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Empirical Study on the Boundary Space Form of Residential Blocks Oriented Toward Low-Carbon Travel

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Abstract: As one of the three major carbon sources in cities, urban mobility has posed severe challenges to the social environment. Promoting low-carbon travel for residents is an important measure for building a low-carbon city and mitigating climate change. However, to date, previous research on residents' low-carbon travel has been more oriented toward urban planning, while quantitative research on the influence of the boundary space form of residential blocks on residents' travel modes, which takes residential blocks as the research objects at the meso- and micro-level, is relatively rare. Residential blocks in China, which were built in the late 1990s, mostly have a large and gated spatial form. Individual residential blocks are often gated by fences, commercial buildings, and other forms of interfaces, forming an independent residential group. Long and closed boundary forms will have a certain impact on residents' choice of low-carbon travel modes, such as walking, riding bikes, and so on. Taking Nanjing as an example, this paper explores the essential factors that impact residents' travel behaviors from the perspective of the boundary space of residential blocks, combining the socio-economic attributes of residents, land use, and transit facilities, and there are four dimensions to the study, including the boundary block scale, types of boundary interface, density and distribution of accesses, and the slow-travel environment, proposing recommended values of the relevant indicators in a targeted manner. This paper selects 21 residential blocks in the main districts in Nanjing, conducting a related survey on the residents' socio-economic attributes and travel characteristics, boundary space form, land use, and transit facilities. The data obtained from the survey are analyzed by correlation analysis and multiple logistic regression analysis, so as to screen out the key variables of the boundary space forms of the blocks that affect residents' low-carbon travel. Meanwhile, on the basis of the appropriate share of low-carbon travel, the unary linear regression model is used to propose ideal recommended values of the key variables of the boundary space forms of the residential blocks. For instance, the block boundary density is recommended to be above 34.38 km/km^2, the permeability coefficient of the block interface should be above 0.43, the commercial interface ratio should be above 18.16 km/km^2, the density of accesses of the blocks is recommended to be above 246.71 km/km^2, and the cross-sectional ratio of the slow-travel roads should be above 0.5.

Keywords: residential block; boundary space form; low-carbon travel; quantitative research; correlation analysis model; multinomial logistic regression model

1. Introduction

Low-carbon transportation is one of the important measures for building a low-carbon city and saving energy. As one of the major carbon emitters in transportation, China's energy consumption of transportation has accounted for 20% of the total social energy consumption. The data show that the average annual growth rate of energy consumption in China's transportation industry over the past three decades is 10.71% [1]. The increase in car ownership and usage [2] has put growing pressures on cities in terms of road carrying capacities, the travel time of residents, urban space expansion, energy consumption, and environmental pollution. Improving the share of residents' low-carbon travel will be one of the important means to cut energy consumption, reduce environmental pollution, improve the urban space quality, and build a pedestrian-friendly city. Low-carbon travel mainly refers to the kind of travel that is based on low-energy consumption and low pollution, which reduces carbon footprint and carbon dioxide emissions during travel. In this paper, the main travel modes include walking and other types of nonmotorized traveling.

As an important part of the urban function, residential blocks play the role of a spatial container for residents' daily activities, the differences in the planning and layout of which will affect residents' choice of travel modes [3,4]. Gehl indicated that the boundary and transition area between buildings and city spaces become a natural location for a wide variety of potential activities that link the functions of a building with life on the street. The more physical features on a facade, the more it invites recreation, seating, exhibition, trade, smoking, and so on [5]. Llewelyn provided criteria for judging design effectiveness, based on the building density of the street frontage, and divided the frontage into five grades. Among them, the most active grade (A) suggested that the frontage should have more than 15 premises every 100 m, as well as more than 25 doors and 25 windows [6]. Southworth and Owens pointed out that in cases where residents have replaced the previous front porch with a garage connected to a house facing the street, this has damaged the street edge permeability between the living space and the street [7]. As the dividing and transitional space between residential blocks and other residential blocks or urban public spaces, the boundary space of residential blocks plays an intermediating role in connecting block spaces and urban spaces [8], mainly including the vertical besieged interfaces of the enclosure of residential blocks, afforestation, commercial buildings, and sidewalks [9]. The boundary space of blocks is necessary for residents' daily travel, and differences in their design will also have an impact on residents' choice of travel mode. Since China implemented the housing policy reform in 1998, large and gated residential communities have gradually come into sight. In addition, several groups of houses in the blocks have been enclosed and sealed off by walls, fences, doors, and other interfaces and the entry of residents outside the blocks has been restricted. The size of a single residential block is often up to 4–6 hectares. Closed residential blocks have won the favor of most residents because of their defined private domain, good landscape environment, and the symbolism of personal status, and they have become a relatively fixed development pattern of residential land use. However, the built environment and the form of residential blocks will have subtle influences on residents' travel modes, and scholars at home and abroad have conducted relevant studies at different levels.

The related attributes of the block boundary space include the boundary scale (residential block scale), the type of enclosing interfaces, accesses, slow-travel environment of the streets, and so on. Relevant scholars have carried out studies on the relationship between the related attributes of the block boundary space and residents' travel, with different emphases. Liu et al. used the data of the U.S. National Household Travel Survey (NHTS) to study the impact of urban spatial structural characteristics on family travel. The results showed that the block scale and accessibility were important factors affecting residents' travel [10]. Based on the study of the urban form evolution in 12 typical cities in Australia and the United States over the last 150–250 years, Siksna et al. found that grid-shaped blocks with a scale of 80–100 m were more conducive to residents' daily life in terms of walking [11]. Lopez conducted a study in Madrid on the influence of boundary zones and facade designs, with a relatively high mix of functions, on the behavior of pedestrians on the streets. It is interesting that this study largely reaches the same conclusions as a similar one conducted in Copenhagen; namely, streets with facades with higher levels of rhythm, detail, and transparency had higher levels of activity in front of the facades [12]. Li Chunju et al. considered that the spatial segmentation formed by the boundary of walls hindered communication over a short distance, and over a long distance, reduced traffic accessibility [13]. Chen Yong et al. thought that walls that were too numerous and too long easily made people feel bored and dull, and sometimes would even make people feel insecure. He suggested that the ratio of permeable interfaces should be controlled at below 50%, and the ratio of architectural (commercial) interface should be controlled at above 40% [14]. Badland et al. posited that street space and walking activity are the basis for the designing of urban space and that it is not possible to solve the problem of urban mobility by widening motorways, but that urban space should improved on the human scale and in terms of comfort, so as to gradually reduce people's dependence on cars [15]. Alfonzo et al. selected 11 blocks in California as a case to study the factors affecting residents' choice of travelling on foot in the existing environment of the block, arguing that the streets with a larger proportion of sidewalks have a higher frequency of traveling on foot [16]. In addition, many scholars have studied the land use and layout of public transport facilities. Jabareen et al. believed that improving the degree of mixed land use can help to achieve a balance between jobs and housing and can influence residents' travel habits, including travel distance and travel modes, thereby further affecting the energy consumption and carbon emissions in residents' daily travel [17]. Cervero and Duncan et al. found that a balance between jobs and housing was conducive to reducing travel frequency. Within a range of 4 miles from residential areas, every 10% increase in similar jobs reduces the number of commuting vehicles by 3.29% per day [18]. At the level of transit facilities, Ewing et al. used the meta-analysis method to conduct a statistical analysis of built environments and transportation, drawing the conclusion that the bus-oriented block planning pattern will have an impact on residents' travel modes and that land use diversity is highly correlated with residents' travel [19]. Shi Fei et al. took Nanjing as an example to study the influence of such factors as the supply of transit facilities on residents' choice to travel by public transportation and came to the conclusion that the supply of transit facilities was an important factor that directly affected residents' choice to travel by public transportation. The distance between residents' position and the nearest subway station and the repetition rate of the bus network had a significant impact on residents' choice to travel by bus [20].

In addition to the built environment of blocks, residents' travel behaviors will also be affected by socioeconomic attributes, such as educational background, income, and car ownership [21–24]. Because of the differences in geography and research scale, the influence of each factor is not completely consistent, but is essential in generating reference factors and experimental data.

Existing studies have analyzed the factors affecting residents' travel from multiple perspectives, some of which have provided recommended data. Most of the research at the level of the city on a large scale focuses on the impact of land use and transit facilities on residents' travel modes. The relevant research at the meso- and micro-level mostly focuses on the block scale, while quantitative research on the relationship between the boundary space form of residential blocks and residents' travel modes is comparatively rarer. In addition, most of the existing studies are about residents' overall travel and commuter travel, while there are relatively fewer studies on the classification of travel according to travel purposes. Finally, due to the different level of economic development and residential space forms for different countries and regions, the distribution of cases during empirical research differs greatly, and the data-based conclusions are not necessarily universal.

Compared with the existing studies, the main contributions of this paper are as follows:

(1) The research of urban planning, with the goal of low-carbon travel, mostly focuses on land use, but research on the objectives and the boundary space of residential blocks is relatively rare. This paper starts from the boundary space form of residential blocks at the meso- and micro-level and conducts research on the impact of its various factors on residents' travel modes, with different purposes, including the block scale, residential block interface, block access, slow-travel environment scale of block roads, and so on. Combined with the influencing factors, such as family socioeconomic attributes, land use, and supply of transit facilities, through the establishment of mathematical models of correlation, multinomial logistic regression, and unary linear regression, the ideal recommended values of relevant indicators oriented toward low-carbon travel are

proposed. This paper explores the significance and value of the theoretical research and practical application of residential blocks in the field of urban planning.

(2) In this paper, the household is used as a basic unit for the study of travel characteristics, instead of individuals, so as to ensure the diversity and comprehensiveness of the surveyed residents' attributes. According to residents' various travel purposes, the travel mode is classified into three types: commuter travel, daily consumptive travel, and daily recreational travel. The effect of the boundary space form of residential blocks is studied in consideration of the different travel types. In addition, the relationship between different types of travel and the required boundary form is discussed.

(3) The research samples of the residential blocks selected in this paper are in the forms of open, semi-open, and gated, i.e., characteristics of residential block spaces from different construction periods in China. Different family economic attributes and boundary space forms of residential blocks have various influences on residents' travel modes, and the research will draw more targeted and comparative conclusions. At the same time, the research results and recommended values of relevant indicators offer a certain reference for the urban design and related planning practices of many cities, whose residential populations have a high density, similar spatial environments, and involve the construction of residential blocks.

