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Advances in master planning of urban underground space (UUS) in China

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ABSTRACT

Following economic growth and urban development in China in the past two decades, rapid urbanization have incurred many pronounced problems to many Chinese cities. Since 2000, key areas in many Chinese cities, drawing on valuable urban development experience from America and European countries, flock to conduct master planning of urban underground space (UUS) development. The compiling practice is conducive to the orderly development of urban space and alleviation of increasing human-land conflicts. Through selecting and analyzing the master planning UUS in Qingdao, this paper first investigates the current problems of UUS development and utilization in China, and then analyzes the planning methods and general thoughts of overall underground space layout. In general, the paper presents some current advanced research findings in the master planning of UUS development in China.

1. Introduction

Control and management of urban land development is indispensable in the urban planning system of many countries (YAO, 2007; Working Group No. 4, International Tunnelling Association, 2000). Master planning of UUS can promote the evolution of urban morphology, and scientific planning theory and planning system regarding UUS can ensure rational and efficient UUS development (Vahaaho, 2013). Coming into force in 2008, the Urban and Rural Planning Law of the People's Republic of China points out that UUS development and utilization of UUS should fit in the development level of economy and technology, follow the principle of overall planning, comprehensive development and rational utilization, fully consider the needs of disaster prevention and damage reduction, civil air defense and communication, conform to urban planning, and abide by planning approval procedures. In terms of certain urban social and environmental functions, underground space development has demonstrated more prominent advantages than surface space development (Ronka et al., 1998). Thus, development and utilization of UUS will bring both new challenges and opportunities to the future development of many Chinese cities. While conducting urban plan compilations, we must take initiative to integrate underground space into master plan, because it has become an imperative need for many Chinese cities to step up and deepen the development and utilization of UUS in order for the alleviation of increasing human-land conflicts (Zhang et al., 2009).

2. Background and current situation of UUS development and utilization in China

Urbanization is growing up steadily throughout China. By the end of 2013, the urbanization rate reached 53.73%, 1.16% higher than that at the end of 2012, which means around 15.7 million rural inhabitants flooded into urban areas in 2013. In the next 10 years, the annual increase rate of China's urbanization is predicted to reach a figure between 0.8% and 1%. By 2020, with an urbanization rate of 56–58%, urban population will increase by 326 million (Shao and Wang, 2013). Nowadays, Chinese cities, while maintaining rapid economic growth, are confronted with many pressing problems greatly threatening urban living environment such as overpopulation, land resources shortage, worsening urban traffic congestion and space environment degradation. The 21st century is viewed as a significant period for urban areas to develop three-dimensional compact structure, in which underground space will be capable of providing 25–40% extra space without taking up precious surface space resources.

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2.1. Background of UUS development and utilization in China

In the 1960s, civil air defense projects led to large-scale development and utilization of UUS in China. During the period from late 1960s to early 1970s, which is generally called "early stage of underground projects", a mass movement, "Building Underground Air-raid Shelters" took place throughout China. Many of them were built by various work units and urban residents, forming an interconnected, extensive tunnel network. However, the lack of overall planning, construction experience, and technical support had led to the poor quality of these projects.

Starting from 1978, efforts have been contributed to studying how to conduct integrated planning of civil air defense and urban development.

At the 1986 Xiamen Conference, the State Committee of Civil Air Defense and Ministry of Housing and Urban–Rural Development jointly issued the Notice on Strengthening the Integration of Civil Air Defense and Urban Development (hereinafter referred to as "Notice"). The "Notice" shifted the dominant perception of UUS which mainly focused on civil air defense at that time, and laid emphasis on the integration of the daily use of civil air defense projects and urban development so as to raise the utilization efficiency of underground space (Wang, 2006). In 1988, this two departments again jointly issued Planning Compilation Methods on Integration of Civil Air Defense and Urban Development (hereinafter referred to as "Method"). According to the "Method", urban overall protection and relevant measures, development planning of civil air defense and development planning of underground space should be the key points for the integration of civil air defense and urban development.

Since 1988, under the guidance of the "Notice" and the "Method", local governments across China started to formulate integrated planning of civil air defense development and urban development. They gradually transformed many civil air defense projects into every day underground projects, and explored other functions of underground space. During this period, the transformation of civil air defense projects formed an important part of UUS development. The features of underground projects of this period can be described as following: while serving both wartime use and peacetime development, the internal environment of underground projects gave more consideration to the aesthetics and amenity during peacetime use so as to give full play to the integration of peacetime economy, environment and social benefits, at the same time, the exposed components of underground projects integrated well with urban life and cityscape. With all these efforts, real progress was achieved in the development and utilization of civil air defense projects.

