

# Configuration in the Development of Urban School District: A Case Study of Beijing, China

Bo Wan<sup>1, 3,\*</sup> Tao Yang<sup>2,3</sup>

<sup>1</sup> School of Architecture and Design, Beijing Jiaotong University, Beijing 100044, China

<sup>2</sup> China Academy of Urban Planning and Design, Beijing 100044, China

<sup>3</sup> School of Architecture, Tsinghua University, Beijing 100084, China

\*Corresponding author. Email: wanbocn@163.com

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**ABSTRACT** The construction of spatial vitality in urban school districts is one of the important goals of contemporary Beijing urban design and can be clearly and deconstructed analysed with quantitative methods. This paper presents a technique aimed to assist in planning and evaluating spatial morphology of urban school district in a metropolitan area by applying space syntax configurational approach. This cognition is of great significance to promote the urban design of the school districts from experience integration to scientific analysis, so as to more efficiently achieve the improvement of urban school district environment quality.

## 1. INTRODUCTION

The school district space in this paper refers to a series of urban public spaces supporting basic education and other related activities that are zoned according to the matching rate between school-age population and educational resources from the urban space perspective and based on the corresponding spatial scale and the principle of near school admission, which have maintained a relatively clear boundary for a period of time and have a clear space region boundary.

In recent years, great progress has been made in China's basic education that has shifted from the stage of realizing "education for everyone" to the stage of "pursuing fair access to educational resources". In this context, how to expand the coverage of quality education resources, how to correctly handle the ownership of quality education resources, and promote the balanced and healthy development of education urban environment has become one of the hot issues in today's society..

## 2. STUDY AREA

After examining the 63 school districts in the contemporary Beijing central city (Figure 1), it can be found that the school, the residential area and the path to school connecting the two in the school district space are the three basic elements of the school space prototype. The natural close connection among the three elements constitutes a picture of the sphere of the basic daily life of ordinary kindergarten children and primary and middle school students.

In general, the dominant school district space structure consists of two aspects: one is the structure of the urban space morphology of the school district itself, such as radial and square grid patterns; the second is the structure formed by the layout of school district function in space, such as the scatter layout pattern of schools, the pattern of connection between schools and residential areas in the layout. In addition to the description and presentation of these dominant spatial features, this paper will make some preliminary explorations on the basic characteristics of the urban space morphology of the school district from urban spatial network configuration feature. To study the space of contemporary school districts in Beijing, we need to understand the overall morphological characteristics of the Beijing school district space.

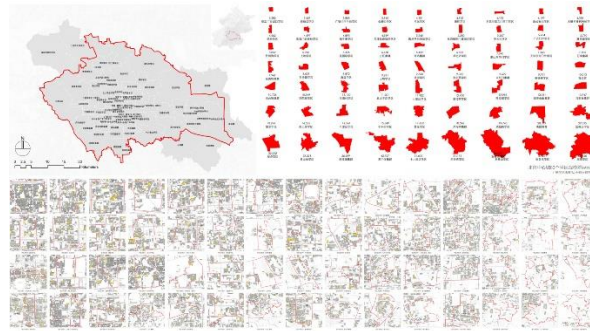


Figure 1 Beijing School District

### 3. Method

Convenient street space accessibility, moderate space development intensity, and reasonable land mix use of space are regarded as three key urban morphology factors for space vitality. How to quantify the three elements? At the same time, it can recognize and explore the spatial characteristics and space development of the school district space. This paper will elaborate on such a purpose. The paper describes and analyses the spatial morphology of the school district based on space syntax method.

Space syntax can objectively describe the mobility and accessibility of people and vehicles in street space to a certain extent through the configuration analysis of the connectivity of urban streets. Through a large number of existing Space syntax and statistics of urban operational status and related research, we can see that high correlation and efficient analysis process give Space syntax an advantage to evaluate the effects of spatial design. Most importantly, the configuration can reflect the integration core, choice core, space efficiency core, etc. of school district space at different spatial scales based on the fact that school district space is virtually urban public space.