2. Research Methods

This paper takes 21 residential blocks in three areas of Nanjing as research samples, obtains the family travel characteristics, socioeconomic attributes, and related built environment data of the residents living in the sample blocks through the survey. The SPSS software is used to analyze the influence of variables, such as residents' socioeconomic attributes and boundary space forms of blocks, on residents' travel. Figure 1 is the flow chart of low-carbon travel-oriented block index optimization. Firstly, a correlation analysis model is established to preliminarily screen out the relevant variables, such as the socioeconomic attributes of the household, boundary space forms of blocks, land use, and supply of transit facilities. Secondly, using a multinomial logistic regression model, the corresponding influential variables, which were screened out preliminarily, are used as covariates to rescreen out the variables of the boundary space form of residential blocks, and the key variables that have the most significant impact on residents' travel modes are obtained. Finally, based on the scatter plot of the relationship between the key variables and residents' travel data, a unary linear regression model is established to estimate the recommended values of the key indicators for the boundary space form of blocks that benefit residents' low-carbon travel. Specifically, the following three steps are included:

Step 1: Preliminarily screening out the primary significant variables. Correlation analysis is a commonly used statistical method in statistics for studying the relevance degree between variables. It uses correlation coefficients, which are usually denoted by 'r', as the measured index to describe the degree of linear correlation between two continuous variables [25]. Based on Pearson-correlation analysis, this paper takes residential blocks as the unit and establishes a bivariate correlation model from dependent and independent variables to preliminarily screen out the independent variables that have a significant influence on residents' low-carbon travel and identify whether the direction of the correlation is positive or negative. The indicators, which include the socioeconomic attributes of the household, boundary space forms of blocks, land use, and supply of transit facilities, are used as independent variables, while the share of residents' low-carbon travel in their commuting and daily consumptive and recreational travel are used as dependent variables.

Step 2: Rescreening out the key variables. Based on the results of the preliminary screening, the multinomial logistic regression model is used to identify the key variables of the boundary space form of the blocks. The preliminary screening out of the factors affecting residents' travel mode has been conducted. Since the correlation analysis can only distinguish the relationship between the individual independent variables and dependent variables, this paper continues to adopt multinomial logistic regression equations, taking households as units; significant variables of boundary space form of residential blocks as independent variables; residents' socioeconomic attributes, degree of mixed land use, and the transit station coverage as covariates; and the share of low-carbon travel of residents' households as a dependent variable. As a result of the combination of multiple-attribute variables, this paper analyzes the influence mechanism of the boundary space form of residential blocks on residents' low-carbon travel.

Step 3: Estimating the recommended value. The unary linear regression is a regression model that studies the linear relationship between dependent variables and independent variables, and its main task is to use the least squares method to estimate the other variable from one of the two related variables. In this paper, the author establishes a unary linear regression model of the key variables of the boundary space form and the residents' travel variables, which are screened out in the second step, to explore the possible linear relationship and estimates the relevant recommended values through the model.

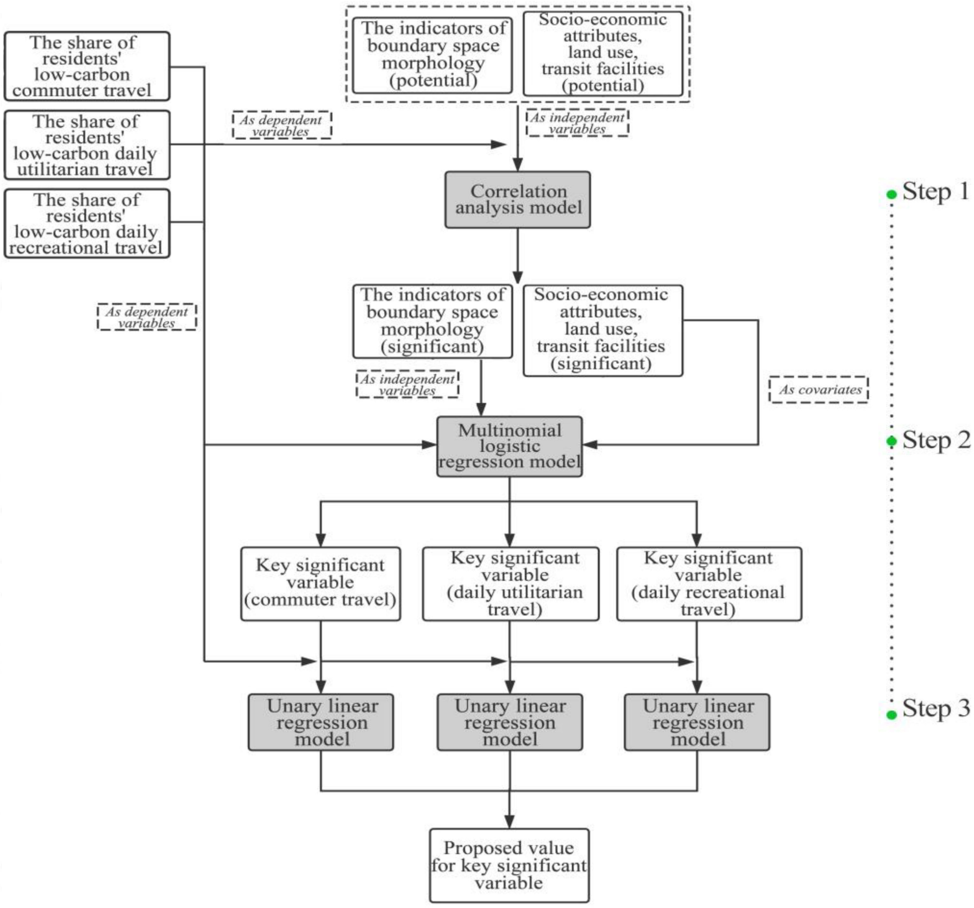


Figure 1. The flow chart of low-carbon travel-oriented block index optimization.

The key indicators of the rescreened boundary space form are used as independent variables, and the share of low-carbon travel for commuting, consumption, and recreation are used as dependent variables so as to establish a unary linear regression equation. The basic linear regression model is as follows [26]:

$$Y_i = f(X_i) = \beta_0 + \beta_1 X_i + u_0, i = 1, 2, 3, \ldots \ldots, n \quad (1)$$

In Equation (1), Y_i represents the low-carbon ratio of a certain travel type of residents living in block I, X_i represents the key indicator of the boundary space form in block I, β_0 is a constant term, β_1 is the coefficient, and n is the number of sample blocks.

3. Survey and Organization

3.1. Overview of the Survey Area

As the capital city of Jiangsu Province, Nanjing is an important central city in the eastern part of China and the second largest central city in the Yangtze River Delta, after Shanghai. At the same time, it has a long history and is one of the seven ancient capitals of China. After the founding of New China, the main districts of Nanjing were mainly limited within the Ming dynasty's rampart. After the 1990s, with the acceleration of urbanization, the old town faced the situation of rapid population growth, insufficient urban space and increasing traffic pressure. In order to alleviate the pressure, the city overcame the limitation of the spatial boundary of the Ming dynasty's rampart and sought to develop around its periphery [27]. It also has new built-up urban areas, such as Longjiang Area, Hexi Area, and Xianlin Area [28], forming a spatial pattern of multicenter development over many areas. The construction of the main districts in Nanjing is mainly based on demolition, reconstruction, and renovation. Some residential blocks have maintained the traditional urban texture, and many gated residential blocks have also been built at the same time. Most of the new urban areas have been built with large and gated residential blocks, whose scale is mostly in the range of 9–16 hm^2. The sample areas selected in this paper include the central city of Nanjing and the new urban areas that have been continuously constructed since the 1990s.

3.2. Selection of the Surveyed Samples

This paper selects the residential blocks that are dominated by residential functions and have a certain degree of representativeness of the three areas in Nanjing as the surveyed samples (Figure 2). In each area, seven blocks are sampled (Figure 3). Among them, X1–7, L1–7, and H1–7 indicate residential blocks number 1–7 in the Xinjiekou area, residential blocks number 1–7 in the Longjiang area, and residential blocks number 1–7 in the Hexi area, respectively. The size of each sample block is between 0.25 and 0.36 km^2. Taking the boundary limitations of the urban road and natural boundaries into account, the defined criteria of the scale are mainly determined by the 5-minute walking time combined with the detour coefficient in the area. The main construction periods of the Xinjiekou area, Longjiang area, and Hexi area correspond to the 1980s, 1990s, and 2000s, generally presenting open, semi-open, and gated characteristics of the corresponding residential blocks, respectively.

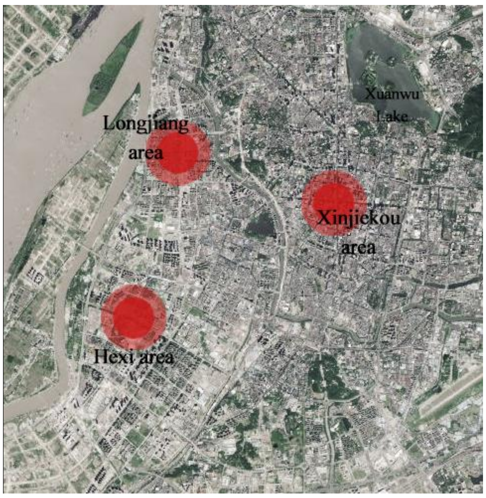


Figure 2. The location map of the three study areas in Nanjing.

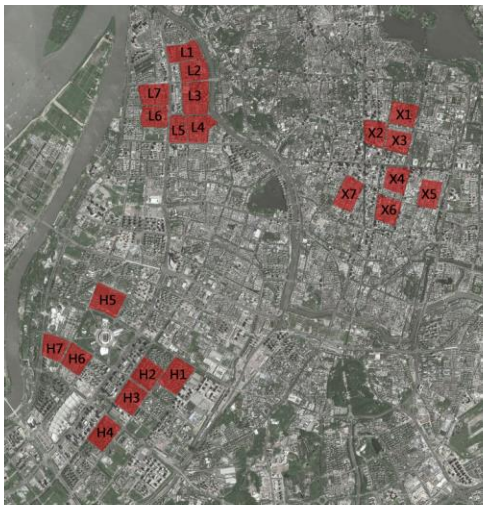


Figure 3. The location map of the 21 blocks in Nanjing.

Among them, the Xinjiekou area is located in the center of the main district. It is an important multifunctional city center in Nanjing for business, commercial affairs, and residence. It is continuously updated on the basis of maintaining the traditional space texture, whose degree of mixed functions and openness of the blocks are relatively high. The construction of residential blocks is widely distributed. There are residential blocks with relatively open space forms, which were built in the 1970s and 1980s, and a relatively small number of gated blocks, which have been newly built since the year 2000. The Longjiang area was developed and built in the 1990s to ease the surging population pressure of the main districts and broke through the boundary of the Ming dynasty's rampart westwards. It is mainly based on residential functions, and the degree of openness and functional mixture of residential blocks is lower compared to those in the Xinjiekou area. The space form of the residential blocks is mostly semi-open. The Hexi area is a new city center that was built in the 2000s, whose scale of residential blocks is relatively larger, with wider urban roads and mostly gated residential blocks. Compared with the Longjiang and Hexi areas, the Xinjiekou area has a friendlier block interface (such as X5, L6, H7 in Figure 4), a higher degree of freedom in terms of residential block accesses (such as X4, L1, H1 in Figure 4), and a more convenient travel environment (such as X7, L4, H6 in Figure 4).

