A Study on the Characteristics and Impact Mechanisms of Urban Vitality in Beijing Commuter Circle Based on Gradient Theory

Jiang Yuxiao, Lu Yiyun, Welcoming the Xia with Ren Lijian

The study of urban vitality has received widespread attention from multiple fields of urban science. However, existing research mainly focuses on the urban scale, with few studies on vitality across administrative regions. Using Tencent Location Based Services (LBS) data, taking the Beijing commuting circle as an example, by constructing urban vitality measurement indicators, analyze the multidimensional spatial pattern of urban vitality; Divide the vitality gradient of Beijing's commuting circle based on the vitality tidal footprint, and explore the spatial characteristics of urban vitality in different gradient areas; Further study the impact mechanism of urban vitality levels in different gradient regions using spatial regression models. Research has found that the commuting circle in Beijing has formed a dynamic spatial pattern of "one main, one secondary, and multiple points"; Divide the central urban area of Beijing into three gradient zones: high, medium, and low, with radius thresholds of 8-22 km, 32-68 km, and 94-134 km, respectively; Except for the Orson area, the gradient level is directly proportional to the energy level of the vitality center and inversely proportional to its hinterland range; Except for the significant positive correlation between road density and land use mix and vitality levels in various gradient areas, the impact mechanism of urban vitality varies in different gradient areas. By revealing the vitality levels and influencing mechanisms of different gradient regions, more precise planning strategies can be proposed from the aspects of regional structure, urban-rural integration, transportation organization, and facility support, thereby promoting high-quality development of urban and rural areas.

Keywords: urban vitality; Gradient theory; Beijing Commuter Circle; Built environment; Impact mechanism

Urban vitality has received widespread attention from urban researchers due to its positive impact on urban resilience, social sustainability, and innovation capabilities. With the acceleration of globalization, major urban diseases such as traffic congestion and imbalanced employment and housing have gradually become prominent, leading to a mismatch between urban functions and vitality levels in some regions, and an imbalanced distribution of urban vitality within and between cities. To address the aforementioned issues, scholars suggest enhancing urban vitality through planning methods, such as enhancing street aesthetics, increasing public spaces, and establishing pedestrian friendly neighborhoods.

Although scholars are continuously deepening their research on urban vitality, these studies mainly focus on the street or city level, with less research on cross administrative scales. With the improvement of urbanization level in our country, the connections between cities have broken the administrative boundaries of cities [9], highlighted by spatial connections dominated by commuting behavior. This also triggers a new research demand to explore the distribution characteristics and impact mechanisms of vitality within the region from the perspective of urban or commuting circles.

This indicates that the urban commuting circle is not only a geographical area where urban residents travel back and forth from their place of residence to their workplace, but also includes various elements such as residents, economic activities, social relationships, and transportation networks within this area. Taking the commuting circle in Beijing as an example, with the continuous improvement of the Beijing Tianjin Hebei comprehensive transportation system, some residents working in Beijing choose to live in the surrounding Beijing area with lower housing costs. Therefore, studying only the urban vitality of the central urban area of Beijing cannot accurately reflect the activity status of residents within the city. By conducting research on urban vitality within the scope of Beijing's commuting circle, we can gain a deeper understanding and grasp of the relationship between Beijing and its surrounding areas, and comprehensively understand the lifestyle and rhythm of residents. In addition, by studying the spatiotemporal patterns and influencing mechanisms of urban vitality in Beijing's commuting circle at the meso and micro scales, the problems in spatial development within the region can be revealed, and targeted optimization of functional spatial organization can be carried out.

"Gradient" refers to the phenomenon of uneven spatial distribution or uneven development stages of things, whose spatial distribution generally increases or decreases along a direction. In terms of metropolitan areas or urban agglomerations, due to the polarization effect of policy, industry, and population concentration towards the central city, high gradient areas of vitality are formed within the metropolitan area. With the expansion of the central city scale, excessive population agglomeration has led to urban problems, resulting in some residents transferring and vitality overflowing, forming different vitality gradients within the region. However, how can different vitality gradients be identified? What is the spatial layout form of vitality gradient? Is the influence mechanism of different vitality gradient zones the same? These issues are not yet clear.

