Research Paper

The correlation between neighborhood environmental characteristics and travel distance:
an analysis using origin-destination data in Harbin, China

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Abstract

The neighborhood environmental characteristics of residential areas (including population density, employment density, road density, mixed land use, and facility accessibility) could affect the travel distance of residents. The daily travel behaviors of residents include commuting, shopping, entertainment, exercise, and etc. If residents need to travel long distances to reach their destination, it will lead to an increase in carbon emissions from urban transportation. In the context of global warming , optimizing the built environment characteristics of neighborhoods to promote short distance travel is crucial for sustainable urban transportation. This article used 74406 travel data from 261 residential areas to study the relationship between the built environment characteristics within a 1500m buffer zone of residential areas and the travel distance in Harbin, and used residential housing prices to characterize socio-economic status. The results indicate that residential areas in new urban areas and suburbs have longer travel distances than those in inner cities. Population density, employment density, land use mixed entropy are negatively correlated with travel distance indicating that employment-residence balance and improving facility accessibility can promote short distance travel for residents. The research results can guide the construction of 15 minute cities that promote short distance and low-carbon travel.

Keywords

Neighborhood environment; Travel distance; OD data; spatial analysis

1. Introduction

In recent years, the severe global climate change and frequent extreme weather events are mainly attributed to energy consumption and carbon emissions from human activities(Wang *et al.*, 2020, 2022). Environmental change affects the global ecosystem and human society, and threatens sustainable development. Reducing CO2 emissions is the key to addressing climate change. Urban greenhouse gas emissions account for about 75% of the global total. Transportation is an indispensable part of daily life for urban residents, with the transportation sector accounting for 24.48% of total greenhouse gas emissions. Residents' daily travel behaviors include commuting, shopping, entertainment, exercise, etc. The urban spatial structure and built environment factors have an impact on residents' daily travel behavior, which in turn affects urban transportation carbon emissions through travel distance, travel mode, travel frequency, etc., among which travel distance is closely related to transportation carbon emissions. If it is necessary to travel a long distance to reach the destination and located in suburban areas with a lack of public transportation, residents tend to prefer private car travel, resulting in higher carbon emissions. When traveling short distances, residents usually walk or ride bicycles to reach their destination, and non motorized modes of transportation have lower carbon emissions.

Neighborhood environment usually refers to the built environment characteristics and socio-economic features within a 15 minute walking distance of a block. The characteristics of the built environment include factors such as population density, employment density, road density, mixed land use, and facility accessibility. Socioeconomic characteristics include housing prices, etc. In previous studies on the impact of built environment on residents' travel behavior and carbon emissions, the research on neighborhood environment at the scales started relatively late and yielded fewer results compared to the macro scale(Qian *et al.*, 2018; Zhu and Hu, 2023). Previous studies have shown that neighborhood environment in residential areas has a significant impact on residents' travel distance. Based on OD travel data from the central urban area of Harbin on November 3, 2023 (with an accuracy of 100×100m), 74406 travel data from 261 residential areas were used to analyze the built environment characteristics, the correlation characteristics between residential housing prices and travel distance, and spatial differentiation within the 1500 meter residential buffer zone. The distribution of residential areas for long-distance travel in Harbin was identified, and the impact of neighborhood built environment characteristics and residential housing prices on travel distance was explored. The research results can guide the construction of 15 minute cities that promote short distance low-carbon travel.

2. Materials

2.1. Study area

The research residential areas need to meet the following two conditions: (1) The number of departure points of travel data within the residential area is more than 50; (2) There is housing price information(https://cd.fang.com/) on the Fangtianxia website. After filtering the data, 74406 travel data from 261 residential areas in the central urban area of Harbin were included in the study. Among them are old residential areas located in the inner city, with medium to low floors and high building density. There are also high-rise newly-built residential communities located in urban new areas, with medium to low building density. The housing prices in new residential areas are generally higher than those in old urban areas.