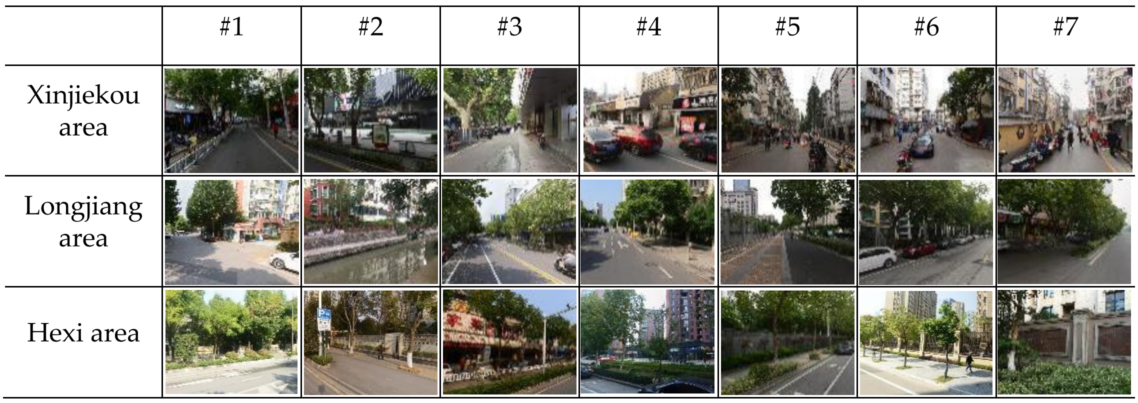


Figure 4. A street view of the 21 sample blocks.

3.3. Survey Content

The survey includes two methods: a questionnaire survey and a built environment survey. The questionnaire survey consists of the households' socioeconomic attributes and family travel data. The built environment survey includes the boundary space form of blocks, land use, and transit facilities.

3.3.1. Residents' Socioeconomic Attributes and Travel Characteristics

This paper collects the socioeconomic attributes' data of households and the characteristics of households' travel in the sample block and compares the differences between households' socioeconomic attributes and travel modes in different areas through a statistical analysis, using the relevant software to make basic preparations for the study of the relationship between residents' travel modes and the block space form.

This survey uses the method of 'simple random sampling' [29,30] for a questionnaire survey. The survey group consisted of 21 graduate students and undergraduates. On average, one investigator was assigned to each sample block for a three-day survey. A total of 1260 questionnaires were issued by the research group, with an average of 60 questionnaires per block. Finally, 1185 valid questionnaires were compiled. In order to avoid the subjectivity of selecting the survey object and reducing the error caused by random sampling, the investigators focused on balancing the distribution of the respondents' age and gender when selecting the survey object and on the homogenization of the survey sites in the areas, and they ensured that the residents investigated were the residents living in the sample blocks. Each questionnaire takes households as the unit [31]; that is to say, the survey object is required to fill in the relevant information of the main family members. The selected survey time is on the weekends, avoiding normal commuting days and trying to ensure the diversity of the respondents.

(1) The survey of households' socioeconomic attributes included the highest educational attainment of family members, the number of permanent household members, the annual household income, and the car ownership of the individual household. Since the survey object in this paper is based on multiple members of the family, the gender and age of the respondents are not included in this survey.
(2) According to different travel purposes, the questionnaires divide residents' travel into commuter travel, daily consumptive travel (mainly referring to daily grocery shopping, etc.), and daily recreational travel (mainly referring to daily strolling, walking dogs, fitness, and recreation). The three categories record the most common transportation modes of each family member. The travel mode is divided into four options: public transportation, non-motor vehicle, walking, and motor vehicle. The first three options are classified into low-carbon travel modes.

3.3.2. Boundary Space Form of Blocks

The survey content consists of four levels: block scale, block boundary interface, the layout of block access, and the slow-travel environment of streets. The data acquisition is mainly based on the Nanjing topographic maps and land use status vector, obtained from the Nanjing Urban Planning Research Center, which are improved by combining them with field observations and measurements.

(1) Block scale. this research uses the concept of 'boundary density', which is the average value of the boundary lengths of residential blocks per unit area, to describe the attribute of the block scale. according to the cad drawing of the current state in nanjing and a field survey, the sum of the lengths and area of the unit plots in the 21 surveyed blocks are measured. the formula is:

$$\text{Boundary density} = \frac{L_i}{S_i} \quad (2)$$

where l_i is the sum of the perimeter per unit plot in block i and s_i is the sum of the area per unit plot in block i.
(2) Boundary interface. This paper investigates the interface enclosure pattern of the boundary of plots in each block, which has a gated or open form. The specific material forms include walls, fences, afforestation, squares, and commercial buildings along the streets. The survey content includes the measurement of different types of interfaces in the blocks and their corresponding lengths. The commercial interface tends to be highly dynamic and has a great influence on the

travel behavior of residents. Therefore, this paper extracts the commercial interactive interface as an important attribute and adopts the concept of the 'permeability coefficient' to describe the defining characteristics of the remaining enclosing interfaces.

a. Permeability coefficient of the interfaces. The block boundary interfaces are classified into gated, semi-open, and open forms according to their different material forms. In order to express and reflect the permeability of interfaces and their interaction with the city, the research adopts a method of assigning values according to their degree of openness and interaction, and it assigns gated, semi-open, and open interfaces the values of 0, 0.5, and 1, respectively.

- Gated interface. The gated interface is not permeable in appearance and is inaccessible in behavior. It imposes mandatory encirclement and limitation on the residential areas, such as physical walls.
- Semi-Open interface. The visual line interaction has a certain degree of participation and is partially separated from while retaining some connection with the public space of the city via iron railings, glass fences, low-lying green spaces, and so on.
- Open interface. The interface that has visual line interaction and behavioral accessibility is the open interface, such as a green field, square, etc.

$$\mathrm{P_i} = \frac{0 \times \mathrm{a_1} + 0.5 \times \mathrm{a_2} + 1 \times \mathrm{a_3}}{\mathrm{C}_i} \tag{3}$$

where P_i is the permeability coefficient of block i, a_1 is the length of the gated interface in block i, a_2 is the length of the semi-open interface, a_3 is the length of the open interface, and C_i is the perimeter of block i (except for the commercial interface).

b. The proportion of the commercial interaction interface.

$$\text{The proportion of the commercial interaction interface } = \frac{\mathrm{L}_i}{\mathrm{C}_i} \tag{4}$$

where F_i is the proportion of the length of commercial buildings along the streets in block i, L_i is the length of commercial buildings along the streets in block i, and S_i is the area of block i. The unit is km/km^2.

(3) Access.

a. The density of access. Through the investigation, the number of accesses in the sample block and the land area, based on the residential function in the block, are obtained. The calculation formula is:

$$\mathrm{X_i} = \frac{\mathrm{N_i}}{\mathrm{S_i}} \tag{5}$$

where X_i is the density of access of block i, N_i is the number of accesses of the residential block in block i, and S_i is the land area, mainly dominated by the residential function in block i.

b. Distribution equilibrium of accesses.

$$\mathrm{S_i} = \frac{\sqrt{\frac{1}{\mathrm{N}}\sum_{\mathrm{n}=1}^{\mathrm{N}}(\mathrm{l_n} - \mu)}}{\mu} \tag{6}$$

This formula gives the dispersion coefficient, which is the statistical indicator that is commonly used in statistics. Here, S_i is the distribution equilibrium of accesses in block i; l_n is the distance between the adjacent accesses n and n + 1; $l_1, l_2, l_3, \ldots, l_N$ are all real numbers; and μ is the arithmetic mean value.

(4) Slow-Travel environment. The width of the sidewalks and the nonmotorized vehicle lanes in the street determine, to a great extent, the comfort of the slow-travel environment. The research uses the proportion of the road cross section for slow travel to express the openness and comfort of the slow-travel space and investigates the width of sidewalks, nonmotorized vehicle lanes, and motorways in the streets of each block, and the proportion of the road space for slow travel is thus obtained. The calculation formulae are:

$$E_n = \frac{W_r + W_n}{W_i} \tag{7}$$

$$E_i = \frac{\sum_{n=1}^{N} E_n \times L_n}{\sum_{n=1}^{N} L_n} \tag{8}$$

where E_i is the weighted average of the cross-section proportion of the roads for slow travel in all streets of block i, E_n is the cross-section ratio of a road in block i, L_n is the length of a road in block i, W_r is the width of the sidewalk, W_n is the width of nonmotorized vehicle lanes, and W_i is the total width of the street.

3.3.3. The Level of Land Use and Transit Facilities

(1) The level of land use. Since information entropy is widely used, domestically and internationally, in measuring the degree of mixed land use, this paper calculates the degree of mixed land use by reference to the calculation method adopted by Mercado and Cervero and divides the land types in the sample blocks into residential buildings, commercial buildings, commercial and scientific research buildings, and public service buildings. The specific formula is as follows [32,33]:

$$M_i = -\sum_{i=1}^{n} (b_i / a) \ln(b_i / a) \tag{9}$$

where n represents the number of land use types in the block, a represents the total area of all land types in the block, and b_i represents the area of the i-th type of land use.

(2) The level of transit facilities. The indicator of the transit station coverage is used to measure the distribution of the transit stations and their service levels, including bus stops and rail transit stations. In the 'Code for Transport Planning of Urban Roads', a radius of 300 m and 500 m are selected as the measurement scale of the bus station service area [34]. Because most of China's blocks are in the form of gated blocks with oversized scales, there are serious detour problems. Therefore, this research selects 300 m as the coverage radius measurement scale and uses GIS tools for calculation, combined with the actual road network form around the stations.

4. Statistics and Preliminary Analysis

4.1. The Level of Residents' Socioeconomic Attributes

Table 1 shows the component percentages of the various components of the households' socioeconomic attributes. The data show that the residents' socioeconomic attributes in the 21 blocks belonging to the three areas vary, but the residents of the seven blocks in the same area have relatively similar component percentages of corresponding data. It can be seen that different urban locations have a certain dispersion effect on residents with relatively different socioeconomic attribute characteristics, while specific urban locations have a certain agglomeration effect on residents with similar socioeconomic attributes.

Table 1. Component percentages of the various components of the households' socioeconomic attributes in the 21 sample blocks (%).

