhile, since the block generally has the same direction with the road network, its direction can be recognized as that of the roads around itself. Hence, the parcel has close relationships with roads within the block (Figure 1). This paper will investigate PD as a spatial metrics to evaluate the urban form, especially the relationship between the road network morphology and the parcels' direction, namely the parcel

direction.

This paper attempts to analyze the pattern of PD resulted from various types of road networks. For instance, during the new town development or downtown re-development, the building orientation (whether facing south or not) and their relationship with the road network are occasionally changed due to the re-plan of roads' direction and width, together with the parcels' layout. In the common sense, such type of development has its benefit in improving the city's total operating efficiency. If the direction of the road network is altered (Figure 2) instead of being followed, a series of undesired issues would occur, such as increased difficulty to protect ecological resources, increased construction cost, hard to retain well-constructed existing roads, and difficult to keep existing lifelines. Otherwise, the existing property may be divided into several new entities, which increases the difficulty of the urban planning implementation and the cooperation between stakeholder and property owners. Therefore, the direction transition of urban road networks results in almost a complete re-placement of the municipal infrastructure, including the green land system, power system, water supply and drainage system and so on. Hence, evaluating urban form variation using PD has profound significances in planning practices.

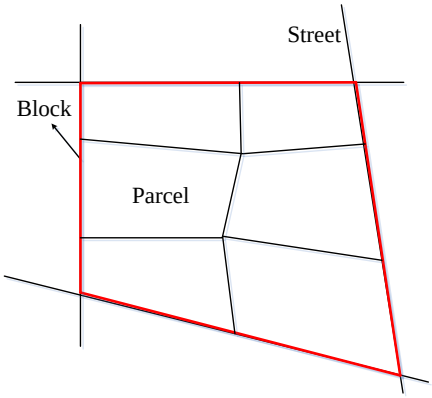


Figure 1. The schematic diagram of the spatial relationship between the road network and parcels

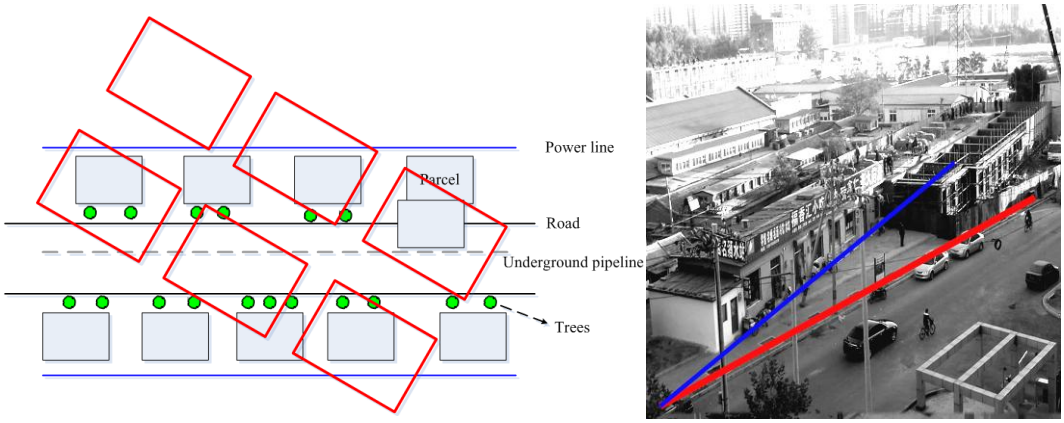


Figure 2. The schematic diagram and the illustrated photo of the changed parcel direction

Note: The slanting parcel in red is the planned layout in the left diagram. The blue line in the right photo is the original parcel direction, and the red line is the already implemented parcel direction determined by the urban plan.

Most of urban form related researches paid attention to the spatial structure analysis without taking PD into account. For instance, the space syntax, as a novel theory for the urban spatial

analysis, is the approach based on the graphic theory (Hiller& Hanson, 1984; Hillier, 1996; Jiang et al., 1999; Jiang et al., 2002), which focuses on the relationship between the urban spatial organization and various aspects of human society through the quantitative description of the human settlement spatial structure. Okabe et al. (2001, 2006a, 2006b) put forward the Spatial Analysis of Network (SANET) as a toolkit to analyze the relationship between convenience stores as points and the streets as a network. SANET proposed the K function and Voronoi polygon based for the network, but the parcel in it is abstracted into a point instead of a polygon. As the developer of ArcGIS, Environmental System Research Institute (ESRI) published Land Parcel Model in 2001, which could assist users managing parcel data as a data model without considering the conception of the parcel direction.

Parcel is the fundamental analysis unit of the urban form. Existing indicators such as area and perimeter mainly focus on its geometric characteristics. For instance, from the geological view, the parcel can be treated as a special polygon consisted by several directed edges. Thus the parcel can be represented by the point sequence and classified into clockwise and anticlockwise types according to the edge direction (Ding et al., 2005; Liu and Wu, 2005). However, it is apparently different from the PD's definition. Maniruzzaman et al. (1994) proposed the compactness indictor for the parcel in GIS, and analyzed the distribution as well as the relationship between compactness indictor and land use types. Xie and Ye (2007) proposed the CTSPA approach to investigate the spatio-temporal dynamics of the urban form. CTSPR analyzes the urban in terms of the amount, shape and size. The parcel direction, however, is not explored in CTSPR. To our knowledge, PD is not yet explored in published literatures.

From the urban planning perspective, the parcel is the urban built-up land, various in size, enclosed by urban street. Meanwhile, the parcel is the basic planning unit in the regulatory detailed planning, which is homogeneous in the planned land use type, the maximum building height, the maximum building density, and the floor area ratio (FAR). The parcel is a basic unit to analyze the urban form, whose attributes include the perimeter, area, edge number, compactness, and so on. Indicators like area are useful in computing FAR and building density in urban planning, and indicators like edge number reflect the parcel geometric form. The parcel direction, as one of significant indicators in the spatio-temporal analysis of the urban form in the parcel level, few researches regarding it has ever been conducted.