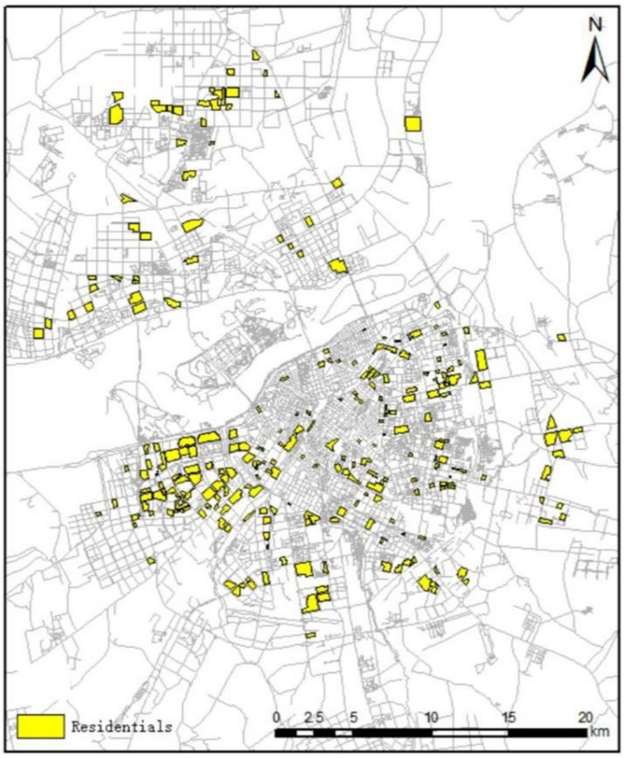

Figure 1. The distribution of study residential areas. Source: self drawn.

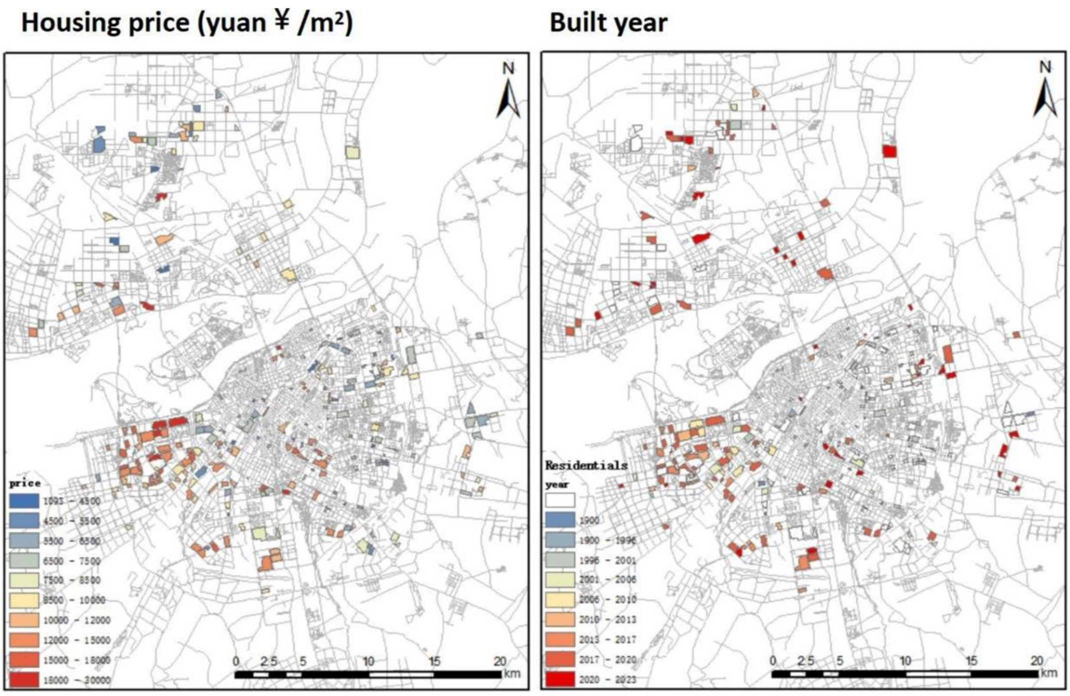

Figure 2. The housing price and built year of residential areas. Source: self drawn.

