Research on Spatial Structure Evolution of Suburban Traffic Network Under the Background of Urbanization Based on Space Syntax

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Abstract. In the process of urbanization, a large number of rural land in suburbs has been converted into urban construction land, and its spatial structure has undergone significant changes. This paper takes Sansheng xiang in the suburbs of Chengdu from 1985 to 2015 as the research object, combined spatial syntactic theory to study the spatial structure evolution characteristics of land in the suburbs during the urbanization. The conclusions are obtained as follows: (1) the spatial accessibility, permeability and utilization rate of the study area have been significantly improved, also the spatial form has evolved from a dendrite to a grid type. The spatial integration degree, connectivity and depth values are optimized to 2.62 times, 3.62 times, 4.52 times compared with the original. (2) The driving factors of spatial evolution mainly include: population mobility, economic scale, building area, and industrial structure, all of which show a good fit to the evolution of spatial structure. (3) In combination with the spatial syntactic theory, the spatial structure optimization micro-intervention method is proposed. By studying the fitting relationship among the spatial integration degree, the connection degree and the axial length, some inefficient space units are found. Besides, the optimization suggestion method is proposed.

1. Introduction
According to the China's sixth census data, between 1978 and 2018, the urbanization rate of China's permanent population jumped from 19.7% to 59.58% [1-3]. The continuous growth of population size is accompanied by the rapid expansion of urban use land. The scholars have studied 7 major cities including China's Beijing-Tianjin-Hebei region, the Yangtze River Delta region, the Pearl River Delta region, Chengdu-Chongqing region, the middle reaches of the Yangtze River, the Central Plains region, and the Ha-Chang region. The continued research on the urbanization process shows [4-9]: 1 urban expansion inflection point appeared around 2000, since then the growth rate of urban construction area has increased significantly. 2 The fractal dimension of city scale distribution got small, while the primacy of central cities and the provincial capital cities strengthened. 3 In the process of urban expansion, most of the incremental part of urban construction land comes from the rural cultivated land.

Rnder the trend of urban expansion, housing sites, cultivated land and collectively managed land of rural areas in the suburbs are gradually transformed into urban land. According to statistics, in the first decade of the 21st century, the net area of cultivated land in China decreased by 10,160.44 km2, accounting for 0.71% of the total cultivated land. To this end, China has delineated the red line of cultivated land protection from the perspective of food strategic security. Moreover, Spatial syntactic theory is common in spatial analysis [10-13], but the research on the spatial structure evolution of urbanized land in suburban areas is relatively weak. This article selects the Sansheng xiang with the
significant loss of cultivated land resources as the research object. Combined with space syntax theory, the study discusses the spatial evolution characteristics of the urban land that the residential land, cultivated land and collectively managed land in rural areas is gradually transformed into.

2. Research methods and data

2.1. Research methods

Related theories often use “space” as an appendage or background to study, focusing on the physical form, object behaviour and social attributes. However, the entry point of spatial syntactic theory is “return to space itself”, and use it as a basis to study the relationship among architecture, society and cognition.

The core concept of spatial syntax is organization (organization is a set of relationships, any of which depends on all other relationships related to it), which is considered that space is a kind of organization existence, and the relationship of space can be represented. Based on this, any set of spatial relationships can be characterized as a topological connection. The topological properties of the organization extend three important quantifiable indicators: Mean Depth, Global Integration and Connectivity.

\[
MD_i = \sum_{j=1}^{n} \frac{d_{ij}}{(n-1)}
\]

In the formula, MD\textsubscript{i} represents the average of the shortest step size of a spatial node from all other spatial nodes. D\textsubscript{ij} represents the shortest path from the node i to the node j.

\[
Ci = \sum_{i=1}^{n} d_{ij}
\]

In the formula, Ci represents the number of spatial nodes adjacent to a certain spatial node. R\textsubscript{ij} indicates that the i-th spatial node is connected to the j-th spatial node, which value is 1.

\[
Gi = Dn(n-2) / 2(MD_i - 1)
\]

In the formula, Dn=2\{n[log2[(n+2)/3-1]+1]/[(n-1)(n-2)]\}.Dn is a normalized parameter and MD\textsubscript{i} represents a relative depth value.