Generally speaking, there are no existing literatures considering PD. The conception, computation approach and application of PD will be introduced in the following context. In the second section we will focus on the definition of PD and computation approach using GIS. In the third section, an empirical study will be conducted based on the dataset of the detailed planning of the Beijing Central Metropolitan Area (BCMA), together with the correlation analysis of PD and other parcel indicators. The spatial variation of the indicator will be discussed in the fourth section. The transition between the historical form and the planned form will be evaluated in the fifth section. Finally, we will come to discussions and conclusions, and put forward the preliminary agenda of the parcel direction research in future.

2 Definition and computational approach

The geometry of the parcel is not unified, and usually is quadrangle. As a special type of polygon, the direction of the longest edge is regarded as the parcel direction *D* (Figure 3), which ranges from -90 ° to 90 ° (including -90 ° and 90 °). The degree can represent the deviation from east, that 0 ° denotes east (E), 90 ° north (N), and -90 ° south (S). The detailed calculation method is provided in Formula 1, in which *A* is the vertex of the parcel *P*, *n* is the total number of the vertexes of *P*, *L* is the edge of *P*, *length* is the length calculation function of line segments, and *y* and *x* are the ordinate and abscissa of vertex respectively.

$$P = \{A_1, A_2, ..., A_n\}$$
$$if\ \ i \neq n, L_i = \overrightarrow{A_i A_{i+1}};\ else\ L_i = \overrightarrow{A_n A_0}$$
$$L = \{L_1, L_2, ..., L_n\}$$

$$Len = \{length(L_1), length(L_2), ..., length(L_n),\}$$ **Formula 1**
$$length(L_k) = \max(Len)$$
$$if\ \ x(A_{k+1}) - x(A_k) = 0\ D(P) = 90\ or\ \ -90\ (\text{randomly})$$
$$else\ D(P) = arctg\ \frac{y(A_{k+1}) - y(A_k)}{x(A_{k+1}) - x(A_k)}$$

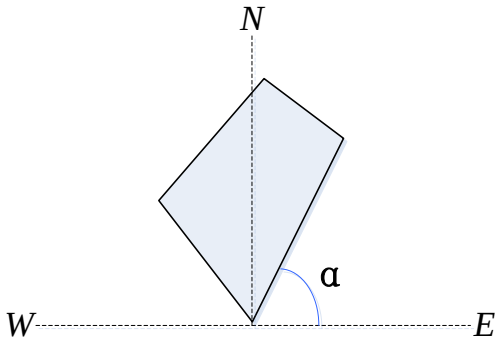


Figure 3. The parcel direction definition diagram

In order to calculate the parcel direction, we adopted Python script language, and developed a toolkit named PARCTION (PARcel direCTION) to calculate the parcel layer based on the GeoProcessing module of ESRI ArcGIS package. The calculation process of PD is as follows:

(1) Convert the polygon parcel layer “Parcel” with the attribute field “ParcelID” as the parcel’s ID into the polyline parcel layer “ParcelLine”, divide polylines using their vertexes, and generate the line segments layer “ParcelLineT” (the layer also has the attribute field of ParcelID, indicating which parcel the segment belongs to).

(2) Analyze “ParcelLineT” based on the field “ParcelID”, identify the longest edge of each parcel, mark it, delete other edges in order to improve the calculation efficiency, and generate the layer “ParcelLineT2”, which records the longest edge of each parcel.

(3) Add X and Y coordination fields respectively for the start point and end point of each

edge in “ParcelLineT2”, add and calculate the field “D” as the parcel’s direction according to Formula 1.

(4) Add the attribute field “D” to the layer “Parcel” standing for the parcel direction, retrieve its value from the field “D” in “ParcelLineT2” matched with “ParcelID”.

Since the parcels’ spatial distribution often changes with time, we chose the raster dataset instead of the vector dataset to facilitate the evaluation of the parcel direction spatio dynamics. The temporal variation D_{ij}^{dt} of the parcel direction can be calculated via Formula 2, in which $P^s{}_k$ indicates the parcel at the start time point, with the total number of *M*, forming the corresponding urban form R^s. $P^e{}_k$ indicates the parcel at the end time point, with the total number of *N*, forming the urban form R^e. *ij* indicates the spatial position. If the variation of the parcel direction is greater than 90 °, it can be denoted by its contra-angle, so the final value of D_{ij}^{dt} is between 0 ° and 90 °(including 0 °and 90 °).

$$R^s = \{P^s{}_k \mid k = 1, M\}$$
$$R^{\mathrm{e}} = \{P^e{}_k \mid k = 1, N\}$$
$$D_{ij}^{dt} = \left| D(R_{ij}^{\ e}) - D(R_{ij}^{\ s}) \right| \qquad \textbf{Formula 2}$$
$$if\ D_{ij}^{dt} > 90 \text{ then } D_{ij}^{dt} = 180 - D_{ij}^{dt}$$

3 Case study at Beijing

3.1 Study area and data

Aiming at the Regulatory Detailed Planning of the BCMA issued in 2006, we computed PD of all the planned parcels based on the definition and calculation method of the parcel direction. There are 24,163 parcels within the study area BCMA, whose area is 923.2 Km^2 not containing the roads areas between parcels. The spatial distribution of the planned parcels is shown in Figure 4, and the statistical description is shown in Table 1, in which $compact = 4 * \pi * \frac{area}{length^2}$.