2.2. Research data and variables

Based on ArcGIS platform, using community AOI data, road network data, public transportation station POI, various service facility POI data(from Baidu Maps), and population density data (2022 LandScan global population density spatial distribution data, from https://landscan.ornl.gov/) to calculate neighborhood built environment variables. Using the 1500 meter buffer zone of residential areas as the neighborhood statistical range, calculate population density, building density, plot ratio, employment density, bus station accessibility, road density at all levels, land use mixed entropy index, and accessibility of various facilities. The method for measuring facility accessibility is to first use road network analysis tools to calculate the facility accessibility range, and then calculate the proportion of the facility accessibility area to the 1500 meter buffer zone (Figure 3: an analysis of primary school accessibility). The housing prices and built year information of the residential area can be crawled up from the Fangtianxia website(https://cd.fang.com/) to measure socio-economic attributes. OD travel data is sourced from Baidu Maps.

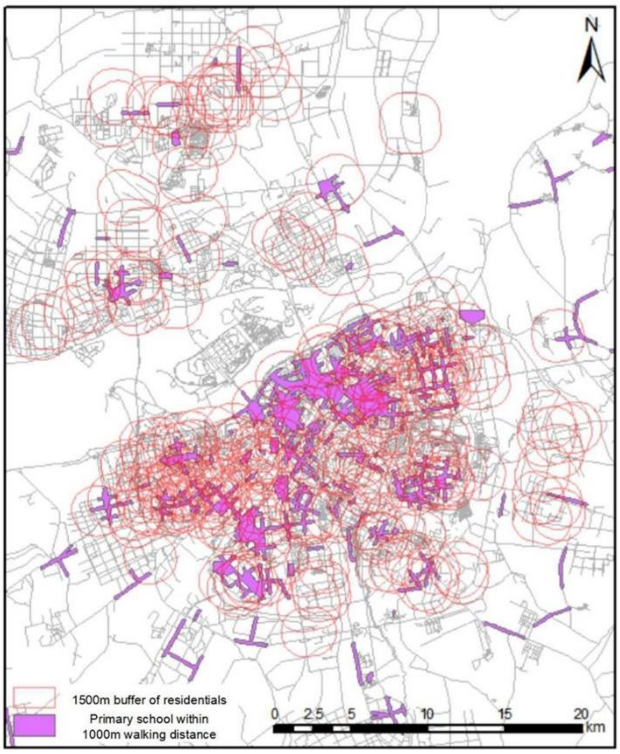

Figure 3.Calculation method for facility accessibility. Source: self drawn.

2.3. Methods

Select OD travel data with departure points located within residential areas, and then conduct spatial auto-correlation analysis and hot-spot analysis on residents' straight-line travel distance (Euclidean distance) , finally identify the spatial distribution of communities with longer travel distances. Spatial auto correlation (Moran I) analysis is used to check the spatial correlation of variables. When the dependent variable has spatial correlation, hot-spot analysis (Getis Ord Gi *), clustering and outlier analysis (Anselin Local Moran I) can be further used to identify high-value clustering and low value clustering areas of the dependent variable. Above steps were completed in ArcGIS 10.8 software. When the dependent variable has spatial correlation, spatial regression methods can be used to analyze the influencing factors of the dependent variable(Zheng, Huang and Sun, 2022). The Moran I calculation formula is as follows:

$$\mathrm{I} = \frac{n \sum_{i=1}^{n} \sum_{i=1}^{n} W_{ij} (x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n} \sum_{i=1}^{n} W_{ij} \sum_{i=1}^{n} (x_i - \overline{x})^2}$$

Then conduct correlation analysis on the built environment variables, housing prices, and straight-line travel distance of residential neighborhoods, and explore the key factors that affect residents' travel distance.