2.2. Data sources

In the space syntax, the axis method, the convex space method, and the viewport segmentation method are three commonly used methods for space division. The convex space method is suitable for the study of interior space in buildings, while the axis method is applicable to the case of the block scale.

On the one hand, the satellite remote sensing image of urbanization process of Sansheng xiang in the suburbs of Chengdu from 1985 to 2015 was selected as the basic research data every 10 years. The axis drawing is drawn as the source data by AUTOCAD drawing software, and then revised by importing into DEPTHMAP software. Later, ARCGIS is used to quantify the key parameters of spatial structure features such as the connectivity, the integration and the depth of Sansheng xiang. [14] On the other hand, the driving factor index data of spatial structure evolution is analysis by consulting relevant literature and statistical data in order to find the fitting degree of the driving factor index and spatial structure evolution.

3. Spatial evolution analysis

3.1. Regional Overview

Chengdu is one of the central cities of China, which is an important political, economic and cultural center in western China. The overall structure of the central urban area of Chengdu is a radial ring network. In recent years, Chengdu has proposed the development strategy of “East-developing, South-expansion, West-control, North-improvement, Central-optimizing”, which focus on the south and the
east and builds urban pattern including “a mountain and two wings”. In the 30 years of Chengdu's expansion process, the transfer of cultivated land to the construction land was mainly concentrated in the suburban area. In 1985, the urban construction land in Chengdu was mainly focused on the first ring area, which expanded beyond the first beltway in 2015 [15].

The Jinjiang District is located in the south-east in Chengdu, located at 104.04' east longitude and 30.40' north latitude. The east of Jinjiang District is next to the Chenghua District, the southeast is bordered by the Longquanyi District, the south is adjacent to the Tianfu New District, the southwest is adjacent to the Jinjiang River, the Fuhe River is adjacent to the Wuhou District and the Gaoxin District, as well as the northwest is connected with the Qingyang District. The total area of the jurisdiction is 62.12 square kilometers.

3.2. Spatial evolution driving force

The practice of human construction is a direct factor leading to the evolution of the spatial structure of study area. Human production and life are simultaneously restricted by the laws of social and economic development. The direct impact of the urbanization process is the increase of urbanization rate and the increase of building area, which indirectly affects the adjustment of industrial structure, the change of economic aggregate and the average. The driving factor characterization data of spatial structure evolution can be counted by consulting the Chengdu Statistical Yearbook.

The urbanization of suburban area has to face an increase in the construction area and the intensity of land development and utilization, accompanied by the urbanization or marginalization of the rural population. Secondly, due to the change in the nature of land use, the proportion of primary industry will decrease, but the proportion of secondary and tertiary industries will increase. The driving force factors reveals the dynamic process of spatial structure evolution in the suburbs from 4 main aspects such as population flow, economic development, building growth, and industrial adjustment (Table 1).

Figure 1. Chart of the spatial evolution driving force indicator (1985-2015)

From the line graph of the various driving factor data(Figure 1), it is known that 2005 is an important turning point: The urban population was basically the same as the rural population around 2005, and it was already 2.51 times of the rural population in 2015; The construction area was maintained at a low level before 2005, also the growth rate was relatively mild. After 2005, it showed an exponential growth pattern. As well as the explosive growth of the construction area from 2005 to 2015 was a major transition period for the urban landscape of study area; The economic aggregate and per capita economic level also experienced a peak period of growth after 2005. In contrast, the economic growth rate of Chengdu began to slow down significantly after 2005; The transformation of rural land to urban construction land boosted economic growth and generates population convection. Meanwhile, it also reduced the proportion of the number of employees in the primary industry and the economic structure to a certain extent. Around 2005, the proportions of the primary industry, the secondary industry, and
the tertiary industry were equivalent. Since then, the proportion of the tertiary industry has continued to rise.

