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Research on Campus Traffic Space Based on Space Syntax Theory: A Case Study of the Main Campus of North China University of Technology

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Abstract As urban construction enters the era of stock development, the overall spatial environment of the main campus of North China University of Technology also needs to be updated. In this paper, the traffic network in the campus is extracted to draw the axis map, and the space syntax theory of Depth Map software is used to quantitatively analyze the integration and intelligence degree of the main campus of North China University of Technology. It is found that the overall spatial integration and intelligence degree of the campus are high, but the local space shows poor accessibility and insufficient space carrying capacity. Specific spatial optimization measures are proposed for the corresponding problems. The study compares and analyzes the experience information obtained from actual research with the quantitative index data, integrates the respective advantages of qualitative and quantitative analysis, and hopes to provide a certain theoretical basis for the construction of related campus space.

Keywords Campus traffic, Space syntax, Traffic space, Variable analysis
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Space syntax theory, which emerged in the 1970s, was first proposed and used by Bill Hillier's group at the University of London's Space Syntax Laboratory[1]. Space syntax is a theory and method to study the relationship between spatial organization system and human society through the quantitative description of human settlements spatial structure including cities, buildings and landscapes[2]. Space syntax abstracts a single space into an independent element based on topological relations, and focuses on the study of spatial accessibility, spatial network pattern characteristics, and the relationship between spatial structure and human activities combined with the idea of graph theory[3]. Traditional research on urban traffic space pays more attention to qualitative research, while quantitative research is slightly insufficient. In this paper, space syntax theory is introduced. It combines variable analysis with graphical language, can eliminate the subjective factors of researchers, and facilitates visual analysis. Therefore, space syntax can evaluate the rationality of space settings and transportation systems at the plan design stage, and identify problems in advance to achieve intensive resource utilization. In recent years, the application of space syntax theory in practical projects has gradually increased, which has promoted the positive development of many fields.

With the implementation of a series of national reform measures, university campuses are also facing various changes and undergoing continuous transformation and optimization. The main campus of North China University of Technology is located in Shijingshan District, Beijing, at the foot of the West Mountain, has a history of more than 70 years, and covers an area of 30 hm^2, with a construction area of more than 400,000 m^2 (Fig.1). Compared with the campus area, the total number of teachers and students is large at present, and some problems in campus transportation needs to be optimized. In this paper, based on space syntax theory, the spatial structure characteristics of the campus will be interpreted, and the traffic status and existing problems of the main campus of North China University of Technology are deeply analyzed and studied. Moreover, reform suggestions are put forward to provide a certain theoretical basis for the future research on the main campus of North China University of Technology.

1 Analysis of spatial structure of road network in the campus

1.1 General situation of the study area

With the continuous development of the surrounding environment of the campus, the campus traffic has undergone many changes, forming today's grid road system and constructing several clear campus axes (Fig.2). The axis from the library information building to Gusong Garden from the south to the north passes through the library, the circular fountain square, the Hanxue teaching building and the avenue composed of thousands of trees, and finally to the rockery landscape of Gusong Garden. The axis is perfectly reflected by the architecture, the square, the avenue, the rockery and other elements. The east-west axis starts from the student service building, passes through Yuxiu square, Chinese Pine Road and Bozhi laboratory building to the west, and extends to the green space on the west side of the laboratory building. Compared with the north-south axis, although it is not prominent enough, the axis relationship has become clearer after multiple renovation and upgrading of the campus space. The spatial sequence of multiple axes helps teachers and students to quickly perceive the overall space of the campus, and provides convenience for teachers and students.

The peripheral roads in the campus are planned as carriageways, and a number of parking spaces are established near the motorway. Various types of parking spaces are built to meet the needs of motor vehicles, such as underground parking lots, above-ground parking lots, roadside parking lots and so on. The internal roads are non-motorized lanes, and a large number of non-motorized parking lots are set up near roads and the entrance of buildings, creating favorable conditions for shared bicycles to enter the campus, and making slow traffic the main way for teachers and students to travel in the campus. The actual use of the space is good, and walking and cycling coexist harmoniously, creating a low-carbon campus life atmosphere. Most of the traffic space in the campus realizes the separation of people and vehicles, and ensures the safety of teachers and students' activities.

