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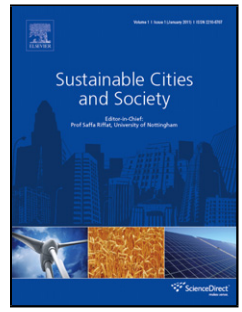

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A spatial design network analysis of street networks and the locations of leisure entertainment activities: a case study of Wuhan, China

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Highlights

- Leisure entertainment facilities have differing point, ring, and ribbon patterns;
- Severance and efficiency are two promising parameters measuring street networks;
- Leisure entertainment activities and street configurations are spatially correlated;
- Spatial equity should be emphasized in the process of leisure-based urban planning;

Abstract: This paper examines the spatially stratified association between various urban leisure activities and street configurations via a spatial design network analysis and attempts to provide insightful implications for the sustainable development of a city by using a typical inland city of China, Wuhan, as an example. The street network is characterized by performing a spatial network analysis of the *closeness*, *betweenness*, *severance* and *efficiency* parameters. The kernel density estimation (KDE) method is employed to measure the proximities of every place to streets and various types of leisure entertainment facilities. The two sets of densities are then analyzed to determine whether spatially stratified correlations exist and whether various leisure entertainment facilities are more spatially correlated with specific street features. The results indicate that a good street network design can be measured not only by closeness or betweenness but also by severance and efficiency. Four street network metrics are spatially correlated with the locations of leisure entertainment activities. Various types of leisure entertainment activities have distinct locational preferences for street networks (e.g., chess and card rooms favor closeness). The conclusions of this paper can help urban planners and policy-makers spatially optimize street networks and leisure venues to develop a sustainable city.

Keywords: Leisure entertainment activities; Spatial design network analysis; Spatial equity; Wuhan.

1 Introduction

The rise of the new economy radically alters the ways that cities and regions can establish and maintain competitive advantages. In the new economy, regional advantages come to places that can quickly mobilize the talents, resources, and capabilities that turn innovations into commercial products (Florida, 2000). As a significant component of the new economy, the leisure industry contributes positively to the attraction of knowledgeable workers and the development of high technology industries, thus promoting the sustainable development of the economy and society.

Leisure activities are foundational in making urban life dynamic and open to social and cultural diversity (Portney, 2013). The leisure industry helps to formulate "quality of place", which is identified as the single most important source of civic satisfaction. The significance of leisure activities has been widely recognized for promoting the happiness and well-being of citizens (Yang, et al., 2012), improving the quality of life and sense of pride of residents (Yang and Kim, 2016), creating livable and sustainable human settlements (Chiesura, 2004), alleviating the pressure of urban life, promoting social cohesion and reducing social inequality (McCarthy, 2002; Ryder, 2004).

Characterizing spatial characteristics facilitates a better understanding of urban form (Liu et al., 2016). The locations of leisure activities possess multiple spatial characteristics, such as spatial accessibility, spatial optimization, and spatial gradient (Devine and Mobily, 2017; Son and Janke, 2015; Jing et al., 2018). The rational distribution of the locations of leisure activities can substantially boost urban vitality and urban competitiveness (Chen et al., 2014) and facilitate environmental, social and health justice (Jing et al., 2018) by improving access to certain types of leisure sites for vulnerable people. These previous studies have contributed to addressing the spatial features of leisure activities. Geospatial analysis is widely utilized to examine the spatiality of certain types of leisure activities, such as parks, gardens, museums, karaoke, and cinemas. However, in addition to how leisure activities are spatially distributed, it is important to understand what factors of the built environment influence the spatial patterns of leisure activities and how the characteristics of the physical environment and leisure functions are mutually dependent.

Many aspects of the built environment have been hypothesized to affect the locations of leisure activities. One aspect that has received frequent attention is the configuration of streets in a road and pedestrian network. Previous studies have emphasized the role of street configurations in shaping the economic or social dynamics and structure of a city (Ni et al., 2016; Wang et al., 2014). A rich body of literature has examined the association between street centrality and the distribution of retail stores (Sevtsuk (2010)), the distribution of karaoke venues (Cui et al., 2016a), the distribution of healthcare facilities (Ni et al., 2016), and the distribution of parks (Wolch et al., 2014). Sevtsuk (2010) analyzed the endogenous agglomeration of retail stores in Cambridge, which is highly influenced by exogenous factors, such as land use and the transportation network. Cui et al. (2016b) concluded that the population, road network and commercial centers are three major factors that determine where karaoke venues are spatially distributed in Nanjing, China. Despite the abovementioned studies, few studies have attempted to quantify the relationship between leisure activities and street networks.

