

Matching of Residential and Commercial Space in Shrinking Cities from the Perspective of Supply and Demand: A Case Study of Yichun City, China

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Abstract: Urban shrinkage is becoming an increasingly common phenomenon in China. The research focus has been the identification, origin, and pattern of shrinking cities. Nevertheless, attention has also been paid to the problems associated with urban shrinkage. The present study examines one typical shrinking city in China, specifically the Yichun District in Yichun City. To explore the matching relationship between residential and commercial spaces, this study analyzes supply and demand data, electricity consumption data and multi-source points of interest (POI) of residents. The results showed that the occupancy rate is not reduced in the context of urban shrinkage, and that the supply level of various commercial facilities is not in decline. Apart from leisure and entertainment facilities, the supply levels of catering, shopping and supporting facilities for life were noted to have improved. In reference to urban shrinkage, the matching relationship between residential and commercial space in the 5-min, 10-min, and 15-min living circles mainly shifted to a high-level equilibrium. The matching relationships between residential space and different types of commercial spaces change in both direction and magnitude. From the perspective of supply and demand, the spatial and temporal changes in the relationship relate to multiple factors, such as the level of economic development, the building age pattern, public transportation accessibility, aging, and residents' willingness to move. This study provides relevant data for managing urban shrinkage. It also helps improve the relationships between residential and commercial spaces and works to optimize the layout and structure of functional urban spaces.

Keywords: urban shrinkage; residential space; commercial space; occupancy rate; supply level of commercial facilities; Yichun District

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1 Introduction

Since the second half of the 20th century, western industrial cities have begun to experience urban shrinkage in the form of population decrease and economic depression (Haase et al., 2014). Long et al. (2015) stated that 180 Chinese cities also experienced a decline in population density, which represents a case of urban shrinkage. Furthermore, Martinez-Fernandez et al.

(2012) warned that urban shrinkage could lead to abandoned housing units in a large number of residential areas and those amenities such as supermarkets may shrink and subsequently close (Nishimoto et al., 2016). Due to population decline and thus decreased demand, the supply of commercial facilities has also correspondingly declined. However, according to Barreira et al. (2017), population decrease does not entail a shrinkage of the spatial environment and degradation of urban

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space. To re-attract residents, city managers strive to maintain the supply of various service facilities (Barreira et al., 2017). Thus, the number of commercial facilities does not necessarily have to decrease. Therefore, it is necessary to explore the matching relationship between residential and commercial space in shrinking cities. This is necessary to cope with the challenge of urban shrinkage and should be done from the perspective of supply and demand.

As both residential and commercial spaces serve important functions within urban space, changes in their relationship will inevitably promote the evolution of the urban spatial structure (Zhou et al., 2008). A population of a certain density is a requirement for the layout of a commercial network. In turn, the formed commercial network attracts the population. At present, various studies have chosen to focus on either residential space or commercial space. The former encompassed research related to the balance between jobs and housing (Sun, 2015; Li et al., 2019), as well as equity in the allocation of public service facilities (Atkinson, 1970; Ogryczak, 2007). The latter concerns research dealing with commercial space structure (Lloyd, 1991; Crewe, 2000), business areas (Hayton, 2000), and consumer behavior (Chai et al., 2008). Nevertheless, few studies were conducted on the relationship between residential and commercial space. It should be noted that some scholars have investigated the connection between population distribution and commercial space (Wang and Gao, 2015; Chen et al., 2017; Wu and Zhou, 2017). For example, Ye et al. (2012) applied spatial correlation analysis and investigated the correlation between the evolution of residential and commercial space. Based on this, they proposed optimization strategies for the current mismatch between residential and commercial space. Furthermore, Xue et al. (2019) calculated the spatial heterogeneity of housing prices and its distinctions in different spatial layouts of retail formats. Lastly, certain scholars also employed network data to quantitatively analyze the spatial connection between urban public service facilities and residential quarters (Shen et al., 2018; Chen et al., 2019). Overall, the correlation between residential and commercial space has been affirmed as research from the perspectives of spatial correlation has been conducted. However, there is a lack of research regarding the matching relationship between residential and commercial space in cities from the per-

spective of supply and demand. Furthermore, scarcely any studies have dealt with the relationship between residential and commercial space and its related factors in shrinking cities.

The term ‘shrinking city’ was first suggested by German scholars Häußermann and Siebel in 1988 (Häußermann and Siebel, 1988). The term was used to describe a previously densely populated city experiencing population decrease and a kind of structural economic crisis. Once this definition was put forth, numerous scholars chose to investigate the pattern (Schetke and Haase, 2008; Blanco et al., 2009), origin (Bontje, 2004), and coping strategies (Schilling and Logan, 2008) of urban shrinkage. In addition, some scholars examined problems such as vacant land (Wachter, 2004) and abandoned houses (Pagano and Bowman, 2004) that emerged both from and in shrinking cities. Urban shrinkage has been noted to harm commercial activities in the construction and real estate industry (Bernt et al., 2014), resulting in the unattractiveness of urban life and commercial activities (Ganser and Piro, 2012; Haase et al., 2012). Since a city’s physical space will not shrink in accordance with population decrease within a short time, the generation of abandoned/vacant houses will lead to a poor match between facilities and housing distribution (Gao, 2015).

In this paper, the occupancy rate is defined as the proportion of houses occupied to the total housing stock. It represents the degree of residents’ demand for surrounding commercial facilities. In a certain region, the average number of commercial facilities owned by each household is defined as the supply level of commercial facilities, i.e., the degree of supply of commercial service facilities available in that particular region. A change in the relationship between supply and demand directly leads to a shift in the relationship between residential and commercial spaces. With the rapid development of internet technology in recent years, the POI has continued to be perfected. At present, it encompasses a detailed description of the spatial and attribute information of a geographical entity, such as its name, address, coordinates, showing the advantage of having a large sample size that covers detailed information (Xue et al., 2019). POI data may assist in better understanding the distribution and number of commercial facilities. Furthermore, it may also improve the analysis of the relationship between residential and commercial spaces,

which in turn may improve the accuracy of information related to commercial space on the microscale. It should be mentioned that some studies used POI data to conduct research on residential space (Shen *et al.*, 2018). However, due to a lack of consideration regarding the actual size of residential communities, the results are partially erroneous. With the gradual electronization of the charging system of the electric power company, the statistics of residential electricity consumption have become more accurate in real-time. As long as residents are living in their houses, power-consuming products will inevitably be used, and electricity consumption will thus be measured. Therefore, using data on residential electricity consumption to carry out a study on residential space is undoubtedly both a more accurate and simpler method compared to statistical data.