Figure 4. The planned parcels of the BCMA (Left: the study area; right: the zoomed-in area of the study area)

Table 1. Statistical description table of the planned parcels' attributes

	Minimum value	**Maximum value**	**Mean value**	**Standard deviation**
Perimeter *length*（m）	26	66,534	769.98	1,071
Area *area*（m^2）	10	6,931,627	38,200	142,715
Compact *compact*	.000	1.000	.581	.221

3.2 Calculation results

The PD calculation results are shown in Figure 5. The mean value of PD for all the parcels is -11.33°, and the standard deviation is 55.67°. The histogram of the PD calculation results is in the row line of Table 3. Most of the parcels in the BCMA are with PD value near NS (90° or -90°) or EW (0°). The parcels in other directions tend to be in a uniform distribution, and most of them locate in the fringe areas outside the central part of the BCMA.

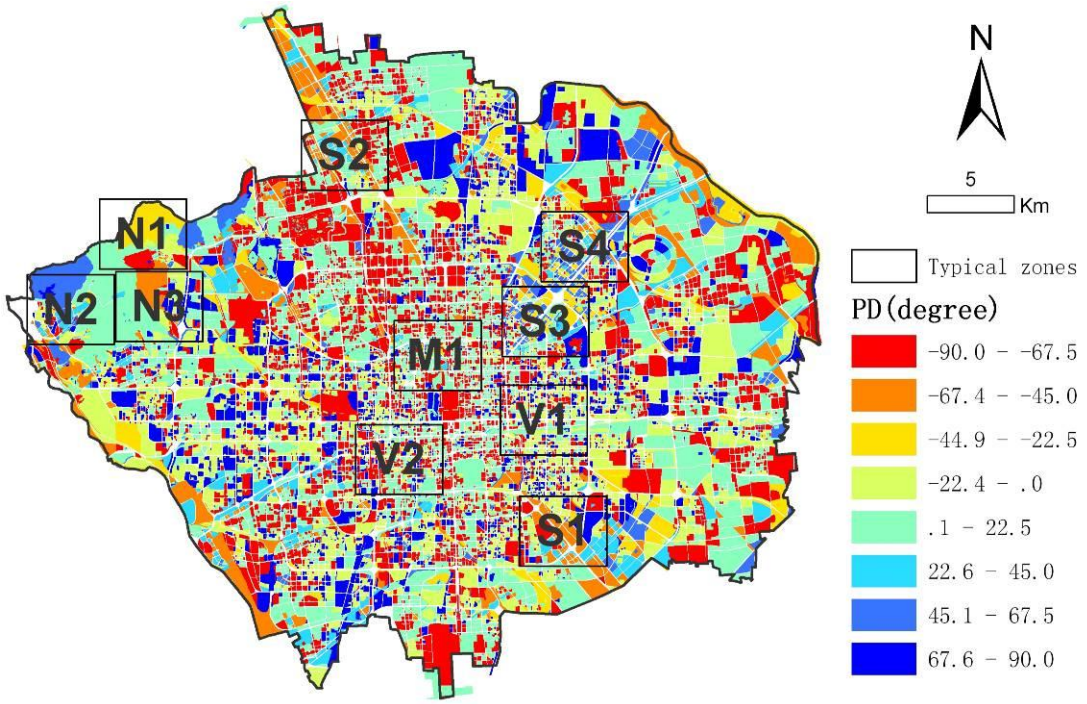


Figure 5. The calculation results of the parcel direction of the planning scheme (the numbers and frames are used in Section 4)

3.3 Correlation analysis of the parcel direction and other indicators

We conducted the correlation analysis of three indicators of the planned parcels, including area, perimeter, compact, and the results are listed in Table 2. The correlation degree of the parcel direction and other indicators is relatively low. Therefore, the parcel direction can be regarded as an independent indicator for the urban form evaluation.

Table 2. Correlation analysis of the planned parcels' indicators

Variable Name		*D*	*compact*	*length*	*area*
D	Pearson Correlation	1	-.023**	.000	.004
	Sig. (2-tailed)		.000	.991	.496
compact	Pearson Correlation	-.023**	1	-.309**	-.069**
	Sig. (2-tailed)	.000		.000	.000
length	Pearson Correlation	.000	-.309**	1	.706**
	Sig. (2-tailed)	.991	.000		.000
area	Pearson Correlation	.004	-.069**	.706**	1
	Sig. (2-tailed)	.496	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