With the development of network science, how to characterize the network structure is important to study real world phenomenon, such as crowd disasters, disease transmission and human cooperation (Helbing et al., 2015; Perc et al., 2017; Wang et al., 2016). According to the qualitative and quantitative features, the network models can be classified into random graph, small-world network, scale-free network, weighted networks and spatial networks (Wang et al., 2016). These network theories and network models provide an effective way to understand the complex and heterogeneous connectivity pattern in the field of social and transport systems. Graph theory is always employed to mathematically formalize networks, being composed of nodes and edges. The complex features can be quantified by the graph theory as degree, connectedness, degree correlations, centrality and betweenness, clustering and community structure (Wang et al., 2016).

The street network as one typical kind of spatial network is widely used in daily life and provides useful information that helps characterize the spatial dynamics of human activities. Centrality indices advanced by space syntax analysis (Porta et al., 2006; Porta et al., 2012) were mainly employed to quantify the location on a street network. Reports have indicated that urban activities are closely associated with various centrality indices (Rui and Ban, 2014). Commercial activities tend to favor streets with high connectivity (Nes, 2005; Scoppa and Peponis, 2015); specialty stores favor streets with high closeness; and department stores or supermarkets prefer streets with high betweenness (Wang et al., 2014). Although the widespread use of centrality indices provides valuable insights into explaining the locations of economic or social activities, the effectiveness of this method has recently been criticized (Stangl and Guinn, 2011). This method does not capture the shape of the links between the intersections or the shape of the intersections themselves (Cooper et al., 2014). Many suggestions have been made for the measurement of physical severance, which considers network characteristics in more detail (Cooper et al., 2014). One of these measurements is directly mirrored in spatial design network analysis (sDNA), which computes 16 different localized network measures that are hypothesized to affect the locations of leisure activities in a given area.

Moreover, to detect the strength of the association between two variables, the correlation coefficient is widely applied. The conventional correlation analysis fails to capture spatially stratified heterogeneity, which is the phenomenon in which within-strata variance is less than between-strata variance, which is widespread in spatial data (Wang et al., 2010).
We assumed the existence of spatially stratified heterogeneity when evaluating the metrics of street networks that would determine the spatial patterns of various leisure activities. If a significant spatial consistency exists between the intensity of a certain factor and the distribution of leisure activities, this factor is recognized to be decisive in the location preferences of leisure activities. Geographical detector (http://www.geodetector.org/) is a new tool to measure spatially stratified heterogeneity and test the spatial association between two variables. This tool has been widely applied in earthquake risk assessment, crop cultivation and environmental health studies (Hu et al., 2011; Luo et al., 2016; Wang et al., 2010). The employment of this new technique could provide valuable insights into the spatial association between street networks and leisure entertainment activities.

This research contributes via the following aspects: first, the spatiality of urban leisure sites and its spatially stratified correlation with street network metrics are identified; second, the sDNA method is employed to characterize street networks in more detail by considering physical severance, and the geographical detector tool is applied to identify the factors of a street network that facilitate or impede the distribution of leisure activities by considering spatially stratified associations; third, case studies are used for an empirical analysis that takes a typical inland city of Wuhan in China as an example.

2 Description of the study area and data sources

2.1 Description of the study area

Until 2016, the added value of tertiary industry constituted 51.6% of China's GDP (gross domestic product) and contributed the most to China's economic growth. Additionally, China's disposable income has risen sharply from 343 RMB in 1978 to 36396 RMB in 2016, which has increased the demand for the development of the leisure entertainment industry (CSB, 2017). As an upper-middle income country, Chinese consumers are reducing their spending on housing and food but spending more on upgrading their lifestyles, i.e., on items such as healthcare, travel and entertainment. According to the 13th five-year plan, the "Healthy China" proposal has become a national strategy, and President Xi has put health at the center of China's policy-making machinery. The leisure entertainment industry plays an important role in developing a "Healthy China" and has massive growth potential as an emerging industry. However, despite its importance to economic growth and human health, the logic underlying the provision of leisure entertainment facilities has yet to be fully explored.

As the capital city of Hubei Province, the economy of Wuhan ranks first in central China and 9th among all cities in China in terms of GDP, arriving at 1191 billion yuan in 2016. The industrial structure of Wuhan's economy is upgrading from the manufacturing industry to the service industry. The tertiary industry contributes 64.9% of the economic development in Wuhan. The cultural and entertainment industry is highly encouraged in Wuhan's 13th five-year plan. As the traffic hub of China, Wuhan's government is devoted to increasing transport investments and accelerating the construction of the urban backbone network. In 2016, the total investment in transport construction reached 709.32 billion yuan and accounted for 6.9% of Wuhan's GDP. Given this background, the opportunity to develop traffic to optimize the spatial layout of leisure activities must be seized.