Therefore, scientifically dividing regional vitality gradients and exploring the impact mechanism of urban vitality at different gradient levels has a positive effect on perceiving the activity level of urban residents across administrative regions and stimulating regional vitality. This study takes the Beijing commuting circle as an example, based on Tencent LBS data, and uses the method of analyzing the tidal footprint of vitality to divide the gradient of urban vitality at the cross administrative scale. At the same time, explore the spatiotemporal distribution structure of urban vitality in the research area, identify the vitality centers and their gradient ranges within the region, and explore the impact mechanism of built environmental factors on urban vitality at different gradient levels.

1. Research data and methods

1.1 Overview of the research area

The commuting circle is a complex spatial form composed of high-speed railway corridors, highway networks, transportation hubs, and industrial layouts. Referring to this concept, the Beijing commuting circle defined in this article refers to the surrounding areas that have a 1-hour commuting connection with the spatial scope of Beijing. Considering that the effectiveness of relevant policy formulation mainly applies to people's governments at or above the county level, this article selects a complete administrative unit of districts and counties, and ultimately determines the scope of Beijing's commuting circle as the entire area of Beijing and Tianjin, as well as some districts and counties of Baoding, Chengde, Langfang, and Zhangjiakou in Hebei Province (Figure 1), with a research area of 63111.82km ^{2} ， The permanent population is 48.3345 million people (as of 2020).

The scope of Beijing's commuting circle in this study far exceeds that of the central urban area of Beijing. In order to more accurately study the cross administrative mobility of population within the Beijing commuting circle and adapt to the spatial granularity limitations of data acquisition, this study chooses to use a 2km coverage of the Beijing commuting circle × A 2km grid is used as the basic analysis unit to replace the original district and county administrative units.

In the study of basic unit construction, by using 2 km × A 2 km grid was used to summarize the data, and 10551 grids were obtained by removing grids with zero data volume (mainly forests, farmland, or large nature reserves) in the study area. Each grid summarizes the number of Tencent user activities to represent the city vitality of the table.

1.2 Research Methods

1.2.1 Exploration of Vitality Space Pattern: Constructing Vitality Measurement Indicators

Use Tencent LBS data to measure the urban vitality of Beijing's commuting circle. Considering the accuracy of mobile data after midnight, the data between 6:00 am and 24:00 am was retained. The dataset includes sampling point ID, sampling point coordinates, and the number of human activities with 18 timestamps (Table 1). Take the average of 5 working days as the average number of human activities for the 18 timestamps at this sampling point.

In order to comprehensively explore the spatial distribution pattern of urban vitality, five urban vitality indicators were constructed based on the collected number of human activities, namely average vitality level, urban vitality stability, daytime vitality level, nighttime vitality level, and diurnal vitality tide, as shown in Table 2.

1.2.2 Vitality Gradient Identification: Vitality Tidal Footprints

Referring to the concept of urban heat island footprint, a dynamic tidal footprint analysis is proposed [17]. The dynamic tidal footprint characterizes the spatial range of urban vitality occurring within a region, and fully and continuously reflects the spatial distribution characteristics of urban day and night dynamic tides. The diurnal vitality tidal value in the central urban area of the city is positive, and the tidal effect gradually weakens from the central urban area to the surrounding areas. Therefore, this article selects Tiananmen Square in the central urban area of Beijing as the center of the vitality tidal footprint. Multiple concentric circles are established at intervals of 2 km to cover the entire research area. The sum of all grid diurnal vitality tidal values (VT) within each concentric circle is calculated, and the relationship between the radius of concentric circles and the diurnal vitality tidal sum is established. The range where the sum of diurnal vitality is zero is defined as the vitality tidal footprint. Meanwhile, based on the changes in the relationship between day and night vitality tides and radius, determine the urban vitality gradient of Beijing's commuting circle. The formula for calculating the dynamic tidal footprint is as follows:

$$\begin{cases} r_1 = 2 \\ A_1 = \pi r_1^2 \\ r_2 = 2 \times 2 \\ A_2 = \pi r_2^2 \\ \quad \vdots \\ r_i = 2 \times i \\ A_i = \pi r_i^2 \end{cases} \tag{1}$$

$$S_i = \sum_{j=1}^{m} V_{\mathrm{T}} \tag{2}$$

In equation (1), Ai represents the area of the i-th concentric circle, ri represents the radius of the i-th concentric circle, i=1,2,3,..., n. type

(2) S represents the sum of day and night active tides in the i-th concentric circle, m represents the number of grids in the i-th concentric circle, and VT represents the day and night active tide values in the grid.

1.2.3 Vitality characteristics of different gradient regions: identification of vitality centers and measurement of vitality center hinterland

By using the neighborhood analysis of ArcGIS, the average vitality level of each grid is extracted for peak points. The identified peak point grid is defined as the vitality center of the Beijing commuting circle, and the natural breakpoint method is used to divide the identified vitality center into five different energy levels. Each vitality center serves as the core area of human activities in the surrounding area, which can be influenced by agglomeration and diffusion effects. The hinterland of the vitality center can be understood as the "force field" of the influence of the vitality center. The strength of the force field in the hinterland of different vitality centers varies, and the formula for calculating the field strength is as follows:

$$F_{ij} = \frac{Z_i}{d_{ij}^a}$$

In equation (3), Fij represents the field strength of the vitality center i on the grid j within the region; Zi is the average vitality level of vitality center i; Daij is the distance from the vitality center i to grid j; A is the distance friction coefficient, usually taken as 2.0.

Due to the influence of various dynamic centers within the study area on any grid j, by calculating the field strengths of each dynamic center and comparing them with each other, the dynamic center with the greatest impact on grid j's field strength can be found, and grid j can be considered as its hinterland.

1.2.4 Mechanism of vitality gradient influence: spatial regression analysis

The evaluation of the vitality gradient impact mechanism used the classic 5D framework in built environment research [19-20], which includes density, destination accessibility, diversity, design, and transportation transfer distance. On the basis of the 5D framework, three possible factors that may affect vitality are added, including infrastructure construction level, economic activity intensity, and greening level, forming the indicator system of this study (Table 3). The POI data comes from the 2019 POI dataset of Gaode Map. The data on road density, bus stops, subway stations, intercity railway stations, and highway entrances and exits are sourced from the Open StreetMap map. Due to data acquisition limitations, this article refers to relevant research both domestically and internationally, using different types of POI data to replace various types of land use data in the Land and Sea Classification for Land Spatial Survey, Planning, and Use Control. By calculating the entropy values of each type of POI, land use diversity is obtained. Among them, the catering service POI represents commercial service land, the public service facility POI represents public management and public service land, and the residential area POI represents residential land. Use enterprise POI to represent the distribution of employment in the secondary industry within the region, in order to represent industrial and mining land.

The data on economic activity intensity and population density are both from the Resource and Environmental Science Data Registration and Publishing System. The data on greening level and infrastructure level were obtained from Sentinel-2 remote sensing images and NPP-VIIRS nighttime light images obtained in April 2019, respectively. In addition, due to some differences in the built environment indicators in the urban center, urban fringe, and rural areas of Beijing's commuting circle, indicators were selected based on subsequent gradient areas during the analysis process.