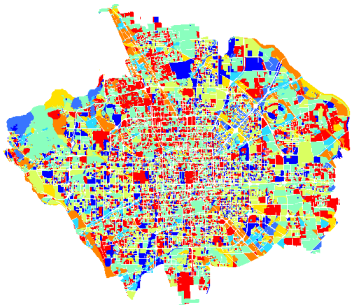
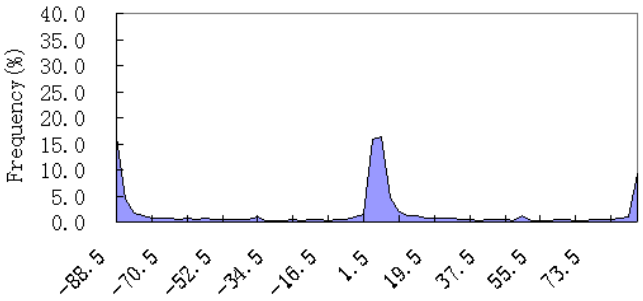
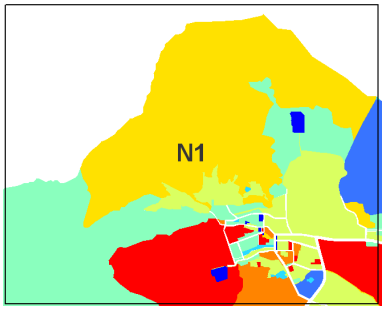
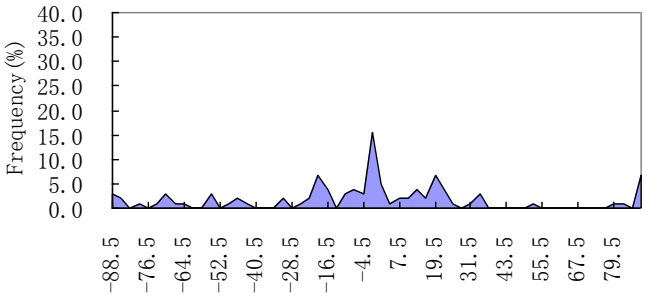
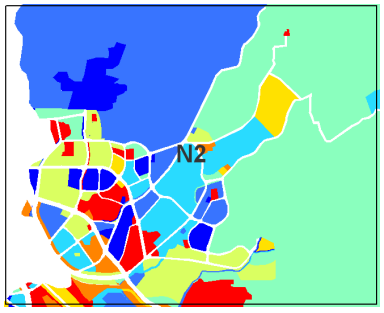
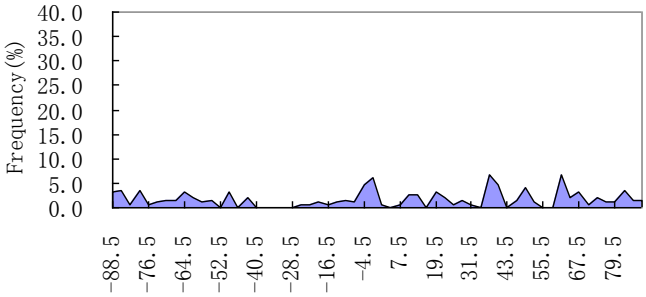
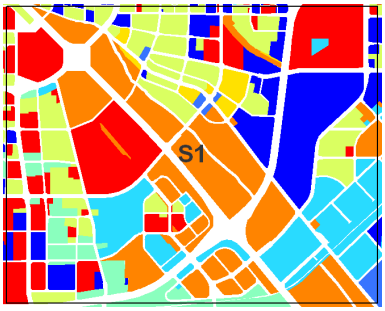
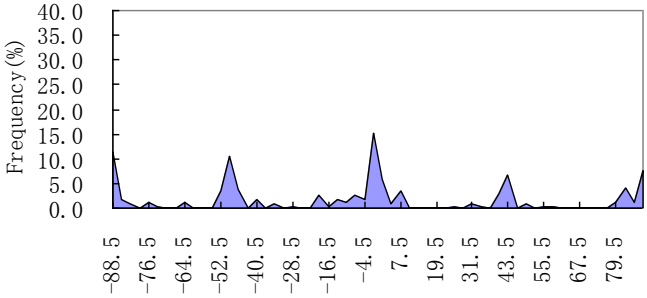
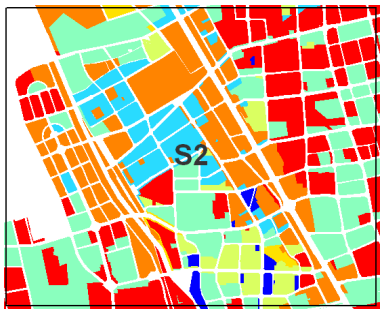
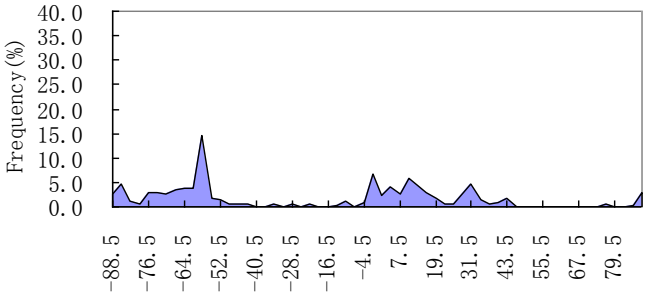
4 Spatial heterogeneity of the parcel direction