#### 3.1. The Global and Local Computational Scale of Space Syntax

Space syntax is a multi-scale urban spatial network quantitative analysis method under the guidance of configuration theory [1]. This method was originated in the 1970s and is a method to express the characteristics of buildings and urban spatial networks and their corresponding socio-economic impacts by quantitative indexes (Hillier B, 1984, 1996, 2005; Hanson J, 2003), the core of its research is to reveal the spatial mechanism in the socio-economic reality and to apply it creatively to space creation.

Space syntax uses a series of variables to measure spatial configuration, among which the two most important ones are integration and choice. Integration is considered to be predictive of to-movement potential, while choice is seen as predictive of through-movement potential (Hillier B et al, 2005, 2007). Based on these two variables, Space syntax proposed a series of theories about spatial configuration and use, such as the theory of natural movement (Hillier B, 1993), the ubiquitous centrality (Hillier B, 2009), and the fuzzy boundary (Yang T, 2007). The theory of natural movement states that the configuration of spatial morphology will influence and even determine the natural frequency of people's movement to a great extent; the ubiquitous centrality means that the centers of the city are not only limited to those at the city level that everyone is familiar to in daily life but are closely related to the scale. In other words, it is possible that the vegetable market in the community is the center of spatial measurement for your daily life radius. The center does not have to be artificially designated but is closely related to the scale of movement. The phenomenon of ubiquitous centers can be regarded as a universal function of the city. Since the school activities in the school district space have the characteristics of daily movement radius, the description of the school space center at different movement radius scales helps to further understand the school district space. The fuzzy boundary refers to the multi-scale differentiation of the urban spatial network. This phenomenon cannot completely coincide with the boundary of

administrative division, but this differentiation can better adapt to the aggregation of socio-economic interactions of different scales.

The computational scale of Space syntax analysis is divided into two categories: global-analysis and micro-analysis. The main paths with high accessibility at the global scale are identified; at the micro-scale, the spaces in the block centers with small-scale accessibility are highlighted (Van Nes A et al, 2012). Considering the integration, choice and space efficiency at two scales, the chosen value of each street is assigned to the school district it is in on the GIS platform, which can be used as a measure of the spatial configuration characteristics of the school district.

There are three reasons why space syntax is used as one of the main methods of school district space research. First, based on graph theory and network science, the method for describing and analyzing urban space has been objective, credible, and persuasive for more than 30 years. Although discussions on limitations of Space syntax and improvement of methods have gradually increased in recent years (Xiao Yang et al., 2014; Ratti C, 2004; Steadman P, 2004), this also indicates that a growing space research theory and method is worthy of being tested, refined and applied in the research and construction of actual space, and the role of Space syntax itself in the field of worldwide urban spatial morphology analysis has been widely recognized; second, based on the spatial uniformity traits unique to the school district space itself, the hierarchical model of scatter distribution of all levels and types of schools can be accurately measured and expressed by categories; third, the configuration analysis can assist in the school's location selection from a spatial topology perspective to a certain extent. For a research object with such a big quantity and wide range, it is particularly important to choose a reasonable model and a suitable method.

The school district space is located in the spatial network configuration of Beijing city. From the calculation results of spatial integration, choice, and space efficiency, it can be seen that there is a difference between school districts. This diversity is due to the difference in spatial position, and more importantly, due to the different configuration characteristics that result from the accumulation of spatial-temporal effects of space growth [2].

### **3.2. Test of Beijing Space Syntax Model**

Before the analysis of the overall configuration of the Beijing school district, the model itself should be verified. There are three elements to ensuring the effectiveness of the model interpretation. First, the research scope should be at the center of the model, reducing the edge effect, second, the hierarchy of scales should be complete. Third, a good correlation with real movement. Due to the scale spanning factor of the study of school district space itself, the model should have a pedestrian-level network. Therefore, the model of this paper basically covers all major transportation networks around schools as far as possible. At the same time, it is necessary to further confirm the information that these models will tell us on the city's operations and urban structure.

