Study on Implementation Strategies of Multifunctional Linear Underground Space: A Case Study in Beijing’s sub-center

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Abstract. DEVELOPMENT CONTROL PLAN FOR THE SUB-CENTER OF BEIJING (2016-2035) says, a facility service ring with complex functions, balanced layout and integrated above ground and underground space will be constructed, which is efficient integrated underground infrastructure, with a total length of about 36.5 kilometers, coordinating the construction of circular underground systems such as subway, utility tunnel, urban underground logistics, and automatic garbage collection and transfer, and jointly building municipal facilities such as hidden municipal facilities, multi-level rainwater control and utilization facilities, emergency evacuation facilities, underground peak-storage and peak-regulation facilities. Aiming at the feasibility of the project, though analyzing in detail the present situation and planning of land use, pipeline and underground space along the ring and surrounding areas, and fully sorting out the functions and space demand characteristics of the major systems in the facility service ring, deeply explore the advanced technologies such as urban underground logistics and automatic garbage collection and transfer, and propose the inclusive and multifunctional underground space implementation strategies, for the meticulous use of underground space.

1. Introduction
DEVELOPMENT CONTROL PLAN FOR THE SUB-CENTER OF BEIJING (2016-2035) says, a facility service ring meets the international cutting-edge technology level, demonstrates the independent innovation capabilities of Chinese manufacturing, and reflects people’s happiness. It is the core basic framework of sustainable urban development, with a total length of about 36.5 kilometers. We will coordinate the construction of circular underground systems such as subway, utility tunnel, urban underground logistics, and automatic garbage collection and transfer, and jointly build municipal facilities such as hidden municipal facilities, multi-level rainwater control and utilization facilities, emergency evacuation facilities, underground peak-storage and peak-regulation facilities.

At present, the relevant plans for the facility service ring are all at a macro level, which is not very guiding for project construction. With the active advancement of the planning and construction of the sub-center, project approval and engineering construction are proceeded in an orderly manner. However the planning and construction of the facility service ring is relatively lagging. Considering complex functions, spatial integration, and huge volume, we urgently need to conduct meso-level research on the facility service ring, to delimit the scope of space control, to propose implementation strategies and to provide technical support for project implementation.
2. Analysis of space requirements and implementation strategies of major systems

2.1. Subway
Figure 2.1 is the planning drawing of the rail transit line of the Beijing Sub-center. The rail transit network in the sub-center is multi-level and high-density system which is called "Circle + Radiation". Metro Line 102 is an important part of the "Circle Line". It is a skeleton line which can transfer to 13 urban rail lines at multiple points. It will help to improve regional comprehensive traffic carrying capacity, and to relieve Beijing of functions nonessential to its role as the nation’s capital. It will be built to realize the direct connection service of the north-south rail in the new and old urban as an important corridor for interconnection.

In order to clarify the management and control requirements of subway, we sorted out relevant standards, specifications, management regulations, safety regulations, etc., and analyzed the horizontal and vertical positions of Metro Line 102 (Figure 2.2, Figure 2.3). Full consideration should be given to the interactive transfer between subway and public transportation, bicycle, pedestrian and other transportation modes. Subway stations should be set to integrate with surrounding land, and the space should be arranged to put people first. The safety issues such as civil air defense, collision avoidance, and sight blocking should be fully demonstrated as the setting of the Sunshine Hall.

2.2. Urban underground logistics
Relying on the intelligent automated logistics system of the sub-center, a loop trunk line system of urban underground logistics which will be built to connect to the whole logistics network. The loop trunk line of underground logistics will use the subway loop. Passenger and freight share the track. It
will effectively alleviate traffic congestion and improve the environment. Building underground logistics with subway can save energy and land to realize efficient and green cargo transportation in the sub-center.

Using survey data, such as "Beijing Statistical Yearbook", we subdivided the types of goods to be transported, and calculated the volume of goods suitable for underground transportation and the capacity of the means of transport. The fuzzy C-means algorithm (FCMA) was used to optimize the location of the group distribution center and determine the logistics end center. In order to ensure that the underground logistics system relying on subway does not affect the normal operation of rail transit, we communicated with typical domestic logistics companies (China Post, SF Express, JDL Express, etc.), and forecasted the land occupation of logistics facilities such as distribution centers and logistics stations. Unifying standards for classification, packaging, loading and unloading, transportation, etc. will help to realize automation, standardization, and intensification, therefore to improve efficiency.