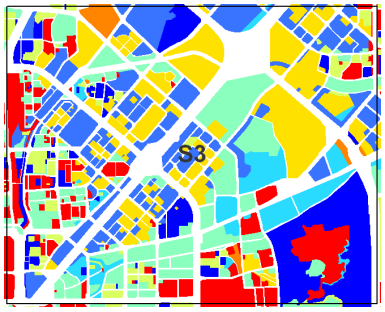
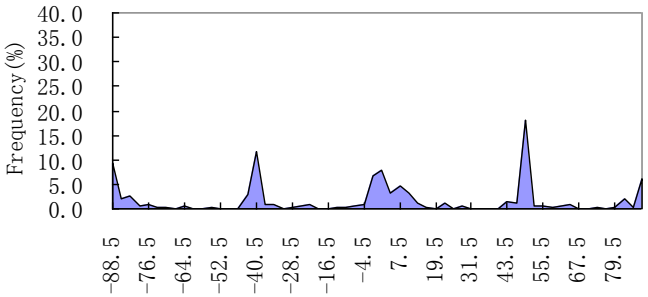
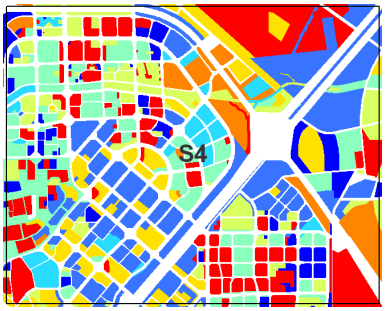
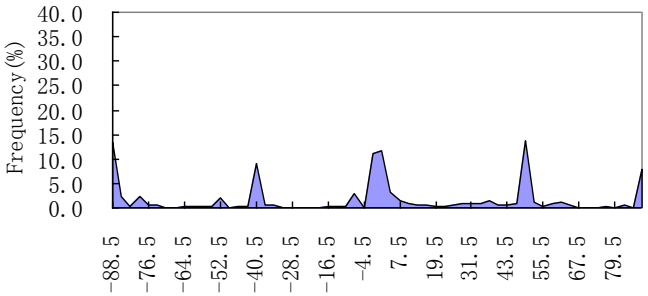
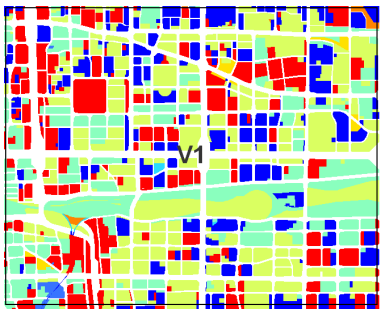
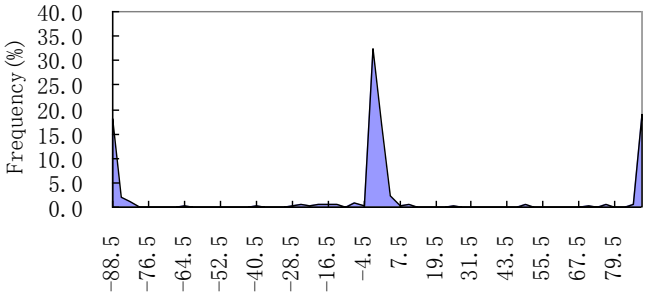
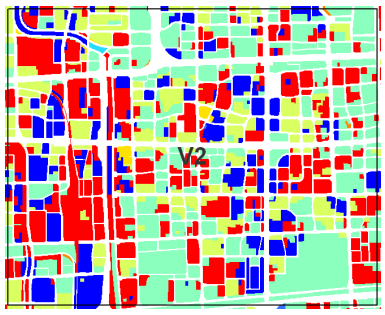
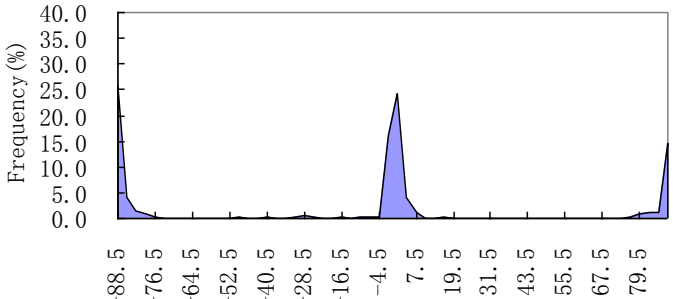
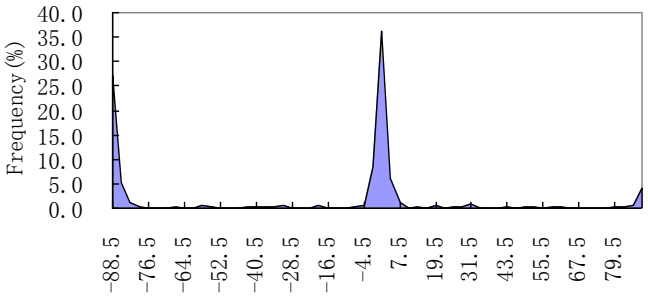
Based on the PD calculation results, there is significantly spatial heterogeneity of PD in the whole study area. Therefore, we should not only evaluate the pattern of PD of the entire region, but also the patterns and their spatial variation in the sub region. According to the morphology of road network as well as the pattern of PD, the whole region can be divided into four types of sub-regions, including natural, oblique, regular, and mixed.

At least one typical sub-region is selected from each type to analyze the spatial heterogeneity of PD (The sub-region IDs are labeled in Figure 5). Natural urban forms (N1 and N2) mainly locate in the western mountains in the study area. Because the land use types of some parcels within these sub-regions are forest or urban green land, the parcels are relatively irregular in shape with low compact indicator value. Oblique urban forms (S1, S2, S3, and S4) are all cut through by urban expressways, and the direction of the adjacent parcels are significantly correlated to the direction of the expressways, such as Wangjing area, Fangzhuang area, and Badaling expressway area (the oblique urban form of Qianmen area is formed owing to the historical reasons). Such radical urban forms in these sub-regions all result from the modern urban planning. Therefore, the oblique form seldom lies in the old city, but mostly in the new built peripheral areas. Regular urban forms (V1 and V2) generally inherit the original gird texture, mostly with PD in the W-E and N-S directions, and the PD variation among the parcels in the regular urban form is relatively low. Mixed urban form (MI) lie in the regions like Shichahai area and Qianmen Oblique Valley, where the oblique and regular urban forms co-exist. The PD variation among the parcels in the mixed urban form is relatively high.

All the analyzed sub-regions with various types of urban form together with their spatial distribution and the PD histogram are shown in Table 3. The PD histograms of each sub-region significantly differ from each other as well as the whole region. Therefore, the parcels in each sub-region can be regarded as the independent sample. Suppose that there is no significant difference among the four types of independent urban forms (the hypothesis H_0), and use Kruskal-Wallis H test to check the hypothesis. The approximate significant level of the hypothesis check is 0.000, which is less than 0.05, and the original hypothesis is then refused. Therefore, there is statistical significance in the PD variation among the four types of urban forms. As a result, the parcel direction can be adopted to evaluate the urban form. Besides, the similarity of the urban forms of the sub-region and whole region can be evaluated through the comparison between the PD distribution in the sub-region and whole region. If the similarity is relatively higher, the whole region can be perceived through the sub-region. That is to say, the sub-region is representative of the whole region. In addition, the mean value and variance of PD in one region can be adopted to represent the diversity of PD.