Movement is a key issue, and the variables of the test of configuration express the characteristics of the movement. The spatial configuration can reflect the real movement pattern to a certain extent, and it is very easy to test that. What is needed is to compare the values of movement potential, and to conduct correlation analysis between the spatial variable of each segment and the actually observed movement volume. The correlation is between 0 and 1, which tells us to what extent the structure be found matches the real situation. As shown in the scatter plot (Figure 2), each point represents a street segment in the Beijing central city area, the horizontal axis represents the spatial choice value at the radius  $n$ , and the vertical axis represents the observed vehicle movement, due to data distribution, logarithms are taken for both axes. If the correlation is absolutely perfect, these points will form a straight line from the bottom left to the top right. As shown, the correlation  $R^2$  of these two variables is almost 0.8, indicating that about four-fifths of the movement distribution depends on the chosen distribution of the Beijing road network. Therefore, in theory, the variables we use to measure the movement potential can effectively predict real movement, even without considering other influencing factors.

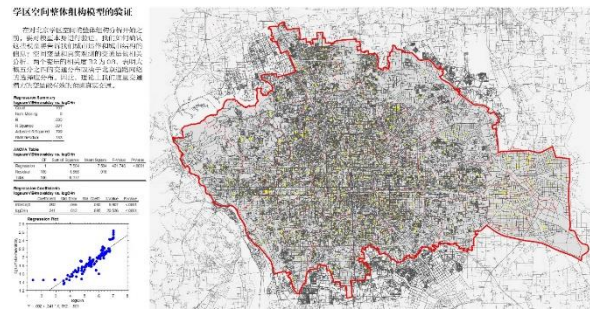


Figure 2 Analysis of the Correlation between Traffic and Space Selectivity in Beijing School District Space

### 3.3. Two Aspects of Urban Spatial Networks

Integration and choice are two aspects of urban spatial networks. Their distribution patterns in space are different, reflecting the behavior patterns of to-movement and through-movement. The total depth can be thought of as the cost of space from one space to all other spaces, and the choice can be seen as the spatial benefit of a space being crossed by other space paths. In terms of mathematical logic, the ratio of choice to total depth is used to measure spatial efficiency. The variable is Dimensionless quantity, that is, it is not affected by the size of the system, and can be used to compare the physical space morphology of different cities, blocks, and streets. Empirical studies have also shown that the variable spatial efficiency almost completely excludes the influence of system size and is highly correlated with the choice (Hillier W R Ge et al, 2012). Therefore, space efficiency is another way to standardize choice. The normalization of integration refers to the theoretical comparison of the mean value of the total depth with the actual total depth, this pattern continues the technical route of the early Space syntax. These two variables are currently widely used in the research and practice at urban, district, and community scales. This paper attempts to apply this analytical method to the research of the school district scale.

In recent years, Hillier, Yang Tao, and Turner have proposed normalization of angle choice and integration (Hillier B, 2012), which is a new improvement in angle analysis. The goal is to make direct comparisons among elements in systems of different sizes. It is necessary to propose a new method of normalization for the angular distance in the segment model, this is because the D-value used to normalize the topological distance in the axis model and the convex space mode is not applicable in the segment model. The normalization of choice stems from the study of the relationship between high choice and great topological depth, that is, the more isolated (with greater topological depth) system has a higher choice. Therefore, the choice is seen as a necessary condition for overcoming the isolation cost in the street network. This is the cost-effective principle proposed by Yang Tao. The new normalized angle choice is named NACH, i.e.:

$$\text{NACH} = \log(\text{CH} + 1) / \log(\text{TD} + 3).$$

In the experiment of Hillier et al., NACH was proved to be irrelevant to the size of the city (based on the number of segments), but rather related to the connectivity of the street. Integration can be more simply interpreted as a comparison between system and city mean values. The normalized angular integration (NAIN) is calculated as:

$$\text{NAIN} = (\text{NC} + 2)^{1.2} / \text{TD}.$$

These two methods of normalization can more easily reveal the internal structure of the spatial morphology, so in the study of the school district space, this method obviously has strong applicability. In theory, according to the maximum and mean values of integration and choice, the overall and local morphological characteristics of urban space can be interpreted. The maximum value can interpret the foreground network of spatial configuration, and the mean value can interpret the background network of spatial configuration. When comparing the maximum and mean values of different school districts, we find that higher values indicate a higher degree of urban structuring; while the mean values reveal to what extent the school districts constitute the shape of the grid, yet they are not a determinant of urban structuring. Similar to the definition of integration, the maximum and mean values of NAIN are related to the level of accessibility in the

street network. The mean value of NACH is related to the continuity of the street in the background network, and the maximum value of NACH can indicate how the foreground network is deformed or interrupted. The values of NACH and NAIN are different for different school districts. The values of NACH and NAIN for different school districts demonstrate different types of school districts, whether it's deformation of regular grid pattern or complete bottom-up organic form.