3. Results

3.1. The spatial distribution characteristics of neighborhood built environment variables

The population density, building density, plot ratio, employment density, and mixed entropy of land use in old urban areas are higher than those in newly built and suburban areas. The total density of roads in the inner city is higher than that in the new area, and there is not much difference in the density of highways and city level roads between the inner city and the new area. The density of block roads in the inner city is higher than that in the new district, and the density of cycling and pedestrian roads in the new district is higher than that in the inner city. The accessibility of subway stations in residential areas of the inner city is generally good, while some residential areas in the new district have good accessibility, and some residential areas have poor accessibility. The accessibility of bus stops in the inner city community is slightly better than that in the new district. In terms of facilities, the accessibility of various facilities in the inner city is better than that in the new district. The accessibility of fresh food stores, vegetable markets, kindergartens, and cultural facilities in the new residential area is weak. Overall, the road network is sparse, the land use is single, the distribution of public service facilities is limited and accessibility is poor in the new district.

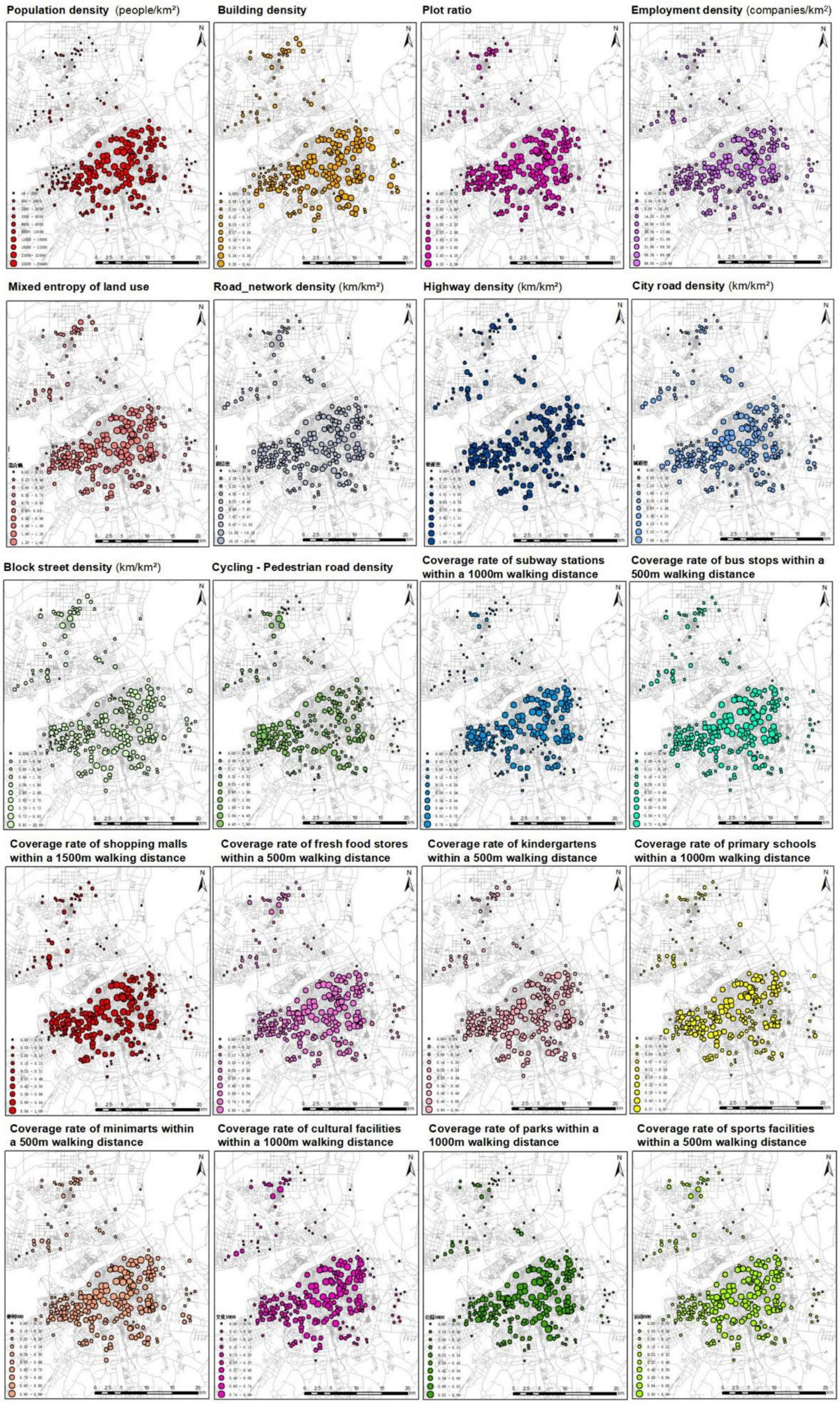

Figure 4. The Spatial distribution of built environment variables. Source: self drawn.

3.2. Spatial auto-correlation analysis of travel distance

Calculate the Euclidean distance (i.e. straight-line distance) of OD travel pairs, conduct spatial auto-correlation analysis and hot-spot analysis on residents' straight-line travel distances, and identify the spatial distribution of communities with longer travel distances. Spatial auto-correlation (Moran I) analysis is used to examine the spatial correlation of variables. The distribution of travel distance has significant spatial correlation. The Moran I results showed that the z-score was 12.22, greater than 2.35, and the p-value was 0.005, less than 0.05, indicating that the distribution of travel distance exhibited certain spatial clustering characteristics. Hot-spot analysis showed that the travel distance of residents in new urban areas and suburbs exhibits high-value clustering, while the travel distance of residents in old urban areas exhibits low value clustering.

