Research Paper

The Impact of Spatial Density on Residents' Perception in Residence-Dominated Metro Station Areas

Taking the Red Line of Harbin Metro in China as an Example

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Abstract

As the city's "essence of the resource chain" and the "new skeleton" of the city's expansion, the rail transit line carries diversified functional elements. The high-density spatial form constituted by the aggregation and composite of these elements can directly affect the residents' psychological perception. This study takes residential-dominated stations in Harbin Metro Line 1 as an example. Based on the service range of 800m, we construct a spatial density model of the metro station areas at the meso-micro scale in three dimensions, namely, building types, land use function, and street system to measure the distribution characteristics and spatial patterns of the elements. The results show that: (1) the overall spatial density elements show "central city clustering hot spots, and dispersed cold spots at the edges of built-up areas". (2) The elements of POI facilities' concentration, functional mixing, and building height are all strong influence factors that have a significant impact on residents' perception. (3) The interaction effect of each factor is mostly a synergistic enhancement. This study can provide a reference for the resource allocation of spatial elements in the metro station areas, to dissolve the negative impacts of spatial creation on the residents under the control of pure indexes, and to promote the sustainable development of the urban space.

Keywords

High-density, Residential-dominated metro station areas, Spatial density, Resident perception, Geo-detector

1. Introduction

According to the survey report of UN-HABITAT, by 2030, more than 60% of the global population will live in cities, and the number of cities with a concentration of more than 10 million people will increase to 43, of which the number of cities in China is about 1/5. Under the double constraints of population pressure and land resource scarcity, the development of urban densification has become an inevitable trend to cope with the spatial and functional needs, and is regarded as an important part of the sustainable urban development strategy in the 21st century.

As a fundamental support for the development of urban densification, rail transit line makes the time distance of the city in different directions shorten dramatically, promotes the high concentration of urban elements such as residential population and resources, and becomes the main axis leading the

development of the city. With the development of rail transit in China, by the end of 2023, a total of 55 cities have opened 306 rail transit lines, with a total length of 10,165.7 kilometers. Rail transit lines change the original urban spatial structure, further catalyze the agglomeration of people and functions, and the space around the stations becomes the most dynamic place in the city. Metro Line 1, as the city's “essence of the resource chain” and the “new skeleton” of the city's expansion, carries the key role of linking the old city with the new district, connecting the subway stations, work and residential space and other aspects of the environment with people, their daily lives and urban development, making the residents of the old city have a strong sense of humor and a strong sense of responsibility. It makes the residents of the old city district have a strong dependence on it. Among them, the residence-dominated stations not only take on the node function of transportation, but also carry more diversified life scenes and functional elements such as residence, consumption, entertainment, etc., realizing the multiple coupling of rail transit and residents' life and urban functions, and further developing into the integrated “rail + life” comprehensive development mode, which is a combination of “station”, city, production and humanities. development mode. However, the excessive concentration of elements makes the development of urban space around the station more and more three-dimensional, emphasizing the quantitative growth, ignoring the quality of social, ecological and other multi-dimensional guarantee. Such a control approach focusing on the measurement of a single indicator makes the station space face many problems such as overloaded infrastructure, lack of open space, crowded population, and tight housing (Figure 1). Therefore, the key issue is to improve the match between station areas and residents' behavioral and psychological needs by means of deploying built environment elements in residential-dominated stations in order to eliminate the negative perception of high density and concentration of elements in station areas.

Figure 1. Advantages and potential problems of urban densification. Source: Self-drawn by the author, 2024.

This study focuses on the residential- dominated subway stations in the old city district, and uses Geodetectors to explore the characteristics of the circled spatial patterns formed by the radiation and attraction of the stations to the surrounding spatial elements after implantation, as well as the evolution of the city's own morphology, in an attempt to reduce the negative perception of spatial density from the perspective of the residents' perceptions. Therefore, this study determines the spatial density elements from the perspective of Urban Morphology, detects the influence of each dimension of spatial density elements on the residents' perception, and identifies the main spatial density elements that affect the residents' perception, so as to better realize the good experience of the residents in the “last kilometer”.

