Analysis of the Spatial Structure of Beijing from the point view of Weibo Data

Liya Yang [1] | Carlos Marmolejo Duarte [2]

Abstract

Beijing as the second largest city in China has a controversial urban structure. Traditional methods usually identify the urban structure of cities by analyzing the employment distribution. This research studies the temporal-spatial structure of Beijing metropolitan area in terms of social media activities. It proposes to utilize Weibo (the Chinese equivalent of Twitter) density to describe the citizens' activities in Beijing in one week and adopt the classic exponential model to identify Weibo sub-centers. It detects sub-centers in different time periods and compares them with the actual urban land uses. Moreover, the studied area extends to the "peripheral districts" of Beijing, thus it assesses the developmental situation of the whole Beijing area. The results indicate that the structure of Beijing indeed shows a polycentric structure according to the distribution of potential Weibo sub-centers, though the only clear spatial structure of Weibo distribution is confirmed by the model is the period of the weekend. These Weibo sub-centers of weekend are the airport, commercial areas, tourist attractions, universities, and mixed-activity areas, which have intense flows of human activities. Weibo data is proved to be a useful data source to study the urban structure and urban functional areas.

Citation

[1] PhD Candidate, Universitat Politècnica de Catalunya, Barcelona's School of Architecture (ETSAB), Centre for Land Policy and Valuations, Barcelona, Spain. (ORCID ID: 0000-0002-0247-2701); [2] Associate Professor, Universitat Politècnica de Catalunya, Barcelona's School of Architecture (ETSAB), Centre for Land Policy and Valuations, Barcelona, Spain. (ORCID ID: 0000-0001-7051-7337, WoS Researcher ID: D-9162-2016, Scopus Author ID: 35178192000). Contact e-mail: li.ya.yang@upc.edu

1. Introduction

The urban structure has long been one of the essential topics in urban geography and planning (Marmolejo-Duarte, et al.2016). Traditional methods mostly utilized official demographic census (Marmolejo-Duarte, *et al.,* 2013) or land-use data to analyse the urban structure. However, these indicators are insufficient to capture the dynamics and complexity of urban systems. They only considered employment and residential activities (De Ureña *et al.,* 2013). However, all the other activities that people carry out outside the workplace or home are frequently ignored (Marmolejo-Duarte & Cerda-Troncoso, 2012).

Nowadays, thanks to the development of geo-technologies, a novel channel that shows the changes and operational mechanisms of urban society is opened. The data generated by the Internet or GPS-tracking can capture the detailed individual activities within cities. Since 2009, the explosion of social media around the world, such as Twitter and Facebook, prompted academic studies based on social media. Despite the ability of social media could break through the limitation of physical distance to some degree, it retains a strong relationship with physical, cultural, and linguistic boundaries (Stephens et al. 2013). Therefore, social media data is a new data source to study the urban structure. For example, Green (2007) discussed the urban structure in terms of the functional perspective, which is based on social network analysis.

Therefore, this paper tries to detect the temporal-spatial structure of the Beijing metropolitan area via Weibo data. Weibo is one of the most popular social media platforms in China where western social media such as Twitter is not used due to censorship. Weibos' function is similar to Twitter which allows users to exchange news or information. According to its earnings report in 2015, the daily active users of Weibo reached 106 million persons in China mainland. In addition, because of the issue of transparency, it is not easy to get the related data to follow the traditional methods for identifying the sub-centers of Beijing, such as data of localized employment and detailed land-uses. Therefore, using the data of daily activities is a way to overcome such data limitations.

This paper choses Beijing as the study area, because it is a very typical megacity that faces many tough challenges and the reform of urban structure. Beijing was one of the top 10 biggest world cities in 2015[1]. The urban scale has been expanded 12 times in 55 years. The total area of modern Beijing has reached to 16,410.54 km2, which consists of 16 administrative districts. Such rapid urban expansion brought heavy pollution and terrible traffic congestion to the city. Although the Beijing government stressed the reconstruction of urban structure through building sub-centers, the model of urban expansion still like ripples which diffused from the downtown. Whether such planed sub-centers effectively affect the urban structure of Bringing deserves to be explored from a broader perspective as it is analysed in this paper. Moreover, the urbanization of Beijing has aroused attention from researchers and officials since many years ago. However, their investigation mainly focused on the urban area within the six districts in the central region, rather than the whole Beijing area. In addition, a few of them introduced social media data to investigate the urban structure of the city.

Therefore, this study prepares to combine urban contexture with Weibo data to detect the sub-centers of Beijing. The studied area extends to "peripheral districts" of Beijing, thus we could evaluate the developmental situation of the whole Beijing area. The part of the literature review summarizes pioneer urban researches that cooperate with the time-geography framework and Weibo data. A brief retrospection on the urban structure of Beijing is offered in the third part. The fourth section introduces the exponential model to identify Weibo sub-centers in terms of different periods of a week. The only clear spatial structure of Weibo distribution is confirmed by the model is the period of the weekend. However, the urban structure of Beijing indeed shows a polycentric structure

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[1] Source: City metric, http://www.citymetric.com/skylines/where-are-largest-cities-world-1051

according to the distribution of potential Weibo sub-centers, though the high-density clusters of Weibo activities mainly gathered in the northern area of Beijing. Despite its inherent limitations, Weibo data successfully identify sub-centers that are not considered by the traditional methods of identification of urban structure, such as university and recreational places.

2. Literature review

2.1 *Time-geography framework and the geo-located data*

The Swedish geographer Torsten Hägerstrand brought up the concept of time-geography in the 1960s which observes the world from a four-dimensional view – two-dimensional matter, space and time. Time-geography considers that human being has temporal and spatial attributes. These two features could be separated and reflect the relationship between individual activities and their surroundings. Hence, the city can be seen as a network of human activities and places. In the early phase, the theory of time geography was mainly applied to empirical studies in small scales, due to the limitation of data collection. For example, the PESASP program led by Bo Lenntorp designed an accessibility model for Karlstad's traffic planning in Sweden (Thrift, 1977). In the 1980s, Allan Pred (1984) began to introduce time geography into the macro-scale of human society, combined with the theory of structuration to explain the relationship between individual activities and social reproduction. In recent years, with the development of technologies, geo-visualization and geo-simulation can be realized in multiple spatial scales, and the precision of tracking location has improved substantially. The applications of time geography have expanded to many fields, such as urban transportation, land use and spatial patterns of specific groups, etc.

In the sphere of urban function study, Yuan et al. (2012) combined POIs (place of interests) datasets of Beijing and two 3-month data of GPS-tracking to identify urban regions of different functions. Qi et al. (2011) analyzed the functional regions of Hangzhou based on Taxi GPS data. This latter research identified three types of regions: train stations, recreational districts, and scenic spots. Yang & Marmolejo-Duarte (2019) extracted the travel traces of Foursquare users to study the functional interrelationship between different urban places.

In the sphere of land use, researchers used mobile positioning data and POIs to classify the vacant housing area of cities in China (Chi, *et al.,* 2015). They identified the vacant housing area based on GPS data which could indicate the patterns of human mobility in a span of 9 months. Liu *et al.* (2012) explored intra-urban land uses in Shanghai from seven-day taxi trajectory data. They borrowed the ecological concept of "source-sink" to characterize the daily travel patterns. According to the Taxi GPS data, a traffic source area is defined as the one having more pick-ups than drop-offs, in other words, there is a net traffic outflow. A traffic sink area is the inverse. Different land uses were associated with different travel patterns. For example, a source-sink area was defined as an area that was a source area in the morning and a sink area in the evening. Therefore, the residential area tended to be associate with the source-sink area.