There are relatively few studies that quantitatively analyze the relationship between residential and commercial spaces in shrinking cities. Moreover, information concerning factors relating to the evolution of this relationship is also missing. To compare the population and commercial service facilities, most studies have selected cities as their basic units. However, they have not considered factors such as the residential area scale, actual occupancy rate and living circle scope. Therefore, this paper will analyze the relationship between residential and commercial spaces in the period between 2013 and 2018 and its changes at different levels of living circles from the perspective of supply and demand. In addition, it will also analyze data regarding household electricity consumption and POI (Point of Interest) data of commercial facilities. In this paper, Yichun District in Yichun City is selected as the study area. The following question will be discussed in this paper: How does the matching relationship between residential and commercial space change, and are there differences in different scales? In addition, since most residents choose to achieve daily consumption by walking (Wood *et al.*, 2010; Azmi and Karim, 2012), this paper recognizes three levels of living circles according to the distances that residents walk at the pace of 5 km/h for 5 min, 10 min, and 15 min. This helps us analyze the changing relationship between residential and commercial spaces at different levels of living circles. Lastly, this paper aims to explain the evolutionary law present in the relationship between residential and commercial spaces in shrinking cities. These findings will enrich the theoretic-

al framework concerned with spatial structure in shrinking cities and provide reference for optimizing the layout of functional urban space and for formulating coping strategies for urban shrinkage in the future.

2 Theoretical Framework

With the progress of urban community correlated theory and improvements in urban planning, the layout of commercial facilities has gradually come to incorporate planning guidance and market allocation. In early theoretical research, many traditional communities were designed without the necessary commercial facilities, which appeared only after residents had moved into the area (Wang and Mo, 2002). Certain scholars suggested that commercial facilities be laid out around or outside the communities (Bookout, 1992; Perry, 1998). However, contemporary theories often advocated for a mix of community functions, as this would achieve a balance between shopping, work, education, and entertainment (Deener, 2007). These theories are centered on providing supporting commercial facilities primarily according to residents' needs. The relationship between supply and demand should be balanced and change proportionately over time. Nevertheless, under the impact of urban shrinkage, a misbalance may develop in this relationship. In the context of urban shrinkage, population loss leads to a decreased number of residential houses, while a change in occupancy rates results in a corresponding change of the residential space. The aging phenomenon caused by population loss tends to change the residents' demand structure for business, with the low-income people having a direct effect on the demand for commercial facilities. The change in demand quantity and structure leads to a change in the commercial space as well. In addition, large population loss in shrinking cities may create a desolate urban atmosphere and motivate the remaining residents to move. This results in further and continuous population loss, causing problems such as residential and commercial vacancies, as well as changes in residential and commercial space. Meanwhile, shrinkage and the urban economic recession contribute to an adjustment of the commercial market. Together, market adjustment and the change in demand affect the supply level of commercial facilities, leading to a final change in the structure of the commercial space. In reference to spatial pattern, urban elements such as building age and public transportation

accessibility influence the distribution of residential and commercial facilities by affecting people's housing and travel choices. The change in residential and commercial space on their own bring about changes in their relationship as well. According to studies on the changes in the relationship in question, the distribution of residential and commercial space can be adjusted. This will enable the supply and distribution of commercial facilities to meet the residents' requirements and will optimize the urban structure so it may cope with urban shrinkage (Fig. 1).

3 Materials and Methods

3.1 Study area

This paper selects the Yichun District in Yichun City, Heilongjiang Province, China as the research area. The research scope (Fig. 2) includes the construction land involving housing information in Yichun District. Yichun City is situated in the northeastern part of Heilongjiang Province, China and is recognized as one of the first resource-exhausted cities in the country. Situated in the center of Yichun City and under the jurisdiction of Yichun City, Yichun District is the administrative, economic and cultural center of Yichun City. When identifying and classifying the shrinkage of different districts in Yichun City, Zhou et al. (2019) found that Yichun District exhibited significant shrinking characteristics. In 2018, Yichun District was noted to have a population of 158.795 thousand people, which is a decrease of 3496

compared to 2013. Furthermore, in 2017, the GDP of Yichun District was valued at 4523.97 million yuan, with the growth rate decreasing by 3.95% compared to 2013. The district has been influenced by both population loss and economic recession, with a slow industrial structure transformation.

3.2 Data source and processing

This paper identifies the residential housing in Yichun District by the residential electricity consumption. This method is both accurate and simple for obtaining statistics related to the status of residential housing. At present, it is worth studying and implementing further (Zhao, 2019). The electricity consumption data are derived from the Power Consumption Department of Yichun City. It includes electricity consumption data as well as location information from January to December between the years 2013 and 2018. In 2013, Yichun District had a total of 57 290 houses, among which only 53 497 were occupied, with 687 480 pieces of effective power consumption data. Conversely, in 2018, there was a total of 68 729 houses, among which 63 663 were occupied, with 824 748 pieces of effective power consumption data. According to user addresses, longitudinal and latitudinal coordinates of household locations were obtained from Baidu Map Open Platform (<https://lbs.baidu.com>). Furthermore, according to the Baidu Map (<https://map.baidu.com>), 54 effective residential communities were identified in 2013, while 58 were identified in 2018 (Fig. 3).

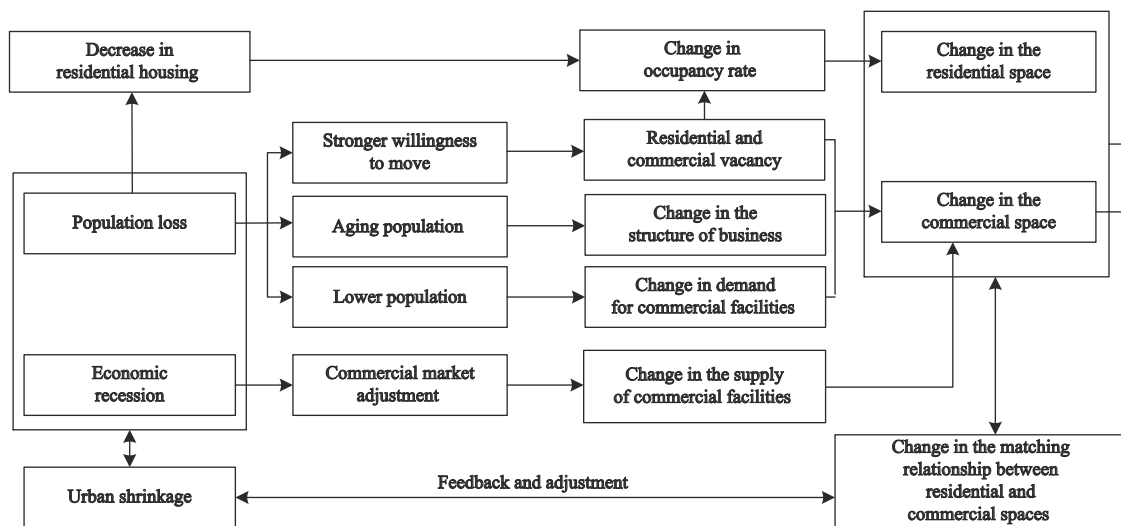


Fig. 1 Theoretical framework for the matching relationship between residential space and commercial space in the context of urban shrinkage