2. Materials and Methods

2.1. Overview

With the transformation of the core value of urban design from “object-centered” to “human-centered”, people's perception of the environment has become the main research object and target. Research shows that among the many factors affecting residents' psychological perception, environmental factors account for 40%-50%, and the rapid growth of urban “volume” gradually reveals the negative marginal effect. However, there are fewer studies on agglomeration diseconomies, and the direction of the impact of spatial density on residents' perceptions has not yet been a more consistent conclusion. Most studies generally agree that higher building densities are more unpleasant and lead to negative perceptions. In contrast, an imagery study conducted in Oslo reported that if the environment is safe and free of noise, high building density may promote social relationships to improve resident perceptions. This suggests that the positivity of high building density on residents' perceptions is conditional and the key lies in the coordination with other environmental elements. With the transformation of the core value of urban design from “object-centered” to “human-centered”, people's perception of the environment has become the main research object and target. Research shows that among the many factors affecting residents' psychological perception, environmental factors account for 40%-50%, and the rapid growth of urban “volume” gradually reveals the negative marginal effect. However, there are fewer studies on agglomeration diseconomies, and the direction of the impact of spatial density on residents' perceptions has not yet been a more consistent conclusion. Most studies generally agree that higher building densities are more unpleasant and lead to negative perceptions. In contrast, an imagery study conducted in Oslo reported that if the environment is safe and free of noise, high building density may promote social relationships to improve resident perceptions. This suggests that the positivity of high building density on residents' perceptions is conditional and the key lies in the coordination with other environmental elements.

Current research on the spatial density elements affecting residents' perceptions mostly focuses on the objective level of physical spatial form. In recent years, scholars at home and abroad have proposed that spatial density elements such as building density, floor area ratio, open space rate, facility agglomeration, land use mixing, openness of street space, and interface coverage have a significant impact on residents' perception. Among them, the intensity of positive perception is significantly higher in neighborhoods dominated by multi-story buildings, large avenues, and neighborhoods with dense road networks than in other types of neighborhoods. With the research on spatial form gradually shifting to the human scale, the related research on density perception has also begun to focus on the design elements at the micro level, with particular attention to the positive impact of specific space types such as street space, green space, etc., on the psychological perception of residents. Quantitative analysis of the impact of green visibility, street aspect ratio, interface density, sky visibility, etc. on the perception of residents, and further use of computer scenario modeling methods to explore when the street interface transparency threshold of 40% of the human visual perception of the highest degree of comfort, a better guide to the creation of space . It can be seen that focusing on the coordination and threshold between spatial density elements in the control can significantly improve the livability satisfaction of residents to the current spatial environment.

2.2. Research Subjects and Methods

Residents' perception of spatial density is the complexity and diversity of the spatial form composed of density elements, which is the result of the interaction between human psychology and spatial environment. The metro station areas as a special public space environment, the radiation attraction of the station makes the space carry diverse life scenes and agglomeration of functions, and the agglomeration and conformity of functions make the station space form present differentiated characteristics, and also make the mismatch between the residents' perception and behavioral needs and the spatial environment.

Based on this, this study starts from the perspective of Urban Morphology and draws on the planar pattern analysis theory of Conzeen's Urban Morphology to measure the image factors and influence mechanisms that have a significant effect on residents' perception from three aspects: building types, land use function, and street systems. Figure 2 shows the overall idea of this study, firstly, from the functional point of view, ten residential-dominated stations in Harbin Metro Line 1 are selected, and the organizational structure and organizational relationship of spatial density elements in the station areas are measured by ArcGIS and Depthmap, and all kinds of influence factors are visualized and analyzed. Secondly, based on the identified influence factors, a questionnaire survey is used to measure the perception status of residents on the density elements, and further analyze the impact of different factors on the perception of residents. Thirdly, based on the identified influencing factors, a questionnaire survey was used to measure the residents' perception of the density elements, and further analyze the perception characteristics of the residents in different stations. Finally, Geodetector were used to detect the single and interactive synergistic effects of the factors, and to analyze the differences in the effects of the density factors and the degree of influence in the station space.

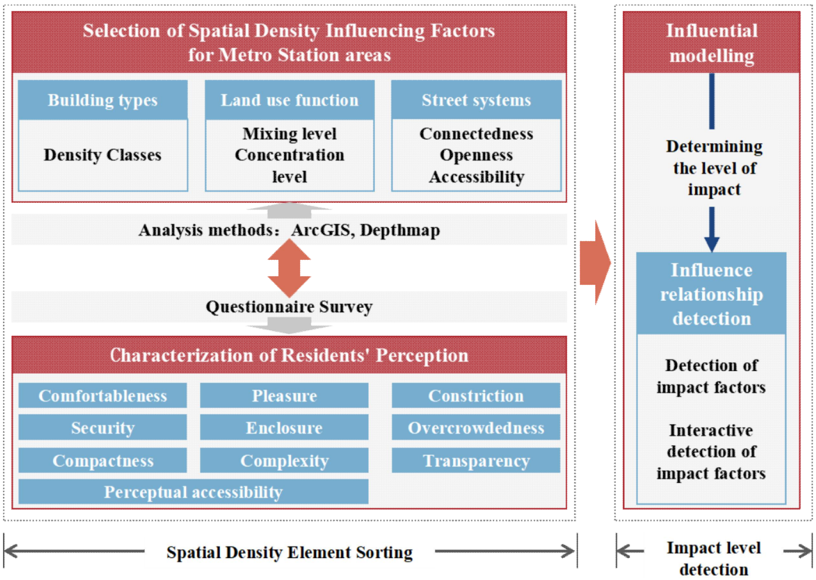


Figure 2. Research ideas. Source: Self-drawn by the author, 2024.