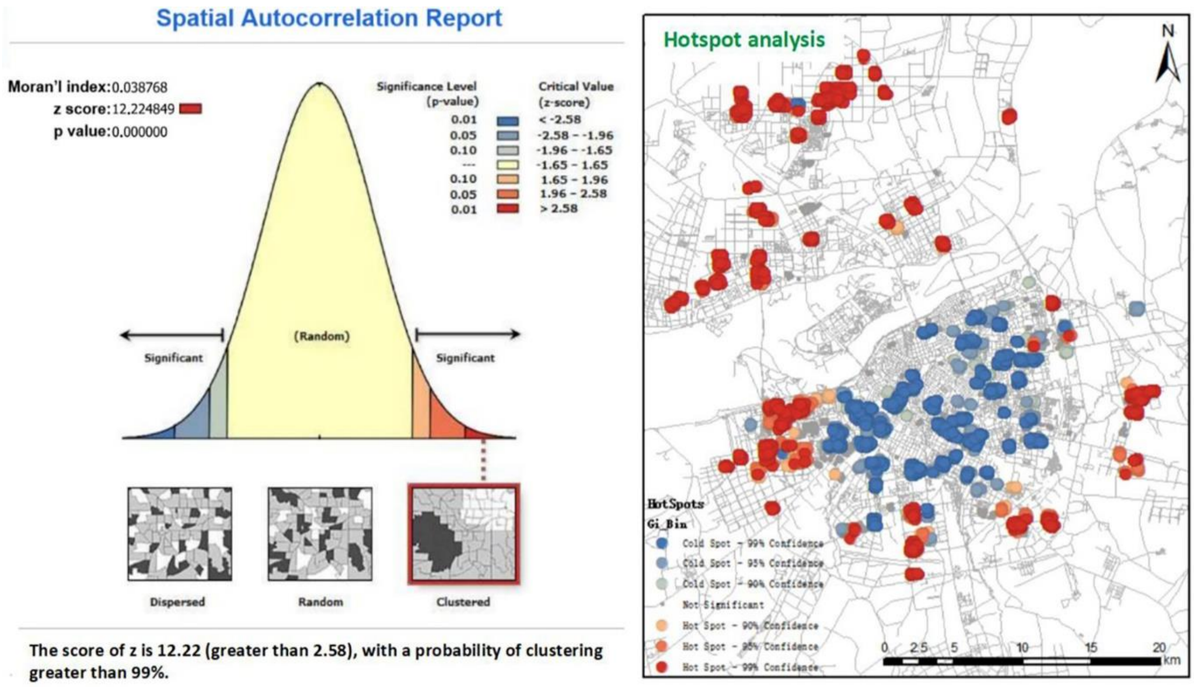

Figure 5. Spatial auto-correlation and hot-spot analysis of travel distance. Source: self drawn.

3.3. Correlation between neighborhood environmental characteristics and travel distance

Calculate the proportion of short and long-distance trips to the total number of trips in each community. Short distance trips are defined as trips with a straight-line distance of less than or equal to 1.5km Increasing the proportion of short distance travel for residents is beneficial for reducing urban transportation carbon emissions.

The least squares regression analysis of neighborhood environmental variables and travel distance shows that population density, employment density, and land use mixed entropy are negatively correlated with travel distance, indicating that employment residential balance and improving facility accessibility can promote residents' short distance travel. In terms of facility accessibility, the coverage of fresh food stores within a 500 meter walk, cultural facilities within a 1000 meter walk, parks within a 1000 meter walk, sports facilities within a 500 meter walk, kindergartens within a 500 meter walk, and middle schools within a 1500 meter walk are all negatively correlated with travel distance.

The communities with a low proportion of short distance travel include low-income communities with housing prices ranging from 5000 to 10000 yuan/m^2, as well as high-income communities with housing prices exceeding 18000 yuan/m^2. The former is because low-income residents find it difficult to afford rent in the city center and have to live in the suburbs, resulting in longer commuting distances; The latter is mainly due to the tendency of residents in high-end residential areas in new urban areas to use private cars for long-distance travel for daily activities such as work and life.