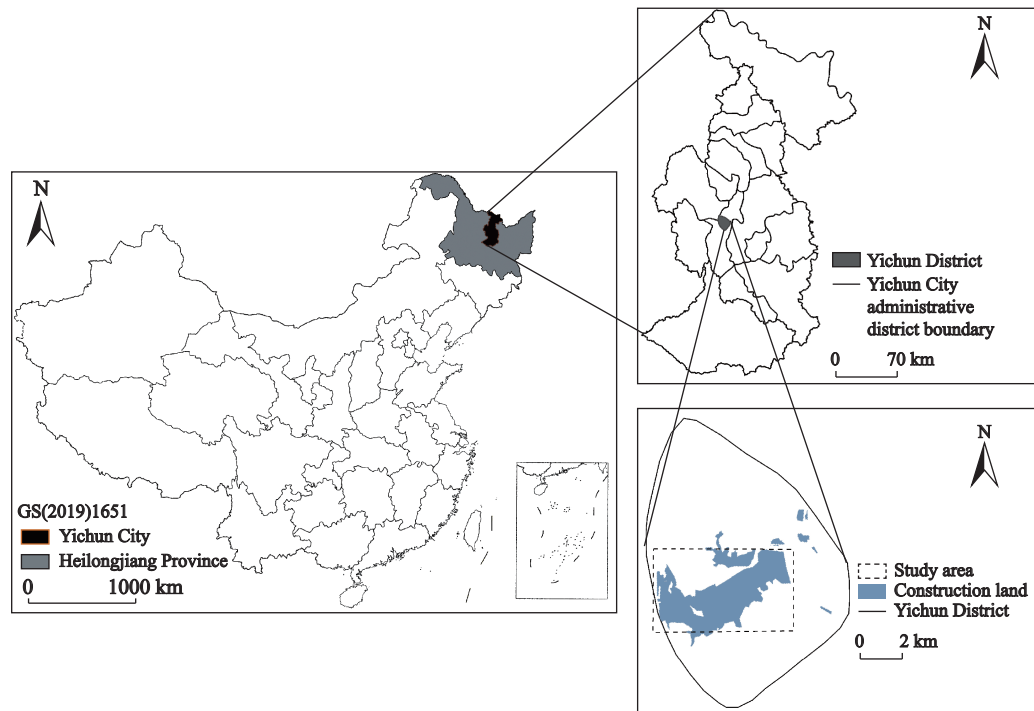


Fig. 2 The location of Yichun District in Yichun City, China



Fig. 3 Distribution of residential communities in Yichun District

This study selected the commercial facilities highly related to residents' lives as the research object. The point data for facilities on POI was used as data for commercial facilities. The data, including point data for restaurants, convenience stores, and theaters were derived from Amap. The Classification of Retail Formats (GB/T 18106–2010) and Code for Classification of Urban Land Use and Planning Standard of Development Land (GB 50137–2011) in China were used to identify the format types less correlated to residents' daily lives. Finally, four categories for commercial facilities were determined, and included catering, shopping, supporting facilities for life, and leisure and entertain-

ment. The number of the various facilities is shown in Table 1. It should be noted that the POI data for 2013 could not be obtained. However, as the change in commercial facilities shows a certain hysteresis with population loss, the POI data of 2014 was used instead. In addition, population and socioeconomic data come from the Yichun Statistical Yearbook for the period 2014–2019.

3.3 Methods

(1) Measurement of occupancy rate

According to the State Grid Corporation of China and data concerning the electricity meter for each household,

Table 1 Points of interest (POI) type and the number of commercial facilities in Yichun District

POI type	Facilities involved	Number in 2013	Number in 2018
Catering facilities	Fast food restaurant, foreign restaurant, Chinese restaurant, coffee shop, tea house, cold drink shop, pastrycook's shop, dessert shop, and catering-related facilities	1121	1858
Shopping facilities	Convenience store, supermarket, clothing, shoes, hats, and leather goods store, personal products/cosmetic shop, flower, bird, insect and fish market, household appliances and electronics store, furniture and building materials market, market, special places of business (pawnshop and auction house), sporting goods store, cultural goods store, franchised store, comprehensive market, and shopping service-related facilities	1723	3179
Supporting facilities for life	Point of sale for lottery tickets, office of telecommunications, funeral facilities, photography, and print shop, booking office, logistics and express delivery, newsstand, travel agency, beauty salon, business premises, maintenance site, laundry, a place for bathing and massage, intermediary agency, information consulting center, post office, pharmaceutical, and health care stores, clinic, hotel, guesthouse, and accommodation-related facilities	1329	2397
Leisure and entertainment facilities	Leisure facilities (amusement park <i>etc.</i>), theatre, entertainment venues (KTV, bar, nightclub, <i>etc.</i>), sports and leisure service venues (club, <i>etc.</i>), comprehensive gymnasium (billiards club, <i>etc.</i>)	273	175

when the electricity consumption of a housing unit in a year is less than 20 kW·h, that unit is considered as 'vacant' (Qiao, 2008). Therefore, the housing for which annual total electricity consumption exceeds 20 kW·h is defined as occupied in this paper. The occupancy rate formula is provided below:

$$v_i = \frac{n_i}{N_i} \quad (1)$$

In Formula (1), v_i denotes the occupancy rate of a residential community i . Furthermore, n_i indicates the number of occupied houses in the residential community, while N_i represents the total number of houses in that residential community.