1.2 Analysis of variable values

Based on the traffic map of the study area, the axis map is drawn, and then variable values are analyzed step by step. It is mainly divided into

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the following steps (Fig.3): firstly, the traffic map of the study area is drawn; secondly, the axis map of the study area is drawn; thirdly, Depth Map software is used to analyze the variables of global integration degree and local integration degree of the axis map; fourthly, the analysis chart, variable data and the actual use of roads in the main campus of North China University of Technology are analyzed.

1.2.1 Analysis of connection value. Connection value refers to the number of nodes adjacent to a node, and its value is positively correlated with the permeability. That is, the larger the connection value, the better the permeability of a road and other roads connected to it[4]. The main campus of North China University of Technology is now divided into 22 areas according to the use function (Fig.4). The connected lines are abstract expressions of the connections between nodes, and it is convenient to calculate the relationship connection values of key nodes.

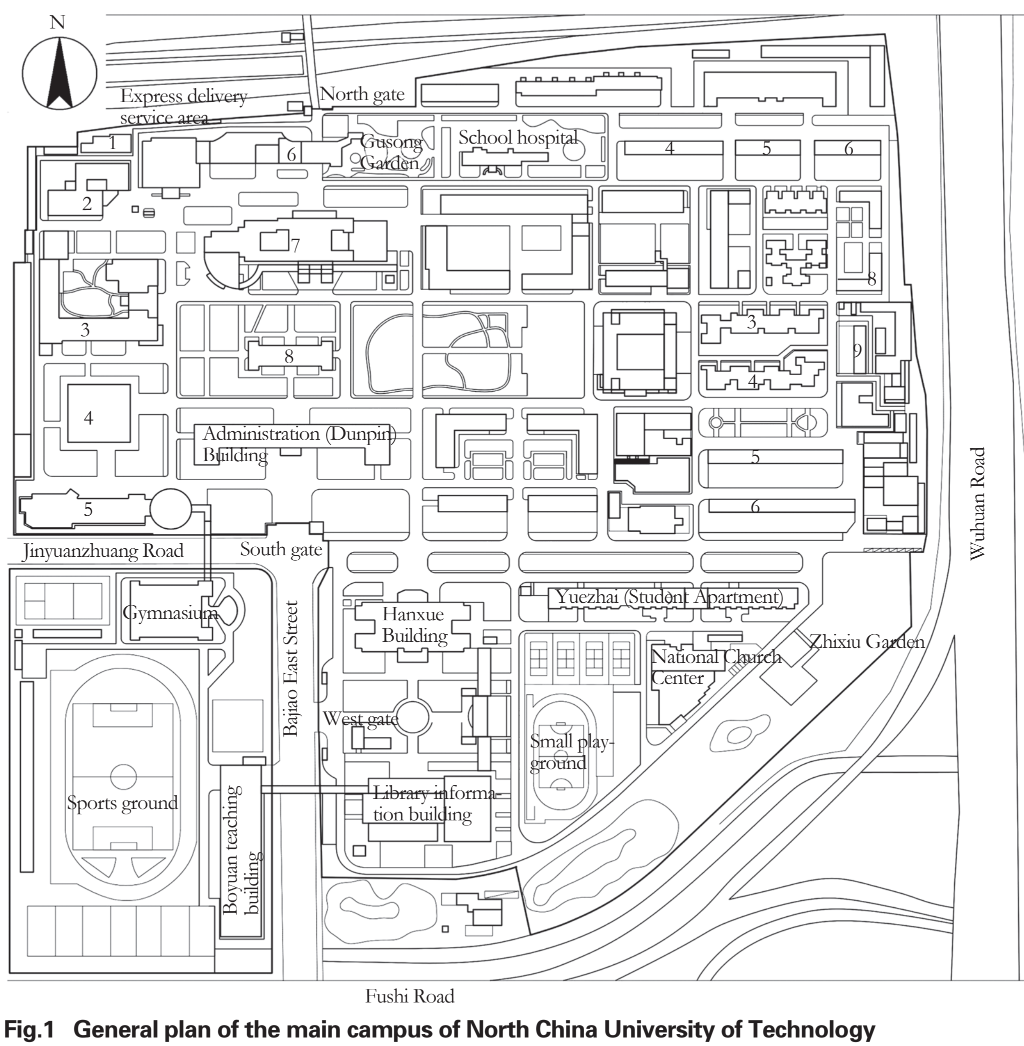
In the partition of functional nodes, the connection value of integrated teaching area, student dormitory area 2 and Guojiao living area is 7 (the maximum), and the spatial permeability is the best. That of Student Living Area 1 is 6, and that of family living area 1, family living area 2, integrated service area, Hanxue teaching building, Gusong Garden, Yuxiu Garden is all 5, while that of administrative building and south gate is 4. Their spatial permeability is relatively good. That of the north gate, express delivery service area, school hospital, logistics service area, sports ground, Boyuan teaching building, library information building, and small playground is 3, and that of east gate is 2. The spatial permeability of these areas is poor. That of Zhixiu Garden is 1, and its permeability is the worst.