Table 1. Changes in main spatial indicators in study area (1985-2015)

| Socio-economic indicators | 1985  | 1995  | 2005  | 2015  |
|---------------------------|-------|-------|-------|-------|
| Population size           |       |       |       |       |
| Total                     | 862.68| 971.68| 1082.03| 1465.75|
| Urban                     | 234.93| 300.86| 543.93| 1047.57|
| Rural                     | 627.75| 670.74| 583.1 | 418.18 |
| Economic Growth           |       |       |       |       |
| GDP                       | 0.87  | 6.47  | 23.76 | 108.01|
| Average                   | 1.01  | 6.7   | 19.67 | 74.27 |
| Growth rate               | 18.4  | 11.8  | 14.0  | 7.9   |
| Industrial Structure      |       |       |       |       |
| Primary                   | 55.5  | 47    | 32.3  | 16.4  |
| Secondary                 | 26.7  | 29.9  | 30.8  | 34.3  |
| Tertiary                  | 17.8  | 23.1  | 36.9  | 49.3  |
| Building area             |       |       |       |       |
| Construction              | 1375.25| 3177.41| 7271.86| 26442.11|
| Completion                | 990.97| 1677.18| 2188.6 | 3148.7 |
| Residential               | 860.68| 1682.58| 4306.92| 12751.42|

3.3. Spatial evolution

The Sansheng xiang is part of the Jinjiang District in Chengdu, between the ring road and the Ring Expressway. It is a shallow hilly area with a high northwest terrain and a low southeast, whose average elevation is of 543 meters. The area is 5 km away from the Second Ring Road. The northern part of the study area is a community dominated by residential and commercial forms. The south retains a relatively primitive rural settlement form and a good ecological environment which is a suburban ecological leisure resort with the theme of agriculture and rural tourism. The northern part of the Sansheng xiang has the typicality of the evolution of suburban spatial structure defined as the east to the Qidu Avenue, the south to the Yinxing Avenue, the west to the Chenglong Avenue and the north to the Third ring road. The total circumference is 9.270km and the total area is 51.157hm².

Figure 2. Remote sensing satellite image of the study area (1985-2015)

Between 1985 and 2015, a large number of the rural housing sites, the cultivated land and the collectively managed land in study area were converted into the urban land (Figure 2). The area has evolved from a dendritic space structure combined of village, farmland, pond and forest into the segmentation of a checkerboard road network and the texture of the reticular space structure with various types of block land (residence, commerce, green space, medical care, education, etc).

With the expansion of the construction land in Chengdu, the construction intensity and the population density of this area have increased remarkably. The changes in the main spatial structure indicators are shown in Table 2.

The spatial pattern change of study area presents two distinct stages, and 2005 is an important node of time. The first stage was from 1985 to 2005 when the spatial structure of the land was slow to change and the original style was maintained. The second stage is from 2005 to 2015 when the spatial structure...
has changed dramatically, which has changed from dendritic to grid-like, at the same time, the intensity of land development has been significantly enhanced. The visual analysis of main spatial indicators is shown in Figure 3.

**Figure 3.** Visualization analysis of spatial indicators in study area

The view of the spatial structure morphology analysis is composed of the road axis and the colour "blue-green-yellow-red" represents the corresponding increase of the spatial structure index.

- From the perspective of the spatial integration. The degree of integration represents the degree of agglomeration or dispersion in a spatial unit and all other space in the system. The greater the degree of integration of a spatial unit is, the better the accessibility and permeability of the spatial unit becomes. The integration reflects the spatial accessibility, which measures the potential of a space to attract traffic of accessibility [16-18]. The average spatial integration
degree of study area has increased from 0.335 in 1985 to 1.211 in 2015, increasing by 261.49% on the original basis. The increase in spatial integration indicates that there was a marked improvement in the land accessibility and permeability of this area, which also shows from the spatial form that the grid spatial structure of is more convenient and efficient than the early dendritic space structure on the exchange and transmission of matter, energy and information.