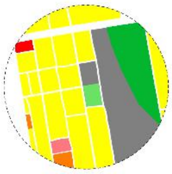
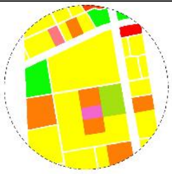
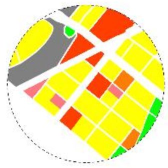
2.2.1. Research Areas

In the process of selecting and establishing metro stations, they are affected by multiple factors such as urban functions, spatial patterns and land properties, forming different spatial functional characteristics, and the differentiated spatial densities and functional fitnesses make the station areas present different spatial characteristics. Among them, the residential-dominated stations, as the most numerous and widely distributed stations, have complex spatial patterns composed of spatial densities that directly affect the quality of life of the residents and the spatial vitality of the station areas, which are closely related to the daily lives of the residents. Therefore, this study starts from the function orientation, and investigates the land use functions in the station areas according to 《the Urban Land Use Classification and Planning and Construction Standards》, in which the residence- dominated stations should meet the land use functions in the station area with residence as the main function and the proportion of land ⩾

40%. Based on this, this study takes the residential- dominated stations in Harbin Metro Line 1 as the research object, and selects a total of 10 samples such as Harbin East Station, Tobacco Factory, West Bridge, and Hexing Road (Table 1).

The delineation of the subway station area is not a fixed value in the related research, and the station area is mostly determined in a circle within a certain range accessible on foot centered on the subway station. According to the TOD model advocated by Peter Calthorpe and the research on TOD development at home and abroad by scholars such as Pan Haixiao and Ding Chuan, the radial influence of the metro station is mostly limited to the range of 500-1,000m; it is defined as a 15-minute walk from the station within the range of 500-800m in 《the Guidelines for Planning and Designing of Areas Along Urban Railways》 issued by the Ministry of Housing and Construction. Area. Therefore, taking into account the spatial characteristics of the metro station area and the walking ability of people of all ages, this study selects the station as the core and the area with a radius of 800m as the research scale of the spatial density of the metro area.

Table 1. Residential-led Metro Station Site Characteristics. Source: Self-drawn by the author, 2024.

	Harbin East Railway Station	Huashu Street	School of Transportation	Taipingqiao Bridge	Tobacco Factory
Site Characteristics					
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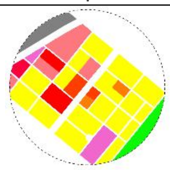
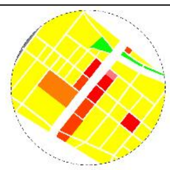
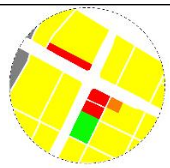
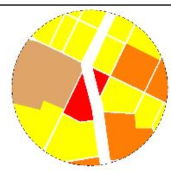
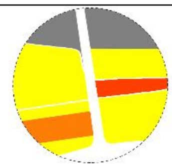
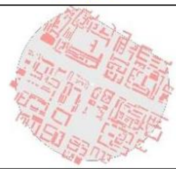
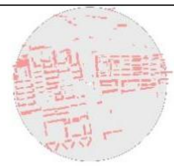
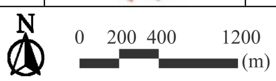
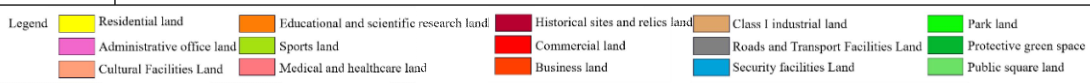
	Medical University First Hospital	West Bridge	Hexing Road	Xuefu Road	Harbin South Railway Station
Site Characteristics					
Planar Texture					
Scale and North					



2.2.2. Research Methodology

2.2.2.1. Optimal Parameters-based Geographical Detector

Geodetector, as a statistical tool for detecting spatially stratified heterogeneity and the driving forces behind it, can detect the influential relationship between one-factor and two-factor interactions on the dependent variable, respectively, so as to explain the driving effect and degree of the independent variable on the dependent variable. In the analysis, discretization of spatial data and spatial scale effects are key issues. The Optimal Parameter Geodetector model based on the GD package of R language adopts a variety of classification methods such as equal intervals, natural discontinuities, quartiles, geometric intervals, standard deviations, etc., and determines the optimal parameters by comprehensively considering various combinations of the discretization methods and the number of interval categories, and then further calculates q-values of each continuous variable related to the geospatial data, so as to select the parameter combination that produces the highest q-value as the optimal parameter combination. discretization method, effectively reducing the interference of subjective selection of discretization methods in traditional research.