Referring to the study by Wang Xuerui et al. [25], a global Moran's index analysis was first conducted, and the results showed that there was a significant spatial autocorrelation in the average vitality level (Moran's I=0.394; p<0.001). Therefore, this article adopts two commonly used spatial regression models, namely Spatial Lag Model (SLM) and Spatial Error Model (SEM), for regression analysis, and selects models through Lagrange test. The formula for calculating the spatial lag model is as follows:

$$y = \rho W_y + X\beta + \varepsilon$$

In equation (4), y is the dependent variable and X is the matrix of explanatory variables, β It is a vector of coefficients, ε It is a vector of random error terms. ρ It is a spatial lag parameter, and Wy is a vector of spatial weights.

The spatial error model is a method for dealing with spatial autocorrelation in error terms, which can be understood as a combination of the standard regression model and the spatial autoregressive model of the error term. The calculation formula is:

$$Y = X\beta + \varepsilon, \quad \varepsilon = \lambda W \varepsilon + \mu, \mu \sim N(0, \sigma 2 I)$$

In equation (5): λ It is an autoregressive parameter that measures the spatial dependence of the error term; μ I is the random error term; σ Is the standard deviation.

2. Spatial distribution characteristics of vitality in Beijing's commuting circle

2.1 Urban vitality spatial pattern

As shown in Figures 2 (a) and 2 (b), the spatial distribution of vitality in Beijing's commuting circle exhibits a hierarchical structure of "one main and one secondary with multiple points", and the level of vitality in the region shows significant differences between cities and between urban and rural areas. Among them, the areas with the highest average level of vitality (VL) are mainly concentrated in the core areas of Beijing's central urban area (within the Fourth Ring Road) and Tianjin's central urban area (within the Central Ring Road). The areas between the Fourth and Sixth Ring Roads in Beijing and the core areas of each district and county also have a high level of vitality, while the vitality level of peripheral rural areas is generally low. Adjacent to the southeastern border of Beijing, there are multiple obvious high vitality gathering areas, such as Langfang City, Xianghe County, Dachang Hui Autonomous County, and the central area of Sanhe City. More than 70% of the research area is a low vitality area with relatively poor development status. The terrain conditions in the northern region have to some extent affected population aggregation and further affected the local vitality level.

The spatial distribution of Vitality Stability (CV) is closely related to regional development patterns. From the distribution chart of vitality stability in Figure 2 (c), it can be seen that the central urban area of Beijing has characteristics such as high urbanization, high economic vitality, and complete living facilities, greatly increasing the population attractiveness of Beijing. The stability of vitality in the core areas of the central urban area of Beijing and other cities and counties within the region is relatively high ($CV<0.506$), while the stability in rural areas is relatively low, indicating significant changes in vitality throughout the day in rural areas. At the same time, Beijing and some areas southeast of Beijing have formed a continuous high vitality and stability area, breaking through the scope of administrative boundaries.

Figures 2 (d) and 2 (e) respectively show the spatial distribution characteristics of daytime vitality level (DV) and nighttime vitality level (NV) in the study area. Figure 2 (f) shows the spatial distribution of diurnal tidal activity. The high value areas of vitality tides are mainly concentrated within the Third Ring Road in the central urban area of Beijing, Zhongguancun, Wangjing, Yizhuang, as well as some areas of Nankai District, Heping District, and Binhai New Area in Tianjin. Low value areas are mainly interspersed around high value areas. In addition, the centers of the counties around Beijing are mainly low value areas.

2.2 Vitality gradient distribution

The "gradient" of urban areas often presents layer characteristics. This article takes Tiananmen Square as the center and uses concentric circles of different radii to calculate the dynamic tides, establishing a corresponding relationship between the sum of day and night dynamic tides and the radius