Planning of urban rail transit (metro) has been studied since the 1990s, which would play a significant part in UUS planning system. Planning and development of rail transit will comprehensively guide the urban renewal along metro lines and stations. Therefore, only conducting rail transit planning cannot meet the new demands of urban development, and it has become an imperative to study and compile comprehensive and practical plans for the development and utilization of UUS along metro lines and around metro stations.

Rapid urban development is sorely in need of studying and compiling master plans of UUS development and utilization. Since December 1997, master planning of UUS development and utilization has been designated as one of the special planning of urban planning system. As a new guide for the management of UUS, Management Regulations on Urban Underground Space Development and Utilization has gone through many beneficial trials and collected valuable experience, which is vigorously promoting development and utilization of UUS in China.

In the 21st century, master planning of UUS development and utilization involves guidance for subsurface solution ratio, and regulatory planning of many urban functional facility systems. Therefore, master planning of UUS needs to be more comprehensive, complex, farsighted and operable. It is a necessity to conduct in-depth and systematic studies on relevant theories, methods and standard systems of UUS development and utilization, and continue to improve it with extensive compiling practice.

2.2. Current situation of UUS development and utilization

Over the past 2 decades, comprehensive development and utilization of UUS have received more and more attention in China, and compilation of UUS planning is gradually meeting the actual urban development demands. Furthermore, more and more attention has been paid to the comprehensive development and utilization of UUS resources in key urban areas and the integration of subsurface and surface environment. In 2010, the People's Government of Beijing City came up with a proposal stating that more efforts should be made to turn civil air defense projects into facilities intended for general public. Moreover, in the Guiding Suggestions on the Planning of Civil Air Defense Projects Utilization in Beijing issued in 2012, Beijing emphasized that the planning of civil air defense projects should be more people-oriented, and more underground civil air defense projects should be applied to solve urban development problems like chronic shortage of parking space and limited public space for daily activity of urban residents. By the end of August 2014, the amount of UUS in Beijing reached 72.68 million m^2 with an annual increase of over 7.3 million m^2. From the point of view of individual project, several underground complexes have been developed. For example, a five-story underground project was planned and finished in the core area of Beijing CBD, with a volume of approximately 0.51 million m^2. In addition to Beijing, other metropolises such as Guangzhou and Shanghai are also making great progress in UUS development in terms of the amount of UUS, reaching 1.9 million (by the end of 2012) and 68 million (by the end of 2013) respectively.

The key to reasonable and deliberate UUS development lies in the scientific and rational planning of UUS development. To this end, UUS resource should be planned as a whole, so as to ensure that space beneath city can be developed orderly and systematically. Problems such as unchecked and scattered development, unbalanced function, limited overall benefits and low efficiency can be avoided. Hence Article 5 in Section 2 of the Management Regulations on Urban Underground Space Development and Utilization is formulated as follows:

- UUS development planning forms an integral part of urban planning.
- While conducting urban master planning, governments at all levels should compile master plans of UUS development based on local development needs.
- Regulations concerning UUS development and utilization subject to UUS master plan should be integrated into urban detailed plans.

As listed in Table 1, many cities in China have finished master planning of UUS development. These compiling practices are conducive to the orderly development of urban space and alleviation of increasing human-land conflicts.

3. Problems and challenges for UUS planning in China

In recent years, many large and medium cities have carried out underground space planning at all levels and made certain

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Table 1
Master planning compilations of UUS development in some Chinese cities.

City	Time	Brief introduction
Hangzhou	1993	While conducting master plan compilation, Hangzhou has come up with 14 research topics among which "Underground Space Planning of Hangzhou" was taken as a key subject to study, and special plan compilation was carried out
Beijing	2004	After the selection of 16 research topics, Beijing has come up with the three-level master plan compilation of UUS development and utilization, i.e., "Master Planning, detailed planning, and immediate construction planning"
Shenzhen	2006	Master planning of UUS was integrated into the urban master planning of Shenzhen to reach unified planning and rational utilization of UUS
Xiamen	2007	As a part of the urban master planning of Xiamen, master planning of UUS has been utilized to coordinate underground space development and utilization, as well as social, economic and environmental development so that the preset strategic objectives would be met
Shenzhen	2011	Master planning of UUS covers downtown Shenyang with a total area of some 1230 km^2. The main development depth is −15 m, while key areas and facilities might be allocated into the medium layer of depth −15 to −30 m. 10 key areas and 20 sub-key areas were established during this compiling process
Nanjing	2011	With unit underground projects as the planning focus in urban central underground space, a cluster layout adjusted to underground space structures was formed with relatively independent space units in main urban areas, new urban areas, new suburban
Bengbu	2012	With public underground space resources development as the planning focus in planning control and guidance, total development volume, total layout structure, vertical layout, key development areas and nodes as well as planning control and layout guidance were formulated
Qingdao	2013	With the rail transit network as the planning support, a "one ring road, three district and multiple central area" UUS layout was developed. The construction of 13 rail transit lines like M1, M2, M3, M4, M6, and R1 will be finished within the planning period. These lines will be taken as axes to connect all key development areas to promote the underground space development of Qingdao
Hefei	2013	The overall layout of UUS in main urban area features "two axes and one ring road, multiple districts and nodes, fingerlike stretches" with 10 key areas, 20 key development nodes
Linyi	2014	Overall layout of UUS in Linyi is characterized with "1 main urban area, 2 suburban areas, 3 axes and multiple nodes". An interconnected and intercommunicated development model of UUS in core area was developed to integrate existing underground resources and interconnect newly built facilities, and emphasize interconnections of long-term resources
Tongren	2014	Overall layout of UUS in Tongren is of "1 axis, 3 core areas and multiple nodes", which can provide overall guidance to the appropriate development depth and developable depth for different facilities