Area	Number	The Highest Educational Attainment of Family Members				The Number of Permanent Family Population				The Annual Households Income (10,000 RMB)				The Number of Cars Owned			
		Junior High School and Below	High School	Bachelor	Master and Above	1	2	3	Morethan 3	Less than 5	5–10	10–20	Morethan 20	0	1	2	3 or more
Xinjiekou	X1	2	10	58	31	10	24	24	42	15	32	47	5	25	47	25	2
	X2	7	3	74	16	12	19	40	29	31	36	26	7	31	52	17	0
	X3	9	12	65	14	2	18	60	21	28	47	9	16	23	60	18	0
	X4	0	8	63	29	3	8	44	44	15	49	20	15	36	63	2	0
	X5	5	7	68	20	2	22	49	27	22	56	12	10	37	61	2	0
	X6	4	22	55	18	4	31	35	31	18	55	24	2	43	41	12	4
	X7	6	9	70	15	4	11	72	13	26	40	17	17	43	38	11	8
Longjiang	L1	0	4	68	28	9	12	56	23	4	42	47	7	11	77	12	0
	L2	5	4	60	32	0	7	56	37	12	53	26	9	16	70	14	0
	L3	2	8	68	22	0	5	52	43	7	53	17	23	17	63	20	0
	L4	0	0	86	14	0	0	78	22	8	2	76	14	8	58	34	0
	L5	10	30	45	15	12	22	40	27	28	53	15	3	28	30	38	3
	L6	4	7	63	26	7	5	60	28	5	53	35	7	11	67	21	2
	L7	4	4	58	33	4	24	44	27	13	49	16	22	18	60	22	0
Hexi	H1	0	10	59	31	0	3	34	62	7	34	28	31	7	69	24	0
	H2	5	0	43	52	3	9	33	55	3	38	19	40	12	57	26	5
	H3	0	16	61	23	3	18	69	10	2	67	31	0	3	69	28	0
	H4	0	16	61	23	3	18	69	10	2	67	31	0	3	69	28	0
	H5	3	18	65	13	3	40	35	22	13	40	37	10	32	52	17	0
	H6	0	3	67	30	3	10	42	45	7	35	45	13	12	68	18	2
	H7	0	4	68	28	9	12	56	23	4	42	47	7	11	77	12	0

The attributes of the 21 blocks are classified according to the three areas, and the differences in the residents' socioeconomic attributes in the three areas are compared laterally. In terms of the highest education qualification, for the Master's degree and above, the data for the Hexi area are slightly higher than those for the Longjiang area and the Xinjiekou area, while for the bachelor's degree and above, the data for the Hexi area are close to those for the Longjiang area, which are slightly higher than those for the Xinjiekou area (Figure 5). For the number of households with three or more permanent residents, the Hexi area is similar to the Longjiang area, which is slightly higher than the Xinjiekou area, which has a higher proportion of two-person families (Figure 6). The overall level of annual household income in the Hexi area is higher than that in the other two areas, which is also consistent with their housing prices (Figure 7). From the perspective of the number of the households that own a car, as shown in Figure 8, the proportion of households with cars in the Hexi area is close to 89%, compared with 84.6% and 66% in the Longjiang area and Xinjiekou area, respectively.

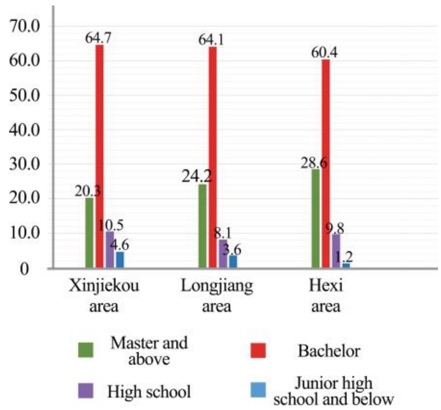


Figure 5. Component percentages of the highest education qualification of the household (%).

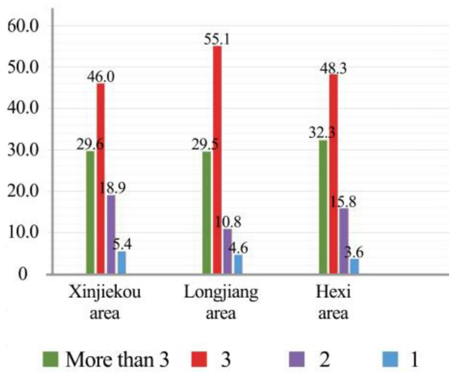


Figure 6. Component percentages of the number of permanent household members (%).

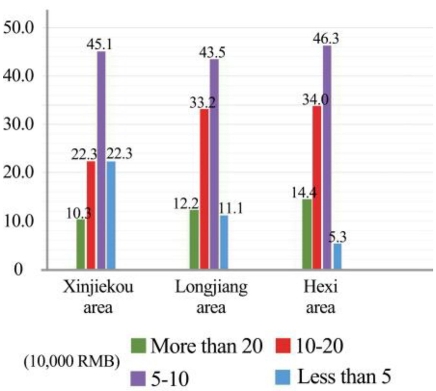


Figure 7. Component percentages of household income (%).

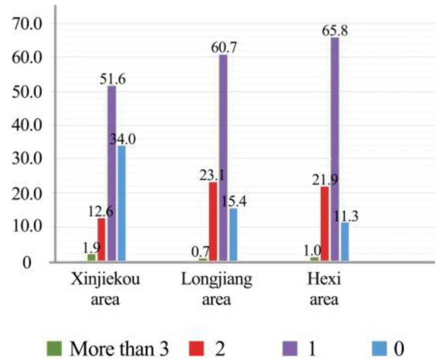


Figure 8. Component percentages of household car ownership (%).

4.2. Residents' Travel

According to the different purposes of residents' travel, this paper divides residents' travel into commuter travel, daily consumptive travel, and daily recreational travel. Questionnaires are used to obtain information about residents' travel characteristics. In order to facilitate the analysis, this research uses the indicator of the share of residents' low-carbon travel to measure the residents' travel situation. The specific formulae are:

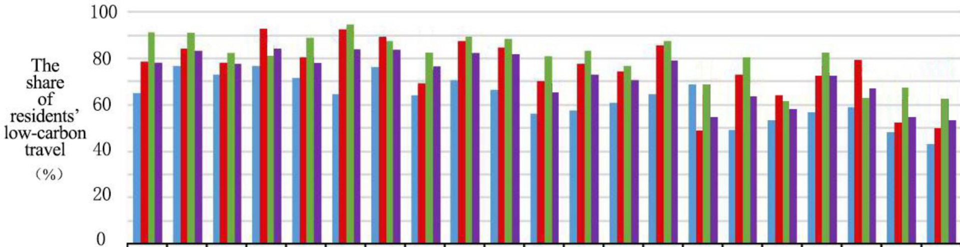
$$P_{CT,i} = \frac{\sum_{I=1}^{n} L_{C,\,I}}{N} \tag{10}$$

$$P_{UT,i} = \frac{\sum_{I=1}^{n} L_{U,\,I}}{N} \tag{11}$$

$$P_{RT,i} = \frac{\sum_{I=1}^{n} L_{R,\,I}}{N} \tag{12}$$

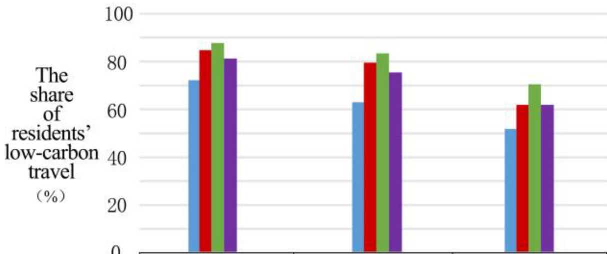
In the above formulas, $P_{CT,i}$, $P_{UT,i}$, and $P_{RT,i}$ represent the share of residents' low-carbon travel for commuting, daily consumption, and daily recreation in block I, respectively; $L_{C,I}$, $L_{U,I}$, and $L_{R,I}$ represent the number of low-carbon travelers in terms of commuting, daily consumption, and daily recreation in family I, respectively; n is the total number of the households in the residential block i; and N is the total number of people in the sample residential block.

Through preliminary classification and statistics, the histograms of the share of residents' low-carbon travel in the 21 sample blocks and the three areas, driven by the three travel purposes, are shown in Figures 9 and 10. For the 21 sample blocks, the share of residents' low-carbon travel for daily recreation and consumption is generally higher than that for commuting, which is consistent with the early expectations and perceptions of this paper. After comparing the three areas, the ranking order of the share of residents' low-carbon travel for commuting, daily consumption, and recreation from highest to lowest are: the Xinjiekou area, Longjiang area, and Hexi area. This shows that different family socioeconomic data, boundary space forms of blocks, land uses, and transit facility environments will have a certain impact on residents' travel. It is worth noting that the average share of residents' low-carbon travel of the three types of travel modes in the Xinjiekou area is 81%, which is a high level. According to the overall situation of residents' travel in the three sample areas, the proportion of residents' low-carbon travel for daily recreation (P_{RT}) is the highest, accounting for 29.2%, followed by daily consumption, which is 27.9%, and the proportion of low-carbon travel for commuting is the lowest, accounting for 23.9%.



	X1	X2	X3	X4	X5	X6	X7	L1	L2	L3	L4	L5	L6	L7	H1	H2	H3	H4	H5	H6	H7
Commuter travel	65	77	73	77	71	65	76	64	71	66	56	58	61	65	69	49	53	58	59	48	43
Utilitarian travel	77	84	77	93	80	93	90	85	89	91	62	74	70	85	49	63	63	72	80	51	50
Recreational travel	91	91	78	81	85	95	87	82	90	85	79	83	77	87	69	80	61	82	63	67	62
Mean	78	84	76	84	79	84	84	77	83	81	66	72	69	79	55	64	59	71	67	55	52

Figure 9. Histogram of the share of residents' low-carbon travel in the 21 sample blocks (%).



	Xinjiekou area	Longjiang area	Hexi area
Commuter travel	72	63	51
Utilitarian travel	85	80	61
Recreational travel	87	83	70
Mean	81	75	61

Figure 10. Histogram of the share of residents' low-carbon travel in the three study areas (%).

4.3. Built Environment of Blocks

4.3.1. Boundary Space Form of Blocks

Block scale: Table 2 shows that value of the block boundary density in the Xinjiekou area is the highest, followed by the Longjiang area and then the Hexi area. The average boundary density of the blocks in the Xinjiekou area is about 30 km/km^2, while the datum for the Longjiang area is about 15.51 km/km^2, in which the datum for the L4 block is only 5.20 km/km^2 due to its excessive scale, dragging down the overall level of the Longjiang area. In addition, the average boundary density of the blocks in the Hexi area is about 14.33 km/km^2. Overall, the boundary density of the blocks in the Xinjiekou area is the sum of the Longjiang area and Hexi area, showing that the block boundary length of the Xinjiekou area is larger than that of the Hexi and Longjiang areas when the block sizes are equal, which means that the blocks in the Xinjiekou area have a relatively small scale and a high road network density.