2.3. Utility tunnel
The utility tunnel is an underground structure and auxiliary facilities built in the city underground to accommodate two or more municipal pipelines. The subway and utility tunnel are both underground projects, and their cooperative construction is the direction that major cities have explored in recent years.

It is advisable to give full play to the advantages of the utility tunnel in the connection of the municipal trunk line system, the municipal connection of service construction projects, and the concentrated crossing of important nodes. Considering the irreversibility of underground engineering, the utility tunnel constructed with other underground projects should be implemented at the same time or pre-embedded.

2.4. Automatic garbage collection and transfer
After more than 70 years of development in pneumatic waste collection technology, more than 2,600 systems have been built and operated all over the world. Automatic garbage collection and transfer system is a whole process system of collection, transfer and treatment. In the sub-center, combined with underground subway lines, relying on some subway stations to set up garbage transfer platforms, adopt the time-shifting peak mode to build a new garbage transfer system.

We deeply cultivated mature domestic and foreign cases of automatic garbage collection and transfer, and explored their service areas, construction backgrounds, operation situations, etc. The result shows that, there is no engineering example at urban large spatial scale, and the service area of the current cases is small (generally less than 10 square kilometers).

Therefore, some pilot projects should be carried out to evaluate efficiency and economy. It should be divided into trunk lines, branch lines, etc. The trunk line system should be considered as a whole with the urban waste transfer system, the branch line system should be considered as a whole with the regional logistics distribution system, and the terminal should be connected with the pneumatic waste transportation system.

At the same time, the connection with the existing garbage transfer and treatment facilities should be considered during the transition period. After implementation, emergency measures should be sufficient to ensure the stable operation of the garbage collection and transfer system.

2.5. Multi-level rainwater control and utilization
The multi-level rainwater control and utilization system is composed of multiple systems of source control, midway transfer and end discharge. Establishing a sustainable rainwater control and utilization system is a requirement for building a conservation-oriented society and water-saving city.

Facilities of the multi-level rainwater control and utilization system such as low elevation greenbelt, green building, rainwater reservoir, etc. can be implemented independently. The multi-level rainwater control and utilization system should be coordinated with flood control and drainage planning, green space system planning, river and lake water system planning, etc., and compatible with sponge city
construction. In addition, shallow rainwater collection facilities should be built as soon as possible in conjunction with the development and construction sequence; deep rainwater tunnel can be constructed separately and implemented in stages using shield tunneling and other technologies.

2.6. Hidden municipal facilities
Hidden municipal facilities refer to the highly standardized, underground, and composite construction of municipal facilities, so that the traditional municipal NIMBY (not in my back yard) facilities, such as sewage treatment plants, garbage transfer stations, garbage disposal sites, and substations, have become ecological positive assets.

At present, the construction methods for the underground construction of municipal facilities have become increasingly mature, and the rapid development of underground excavation technology and underground construction technology can support the construction of underground facilities. The study proposed that hidden municipal facilities can be implemented independently as the project progresses. By studying the characteristics of different municipal facilities, water facilities, power facilities, and closed garbage collection stations should be installed underground, and gas facilities can be installed underground against actual conditions.

2.7. Emergency evacuation facilities
The urban emergency support system includes disaster prevention facilities, emergency support infrastructure and emergency service facilities.

To further improve the disaster prevention system, we proposed to establish a three-dimensional emergency shelter system, by incorporating some subway stations as emergency shelters, which is called "scattered point layout". The platform layer of subway station without sunshine hall can be used as emergency shelters, and the station with sunshine hall should be combined with the surrounding green square to increase emergency shelter.

2.8. Underground peak-storage and peak-regulation facilities
The underground peak-storage and peak-regulation facilities combine the energy storage system with the development and utilization of underground space to realize the unified planning, integrated design, standardized construction and professional management of regional cooling, heating, and power supply. They will help to solve the problems of the utilization of peak and valley electricity and waste heat, and to promote the efficient coupling application of multiple energy systems.