(Figure 3). The sum of day and night active tides increases first and then gradually decreases with the increase of the radius of the concentric circle. At 110 km, the sum of positive and negative values of active day and night tides is equivalent, and the sum of active tides is 0, reaching the maximum range of the Beijing commuting circle. On this basis, based on the changes in the slope of the dynamic tidal footprint line in Figure 3 and the urban-rural transition characteristics of the Beijing commuting circle, the research area can be divided into four types of areas, namely the ideal high, medium, and low vitality gradient areas formed from the central urban area outward in sequence, and the areas more than 110 km away from the center are defined as other areas. Specifically, the diurnal vitality tides first increase with the increase of radius, and in most areas within the corresponding concentric circle, the daytime vitality level is higher than the nighttime vitality level. At a radius of 16 km, the diurnal vitality tides reach their peak. Afterwards, the diurnal tidal activity gradually decreased. In the area with a radius of 16 km to 60 km, the corresponding tidal activity experienced a process of rapid decline and then slowing down. However, when the radius exceeded 60 km, the rate of decline tended to stabilize until the diurnal tidal activity decreased to 0 at a radius of 110 km. Based on the spatial distribution of the central urban area, urban fringe areas, and peripheral rural areas in Beijing, 16 km, 60 km, and 110 km are determined as the critical values for dividing into high, medium, and low vitality gradient areas.

Figure 4 (a) shows a schematic diagram of the urban vitality gradient in an ideal concentric circle pattern, with Tiananmen Square as the center, a circle with a radius of 16 km as the high vitality gradient area, a concentric circle with a radius of 16-60 km as the medium vitality gradient area, and a circle with a radius of 60-110 km as the low vitality gradient area. Considering the main development direction and natural terrain conditions of Beijing, dividing gradients into concentric circles may not accurately express the actual vitality distribution of Beijing's commuting circle. Therefore, this study repeated the dynamic tidal footprint experiment in 8 equally divided directions to determine the dynamic gradient footprints in each direction, and obtained the dynamic gradient map of the Beijing commuting circle in different directions [Figure 4 (b)]. The radius threshold of each dynamic gradient area was determined based on the radius size in different directions within each gradient. Specifically, the radius threshold range for high gradient areas is 8-22 km, which includes all areas of the Third Ring Road in Beijing and some areas from the Southwest Fourth Ring Road to the Fifth Ring Road; The threshold range for the boundary radius of the medium gradient area is 32-68 km, with a longer radius in the southwest northeast direction and shorter in other directions. In addition to Beijing, it also includes some areas of Zhuozhou, Langfang, and North counties; The threshold for the boundary radius of low gradient areas is 94-134 km, and the radius of the Southeast Beijing Tianjin Corridor is the shortest of 94 km, mainly including some areas of Wuqing District, Tianjin City. Other directions include not only Fangshan, Yanqing, and Pinggu within Beijing, but also parts of Jizhou District, Zhangjiakou, Baoding, and Chengde. Overall, the level of regional vitality decreases sequentially along the high gradient area, medium gradient area, and low gradient area.

The high gradient area is mainly composed of high-density urban built-up areas, the medium gradient area is mainly composed of the peripheral urban edge areas of the central urban area of Beijing, and the low gradient area is mainly composed of rural areas and the county center of the peripheral areas of Beijing.

2.3 Each gradient vitality center and its hinterland range

50 vitality centers within the study area were identified through ArcGIS mountaintop analysis, as shown in Figure 5 (a). Using the average vitality level as the standard, the energy levels of each vitality center were divided into 5 levels using the natural breakpoint method (Figure 6). The vitality level of the Aosen area is significantly higher than other vitality centers, making it the only primary vitality center. This area has complete supporting facilities and is the area with the highest residential density in the research area, with concentrated and relatively balanced occupational and residential functions. The secondary vitality center includes different areas within the central urban area of Beijing, such as the CBD core area and Zhongguancun. The regional employment function is slightly stronger than the residential function, and the regional vitality level is relatively high. The third level vitality center is composed of areas such as Communication University, Yizhuang, and Sihui outside the central urban area of Beijing, as well as the central urban areas of Tianjin, Baoding, Zhangjiakou, and Langfang, with a relatively balanced distribution. The fourth and fifth level regions are mainly located in the central areas of districts and counties in the outskirts of Beijing and some districts and counties around Beijing. These regions are mainly located in the peripheral areas with weaker economic development levels within the research area. It is worth noting that the vitality centers in the three northern counties, which are closely related to personnel in Beijing, belong to the fourth and fifth level vitality centers respectively, with a relatively low level of vitality.