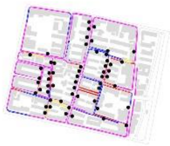
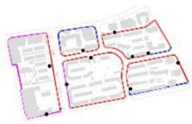
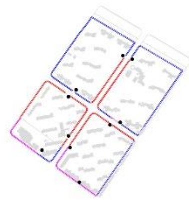
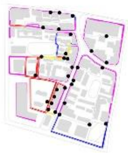
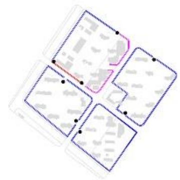
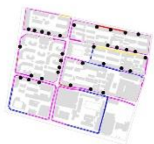
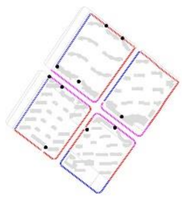
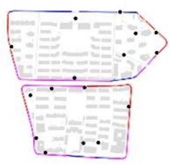
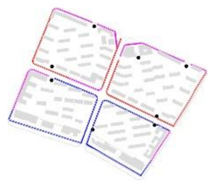
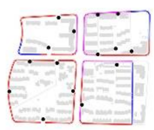
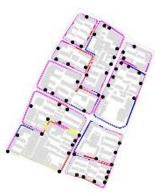
Table 2. Statistical spatial form data of the 21 sample block boundaries.

Area	Number	Block Scale	Boundary Surface		Accesses		Slow Travel Environment	Land Use	Transit Facilities
		Boundary Density	Permeabi-lity Coefficient	Commer-cial Surface	Density	Distribution Equilibrium	Proportion of the Road Cross-Section	Mixed Degree of Land Use	Transit- Station Coverage
Xinjiekou	X1	43.88	0.32	17.04	224.00	0.91	0.41	1.26	0.81
	X2	25.11	0.42	14.53	187.50	0.78	0.42	1.33	0.85
	X3	34.00	0.27	18.40	183.33	1.08	0.45	1.23	0.72
	X4	28.58	0.58	12.71	131.58	0.55	0.41	1.25	0.67
	X5	22.00	0.38	13.25	365.00	0.94	0.43	0.90	0.62
	X6	26.81	0.30	10.68	185.00	0.78	0.41	1.18	0.60
	X7	29.75	0.36	14.46	252.17	0.70	0.41	1.01	0.90
Longjiang	L1	18.35	0.39	4.10	52.63	0.54	0.28	1.24	0.66
	L2	22.00	0.34	3.10	90.00	0.65	0.33	0.93	0.60
	L3	19.50	0.42	4.46	65.38	0.85	0.42	1.20	0.55
	L4	5.20	0.27	4.96	61.54	0.61	0.34	0.99	0.79
	L5	14.31	0.28	4.40	53.85	0.52	0.30	1.10	0.83
	L6	14.21	0.38	4.00	71.43	0.51	0.37	0.91	0.83
	L7	15.00	0.22	10.59	76.19	0.64	0.46	1.12	0.97
Hexi	H1	12.03	0.21	1.80	40.00	0.54	0.37	0.89	0.98
	H2	12.43	0.03	1.58	50.00	0.40	0.43	1.03	1.00
	H3	13.71	0.30	4.08	45.45	0.74	0.34	0.84	0.92
	H4	13.29	0.29	2.37	50.00	0.54	0.28	0.83	0.92
	H5	13.50	0.24	4.27	229.63	0.30	0.29	0.81	0.90
	H6	14.04	0.25	0.96	64.71	0.64	0.32	0.71	0.52
	H7	21.31	0.27	7.59	47.37	0.50	0.34	0.90	0.50

Boundary interface: The permeability coefficient was introduced in Section 3.3.2 of this paper. It divides the block interface according to its openness, and the specific value is calculated by the formulae through the assignment of this paper. This method can intuitively uncover the difference in various block interfaces between different areas and facilitate the analysis of SPSS data in a later stage. Table 3 is the interface types and distribution of accesses of the boundary spatial form of the 21 blocks. The data analysis shows that the ranking order of the permeability coefficient of the interface, from highest to lowest, is as follows: the Xinjiekou area, Longjiang area, and Hexi area. This indicates that the openness degree of the block interface in the Xinjiekou area is higher than that in the Longjiang area, and the openness of the latter is higher than that in the Hexi area, which is in line with our field survey. As far as the proportion of commercial interfaces is concerned, since the proportion of commercial buildings in the Xinjiekou area is higher than that in the other two areas, while such buildings are usually laid out along the streets, the proportion of commercial interfaces in the Xinjiekou area is still higher than that in the other two areas, and the datum for the Longjiang area is higher than that for the Hexi area.

Accesses: The research at the level of accesses includes the density and the distribution equilibrium of accesses. The data analysis shows that the density of accesses in the Longjiang area is slightly higher than that in the Hexi area, while the value of this indicator in the Xinjiekou area is more than three times that in the Longjiang area and four times as much as that in the Hexi area (Table 2, Table 3). The author believes that this is related to the openness degree of the block boundary, because the Xinjiekou area is the most open area of the three areas. In terms of the distribution equilibrium of accesses, there is little difference between the three areas. The data for the Xinjiekou area are slightly higher than those for the Longjiang area, and those for the latter are slightly higher than those for the Hexi area. The smaller the dispersion coefficient value, the more uniform the distribution, so the distribution of accesses in the Hexi area is more uniform.

Table 3. The interface types and distribution of accesses of the boundary spatial form of the 21 blocks.

Number	Xinjiekou Area	Longjiang Area	Hexi Area
#1			
#2			
#3			
#4			
#5			
#6			
#7			
Legend	Interface level: Closed boundary; Semi-open boundary; Open boundary; Business boundary		
	Access level: ● access		

Slow-travel environment: As shown in Table 2, the average cross-section ratios of the Xinjiekou, Longjiang, and Hexi areas are 0.42, 0.36, and 0.34, respectively. Overall, the cross-section ratio of the

Xinjiekou area is higher than that of the other two areas, while the data for the Hexi area and Longjiang area do not have many differences. The author believes that Xinjiekou, as the old town of Nanjing, has numerous and well-connected lanes, and the narrow and long lanes raise the cross-section ratio of the roads in the whole Xinjiekou area. While the roads in the Hexi area are generally wider than that in the Longjiang area and Xinjiekou area, the widths of the footpath and nonmotorized vehicle lanes in the Hexi area are relatively ideal.

4.3.2. Land Use and Transit Facilities

Land use: The land use attributes of the 21 sample blocks are shown in Tables 2 and 4. The three areas are mainly filled with residential buildings, followed by commercial buildings, public service buildings, and commercial and scientific research buildings. The proportion of commercial and scientific research buildings in the Hexi area is around zero, which is because the commercial and scientific research buildings in the Hexi area are mostly concentrated near the Hexi CBD (Central Business District) and the survey samples selected in this paper are the blocks that are dominated by a residential function. In general, ranked from high to low, the average values of the degree of mixed land use in the three areas are: 1.166 in the Xinjiekou area, 1.071 in the Longjiang area, and 0.857 in Hexi area.

Table 4. The land use properties of the 21 sample blocks.

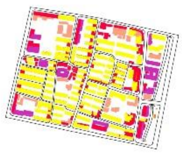
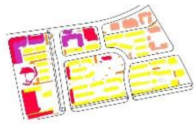
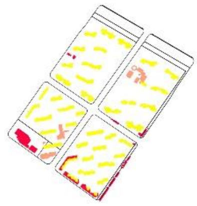
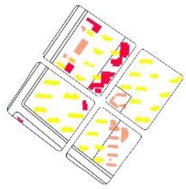
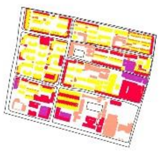
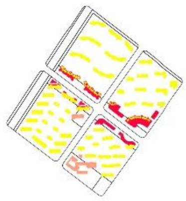
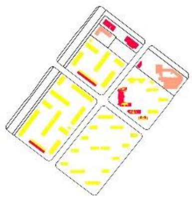
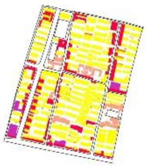
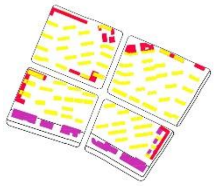
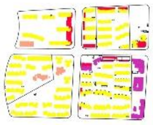
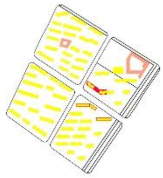
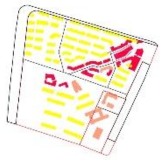
Number	Xinjiekou Area	Longjiang Area	Hexi Area
#1			
#2			
#3			
#4			

Table 4. *Cont.*

Number	Xinjiekou Area	Longjiang Area	Hexi Area
#5			
#6			
#7			
Legend	Residential buildings; Commercial buildings; New buildings; Public service buildings; Commercial and scientific research buildings		

Transit facilities: The transit station coverage of the 21 sample blocks is shown in Tables 2 and 5. The transit station coverage in the Xinjiekou area is the lowest, with an average level of 73.9%, followed by 74.7% in the Longjiang area. The transit station coverage in the Hexi area is the highest, reaching 82%. In general, the transit stations in each sample block are well distributed, and the mean value of the transit station coverage of a 300-m radius in the three areas is above 73%.

Table 5. The transit station coverage of the 21 sample blocks.

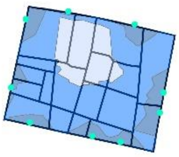
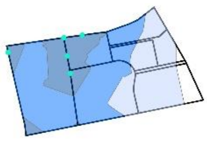
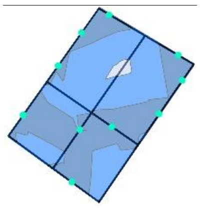
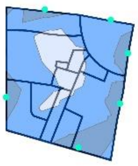
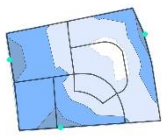
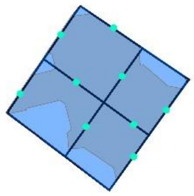
Number	Xinjiekou Area	Longjiang Area	Hexi Area
#1			
#2			

Table 5. *Cont.*

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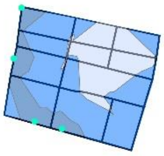
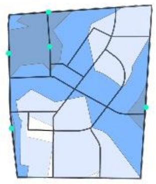
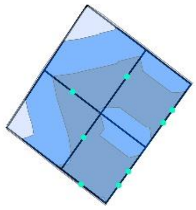
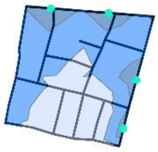
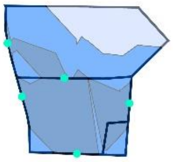
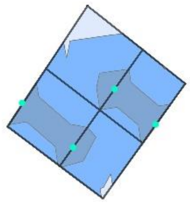
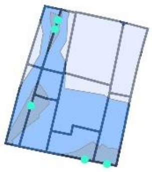
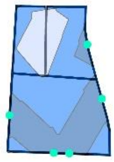
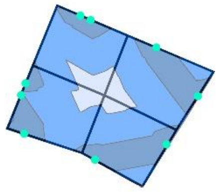
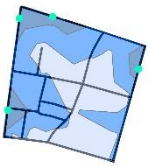
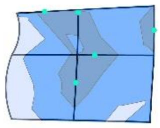
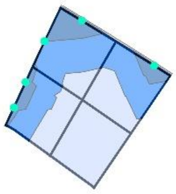
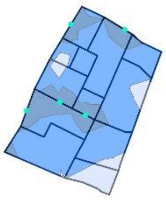
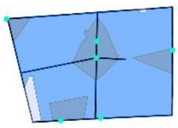
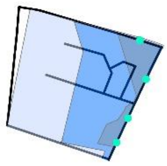
#3			
#4			
#5			
#6			
#7			
Legend	Transit station; 100-m accessible area; 300-m accessible area; 500-m accessible area		

5. Correlation Analysis of the Various Influencing Factors and Residents' Travel

This section adopts the correlation analysis to describe the degree of correlation between two variables using the Pearson correlation coefficient. The correlation analysis model is established, taking blocks as units; the residents' socioeconomic attributes, degree of mixed land use, transit station coverage, and boundary space form of blocks as independent variables; and the share of residents' low-carbon travel in the block ($P_{CT,i}$, $P_{UT,i}$, $P_{RT,i}$) as the dependent variable, exploring the correlation between the residents' socioeconomic attributes, the built environment of blocks, and the share of residents' low-carbon travel, preliminarily screening out the significant indicators that affect residents' low-carbon travel.