Wuhan is located between latitudes 29°58'-31°22'*N* and longitudes 113°41'~115°05'*E* and is divided by the Yangtze and Hanjiang Rivers into Wuchang (referring to the Wuchang District, Qingshan District and Hongshan District), Hankou (referring to the Jianghan District, Jiang'an District and Qiaokou District) and Hanyang (referring to the Hanyang District). Known as "the city with hundreds of lakes", the water coverage ratio in Wuhan reaches up to 26.10% of the total land area. The majority of lakes and rivers break the continuity and integrity of urban space to some extent, thus creating the unique landscape of Wuhan shown in Figure 1. Our study focuses on the central area of Wuhan with a land area of 863 km^2, where 62% of the population (approximately 6.61 million people) resides. Over 70% of leisure entertainment facilities are clustered in urban Wuhan.

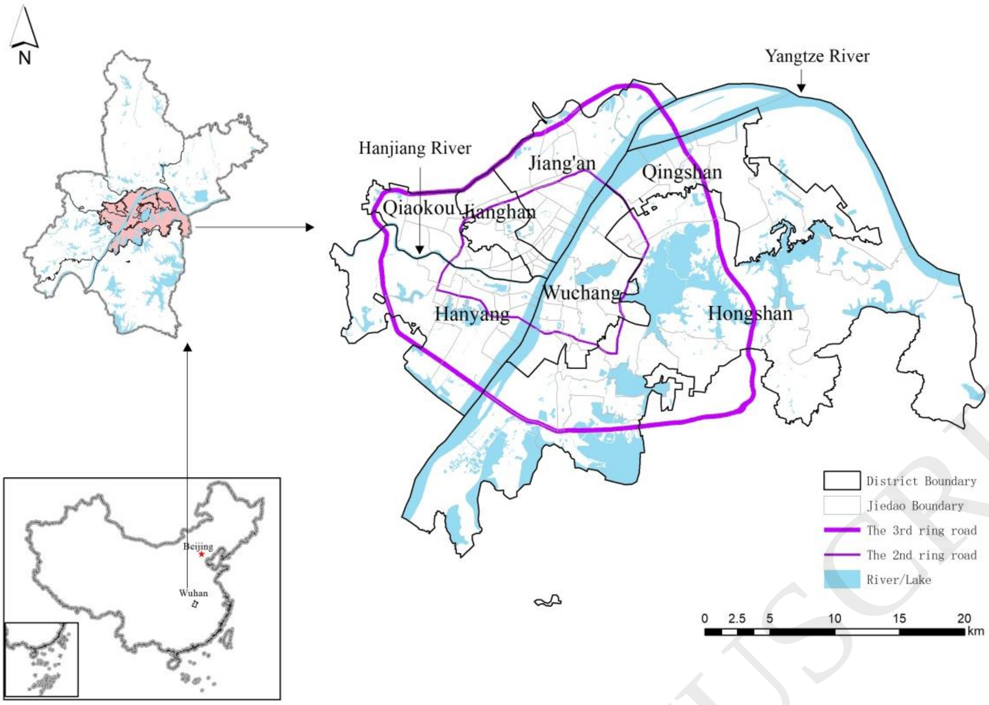

Figure 1 The study area – the central area of Wuhan in China (including seven urban districts as labelled in the map: Jiang'an, Jianghan, Qiaokou, Hanyang, Wuchang, Qingshan and Hongshan; the urban Wuhan can be divided into three-dimensional urban polycentric configuration by the 2nd and 3rd ring roads, namely the 1st-level urban centre, the 2nd-level urban centre and the 3rd-level urban centre.)

2.2 Data sources and preparation

To build the database of leisure entertainment facilities, we extracted points of interest (POIs) and the street network from the Baidu Map and Gaode Map (www.baidu.com, https://www.amap.com/). The final data set included 2914 leisure entertainment facilities in the study area. According to the classification of cultural and related industries issued by the China Statistics Bureau, we divided all leisure entertainment facilities into *bars, chess and card rooms, cybercafés, theaters, KTVs, parks, and stadiums (including gymnasium)*.

- Bars: As a type of personalized consumption, bars have become a popular venue for youthful relaxation. Initially, bars tended to be distributed around foreign embassies, foreign neighborhoods and foreign language schools. There are 246 bars in the study area.
- Chess and card rooms: These facilities provide Mahjong, poker and all types of chess activities. They are popular recreational areas for local residents. With the popularity of board games, chess and card rooms have begun to become popular among youth. There are 838 chess and card rooms in the study area.
- Cybercafés: These facilities used to be important places for residents to access internet services when computers and the internet were costly for most people. However, in the internet epoch, cybercafés are regarded as "sunset industries" and are not as appealing as before but have become a place for e-sports. Many cybercafés are seeking to upgrade their computer hardware, create an elegant environment and provide catering services. There are

811 cybercafés in the study area.