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In the sphere of the spatiotemporal structure of urban space, Marmolejo-Duarte & Cerda-Troncoso (2020) used the density of people's daily activities using origin/destination travel data to identify the sub-centers in the Metropolitan Region of Barcelona. *The Livehoods Project* (Cranshaw, *et al.,* 2012) utilized Foursquare data to identify characteristics of residents' activities in different areas of Pittsburgh in the United States. Jiang *et al.* (2012) studied the urban spatial-temporal structure through an open resource --"Travel Tracker Survey" conducted by the Chicago Metropolitan Agency for Planning in 2008. They aggregated individuals' activity patterns and proved that the daily routines of citizens could be greatly detected and predicted

2.2   *Previous studies of the Beijing urban structure*

Since the end of the 1990s, the urbanization issues of Beijing city have drawn much attention from researchers. Many studies investigated the Beijing metropolitan area from various perspectives and methods. Besides the traditionally documental study (Ai, et al. 2008), remote sensing and GIS have become the prevalent techniques to analyse the urban structure and land use of Beijing (Wu et al. 2006; Xie et al. 2007; Kuang, 2012). The conclusion of these coincides in suggesting that urban sprawl mainly eroded areas of cropland around Beijing. Another important approach is to utilize census data to investigate the social-spatial structure of the city. Feng and Zhou (2003) utilized the second and the fifth Chinese national census in 1982 and in 2000 to compare the changes of the social-spatial structure of Beijing. Huang et al. (2015) used companies registered data to investigate the potential employment sub-centers in Beijing. Interestingly, the former stated that the social-spatial structure of Beijing already shows some characteristics of the polycentric model, but Huang's study showed that the city was still monocentric.

In recent years, "Big Data" has also involved in studies of Beijing city. Beijing City Lab launched a project—SinoGrid to collect various aspects of city life based on 1 km2 fishnet. Long et al. (2013) combined remoting images, POIs data, and Weibo check-in data to explore the degree of mixed land-use in Beijing. They concluded that land-use mixing is higher in the central areas of the city than the peripherical ones. Microsoft Research utilized taxi data combined with POIs to discover the functional regions in Beijing (Yuan, et al. 2012). After comparing with the actual urban contexture, they concluded that the POIs and mobility patterns could be a powerful tool to identify the land uses of a city. Wang et al. (2016) identified seven types of land use clusters in Beijing using Weibo and POIs data. They divided the Beijing area into cells with 0.4 km2 and cluster these cells using the hourly frequency of Weibo on each cell. Based on the temporal active trend of the cluster, they estimated the type of land use and verified it by mining the contents of these Weibos. In summary, the urban structure of Beijing has been explored by various perspectives and technics. However, these studied primarily focus on the land-uses or urban functions, rather than the urban structure. Therefore, our research aims to investigate the urban structure of Beijing based on Weibo activities for filling the gap.

3. Brief evolution of the urban structure of Beijing

Beijing is the second-largest city in China, also the political, cultural and technological innovation center of China. The current Beijing consists of 16 districts and more than 20 million permanent residents. Meanwhile, according to the Beijing City Master Plan 2004, the functional structure of Beijing city consists of the capital core zone, the expanded functional zone, the new developing zone and the ecological conservation zone (Figure 1).

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The capital core zone includes Dongcheng and Xicheng district, which is the national political center. The expanded functional zone undertakes the largest proportion of employment and urban services. The new developing zone is the region for future urban development, as well as the agricultural basement. The ecological conservation zone accounts for 53.3% of the total area of Beijing, which aims to preserve the water resources and the ecological environment.

The modern urban structure of Beijing basically inherits the structure of the Qing Dynasty – centered on the Forbidden City, organized on the north-south axis. In 1949, at the beginning of the People's Republic of China, Beijing was just a city where had 1.65 million people. In 1953, the Beijing government brought up *Key Points of Draft Plan for Reconstructing and Expanding Beijing*. Based on the plan, urban expansion followed a monocentric model based on four concentric ring roads and several radial ones. However, the heavy industrial pollution in the late 1970s urged the government to change the urban plan. In 1983, the Beijing government published the *Master Plan of Beijing Urban Construction*. Since then, the southern part of Beijing has gradually declined, due to the removal of heavy industrial factories. On the contrary, the northern part of the city, especially Zhongguancun, has been developed rapidly, because several famous universities were located in this area, such as Tsinghua University and Peking University.

Figure 1. **The functional zones of Beijing according to the 2004 City Master Plan**
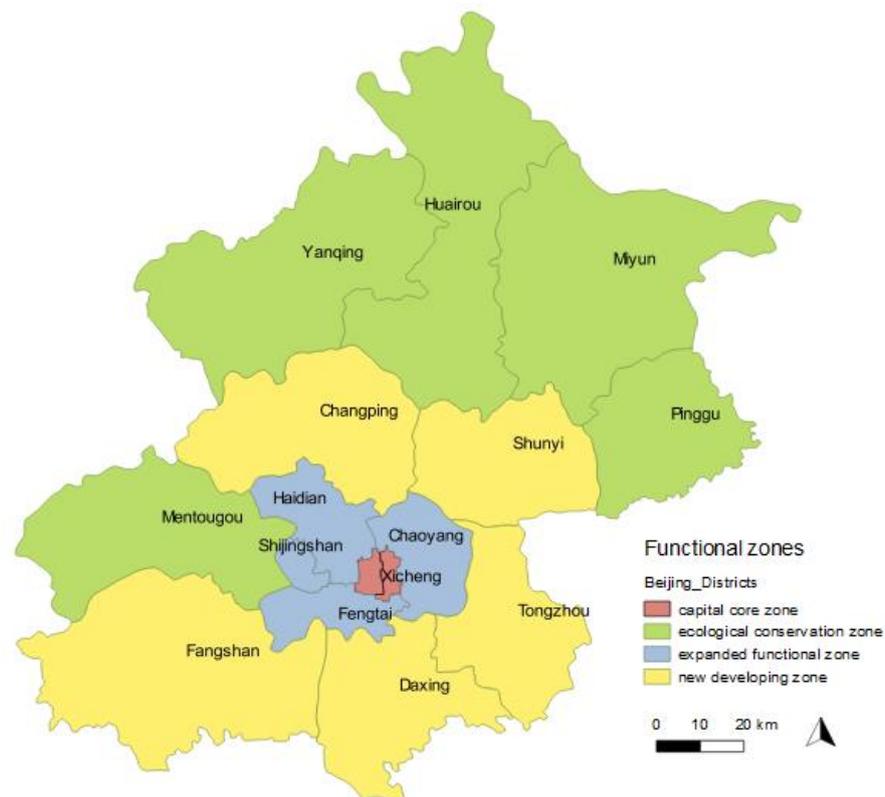

Source: self-elaboration

Ten years later, the *Beijing Master Plan (1991—2010)* emphasized the importance of controlling the scale of the central city. It planned to reconstruct the urban structure from monocentric mode to "dispersed clusters". Beijing government prepared to build 10 satellite cities to disperse the population. After the new millennium, the model of dispersed clusters indeed helped to disperse the population in the downtown to some degree, whereas the population was soaring in the surrounding areas. The

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Beijing government decided to reform the urban structure in 2001. The monocentric model was replaced by a multi-centric development scheme. The layout of *Beijing City Master Plan 2004* was "Two Axes – Two Belts – Multi-centers" (Figure 2). "Two axes" refers to the traditional north-south axis and the horizontal line along with Chang'an Street, which aims to protect the traditional spatial structure and its cultural values. "Two-belts" divides Beijing city into an eastern development belt and western environmental belt. "Multi-centers" plans to build several functional centers that could adapt to the requirements of globalization, for example, Zhongguancun Science Park, GuoMao CBD, Olympic center, etc. It planned to build 11 new cities to disperse the population.