The relationship between population density, plot ratio, building density, and short distance travel ratio shows an inverted U-shaped trend. The population density of residential areas with a high proportion of short distance travel is between 8000-24000 people/km^2, and the mixed entropy of neighborhood land use is approximately between 0.6-1.2. For residential areas with a high proportion of short distance travel, the coverage of the neighborhood bus stop within a walking distance of 500m is approximately between 0.45-0.7. The density of expressways and city level roads in residential areas with a high proportion of short distance travel is lower than other residential areas, while the density of block roads and slow lanes is higher than other residential areas. This indicates that reducing the density of wide lanes, increasing the appropriate scale, and adapting to pedestrian and cycling density are conducive to promoting residents' short distance travel, and encouraging zero carbon transportation modes such as non motorized travel, which can greatly reduce urban transportation carbon emissions.

In residential areas with a high proportion of short distance travel, the coverage of many facilities within walking distance is relatively high (between 0.4-0.7) compared to other residential areas, including fresh food stores and markets, convenience stores, kindergartens, primary schools, secondary schools, cultural facilities, parks, and sports facilities. Some residential areas with a high proportion of short distance travel have a lower coverage of walking distance for shopping malls. The reason is that there are many small shopping facilities in the old city area, such as vegetable markets, fresh food stores, convenience stores, and clothing stores. Residents can reach various small shopping points within a short distance, while there are fewer concentrated large supermarkets. Large shopping malls are often located in new areas with fewer facilities, single land use, wide roads, and low road network density. Residents in new areas tend to prefer long-distance shopping with private cars, and may not necessarily shop nearby.