1.2.2 Analysis of control value. Control value refers to the accessibility of space. The higher control value of space indicates that its control over the external environment is better than that of surrounding nodes, and the accessibility of this space is better. Control value can also reflect the control degree of a space over the entire campus space[5]. Its calculation expression is as follows:

$$K_i = \sum_{j=1}^{k} \frac{1}{C_j} \quad (1)$$

where K_i is control value; k is the number of nodes adjacent to node i; C_j is the connection value of node j adjacent to node i.

According to the above formula, the larger the connection value of a node, the larger the control value. After calculation, the specific control values of 22 areas can be obtained (Table 1). Among them, the control value of Guojiao living area in the main campus of North China University of Technology is the highest, up to 2.43, followed by integrated teaching area (1.71), student dormitory area 2 (1.48), and family living area 2 (1.34). That of Zhixiu Garden is the lowest (0.14), which is consistent with the actual experience. That is, Guojiao living area and integrated teaching area are easy to reach, while Zhixiu Garden is the most difficult to reach, and there are few teachers and students



Section	Number	Name
Integrated teaching area	1	Practice workshop
	2	Teaching practice building
	3	Bocai building
	4	Jingxue building
	5	Guangxue building
	6	Haoxue building
	7	Lixue building
	8	Bozhi experimental building
Family living area 2	1	Residence (16)
	2	Residence (15)
	3	Huizhai (students)
	4	Residence (8)
	5	Residence (9)
	6	Residence (10)
Family living area 1	1	Young teachers building
	2	Residence (14)
	3	Residence (13)
	4	Residence (12)
	5	Residence (11)
	6	Residence (7)
	7	Residence (4)
	8	Residence (5)
	9	Residence (6)

Fig.1 General plan of the main campus of North China University of Technology

here.

1.2.3 Analysis of depth value. Depth value refers to the topological distance between a space node and another space node. Depth value is not the distance in the sense of time, but the distance in the sense of space topology. Depth value represents the convenience of a space node. The larger the depth value, the farther the distance to the next space node, and the worse the accessibility[6]. Its formula is as follows:

$$MD = \sum_i^n d_{ij}/(n-1) \quad D = \sum_i^n d_{ij} \tag{2}$$

where *MD* is depth value; *n* is the number of nodes; *D* is the minimum number of steps between nodes *i* and *j*.

