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RESEARCH ON UNDERGROUND SPACE LMAGE AND PRACTICE OF THREE-DIMENSIONAL URBAN DESIGN

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Abstract: Underground spaces exhibit distinct spatial and organizational characteristics compared to above-ground environments, leading to significant differences in human perception, cognition, and urban image elements. Building upon Kevin Lynch's foundational theory on urban image, which highlights subway stations as key examples of urban separation with conceptual connections to the surface, this research investigates the urban image of underground spaces. The study employs a mixed-methodology approach, utilizing structured interviews and cognitive map drawing exercises within two established underground complexes in Guangzhou: Huacheng Square and Tianhe business district. This primary data collection is further informed by emerging techniques in 3D reconstruction of underground structures, which aid in characterizing the unique elements of the underground urban image. The research comprehensively summarizes the defining features of these elements and delves into their organizational principles. Furthermore, it explores the integrated spatial image organization between above-ground and underground spaces. Based on this analysis, the study proposes formative principles for organizing underground spatial forms and for three-dimensional urban spatial organization that synthesizes above-ground and underground image elements. These principles are intended to serve as fundamental methods for underground space planning and city design. The practical application and validity of these proposed principles have been tested and demonstrated through implementation in the Xi'an Port District urban design project.

Keywords: Underground space, Image, Three-dimensional Urban Design, Spatial form

1. INTRODUCTION

Underground spaces are characterized by relative enclosure, artificial interior architecture, and vertically layered structures. The separation between above-ground and underground spaces, insufficient indoor lighting, and visual obstruction from building structures all limit human field of vision, making the perceptible elements in underground spaces far fewer than those above ground, lacking abundant image-supporting elements.

At the same time, the various functions of underground space must be organized on different vertical levels. Coupled with modern cities that coordinate above-ground and underground spaces connected to urban rail transit stations, people's cognition of space must shift from the two-dimensional characteristics of ground space to a more complex and less readily understood three-dimensional space that combines horizontal and vertical features[4] .

Kevin Lynch's "The Image of the City" already noted that underground spaces such as subway stations are a significant case of city separation, and they have intangible, conceptual connections with the surface (Kevin Lynch, 2001）. However, because of the particular spatial characteristics of underground spaces, they are quite different from the above-ground spaces in spatial perception and cognition and possess unique image characteristics.

This research on urban underground space image builds on Kevin Lynch's pioneering studies and uses the method of interviews plus drawing cognitive maps on actual, constructed underground space cases, to summarize in depth the characteristics of each image element in the urban underground space, to study the organization of these elements and their above-below three-dimensional spatial image organization, and to propose certain principles for underground spatial form and three-dimensional city spatial organization. These can serve as basic

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methods and theories for underground space planning and three-dimensional city design, and have been further applied in the urban designs of Xi'an Port Area and the southern area of Guangzhou Pazhou.

2. METHODS

2.1. The cognitive mapping approach

The study was conducted through in-depth, semi-structured interviews where participants were actively engaged in drawing their mental maps of the underground spaces. This method directly draws inspiration from Kevin Lynch's technique in The Image of the City, where residents were asked to sketch their mental images of the urban environment to identify key elements like paths, edges, districts, nodes, and landmarks. In this study, each combined interview and mapping session lasted approximately 30 minutes, resulting in a collection of 40 cognitive maps. This qualitative technique allowed researchers to gain a deep, nuanced understanding of how different user groups perceive, navigate, and remember the spatial layout and defining features of the underground environment, effectively capturing the legibility and imageability of the space as per Lynch's framework.