(2) Measurement of the supply level of commercial facilities

Based on radii of 300 m, 500 m, and 800 m, the residential community is divided into three buffer zones representing 5-min, 10-min, and 15-min living circles. ArcGIS 10.2 is used for buffer zone analysis. The number of the different commercial facilities in each buffer zone is equal to the number of facilities in residential areas in the corresponding level of the living circle. The formula for measuring the supply level of the commercial facilities is given below:

$$c_i = \frac{m_i}{N_i} \quad (2)$$

In Formula (2), c_i indicates the supply level of the commercial facilities within a residential community i . Furthermore, m_i represents the number of commercial facilities in the living circle, while N_i indicates the total

number of housing units in the residential community.

(3) Kernel density estimation method

The Kernel density estimation method analyzed the spatial agglomeration of houses and commercial facilities. The goal is to determine the density value for each grid point by using a moving cell. Afterwards, the diagram is output to achieve a continuous change in grid point density. The formula for the Kernel density function $f(x)$ at point x is as follows (Tu et al., 2019):

$$f(x) = \frac{1}{r^2} \sum_{i=1}^n k\left(\frac{x-x_i}{r}\right) \quad (3)$$

In Formula (3), r denotes the threshold value for distance attenuation. Next, n represents the number of elements whose distance from the position point x is not greater than r . Furthermore, the k function represents the spatial weight function. Its geometric meaning indicates the density value reaches its maximum at each core element x_i , and continuously decreases as it moves away from x_i until its value decreases to 0. At this point, its distance from the core element x_i reaches the threshold value r .

(4) Global spatial autocorrelation

Global spatial autocorrelation is a description of the attribute values' spatial characteristics across the region. Indicators are calculated in order to analyze the overall spatial correlation and the degree of spatial variation between the elements. One of the most commonly used metrics for this is Moran's I . The formula for the Moran's I index is provided below (Meng et al., 2005; Zhang et al., 2021):

$$I = \left(\frac{n}{\sum_i \sum_j W_{ij}} \right) \left(\frac{\sum_i \sum_j W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2} \right) \quad (4)$$

In Formula (4), W_{ij} denotes the spatial weight matrix, while n represents the number of regional cells. Finally, x_i , x_j indicate the observed value of the i -th, j -th cells respectively, and \bar{x} represents the average value of the observations.

(5) Local spatial autocorrelation

Global spatial autocorrelation presumes that only one trend in space and that fills the entire region. However, spatial heterogeneity among regional elements is not uncommon. Thus, local statistical methods are necessary to calculate the local correlation properties of each spatial element attribute, as this will help to reveal the heterogeneous characteristics of spatial differences. Most commonly, bivariate local spatial autocorrelation is used to uncover the spatial association of geographic elements. The formula is as follows (Zhang et al., 2021; Zhao et al., 2021):

$$I_i = z_i \sum_j W_{ij} z_j \quad (5)$$

In Formula (5), z_i and z_j denote the normalized values of the observations of regions i and j . Furthermore, I_i represents the local spatial autocorrelation index. According to this index, the study unit is divided into four spatial association patterns according: 'high-high' region, 'low-low' region, 'high-low' region, and 'low-high' region.

4 Results

4.1 Residential and commercial spatial distribution characteristics and correlation

Based on the spatial distribution of housing units, there

were 53 497 occupied houses in Yichun District in 2013. In 2018, this number increased to 63 663. The number of houses at the edge of urban built-up areas increased significantly. The spatial distribution characteristics of the houses were analyzed according to the Kernel density method. The results indicated a single-center pattern in 2013, with the Weixing and Gaochao communities having the highest density (18 322.0, 21 375.6). This high-density value decreased to (18 062.2, 21 072.4) in 2018, while the pattern changed to a double-center dominated distribution, with both the Weixing and Gaochao communities and the Tiancheng Imperial Garden (15 051.8, 18 062.1). Overall, the distribution density progressively decreased from the old urban district in the center towards the southwestern and north-eastern areas. In reference to urban shrinkage, the distribution density and number of occupied houses in Yichun District did not decrease. Furthermore, the population loss does not indicate that entire households emigrated.

Based on the development status of Yichun District and the areas with high Kernel density, the Weixing and Gaochao communities are categorized as the center of the built-up area in Yichun District. The occupancy rate of each residential community is shown in Fig. 4. Furthermore, Fig. 4 indicates that the overall occupancy rate in Yichun District decreased over time, specifically from 93.4% in 2013 to 92.6% in 2018. In addition, the occupancy rates were observed to have the spatial characteristics of high inside occupancy and low outside occupancy, with evident spatial differences between 2013 and 2018. During the period from 2013 to 2018, the occupancy rate of the central regions decreased, while the occupancy rate within marginal areas increased.

From 2013 to 2018, the overall supply scale of commercial facilities in Yichun District has continuously in-

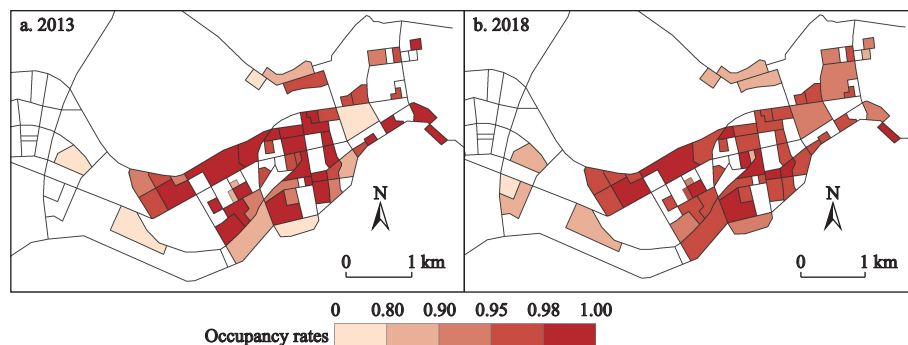


Fig. 4 Spatial and temporal distribution of occupancy rates in Yichun District in 2013 and 2018

creased. However, the supply of different types of commercial facilities varied notably. The number of commercial facilities increased from 4446 to 7609. More specifically, the number of catering, shopping, and living facilities all increased, while the number of leisure and entertainment facilities significantly decreased. Similar to residential distribution, the Kernel density analysis indicated that the distribution of commercial facilities predominantly showed agglomeration in the urban center, as the range of high-density values increased from (2132.7, 2488.0) in 2013 to (3040.5, 3547.1) in 2018.

Moreover, based on the spatial and temporal distribution of the supply level of commercial facilities in each residential community (Fig. 5), the overall supply level of commercial facilities increased during the 2013–2018 period. As the level of living circle enhanced, the number of residential communities with a large number of commercial facilities increased. The trend firstly increased in the central area and then witnessed an increase in the peripheral areas as well.