achievements with regard to UUS development. However, UUS planning in China still faces many problems.

Firstly, the fact that the development of planning compilation is lagging far behind that of actual demand has long existed, besides, there is lack of relevant compiling standards and specifications in the planning of urban underground space. Though the process of UUS planning has contained some basic planning indexes, it lacked detailed and regulatory requirements of UUS development, or the regulations and stipulations are too principle-dependent to be supervised or carried out (Zhang and Liao, 2011). There are a lot of things needed to be complemented, improved and perfected in such fields as planning concept, planning system, planning content, rules or standards, depth and expression of planning compilation, legal procedures, and planning implementation.

Secondly, compared to surface planning system, the competitiveness and importance of UUS planning are weak. Research achievements of UUS planning in China mainly focus on utilization index and demand forecasting of underground space. Besides, some of the indexes are not specific enough and can provide guidance only for development timing and objectives of urban underground space at macro level. UUS planning in China remains an emerging field with a short development history.

Thirdly, there are not any national compiling specification or standards concerning UUS planning in China, in other words, there isn't any unified framework of UUS planning existing in China. Hence scientific academies and research institutes are still feeling their way in such fields as compilation, depth and methods of UUS planning.

It is very significant for China to understand the positioning of UUS master planning in urban planning system and its characteristics, and improve its contents, methods and relevant system of laws and specifications. Besides, future UUS development shall follow the fundamental principles of "establishing a high-intensive and network-oriented urban underground space in view of environment and traffic concerns" (Su and Ai, 2009) so as to develop a "sustainable social city" (Sterling et al., 2012).

4. Master planning of UUS in China: Positioning, strategic importance, characteristics and contents

4.1. Positioning of master planning of UUS

As a special type of urban space, i.e., a hermetic space enclosed by media like rocks or soil, underground space, although its development is quite different from that of surface space, is a significant resource for cities to solve the problems caused by urbanization, especially the problems related to traffic and environment (Bobylev, 2009). Therefore, UUS planning should be integrated as a part in the master planning (Japan Tunnelling Association, 2000) of all major cities and master planning of UUS should be an important part of urban planning system in China (Table 2). Master planning of UUS will play an active role in coordinating different needs of UUS in various regions and under different urban systems, which will have significant influence on the overall development of urban areas. Thus, it shall be included in, compiled and implemented in line with urban master planning so as to guide the compilation of detailed planning and relevant urban development concerning the utilization of underground space. The major concern of master planning of UUS is to appoint subsurface solutions out of different purposes, and to coordinate different underground plans of function systems. At present stage, the basic task of the master planning of UUS in China is to protect UUS resource and the eco-system of urban environment, to improve urban functions and environment in order to secure and create a safe, sound and comfortable urban life.

4.2. Strategic importance of the master planning of UUS

Master planning of UUS is a planning for systematic development and utilization of subsurface space in urban areas. The fundamental social function is to serve as an essential guideline for UUS development and management, a premise and basis for rational UUS development as well as one of the means to realize social and economic development objectives. Its specific strategic importance is reflected in four aspects as follows (Wang et al., 2014):

Firstly, it implements and coordinates the contents and requirements related to UUS development and utilization in urban master

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Table 2
Urban planning system of China.