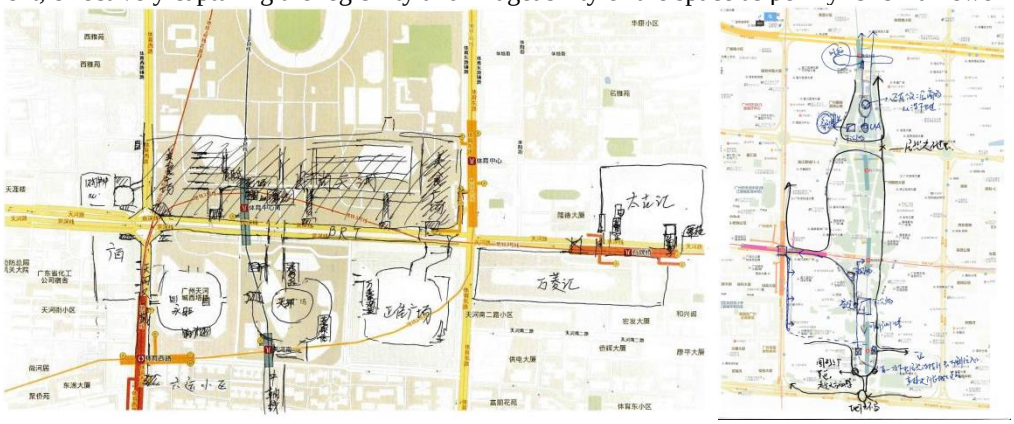

Figure 1. *Cognitive Map Drawings from the Research*

2.2. Questionnaire Survey

The questionnaire survey was developed and deployed as a complementary quantitative tool to validate and generalize the findings from the in-depth cognitive mapping exercises. Following Lynch's principle of gathering diverse public perceptions, the survey, distributed to 302 respondents, was specifically designed based on preliminary insights from the interviews. It aimed to systematically investigate public attitudes, usage patterns, and behavioral characteristics within the underground space. The questions ranged from eliciting first impressions and usage scenarios to probing wayfinding strategies and the recall of memorable spatial elements, effectively translating Lynch's qualitative focus into a structured format to quantify the presence and strength of imageability elements and spatial experiences on a broader scale

3. CASE ANALYSIS

3.1. Case Selection and Investigation

This case study selects two cases: Huacheng Square ,and the Tianhe business district. Huacheng Square is located in the central area of the Zhujiang New Town CBD in Guangzhou. It was completed and put into use in 2010. The ground level consists of a plaza and park, while the underground area is an integrated complex featuring commercial, transportation, municipal, and parking functions. It connects multiple land parcels around the square as well as the metro station, forming a relatively complex underground space network system. The underground space in the Tianhe business district is a network system gradually formed by multiple projects constructed at different times over the past two decades.

Both cases are of a certain scale, with comparable overall size, and have formed sizable urban underground space systems, making them highly representative for research on urban underground space image.

3.2. Roads and Nodes: The Framework of Underground Imagery

The cognitive maps were classified by the main shape elements into three types: point + line, surface, and composite (Table 1). It can be seen that the number of "point + line" elements is much higher; these mainly depict frequently traveled routes, enabling certain descriptions along the way, which to a certain extent is related to the dominant function of underground space for transportation. Respondents who drew "surface" maps are more familiar with the underground space and generally understand its spatial structure. Respondents who drew "composite" maps are extremely familiar with the underground space, clearly comprehending the overall structure, not only the framework of underground paths and nodes but also descriptions of areas and rich memories of various landmarks, and can even accurately correspond them to the surface spaces above.

Table 1. *Statistics on Types of Cognitive Map Shapes*

Case	Point + line type	Surface type	Composite type
Huacheng Square	14	4	2
Tianhe Business District	10	6	4

3.3. From Local to Global: Cognitive Formation of Imagery

By analyzing the integrity of the underground space depicted on the cognitive maps, three levels were identified (Table 2): overall completeness, many local parts, and few local parts. The two cases displayed different features. In Huacheng Square, underground space is divided into three weakly connected zones, resulting in cognitive maps characterized mainly by many local areas; whereas in the Tianhe Business District underground space, the presence of many nodal spaces and a simple vertical correspondence led to more overall cognitive maps.