- Theaters: As a relatively old and influential type of leisure activity in China, most theaters are small-scale and single-functional. Due to significant improvement of the living standards, theaters have become commonplace for urban residents. There are 93 theaters in the study area.
- KTVs: These facilities first appeared in China in the late 20th century as leisure places where people can sing using a microphone. KTVs as a form of entertainment soon burgeoned throughout mainland China. There are 431 KTVs in the study area.
- Parks: Parks include municipal public parks, zoos, aquariums and amusement parks, and they encourage physical exercise, support social interaction and enhance public health. There are 226 parks in the study area.
- Stadiums: These facilities include specialized stadiums, comprehensive stadiums and gymnasiums, and they are mainly designed for outdoor activities. There are 269 stadiums in the study area.

All road networks are made up of a set of nodes connected by links. Nodes always have physical positions, and links always have a physical shape (Cooper et al., 2014). A key component of sDNA is to standardize the network link as a unit of analysis to avoid the modifiable areal unit problem. Network link density tends to proxy interesting activities of some sort; specifically, link density can be correlated with the density of jobs and homes by as much as 99% (Chiaradia et al., 2013).

Another key component of sDNA is selecting a scale of interest according to the study by Cooper et al. (2014). This scale defines how much of the surrounding network is considered when computing descriptive statistics for each link. As we are studying the locations of leisure entertainment activities, this scale is likely to match sensible walking or driving distances. This distance that is used is referred to as the network radius.

3 Methodologies

3.1 Kernel density estimation (KDE)

Kernel density calculates the density of the point features around each output raster cell. Conceptually, a smoothly curved surface is fitted over each point. The surface value is highest at the location of the point and diminishes as the distance from the point increases, reaching zero at the search radius distance from the point. KDE typically visualizes clusters of certain events. Peak values indicate clusters or hot spots of the events' distribution, while low values represent less-frequently occurring events (Cai, Wu and Cheng, 2013). This technique is widely employed for point pattern analysis (Bailey and Gatrell, 1995).

The kernel density estimation (KDE) method is used to transform discrete locations to a continuous raster system at the same scale so that the spatial layouts of various leisure entertainment facilities can be compared. The bandwidth and cell size are two parameters that have an impact on the outcome of the KDE (Anderson, 2009). Since the average distance of each *jiedao* to its neighborhood is approximately 2000 m, we set the bandwidth to 2000 m. The cell size is set to 100×100 m, and the raster layer consists of 201 903 grid cells (501 columns by 403 rows) for the study area.

3.2 Spatial design network analysis (sDNA)

The sDNA method is a sophisticated technique for urban network analysis that evolved from conventional space syntax (http://www.cardiff.ac.uk/sdna/). By redefining the nodes and links in graph theory, sDNA employs street network links as a unit of analysis rather than node points (Chiaradia et al., 2014; Cooper, 2015; Kang, 2017). Superior to accessibility analyses, graph science, and space syntax, sDNA can model localized network accessibility, centrality, navigability indices pertaining to radius-based networks, destination density, detour and flow, and it can also link structures and shapes at user-specified network scales (Sarkar et al., 2015b). This approach allows analysts to capture behaviorally meaningful subtleties in urban street networks.

According to the studies conducted by Kang (2017) and Cooper et al. (2014), we chose four key metrics in terms of *closeness*, *betweenness*, *severance*, and *efficiency* that represent the multidimensional characteristics of street networks (Cooper et al., 2014; Sarkar et al., 2015a), as shown in Table 1.

- *Closeness* reflects the connection and reachability between the local part of the space and all other spaces in the system. A path that is close to destinations is more likely to be selected by people. *Closeness* is measured by the mean Euclidean distance (MED) between the origin and all reachable destinations within a radius and network quantity penalized by Euclidean distance (NQPED). The hypotheses behind these two measurements are an optimum built environment density for leisure entertainment facilities and a large physiological barrier between the origin and its neighborhood for twisting environments.
- *Betweenness* estimates how each network link is populated as entities move throughout the system and thus assesses all possible trips passing through a network link. This factor is measured by flow prediction on the basis of the shortest Euclidean path distance and hypothesizes an optimum level of pedestrian flow for leisure entertainment activities.
- *Severance* reflects the opposite of connectivity in network detour analyses. This factor is measured by the mean crow flight (MCF) distance and diversion ratio, which proxy the cognitive difficulty of navigating by measuring how twisted the local network is.
- *Efficiency* measures the navigability of the connected links that cover the space or the distance in local areas. This factor can be measured by the convex hull maximum radius (HULLR) and convex hull shape index (HullSI), which hypothesize more opportunities for pedestrian interaction with greater efficiency of navigation on foot.