Figure 2. **The layout of Beijing Master Plan 2004**

(a)   (b)
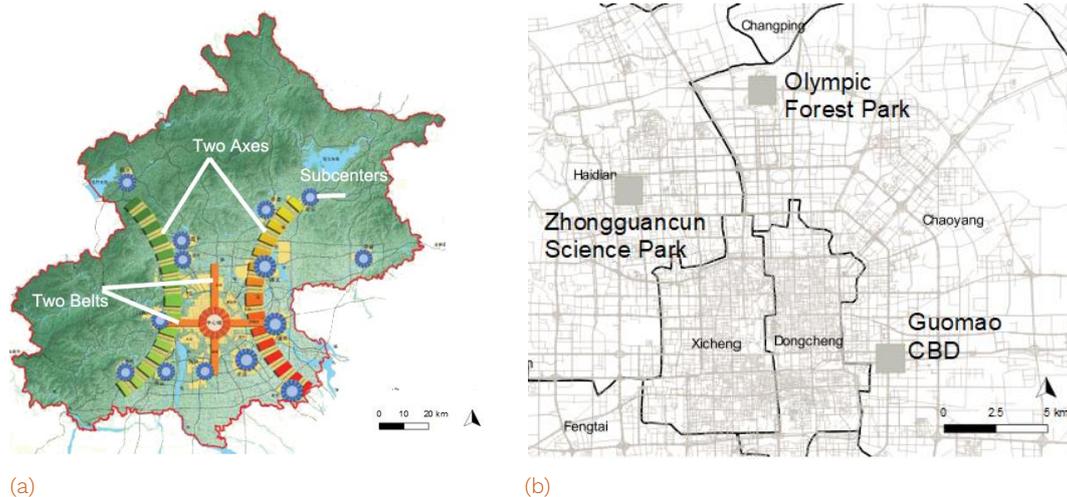
Source: (a)Beijing Master Plan, 2004; (b) self-elaboration

In 2016, according to the *Beijing Municipal Commission of Urban Planning*, the urban structure of Beijing will be transformed into "one central city, one deputy city, two-axes and multi-sub-centers". The deputy city undertook part of the administrative function of Beijing.

In summary, as the speed of urban expansion of Beijing is so fast the controversy of the urban structure of Beijing remains, this paper using Weibo data to detect the sub-centers can provide a new sight to analyze the urban structure of the city. Moreover, because the data coverage covers New developing zones and ecological zones, it can evaluate the developmental situation of the whole Beijing area.

4. Methodology

4.1 Research design

We calculated the cumulative density of Weibo-messages in Beijing to identify Weibo sub-centers. Meanwhile, a comparative study will help us to identify the function of the sub-center. Because it is hard to obtain the latest official document of cadastral information and land use, we made a direct comparison with Google map and Baidu map which is the most popular electronic map in mainland China. The current version map can help us to observe the latest status of land-uses. The third step was to analyze the frequency of Weibo messages in terms of different time periods. Based on the results, this paper built a regression model to distinguish the Weibo sub-centers during the week,

workdays and weekends, then make an urban contexture analysis of Beijing city. It tried to discuss in which degree Weibo data could reflect the urban tissue, and the type of land uses of these sub-centers.

4.2   Data collection

Weibo is one of the most popular social media in China, whose functions are similar to Twitter. A user can post words, pictures, mention or talk to other people via this platform. Every message sent by a user is called a "Weibo". Users can create a "nickname" for their Weibo accounts, but all users should register with true identities.

The total users of Weibo are over 500 million in China. According to *Weibo Development Report 2014*, the main users were among 19-35 years old, accounted for 72% for total users. The monthly active users have reached 167 million, the whole Beijing area took up 8.7% of them. Considering the total population was 21.52 million in 2014, it suggests that half of the people in Beijing use Weibo time to time. Therefore, it is reasonable to utilize Weibo data to explore the urban space of the Beijing area.

The API (Application Programming Interface) is a set of routines, protocols, and tools for building software applications. It allows developers and researchers to access the database of an electronic platform. Many popular websites, such as Twitter and Facebook, provide free APIs for the public. Weibo API also provides free resources for researchers, though there are many restrictions. For instance, the maximum number of inquiring data is 1,000 times per day, and one inquiry only can get 2,000 messages. Despite the restrictions, Weibo API offers various open ports of data to researchers: Weibos per user, user's basic information, network relationship of accounts, geographic information, etc. Therefore, we could get a lot of useful information about citizens through Weibo API, especially the port of geo-information allows researchers to explore the dynamic activities in a city.

Figure 3. **Monitoring points and its range**

District	Latitude	Longitude	Monitor-Radius(km)	Monitoring Areas(km2)
Districts of Dongcheng and Xicheng	39.915974	116.385956	4.31	58.359
Chaoyang1	39.910231	116.526678	7.63	182.894
Chaoyang2	40.024454	116.473704	7.55	179.079
Haidian1	39.996334	116.27558	7.56	179.553
Haidian2	40.089426	116.151917	3.6	40.715
Shijingshan	39.919546	116.205842	4	50.265
Tongzhou1	39.914332	116.704191	6	113.097
tongzhou2	39.76988	116.73304	10	314.159
Changping	40.15804	116.355207	10.5	346.361
Shunyi (airport included)	40.114097	116.662694	11	380.133
Daxing	39.696295	116.402051	11	380.133
Fengtai1	39.835938	116.373859	3	28.274
Fengtai2	39.852911	116.282106	4	50.265
Miyun	40.403709	116.866321	10	314.159
Fangshan	39.676711	116.090903	11	380.133
Mentougou	39.964773	115.977905	11	380.133
Pinggu	40.175009	117.121087	11	380.133
Huairou	40.332106	116.633393	7.5	176.715
Yanqing	40.459453	115.97512	11	380.133
Total monitoring areas				4314.692

(a) List of monitoring points

(b) Schematic diagram of the monitoring range

Source: own elaboration

In this study, we utilized the access port of "nearby Weibo" to collect data, which supported to record data around a "monitoring point" (the maximum radius is 11 km). The port can track those Weibo messages that users agreed to share their immediate geo-location. The message flow included the original posts and forwarded messages in the monitoring area by chronological order. Because of the limitation of accessing the port per day, it is impossible to cover all areas. We set 19 central points to monitor the data (Figure 3), considering the technical limitations of the application and the current

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situation of build-up areas. After the pre-test of data collection in March and April of 2016, we decided to deliver more tracking frequency and scale to those areas where have had a higher volume of data. Each monitoring circle was restricted in one district and was avoid overlap. We tried to cover the central areas as much as possible. For the outer-districts, such as Huairou, Pinggu, Miyun and the others, the monitoring center-point was set in their central town. The measure of monitor-radius is accomplished by Google Maps' tool which can measure the distance between two points on the map.

The temporal range of data is from 00:00 on the 11th of April to 24:00 on the 17th of April. This time-period avoided vacations and festivals of China, thus it could represent the normal situation of Beijing city. After eliminating null data, the total Weibos of the study were 53,967. Three districts appeared data loss in some periods. The amount of Weibo in Haidian district has fallen suddenly on Wednesday due to the data lost from 17:07 of Wednesday to 3:00 on Thursday. Shunyi lost data from 17:52 on Saturday to 16:52 on Sunday. Fengtai lost 16 hours' data from Wednesday to Thursday. However, this loss of data would not affect the analysis greatly, because Shunyi and Fenngtai district generated fewer Weibos in the pre-test, which were below than 15 Weibos per hour. Although Haidian district had a higher frequency, it only lost 10 hours' data. In order to compensate for the loss, the hourly frequency of Weibo of each of the three districts was filled in the lost hours separately.

4.3   Quadrat analysis

In order to identify the Weibo sub-centers, it is necessary to divide the city into equal zones to calculate the density of Weibos. Considering that the urban shape of Beijing city is squared and composed of orthogonal roads (Figure 4), it is reasonable to adopt quadrats to calculate the Weibo density.

Figure 4. **Detail of Beijing urban tissue**

(a) the urban shape of Beijing within the 5th belt   (b) A piece of the urban tissue of Beijing

Source: own elaboration

The more points gathered in a quadrat; the higher the density of the quadrat. Therefore, the size of the grid plays a pivotal role in the analysis. McDonald *et al.* (1994) used 1.29 km² of a grid as their research unit in Chicago. Giuliano *et al.* (1991) used 'transportation analysis zones' which is defined by the California Association of Government (SCAG). The average area of analysis zone is about 8 km². McMillen *et al.* (2003) used a quarter square mile (about 0.65 km²) as the basic unit of observation in Chicago, because the small unit can find out those low-density regions in the midst of high-density areas. Our unit of the grid is determined by a statistical method. According to the study of Griffith and Amrhein (1994), the formula of optimized quadrat area is:

$$\text{Quadrat area} = 2A/q \qquad (1)$$

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A represents the surface of the studied area, *q* is the number of points. The studied area is calculated by the actual monitoring area, not the whole urban area. Therefore, the area of studied range is calculated by the formula of the circle:

$$\text{Quadrat area} = \frac{\sum_{i=1}^{19} 2\pi r_i^2}{q} \qquad (2)$$

where *r* is the radius of the monitoring radius, *i* is the serial number of monitoring circle.