Table 3. Comparisons of urban forms in various typical areas

Type	ID	Spatial Distribution	PD Histogram
The whole study area			
Natural urban form	N1		
	N2		
Oblique urban form	S1		
	S2		

Type	ID	Spatial Distribution	PD Histogram
	S3		
	S4		
Regular urban form	V1		
	V2		
Mixed urban form	M1		

Note: the color of parcels in the maps corresponds to the color classification in Figure 5.

5 Temporal heterogeneity of the parcel direction

5.1 The calculation of the parcel direction for the historical form

In order to analyze the temporal dynamics of the planned urban from and historical urban form in terms of the parcel direction, we primarily identified and analyzed the historical urban form of Beijing, and calculated PD using the Beijing historical map of 1947[1] as shown in Figure 6 (the extent of this map does not equal to the planned extent due to limited dataset resources). However, most areas in the map are not urban built-up in 1947, so we treated the polygons divided by road networks as parcels. Based on the historical map, the urban form in 1947 appeared the triangular mesh structure instead of the regular road networks in W-E and N-S directions. The orientation of settlements did not follow the direction of the road network, mainly because settlements were small in scale, and the road between settlements is usually the straight line.

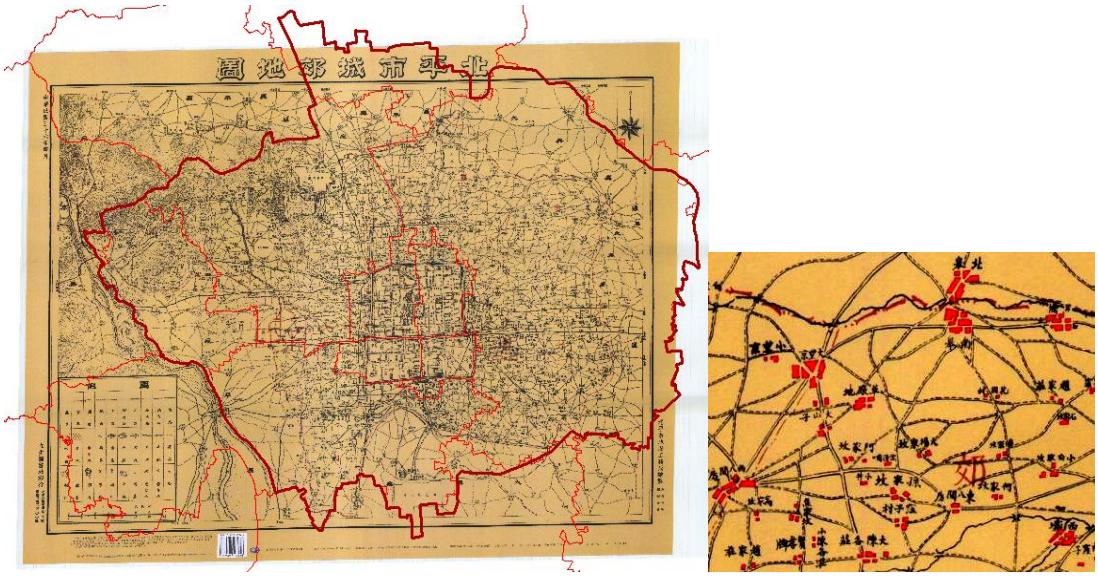


Figure 6. The historical map of Beijing and its partial zone in 1947 (The thick red line is the BCMA, and the thin red line is the district-level administrative divisions. Source: Engineering Department of Peiping Municipal Government, 2007)

The PD calculation results are shown in Figure 7, after the above historical map is digitalized into the parcel dataset with the vector format. The historical parcels were more irregular than the planned parcels.

5.2 The comparison of the parcel direction of the planned and historical forms

In order to compare the parcel direction of the historical urban form (1947) and the planned urban form (aimed to be realized in 2020), the two parcel layers were converted to raster format. Due to the difference of the spatial extent between the historical and planned urban forms, the intersection of the two urban forms was determined to be the comparative analysis spatial extent (the non-white area in Figure 8, with the total area of 976.2 km^2). The comparison result of the parcel

direction for the two urban forms is shown in Figure 8. The mean value of changed PD is 38.20°, and the standard deviation is 30.16°. In general, parcels with changed PD value of near 0° or 90° are relatively more.