Planning stage	Planning level	Planning contents
Urban system planning	Urban system planning	Five levels: national, provincial (autonomous region), cross-administrative region, city and county levels
Urban master planning	Outline of urban master planning	Programmatic documents like outline of city-town system planning
	Urban master planning and underground space resource utilization	City-town system planning Land use planning Urban central area planning (or extra underground space special planning) Underground space resource utilization planning of urban central area
	Urban infrastructure planning	Special infrastructure planning for urban transport, municipal and public service
	Urban zoning planning	Urban zoning planning of surface space Urban zoning planning of underground space
Urban detailed planning	Regulatory detailed planning	Regulatory detailed planning of surface space Regulatory detailed planning of underground space in key areas
	Construction detailed planning	Construction detailed planning of surface space Construction detailed planning of underground space

planning, zoning planning and other comprehensive planning, as well as those contents and requirements in special planning such as rail transit, public service facility and park facility;

Secondly, it focuses on overall layout and comprehensive arrangement of underground space, gives overall consideration for exploitation of UUS resource, and comprehensively coordinates the relation between underground space and urban development;

Thirdly, it serves as a guidance for detailed planning of underground space and special planning involving utilization of underground space like rail transit planning;

Finally, it can facilitate the achievement of intensive but scientific and systematic UUS development, promote comprehensive coordination between surface and subsurface and realize sustainable urban development.

4.3. Characteristics of master planning of UUS

As mentioned previously, UUS planning need to coordinate underground functions with surface space. Thus UUS planning would be of more significance as city grows larger and land use becomes more intensive. Not only the building and developing needs of individual projects, but the interaction among underground projects, e.g., depth relation in particular, should be taken into consideration when compiling UUS planning. Hence, UUS planning should involve factors in such fields as meteorology, engineering geology, hydrogeology, and other factors such as economy, society, environment and culture as well. In general, master planning of UUS has characteristics of four aspects.

The first one is prospective. Projects constructed below the surface is different from that on the surface because it cannot be rehabilitated (Sterling, 2005). For this reason, it demands that urban planners must make clear of the development strategies and objectives of urban space, prospectively predict the demand of UUS, and identify the function of and overall layout of UUS in short, medium and long term. Any mistake will cause great waste of UUS resource in the future;

The second one is systematicness. In master planning of UUS, UUS is regarded and planned as a part of the entire urban system, making UUS planning not only a complete and independent system, but also a sub-system of the entire urban system;

The third one is professionally demanding. In China, UUS planning usually involves many professions such as urban planning, transportation, municipal infrastructure, urban environment, disaster prevention and civil air defense and so on. The planning should fully consider the characteristics and requirements of various professions, and apply new technology and new process to the utilization and development of UUS;

The last one is law-based. Master planning of UUS should be based on the existing laws and policies, and the conception of ruling by law should be underlined so that laws and policies concerning UUS can be implemented into planning.

4.4. Contents of master planning of UUS

Master planning of UUS should reflect the requirements of urban master planning as well as zoning planning, and take into account of natural, economic, social and technological factors. Contents of master planning of UUS should include UUS development strategy, evaluation of UUS resource, prediction of demands, overall layout, and special planning of multiple functional facility systems. See Table 3 for more details.

5. Overall layout method of UUS

Based on urban characteristics and dimensions, overall layout of UUS should be in accordance with the requirements of urban master planning with regard to policies, strategies, and relative function, form and scale of surface construction. In other words, overall layout of UUS is a result of comprehensive consideration of social economy and technology, history and culture, and solutions of various conflicts etc. Generally, overall layout of UUS will play a guiding role of development direction in overall arrangement and interrelation of UUS, and provide guidance for detailed planning and planning regulations. Therefore, overall layout of UUS should be reasonable and scientific so as to effectively reflect and solve urban development problems.

It is noteworthy that overall layout of UUS should be flexible enough so that it can be improved or adjusted to accommodate emerging development needs.

UUS is not only the reflection of urban morphology and urban fabric, but also the extension of urban functions. The morphology of UUS is an underground system which is formed by various underground structures, shapes and corresponding correlations, and coordinates with urban morphology (Wang, 2000). UUS is a kind of discontinuous artificial space in horizontal and vertical dimensions. The components of UUS can be summarized as point space, linear space, complex underground space that comprises point and linear spaces, and underground development axis.

Therefore, overall layout methods of UUS can be concluded as following:

(1) Development direction of UUS should be based on urban morphology. Coordination with the urban morphology is the basic requirement of UUS morphology. Generally, there

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Table 3
Contents of master planning of UUS.

Project	Contents	
Upper level planning analysis	Urban master planning	Planning scope, urban space development strategy, urban space and land use planning in the short, mid and long term, central urban area planning, guideline and principles of underground space planning, etc.
	Zoning planning	
	Urban comprehensive traffic planning	Planning scope, prediction of traffic flow, transportation development goal, road system planning, etc.
	Urban rail transit planning	Urban rail transit network planning
Analysis and appraisal of current situation of UUS	History of urban underground space utilization, overview of current situation of UUS, present situation of urban underground traffic, municipal infrastructure and public service facilities, etc.	
Investigation and evaluation of UUS resource	Investigation and evaluation of UUS resource and establishment of evaluation systems (including evaluation system for the distribution and capacity of underground space resource, evaluation system for project suitability and evaluation system for the comprehensive quality of underground space resource)	
Forecast of functional demands and development volume of UUS development	Forecast based on comprehensive demands, land use intensity, function demands and zoning planning demands	
Objectives and development Strategies of UUS planning	Development objectives (overall objective, objectives in the short, medium and long term and future vision), strategies for UUS development and layout, and guidance for special system planning	
Overall layout planning of UUS	Overall layout basis, overall layout planning of UUS, zoning development guidance, classified guidance for underground space development, vertical layout planning and vertical classified guidance for underground space development	
Function systems planning	Underground planning of rail transit system, road system, parking system, public service system, municipal facility system, warehousing facility system and comprehensive disaster-prevention system	
UUS planning in the short term and future vision	Urban underground space development in short, medium and long term and its future vision	