Table 1 Metrics of the street network configurations and relevant hypotheses

Metric	Measurement	Description
Closeness	Mean Euclidean distance (MED)	Mean length in Euclidean metrics between the origin and all reachable destinations within a radius
	Network quantity penalized by Euclidean distance (NQPED)	Number of links divided by the Euclidean length along networks within a radius
Betweenness	Betweenness (BTA)	Flow prediction based on the shortest Euclidean path distance

Severance	Mean crow flight (MCF)	Mean crow flight distance between the centers of two links within a radius
	Diversion ratio (DIVA)	Mean path distance to crow flight length per route
Efficiency	Convex hull maximum radius (HULLR)	Maximum radius of the convex hull shape covering street networks within a specific radius

Source: Partially modified from Cooper et al. (2014) with additional information by the author.

3.3 Spatially stratified correlation analysis

The geographical detector tool has less-constrained assumptions than other techniques. This tool mainly consists of four functions: the risk detector, the factor detector, the ecological detector and the interaction detector. The factor detector q-statistic measures the spatially stratified heterogeneity of variable Y (referring to the kernel density of various leisure facilities) or the determinant power of the covariate X (metrics of street network configurations) of Y. The determinant power of covariate X to the spatial pattern of leisure facilities, or the q-statistic, is defined as follows:

$$q = 1 - \frac{1}{N\sigma^2}\sum_{h=1}^{L} N_h \sigma_h^2$$

where N and σ^2 represent the number of units and the variance in population Y in a study area, respectively, with population Y composed of L strata ($h = 1, 2, \dots, L$); and N_h and σ_h^2 represent the number of units and the variance in Y in stratum h, respectively.

When $q \in [0,1]$, Y does not have spatially stratified heterogeneity, and when q is equal to 0, no association exists between Y and X. When q is equal to 1, Y has perfect spatially stratified heterogeneity or Y is completely determined by X.

4 Results analysis

4.1 Statistical distributions of street configurations

People may perceive the configurations of street networks differently when walking and driving. We set the neighborhood radius of the walking and driving modes to 2 km and 15 km, respectively. To compare the effects of these two modes on the locations of various leisure entertainment facilities, four metrics, namely, *closeness*, *betweenness*, *severance* and *efficiency*, in terms of six indicators (which have been elaborated in Table 1) are derived from the sDNA software under the walking and driving modes, as shown in Figures A1 and A2 of the Appendix. All statistics are produced per individual link.

In addition to the frequently used indices representing closeness and betweenness, the degree of severance in the road network has received frequent mention. Street networks with less severance will create more opportunities for people to walk or drive and thus improve urban vitality. As shown in Figure A1and Figure A2, less severance in the walking mode is found in the urban fringe or scenic spots, where the street design and the neighborhood environment are more suitable for walking. However, more severance in the driving mode may inhibit driving behaviors, which was found in the major roads connecting the city center and the new towns, as well as scenic spots.

The most promising parameter is HULLR, which measures something akin to the inverse of physical severance. High HULLR values indicate that the nearby network efficiently covers Euclidean distance. As shown in Figure A1and Figure A2, high HULLR values are found in main urban roads in both modes.

4.2 Spatial distribution of leisure entertainment activities

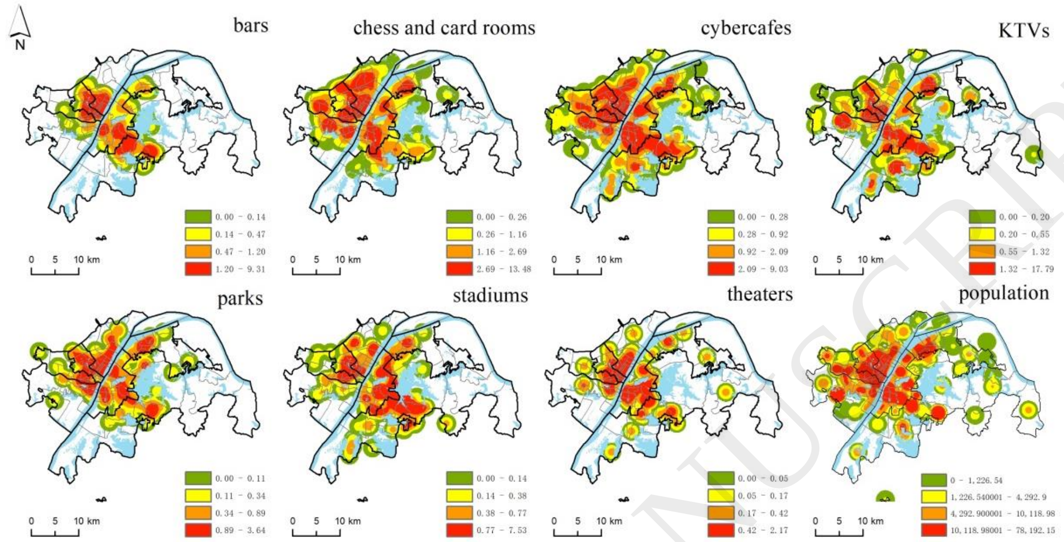

Figure 2 Spatial layouts of various leisure entertainment facilities: the red colour represents high density whereas the green colour represents low density.