- From the perspective of the spatial connectivity. The degree of connectivity represents the degree of direct connection of a spatial unit to all other space in the system. The greater the degree of connectivity of a spatial unit is, the better the permeability of the spatial unit becomes. The average spatial connectivity degree of the district has increased from 1.942 in 1985 to 2.724 in 2015, increasing by 40.27% on the original basis. The increase in spatial connectivity indicates that the spatial permeability in this district has improved. In terms of the practical significance, it is convenient for people that enhancing the permeability between the spatial units of study area and increasing the interactivity, which has a good effect on promoting communication between the people.

- From the spatial average depth value. The depth value represents the topological reachability of the spatial unit, equal to the number of spatial transitions to a appointed spatial unit. The depth values have more sociological and behavioral significance, meaning that spatial units with the high depth values have relatively poor accessibility associated with blind areas and criminal activities [19-21]. The average spatial depth of the area has decreased from 18.472 in 1985 to 4.559 in 2015 and its spatial integration was reduced by 305.17% on the basis. The decrease in the spatial average depth value demonstrates that the spatial accessibility has been improved greatly.

### Table 2. Changes in main spatial indicators in study area (1985-2015)

| Index | Integration | Connectivity | Mean Depth |
|-------|-------------|--------------|------------|
|       | min | max | avg | min | max | avg | min | max | avg |
| 1985  | 0.1249 | 1.3516 | 0.3351 | 0 | 4 | 1.9415 | 1 | 45.1859 | 18.4726 |
| 1995  | 0.1136 | 1.6982 | 0.3248 | 0 | 4 | 1.9586 | 1 | 41.8741 | 18.0458 |
| 2005  | 0.1442 | 1.7381 | 0.41895 | 0 | 8 | 2.1081 | 1 | 42.4501 | 16.0109 |
| 2015  | 0.6912 | 2.1567 | 1.2105 | 0 | 9 | 2.7241 | 1 | 7.1226 | 4.5594 |

In terms of the practical significance of the value, the grid spatial structure is more effective than the early dendritic space structure to avoid blind areas and criminal activities, which is of great help to the social stability and the urban management. The change of study area is a microcosm of the spread of cities to the countryside, which allows us to understand the differences of urban and rural as well as the process of urbanization of population, land and industry from an intuitive and microscopic perspective. In terms of the evolution of the spatial structure in study area in 1985 to 1995, the urbanization process of the district has accelerated remarkably since 2005, when the inner city of Chengdu started to develop beyond the three-ring area. During the transition from agricultural land to construction land in the suburbs of the city, its space changed from dendritic structure to grid, whose spatial integration, connectivity and average depth were optimized. Meanwhile, the space accessibility, the permeability and the utilization have been dramatically enhanced [22], so that! it is more suitable for the social and economic activities of human beings in a large-scale, high-density state.

#### 3.4. Micro-intervention of spatial structure optimization

##### 3.4.1. Micro-intervention

With the continuous development of social economy, urban material space is difficult to meet new life needs. It is a normal phenomenon to improve cities by urban renewal, and it is also the inevitable development of cities. But the city is a complex organic system which the existing theoretical research cannot fully cover. Large-scale changes in existing urban spaces and environments will bring about dramatic changes in the pattern of benefits, also will have a profound impact on people's lives and result in many uncertain consequences. Partial and small changes in urban space can motivate the city's own initiative. This process of micro-renewal is not only closer to the development of the city
itself, but also is easier to control to bring positive Benefits. Most of the reconstruction of old city in China in the past 30 years have adopted the method of demolition and renovation, and this kind of renewal method can greatly enhance the urban style. But the method often means the change of land use, the disappearance of lifestyle and the sense of belonging and identity of the environment have also gone. Urban micro-intervention is a special approach involving governments, citizens and designers to update buildings, courtyards and street spaces in a micro-intrusive, sustainable, small-scale, and step-by-step manner, which makes the old city maintain a strong life atmosphere and unique charm. Meanwhile, the update is not only limited to the renovation of buildings and facilities, but also concerned to the improvement of the standard of life of the citizens and the maintenance of the vitality of the area.

