Research on the Comprehensive Development Level of Urban Metro and Underground Civil Architecture Spaces in Metro Station Areas: A Case Study of Huachengbei District

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Abstract . As urban land becomes increasingly scarce, the development of underground spaces becomes particularly crucial. Taking the Huachengbei Central Business District in Shenzhen as a case study, this research employs the Analytic Hierarchy Process (AHP) to construct indicators aimed at establishing a measurement index system for the comprehensive development level of underground spaces within metro stations and their vicinity in urban central areas. The study reveals a score of 0.5477 for the comprehensive development level of underground public spaces and urban rail transit in Shenzhen's Huachengbei Central Business District. While the individual indicators for urban rail transit, urban development, and central district development are not exceptionally high, they exhibit commendable performance, indicating that the Huachengbei Central Business District possesses certain advantages and potential in the comprehensive development of underground public spaces and urban rail transit. These research findings are expected to furnish decision-makers, urban planners, and stakeholders with information enabling them to make informed decisions aimed at enhancing the overall urban environment and quality of life.

Keywords : Underground Civil Architecture Spaces; Underground Architecture Design; Underground Spaces in Metro Station Areas; Integration

1 INTRODUCTION

The development of underground space in the era of stock planning is an important way to expand the spatial capacity of urban central districts. Compared to cities without established rail transit systems, the interaction between traffic and land in cities with rail transit is mainly connected through above-ground traffic networks. In cities with rail transit systems, urban rail transit lines and stations are generally located underground. With the improvement of urban rail transit systems, the system of underground rail transit and underground public space has become an important part of the opera-

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tional system of urban central districts. Existing research either only considers urban underground public space from the perspective of urban spatial stereopsis or treats urban underground space solely as an extension of above-ground urban space, emphasizing its role as ancillary functions. However, this does not match the increasing role of underground public space in urban central districts, especially as rail transit continues to play a larger role in relieving traffic congestion in central areas. Therefore, measuring the integrated development level of subway and station-domain underground space in urban central districts and analyzing the characteristics of coordinated development between subway and station-domain underground space can help improve the efficiency of space utilization in urban central districts.

2 LITERATURE REVIEW

Existing research on the interaction between urban rail transit and land use indicates that the impact of urban rail transit on station-area land use is mainly concentrated in land development intensity, land accessibility, land use structure, and functions[1]. The coordination relationship between complex rail transit stations and surrounding land uses is quantitatively measured through coupling coordination[2]. Within the rail transit station domain, there have been significant changes in the proportions of residential, public service, and commercial land, and due to the improvement of public accessibility by rail transit, the intensity of land development has increased, further enhancing its locational advantages and promoting the efficiency of land use[3]. Some scholars have used POI data to study the internal and external spatial vitality of rail transit and commercial spaces, finding that rail transit promotes the differentiation of surrounding commercial spaces and forms commercial hotspot areas[4]. Additionally, research on low-carbon transportation indicates that a high road network density can effectively promote residents to choose low-carbon modes of travel such as walking, cycling, and public transportation[5]. Zhe et al. (2014) proposed that in urban planning, optimizing rail transit lines and stations can enhance the connectivity and accessibility of rail transit station surroundings, and the highly accessible surrounding underground public spaces also affect the flow and capacity of rail transit networks[6]. Se-Young et al. (2005) studied Techno-mart and COEX shopping centers in Seoul, South Korea, and analyzed the impact of spatial layout on pedestrian flow and traffic volume characteristics[7]. Luo et al. (2014) studied the relationship between traffic volume generated by the Poisson distribution function and time based on the factors influencing urban commercial complexes on the traffic network[8]. F. Ma et al. (2019) introduced the perspective of traffic network centrality to explore the coordinated coupling relationship between urban rail transit and the development of surrounding plots[9]. Cities constructing rail transit are mostly those with continuous population growth, and the population in central districts will continue to agglomerate in the future. As surface space resources become increasingly precious, some cities have combined rail transit with the development of underground public space systems in urban central districts to achieve expansion. For example, in Shenzhen, where the subway system is

well-established, the concept of building an "underground city" combined with rail transit was proposed in 2017.