Figure 2 displays the spatial layouts of various leisure entertainment facilities and the population density. According to their different layout characteristics, we can classify the spatial layout into spot, the ring and ribbon patterns.

The spot pattern occurs in the spatial layouts of bars, KTVs and theaters. These activities tend to be concentrated in one area (usually a city center), and the activity expands into surrounding areas within a relatively short radius because of cost-minimizing location decisions, with the advantages of large-volume population flow and convenient transportation. Bars are more concentrated within the 2nd ring, whereas KTVs and theaters are more widespread and diffuse from urban cores to the peripheral newly developed areas in the 3rd ring.

The ring pattern refers to the agglomeration intensity of leisure entertainment facilities, which decreases as the distance increases within a buffer zone. Chess and card rooms, cybercafés, stadiums and parks have ring-like spatial patterns. The distributions of these leisure entertainment facilities are in close accordance with the spatial patterns of the population, and they mainly serve local residents and are distributed along the streets. Therein, entertainment activities, such as chess and card rooms and cybercafés, have higher densities than leisure facilities, such as parks and stadiums. Chess and card rooms favor the location of old Hankow, where population aging is evident in these residential neighborhoods. This activity becomes an important way for elderly people to communicate and entertain themselves by playing cards, chess or Mahjong. In contrast, cybercafés are more evenly distributed in Wuhan. Compared with other leisure entertainment facilities, the distribution of cybercafés forms a long cluster along Wuluo Road, which is highly related to the agglomeration of universities and enterprises along the street.

From the leisure perspective, it is interesting to observe more parks in old Hankow, whereas there are more stadiums in the new town of Wuchang, which may be attributed to housing reform and the population structure of Wuhan. For historical reasons, most old communities are situated in old Hankow. The Danwei, as a representative of the state (or the collective), including the public-owned enterprises, institutions and government offices, took direct charge of the development, distribution and management of public housing for its employees (Wang and Chai, 2009; Zhu, 2000). However, this type of *Danwei* welfare housing lacks green space planning within the community. Instead, public parks were planned by the government for residents to use for physical activities during their leisure time. However, for the newly developed town of Wuchang, the provision of public housing was mostly committed to the market as a result of housing reform, and the development of market housing was recognized as an efficient method to increase government income and promote economic growth. To attract purchasers, this type of commodity housing is usually equipped with private green space for local residents. In addition, an agglomeration of universities in Wuchang provides inexpensive land for the construction of stadiums and the clustering of young people, and students in Wuchang create larger demands for outdoor sports in stadiums than in Hankow, which has a large aging population.

The ribbon pattern is evident in Wuhan, and various leisure entertainment facilities tend to be distributed along the Yangtze River, Han River or arterial streets. Bars, cybercafés, stadiums and KTVs are mainly distributed in parallel or perpendicular to the Yangtze River. According to the above analysis, growth points (including those representative and influential leisure entertainment facilities) and development axes (including roads and river systems) play an important role in the spatial optimization of leisure entertainment activities. The effect of the point-axis structure on arranging the spatial layout of leisure entertainment facilities is significant in many Chinese cities.

4.3 Spatially stratified correlations between street configurations and leisure entertainment activities

The KDE method is used to convert the link-based street indicators to the same raster system used for the leisure entertainment locations. A fishnet with the width and height of the cell both set to 500 m is constructed, and 3828 sample points are set at the center of each fishnet cell to extract the corresponding values of street indicators and the kernel density of various leisure entertainment facilities. Based on the requirements of the geographic detector tool, six street indicators are transformed from continuous values to categorical values by K-means clustering.

Table 2 presents the results of the q statistics between street indices and the spatial distribution of leisure entertainment activities, which demonstrates the contribution of each street indicator to the distribution of each leisure entertainment activity under the driving and walking modes. Regardless of other influencing factors, the maximum contribution of street configurations to explaining the distribution of cybercafés is 66% closeness, whereas the minimum contribution to explaining the distribution of KTVs is 16% betweenness, which illustrates that cybercafés are preferably situated in places with closeness, whereas KTVs avoid venues with a large flow of passengers.