By analyzing the energy level distribution of vitality centers in different gradient areas and their influence on the hinterland, we can further understand the vitality characteristics of different gradient areas within the Beijing commuting circle. In terms of energy level distribution of vitality centers, the statistical identification of vitality centers based on the division of high, medium, and low gradients was studied, and the results are shown in Figure 5 (b) and Table 4. Overall, the number of vitality centers in each gradient region is relatively balanced. The energy level of vitality centers in high gradient regions is higher, with the previous three levels being the main energy level. The middle gradient region mainly includes third and fourth level vitality centers, while the ability of vitality centers in low gradient regions is lower, with the fifth level vitality center being the main energy level. From the perspective of the hinterland of the vitality center, the hinterland of each vitality center can be determined by calculating the field strength of each vitality center. As shown in Figure 5 (c), the boundaries of each vitality center are clear, and there is basically no competition for hinterland. The Aosen area with the highest vitality level has the largest range of vitality centers in the hinterland, with a characteristic of spreading northwestward. This distribution feature may be related to the lack of vitality center distribution in the northwest of the central urban area of Beijing. The rest of the vitality centers have clear contiguous hinterland around themselves, and the regional distribution of vitality is more obvious. The dynamic hinterland of the Beijing Tianjin Corridor located in the southeast is relatively evenly distributed, while the distribution of dynamic centers in the northwest is relatively small. The range of vitality center hinterland is calculated according to the high, medium, and low gradients as shown in Figure 5 (d). Except for the larger hinterland in the Aosen area, the size of the other vitality center hinterland is inversely proportional to its gradient level. That is, the vitality center hinterland in the high gradient area is smaller, the vitality center hinterland in the low gradient area is generally larger, and the vitality center hinterland in the medium and low gradient area is mainly concentrated in the southeast direction of the study area.

3. The impact mechanism of vitality gradient in Beijing's commuting circle

In order to explore the relationship between built-up environmental factors and urban vitality levels at different gradient levels, spatial regression models were established using high gradient, medium gradient, and low gradient regions as the research scope in Figure 4 (b), with the average vitality level as the dependent variable. According to the results of the Lagrangian factor test, the SEM model is used for high gradient areas, and the SLM model is selected for medium gradient and low gradient areas. The analysis results indicate that the impact mechanism of urban vitality varies in different gradient regions, and the degree of land use mixing and road density have a significant impact on the level of urban vitality in each gradient. Based on Table 5, it can be further summarized that the built up environmental factors and their influencing mechanisms affect the average vitality level in different gradient regions:

For high gradient areas, building density (0.001), enterprise POI (0.319), land use mix (24.203), road density (578.699), presence of subway stations (226.152), and normalized vegetation index (24.659) are significantly positively correlated with the spatial distribution of vitality levels. The distance to the main employment center in Beijing (-40.612) is significantly negatively correlated with the spatial distribution of vitality levels, This result is consistent with previous studies on urban vitality in central urban areas [20-21]. The convenient transportation system and high-density lifestyle greatly promote the flow of people and spatial connections between different functions in the region, which is conducive to better stimulating urban vitality. A higher level of greenery in high-density areas can provide better recreational functions for residents in the area and improve their quality of life. The clustering of enterprises and closer proximity to the main employment centers in Beijing are conducive to enhancing labor attraction and stimulating urban economic vitality.