According to the above formula, the depth values of 22 zones are obtained (Table 2). The depth value of east gate is the highest (3.33), followed by Zhixiu Garden (3.14), and the accessibility of the two spaces in the campus system is poor. In actual use, except for some students who have to enter the school from the gate due to class and scientific research needs, other students rarely pass through the gate, which is consistent with the spatial characteristics reflected in depth value. Integrated teaching area (1.95) and student dormitory area 2 (2.00) have lower depth values, and their spatial accessibility is better. The total depth of the campus is 53.90, the average depth is 2.45, being at a low level.

Considering the transformation needs under the continuous development of the school, the relationship between carbon emission and space syntax depth value in the material transportation stage of each area is studied based on the analysis data of depth value and the *Standard for Building Carbon Emission Calculation* (GBT 51366−2019).

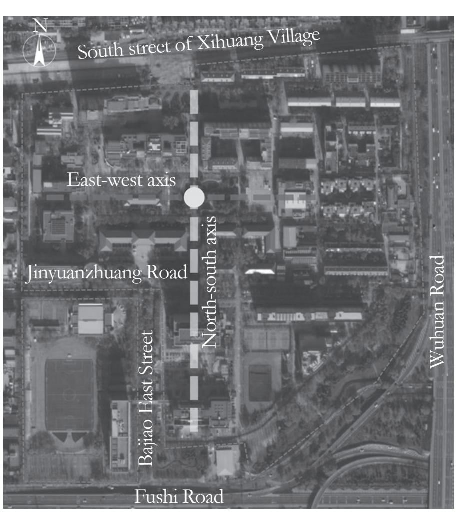


Fig.2 Satellite image of the main campus of North China University of Technology

The conclusion of this study can effectively promote the formulation of carbon reduction strategies for materials transportation in the stage of campus renovation. The formula of carbon emission in the transportation stage of building materials in the standard for carbon emission calculation is adopted:

$$C_{ys} = \sum_{i=1}^{n} M_i D_i T_i \tag{3}$$

where C_{ys} stands for carbon emission during transportation of building materials ($kgCO_2e$); M_i represents the consumption of the main building material *i* (t); D_i is the average transportation distance of building material *i* (km); T_i represents the carbon emission factor per unit weight transportation distance [$kgCO_2e/(t{\cdot}km)$][7] under the transportation mode of building material *i*.

With reference to the formula, it is assumed that in the renovation project of a certain area in the main campus of North China University of Technology, a specific means of transport and a fixed usage of building materials are used, and the smaller the average transportation distance of building materials, the smaller the carbon emission during the transportation of building materials in the campus. Considering the actual operating environment of the campus, the south gate is the import and export of large vehicles such as transport vehicles of building materials. Therefore, the south gate is taken as the node connecting the interior and exterior of material transportation, and the average distance between each area and the south gate is calculated separately (Table 2).