5.1. The Variables of Households' Socioeconomic Attributes

The results of the correlation analysis between the variables of households' socioeconomic attributes in the 21 sample blocks and the variables of the share of low-carbon travel are shown in Table 6:

(1) The highest educational attainment of the family members. The degree of family members' educational attainment is not related to daily consumptive travel or daily recreational travel. There is a positive correlation between the family members whose highest educational attainment is a junior high school diploma or below and the share of residents' low-carbon travel for commuting, indicating that the households with lower academic qualifications are more inclined to choose low-carbon travel in terms of commuting. This may be related to the relatively lower socioeconomic status and the restrictions imposed on such families in terms of the choice of car travel.

(2) Permanent number of household members. In this research, the permanent number of household members does not show a correlation with the choice of residents' travel modes.

(3) Annual household income. Households with an annual income of less than 50,000 RMB have positive correlations with the share of their low-carbon travel for commuting, daily consumption, and daily recreation. However, the households with an annual income between 100,000 RMB and 200,000 RMB have not shown a correlation with daily recreational travel, but rather a negative correlation with the share of their low-carbon travel for commuting and daily consumption, indicating that residents have a higher possibility of low-carbon travel in households with lower annual incomes, while the households with higher annual incomes prefer car travel. The reason for the result may be due to the relatively low income level, which makes residents more inclined to choose a more economical travel mode.

(4) Family car ownership. This indicator has the strongest relationship with residents' travel. Residents without cars in the family usually choose a mode of low-carbon travel. In the analysis results, residents with no cars in the family are positively related to all the three types of low-carbon travel, the correlation of which is very significant. The families with only one car have a negative correlation with the proportion of low-carbon travel for daily recreation. The families with two cars have no correlations with daily recreational travel, but rather have a negative correlation with commuter and daily consumptive travel; that is to say, the families with two cars tend to choose car travel when commuting and shopping.

Table 6. The results of the correlation analysis between the variables of households' socioeconomic attributes and the variables of the share of low-carbon travel.

Households' Socio-Economic Attributes		Commuter Travel		Consumptive Travel		Recreational Travel	
		Correlation Coefficient (r)	P Value (Sig)	Correlation Coefficient (r)	P Value (Sig)	Correlation Coefficient (r)	P Value (Sig)
The highest educational attainment of family members	Junior high school and below	0.438	0.047 *	0.369	0.099	0.430	0.052
	High school	0.014	0.951	0.184	0.424	−0.001	0.995
	Bachelor	0.217	0.344	0.003	0.991	−0.098	0.674
	Master and above	−0.379	0.090	−0.280	0.219	−0.046	0.842
The number of permanent family population	1	0.033	0.887	0.037	0.874	0.150	0.517
	2	0.152	0.510	0.317	0.162	0.071	0.758
	3	0.071	0.758	−0.035	0.882	−0.148	0.522
	More than 3	−0.191	0.408	−0.196	0.394	0.064	0.782
The annual households income (10,000 RMB)	Less than 5	0.672	0.001 **	0.483	0.027 *	0.490	0.024 *
	5–10	0.161	0.485	0.303	0.181	0.057	0.806
	10–20	−0.447	0.042 *	−0.443	0.044 *	−0.305	0.178
	More than 20	−0.147	0.525	−0.172	0.456	−0.055	0.812
The number of cars owned	0	0.663	0.001 **	0.661	0.001 **	0.496	0.022 *
	1	−0.324	0.152	−0.375	0.094	−0.451	0.040 *
	3	−0.487	0.025 *	−0.434	0.049 *	−0.139	0.547
	3 or more	0.035	0.881	0.120	0.605	0.280	0.219

Note: * indicates a correlation coefficient of a p value less than 0.05; ** indicates a correlation coefficient of a p value less than 0.01.

On the whole, the families with an educational attainment of a junior high school diploma or below, an annual income of less than 50,000 RMB, and no cars showed positive correlations with the three types of low-carbon travel. Meanwhile, the families with an annual income of 100,000–200,000 RMB and two cars showed negative correlations with the proportion of low-carbon travel for commuting and daily consumption. Based on the data in Figures 5–8, this paper believes that this may be due to the higher level of educational attainment, which generally corresponds to a higher annual household income of the residents. Their superior economic conditions mean they tend to live in the residential blocks that have been built in recent years, have a higher degree of modernization, and be more concentrated on closed-off management, such as in the Hexi area in this paper. The built-up environment conducive to travel by motor vehicle may also further prompt them to buy cars, allowing them to choose cars for commuting and daily consumption. In addition, from the analysis of the survey data, we believe that in Nanjing, a second-tier large city which is smaller than metropolises such as Beijing, Shanghai, Guangzhou, and Shenzhen, the built-up environment plays an important role in the selection of people's residence, which brings people with the same attributes together. In other words, people with similar socioeconomic attributes are more likely to choose the same residences and lifestyles.

5.2. The Variables of the Boundary Space Form of Blocks

The results of the correlation analysis between the boundary space form of the blocks and the share of residents' low-carbon travel in the 21 sample blocks are shown in Table 7:

Table 7. The results of the correlation analysis between the boundary space form of the blocks and the share of residents' low-carbon travel.

Boundary Space Form		Commuter Travel		Consumptive Travel		Recreational Travel	
		Correlation Coefficient (r)	P Value (Sig)	Correlation Coefficient (r)	P Value (Sig)	Correlation Coefficient (r)	P Value (Sig)
Block scale	Boundary density (km/km^2)	0.598	0.004 **	0.483	0.027 *	0.461	0.035 *
Boundary surface	Permeability coefficient	0.664	0.001 **	0.566	0.007 **	0.293	0.197
	Commercial surface (km/km^2)	0.694	0.000 **	0.482	0.027 *	0.459	0.037 *
Accesses	Density	0.658	0.001 **	0.438	0.047 *	0.542	0.011 *
	Distribution equilibrium	0.517	0.016 *	0.302	0.184	0.424	0.056
Slow travel environment	Proportion of the road cross-section	0.448	0.042 *	0.301	0.185	0.436	0.048 *

Note: * indicates a correlation coefficient of a p value less than 0.05; ** indicates a correlation coefficient of a p value less than 0.01.

The level of the block scale: The boundary density variable of blocks is positively correlated with the share of the three types of residents' low-carbon travel, and it is a relatively significant correlation; that is, the larger the total length of the boundary per unit area of the block, the more the residents tend to choose low-carbon travel, indicating that the blocks with a relatively small scale are conducive to residents choosing low-carbon travel modes for commuting, daily consumption, and daily recreation.

The level of the interface: The permeability coefficient of the block boundary interface is positively correlated with the share of low-carbon travel for commuting and consumption. The higher the permeability coefficient of the interface, the more likely it is that residents will choose low-carbon travel for commuting and daily consumption. However, unexpectedly, the daily recreational travel mode does not show a significant correlation with the permeability coefficient of the interface. In terms of the proportion of business interfaces, the analysis results show that they have a significant positive correlation with residents' commuter travel and daily consumptive travel, as well as daily recreational travel.

The level of access: The density of accesses has a positive correlation with the share of the three types of residents' low-carbon travel, among which the correlation with low-carbon travel for commuting is more significant, indicating that the density of accesses of residential blocks has an impact on residents' daily travel. The distribution equilibrium of accesses to the block is only positively related to the share of residents' low-carbon travel for commuting, and there is no correlation with consumptive and recreational travel. According to the data analysis of the accesses of the field survey, the density of the accesses in the Xinjiekou area is much higher than that in the other two areas, but the distribution equilibrium of accesses is not as significant as that of the other two areas. The mutual influence of the two indicators leads to the results shown in the above table.

The level of the slow-travel environment: The variables of the slow-travel environment show a positive correlation with the proportion of low-carbon travel for commuting and daily recreation, but they have no correlations with that of daily consumption.

In general, the share of residents' low-carbon travel for commuting is positively correlated with each indicator of the boundary space of the blocks. The daily consumptive travel has a positive correlation with the block scale, interface permeability coefficient, commercial interface ratio, and the density of accesses. Daily recreational travel has a positive correlation with the block scale, commercial interface ratio, density of block accesses, and slow-travel environment.

5.3. The Variables of Land Use and Transit Facility

The results of the correlation analysis between the variables of the degree of mixed land use and transit station coverage and the share of residents' low-carbon travel in the 21 sample blocks are shown in Table 8.

Table 8. The results of the correlation analysis between the variables of the degree of mixed land use and transit station coverage and the share of residents' low-carbon travel.

		Commuter Travel		**Consumptive Travel**		**Recreational Travel**	
		Correlation Coefficient (r)	**P Value (Sig)**	**Correlation Coefficient (r)**	**P Value (Sig)**	**Correlation Coefficient (r)**	**P Value (Sig)**
Land use	Mixed degree of land use	0.609	0.003 **	0.610	0.003 **	0.646	0.002 **
Transit facilities	Transit station coverage	−0.042	0.857	−0.046	0.843	−0.010	0.964

Note: ** indicates a correlation coefficient of a p value less than 0.01.

The level of land use: There is a significant correlation between the variable of the degree of mixed land use and the share of residents' three types of low-carbon travel, presenting a positive correlation; that is to say, the higher the degree of mixed land use, the more likely it is that the residents in the blocks will choose a low-carbon travel mode for commuting, consumption, and recreation.

The level of transit facilities: The analysis results show that the correlation between the transit station coverage and the residents' three low-carbon travel modes is not significant, and it has certain differences to the predictions of the previous study in this paper. The analysis shows that the reason for the result may be that the average transit station coverage within the 300-m radius in the area is more than 73%, the number of public transit stations and their distribution level are fairly good, and the difference between the areas is relatively small, so there is no significant correlation.