The total area of monitoring circles equals 4,314.70 km², and the number of points (*i.e.* Weibo messages) is 53,967, thus the statistical optimum quadrat area is 0.16 km² (i.e. the length of the side is 0.4km). Based on this size, we also expand the length of side triple and sextuple respectively for comparative reasons, because the size of the units in previous researches is larger than the one we calculated (Table 1). The medium one is similar to previous studies. The largest one significantly reduces the percentage of minimum value, however, it cannot match the boundary of the monitoring circle very well. It enlarges the total monitoring area. Therefore, the largest size is excluded.

Table 1. **Three different sizes of quadrat**

Quadrat side (km)	Number of Quadrats	Minimum number of Weibo in one quadrat	Percentage	Maximum number	Mean	Standard Deviation
0.4	6952	1	33.5%	442	7.76	16.75
1.2	1814	1	23%	887	29.53	69.22
2.4	705	1	16%	1831	75.98	196

Note: the quadrats that do not contain Weibo messages were excluded from the sum of quadrats.

Source: own elaboration

Next, Anselin Local Moran's I (Arcgis 10.2) is introduced to test the clustering degree of points based on medium and small grids respectively. If there is no significant clustering area, or the distribution is dispersed, it indicates that Weibo data is probably useless in detecting the urban structure. Both grids (Figure 5) show strong trends of concentration, however, the medium grid (1.2 x 1.2 km) (Figure 5-a) fails to distinguish those areas of lower density in the central city. Therefore, we use the small size of the grid as the unit to calculate the density.

Figure 5. **Anselin Local Moran's I Result**
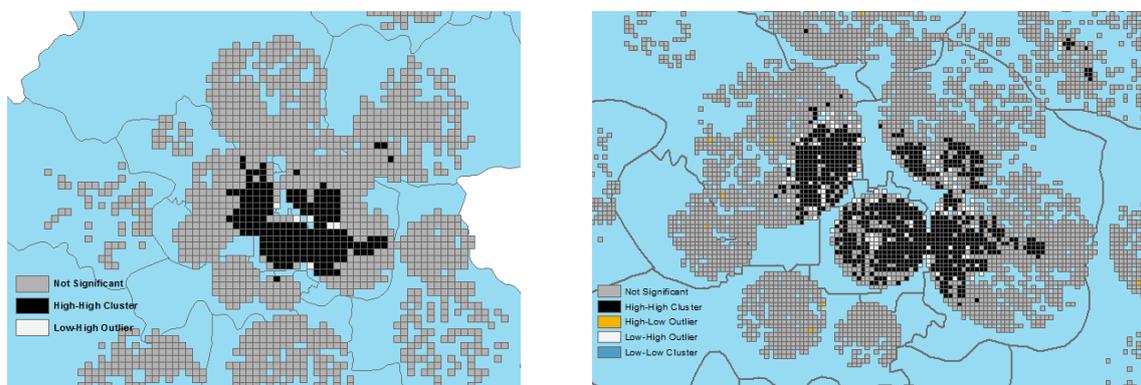
(a) Grid: 1.2 x 1.2 km

(b) Grid: 0.4 x 0.4 km

Source: own elaboration

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4.4   Identification of Weibo sub-centers

This paper tries to identify Weibo sub-centers in four periods – workdays (Monday to Friday, from 8:00 to 20:00), nights (Monday to Friday, from 23:00 to 6:00), the weekend and the whole week. A potential sub-centers should satisfy two criteria: 1) it should be located in the High-High cluster which is based on the Anselin Local Moran's I Result; 2) the density of the potential area should be above the mean Weibo density of the HH cluster plus one Standard Deviation. The first condition selects out those high active grids. The second condition excludes those grids of lower density in the HH clusters. After the selecting out those cells that satisfy the criteria, we aggregate these cells into potential sub-centers through nearest-neighbor principle. The standard of aggregation is that the distance between two qualified grids is equal or less than 0.4 km.

As we detect sub-centers using the density approach, there are three major methods (Roca Cladera *et al.,* 2009): reference thresholds, parametric methods, non-parametric methods. The reference threshold is to set a statistical or numerical threshold to select out sub-centers, such as a threshold of the density of employment or density of workplaces (Garcia-López and Muñiz, 2010; Giuliano and Small, 1991). This method can be used to compare the results of a single city in different periods. However, when the stricter statistically rigorous is demanded, the parametric or non-parametric modelling has more advantages. Since the monitoring range of our dataset does not cover the whole of Beijing, it is hard to estimate a continuous surface of density to introduce the non-parametric model. Therefore, we adopted the classic negative exponential model (McDonald and Prather,1994) to identify Weibo sub-centers. Firstly, we assume that the distribution of density of Weibo also follows the similar pattern of the employment distribution - it decreases as the distance to the city center or CBD increases. Secondly, our model only restricts to the potential Weibo sub-centers:

$$D(x_i) = D_0 e^{-\alpha x_i + b} \qquad (3)$$

$D(x_i)$ corresponds to the Weibo density of a given i potential sub-center, and x_i is defined as the Euclidian distance from the mean center of the i potential sub-center to the sub-center which has the highest Weibo density (which in turn is assumed to be the Beijing' CBD). α is the slope of the density that is reduced departing from the Weibo CBD. Since the negative exponential model is nonlinear, we transform it into the linear form for calculation purposes:

$$\ln D(x_i) = -\alpha X i + C \qquad (4)$$

where $C = \ln D_0 + b$.

Finally, based on unstandardized residual values from the model, two thresholds are introduced to the test of identification of the sub-centers: 1) the residual value of a confirmed sub-center should be positive and is equal or above the mean value of all residual values plus one standard deviation; 2) the residual value of a confirmed sub-center is positive and above the mean value of all residual values. The final threshold is decided by the analysis of the social-economic profile and the actual urban land use.

5. Results for the identification of Weibo sub-centers

## 5.1   Temporal variation of Weibo messages

Figure 6 (a) shows the variation of Weibo activities along one week. The Saturday and Monday has the highest number of Weibos. The least active day is the Friday. The Weibo activity is slightly higher at the weekend than during workdays (Figure 6 (b)). According to *the 2015 Weibo Search Engine White-Book*, the first and second rank of searching frequency are news and celebrities. It indicates that

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people mainly use Weibo as a source of information and as an entertainment application. In terms of the hourly Weibo activities (Figure 6 (c)), the most active period is from 21:00 to 0:00 on workdays and the weekend. Therefore, it is reasonable to deduce that the majority of users enjoy their leisure time after 21:00 pm. The average Weibo activities on workdays are higher than the weekend before 12:00 am. After 14:00, the average frequency of weekend is higher than the workdays. It reflects the habitual differences between workdays and weekend.