## 4. Results

### 4.1. NACH and NAIN of Beijing under Rn and R5km

From the perspective of spatial morphological configuration, in the larger contemporary Beijing city area, based on the differences in movement scales, a clear foreground network can be seen (Figure 3, Figure 4). As shown in Figure 4, in the calculation of the global spatial efficiency Rn, space with a value greater than 1.4 is identified. The "two-axis, two-band, multi-center" urban structure presupposed by the 2004 version of the Beijing urban spatial structure plan has now become very obvious after more than ten years of development. The overall spatial structure is basically established, and the overall radial and ringlike spatial structure are very clear with close horizontal connections; at the same time, it can be seen that the actual urban space structure is closely related to the spatial layout proposed by the 2016 new Beijing General Regulations. As shown in Figure 5, in the calculation of the normalized integration R5km (the core of the old city like a shape of square approximately 5km\*5km), the urban spatial structure of "one core area, one city central area, one city sub-center area, two axes, multiple points and one district" is clearly identified.

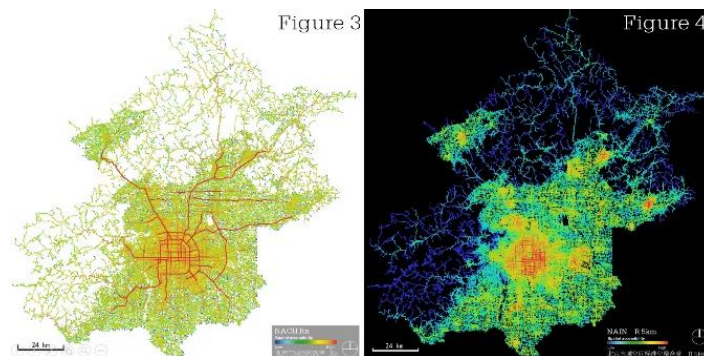


Figure 3 NACH\_Rn of Beijing (Left)

Figure 4 NAIN\_R5km of Beijing (Right)

### 4.2. Core of NACH and NAIN of Beijing School under R1km

The overall structure of the city is studied using a normalized choice with minimum angular variations and a radius of n. By highlighting the space where the value is greater than 1.4, we can see that the radial structure of Beijing is obvious. Some of the school districts either are crossed by the highlighted radiated lines, or have an edge that is the radiated line itself. At the same time, the horizontal connection among the radiated roads is also prominent (Figure 5).