Relying on regional energy stations, the underground peak-storage and peak-regulation facilities can be implemented independently, with a scattered point layout model. It is planned to set up energy supply centers in cluster centers, large public buildings and other nodes with high energy demand around the facility service ring. The energy supply centers should be set as close as possible to the ring, so that their energy supply radiate to the surrounding blocks.

3. Delineation of Control Area
Linear municipal and transportation infrastructure such as municipal pipelines, utility tunnel, and subway are basically located under urban roads, and infrastructure and public security facilities can also be arranged in conjunction with rivers, green space and other public land.

In addition to the spatial control of the facility service ring, it is also necessary to consider the connection between the construction land on both sides of the facility service ring and itself to provide better infrastructure services for the city.

Based on the above analysis, we took municipal pipelines, utility tunnel, subway and other linear municipal and transportation infrastructure as the framework, roads, rivers, green space and other suitable public land as supplements, and considered the connection between the construction land and the facility service ring as well. In the end, two-level control area of the facility service ring were comprehensively determined. The first-level control area emphasized control, and the second-level control area emphasized integration.
3.1. The first-level control area

3.1.1. Urban roads where the facility service ring is located and the green belts on both sides of the roads along the route (Figure 3.1).

3.1.2. The intersecting roads where the subway stations are located and the green belts on both sides of the roads. Metro Line 102 has a transfer station at the intersection as shown in the Figure 3.2. The intersecting road and the green belts on both sides of the road are designated as the first-level control area.

3.1.3. At the intersection of the facility service ring and rivers, railways, expressways and above-level urban roads, extend 30 meters along both sides of the facility service ring. As shown in Figure 3.3, when municipal pipelines and other infrastructures pass through important nodes, in order to avoid bridges, culverts and other structures, the municipal pipelines need to be routed to both sides. Therefore, in case of such nodes, extend 30 meters along each side of the facility service ring.
3.1.4. **Area on both sides of the facility service ring which can be used as free space.** If the road where the facility service ring is located is the current road, the current pipelines under the road need to be relocated when the facility service ring will be implemented.

As shown in Figure 3.4, the adjacent planned road on the west side of the current road has not been implemented, so it can be used as a space for the existing pipelines to be moved before the implementation of the facility service ring. Therefore, the planned road on the west side is included in the first-level control area.

![Figure 3.4 Schematic diagram of area on both sides of the facility service ring which can be used as free space](image)

In summary, the first-level control area of the facility service ring is shown in Figure 3.5. It is required that the above-ground and underground projects within the scope of first-level control area need to be considered as a whole, and the projects that cannot be implemented at the same time need to be reserved or pre-buried. The integrated construction of above and underground spaces is emphasized in the first-level control area.

![Figure 3.5 Schematic diagram of the first-level control area of the facility service ring](image)

3.2. **The second-level control area**

In order to sort out and analyze comprehensively, we expanded the scope of research as shown in Figure 3.6, and conducted a cross-comparative analysis of characteristics for factors such as the nature of land use, current situation, and project approval.
3.2.1. *Divided by "controllable"*. After combing and analyzing, the land within the scope of research is divided into three categories: current status, under construction, and unbuilt. Among them, the current land is subdivided into potential for renovation and no potential for renovation, the land under construction is subdivided into with approval procedures and without approval procedures (which is in the publicity period actually), and the land for unbuilt projects is subdivided into approved and unapproved. Their distribution diagram is shown in Figure 3.7.

![Figure 3.6](image)

**Figure 3.6 Schematic diagram of the research scope of the second-level control area**

![Figure 3.7](image)

**Figure 3.7 Schematic diagram of characteristics of the land within the scope of research**

The current land with no potential for reconstruction means that it cannot be reconstructed or there is no reconstruction plan within a long period of time, and the status quo will be maintained. The study believes that it is "uncontrollable".

The land under construction (including approval procedures and no approval procedures but in the publicity period) has been planned, designed, and constructed in recent years, with complete procedures, complete procedures, and legal compliance, so it will become "uncontrollable" when the facility service ring is implemented.