In the research of detecting the differences in the spatial distribution of independent variables and dependent variables, it is generally based on four modules: factor detection, ecological detection, interaction detection and risk detection Therefore, this study takes the residents' perception as the dependent variable and the spatial density elements of each level as the independent variables, and utilizes factor detection and interaction detection to explore the main driving factors and driving mechanisms of the spatial density of metro station areas on the residents' perception under the effect of a single factor and a double factor, respectively. The factor detector measures the degree of influence of spatial density elements on residents' perceptions by q-value.

2.2.2.2. Space Syntax

Spatial Syntax, as one of the methods of quantitative analysis of spatial morphology, can quantitatively react to the accessibility or connectivity of spatial environmental structure by analyzing the spatial layout of cities or buildings, thus explaining the intrinsic mechanism of spatial morphology evolution, and thus has been widely used in the fields of urban morphology and urban spatial structure. The commonly used analytical models include visual field model, convex space model, axis model and line segment model, in which the axis model is based on the true distance of the road and the turning angle of the road as the main calculation factors, which has a higher credibility in calculating the radius of the road at different distances. Therefore, the axial model is chosen in this study to analyze the accessibility of the street system. In terms of analyzing parameters, the three influencing factors of Integration, Choice and Connectivity are chosen to calculate the openness of station space based on the viewpoint model, which is characterized by the viewpoint Integration.

2.2.3. Data Sources

This study mainly uses several vector data containing road network data, building data, POI data land use data within the study area. On this basis, the road data are simplified into a network composed of road centerlines through screening, topology checking, and modification; the building data are calculated according to the principle of 3m/floor for their building heights; the POI data are reclassified; and the land use functions in the master plan are corrected based on the urban land use functions shown in Baidu Maps, so that the spatial density of the subway station area can be visualized.

2.3. Selection of Indicators

2.3.1. Selection of Spatial Density Indicator Factors for Metro Station Areas

Spatial density reflects the objective distribution of various urban components (including social groups, physical facilities, economic activities, etc.) at the spatial scale. Therefore, the spatial density in this study focuses more on the meso-micro spatial patterns constituted by the combination of physical spatial forms. The meso-morphology mainly refers to the topology of the road network and the planar morphology of the facility layout in the station area, while the micro-morphology focuses on the three-dimensional geometric morphology of the buildings and street space in the station area. Therefore, when selecting the spatial density elements affecting residents' perception, on the one hand, taking the previous research as the benchmark, and on the other hand, drawing on the planar pattern analysis theory of Conzeen's urban morphology, the urban morphology and spatial density are divided into three dimensions: the building types (including the buildings and plots), the land use function, and the street system.

Table 2. Index system of spatial density elements in residential dominated subway station areas. Source: Self-drawn by the author.

Dimension	First Indicators	Secondary Indicators	
Building Types	Density Classes	Building density（X_1）	
		Floor area ratio（X_2）	
		Height（X_3）	
Land use Function	Mixing Level	Land use mixing（X_4）	
	Concentration Level	Density of POI facilities（X_5）	
		POI facility agglomeration kernel density（X_6）	
Street Systems	Connectedness	Road network density（X_7）	
	Openness	Openness of the sky（X_8）	
		Closeness（X_9）	
	Accessibility	Integration	Global integration（X_{10}）
			Local integration（X_{11}）
		Choice	Global choice（X_{12}）
			Local choice（X_{13}）
		Connectivity（X_{14}）	

Based on this comprehensive consideration, the spatial density index factor of metro station area including three dimensions of building types, land use function and street systems, six elements of density classes, mixing level, concentration level, connectedness, openness and accessibility and corresponding 14 factors were finally constructed (Table 2), in order to study the differential impact of the uneven characteristics of the spatial density of metro station area on the perception of residents.

2.3.2. Measurement of Residents' Perceived Characteristics

Perception, as a bridge and a continuous inward channel for the built environment to interact with the human psyche, is the main way for people to evaluate their surroundings. This study focuses on residents' perception of spatial layout patterns and planar texture patterns composed of density elements, including two-dimensional and three-dimensional spatial features. Therefore, it is mainly based on the five dimensions of imagery, enclosure, human scale, transparency, and richness proposed by Ewing , and on this basis, the perceptual results of tension, security, and crowding brought about by complex urban spatial organization are derived. The questionnaire was used to describe the residents' perceptions of comfort, pleasure, enclosure, security, constriction, crowding, compactness and transparency created by the spatial density elements from multiple perspectives.