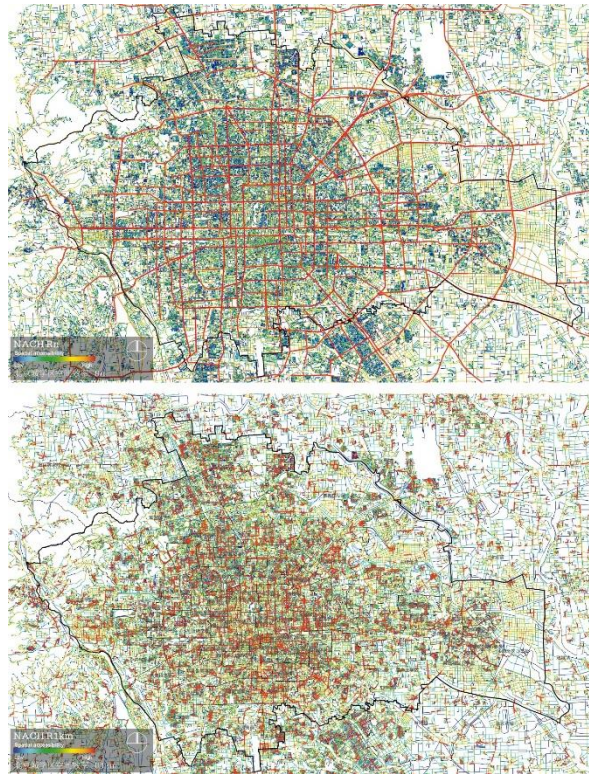


Figure 5 NACH Rn and R1km of Beijing School District

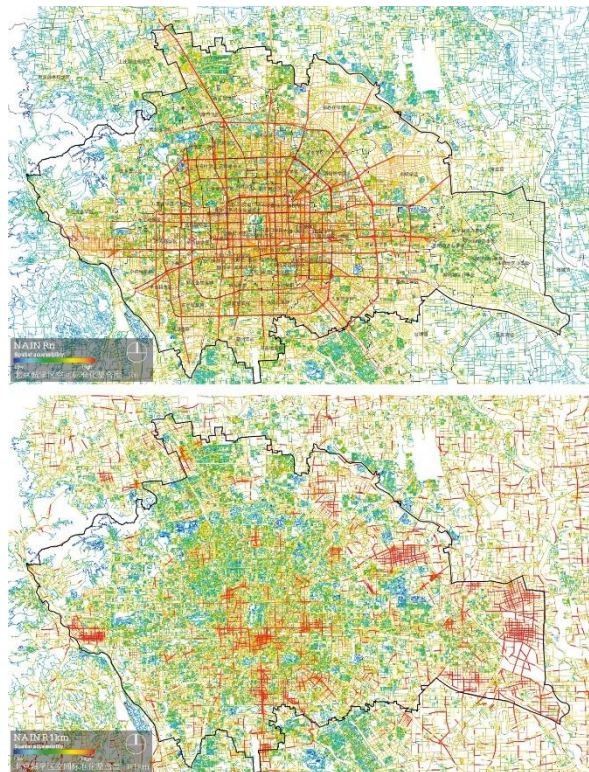


Figure 6 NAIN Rn and R1km of Beijing School District

As shown in the figures (Figure 5, Figure 6), in the diagram of global space efficiency and global normalized integration, we can clearly interpret the overall structure of urban space.

The administrative boundary of the school district has become a boundary for the management of educational resources. The spatial efficiency and normalized integration at a local 1km radius show a more refined core space in the school district, in particular, the space efficiency core at a 1km radius has a close relationship with almost the residential areas and schools in space of all the

school districts (Figure 7). At the same time, because these two variables eliminate the scale effect, the spatial efficiency and normalized integration of the network structure of all school districts can be compared in terms of mean and maximum values.