According to the data in Table 2, the data

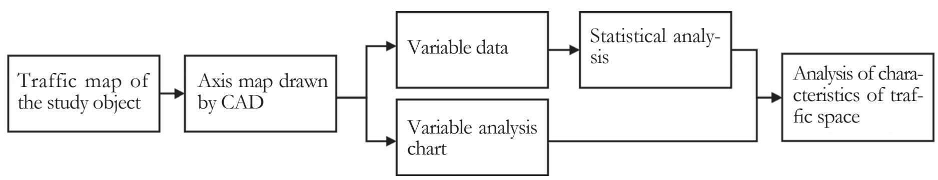


Fig.3 Process of variable analysis

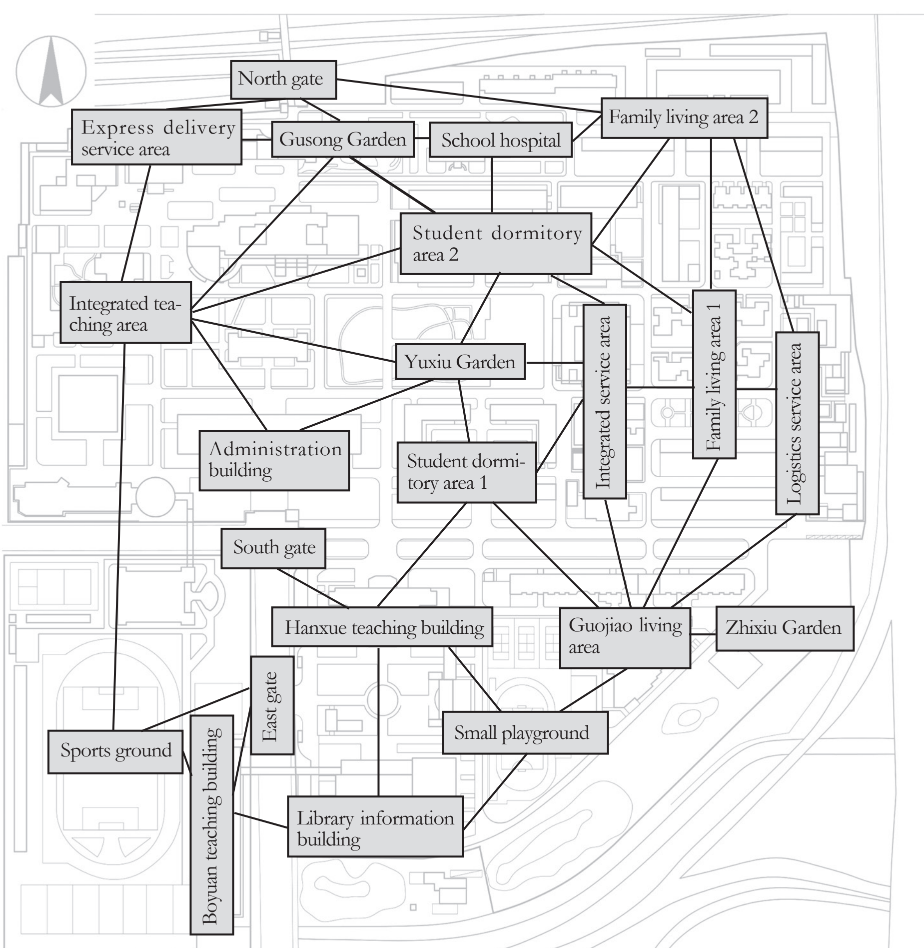


Fig.4 Simplified distribution diagram of campus nodes

chart of depth value and distance value in each area is drawn (Fig.5). Distance value is small, and the fluctuation of the chart is not obvious, so 5 is selected as the expansion coefficient to facilitate the observation of the change relationship between distance and depth values. In the figure, the changing trend of distance value is basically the same as that of depth value, reflecting a high correlation between the two. The poor coordination between the south gate and the east gate is due to the fact that the south gate is the starting point of distance calculation, and the south gate is connected to the east gate by an off-campus road. The high correlation indicates that the carbon emissions in the transportation stage of materials in the site can be predicted by the depth value of space in the campus, so the value can be used as a reference index for spatial optimization to guide the renovation and renewal of the campus.

1.2.4 Analysis of integration degree. Integration degree represents the degree of agglomeration or dispersion between a certain spatial element and other spatial elements in a spatial system, and measures the potential of a space to attract arriving traffic. The greater the degree of spatial integration, the higher the accessibility and centrality, and the easier it is to attract the flow of people[8]. According to the size of the research radius, it can be divided into global integration degree and local integration degree.