The results of residential and commercial space indicate that commercial space is predominantly distributed in the old urban area in the central part of the city. Nev-

ertheless, it does expand to the southwestern and northeastern parts of the district, which is subsequently followed by a change in residential space distribution. The bivariate spatial autocorrelation analysis of housing rates and commercial facility supply levels (Table 2) shows a significant spatial correlation between commercial and residential spaces within all levels of living circles. In addition, it indicates an increasing trend within the 10-min and 15-min living circles and a falling one within 5-min living circles.

4.2 Matching relationship between residential and commercial space in the context of urban shrinkage

To understand the relationship and changes between residential and commercial space in Yichun District, this study used a local spatial autocorrelation analysis between the residential rate and level of commercial facility supply in the district. Furthermore, it illustrated the results in order to derive a local indicators of spatial association (LISA) clustering diagram of the residential rate and commercial facility level (Fig. 6). The clustering results managed to classify the matches into four modes: ‘high-high’, ‘low-low’, ‘high-low’ and ‘low-high’. Firstly, the ‘high-high’ mode indicates a high oc-

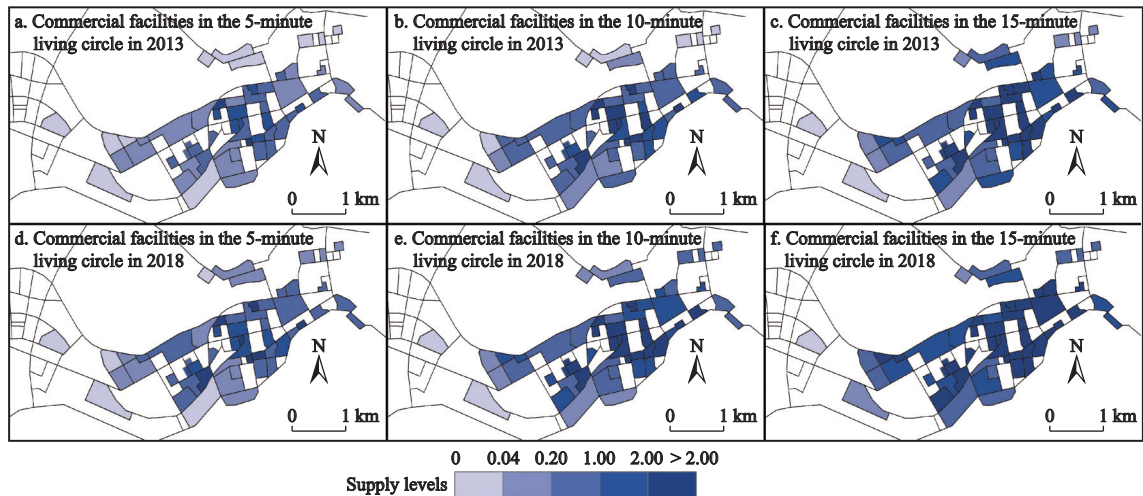


Fig. 5 Spatial and temporal distribution of the supply levels of commercial facilities for different living circles in Yichun District

Table 2 Moran index between the level of commercial facilities and housing units in Yichun District

Item	Commercial facilities in 5-minute living circle	Commercial facilities in 10-minute living circle	Commercial facilities in 15-minute living circle
Residential housing in 2013	0.236***	0.253***	0.241***
Residential housing in 2018	0.232***	0.257***	0.255***

Note: *** means being significantly correlated at the significance level of 1%

cupancy rate as well as a high supply level of commercial facilities. This shows that the supply and demand relationship between the two spaces is in a state of high-level balanced development. Secondly, the ‘low-low’ mode refers to both a low occupancy rate and low supply level of commercial facilities. This illustrates that the supply and demand relationship between the two spaces is in a low state of equilibrium. Thirdly, the ‘high-low’ mode indicates a high occupancy rate but a low supply level of commercial facilities. This points to a shortage of commercial facilities, which are lagging in development. Lastly, the ‘low-high’ mode describes a low occupancy rate and high supply level of commercial facilities. This indicates the existence of oversupplied commercial facilities with advanced development.

Based on the results of the occupancy rate and supply level of commercial facilities (Fig. 6), the number of ‘low-low’ and ‘high-low’ types of residential communities exhibited a general decrease from 2013 to 2018. This shows that the shift in the relationship between residential and commercial spaces is moving from insufficient supply to a high level of equilibrium. While the ‘high-high’ and ‘high-low’ neighborhoods are concentrated in the urban center, the ‘low-low’ type ones are mainly distributed at the edge of urban areas. Furthermore, the number of ‘low-low’ and ‘high-low’ types of residential communities within the 5-min living circle is relatively large while the number of ‘high-high’ types is relatively small compared to the 10-min and 15-min living circles. This pattern indicates that the supply level of commercial facilities within a 5-min walk-

ing distance of residential areas requires improvement.

4.3 Changes in matching relationship between residential space and different types of commercial spaces in living circles of different levels

During the period between 2013 and 2018, the relationships between residential and commercial spaces exhibit significant differences in both type and scale. Based on the changes in space type (Fig. 7), the relationship between residential space, catering space, and supporting facilities for life changed to a high-level equilibrium in all the living circles. Furthermore, the relationships between residential and shopping space shifted to a high-level equilibrium in the 5-min and 10-min living circles. However, this relationship did not change significantly in the 15-min living circle. Conversely, the relationship between residential space and leisure and entertainment space is opposite to the relationships between residential space and other spatial types, and changes to the direction of short supply in various living circles. In relation to urban shrinkage, the overall supply of commercial facilities is still on the rise, while the supply of leisure and entertainment facilities is showing an overall downwards trend. In addition, the population of shrinking cities tends to show an aging trend, which in turn leads to a demand for structural changes. In other words, there is a differentiation in the supply direction of various commercial facilities, leading to a continuous decrease in the original supply of leisure and entertainment facilities that are suitable for young people, and a lack of the supply of entertainment facilities suit-