Figure 6. **Temporal distribution of Weibo activities**
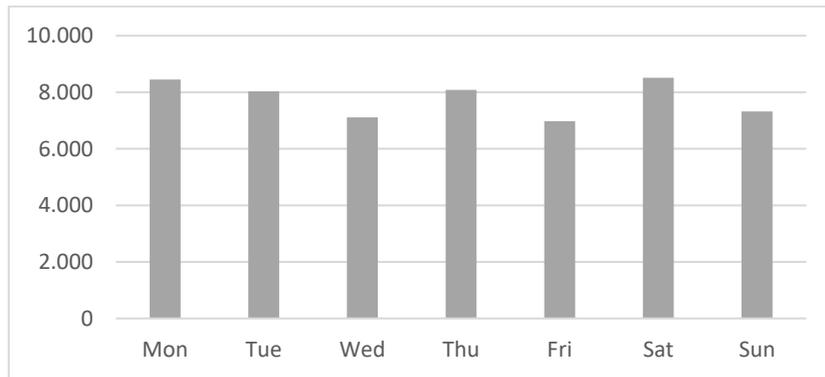
(a) Distribution of Weibos per day
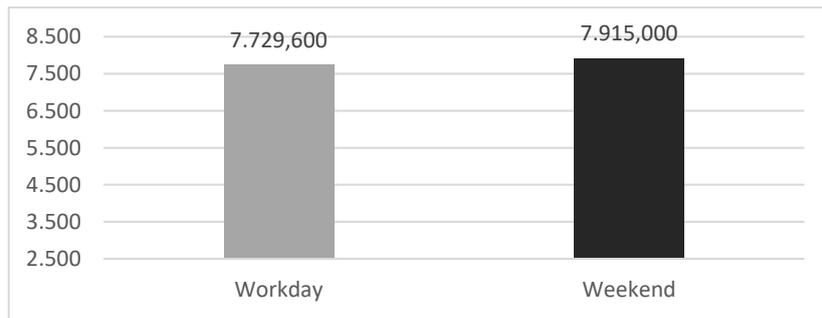
(b) Daily average frequency of Weibos during workdays and the weekend
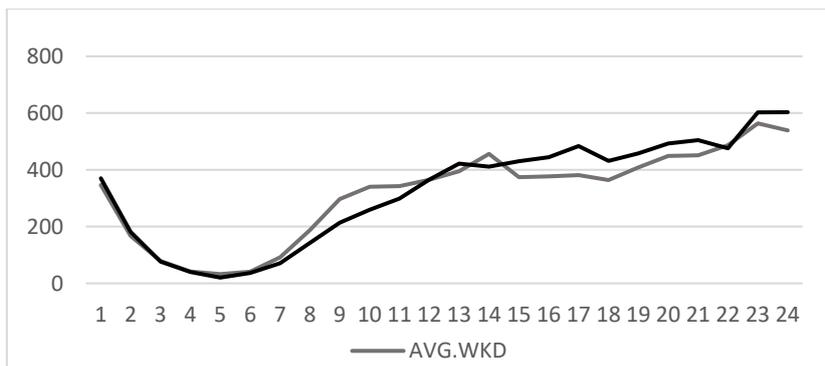
(c) Average frequency of Weibo messages per hour

Source: own elaboration

5.2   Spatial distribution of Weibo density

Figure 7 shows that grids with high-density mainly concentrated in the central zone and in the expanded functional zone. There is a decreasing tendency of Weibo density from the central area to

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the periphery. The density of the developing zone and ecological conservation zone is lower than the central city in general. It is coincident with the lower density of population and urban constructions in these areas.

Figure 7. **3D Weibo density panorama**
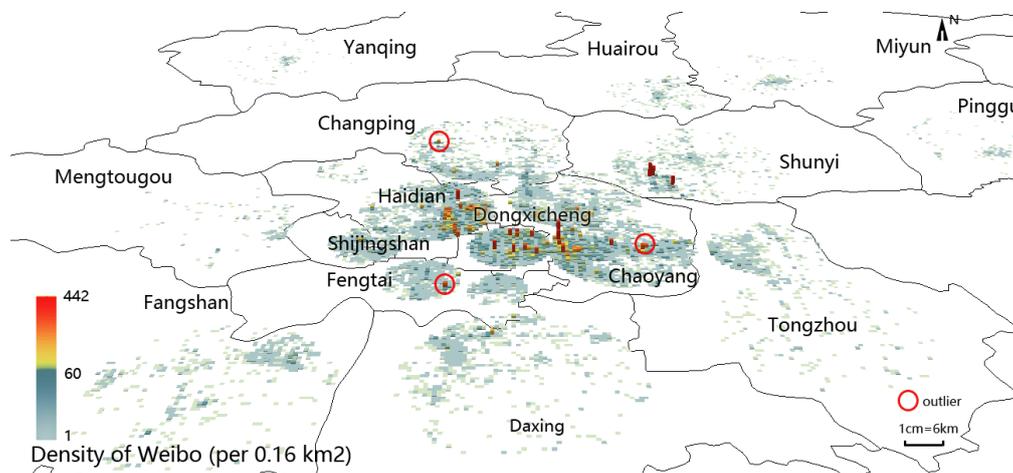
Source: own elaboration

Besides the airport in the Shunyi district, there are three places of higher density which surrounded by low-density cells. Compared to the actual urban contexture, they are located in universities, such as Capital University of Economics and Business in Fengtai district, the Communication University of China and Beijing International Studies University in Chaoyang district, and the zone of a university in Changping district.

Figure 8. **3D view of Weibo density in the central area of Beijing**
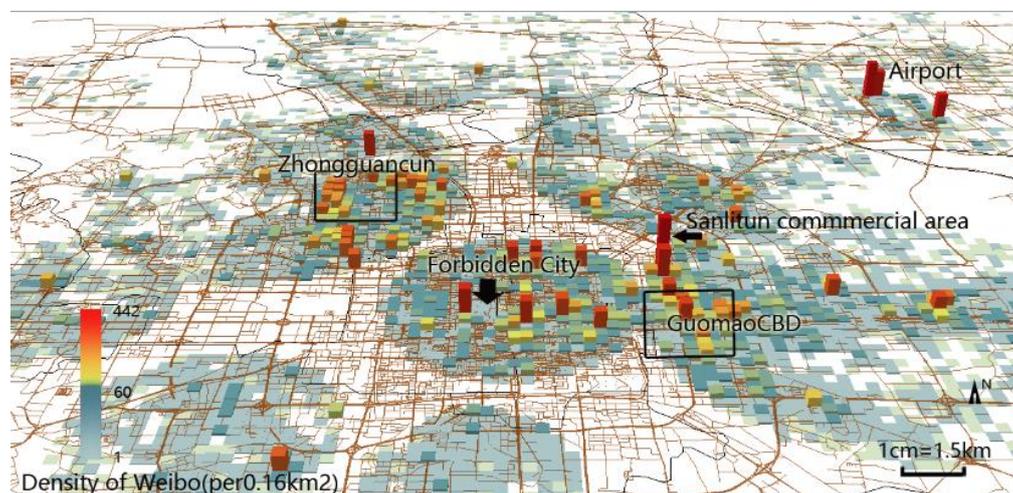
Source: own elaboration

If we check the density map closely (Figure 8), the distribution of density in the central area is actually variable from place to place, rather than the same intensity. From the Guomao CBD to Sanlitun, there is a high-density area along with the third ring road, because many office towers are constructed in the area. Figure 9 contains a partial view of Guomao CBD along with the third ring road. The CCTV headquarter, China Merchants Tower and many other famous towers all gather in these streets.

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Figure 9. **3D view of urban contexture in the Guomao CBD area**
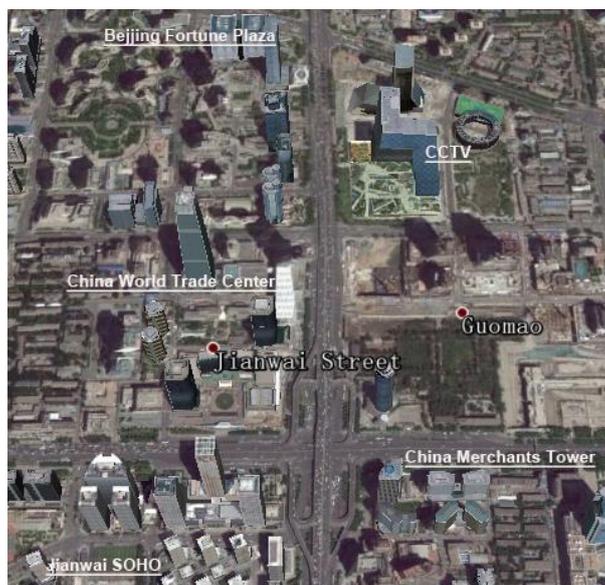
Source: Google earth

Within the second ring road, the density around Forbidden City actually was not very high, because the central government and Beijing government are located in the area (Figure 10). Tian'anmen Square and Mausoleum of Mao Zedong are in front of the Forbidden City. Thousands of tourists visit these two places every day, thus the density rises[2]. Similarly, the higher density in the northern part of the traditional center was formed by tourism, because many Hutong (a kind of typical residential construction and culture of Beijing) are located here.