Depth Map1.0 software is used to obtain the analysis diagram of global integration degree for the main campus of North China University of Technology (Fig.6). The integration degree of red and orange roads is high, while the integration degree of green and blue roads is low. The integration degree of Fatong Road, Yulan Road, Chongde Road and Xiude Road in the campus is the highest, and these four intersecting roads are located in the core area of the school network and are the main roads inside the campus. There are a large number of roads connected with them, so they are closely connected with the surrounding space. According to the above analysis, these roads connect several areas with high control and connection values, including the integrated teaching area, Guojiao living area and student dormitory area, indicating that the spatial accessibility and permeability here are good, and it is the core area of the campus transportation system. Chongde Road is an important north-south axis in the campus, and its high integration degree is consistent with the actual importance, reflecting the rationality of space syntax as a traffic analysis tool.

In addition, the integration degree of Mingde Road, Houde Road, Huide Road, Gusong Road, and Guohuai Road is also high. Mingde Road connects all the teaching and laboratory buildings in the teaching area, and its high integration reflects its importance as a regional main road. The southeastern plot of the main campus of North China University of Technology is the development and expansion area of the school. Houde Road and Huide Road, as the main north-south roads connecting the old and new plots, well undertake the task of serving the daily needs of teachers and students, and the high value of integration degree is consistent with the actual experience. Gusong Road and Guohuai Road connect the integrated teaching area and the living areas of students and family members in the east-west direction, integrating a variety of functional spaces, and the high integration degree also reflects the characteristic.

Secondly, the integration degree of road axes within each area is middle, because most of them serve the interior of the areas, and are weakly connected with the main roads of the campus.

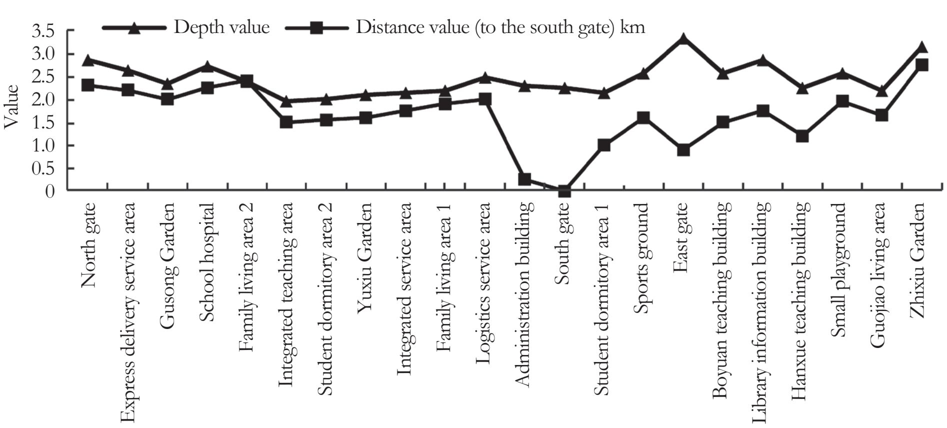


Fig.5 Changes in the depth and distance values of each region

The integration degree of roads in the peripheral areas of the campus, such as the stadium, family living area 1, logistics service area and Zhixiu

Garden, is the lowest, and they are far from the main roads of the campus and the teaching areas. The single walking route leads to poor spatial agglomeration and less pedestrian flow. In the express delivery service area, the integration degree is low, but the flow of people on weekdays is large, and the congestion phenomenon occurs when the demand of teachers and students for express service surges, which is quite different from the spatial analysis results.

According to the comprehensive analysis of the global and local integration degree (Fig.7), Yulan Road and Chongde Road both have high integration degree in the two analysis charts, indicating that the integrated teaching area and Hanxue teaching building have the highest accessibility. The number of axes with high local integration degree is larger than that of the global integration degree, because Gusong Road, Yinxing Road and Guohuai Road run through the campus from the east to the west, closely connecting the integrated teaching area with other areas. The integration degree of Fatong Road is low, showing that the interrelation between this space and the space within 3 steps away from it is weaker than that between this space and other spaces in the system, and the accessibility of local space is lower than the overall accessibility. Regions with low integration degree are similarly distributed in both graphs.