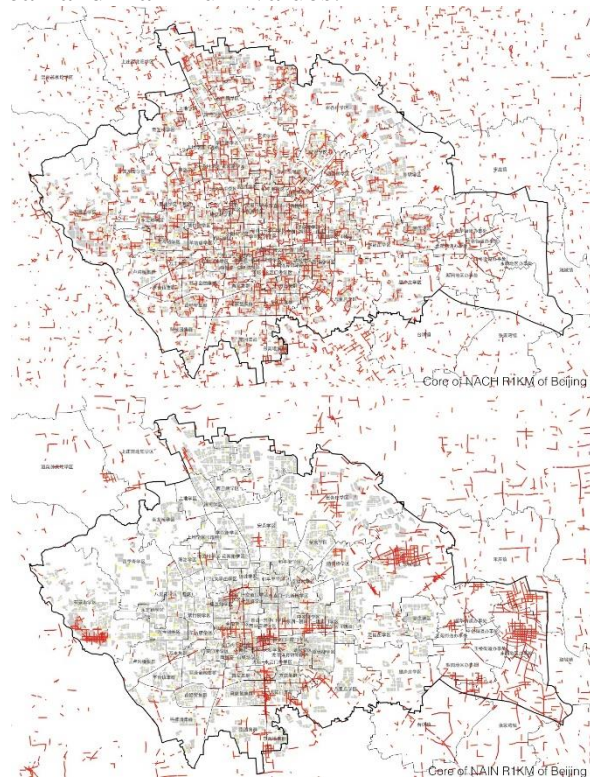


Figure 7 Core of NACH and NAIN of Beijing School under R1km

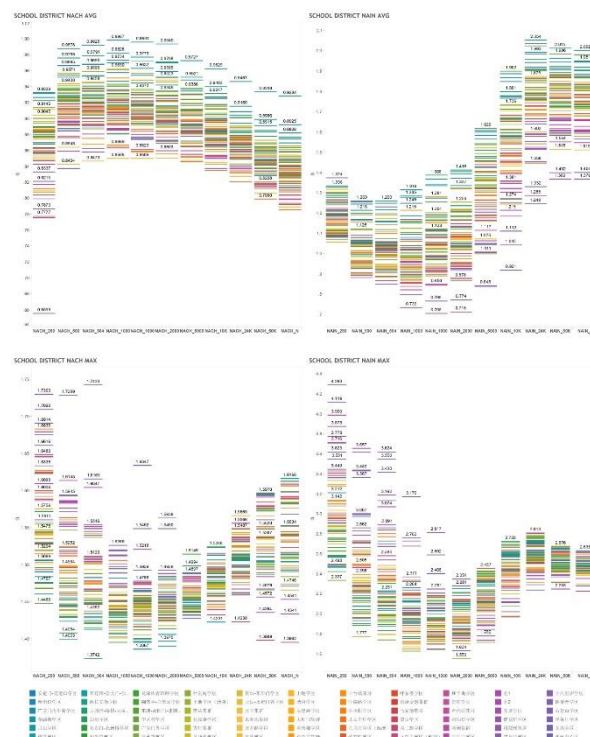


Figure 8 Comparison of NACH\_avg/max, NAIN\_avg/max of all school district, Each line represents a school district

#### 4.3. Comparison of NACH\_avg/max, NAIN\_avg/max of all school district

As shown in Figure 8, with the space efficiency mean value as an example, there are two interpretations. The first is the changing trend of the network space efficiency of the school district with the increase of the radius, and the second is the dispersion of the spatial efficiency values of

the school district with the increase of radius. With the increase of radius, the spatial efficiency of all school districts increases first and then decreases. During the whole change process, the highest value of the mean values of spatial efficiency of all school districts appears at 1000m, which indicates that there is an optimal scale for space efficiency in the spatial network of the school districts. Taking the normalized spatial integration mean value as an example, the mean value of the normalized integration of all the school districts first falls and then rises with the increase of radius, and the peak appears at a radius of 24km, which indicates that there is an optimal scale for spatial integration in spatial network of each school district. At the same time, the dispersion of the mean values of the spatial efficiency and normalized integration of all school districts under different radii is weaker than the dispersion of the maximum values of NACH and NAIN. The span between the maximum and minimum values of the normalized integration mean values is still slightly larger than the span of mean values of the spatial efficiency. The distribution is a relatively intuitive way to show the situation. The extreme value and the mean value of the normalized integration basically rise or fall with the same tendency with the increase of radius, and the difference between the maximum value and the minimum value is relatively consistent in each radius study; the extreme value of space efficiency shows a pattern of decreasing first and then rising with the increase of radius. The lowest point of the extreme value appears at a radius of about 1600 meters. At the same time, at 5km, the extreme values of the spatial network of the school district have the smallest degree of dispersion and the distribution is relatively concentrated, and rise slowly as the radius continues to increase. At the same time, we can see that the dispersion degree of space efficiency extreme values is the largest at a radius of 250 meters. The extreme value of the normalized integration displays a trend where it decreases first, then rises, and then returns to a stable state with the increase of the radius, the lowest point of the extreme value appears at around 1km and 1.6km, the local high point with the smallest dispersion occurs at 24km, then it tends to be stable with the increase of radius. Likewise, the dispersion degree of normalized integration extreme values is the largest at a radius of 250 meters, and the overall dispersion degree gradually decreases with the increase of radius.