Table 4
Relation between surface space and possible functions of underground facilities.

Type of surface space	Possible functions of underground facility	Characteristics of surface environment
Hospital	Outpatient department, inpatient department, garage	Convenient transportation, quiet
Plaza in front of railway station	Commercial center, hotel, recreational space, garage, subway station, transfer center of public transport	Gathering and evacuation, bustling
Plaza in front of government building	Garage, reception	Gathering and evacuation, quiet
Factory	Laboratory, workshop, warehouse, auxiliary workshop	Factory zone
Residential areas	Basement, civil air defense work, garage, business or service project	Living zone
Road	Traffic work, municipal public facility	Noisy, large traffic flow
Commercial center	Underground street, underground complex, recreational space, garage, subway station, etc.	Bustling and crowded
Road intersection	Underpass, transportation hub, underground mall	Bustling, large traffic flow
School	Laboratory, practice workshop, library, gymnasium, garage, gym, etc.	Quiet
Land for special use	Storage, fortification, and disaster protection	Special terrain, important shelter
Plaza for public leisure	Garage, underground shopping center, station of artery traffic, sunken plaza	Open space that can accommodate a lot of people
Scenic spot and historic sites	Traffic, recreational space, infrastructure and service facility	Sightseeing, lots of tourists
Abandoned space and natural cave	Landscape, storage, aquaculture, factory warehouse	In the suburbs or in the outside of the city, but not too far from the urban center

are three kinds of morphologies of UUS: single axis, multiple axes with ring, and multiple radial axes. In most of the cases, rail transit lines can serve as urban traffic axes and development axes of UUS as well.

(2) Development framework of UUS should be based on urban rail transit network. The urban rail transit lines connect urban areas, where buildings interconnect each other through passageways or underground arcades which finally connect with rail transit stations, thus catalyzing the formation of underground space network in the center of the urban. From this point of view, urban rail transit network is a comprehensive reflection of urban spatial structure. If based on urban rail transit network, overall layout of UUS can fully reflect the aspects of urban relationships.

(3) Overall layout of UUS should be based on the function of underground facilities. As main components of urban space, surface and underground space cannot be isolated from each other. UUS planning should give full consideration to complementary role it will play for the function of surface facilities. The corresponding relationship between surface and subsurface shows the constantly evolving objective laws of urban space. The functions of the underground space development often relates with the function and environment of surface space (Table 4).

In addition, overall layout of underground space in old urban areas should take into account of requirements and objectives of urban space development, e.g., requirements of traffic flow in old urban areas and specific objectives and requirements of urban renewal etc. In this respect, valuable cityscape should be protected, and worthless buildings should be demolished and transformed into leisure square with green space and fountains. In this kinds of areas, underground parking or commercial space can be set up under plazas. Different underground function spaces should be arranged along street, and interconnected with basements of surface buildings if necessary. Underground street, underground complexes, and rail transit station located below central plazas or downtown areas can serve as functional hub of underground space and evacuation center.

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Fig. 1. Location map of Qingdao.