Existing research has predominantly focused on the collaborative development of metro station area spaces, while there has been relatively limited study on the quantification of the collaborative relationship between metro systems and their surrounding underground spaces. Therefore, by integrating the hot topics of civil engineering and urban planning design, this study proposes to take the Huachengbei Central Business District in Shenzhen as a case study to construct an indicator system for evaluating the integrated development level of metro stations and their surrounding underground spaces. Clarifying the quantitative results of these indicators is crucial for promoting the integration of underground public spaces and rail transit in urban central areas, thus achieving sustainable development in city centers.

3 RESEARCH AREA AND METHODOLOGY

3.1 Study Area

Shenzhen is one of China's major sub-provincial cities and economic special zones, serving as a global hub for technology, research, manufacturing, finance, and transportation. Located in the central part of Guangdong Province, Shenzhen is the fourth-largest city in China by population. As of the end of 2019, the urban population reached 13.374 million, making it a typical city with a multi-center system. The Huaqiangbei Central District in Shenzhen, discussed in this study, is one of the many central districts in Shenzhen, focusing on commercial and business functions. It belongs to Futian District of Shenzhen City, Guangdong Province, and is situated in the eastern part of Futian District. It is adjacent to Guifeng Street in Luohu District to the east, and borders Huafu Street to the west. To the south, it faces Shennan Road, adjacent to Nanyuan Street, while to the north, it ends at Hongli Road and Huafu Road, connecting with Yuanling Street. The area covers an area of 1.499 square kilometers within Futian District. The current land use and underground space development status in the central area are shown in Figures 1 and 2.

Fig. 1. Land use status in Huaqiangbei

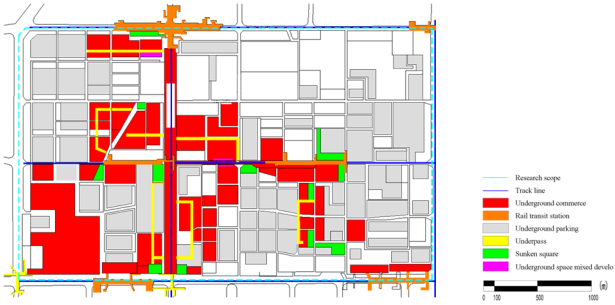

Fig. 2. Current situation of UUS

3.2 Research Methodology

Considering that this study aims to measure the collaborative development level of a single case, the Analytic Hierarchy Process (AHP) is chosen as the research method due to its effectiveness in elucidating the relationships between various indicators.The integrated development level measurement described in this study is a comprehensive measurement based on multiple indicators. It mainly involves dimensionless processing of the data obtained through mathematical and statistical analysis of each indicator, thereby obtaining dimensionless values for comparative analysis. After determining the weights of the indicators, the final measurement results of the criterion layer indicators are obtained. This allows for comparative analysis of individual city indicators and cross-city comparisons. The main steps include defining measurement objectives, determining measurement objects, establishing a measurement indicator system, determining the method of summing up indicator statistical results, determining indicator weights, dimensionless processing of indicator statistical results, and obtaining measurement results through weighted sum of indicators. This study utilizes the Analytic Hierarchy Process (AHP) for measurement, as follows:

(1)Establishing the Hierarchy Structure:

Firstly, identify the indicators to be evaluated and construct the hierarchical structure of evaluation indicators. The indicators are divided into different levels, including the objective layer, criterion layer, and scheme layer. For example, the objective layer can be the overall level of integrated development of subway and station-domain underground space, the criterion layer can be specific indicators in various aspects, and the scheme layer can be different subway stations or subway lines.

(2)Constructing Judgment Matrices:

For the relationship between the criterion layer and the scheme layer, construct pairwise comparison judgment matrices. Fill in the importance comparison values between each pair of indicators through expert surveys or expert judgment, using a scale of 1-9, where 1 indicates equal importance, 3 indicates slight importance, and 9 indicates extreme importance.