Table 2. *Analysis of Cognitive Map Integrity*

Case	Few local parts	Many local parts	Overall completeness
Huacheng Square	12	7	2
Tianhe Business District	3	8	9

3.4. Underground Image Tied to Above-ground Elements

Almost all respondents marked a number of above-ground spatial elements, indicating that ground space image elements play a key role in the cognition of underground spaces (Table 3). Most respondents habitually correspond underground space image elements to surface space, and use the ground image as reference and coordinate to organize underground space imagery, with only a few cases where underground space is used as the base for organizing the above-ground spatial image.

Table 3. *Number of Surface Spatial Elements*

Case	Few (<3)	Moderate (4-8)	Many (>8)
Huacheng Square Underground Space	2	12	6
Tianhe Business District Underground Space	2	7	11

4. DISCUSSION

4.1. Distinct Characteristics of Underground Space Image Elements Compared to Above-Ground

Compared to Kevin Lynch's established elements of above-ground urban imagery (paths, edges, districts, nodes, landmarks), underground space imagery exhibits distinct characteristics due to its enclosed, interior nature. Paths are the dominant skeletal element in underground cognition, requiring exceptionally high clarity and

continuity in both plan and vertical connections to compensate for the loss of natural orientation cues. Nodes, such as subway stations and sunken plazas, become critically strategic focal points, often possessing landmark qualities and serving as vital integration points connecting the underground with the above-ground world. Districts are primarily perceived through internal thematic differentiation rather than clear physical boundaries. Edges are often virtual or perceived rather than physically distinct, and their permeation is crucial for wayfinding. Landmarks are rare in a traditional, monumental sense; instead, their function is fulfilled by memorable nodes or relies heavily on intensified artistic and cultural elements and signage systems to aid navigation in the homogeneous environment. This underscores that underground space imagery is more dependent on intentional design for legibility compared to the above-ground.

4.2. Paths: The Skeletal Framework with Heightened Continuity Requirements

Paths serve as the dominant element in structuring underground space imagery, forming the fundamental framework for cognitive maps. Unlike above-ground networks, these paths demand heightened continuity—both planar and vertical—to compensate for limited orientation cues. Breaks in vertical connectivity significantly impair wayfinding, as observed in complex underground transitions where disorientation frequently occurs.

Underground paths are cognitively simplified into straight-line connections between clearly defined origins and destinations, such as subway stations.（He Ye, 2015） This mental compression mirrors schematic subway maps, where complex routes are reduced to direct lines. The necessity of unambiguous start and end points further distinguishes underground path perception from the more networked understanding of surface roads.

4.3. Nodes: Strategic Focal Points and Integration Hubs

Nodes function as strategic focal points and integration hubs within underground space imagery, serving as the second most dominant element after paths. Typical nodes—such as subway stations, sunken plazas, and atriums—play a more prominent role underground than above ground due to the limited visual references. At the macro level, metro stations often structure the city's image for passengers and act as catalysts for urban development through concepts like TOD. At the micro level, key nodes help users organize mental maps and form the structural framework of complex underground areas.

Underground nodes frequently exhibit landmark qualities by offering volumetric contrast or functional significance within homogeneous environments. They also act as critical interfaces connecting above-ground and underground imagery, enabling vertical spatial integration. When a node is recognizable both above and below ground, it significantly enhances overall spatial continuity and supports cohesive wayfinding across levels.

4.4. Region: Thematic Zones with Weak Physical Boundaries

Regions in underground spaces are primarily defined by thematic features—such as architectural style, commercial character, or visual themes—rather than physical boundaries. Perceived from within, these areas rely on strong internal uniformity and repetitive spatial characteristics to enhance recognizability and provide a sense of direction (Li Wei et al, 2011). Examples include zoning in underground shopping malls or parking areas where different sections are distinguished by thematic elements rather than structural divisions.

Vertical stratification plays a critical role in organizing underground regions, both in relation to above-ground spaces and within multi-level underground structures (Liang Yu, 2013). Functional differentiation across levels necessitates intentional visual or nodal connections—such as atriums, elevators, or consistent signage—to maintain spatial continuity and prevent cognitive fragmentation between layers.