The questionnaire includes two parts: (1) the basic attributes of the respondents, including gender, age, occupation, cultural level, place of residence, etc.; (2) the respondents' perceptions of the spatial density of the residence-led station area, which is characterized by 10 indicators, including comfortableness, pleasure, constriction, security, enclosure, overcrowdedness, compactness, complexity, transparency, and perceptual accessibility, to describe the residents' perceptions of the spatial characteristics of the station area. To describe the results of residents' perception of the spatial characteristics of the station area and the distribution of density elements, a five-point Likert scale is used, with “5, 4, 3, 2, 1” assigned to “very satisfied”, “satisfied”, “average”, “dissatisfied” and “very dissatisfied”, so that the residents' scores reflect the perceived spatial density of the metro station area.

3. Result Analysis

3.1. Distribution of Influencing Factors of Spatial Density in Metro Station Area

Calculate the 14 key factors of the six levels identified in Table 3, characterize the spatial density level of the station with the mean value of each influence factor, and visualize and compare the analysis of some of the factors (Figure 3).

(1) From the perspective of the density class hierarchy(Figure 3a,3b,3c), the spatial pattern of the construction intensity of each site is characterized by diversity due to differences in location. The overall situation of “local aggregation, high center site and low edge site” is presented, and there are fewer high-intensity development sites. The principle of graded density advocated by TOD theory has not yet been realized, and the central city site is relatively mature.

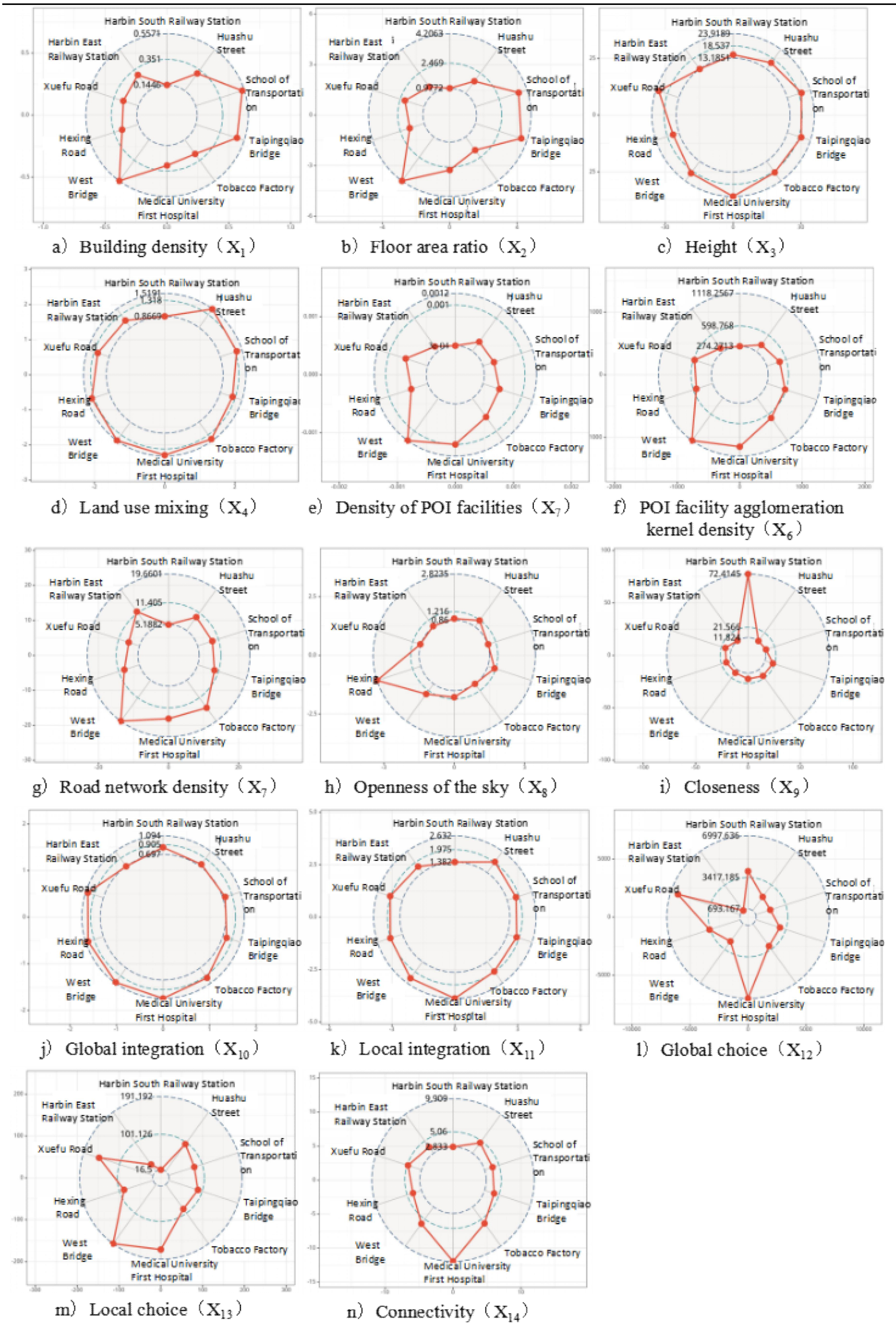
(2) From the viewpoint of mixing degree level (Figure 3d), the overall mixing degree presents high mixing characteristics with balanced distribution, a few sites have functional monotonous development, and the spatial distribution of high and low values shows a certain clustering trend. The residential function of the residential-led stations attracts related supporting functions to form a “functional core” around the stations, which greatly improves the land intensification and spatial vitality in the station space.