Different driving/walking modes also have different preferences for various street configurations. Closeness is significant for both walking and driving in explaining the distribution of leisure entertainment activities, whereas walking prefers betweenness, perhaps for a sense of security. Severance and efficiency are both slightly more important under the walking mode because these two metrics can reflect their physiological barriers and navigation complexity when people walk through a ‘twisted’ road network.

Different street metrics contribute differently to the distribution of various leisure entertainment activities. Overall, the determining power of street metrics over the distribution of cybercafés, as well as chess and card rooms, is the highest, whereas that of KTVs is the lowest. The spatiality of cybercafés, as well as chess and card rooms, is more closely linked to the street network configurations, whereas the locations of KTVs barely reflect the traffic network. Other influential factors, such as the attractiveness of the commercial center and internal agglomeration, may have strong explanatory power over the distribution of KTVs.

Specifically speaking, chess and card rooms favor closeness in both modes because most people tend to play cards or chess with their friends or in familiar neighbors. The influence of closeness on the distribution of cybercafés is the strongest, whereas that of severance is the weakest. Therefore, easy accessibility to cybercafés is the most important factor, whereas the psychological barrier of navigation has almost no effect on its distribution. Bars and stadiums prefer closeness in the driving mode and betweenness in the walking mode. When people drive to a bar or stadium, traffic accessibility is their foremost consideration. However, when they choose to walk, they prefer a bar or stadium with large betweenness. Betweenness also has the strongest explanation for the distribution of parks and theaters under both modes.

Table 2 *q* statistics between street indices and spatial distribution of leisure entertainment activities for driving/walking modes

	Closeness				Betweenness		Severance				Efficiency	
	MED		NQPED		BTA		MCF		DIVA		HULLR	
	Driving/walking		Driving/walking		Driving/walking		Driving/walking		Driving/walking		Driving/walking	
Bars	0.29	0.26	0.37	0.4	0.36	0.42	0.26	0.33	0.28	0.28	0.3	0.31
Chess and card rooms	0.47	0.45	0.58	0.58	0.45	0.54	0.51	0.54	0.49	0.48	0.52	0.53
Cybercafés	0.6	0.57	0.66	0.66	0.59	0.65	0.58	0.64	0.59	0.57	0.62	0.62
Stadiums	0.37	0.41	0.38	0.42	0.33	0.47	0.32	0.37	0.35	0.35	0.35	0.36
KTVs	0.19	0.18	0.19	0.24	0.16	0.22	0.2	0.21	0.2	0.17	0.21	0.2
Parks	0.32	0.33	0.44	0.43	0.49	0.44	0.33	0.38	0.34	0.32	0.36	0.36
Theaters	0.31	0.28	0.43	0.36	0.47	0.38	0.3	0.34	0.29	0.28	0.32	0.32
Average	0.36	0.35	0.44	0.44	0.41	0.45	0.36	0.40	0.36	0.35	0.38	0.39

4.4 Policy implications

The city is a phenomenon of structured complexity. Good cities tend to balance a reasonably ordered city form and places of numerous and varied meetings and transactions (Montgomery, 1998; Sung and Lee, 2015). By examining the city from the perspective of street configurations, we find that a good street network design cannot be measured by only closeness and betweenness. Severance and efficiency are two promising parameters that can reflect the physical and psychological barriers of the walking/driving behaviors of people on the street. In this paper, we note that the city center does not provide a suitable walking environment for meetings or relaxation, and the major roads that connect the urban centers to the urban fringe have low efficiency for driving. This phenomenon is widely observed in large cities in China. Based on the results of this study, policies should be enacted to optimize the street network design and enhance traffic demand management. More strategies of leisure-related urban redevelopment should be proposed in the urban center to create a livable environment for urban residents.

The spatial features of leisure entertainment activities, such as the location, density and neighborhood contexts, are essential for scientific urban planning. For example, various types of leisure entertainment activities have distinct locational preferences. Leisure entertainment activities are highly consistent with population distribution, resulting in the sparse distribution of leisure facilities in the suburbs. Moreover, as a result of housing reform and development trajectories, urban parks are well planned in the old town. Thus, urban planners should emphasize the spatial equity of commercial services and parks to improve city life in new towns and suburbs. A geospatial analysis could help urban planners locate the places where the demand and supply of leisure activities are mismatched.

5 Conclusions

The paper examines the geography of street network features in a typical inland city, Wuhan, by using the sDNA method. In addition to the widely recognized features of closeness and betweenness, the sDNA method is capable of capturing both severance and efficiency, which are important to reflect the physical environment of the streets that people use for walking/driving. The KDE method is employed to measure the proximity of every place to streets and various types of leisure entertainment facilities. The two sets of densities are then analyzed to determine whether spatially stratified correlations exist and whether various leisure entertainment facilities are more spatially correlated with specific types of street features.