A total of 1019 blocks of the current land with no potential for renovation and the land under construction accounts for 37.2% of the total land use (2740 blocks) within the scope of the research. The area is about 12.65 square kilometers, accounting for 49.6% of the total land area (25.49 square kilometers) within the scope of the research. See Table 3.1 for details.

| Category                          | Number(block) | Area(square kilometers) |
|-----------------------------------|---------------|-------------------------|
| Current Status                    |               |                         |
| with no potential for reconstruction(black) | 792           | 6.18                    |
| with potential for reconstruction(blue)    | 571           | 2.28                    |
3.2.2. **The cross-comparative analysis of characteristics.** According to the nature of the land, the land use in the research scope is divided into public service, commercial, village construction land, special land, water area and green land, multi-functional, industrial, residential, transportation and municipal, a total of 9 types of land.

The 6 types of lands divided by "controllable" and the 9 types of lands divided by the nature of the land were subjected to characteristic cross-analysis, and 54 characteristic cross-analysis graphs and related attribute table data were obtained.

Taking the cross-analysis of the existing land with no potential for renovation and the public service land as an example, extract all the current lands with no potential for renovation and all the public service lands in the research range, and make a cross analysis between the two. Information on the number, location and area of public service land with no potential for renovation within the scope of research can be obtained, as shown in the figure below.

![Cross-analysis diagram of existing lands with no potential for renovation and public service lands](image)

The above cross-analysis diagram shows, within the scope of the study, there are a total of 103 land plots with two attributes of "current status without potential for renovation" and "public service category", with a total area of approximately 1.098648 square kilometers.

By means of the geographic information system, the current land with no potential for renovation is combined with all 9 types of properties plots are cross-analyzed, and a total of 9 cross-analysis diagrams of current land with no potential for renovation and other types of land can be obtained.

Through feature intersection, we analyzed the land one by one, and chose the land that meets the principles of the delimitation of the secondary control zone to form the secondary control zone of the facility service ring, as shown in Figure 3.9.
4. Conclusion and suggestion

4.1. Find out the current situation and consolidate the space foundation
The existing research on underground space of the sub-center only focuses on the underground space of the "planar" construction land. This research is the first to systematically analyze the underground space of urban roads where the “linear” infrastructure such as subway and utility tunnel is located. Reconnaissance, topographic maps, image maps, pipeline surveys, municipal engineering comprehensive planning databases, planning approval geographic information data and other multiple technical means are applied to find out the current situation and planning implementation. We sorted out the use of underground space in plane and vertical, and analyzed the potential constraints in project implementation.

4.2. Explore the characteristics of each system and demonstrate the feasibility of spatial integration
There are no mature cases of spatial integration of different infrastructures at home and abroad. Based on the in-depth exploration of the functional characteristics, space requirements, and safety control requirements of the eight major systems, we sorted out and analyzed relevant standards and specifications, and demonstrated the safety and feasibility of the spatial integration of various systems (such as urban underground logistics, utility tunnel and subway) for the first time. After analyzing the necessity, adaptability, and compatibility of each system, we conducted qualitative analysis and quantitative calculation.
Besides, urban infrastructure is not limited to the eight major systems that have been proposed. This study further proposes that "each function is not unique to the facility service ring, and the facility service ring does not exclude any single function". Space inclusiveness and facility sharing should be seriously considered with the lead of subway.

4.3. Emphasize integration, implement classified policies to ensure implementation of management and control
While focusing on underground space, this research focuses on urban roads, circular green belts, circular slow-moving systems, building front areas, construction land, etc. Fully implement the urban form, architectural style, color, fifth facade and other urban design content on the ground, and emphasize the tolerance, integration and integration of space in the underground, so that to realize the benign interaction between the ground and the underground, the organic connection inside and outside the road, and the overall space sharing and supplement.
At the same time, it pays attention to the unified coordination of development and construction sequence, abandons the traditional thinking of "first come, first served", advocates reserved embedding, emphasizes integrated planning and construction, and ensures that control measures are implemented with the project.