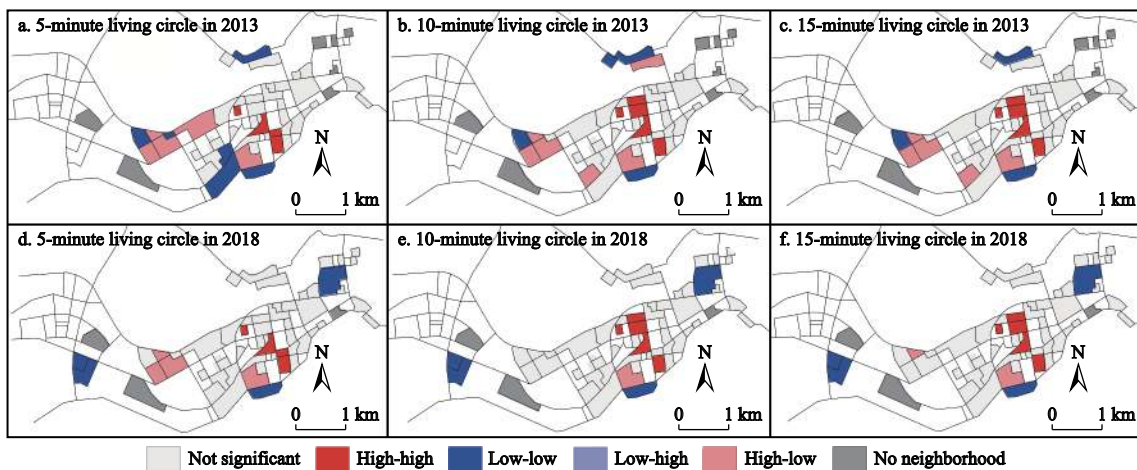


Fig. 6 Local indicators of spatial association (LISA) clustering map of residential and commercial space at different levels of living circles in Yichun District

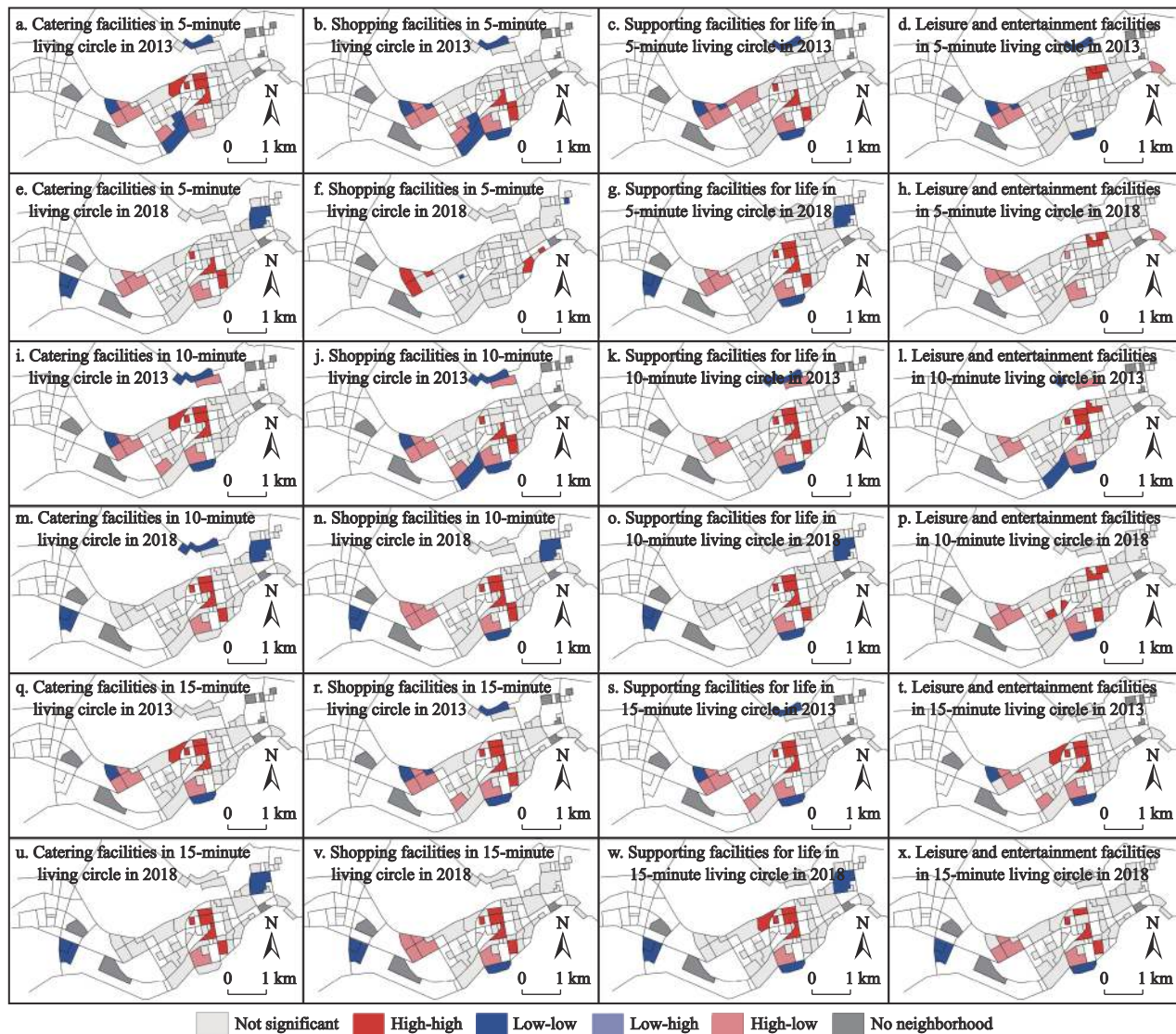


Fig. 7 Local indicators of spatial association (LISA) clustering map of residential space and different types of commercial spaces in the living circles of different levels in Yichun District

able for the elderly.

In terms of distribution, spaces with ‘high-high’ matches between residential space and catering on the one hand and living supporting space on the other are distributed mainly in the urban center at all levels of the living circles. Residential and shopping spaces belonging to the ‘high-high’ type are either distributed in the peripheral areas of the city in the 5-min living circle or are concentrated within the 10-min and 15-min living circles in the urban center. Furthermore, the ‘high-high’ type of residential and leisure and entertainment space is distributed in the peripheral areas of the city. Simultaneously, their distribution changed from a central agglomeration in 2013 to a decentralized layout in 2018 in

the 10-min and 15-min living circles. In reference to the relationships between residential space and the four types of commercial spaces, ‘low-low’ type residential communities are distributed in the peripheral areas of the city at all levels of the living circles. Furthermore, the ‘high-low’ type is scattered predominantly in the western part of the urban area, without the distribution of ‘low-high’ type.