3.4.2. Identification of intervening spaces. In the study area, space syntactic theory can be used to identify negative space and inefficient space, so as to accurately locate the path of spatial update intervention. In the space syntax theory, the degree of connectivity, the control value and the local integration are the characteristics of the spatial structure at the local level. The integration degree describes the structural features at the overall level. The intelligibility is used to describe the correlation between such local variables and global variables. From the perspective of the whole and the part, we can propose a targeted method for micro-intervention of the spatial structure (Figure 4).

Figure 4. Spatial scatter plot of study area

In terms of the overall level. If the spatial unit with high connection value has high integration, then this spatial unit has better comprehensibility. Taking the spatial connection degree as the horizontal axis and the spatial integration degree as the vertical axis, the scatter plot model of the spatial structure is obtained: \( y = 0.143x + 0.794 \), where the space unit in the lower left corner is the less understandable part. By observing the spatial scatter plot model, it can be seen that the overall positive correlation of the region is good. Some of the spatial units below the fitted line have poor comprehensibility, therefore, the road network corresponding to the axis map needs to enhance the connection degree with other roads in the future urban road planning and construction as well as improve the mutual permeability between the space.

In terms of the partial level. In the current spatial structure, the length of the axis is the horizontal axis and the spatial integration is the vertical axis. Hence the spatial structure scatter plot model is obtained: \( y = 3.271x + 1.072 \), where the space unit in the upper right corner is the part of the axis length and the higher integration degree. By comparing the spatial scatter plot with the spatial structure diagram, the longer the axis length, the higher the spatial integration is. Therefore, the use of a straight road network structure in a spatial planning layout has better spatial accessibility and permeability than a road network structure having a turning radius [23-24]. A flat road network structure should be used between the space units in the study area to improve the utilization of space, moreover, within the space unit, a natural road system can be used to break the monotony.

4. Conclusion
The suburban area of city is the main battlefield of China's urbanization, which is also the area with the most significant change in spatial structure. Spatial syntax transforms spatial units into topological relationships and quantifies this structural relationship. Based on the satellite remote sensing maps of
the area in different periods, this article studies the spatial evolution characteristics of the suburbs in Chengdu by spatial structure representation parameters.

(1) With the transformation of a large number of cultivated, house sites and collectively-operated land in the suburbs, the spatial structure of the suburbs has also changed from dendritic to grid-like. The spatial evolution of the study area can be divided into two stages: 1985-2005 and 2005-2015. The spatial change in the first stage is moderated, but the spatial change in the second stage is more significant. Built in the past 30 years, the spatial integration of the study area has increased to 2.62 times, the connection degree has increased to 3.62 times, and the average depth has increased to 4.52 times. The accessibility, permeability and the utilization of space have been significantly improved, which is more adaptable to modern large-scale, high-density production and living conditions.

(2) From the perspective of social and economic development, the driving factors of spatial structure evolution in urban suburbs mainly include 4 aspects: building area increase, population convection, industrial structure change and economic level improvement, of which data showed a two-stage characteristic with a watershed in 2005. By analysis the trend graphs of these specific indicators, we can find that the spatial evolution index and the spatial structure evolution have a high degree of fitness, showing a significant positive correlation.

(3) In recent years, most of China's cities have entered the late stage of urbanization, and its economic slowdown is an important sign. The urban renewal problem can be intervened in combination with spatial syntax to achieve precise reconstruction. Through the relationship among integration degree, connection degree and axis length, the inefficient and negative spatial units in the study area can be found, and the optimization suggestions are proposed for this.

The study of spatial structure evolution of the study area in Chengdu has made us clear about the growth process of China's cities and urban agglomerations in recent decades. Considering the current situation of China's population structure, the expansion of major cities is gradually slowing down, and some small and medium-sized cities are experiencing population shrinkage. The optimization of the internal spatial structure of cities will become the focus of the future urban planning and practices.

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