(3) From the perspective of concentration level (Figure 3e,3f), the spatial concentration of POI facilities in the station space is relatively strong, and all of them have formed point-like cores in the station space, with relatively complete public service facilities. Among them, the high value area of concentration within each station area mostly overlaps with the station location, but there also exists a certain divergence phenomenon, and the synergy between POI facilities and subway stations is poor. And the unevenness of the spatial development of each station area, the central city station's facility concentration characteristics are more significant, indicating that the location and the concentration of facilities on the station's service capacity is still a major limitation.

(4) From the viewpoint of connectivity level(Figure 3g), there are differences in the connectivity of roads in the station space, the density of the road network of the stations in the center of the city is significantly higher than that of the stations located at the end of Line 1, and the shape of the road network has more obvious grid characteristics, so that the street system has better connectivity. The road network density of the stations at the edge of the built-up area is lower, and the radiation influence of the stations is relatively weak.

(5) From the perspective of openness hierarchy (Figure 3h,3i), the openness in the station space shows a balanced high openness pattern. And there is a certain similarity between the distribution of street enclosure and sky openness, mostly distributed along the streets. This is also flanked by the lack of open spaces such as parks and squares in the current station.

(6) From the viewpoint of accessibility hierarchy (Figure 3j,3k,3l,3m,3n), there is a center-edge feature in the accessibility degree of station space. From the figure, it can be seen that the areas with higher degree of integration and connection of the street system in each station area basically coincide with the entrance and exit space of the subway station, indicating that the road connectivity in the station area is high, and it has better accessibility and spatial vitality. In terms of selectivity, the distribution within the station space is basically consistent, the overall synergy of the street network is stronger, and the local spatial network is integrated with the global spatial network, which has higher accessibility and greater commercial potential. On the other hand, the accessibility of some stations is low, and the lack of intertwined road connections between different neighborhoods leads to obstacles in walking through the area, resulting in uneven spatial development as a whole.



a) Building density (X_1) b) Floor area ratio (X_2) c) Height (X_3)

d) Land use mixing (X_4) e) Density of POI facilities (X_7) f) POI facility agglomeration kernel density (X_6)

g) Road network density (X_7) h) Openness of the sky (X_8) i) Closeness (X_9)

j) Global integration (X_{10}) k) Local integration (X_{11}) l) Global choice (X_{12})

m) Local choice (X_{13}) n) Connectivity (X_{14})

Figure 3. Calculation results and statistics of spatial density elements in residential dominated subway station areas. Source: Self-drawn by the author, 2024.

3.2. Characterization of Residents' Perception

The time of this research is April-May 2024, the object is to live in the scope of the station residents, the questionnaire distribution time as far as possible involving rest days and working days in the morning, afternoon and evening three hours, a total of 300 questionnaires recovered, to get a valid questionnaire 285, the validity rate is 95%. Based on the obtained questionnaire results were tested for reliability and validity using SPSS. The results showed (Table 3) that the overall reliability (Cronbach's α) coefficient value of the questionnaire was 0.871 (reference value > 0.7), and the overall results had a high level of confidence and reliability. The validity was further verified using KMO and Bartlett's test, and the KMO value of 0.825 was (reference value > 0.7), indicating that the validity of the data was very good. And the significance of Bartlett's test of sphericity was (P < 0,001), indicating structural validity among the factors.

Table 3. Reliability and validity test results. Source: Self-drawn by the author.

Cronbach's α coefficient value		0.871
KMO		0.825
Bartlett's test of sphericity	Approximate chi-square	629.678
	Number of degrees of freedom	136
	Significance	0.000

Among the respondents, 53.7% were male and 46.3% were female, and in order to explore the spatial heterogeneity of residents' perceptions in different sites, we evaluated the residents' perceptions based on a five-level Likert scale with 10 levels of comfort, pleasure, crowding, and compactness, and calculated the perceptual scores of each dimension by averaging the scores, which characterize the level of residents' perceptions of the site. level, where a higher score represents a stronger perception of residents.