#### **4.4. Comparison of NACH\_1km/n, NAIN\_1km/n of all school district**

Through the study of the mean and maximum values of spatial efficiency in units of school districts that change with the increase of radius, we have a preliminary judgment on the configuration characteristics of the school district space. For each school district, the mean value of spatial efficiency within its boundary is calculated, including the spatial efficiency mean value at  $R = 1$  km and  $R = n$ , as local (community scale) and global (urban scale) spatial efficiency. A coordinate graph is plotted, the horizontal axis is the spatial efficiency mean value of the school district at the global scale, and the vertical axis is the spatial efficiency mean value of the school district at the local scale. It can be seen from the distribution of NACH and NAIN in the contemporary Beijing school districts at the global and local scale that the spatial efficiency and normalized integration of the school district in the central city are relatively high (Figure 9). The method of standardization makes it easier to reveal the internal structure of the urban morphology and allows us to compare the street structures of different school districts.



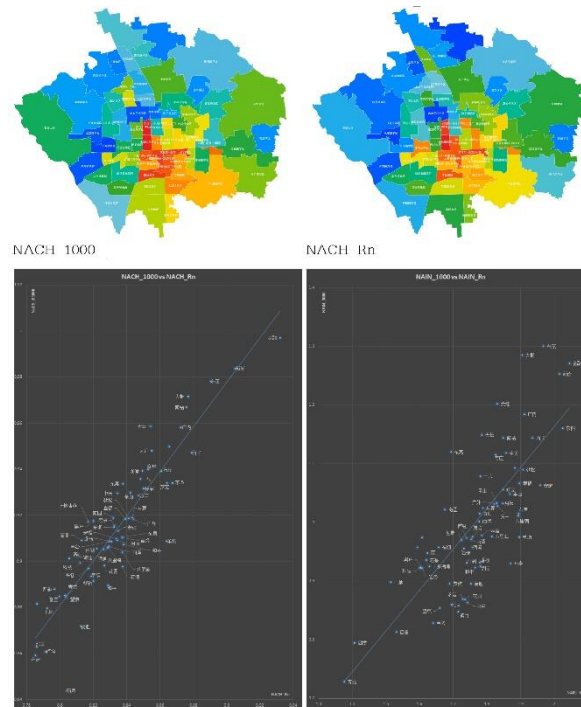


Figure 9 Comparison of NACH\_1km/n, NAIN\_1km/n of all school district

From a macro perspective, urban space is continuous in its entirety; however, the individual's perception and experience of the city is based on the perception of local spatial fragments. The integration of these local spatial experiences by the individual constitutes his/her own perception and interpretation of the overall space. The scope of school district space is clearly defined by the administrative government. This space area is based on the road network. Therefore, the spatial integration and spatial efficiency of a region indicate to some extent the spatial level of the space as a whole in the city. When these school districts are lined up one by one (Figure 9), readers can distinguish which regions are the most active and which region spaces have the highest efficiency by colour (the value decreases in the order of red, yellow, green, and blue). This is to measure the school districts by evaluating the spatial configuration status of individual school districts in the city. At the same time, in a single school district, the integration, choice, and space efficiency of the interior space of the school district can also be compared. For example, how is the spatial integration of the path to school? How is the integration and efficiency of the road in front of the gate of the schools?

## 5. Conclusions and Further Possibilities

The study of spatial morphological characteristics of the school district based on the quantification of key morphological elements has become a reality. From the perspective of urban spatial morphology, the spatial vitality of the school district depends on the agglomeration of convenient street space accessibility, moderate spatial development intensity, and reasonable land mix use of space at the same time and in the same space. Along with the agglomeration of these spatial morphological elements, the spatial vitality of the school district will be correspondingly improved. From the perspective of spatial vitality, the spatial vitality of the school district can be expressed as the intensity of selective activities of parents and children.

## Acknowledgment

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## References

- [1] Hillier B, Yang T, Turner A. Normalising least angle choice in Depthmap—and how it opens up new perspectives on the global and local analysis of city space[J]. JOSS, 2012, 3(2): 155-193.
- [2] Bo, W. A Preliminary Study on The Characteristics of Spatial Form of Contemporary Beijing School District [C]//Sheng, Q. (ed). Proceedings of the 12th International Space Syntax Symposium. Beijing, China: Beijing Jiao Tong University Press, 2019