Research has found that the accessibility of neighborhood facilities has a significant impact on residents' travel distance. In the future 15 minute community life circle planning, emphasis should be placed on facility accessibility indicators, including bus stop accessibility, slow lane density, school accessibility, shopping facility accessibility (such as fresh produce stores and markets), cultural facility accessibility, park and sports facility accessibility, etc.Enhance the attractiveness of neighborhood centers to promote residents' short distance travel, including school, shopping, entertainment, and other travel behaviors. Short distance travel is beneficial for reducing urban carbon emissions, which is crucial for promoting the construction of low-carbon neighborhoods and cities.

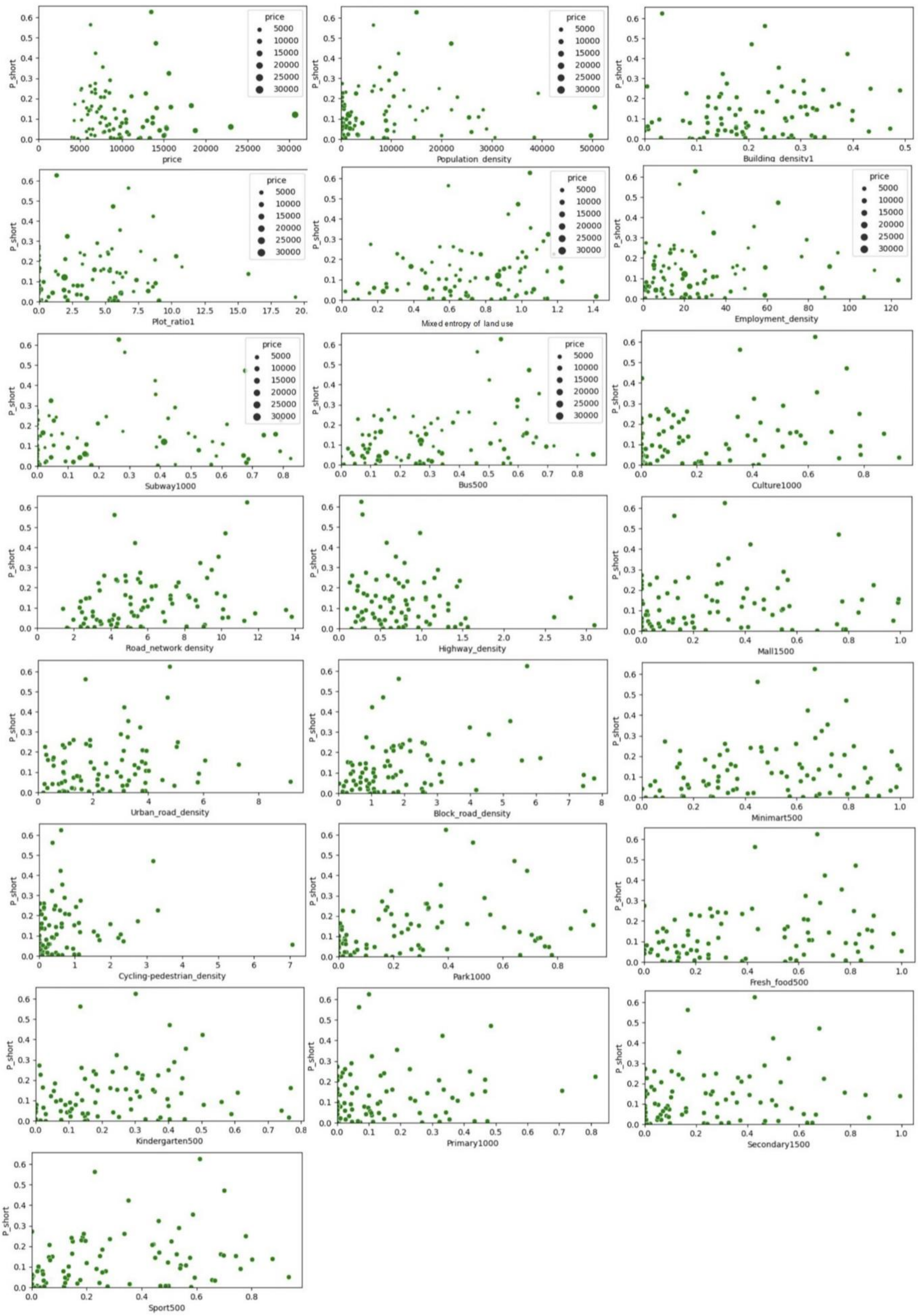

Figure 6. Correlation analysis between neighborhood environment characteristics and travel distance. Source: self drawn.

4. Planning strategy

Developing satellite cities with balanced employment and housing, as well as self-sufficient multi center cities, can greatly reduce the emissions of high emitters. Cultivating multi center city forms and satellite cities with balanced employment and housing is a key step in reducing transportation carbon dioxide emissions in the future. Improve the service level of urban sub centers and satellite cities, allowing residents to travel nearby to their destinations instead of going to traditional city centers.

From the perspective of the entire life cycle, the life cycle emissions of riding a bicycle can be more than ten times lower than those of riding a car. Research in Riyadh, the capital of Saudi Arabia, has shown that the success of the subway requires a very favorable walking environment, prompting people to choose the subway over cars or taxis(Anwar *et al.*, 2023). Therefor, the construction of a slow traffic environment around subway stations and residential neighborhoods is crucial. For example, in the old urban area of Pucheng County, a bicycle travel mode is being developed with bicycle lanes spaced 350-450m apart; The proportion of pedestrian roads to the total road area should be 15-20%, and the road width should be limited(Hou *et al.*, 2019).