Overall (Figure 4), the residents' perception of the spatial density level of the station area within each site shows that there is no obvious difference between the dimensions, but the overall difference in the level of perception is significant. Among them, the overall perception level of Hexing Road and Harbin East Station is low, attributed to the road division space and strong mobility within the station area, which reduces the residents' safety perception; while Xuefu Road and other stations have a higher perception level due to the presence of large-scale commercial or cultural facilities within the station area space, which matches the residents' psychological feelings and behavioral needs better. From the perspective of perception dimensions, the higher level of comfort and accessibility to the station space indicates that residents have a stronger perception of the comfort and accessibility of the space created by the current density elements. At the same time, the level of crowdedness and compactness is lower, indicating that the current layout of station space density elements is more compact.

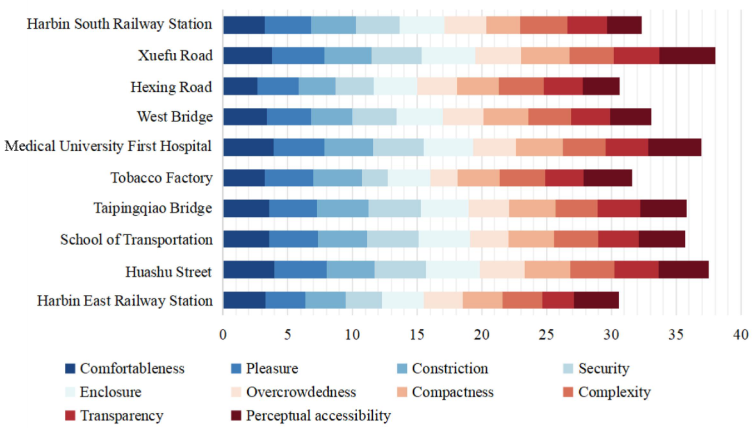


Figure 4. Perception results of residents in the subway station area space. Source: Self-drawn by the author, 2024.

3.3. Detection of Influence Factors on Residents' Perception

In order to explore the influence factors of the spatial density of the metro station domain on residents' perception and the degree of their influence, the Geodetector model based on the optimal parameters is calculated, and the results show (Table 4) that, except for the density of POI facility agglomeration kernel (X_6), the openness of the sky (X_8), the degree of global integration (X_{10}), and the degree of local integration (X_{11}), whose influence on residents' perception is insignificant, the rest of the factors pass the significance test . Comparison of q-values reveals that the effect of each density factor on residents' perception is smooth and higher than 0.5. Among them, the degree of connectivity (X_{14}) has a highly significant effect on residents' perceptions (with an explanatory power of 0.7492), and the degree of connectivity of the street system plays an important role in influencing residents' perceptions of spatial densities in the station area. Volume ratio (X_2) and enclosure (X_9) also have a significant effect on residents' perceptions, but the explanatory power is relatively weak.

Overall, except for the elements that do not have a significant effect, the rest of the spatial density elements in the residential-dominated stations have a strong influence on the perception results, and more attention should be paid to the configuration of the overall density elements within the station space.

Table 4. Detection results of influencing factors perceived by residents. Source: Self-drawn by the author.

Impact factor	q-value	p-value	impact factor	q-value	p-value
Building density（X_1）	0.5693	0.0426**	Openness of the sky（X_8）	0.1703	0.6231
Floor area ratio（X_2）	0.6843	0.0071**	Closeness（X_9）	0.6837	0.0121**
Height（X_3）	0.5327	0.0404**	Global integration（X_{10}）	0.3070	0.3475
Land use mixing（X_4）	0.4920	0.0230**	Local integration（X_{11}）	0.3677	0.1267
Density of POI facilities（X_5）	0.5186	0.0257**	Global choice（X_{12}）	0.5814	0.0398**
POI facility agglomeration kernel density（X_6）	0.4068	0.1631	Local choice（X_{13}）	0.5633	0.0078**
Road network density（X_7）	0.5492	0.0465**	Connectivity（X_{14}）	0.7492	0.0001***

3.4. Interaction Detection of Influencing Factors on Residents' Perception

Through geographic interaction detection, it is possible to more accurately explain what kind of elemental factors play an enhancing role in the degree of influence on residents' perceptions, so as to determine the short-board factors that affect residents' perceptions. The results show that there is an interaction between the influence of each factor on residents' perception, which is manifested as Enhance, nonlinear, Enhance, bi- and Weaken, nonlinear (Figure 5), reflecting the fact that residents' density perception in the station space is affected by a variety of factors together.