4.4 Related factors of differences in matching relation types between residential and commercial space

(1) Economic development level

The level of regional economic development provides support for the supply of commercial facilities. Further-

more, it impacts the demand scale and structure of commercial facilities. As the economic, political and cultural center of Yichun City, Yichun District has advantages regarding its factor agglomeration ability, radiation and leading ability in the region. From 2013 to 2018 and during the decline of the Yichun City's regional GDP (with an average annual growth rate of -0.04%), the regional GDP of Yichun District increased from 3942.24 million yuan to 4784.45 million yuan, achieving an average annual growth rate of 4.96% . The proportion of the regional GDP also increased from 14.4% to 17.5% . In addition, the Yichun District field survey, which took 1% of the total population as the sample, found that the proportion of residents with a monthly income of either 3000–5000 yuan or more than 5000 yuan was the highest. Specifically, it was estimated to be up to 37.8% , thus far exceeding the average level of the whole urban area by a total of 26.2% . Thus, Yichun District exhibits a strong economic foundation with the residents' income and consumption level being relatively high. In turn, this makes the improvement of the level of commercial facilities possible and explains the overall transformation of the supply level of commercial facilities in Yichun District.

(2) Spatial pattern of building age

To a certain extent, the spatial pattern of the residential buildings' age reflects the evolution of urban residential construction (Liu *et al.*, 2021). Residential communities differing in ages have clear distinctions in their location and facilities. In turn, these distinctions impact the temporal and spatial differentiation of the residential rate. According to the statistical results, the buildings in each residential community in Yichun District present a spatial pattern of 'old buildings in the center and new ones in the periphery'. As of 2018, residential communities that have a high building age (between 15 and 30 yr) are distributed mainly in the center of the city. On the other hand, those with construction age of fewer than 7 yr are distributed primarily in the city's periphery. In 2013 and 2018, there was a positive correlation between the building age and occupancy rate of residential communities at the confidence level of 1% and 5%, respectively. In other words, the spatial distribution of high building age and high occupancy rate was consistent. This indicates less internal migration caused by incomplete functions of old houses in the old urban area and the deterioration of the living environment.

Furthermore, the impact of housing suburbanization on housing vacancy was not shown to be significant, with the main trend of population flow being outflow (Qi *et al.*, 2017; Zhou *et al.*, 2019). Compared to new residential areas, old ones situated in the urban center have the advantages of employment location and convenient service facilities. To a certain extent, this may explain the high occupancy rates in the urban center and the low occupancy ones in the periphery. It may also help explain why the 'high-high' type residential communities are predominantly concentrated in the urban center.

(3) Public transport accessibility

Based on the public transport stations POI data and traffic network data of the Yichun District in 2018, this paper examines the connection between the accessibility to public transport and the scale difference of the spatial relationship between residential and commercial space in the district. The average value of public transport accessibility in Yichun District is 6.7 min. In relation to spatial distribution, the accessibility of public transport presents a circular structure moving from the center to the periphery. The accessibility to the urban fringe is the worst, with the accessibility value distributed between 7.36–11.00 min. On the other hand, the accessibility to the central urban area is the best, with the accessibility to public transport measured between 4.08–4.68 min. Residents have greater spatial flexibility when choosing public services and commercial facilities. The distribution characteristics of accessibility are consistent with the spatial structure of residential and commercial space matching types. The results confirm that the central area has a high occupancy rate and supply level of commercial facilities. Conversely, the periphery has both a low occupancy rate and supply level of commercial facilities. Furthermore, the results indicate that the difference in public transport accessibility may lead to different choices regarding housing and commercial services. In other words, areas with greater public transport accessibility will attract both residents and commercial service facilities.

(4) Characteristics of aging

The imbalance in population structure is caused by population aging. It is recognized as an important social feature of urban shrinkage (Meng *et al.*, 2021). Due to a single industrial structure and job reduction, Yichun District has experienced a significant labor outflow, which has exacerbated the regional aging situation even

more. More specifically, Yichun District has experienced a large outflow of young people aged 15–39 (Gao and Long, 2017), leading to a decrease in the demand for entertainment facilities suitable for the younger generations. When the number of other types of commercial service facilities increased in Yichun District, the number of entertainment facilities decreased by 35.9%. The imbalance in age structure may be concluded to have a great impact on the supply of entertainment facilities. Thus, leisure and entertainment facilities in Yichun District should pay more attention to the supply of aging facilities and coordinate the relationship between the supply of such facilities and the needs of residents.

(5) Residents' willingness to move

In the field survey of residents' willingness to move, the number of residents 'willing to move within one year' accounts for 32.4% of the total number of respondents, ranking second among all the districts in Yichun City. Furthermore, this number is significantly higher than the municipal average level of 25.6% (Liu et al., 2021; Fu et al., 2022). In reference to urban shrinkage, residents in Yichun District will still have an outflow trend in the future, inevitably leading to a certain level of both residential and commercial housing vacancy. The paper used the total electricity consumption of one household in one year, which did not exceed 20kWh to discriminate vacancy. Furthermore, it conducted statistical analysis on the vacancy level of residential housing and commercial housing in Yichun District. The results show that both residential and commercial vacancy exhibit a spatial pattern of 'low center and high periphery'. As a whole, the commercial vacancy rate is higher than the residential vacancy rate. This may be related to the relationship between residential and commercial spaces. More specifically, the 'high-high' type is concentrated in the central area, while the 'high-low' type is dispersed throughout the region and no 'low-high' type distribution is present. In addition, the high value areas of commercial vacancy are more present in the peripheral rather than in the urban area, matching the distribution of the 'low-low' type.

5 Discussion and Conclusions

5.1 Discussion

From the perspective of supply and demand, the relationship between residential and commercial space in

shrinking cities is of great research value. Contrary to existing research, this study investigated the relationships between residential and commercial spaces from the perspective of residence demand and commercial facility supply. It noted that the occupancy rate of residential communities did not necessarily decrease in the context of urban shrinkage. This conclusion is similar to the one drawn by Zhou et al. (2019), in which the population decrease in Yichun District was ascribed to an insufficient housing supply. The spatial distribution of the occupancy rate is 'high inside and low outside'. Nevertheless, the occupancy rate decreased in the central areas and increased in the peripheral areas. This indicates that housing suburbanization, which is caused by urban fringe development and the deterioration of the living environment in old urban areas, impacts residential distribution (Yu et al., 2012). However, due to poor prospects in urban development, there are few urban migrants, with population outflow still being the main trend (Qi et al., 2017; Zhou et al., 2019).