(3)Consistency Check:

Conduct a consistency check for each judgment matrix, using consistency indicators (CI) and consistency ratios (CR) to determine the consistency of expert judgments. If CR is less than a set threshold (usually 0.1), the judgment matrix is considered consistent.

(4)Calculating Weights:

Use the eigenvalue method to calculate the weights of each indicator. Normalize the weights to obtain the final weights of each indicator.

(5)Comprehensive Evaluation:

Multiply the final weights of each indicator by its scores under specific schemes to obtain the comprehensive scores.

(6)Ranking and Result Analysis:

Based on the comprehensive score results, rank each indicator and analyze the superiority and inferiority of each indicator. Analyze the final evaluation results.

4 CONSTRUCTION OF MEASUREMENT INDICATOR SYSTEM

The integrated development of underground public space and urban rail transit in urban central districts in China involves urban development, society, economy, and falls within the realm of urban construction. Indicators related to urban construction, such as the level of urban construction and urban economic development, population size, and population density, are closely related and serve as reference criteria for planners to select schemes. Combining the constituent elements of integration development summarized in the previous chapters and following principles such as independence, practicality, and operability, the indicator system is constructed. It comprises urban rail transit development indicators (D_1), urban development indicators (D_2), urban underground space development indicators (D_3), urban central district development indicators (D_4), and urban central district development indicators (D_5) as the target layer, reflecting the integrated development level of underground public space and urban rail transit in urban central districts (D). Considering that this study focuses on the integrated development level of underground public space and urban rail transit in urban central districts, the corresponding urban central district development conditions can better reflect the measurement objectives of the target layer. Therefore, after comparing and analyzing urban central district development indicators with urban development indicators, two indicators, namely urban per capita GDP and urbanization rate, identified in the correlation analysis are removed. Additionally, indicators related to ongoing rail transit lines and stations are excluded as the measurement focuses on the integrated development level of underground public space and urban rail transit in urban central districts as of 2019. Finally, the construction of the measurement indicator system includes 5 criterion layer indicators and 25 indicator layer indicators, as shown in Table 1.

Table 1. Index system

	Indicator Types	Indicator composition
The integrated development level of the subway and its station underground space in the city center area	Urban rail transit development index (D_1)	Annual average daily passenger flow D_{11}
		Number of lines in operation D_{12}
		Number of operating sites D_{13}
		Operating mileage D_{14}
		Passenger flow intensity D_{15}
	Urban development index (D_2)	Urban housing price D_{21}
		Urban population size D_{22}
		Demographic appeal D_{23}
		Intensity of human activity D_{24}
		The tertiary industry accounts for D_{25}
		Vehicle density D_{26}
	Urban underground space construction index (D3)	Development intensity of underground space in built-up area D_{31}
		Per capital underground space size D_{32}
		Social dominance rate of underground space D_{33}
		Parking underground conversion rate D_{34}
		Comprehensive utilization rate of underground space D_{35}
	urban central area development index (D4)	GDP per capital in urban area D_{41}
		Urban population density D_{42}
		Urban permanent population D_{43}
	Urban central area rail transit index (D5)	Density of urban central rail transit network D_{51}
		Station density in the central urban area D_{52}
	Urban central area construction index (D6)	Urban central area land areaD_{61}
		Urban center area built-up area D_{62}
		Scale of underground space in urban central area D_{63}
		Scale of underground public space in urban central area D_{64}