4.5. Boundaries: Thematic Zones with Weak Physical Boundaries

Boundaries in underground spaces are predominantly perceptual rather than physical, emerging as transitions in materials, lighting, or spatial scale rather than as tangible linear or surface-like separators. These boundaries are often inconsistent with structural or engineering limits and are sensed more subtly compared to above-ground contexts, where edges tend to be visually explicit and geographically defined.

To form a coherent and imageable spatial system, underground boundaries must be visually or functionally dissolved. Physical or visual continuity—achieved through shared elements like atriums, aligned pathways, or natural lighting—can integrate adjacent areas, weaken the perception of separation, and enhance wayfinding. Successful boundary treatments thus prioritize permeability and interconnection, transforming conventional divisions into opportunities for spatial fluency and place-making.

4.6. Landmarks: Rarely Physical, Often Cultural or Nodal

Landmarks in underground spaces demand intentional reinforcement due to the lack of natural visual cues and spatial homogeneity. It is difficult to establish large-scale physical landmarks; instead, distinctive nodes with volumetric contrast or those enhanced through cultural, artistic, or architectural treatments often assume landmark roles. These elements provide crucial visual anchors and support spatial identity in an otherwise uniform environment.

Signage systems serve as essential artificial landmarks, especially for new users who rely on them for primary navigation (Guo Mei, 2012). As users become familiar with the space, they depend more on path-based features and internal imagery, using signage mainly for ambiguity resolution or confirmation. Thus, an effective landmark system combines clear signage with designed spatial features to strengthen overall imageability.

5. RESULT

5.1. Organizing Imageability and Spatial Framework through "Path" Elements

Design and organization of underground paths are fundamental for spatial form in underground spaces. Underground roads, while serving their traffic function, should also have clear directionality, continuity, starting, and ending points. For urban underground space networks, a simple underground road structure and spatial form will help simplify imageability elements in the mind, enabling clearer mental images. This is particularly vital in underground spaces with almost no external references; the comparison between the readability of the Huacheng Square and Tianhe underground spaces serves as a clear example.

5.2. Strengthening the Imageability of "Node" Elements

First, further emphasizing the start and endpoints of underground roads as imageable spatial nodes will enhance the overall imageability of underground space. Second, reinforcing nodes that connect to the above-ground space—often realized with sunken plazas or skylights—can create a strong sense of place. Third, strategically creating spatial node elements with landmark features, particularly those with significant changes in spatial scale, often form the core of underground spatial organization, with key underground roads connecting to them, resulting in a clearly imageable radial underground network spreading out from the center.

5.3. Organizing Other Imageability Elements Based on "Path + Node"

Underground roads can use themed boundary features to create underground regions with different themes, which further enhances the sense of orientation, scale, and measurability in the space.

The connection between two underground regions can further break the constraints of underground boundaries; the joining surfaces can enhance interpenetration between the two regions and even form underground spatial nodes, further improving the imageability of underground road connections.

For underground landmarks, in addition to improved signage systems, commercial and service facilities can further enrich boundary element features. Moreover, since underground landmarks have distinctive scale characteristics, aspects of culture, art, and creativity should also be considered and synergistically enhanced with spatial node elements.

6. PRACTICAL IMPLEMENTATION

The research findings on underground space planning theories have been applied in the urban design of the Xi’an Port District urban design project. The Project is situated in the Xi'an International Trade & Logistics Park (Xi'an Port Area), a nationally significant modern logistics and international trade hub in western China. Located in the northeastern part of Xi'an,

6.1. Creating a Vertically Integrated Urban Vitality Corridor along the Central Axis:

Along the central axis, create a three-dimensional urban park vitality zone consisting of a ground waterfront slow-moving lane, a slow-moving lane on the first underground floor, and an underground rail transit on the second underground floor, with transportation, recreation, and comprehensive service functions as the main features.

The design centers on three major public transport hub cores: Tiyu Zhongxin Station, Shuangzhai Station, and Gangwu Avenue Station. Additionally, a hierarchical node system is implemented: larger three-dimensional park nodesare formed at the center of each 800m×800m block, while smaller internal spatial nodesare created within every 300m×400m block. These nodes are interconnected through the central axis and a public underground space system, forming a cohesive and continuous urban public spatial network.