Among them, the ones with the highest explanatory power are building density (X_1) ∩ height (X_3), POI facility density (X_5) ∩ enclosure (X_9), road network density (X_7) ∩ connectivity (X_{14}), etc., among which building density, road network density, enclosure and other elements show enhancement when interacting with other elements, and have a dominant enhancement in influencing the perception of residents' density, which suggests that station space has a strong relationship with the above elements due to its own radiation attraction. This indicates that the station space, due to its own radiation attraction, will have a large marginal effect when combined with the above elements, which is a key role in influencing residents' perception. On the other hand, local choice (X_{13}) and connectivity (X_{14}) show a non-linear weakening effect when interacting with individual elements, indicating that there may be a certain threshold effect of the influence of these elements on the residents' perception, and that attention should be paid to the reasonable configuration of these elements in the creation of the station area space to realize the coordination of the overall spatial form, so as to give the residents a positive perception of the density.

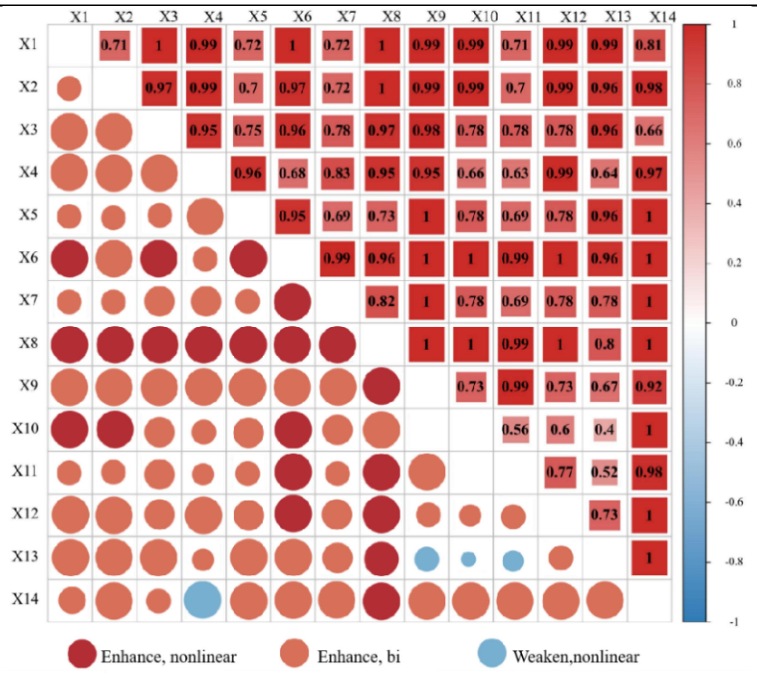


Figure 5. Interaction detection results of influencing factors. Source: Self-drawn by the author, 2024.

4. Conclusion and Discussion

Starting from the theory of Conzeen's urban morphology, this study, based on the three dimensions of building types, land use function, and street system, synthesizes related studies and constructs a spatial density index system including three dimensions, six elements, and corresponding 14 factors, so as to conduct an in-depth analysis of the organizational characteristics of the spatial density of the residence-dominated station area and its degree of influence on the residents' perception. Firstly, the spatial density of residential-dominated station areas is quantitatively visualized through ArcGIS and spatial syntax; secondly, the main driving factors affecting residents' perception are explored based on the optimal parameter Geodetector model.

The main conclusions are as follows: (1) The spatial densities of the three dimensions of residential-led stations are characterized by differentiation, and the overall situation of "concentrated hotspots in the central city, dispersed in multiple cores, and dispersed coldspots at the edges of built-up areas" is presented. (2) The results of factor detection show that the level of residents' perception is characterized by composite nature and influenced by a variety of factors. However, the impact of each density factor on residents' perception is relatively robust, in which the degree of connectivity has a highly significant impact on residents' perception, and the volume ratio and enclosure degree also have a significant impact on residents' perception, but the explanatory power is relatively weak, which is a secondary impact factor, reflecting that the degree of access to the street system and the 3D spatial pattern play an important role in dissolving the residents' negative perceptions. And the effect of POI facilities agglomeration kernel density, sky openness, and integration degree on residents' perceptions is not significant. (3) Through the analysis of interaction factor detection, it is found that the influence of each factor on residents' perception has interaction effects, and the results show that the elements of building density, road network density, and degree of enclosure show enhancement when interacting with other elements, and have a dominant enhancement effect in influencing residents' density perception, indicating that the station area space, due to its own radial attraction, has a large marginal effect when combined with the above elements. On the other hand, local selectivity and connectivity are nonlinearly weakened when interacting with individual elements, showing a certain threshold effect.

The purpose of this study is to explore the influence mechanism of spatial density elements in residential-dominated metro station areas, with a view to forming a sustainable spatial density configuration model based on perception, in order to eliminate the negative impacts of spatial creation on residents under the control of pure indexes, and to promote the sustainable development of urban space. However, there are some limitations in this study: there is some subjectivity in the investigation of residents' perceived characteristics, and there are some limitations in the representativeness of the spatial density factor selection, and the direction of the influence on residents' perception still needs further research. In the future, the residents' perception and influence factors can be identified more accurately through VR simulation, skin electric detection and other methods

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