1.2.5 Analysis of intelligence degree. Intelligence degree is used to represent the correlation between global and local integration degree, reflecting the ability to perceive the overall space from the connectivity of the local space. The correlation coefficient between the two R^2 is calculated by Depth Map software. As the fitting coefficient of scatter plot function, R^2 shows the accuracy of regression line prediction trend[9]. The value of R^2 is greater than 0 and less than 1, and the larger the value, the better the degree of coordination between the global and local integration degree. After calculation, a scatter plot with the global integration degree as the X axis and the local integration degree as the Y axis is obtained (Fig.8), and the correlation coefficient $R^2 = 0.73$ (when $R^2 > 0.7$, there is a significant correlation between the horizontal and vertical axes). The analysis shows that the correlation between the local space and the whole space in the main campus of North China University

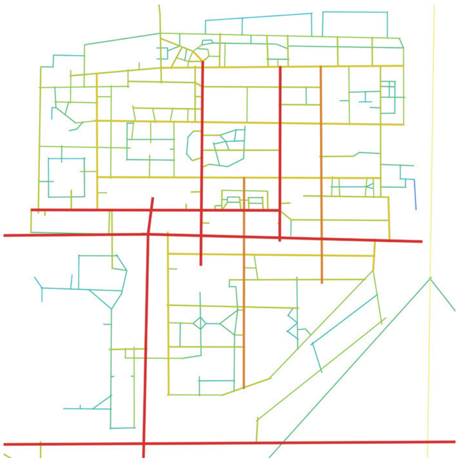


Fig.6 Global integration degree

Fig.7 Local integration degree

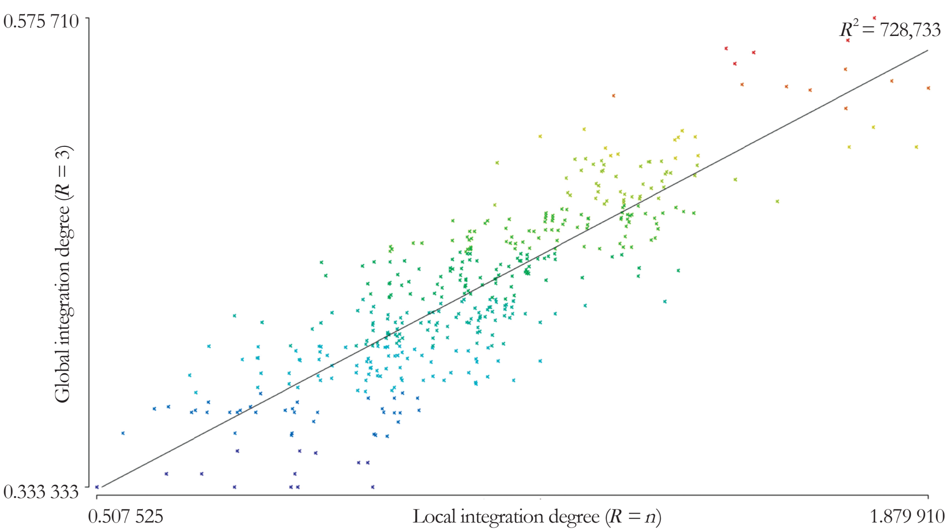


Fig.8 Intelligence degree

of Technology is high, and the road network structure of the campus is clear, and the spatial accessibility is high. higher intelligence degree can help users build a panoramic picture of the entire system and understand more information about spatial accessibility[10].

2 Evaluation and suggestions of traffic space

2.1 The connection between local spaces is weak

Seen from the whole study area, the function of space system basically meets the needs of campus space in use. However, from the integration degree, it can be seen that some regions are weakly connected. The southwest area of the school is connected to the off-campus road through an east school gate, and is only connected to the main space of the school by two bridges. The weak spatial connection leads to the low integration degree of the internal axes of the area. It reflects the relative isolation and low spatial accessibility of this area. The analysis results are basically consistent with the current use situation. In order to improve the spatial accessibility and vitality of the stadium, it can be considered to increase the transportation connection modes of adjacent areas, design one or more underground connection spaces with humanistic, landscape, architectural elements and fashion beauty, strengthen the connection between the integrated teaching area and the stadium, and facilitate people to carry out sports activities.