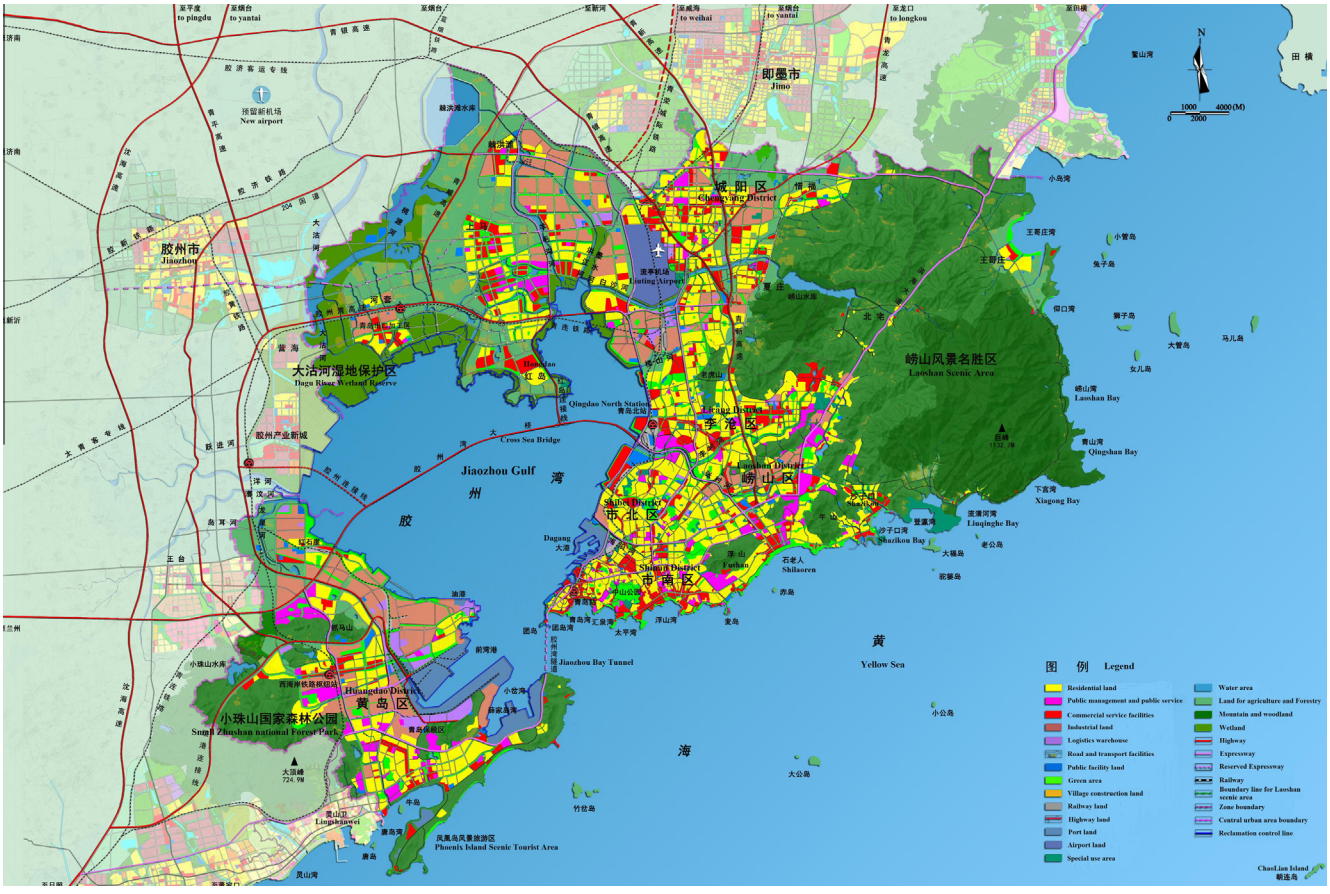

Fig. 2. Master planning of urban areas in Qingdao.

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Table 5
Evaluation system of UUS resource in Qingdao.

Themes of evaluation system	Subthemes of evaluation system	Notes
Evaluation system of distribution and capacity estimation of UUS resource	Evaluation of restricted development division	Distribution and restricted grade of UUS resource should be put forward
	Capacity estimation of UUS resource	Partition amount and characteristics amount of UUS resource should be calculated
Evaluation system of engineering suitability of underground space resource	Evaluation system of geological conditions	Grade division of engineering influences of UUS resource regarding geological conditions should be put forward
	Evaluation system of current construction status of surface and subsurface	Grade division of engineering influences of UUS resource regarding current construction status should be put forward
Comprehensive quality evaluation system of underground space resource	Evaluation system of engineering suitability	Influences of objective conditions (i.e., geological conditions and current construction status of surface and subsurface) of UUS resource should be considered
	Evaluation system of potential development value	Influences of subjective conditions (i.e., spatial location conditions and functions of surface spaces) of UUS resource should be considered

6. Case study: Master planning of UUS in Qingdao

6.1. Background analysis

Located in the eastern coast of China, Qingdao is playing a significant role in national spatial economic allocation layout system (Fig. 1). With the rapid development of Qingdao, various urban problems are emerging, e.g., shortage of urban land resources, land prices rising, real estate prices soaring, severe traffic jam in the business centers, extensive urban sprawl etc. This has led to more difficulties in improving urban space functions. In this case, development and utilization of UUS becomes one of the important ways to solve these problems, and it also is the necessary way to realize sustainable development of Qingdao.

Per capita GDP of Qingdao was $5170 in 2005, and reached $10,285 in 2010, which provides an important basis for UUS development. The construction of Jiaozhou Bay subsea tunnel, rail transit line 2 and line 3, and Blue Silicon Valley line marked that UUS development in Qingdao had entered the period of high-speed development. Moreover, development of rail transit network will catalyze more large-scale development and utilization of UUS in Qingdao.