For medium gradient areas, population density (0.011), catering and shopping POI (0.078), residential area POI (0.122), land use mix (13.534), road density (378.078), and infrastructure level (5.794) are significantly positively correlated with the spatial distribution of vitality level, while the distance to the main employment center in Beijing (-143.233) is significantly negatively correlated. For this region, enterprise POI and normalized vegetation index no longer have a significant correlation with urban vitality, while residential and dining shopping POIs show a significant correlation. This may be because the construction land in medium gradient areas is mainly for residential and residential related living services, and there is a significant difference in industrial agglomeration capacity compared to high gradient areas. Therefore, population agglomeration capacity and factors serving residents' daily lives have a positive impact on urban vitality. In addition to road density and land use mix, the distance to Beijing's main employment centers is still considered the most important factor affecting the vitality of the region, indicating that the employment population activity range of Beijing's main employment centers (Financial Street, CBD, Zhongguancun) can cover medium gradient areas.

For low gradient areas, population density (0.013), public service facility POI (0.693), residential area POI (0.069), land use mix (3.424), road density (181.476), gross domestic product (0.000), and infrastructure level (2.735) are significantly positively correlated with average vitality level, and the distance to the employment center no longer has a significant correlation. Overall, low gradient areas exhibit a similar dynamic impact mechanism to medium gradient areas. However, as the distance to the central urban area further increases, the connection between residents in low gradient areas and the central urban area of Beijing further weakens. The level of vitality in this area is mainly influenced by the level of various local living service facilities and the level of economic and social development. It is worth noting that no significant correlation was found between the distance to intercity stations and highway entrances and exits and the vitality level of medium and low gradients.

4. Conclusion and Discussion

With the goal of exploring the spatial distribution and impact mechanism of urban vitality across administrative regions, this article focuses on 2 km × Using a 2 km grid as the research unit, LBS data and other multi-source urban big data were used to accurately evaluate the spatial distribution characteristics of Beijing's commuting circle vitality, clarify the gradient structure within the study area, and explore the impact mechanism of urban vitality in different gradient areas.

Firstly, the level of spatial vitality shows significant differences between cities and between urban and rural areas at the cross administrative scale, revealing the uneven pattern of population agglomeration capacity and development level within Beijing's commuting circle. With the improvement of urbanization level, household registration, employment and other related policies in various regions are constantly relaxing restrictions. China's population policy has shown a gradual transformation from restrictions to promotion for the residence of floating population. However, the high housing and living costs in big cities still encourage some residents to choose the center edge commuting mode. Therefore, cross administrative vitality research can more effectively and accurately evaluate the spatial distribution characteristics of regional vitality.

Secondly, based on the gradient theory, the dynamic tidal footprint is applied to identify the dynamic gradient layers and their threshold ranges in the Beijing commuting circle. From a human perspective, the spatial distribution characteristics of vitality in large-scale areas are identified based on spatiotemporal behavioral characteristics, which can provide reference for the study of vitality at the scale of metropolitan and urban agglomerations [27]. In the process of planning and formulation, it is necessary to standardize the distribution of industries within the research area, promote the relocation of some industries in Beijing, build more employment centers, improve the matching degree between residents' commuting needs and the urban comprehensive transportation system, and gradually improve the overall vitality level of medium and low gradient areas.

Thirdly, through the analysis of the vitality mechanisms of various gradient cities, the study found that there are differences in the influencing factors of vitality in high, medium, and low gradient areas within Beijing's commuting circle. Improving road density and land use mix have a significant positive impact on the vitality level of each gradient area. Clarifying the main built environmental factors that affect the vitality level of different gradient areas can help find ways to enhance the urban vitality of the region in the construction of the "three major projects" in the new era, such as affordable housing, urban village renovation, and public infrastructure construction for both emergency and urban use.

This article provides a new perspective for the study of urban vitality in the metropolitan area by identifying different gradient areas of urban vitality within the Beijing commuting circle, and provides refined references for the optimization of regional vitality spatial structure and rational functional layout. Subsequent research can consider the relationship between the vitality level and stability of workdays/rest days and the built environment in different gradient areas, further clarifying the spatiotemporal characteristics of urban vitality in different gradient areas.