2.2 The design of road bearing capacity should be improved

Based on the above research, it can be found that the bearing capacity of some roads is not coordinated with the actual load. There is little difference in road grade between Yade Road, Bozhi Experimental Building East Road and Chongde Road, but Chongde Road has a huge pedestrian flow, and there will be congestion during the peak hours. The intervention of other transportation means such as bicycles further aggravates this phenomenon. In order to solve this problem, it is necessary to optimize the road grade, appropriately widening Chongde Road to improve its carrying capacity, optimize the parking space, and effectively expand the use area of slow traffic space.

2.3 The quality of local space is low

From the analysis of connection value and integration degree, it is found that the location permeability and spatial accessibility of the express service area are poor, and the accessibility of internal paths in some areas is low. Through the actual survey, it is found that students have a large demand for express delivery services, resulting in greater traffic pressure on the roads. In response to this problem, without changing the existing layout of the school, the time and route of delivery vehicles should be limited to ensure the safety of students. In addition, the spatial identification of the paths in the area with low accessibility is not strong, and the facilities are insufficient, which seriously affects the use experience. To optimize the use of leisure space, the school should build a number of iconic landscape pieces and space nodes to improve the quality of campus space and create a unique publicity card.

3 Summary

At present, there are few studies on the design and optimization of campus traffic. The purpose of this paper is to apply the quantifiable characteristics of space syntax to campus traffic, so as to explore the feasibility direction of traffic optimization. The road network system in the main campus of North China University of Technology are analyzed and studied by using space syntax theory and tools, and a new technical process is provided to analyze the spatial characteristics of road network in the campus, so as to provide theoretical basis and strategic guidance for the future optimization design of road network in the campus. The model size of the current study is limited, and the data is affected to some extent, which needs to be further optimized.

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Table 1 Connection and control values of space syntax

Functional area	Connection value	Control value
North gate	3	0.73
Express delivery service area	3	0.68
Gusong Garden	5	1.29
School hospital	3	0.54
Family living area 2	5	1.34
Integrated teaching area	7	1.71
Student dormitory area 2	7	1.48
Yuxiu Garden	5	0.90
Integrated service area	5	0.85
Family living area 1	5	1.02
Logistics service area	3	0.54
Administration building	4	0.76
South gate	4	0.76
Student dormitory area 1	6	1.24
Sports ground	3	0.98
East gate	2	0.67
Boyuan teaching building	3	1.17
Library information building	3	0.87
Hanxue teaching building	5	1.23
Small playground	3	0.68
Guojiao living area	7	2.43
Zhixiu Garden	1	0.14

Table 2 Connection, depth and distance values of different functional areas based on space syntax

Functional area	Connection value	Depth value	Distance value (to south gate)//km
North gate	3	2.86	0.46
Express delivery service area	3	2.62	0.44
Gusong Garden	5	2.33	0.40
School hospital	3	2.71	0.45
Family living area 2	5	2.38	0.48
Integrated teaching area	7	1.95	0.30
Student dormitory area 2	7	2.00	0.31
Yuxiu Garden	5	2.10	0.32
Integrated service area	5	2.14	0.35
Family living area 1	5	2.19	0.38
Logistics service area	3	2.48	0.40
Administration building	4	2.29	0.05
South gate	4	2.24	0.00
Student dormitory area 1	6	2.14	0.20
Sports ground	3	2.57	0.32
East gate	2	3.33	0.18
Boyuan teaching building	3	2.57	0.30
Library information building	3	2.86	0.35
Hanxue teaching building	5	2.24	0.24
Small playground	3	2.57	0.39
Guojiao living area	7	2.19	0.33
Zhixiu Garden	1	3.14	0.55

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