According to Master Plan of Qingdao City (2011–2020), Qingdao will rely on the national marine strategic requirements of "towards deep sea and towards high-tech", implement the space development strategy of "planning as a whole, and achieving linkage among three urban areas of Qingdao (i.e., eastern coastal area, western coastal area and northern coastal area), expansion via ribbon axes, ecological spacing, and cluster development", and accelerate the speed of building an ecological bay metropolis. By the year of 2020, Qingdao will build the three urban areas surrounding Jiaozhou Bay, which are functionally complementary and interdependent while maintaining its own characteristics, forming the core area of Greater Qingdao (Fig. 2). Under this background, planning area of UUS and civil air defense had exceeded the scope which had been identified in Qingdao Urban Underground Space

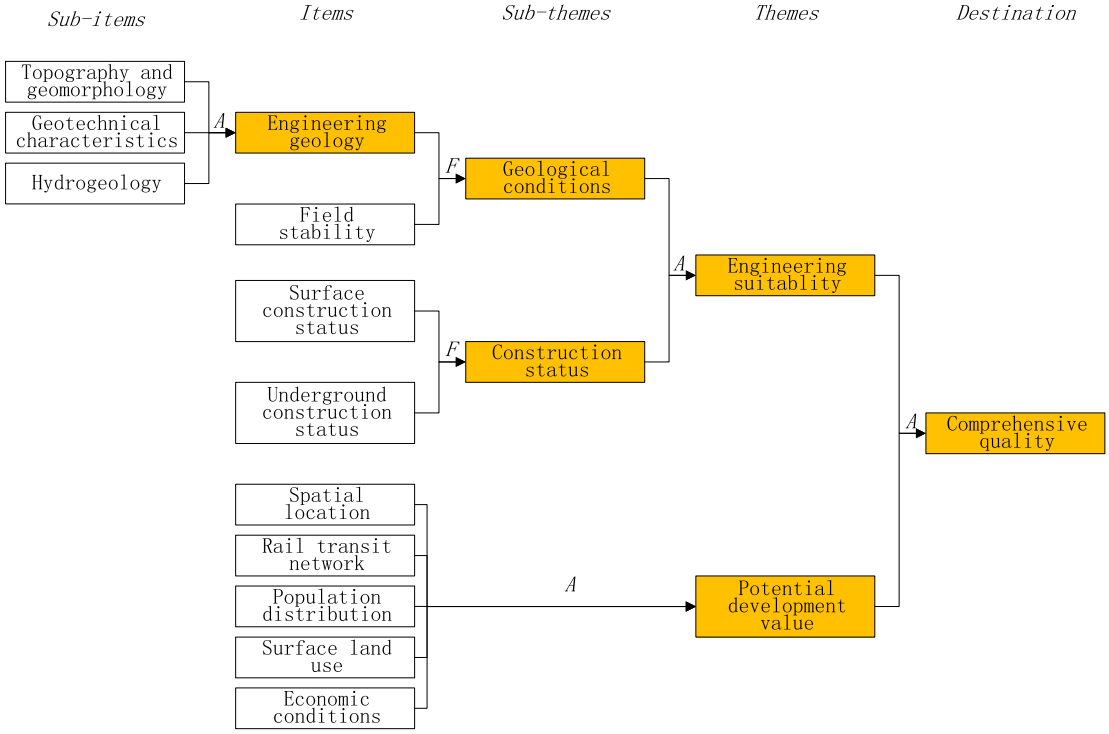

Fig. 3. Process of quality evaluation of UUS resource in Qingdao based on ArcGIS.

Development and Utilization Planning (2006–2020). In addition, Qingdao are facing increasing problems such as space shortage, traffic jam, and environmental degradation. Therefore, it is necessary for Qingdao to prepare a new master planning of UUS in the entire city to guide the orderly development and utilization of UUS resources. This is a significant step for Qingdao to keep the coordinated development between surface and subsurface, promote the energy-saving and environment-friendly urban construction, realize the sustainable development, and keep in accordance with the principle formulated in urban master plan (i.e., hybrid mixing peacetime with wartime, emphasizing key points and coordinating with urban development).

6.2. Present situation of UUS development and utilization in Qingdao

By the end of 2012, the amount of UUS in key planning areas reached about 22.27 million m^2, mainly distributed in the developed eastern coast areas, of which Shinan District was the most intensive area. In terms of development level, utilization at the depths of down to 10 m below the surface, that is, one or two basement stories, is the priority, occupying about 90% of the total amount. For a long time, underground space construction in the key planning area is based on ownership of surface space. It usually develops independently by combining with residential and commercial real estate project. Therefore, there is lack of organic organization and interconnection between adjacent underground spaces. As the rail transit projects begin, joint development benefit among adjacent underground space is gradually encouraged in urban areas and researches on more advanced development mode of UUS is started. However, the exploration is still in the planning stage, not fully launched.