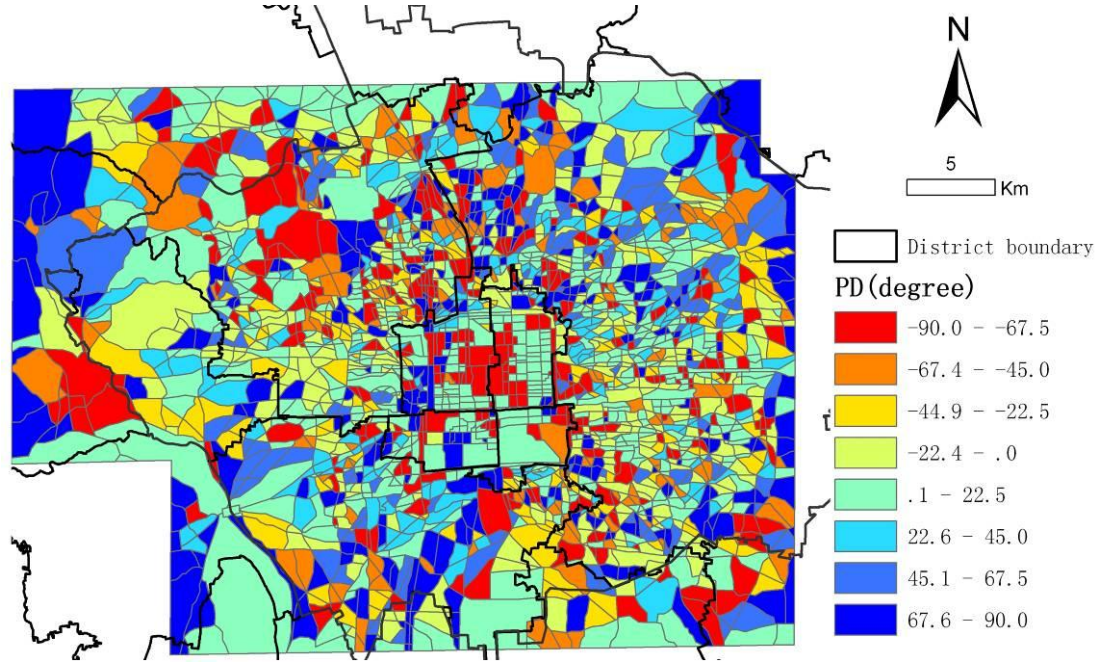


Figure 7. The parcel direction calculation results of the urban form in 1947

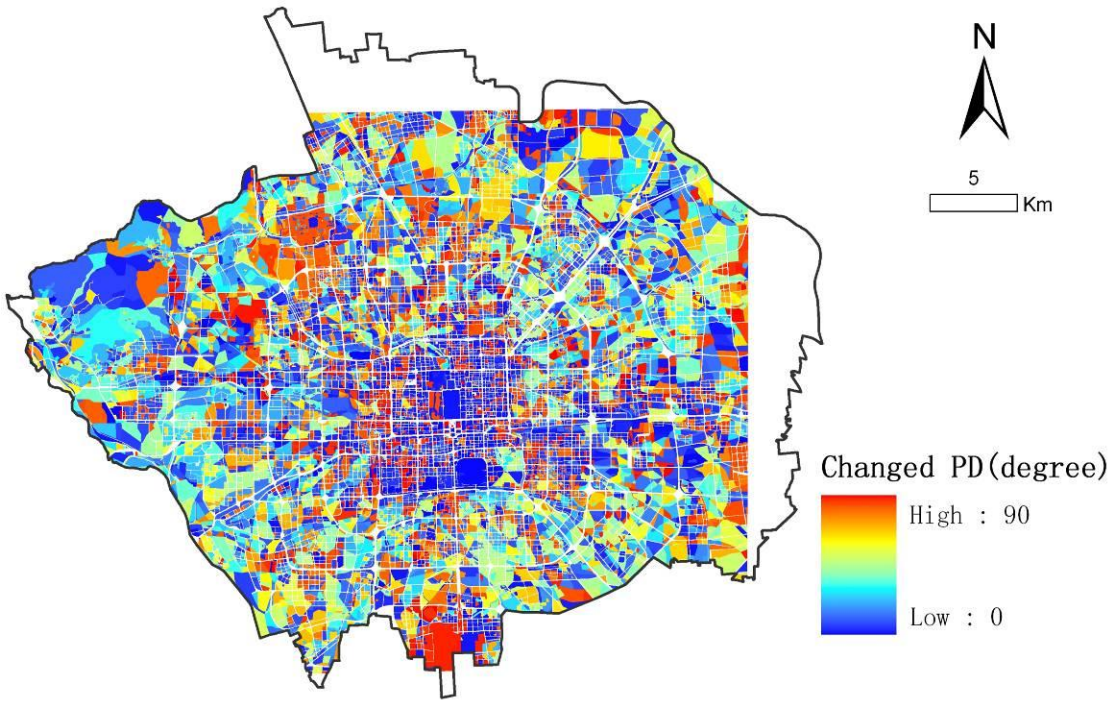


Figure 8. The comparison map of the planned and historical urban forms

Considering that the parcel direction in Beijing is relatively regular and mostly in W-E or S-N direction, if the changed PD is between 30° and 60°, it can be assumed that there is variation in the parcel direction. Then the historical and planned parcels can be considered inconsistent (namely reversed). According to this definition, the PD reversed parcels are shown in Figure 9, with the

total area of 185.6 km^2 (accounted for 19.0% of the whole analysis area). Based on the comparison result of the parcel direction, the parcels with reversed PD mainly locate in historical remaining areas, ecological land use areas, and the newly constructed express way adjacent areas.