Create compact and self-sufficient communities, ensure the rationality and convenience of surrounding infrastructure, and strengthen the guiding role of external living environment on residents' lifestyles. The daily travel behavior of residents is closely related to the external environment, and increasing land use mix and accessibility will improve residents' low-carbon behavior level. Therefore, it is necessary to guide residents' daily travel patterns through measures to improve the built environment, such as improving land use combinations, shortening the distance between bus stops, and improving accessibility(Zhang *et al.*, 2019). The research results in the old urban area of Pucheng County suggest that the coverage rate of bus stops with a 150 meter radius buffer is 40-50%, the coverage rate of shopping services with a 50 meter radius buffer is 45-60%, and the coverage rate of entertainment facilities with a 100 meter radius buffer is 50-70% (Hou *et al.*, 2019).

5. Conclusion

This study analyzed the relationship between the built environment characteristics and socio-economic attributes of neighbors and residents' travel distance through 74406 OD travel data from 261 residential areas in Harbin, China. The neighborhood environment affects people's travel behavior, which in turn affects urban carbon emissions. Promoting residents' short distance travel is beneficial for reducing transportation carbon emissions. Research has found that the relationship between population density, mixed entropy of land use, and short distance travel rate exhibits an inverted U-shaped trend. Improving the density of neighborhood streets and cycling pedestrian roads can promote residents' short distance travel in the neighborhood. The accessibility index of facilities in the 15 minute community living circle is very important. Higher accessibility of educational, cultural, shopping, and sports facilities is conducive to promoting residents' short distance travel, including school, shopping, entertainment, and other travel behaviors.

There are some limitations in this study. There is a non-linear relationship and threshold effect between some neighborhood environmental feature variables and driving distance and short distance driving ratio, which requires further research using machine learning methods such as gradient enhanced decision trees. Due to the lack of records of residents' transportation modes in OD travel data, it is necessary to collect more information about transportation modes to calculate the carbon emissions of residents' travel, in order to study the impact of neighborhood building environmental characteristics on residents' travel carbon emissions, clarify neighborhood building environmental indicators that help reduce travel carbon emissions, and guide 15 minute community life circle and block planning for low-carbon travel.

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