The spatiality of leisure entertainment activities addresses the sustainable development of cities and the quality of life of citizens. Leisure-guided spatial planning is conducive to promoting health justice and reducing social inequality. Investigation of the association between street networks and leisure entertainment activities helps to optimize road design, enhance traffic demand management, and implement more strategies for leisure-related urban redevelopment. This paper uses techniques such as KDE, sDNA, and spatially stratified correlation analysis and concludes with the following results:

- By examining the city from the perspective of street configurations, we find that a good street network design cannot be measured not only by closeness and betweenness but also by severance and efficiency.

- The distribution of leisure entertainment facilities demonstrates significant spatial agglomeration. Various leisure entertainment facilities are spatially different in their agglomeration extents and distributional directions.
- The spatial correlation between leisure entertainment activities and street network features is revealed. Various types of leisure entertainment activities have distinct locational preferences for street networks.

According to the results, this paper sheds some insights into policy implications. Future policies should optimize the street network design and enhance traffic demand management. More leisure-related urban redevelopment strategies should be proposed in the urban center to create a livable environment for urban residents. Moreover, urban planners should emphasize the spatial equity of leisure entertainment activities to improve city life in new towns or suburbs.

Finally, this study has a few limitations. First, we fail to consider the street traffic volume, which contributes to the features of the street conditions. Second, a better understanding of the detailed causative mechanisms of the relationship between the location preferences for entertainment facilities and the measured street pattern metrics is needed. Finally, knowledge of the dynamic correlations between multiple features of street patterns and the spatial distribution of entertainment facilities is lacking due to our use of cross-sectional rather than panel data.

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Appendix:

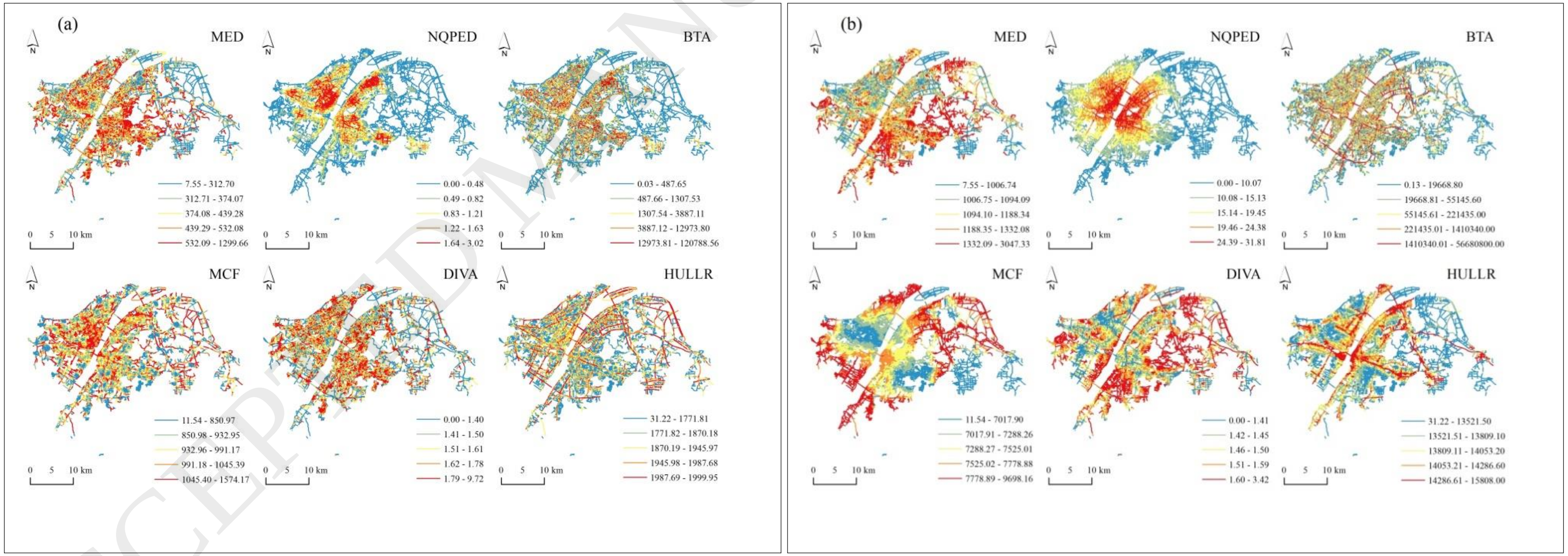

Figure A1 Spatial patterns of six street metrics under the walking mode (a) and under the driving mode (b): red colour represents high value whereas blue color represents low value; MED and NQPDA measure the closeness of the street network; BTA measures the betweenness of the street network; MCF and DIVA measures the severance whereas HULLR measures efficiency of the street network.

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