As a professional sub-center among many central districts in Shenzhen, the Huaqiangbei Central District, with its unique business and commercial functions as the core, has demonstrated the significant characteristics of the integrated development of underground public space and rail transit. First of all, from the data, it can be seen that the measurement result of the integrated development level of underground public space and rail transit in the Huaqiangbei Central District is 0.5477, indicating that the region has achieved certain results in the integration of underground space and rail transit. In terms of urban rail transit development, the measurement result of Huaqiangbei Central District is 0.5811, indicating that the area has certain foundation in the construction of subway and other rail transit. As an important mode of transportation in modern cities, urban rail transit can not only effectively alleviate the pressure of ground transportation, but also promote the rational utilization and development of urban space. By building a sound subway network, Huaqiangbei Central District provides citizens with a convenient and efficient way of travel, and also creates favorable conditions for the development and utilization of underground space. In terms of urban development, the measurement result of Huaqiangbei Central District is 0.7975, indicating that the area has a high level in the overall development of the city. As an important part of Shenzhen, Huaqiangbei Central District relies on its unique geographical location and resource advantages to attract a large number of talents, funds and technologies, and promote the rapid development of the city. At the same time, the area also actively interacts and cooperates with surrounding areas, forming a

multi-center system urban development pattern. In terms of urban underground space development, the measurement result of Huaqiangbei Central District is 0.3720, which is relatively low, but also shows the potential and space of the district in the development and utilization of underground space. With the acceleration of urbanization and the increasing tension of land resources, the development and utilization of underground space has become an important direction for urban development. As a business and commercial center in Shenzhen, the development and utilization of underground space in Huaqiangbei Central District is of great significance for enhancing urban functions and optimizing urban spatial structure. In terms of the development of the urban center, the measurement result of Huaqiangbei Central District is 0.6267, indicating that the area has certain advantages in the development of the urban center. As one of the main business and commercial districts in Shenzhen, Huaqiangbei Central District has gathered a large number of high-end industries and high-quality resources, providing strong support for the economic and social development of the city. At the same time, the area also focuses on the inheritance and innovation of urban culture, creating a series of cultural activities and brands with local characteristics.

However, in terms of urban center development, the measurement result of Huaqiangbei Central District is 0.1676, which is relatively low. This indicates that the area still faces some challenges and problems in the development process of the central area, such as the rational use of land resources, environmental protection, traffic congestion, etc. In order to further enhance the development level of Huaqiangbei Central District, it is necessary to strengthen planning guidance and policy support, promote the deep integration of underground public space and rail transportation, and achieve sustainable development of urban space.

5 MEASUREMENT RESULTS AND ANALYSIS

The measurement result of the integrated development level of underground public space and urban rail transit in Shenzhen's Huaqiangbei Central District is 0.5477. The measurement results of criterion layer indicators such as urban rail transit development, urban development, urban underground space development, urban central district development, and urban central district development are 0.5811, 0.7975, 0.3720, 0.6267, and 0.1676, respectively. Shenzhen's Huaqiangbei Central District exhibits a pattern of strong ability, low capacity, and high uniformity in the integrated development of underground public space and urban rail transit.

Regarding urban rail transit development measurement, Shenzhen operates 11 subway lines with high numbers of operating stations, mileage, and passenger flow intensity, positioning its urban rail transit development measurement at the forefront nationwide. Regarding urban development and urban central district development measurements, Shenzhen's scores in various data aspects are exceptionally high, indicating strong development momentum in urban underground space and central district development (Table 2). As for urban central district development measurement, this chapter primarily investigates the integrated development level of underground public space and urban rail transit in urban central districts. The continuous scale of under-

ground public space and its corresponding urban central district land use scale are included in the measurement indicator system. Although Shenzhen's Huaqiangbei Central District occupies a relatively small area, its various indicators rank among the top nationwide, indicating a high level of integrated development overall.

Table 2. Summary of measurement index values of integrated development level

D_1	D_{11}	D_{12}	D_{13}	D_{14}	D_{15}	——
	521.7225	11	284	410.66	1.61	——
D_2	D_{21}	D_{22}	D_{23}	D_{24}	D_{25}	D_{26}
	54790	1337.4	10.001	23.742	60.9	1719.17
D_3	D_{31}	D_{32}	D_{33}	D_{34}	D_{35}	——
	5.1	3.5	0.306	0.254	0.156	——
D_4	D_{41}	D_{42}	D_{43}	D_{44}	D_{45}	——
	299762	21140	166.29	3.66	4.00	——
D_5	D_{51}	D_{52}	D_{53}	D_{54}	——	——
	149.9	600	93.5	20.5	——	——