Figure 10. **3D view of Weibo density in traditional city center and Haidian**
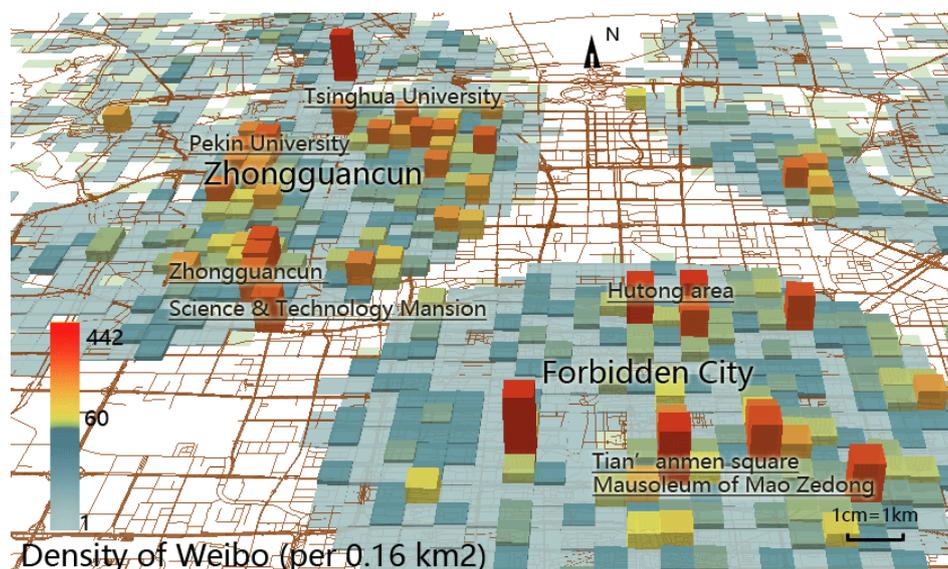
Source: own elaboration

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[2] As the roaming service of mobile is very cheap even free (depends on the type of contracts) in China, the willingness that tourist use Weibo is not affected by mobile roaming.

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In the Haidian district, universities and office areas are the main types of land use. In the past two decades, Zhongguancun has gathered nearly 20,000 high-technology enterprises, including Lenovo and Baidu. The higher density grids distribute along with Zhongguancun Streets and Chengfu Road in general. It matches the distribution of technological companies in this area. According to the introduction on Zhongguancun Science Park's official website, the distribution of these companies approximately starts from Zhongguancun Street, then goes up to Chengfu Road, forms an "F"-shape area.

5.3   Identification of Weibo sub-centers in Beijing

Figure 11 shows that all potential Weibo sub-centers are located in Chaoyang, Haidian, Dongcheng, Xicheng and Shunyi Districts. The potential Weibo sub-centers of one week are less than other periods because the average density is the highest (Table 2) so that only 72 grids satisfy with the criteria abovementioned, which only account for 2% of total grids. The potential sub-centers of days (Figure 11-(b)) and nights (Figure 11-(c)) of workdays are quite close to each other. However, the density of Weibo activities is weaker in the night.

Table 2. **Statistical description of potential Weibo sub-centers and distance**

	Ln_Density					Distance to Weibo-CBD(km)				
	Mean	Std.	Range	Min	Max	Mean	Std.	Range	Min	Max
One week	6.569	0.264	0.921	6.271	7.193	6.626	3.952	13.321	0.000	13.322
Weekend	5.682	0.376	1.647	5.267	6.913	6.394	3.774	14.882	0.000	14.882
Day_workday	5.887	0.318	1.014	5.546	6.560	7.245	3.964	14.882	0.000	14.882
Night_workday	5.002	0.212	0.722	4.666	5.388	7.602	3.934	14.834	0.000	14.834

Source: own elaboration

In terms of land uses (Table 3), it changes with different periods. Mixed area, university, transportation hub, and tourist attraction show more active in workdays, while sub-centers of university decrease in the weekend. None of the potential sub-centers belong to the residential area in the time span of one week (Figure 11- (a)) and day-period of workdays (Figure 11- (b)).

Commercial and office areas (1, 5, 9, 22, 27) are the major types of land use for Weibo sub-centers considering the complete week period. In the day–period of workdays, two important railway stations—Beijing Northern Station (23) and Beijing Eastern Station (8) appear as potential Weibo sub-centers. It is possibly caused by their function as transportation hubs that connect with Beijing suburban trains. Especially, many Interprovincial trains pass through Beijing Eastern Station, thus it is also an active area during the night.

Compared with the day-period, besides the two universities in the eastern part (18,19), there are more potential Weibo sub-centers in the night of workday concentrated in the northwest part where many universities are located. It implies that the main active users during the night-period are students of universities.

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Figure 11. Distribution of potential Weibo sub-centers in Beijing

(a) One-week

(b) Day of workdays

(c) Night of workdays
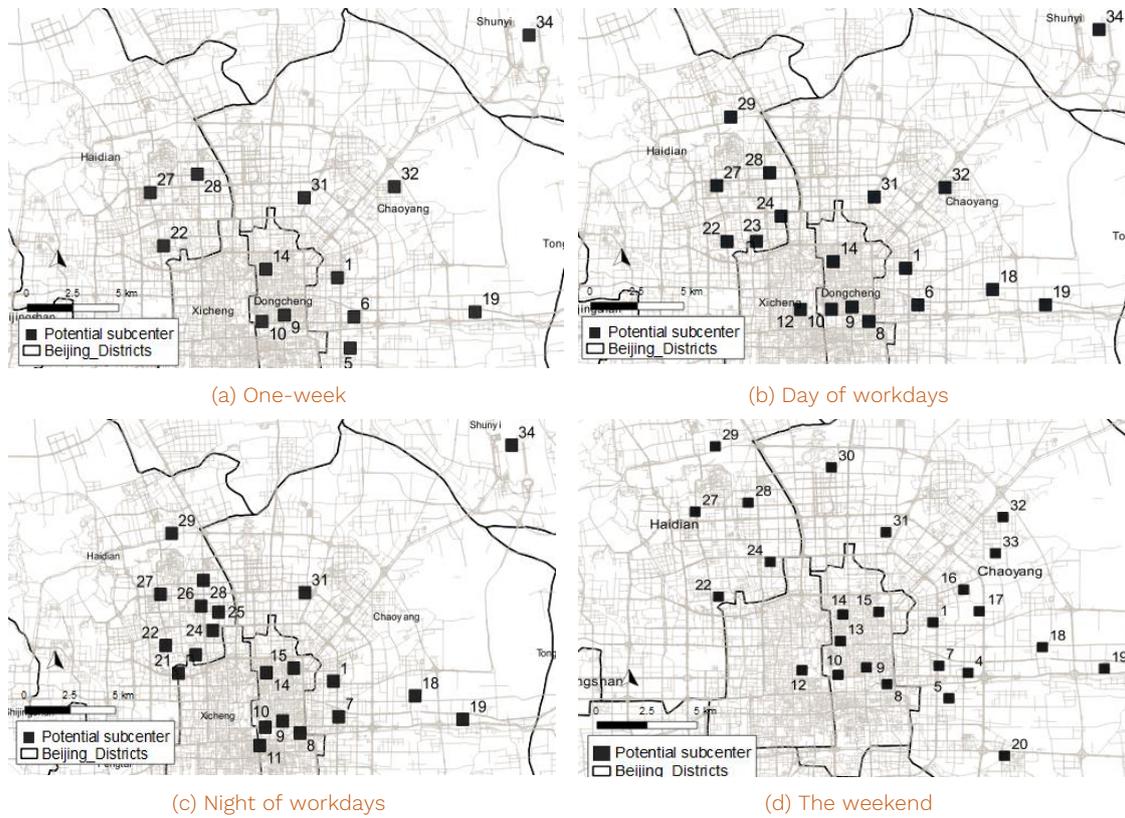
(d) The weekend

Source: own elaboration

During the weekend (Figure 11-d), tourist attractions (10,13,14) and recreational areas (16,17,20,30,32) account for 40% of total potential sub-centers; for example: 10 is Tian'anmen Square, 13 and 14 are Hutong areas, and 16 is the 798 Art Zone. Three residential places (5, 16, 31) are shown as potential sub-centers. Some recreational places only appear active at the weekend. For example, 20 is an amusement park, and 30 is the Olympic Forest Park. Both of them are far away from the city center, thus such Weibo activity is probably generated from the users who live in Beijing and visit such venues.