6. Identification of the Key Indicators of the Boundary Space Form of Blocks

The correlation analysis describes the relationship between any two variables of residents' travel and of the potential influences. Therefore, this paper uses the multinomial logistic regression model to analyze the influence of various indicators of the boundary space form of blocks on residents' travel, when the variables, such as the socioeconomic attributes, degree of mixed land use, transit station coverage, and the boundary space form of blocks, work together. This paper divides the share of households' low-carbon travel into four categories, namely $\pi0$, $\pi1$, $\pi2$, and $\pi3$, according to the three points of 25%, 50%, and 75%. $\pi3$ is set as a reference category, and $\pi0/\pi3$, $\pi1/\pi3$, and $\pi2/\pi3$ represent the comparison of the share of the first three types of low-carbon travel with the share of low-carbon travel of more than 75%. From this, the multiple logistic regression model can be established to rescreen out the key variables from the boundary space form of the residential blocks that affect residents' travel modes.

In the multinomial logistic regression analysis, based on the sample travel data of 1185 households, this paper takes households as the units and the boundary density, permeability coefficient, commercial interface ratio, density of accesses, distribution equilibrium of accesses, and cross-section share of roads as the independent variables, which are preliminarily screened out at the level of the boundary space form of blocks. This paper takes the residents' socioeconomic attributes, land use, and the significant variables preliminarily screened out at the level of transit facilities as covariates and the share of the households' three types of low-carbon travel as the dependent variables, so as to establish the multinomial logistic regression model.

The results of the regression analysis are shown in Tables 9–11. Combined with the covariates of the residents' socioeconomic attributes, land use, and transit facilities, we can see that at the level of residents' commuter travel, the three indicators, including the boundary density of blocks, the density of accesses, and the share of the cross section of roads, have a significant positive correlation with residents' low-carbon travel modes. In terms of daily consumptive travel, the three indicators of the block boundary density, commercial interface ratio, and interface permeability coefficient are significantly and positively correlated with low-carbon travel modes. In terms of daily recreational travel, the two indicators of the commercial interface ratio and the density of accesses are significantly positively correlated with those of residents' travel modes. It should be noted that in the results of the multinomial logistic regression analysis, the variable of the slow-travel environment shows a significant positive correlation with the proportion of low-carbon travel for commuting, but shows no correlation with that of daily recreation, which is different from the expectation of this paper. Based on the comparison and analysis, we believe that the reason may be that the average cross-section ratios of slow-travel roads in the Xinjiekou area, Longjiang area, and Hexi area are 0.42, 0.36, and 0.34, respectively, among which the difference is relatively small compared with other indicators. At the same time, the reason for the high cross-section ratio of the slow-travel roads in the Xinjiekou area is that there are more narrow roadways and dense road network in the area, which has certain advantages for commuters who are in a hurry. While the roads in the Hexi area are relatively wide, although the ratio of slow-travel roads is relatively low, the real width of the slow-travel roads is not narrow, so it still provides a good environment for daily recreation. However, in terms of the low-carbon travel behavior of commuting, the wider driveways in the Hexi area do not have the same advantages as those in the Xinjiekou area. Overall, the indicators of the boundary space form of blocks that have been rescreened out have a higher degree of influence on the residents' travel modes, and the larger the indicator, the higher the share of low-carbon travel.

Table 9. The results of the multinomial logistic regression analysis between the boundary spatial form variables and the share of residents' low-carbon commuter travel.

Effect	Model Fitting Conditions	Likelihood Ratio Test		
	−2 Logarithmic Likelihood	Chi-Square	Degrees of Freedom	Sig
Intercept	1,102.428a	0.000	0	
Boundary density	955.341	25.043	3	0.000 **
Permeability coefficient	934.244	3.947	3	0.267
Commercial surface	935.248	4.950	3	0.175
Density of accesses	945.054	14.757	3	0.002 **
Distribution equilibrium of accesses	935.826	5.529	3	0.137
Proportion of the road cross-section	940.996	10.699	3	0.013 *

Note: * indicates a correlation coefficient of a p value less than 0.05; ** indicates a correlation coefficient of a p value less than 0.01; "a" indicates that this simplified model is equivalent to the final model.

Table 10. The results of the multinomial logistic regression analysis between the boundary spatial form variables and the share of residents' low-carbon daily consumptive travel.

Effect	Model Fitting Conditions	Likelihood Ratio Test		
	−2 Logarithmic Likelihood	Chi-Square	Degrees of Freedom	Sig
Intercept	705.258 [a]	0.000	0	
Boundary density	863.800	29.094	3	0.000 **
Permeability coefficient	862.563	27.857	3	0.000 **
Commercial surface	847.491	12.786	3	0.005 **
Density of accesses	840.282	5.577	3	0.134

Note: ** indicates a correlation coefficient of a p value less than 0.01; "a" indicates that this simplified model is equivalent to the final model.

Table 11. The results of the multinomial logistic regression analysis between the boundary spatial form variables and the share of residents' low-carbon daily recreational travel.

Effect	Model Fitting Conditions	Likelihood Ratio Test		
	−2 Logarithmic Likelihood	Chi-Square	Degrees of Freedom	Sig
Intercept	347.457 [a]	0.000	0	
Boundary density	628.291	1.653	3	0.647
Commercial surface	646.944	20.306	3	0.000 **
Density of accesses	650.625	23.987	3	0.000 **
Proportion of the road cross-section	631.252	4.614	3	0.202

Note: ** indicates a correlation coefficient of a p value less than 0.01; "a" indicates that this simplified model is equivalent to the final model.

7. Estimation of the Recommended Value of Key Indicators for the Boundary Space Form of Blocks That are Conducive to Residents Choosing Low-Carbon Travel

According to the results of the correlation analysis and multinomial logistic analysis, a scatter plot is drawn of the relationship between the key variables of the boundary space form of blocks and the three types of travel modes. From the trend lines depicted in the scatter plots in Figures 11–15, it can be found that there may be a certain linear relationship between the indicators of the boundary space form of blocks and the share of residents' low-carbon travel. Therefore, a unary linear regression equation is established to estimate the corresponding recommended values.

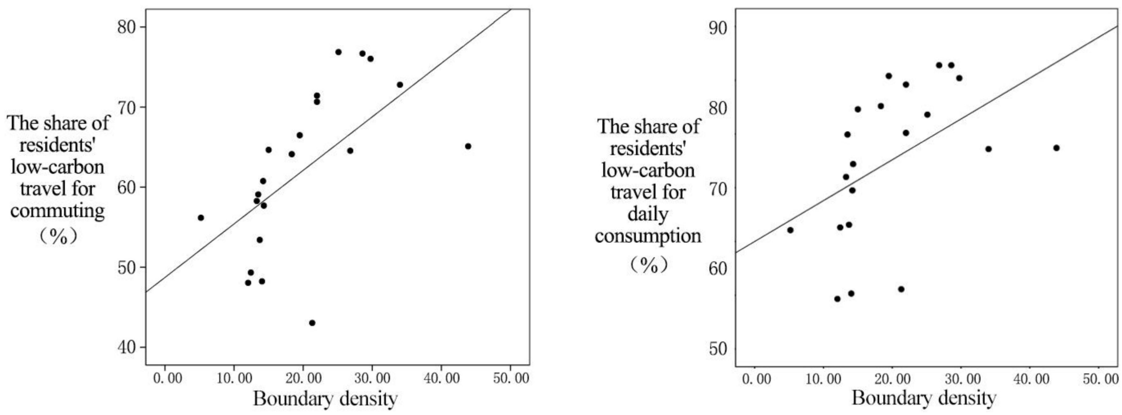


Figure 11. Scatter plot of the relationship between the variable of the block boundary density and the share of residents' low-carbon travel for commuting and daily consumption.

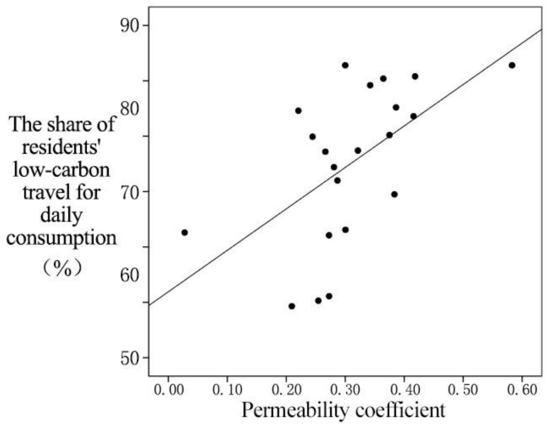


Figure 12. The scatter plot of the relationship between the variable of the permeability coefficient and the share of residents' low-carbon travel for daily consumption.

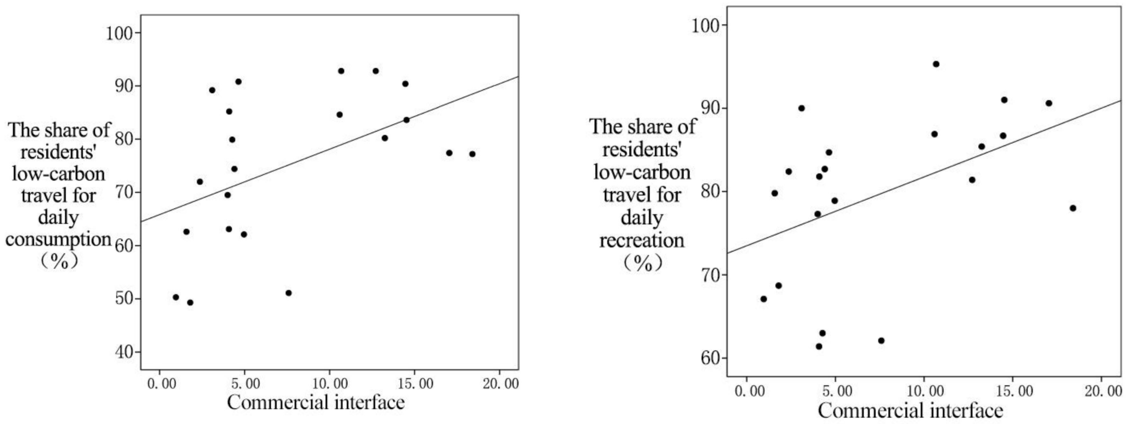


Figure 13. Scatter plot of the relationship between the commercial surface ratio and the share of residents' low-carbon travel for daily consumption and daily recreation.