6 CONCLUSION AND DISCUSSION

6.1 Conclusion

This study constructed an indicator system to measure the integrated development level of underground public space and urban rail transit in Shenzhen's Huaqiangbei Central District. The specific conclusions are as follows:

(1) The integrated development level of underground public space and urban rail transit in Shenzhen's Huaqiangbei Central District scored 0.5477. Although not exceptionally high, criterion layer indicators such as urban rail transit, urban development, and urban central district development performed well, indicating that Huaqiangbei Central District has certain advantages and potential in the integrated development of underground public space and urban rail transit.

(2) In terms of urban rail transit development, Shenzhen's subway lines, operating stations, mileage, and passenger flow intensity rank at the forefront nationwide, reflecting Shenzhen's leading position in urban rail transit.

(3) Regarding urban development and urban central district development, Shenzhen's scores in various data aspects are high, indicating that the urban development and central district development levels are relatively good, providing a solid foundation for the integrated development of underground public space and urban rail transit.

(4) Although Huaqiangbei Central District's underground public space occupies a small area, its other indicators rank among the top nationwide, indicating a high overall level of integrated development. This demonstrates that Huaqiangbei Central District maximizes the potential of underground space within its limited area, complementing the development of the urban central district.

6.2 Discussion

Furthermore, based on the results of this study, several suggestions can be proposed for future research directions and practical applications. Firstly, further exploration into the specific factors driving the comprehensive development of underground spaces within metro stations and their vicinity could provide deeper insights into optimizing urban infrastructure and transportation systems. Secondly, considering the increasing importance of underground spaces in urban development, there is a need for more comprehensive studies on the integration of urban planning, civil engineering, and transportation management to maximize the utilization of underground spaces while ensuring sustainable development. Lastly, practical applications could involve incorporating the findings of this research into urban planning and infrastructure projects, particularly in areas facing similar challenges of urbanization and limited land resources. Implementing strategies to enhance the integration of underground public spaces and rail transit systems can significantly contribute to creating more sustainable and livable urban environments. Overall, the findings of this study not only shed light on the specific case of the Huachengbei Central Business District but also offer valuable guidance and inspiration for future research endeavors and practical initiatives aimed at advancing urban development and sustainability.

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REFERENCES

1. Handy S .Smart Growth and the Transportation-Land Use Connection: What Does the Research Tell Us?[J].International Regional Science Review, 2005, 28(2):146-167.
2. Choi J , Lee Y J , Kim T ,et al.An analysis of Metro ridership at the station-to-station level in Seoul[J].Transportation, 2012, 39(3):705-722.
3. John,Florida Atlantic University Renne.Transit-oriented development and ports: A national analysis in the United States[J].Journal of Transport & Land Use, 2018, 11(1).
4. Turner V K. The environmental consequences of residential land tenure in single family neighborhoods[J]. Land Use Policy, 2022, 114: 105959.
5. Kaza N. Urban form and transportation energy consumption[J]. Energy Policy, 2020, 136: 111049.
6. Zhe Lin,Byung-Joon Song,Beom Chu. Analysis of Trend on the Planning Characteristics of Internal Streets within Mixed-use Commercial Complexes - Focused on the Mixed-use

Commercial Complexes in Seoul City -[J]. Korean Institute of Interior Design, 2014, 23(4): 211-219.
7. Song s y Song-B-H. A study on visitors' circulation pattern and amount of traffic in the multi-purpose commercial complex[J]. Korean Institute of Interior Design Journal, 2005, 14(5): 236-244.
8. Luo Y L, Zhang C X. Basic Methods of Peak-Hour Traffic Generation Forecast about Urban Commercial Complex[J]. Applied Mechanics and Materials, 2014, 488: 1400-1404.
9. Ma F, Ren F, Yuen K F, et al. The spatial coupling effect between urban public transport and commercial complexes: A network centrality perspective[J]. Sustainable Cities and Society, 2019, 50: 101645.