Moreover, it is worth noticing that the highest density area locates at the Beijing International airport (Figure 11-(a)(b)(c), 34) during the one week-period and workdays-period. It may be caused by its enormous passenger flows. According to ACI´s data[3], Beijing airport got the No.2 rank of total passenger traffic among 1,144 airports worldwide in 2015. The enplaning and deplaning passenger was nearly 90 million in 2015. Thus, Beijing airport is a functional hub on a national scale without any doubt.

However, the airport is excluded from our regression model aimed at confirming Weibo sub-centers, because it is unreasonable to set the airport as the central point of the model and its importance corresponds to the national interests, not just the intra-urban one. Furthermore, in a preliminary model test, the inclusion of the airport reduces the coefficient of determination (R square) significantly, due to its highest density and further distance to the central city (about 25.5 km).

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[3] ACI : Airports Council International. Data source link: http://www.aci.aero/News/Releases/Most-Recent/2016/04/04/ACI-releases-preliminary-world-airport-traffic-rankings-

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Table 3. The land use type of overlapping potential sub-centers

Code of Sub-center	Period				N. of overlapping subcenter	Land use
1	Day	Night	One week	Weekend	4	Commercial area
4				Weekend	1	Commercial area, subway station
5				Weekend		Residential area
6	Day				1	Guomao CBD
7				Weekend		Guomao CBD
8		Night			1	Beijing East railway station
9	Day	Day				Commercial area
10	Day	Night	One week		3	Tourist Attraction
11		Night				Residential and tourist area
12	Day			Weekend	2	Tourist Attraction
14		Night	One week		2	Tourist Attraction
15		Night			1	Residential and tourist area
16				Weekend	1	Residental area
17				Weekend	1	Chaoyang park
18	Day				1	Commercial area
19	Day	Night	One week		3	University
20				Weekend		Amusement park
21		Night			1	Mixed area(office, commercial and university)
22	Day		One week	Weekend	3	Mixed area(office, commercial and university)
23	Day				1	Commercial area, Beijing Northern Railway Station
27	Day	Night	One week	Weekend	4	Mixed area(office, commercial and university)
28	Day		One week		2	University
29	Day	Night		Weekend	3	University
30				Weekend	1	Olympic Forest Park
31				Weekend	1	Residential area
32				Weekend	1	798 Art zone
33				Weekend	1	Mixed area(office, commercial and residential)
34	Day	Night	One week		3	Beijing International Airport

Source: own elaboration

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Now, we adopt the logarithmic linear regression model to test these potential Weibo sub-centers. Rather than the traditional central point, the potential Weibo sub-center which has the highest average density of Weibo (Weibos per km²) is chosen as the center to calculate the distance (*i.e.* Weibo-CBD). Therefore, the most relevant potential Weibo sub-center - the Sanlitun commercial area is set as the central point to calculate the distance. It has the highest density of all periods after the airport, which is a famous landmark in Beijing which consists of popular culture hubs, commercial centers, and more than 200 bars.

Table 4 is the summary of models for each different period. At the 90% confidence level, the only model that resulted in an acceptable statistical significance is that of the weekend Weibo density. The distance could explain 14.3% of the variation of Weibo density during the weekend. In terms of one-week period, although the model distance from the point of comparative highest Weibo density could explain 21% of the variation of Weibo density, the statistical significance rejects the model result. However, the model is completely ineffective for the two periods of workdays, which adjusted R^2 is negative. It is caused by the R^2 is almost zero which means that the distance cannot explain the variance of Weibo activities during the workday. One possible explanation is that those potential sub-centers in Haidian districts impact the model because they were almost absent in the weekend period (Figure 11(d)).

Table 4. Model Summary for the four periods

(a) Model summary

| Model	R^2	Adjusted R^2	Std. Error of the Estimate	F	Sig.
One week	0.210	0.132	0.246	2.671	.133
Day_Workday	0.000	–0.660	0.328	.004	.953
Night_workday	0.030	–0.022	0.221	1.616	.230
Weekend	0.143	0.106	0.356	3.853	.062

(b) Coefficients

Model		Unstandardized Coefficients		Standardiz-ed Coefficient-s	t	Sig.
		B	Std. Error	Beta		
One week	(Constant)	6.773	.143		47.264	.000
	Distance(km)	–.031	.019	–.459	–1.634	.133
Day_workday	(Constant)	5.896	.170		34.721	.000
	Distance(km)	–.001	.021	–.016	–.060	.953
Night_workday	(Constant)	3.250	.106		30.601	.000
	Distance(km)	–.011	.012	–.195	–.844	.410
Weekend	(Constant)	5.924	.142		41.630	.000
	Distance (km)	–.038	.019	–.379	–1.963	.062

Source: own elaboration

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Such a lower explanatory percentage possibly indicates that the urban structure of Beijing belongs to a polycentric model from the perspective of Weibo activities. However, another possibility is that the directions of the distribution of these potential points may influence the result. In other words, the development of sub-centers is not exactly symmetrical. Thus, we set point 1 as the center to divide the map into four quadrants (Figure 12). This division separates the Guomao CBD, Zhongguancun area, traditional center and airport into different quadrants, thus it can alleviate the effect of opposed directional development trends. Because the 34th - airport is not involved in the model test, the 32nd is added into the second quadrant. The confirmed sub-center is the sum of each quadrant's result.

Figure12. **The classification of workday's potential sub-centers**
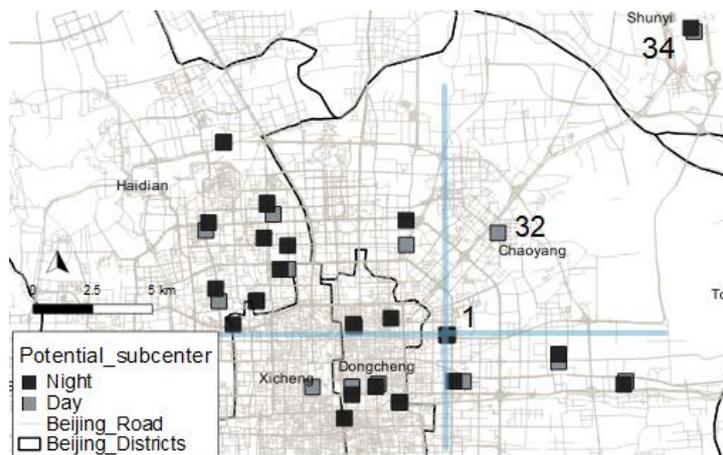
Source: own elaboration

However, none of the models is shown statistical signifance (Table 5). The model is still completely ineffective during the day-period. The adjusted R² of the night period is improved after the classification because it eliminates the effect of different directional development trends. The potential candidates of the fourth quadrant have a lower density of Weibo than the candidates of other quadrants which are located at a similar distance. The first and second quadrant suffer the least influence from the distance. Because their average density is very high, more or less equals to the Guomao CBD area, but they are far away from the central point. Compared with the fourth quadrant, the third quadrant also presents that the distance has weak influence. One possible reason is that the third quadrant belongs to the traditional center of the city, and the fourth quadrant is near to the suburban area.