Furthermore, the overall supply level of commercial facilities in Yichun District was found to have changed to a high-level equilibrium. Although Yichun District is experiencing shrinkage, the above indicates that as the political and economic center of Yichun City, this district has a high agglomeration capacity. Moreover, its level of economic development has comparative advantages, creating conditions for the possible improvement of the level of commercial facilities in the region. The relationship between residential space and leisure and entertainment space changed in the direction of short supply, while the number of leisure and entertainment facilities experienced a significant decrease. In reference to the change in residents' demand, the rapid loss of population was accompanied by a serious imbalance in the age structure. In other words, the massive outflow of labor lead to the aging of the population and a decrease in the demand for entertainment facilities suitable for younger people. Therefore, population reduction and aging resulted in significant changes in the demand quantity and structure of leisure and entertainment facilities. With respect to the theoretical framework, this observation provides a solid empirical case for the change of commercial facility supply. Similarly, Aiello et al. (2010) argued that the residential satisfaction of aged residents was less affected by sports or leisure/entertainment facilities. In addition, when determin-

ing the relationship between the occupancy rate of residential communities and the supply level of commercial facilities, it is found that the supply level of commercial facilities must be improved and that the supply of commercial facilities in some residential communities is still insufficient. This is contrary to research conducted by Nishimoto et al. (2016), who argued that various convenient living facilities in shrinking cities will either shrink or be closed. (Nishimoto et al., 2016). It indicates that urban shrinkage does not necessarily lead to the reduction of commercial facilities. With the change in household characteristics and population structure, the spatial layout and supply of commercial facilities should be adjusted accordingly.

The 5-min, 10-min and 15-min living circles showing characteristics of 'high-high' type communities are distributed in the central urban area. Secondly, the 'high-low' type communities are situated in large area around the center, while 'low-low' type communities are found at the edge of the built-up area. The above indicates that there is a certain lag in supporting commercial facilities in the development process of shrinking urban areas. This differs from the conclusion that the suburbanization of housing is more consistent with the process of commercial development (Yu et al., 2012). When compared to 10-min and 15-min living circles, the 5-min living circle contains more 'high-low' and 'low-low' types of communities, while the supply of commercial facilities lags behind, confirming that convenient shopping facilities in shrinking areas are more likely to be unable to meet market demand (Nishimoto et al., 2016). Furthermore, the results show that shrinking cities should focus on adjusting the relationship between housing and elementary living needs.

Compared to other studies, the present one analyzes actual households to improve the data accuracy further. Most current studies use residential communities as point data or match commercial facilities according to either traditional statistics or estimated population data. Nevertheless, without considering the actual size of households in each residential community, all results will be partially problematic. Although Wu and Zhou (2017) tried to obtain resident data through a sampling survey, the impact of research cost and time resulted in a small sample size, which limited the research to a certain extent. To compensate for this type of issue, the present study based its analysis of the living state of

housing on residential power consumption data. To ensure that the data is accurate, households with less than a certain amount of electricity consumption were considered vacant. In addition, the annual power consumption of households was selected as the standard measurement for vacancy, avoiding vacancy due to seasonal or temporal factors.

The results illustrate that the occupancy rate of residential communities does not decrease within the context of urban shrinkage. Therefore, it is necessary to better understand the residents' living conditions in each residential community, as well as to optimize the functional layout and urban development, and enhance the cities' ability to cope with urban shrinkage. Furthermore, the direction of change in matching types between residential space and the different types of commercial spaces differs, while the magnitude of change is not consistent at different scales. Future research should consider the state of housing further. From the perspective of different types and scales, this study proposes collaborative optimization strategies, suggestions on residents' demand and the supply of commercial facilities to solve the actual matching problem in shrinking cities. In turn, this provides a reference point for coping with urban shrinkage and improving the matching relationship between residential and commercial space.

5.2 Conclusions

To discuss the changing relationship between residential space and commercial space in shrinking cities, this study employed both residential electricity consumption data and POI data for Yichun District. Several conclusions have been drawn.

(1) Firstly, the occupancy rate of residential communities in Yichun District is not in decrease. Furthermore, the number of residential communities for which the supply level of various commercial facilities is above the mean value has also experienced an increase. This serves to show that urban shrinkage does not imply reduction in the occupancy rate and supply level of various commercial facilities.

(2) Secondly, residential space and commercial facilities illustrate a significant correlation in space, and the changing direction of commercial space and residential space in Yichun District is matched. In general, the relationship between residential and commercial space changed from insufficient supply to high-level equilibri-

um between supply and demand, with leisure and entertainment facilities experiencing short supply and uneven layout. Lastly, the residential communities that had the three types of high-level equilibrium, short supply, and low-level equilibrium were distributed in a ring pattern, directed outwards from the urban center to the peripheral regions.

(3) Lastly, from the perspective of supply and demand, the relationship between residential and commercial space may be related to multidimensional factors. For one, the level of economic development supports the supply of commercial facilities. On the other hand, the buildings' age and the accessibility to public transportation influence the pattern of occupancy and commercial facilities. Furthermore, population aging impacts the supply of commercial facilities by changing the demographic structure. Lastly, the residents' willingness to move affects the relationship between occupancy and commercial facilities leading to further population loss and future housing vacancies.

Based on the aforementioned conclusions, it may be concluded that population loss and economic recession lead to changes in the relationship between housing and commercial facilities. In relation to the above mentioned, there is an urgent need to reasonably allocate and supply diversified commercial service facilities by layers and classifications. Furthermore, it is necessary to optimize the relationship between supply and demand at the level of each living circle. This paper has selected the living circle as the basic unit to measure the matching relationship between residential and commercial spaces. This selection is consistent with the living circle standard that emphasizes a walking scale and basic service supply in contemporary domestic urban planning. Furthermore, it is also in line with the actual needs of urban planning. According to the results of residents' demand and commercial facilities supply in each living circle, the facilities with oversupply and short supply are distributed appropriately and according to the actual demands. The overall supply of leisure and entertainment facilities at all levels of living circles is insufficient. In reference to the increasing number of urban elderly population, shrinking cities need to increase chess and card rooms and other aging leisure and entertainment facilities. This will improve the overall relationship between residents and various types of commercial space. Simultaneously, the urban public service system should be im-

proved, while the needs fully of urban residents for various commercial service facilities should be extensively investigated. Furthermore, public participation needs to be encouraged and strengthened, while 'smart decline' should be adopted as a new development idea. It should be noted that this study focused mainly on electricity consumption data and households' POI data. However, it classified only the housing with an annual electricity consumption exceeding 20 kWh as residential, without further division or analysis of the residential types. It is therefore necessary that future research considers various housing types when investigating the relationship between commercial and residential space.

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