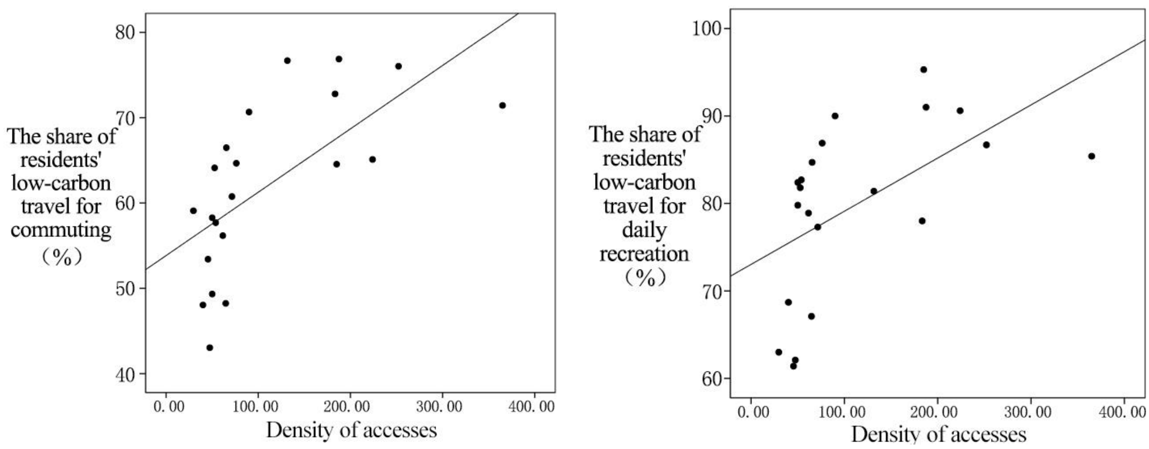


Figure 14. Scatter plot of the relationship between the density of accesses of residential blocks and the share of residents' low-carbon travel for commuting and daily recreation.

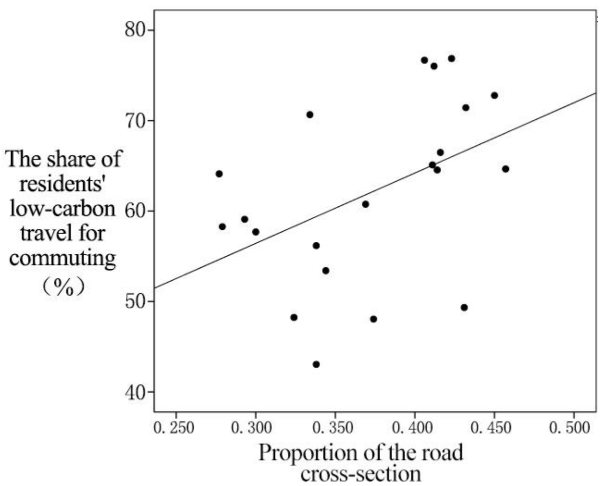


Figure 15. Scatter plot of the relationship between the variable of the cross-sectional ratio and the share of residents' low-carbon travel for commuting.

7.1. Block Scale

Boundary Density

The scatter plot of the relationship between the variable of the block boundary density and the share of residents' low-carbon travel for commuting and daily consumption is shown in Figure 11. Assuming that other influencing factors remain unchanged, the linear regression equations of the boundary density and low-carbon travel modes for commuting and daily consumption are:

$$y = 0.49 + 6.69 \times 10^{-3} \times x \tag{13}$$

$$y = 0.6 + 7.6 \times 10^{-3} \times x \tag{14}$$

The meaning of the equation is that with the other influencing factors remaining unchanged, for every 10 km/km^2 increase in the block boundary density, the share of residents' low-carbon travel for commuting and daily consumption increases by 6.69% and 7.6%, respectively.

In this research, 81%, being the city's overall share of low-carbon travel, is used as the measurement criteria of the blocks oriented toward low-carbon travel, mainly referring to the related foreign and domestic indicators. In the Tokyo Metropolis, only 11.7% of the residents travel by motor vehicles and the share of low-carbon travel is close to 90% [35]. Hong Kong, China, with a high-density population and a compact urban form, is one of the most sustainable cities in the world. According to statistics, the daily share of residents' low-carbon travel in Hong Kong is as high as 90% [36]. As a forerunner of China's slow-travel practice, the government of Hangzhou approved the 'Hangzhou Ped & Bike System: Guidelines for Planning' in 2008, and it is expected that the share of residents' low-carbon travel will reach 81% by 2020 [37]. For the sample areas in this paper, only the overall share of low-carbon travel in the Xinjiekou area reached a high level, of about 81%. However, there are still some gaps in the low-carbon travel of the remaining areas, which are even more substantial when compared with Hong Kong and Tokyo. Based on the current situation of Nanjing city and the step-by-step principle, this paper selects 81% as the overall share of low-carbon travel in Hangzhou as the stage target of the sample area in this paper, combined with the share of the three types of low-carbon travel of the total travel, according to the statistics, and converts the total proportion of low-carbon travel of 81% into the proportion of the three types of low-carbon travel. We can thus obtain that P_{CT} = 72, P_{UT} = 84%, and P_{RT} = 88%. Substituting the data into the equations, we can obtain the corresponding block boundary density values of 34.38 and 31.58, so the block boundary density oriented toward low-carbon travel is recommended to be above 34.38 km/km^2.

7.2. Boundary Interface

7.2.1. Permeability coefficient

The scatter plot of the relationship between the variable of the permeability coefficient of the block interface and the share of residents' low-carbon travel for daily consumption is shown in Figure 12. Assuming that other influencing factors remain unchanged, the linear regression equation of the interface permeability coefficient and low-carbon travel modes for commuting and daily consumption is:

$$y = 0.52 + 0.75 \times x \tag{15}$$

The meaning of the equation is that with the other influencing factors remaining unchanged, for every 0.1 increase in the permeability coefficient of the block interface, the share of residents' low-carbon travel for daily consumption increases by 7.5%. Inputting P_{UT} = 84% into the equation, we can determine that the corresponding permeability coefficients of the block interface is 0.43. Therefore, the permeability coefficient of the block interface oriented toward low-carbon travel is recommended to be above 0.43.

7.2.2. Commercial interface ratio

The scatter plot of the relationship between the commercial interface ratio of the block and the share of residents' low-carbon travel for daily consumption and daily recreation is shown in Figure 13. Assuming that other influencing factors remain unchanged, the linear regression equations of the commercial interface ratio and low-carbon travel modes for daily consumption and daily recreation are:

$$y = 0.66 + 0.01 \times x \tag{16}$$

$$y = 0.73 + 8.26 \times 10^{-3} \times x \tag{17}$$

The meaning of the equation is that with the other influencing factors remaining unchanged, for every 10 km/km^2 increase in the commercial interface ratio, the share of residents' low-carbon travel for daily consumption and daily recreation increases by 10% and 8.26%, respectively. Inputting P_{UT} = 84% and P_{RT} = 88% into the equations, we can determine that the corresponding commercial interface ratios are 18 and 18.16. Therefore, the commercial interface ratio oriented toward low-carbon travel is recommended to be above 18.16 km/km^2.

7.3. Accesses

Density of Accesses

The scatter plot of the relationship between the density of accesses of residential blocks and the share of residents' low-carbon travel for commuting and daily recreation is shown in Figure 14. Assuming that other influencing factors remain unchanged, the linear regression equations of the density of accesses and the low-carbon travel modes for commuting and daily recreation are:

$$y = 0.54 + 7.43 \times 10^{-4} \times x \tag{18}$$

$$y = 0.73 + 6.08 \times 10^{-4} \times x \tag{19}$$

The meaning of the equations is that, with the other influencing factors unchanged, for every 100/km^2 increase in the density of accesses, the share of residents' low-carbon travel for commuting and daily recreation increases by 7.43% and 6.08% respectively. Substituting P_{CT}=72% and P_{RT}=88% into the equations, we can obtain that the density of accesses of the corresponding blocks are 242.26 and 246.71, so the density of accesses of the blocks oriented for low-carbon travel is recommended to be above 246.71/km^2.

7.4. Slow-Travel Environment

Cross-Sectional Ratio of the Roads

The scatter plot of the relationship between the variable of the cross-sectional ratio of residential blocks and the share of residents' low-carbon travel for commuting is shown in Figure 15. Assuming that other influencing factors remain unchanged, the linear regression equation of the cross-sectional ratio and the low-carbon travel for commuting is:

$$y = 0.33 + 0.78 \times x \tag{20}$$

The meaning of the equation is that with the other influencing factors remaining unchanged, for every 0.1 increase in the cross-sectional ratio, the share of residents' low-carbon travel for commuting increases by 7.8%. Inputting PCT = 72% into the equation, we can determine that the corresponding cross-sectional ratio is 0.5. Therefore, the cross-sectional ratio of the roads oriented toward low-carbon travel is recommended to be above 0.5.

8. Conclusions

Since the reform of China's housing policy, gated residential blocks have won the favor of many residents in China, with their good closure and safety, and have quickly become the mainstream organizational model for living spaces which dominates the market [38]. However, the other characteristics of the gated blocks, such as their unsuitable scale and strict closure, have posed severe challenges to urban mobility. Based on low-carbon travel, this paper attempts to provide suggestions for the construction of blocks from the perspective of the block boundary space form. The SPSS analysis software is adopted to carry out a correlation analysis and multinomial logistic regression analysis of the survey data of residents' socioeconomic attributes, block boundary space forms, land use, public transit facilities, and modes of travel in the sample block. Finally, this paper estimates the recommended values based on the linear relationship between the variables.

From the research, this paper argues that there are related variables that have a significant influence on residents' travel modes in terms of the variables of residents' socioeconomic attributes and the boundary space form of blocks, and the same variables have various impacts on various types of residents' travel modes. The results show that the indicators of the block scale, boundary interface, density of block accesses, and slow-travel environment are closely related to residents' travel behavior. Based on the linear correlation between the above indicators and the residents' travel modes, this paper estimates the ideal recommended values of the residential blocks oriented toward low-carbon travel: It is recommended that the block boundary density should be above 34.38 km/km^2, the permeability coefficient of the interface should be above 0.43, the commercial interface ratio should be above 18.16 km/km^2, the density of accesses should be above 246.71 km/km^2, and the cross-sectional ratio of the roads should be above 0.5.

In light of the fact that the construction of residential blocks in China is still dominated by the closed pattern, as well as high-rise and high-density development forms, for example, the floor area ratio of the Xinjiekou area, Longjiang area, and Hexi area are around 2.0, 1.5, and 2.0, respectively. Based on the above research results and the recommended values of indicators, we have explained and visualized the indicators at the planning level. According to the boundary density value, this paper suggests that the residential block scale oriented toward low-carbon travel should be controlled within a radius of 125–200 m. If the side length of the residential block is 125 m, the commercial interface in the area is recommended to be 283 m or more, and the number of accesses should be controlled at 3–4 or above. The width of the slow-travel road should be up to half of the total width of the street. Of course, the data should be combined with the specific width of the street, because they are not fully suitable for the larger-scale urban expressways, trunk roads, and other wider streets.

This paper believes that the research results can provide practical referential advice, especially for developing countries, such as China, with relatively large block scales, gated space forms, a large population density, and high-speed development in the field of urban design and planning. However, it should be noted that due to the various political and economic backgrounds and natural and cultural environments of different countries and regions, it is still essential to make adjustments according to the actual situation of the area and put forward some specific suggestions during the planning of the boundary space of residential blocks.

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