Table 5. **Model Summary of Workdays and nights of workdays**

Model		1st&2nd quadrant	3rd quadrant	4th quadrant
Day workday	R^2	0.008	0.051	0.203
	Adjusted R^2	-0.116	-0.265	-0.196
	Std. Error of the Estimate	0.378	0.435	0.389
	F	.063	.163	.509
	Sig.	.809	.714	.550
Night workday	R^2	0.128	0.472	0.356
	Adjusted R^2	0.049	0.296	0.034

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	Std. Error of the Estimate	0.218	0.227	0.262
	F	1.616	2.679	1.107
	Sig.	.230	.200	.403

(b)   Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
Day_workday 1st&2nd quadrant	(Constant)	5.900	.263		22.451	.000
	Distance(km)	-.007	.028	-.088	-.250	.809
Day_workday 3rd quadrant	(Constant)	6.251	.395		15.829	.001
	Distance(km)	-.033	.081	-.227	-.403	.714
Day_workday 4th quadrant	(Constant)	6.232	.312		19.973	.002
	Distance(km)	-.040	.056	-.450	-.714	.550
Night_workday 1st&2nd quadrant	(Constant)	3.362	.144		23.385	.000
	Distance(km)	-.019	.015	-.358	-1.271	.230
Night_workday 3rd quadrant	(Constant)	3.558	.213		16.720	.000
	Distance(km)	-.074	.045	-.687	-1.637	.200
Night_workday 4th quadrant	(Constant)	3.344	.209		16.020	.004
	Distance	-.039	.037	-.597	-1.052	.403

Source: own elaboration

In summary, the only clear spatial trend of Weibo density is the weekend in terms of the model results. It is probably caused by the spatial diversity of Weibo density in these periods. Except for the weekend, the variation of Weibo density is too small to present the evident correlation with the distance. The Weibo density has the largest variation in the weekend (Table 2), which standard deviation is nearly double that of other periods. On the contrary, the mean distance of all potential sub-centers to the Weibo center is the lowest at the weekend.

Table 6. The tested sub-centers of weekend based on two standards

	Standard	Sub-center
1	Positive Residual ≥ Mean of all residuals +Std. Deviation	1,12,31
2	Positive Residual ≥ Mean of all residuals	1,4,12,14,18,22,27,29,31

Source: own elaboration

Therefore, we only select the final Weibo sub-centers at the weekend (Table 6). The confirmed Weibo sub-centers at the weekend are the numbers of 1, 12, and 31 following the stricter standard, while there are eight sub-centers if we use the mean-standard. The stricter one appears one commercial areas (1), one tourist attraction (12) and a residential area (31). Combined with the actual social-economic profiles, we tend to adopt the mean value as the standard of selecting sub-center. The number 18 (Table 7) is a shopping mall. The number 12 and 14 are in the traditional urban center. The number 22 and 27 are areas of mixed land uses and located in Zhongguancun, Haidian district. The Haidan district accounts for 17.9% of total permanent residents of Beijing in 2014. Moreover, Zhongguancun is a huge employment center as well as an important commercial area of Beijing.

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According to *Zhongguancun Report 2014*, 1,899 million people worked in Zhongguancun area. Considering many companies still operate at the weekend and, it is reasonable to include this area as a sub-center at the weekend.

Table 7. **The land use type of confirmed sub-centers at the weekend**

Code of Sub-center	Land use
1	Commercial area
4	Commercial area, subway station
12	Tourist Attraction
14	Tourist Attraction
18	Commercial area
22	Mixed area(office, commercial and university)
27	Mixed area(office, commercial and university)
29	University
31	Residential area
34	Beijing International Airport

Source: own elaboration

The distribution of Weibo sub-centers of the weekend is not located at the very center of Beijing city (Figure 13), many of them are out of the second ring road and concentrated in the northern part of Beijing. The figure also overlaps the potential sub-centers of the other three periods for comparison. The overlap between weekend sub-centers and other potential areas are only two of them: the number 1 is located in Chaoyang district and the number 27 are in the Haidian district. However, most of the potential sub-centers in different periods are quite close to each other. There are seven places overlap in three different periods: the airport, universities, Dongdan commercial area, and Tian'anmen Square and Guomao CBD. All types of these land use could maintain a higher intensity of human activities.

Figure 13. **Confirmed sub-centers at the weekend and overlapping potential areas**

Source: own elaboration

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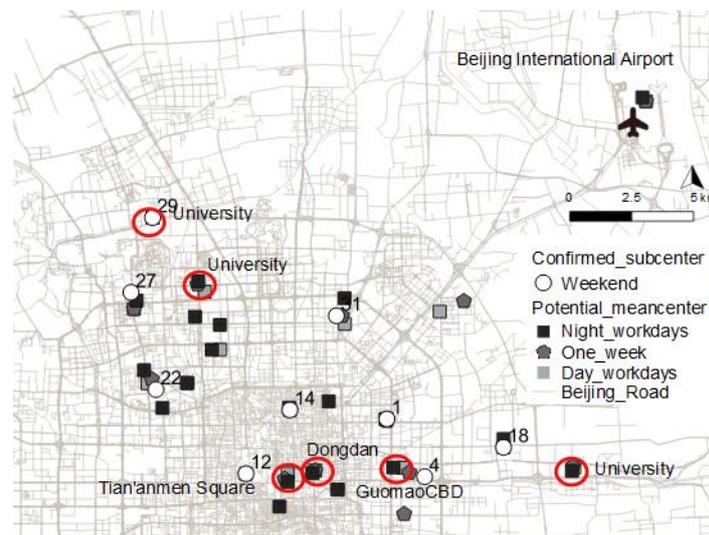
6. Discussion and conclusion

In summary, the urban structure of Beijing is indeed polycentric, though the high-density clusters mainly gathered within the fifth ring road of Beijing. Statistically, according to the result of the model, the period of weekend is the only one which presents the polycentric structure: there are sub-centers which Weibo-density is above to what is predicted by the distance of them from the Weibo-CBD. However, the poor performance of the negative exponential model also indicates that the Weibo density only has a weak correlation with the distance to the center. Moreover, as the Local Moran I's results show, the Weibo activities actually varies from place to place within the central area. Those Weibo sub-centers can present the major urban active areas, such as Zhongguancun, the traditional city center and the airport, etc. Last but not the least, it is necessary to stress that Weibo sub-centers are not employment centers. The employment center only considers the working activities rather than other human activities, such as recreational activities or tourist activities. The failure of the model may indicate that the empirical analysis of urban spatial structure requires more than pure employment analysis.

All Weibo sub-centers of the weekend and those potential areas of other periods are located in the northern part of Beijing. It is probably caused by the development of the educational zone since the 1950s and the falling of the first industries in the southern area due to the change in planning restrictions produced by the air pollution evident since the 1970s. Accordingly, the lack of Weibo sub-center in the southern part of Beijing is associated with the economic structural reform, because many heavy industry factories were located in that area.

Secondly, Weibo data is proved to be a useful data source to study the urban structure and urban functional areas. Those confirmed Weibo sub-centers actually belong to regions where are vivid zones, such as commercial areas and places of interest. Compared with the employment data, Weibo data can reflect the various types of land use more directly. Moreover, the employment data exclude the possibility that zones of universities could be potential sub-centers. Because most of the undergraduates and graduates live in the dormitories of universities in China, it forms another type of center of human activities.

Thirdly, the Weibo potential sub-centers imply the difference of human activities in different periods. It can be observed the difference in active Weibo areas between workdays and the weekend. For example, Zhongguancun as a major employment center of Beijing has more active grids during workdays than at the weekend. Meanwhile, it is reasonable to infer that working people post fewer Weibos in working places during workdays, and thus tourist attractions display a higher degree of activities in workdays by contrast. Conversely, people tend to go to recreational places or stay at home at the weekend, hence, commercial and residential areas are more active in the weekend.

Nevertheless, Weibo data exhibit limitations when it is applied to study the urban structure. Firstly, it cannot identify land uses without using exogenous data. The distribution of Weibo density is not enough to describe the whole situation of the city. It relies on other data that can provide the details of the land-use and social-economic information of a specific area. Secondly, the bias that is caused by types of users and users' preferences could affect the representativeness of Weibo data. For example, the major users of Weibo are aged from 18 to 35 years-old who tend to stay in other places longer than in their homes, thus the distribution of Weibo could not reflect residential areas very precisely.

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Authorship

The first author has been in charge of data collection, analysis and writing paper, and the second author has made the guidance and revision of the paper

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