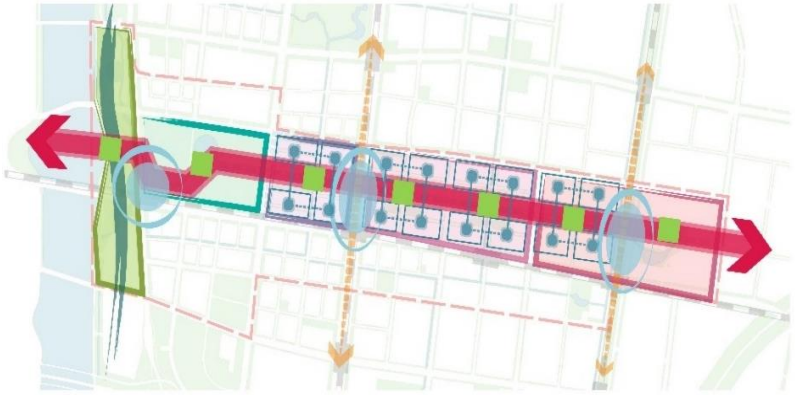

Figure 2. *Connections between blocks.* （*Drawn by the author*）

Through the sunken square, sunken courtyard, evacuation stairs and vertical transportation facilities, convenient connection between the ground and underground is achieved. The second-floor platform is connected with the central square, the overhead subway station and the surrounding buildings to form a whole. Provide convenient and fast walking space for pedestrians. The ground pedestrian system combines the road's slow lane and the waterfront slow lane as the main slow lane, focusing on creating a landscape environment and creating a relaxed and casual walking atmosphere. The public underground pedestrian passage is straightened as much as possible, with a single main passage forming the skeleton and secondary passages to complete the network, and at the same time connect with the subway and development plots.

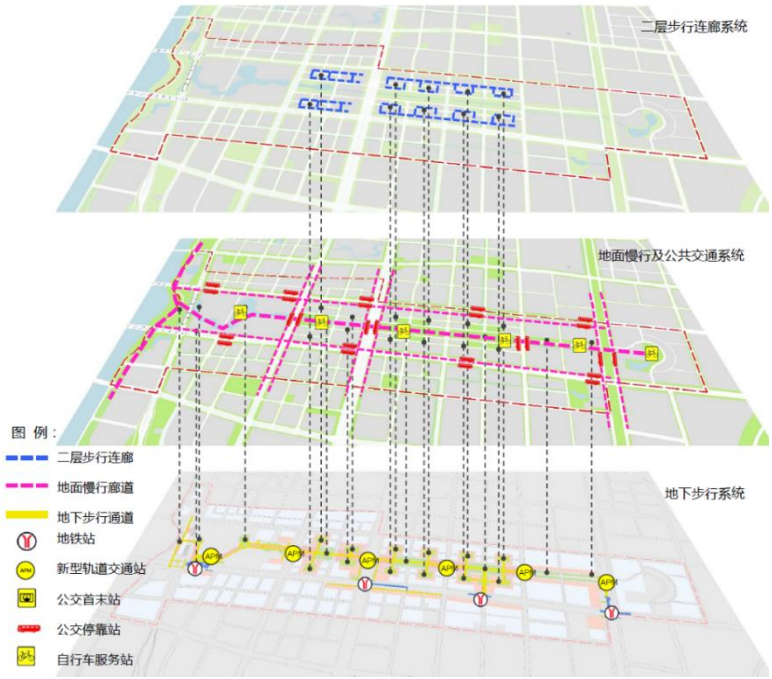

Figure 3. *Diagram of the connection between the underground pedestrian system and the ground level* （*Drawn by the author*）