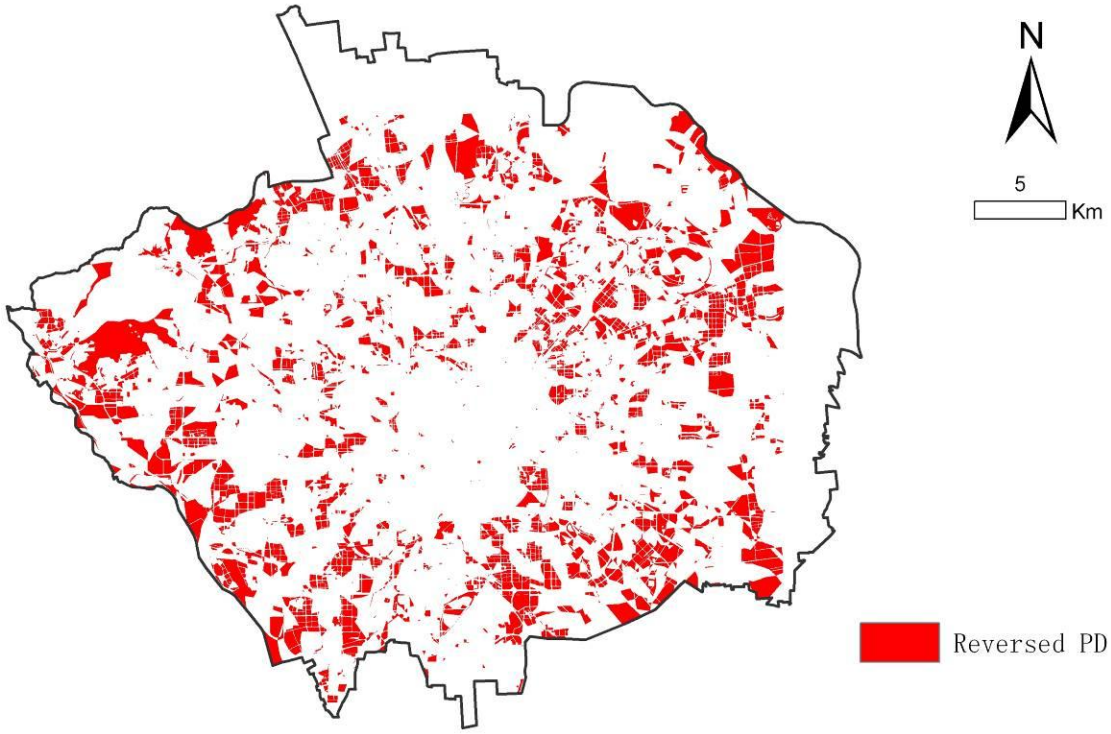


Figure 9. The parcels with the reversed parcel direction

In view of the phenomenon of the PD reversed parcels, during the compilation of the urban plan, transport planners generally adhere to the form of intersecting the direction of the oblique highways vertically, because it is in accordance with the existing relevant design specifications. However, this process is lack of flexibility. The triangle area forms, which are denounced by transport planners, can be treated flexibly through modifying the original design scheme, such as delimitating some trapezoidal parcels to solve the problem of oblique intersections, which is quite common in existing old districts, but extremely rare in new districts.

6 Conclusions

In this paper we brought forward the indicator definition of the parcel direction, which was analyzed in both of the spatial dimension and temporal dimension. The conclusions are as follows: (1) In terms of the parcel direction, the urban form of the Beijing Central Metropolitan Area can be divided into the normal, oblique, mixed, and natural types. (2) The parcel direction is not significantly correlated with the perimeter, area, or compactness indicators of the parcel. (3) The parcel direction is explicitly heterogeneous in space, and the parcel direction in the sub-region of the BCMA varies from each other as well as the entire BCMA. Therefore, the probability density function of the parcel direction can be used to evaluate the urban form. (4) The parcel direction can be used to evaluate to what extent the planning form inherits from the historical urban form, and has the potential to be adopted in the quantitative evaluation of the urban planning scheme.

The parcel direction is considered as a new indicator for the description of the urban form, and plays a significant role in the analysis of the influence of the road network urban form on the adjacent parcels. If in urban planning practices, the urban planners consider not only the indicators like the parcel area and compactness, but also the parcel direction, the economic and ecological influences of the planned road networks can be quantitatively evaluated to promote the more sustainable planning scheme. Although this paper brought forward the definition, the calculation method and the empirical analysis of the parcel direction, it still lacks of relevant in-deep findings in theory, and the theoretical characteristics of the parcel direction should be analyzed from the perspective of data mining in the near future to promote the indicator's further and wider applications.

References

[1] Asami, Y., Kubat, A.S., and Istek, C. 2001. Characterization of the street networks in the traditional Turkish urban form [J]. Environment and Planning B: Planning and Design, 28(5), 777-795.

[2] Ding, J., Jiang, N., and Rui, T. 2005. Orientation, Convexity-Concavity and Inclusion Query Algorithms for Polygons Using the Edge-Azimuth-Length Concept [J]. Journal of Computer-aided Design & Computer Graphics, 17(6), 1233-1239. (*in Chinese*)

[3] Engineering Department of Peiping Municipal Government. 2007. Beijing suburb map [M]. Beijing: Chinese Map Press. (*in Chinese*)

[4] Hiller, B, and Hanson. 1984. The Social Logic of Space [M]. Cambridge: Cambridge University Press.

[5] Hiller, B. 1996. Space is the machine [M]. Cambridge: Cambridge University Press.

[6] Http://support.esri.com/index.cfm?fa=downloads.dataModels.filteredGateway&dmid=11 (accessed on 2009-6-29)

[7] Jiang, B., and Claramunt, C. 2002. Integration of space syntax into GIS: new perspectives for urban morphology [J]. Transactions in GIS, Blackwell Publishers, 6(3), 295-309.

[8] Liu, X., and Wu, L. 2005. A Rapid Identification for the Orientation and Vertices Convexity-Concavity of Simple Polygon [J]. Journal of Engineering Graphics, 4, 124-129. (*in Chinese*)

[9] Maniruzzaman, K.M., Asami, Y., and Okabe, A. 1994. Land use and the geometry of parcels in Setagaya Ward, Tokyo [J]. Theory and Application of GIS, 2(1), 83-90.

[10] Okabe, A., and Yamada, I. 2001. The K-function method on a network and its computational implementation [J]. Geographical Analysis, 33(3), 271-290.

[11] Okabe, A., and Satoh, T. 2006a. Uniform network transformation for points pattern analysis on a non-uniform network [J]. Journal of Geographical Systems, 8, 25-37.

[12] Okabe, A., Okunuki, K., and Shiode, S. 2006b. The SANET Toolbox: New Methods for Network Spatial Analysis [J]. Transactions in GIS, 10(4), 535-550.

[13] Xie, Y., and Ye, X. 2007. Comparative tempo-spatial pattern analysis: CTSPA [J]. International Journal of Geographical Information Science, 21(1), 49-69.