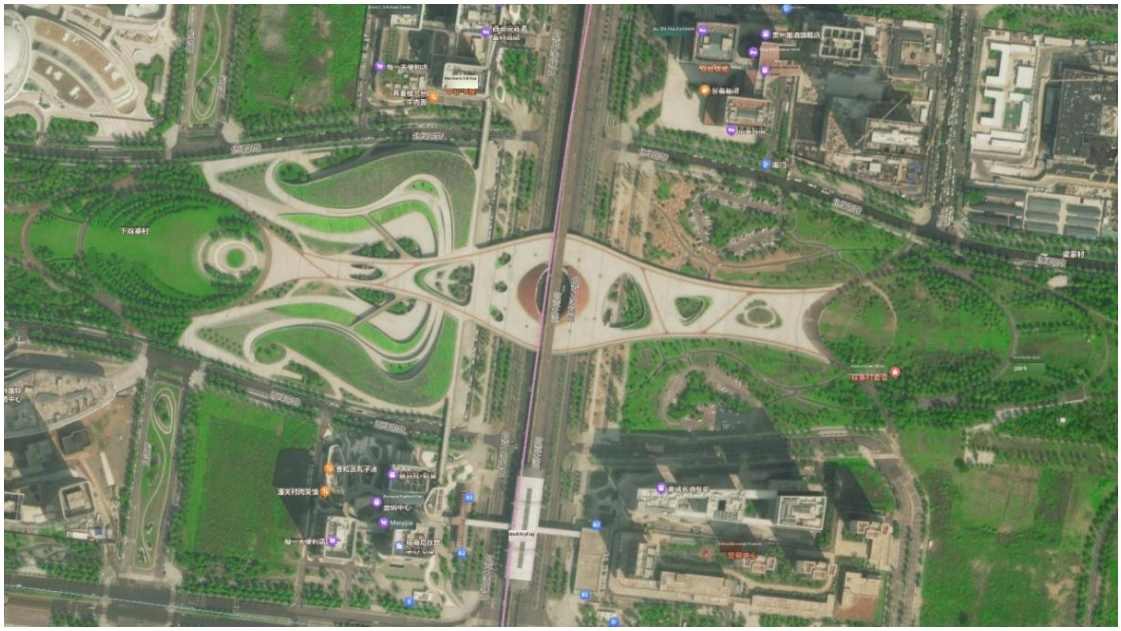

Figure 4. *Satellite imagery （https://map.baidu.com/）*

6.2. Create nodes and landmarks with distinctive regional characteristics.

At important nodes, the integration of above-ground and underground public spaces is achieved through the organization of two image elements, landmarks and nodes, in three-dimensional space. For example, at the Olympic Sports Center Station in the Port Authority District, based on the principle of three-dimensional urban image organization, an underground distribution hall is set up at the location of the underground passage from the subway station to the Olympic Sports Center, and the hall is treated with a glass roof that can be illuminated. Citizens can see the Olympic Sports Center building through the lighting roof on the first floor below, which can quickly identify the space and effectively integrate the above-ground and underground spaces. This principle has been fully implemented in the subsequent engineering design and implementation, and has now been completed, as shown in the satellite image.

Figure 5. *Renderings of the sunken square （Drawn by the author）*

Figure 6. *Figure7. Satellite imagery （https://map.baidu.com/）*

7. CONCLUSION

Influenced by the special underground space environment and cognitive mode, the image elements of underground space have their own unique characteristics compared with the image elements on the ground, and there are also certain particularities in the relationship and organization of the image elements. Organizing the image of underground space in combination with the characteristics and relationship of the image elements of underground space is an important principle of underground space morphology organization.

At the same time, the ground space image is an integral part of the city image, and the ground space is also an important reference for the underground space image. There are many connections between the underground space image elements and the ground image. How to deal with the connection between the ground and underground image elements is an important design principle for achieving the integration of urban space.

With the rapid growth of urban underground space construction, the connection between underground space construction and urban ground construction is expanding and strengthening, showing a trend of mutual penetration and mutual influence. It is necessary to change the current situation that urban design only focuses on ground space form. The results of this study can be used as an important principle and method for the organization of urban underground space form and the organization of the overall urban space form, further guiding the development of urban underground space and three-dimensional cities.

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