Compared with the developed cities at home and abroad, there is still a large gap in UUS development between Qingdao and those cities. To some extent, UUS use in Qingdao is of single-function, and development mode is backward. Moreover, development and utilization of UUS in Qingdao lags behind the demand of urban development (the total floor area of UUS is only 3.1% of the total built-up area of surface), and construction standard is low. All

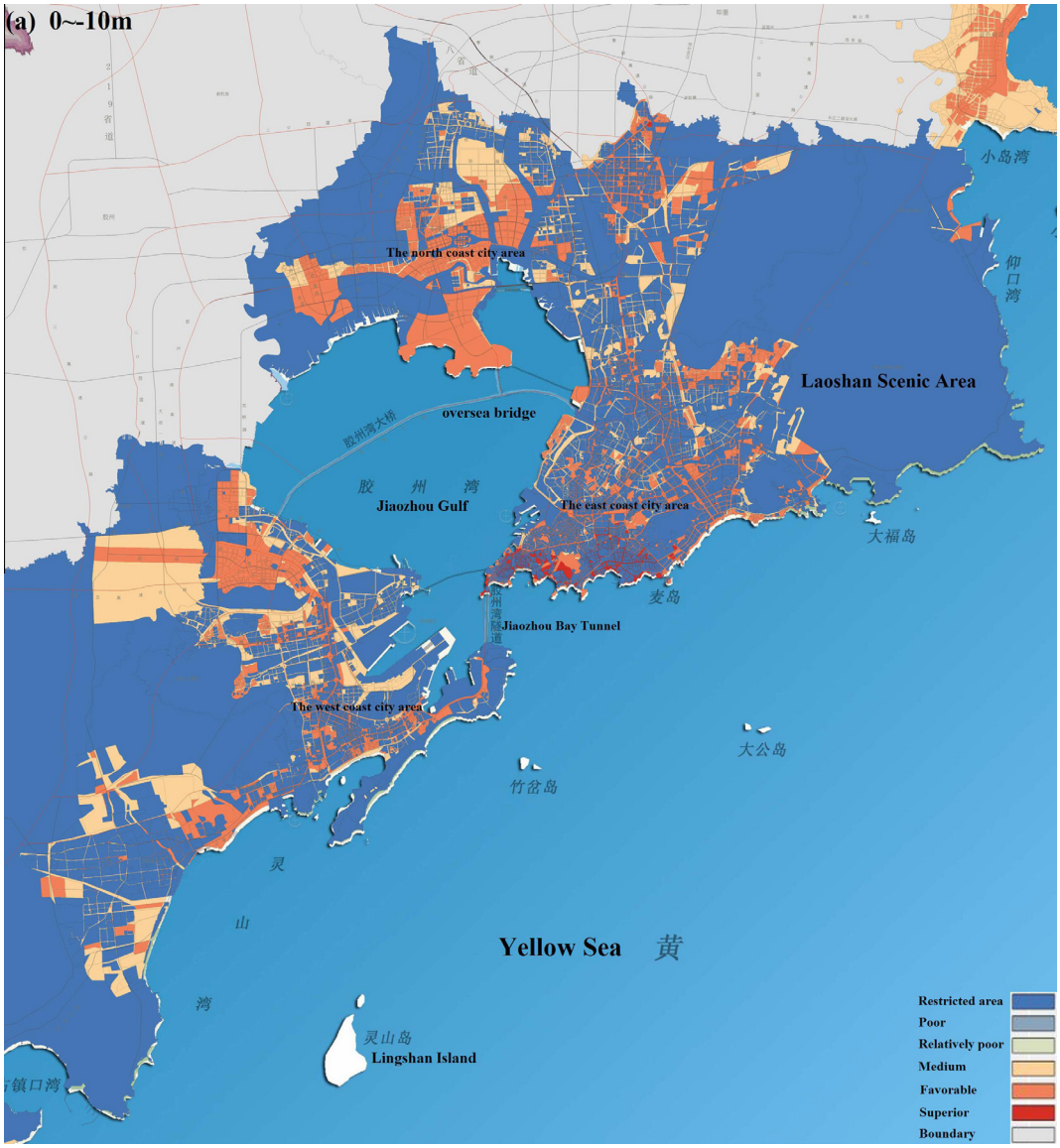

Fig. 4. Comprehensive quality evaluation of UUS in urban areas of Qingdao: (a) 0 to −10 m; (b) −10 to −30 m; (c) −30 to −50 m; (d) −50 to −100 m.

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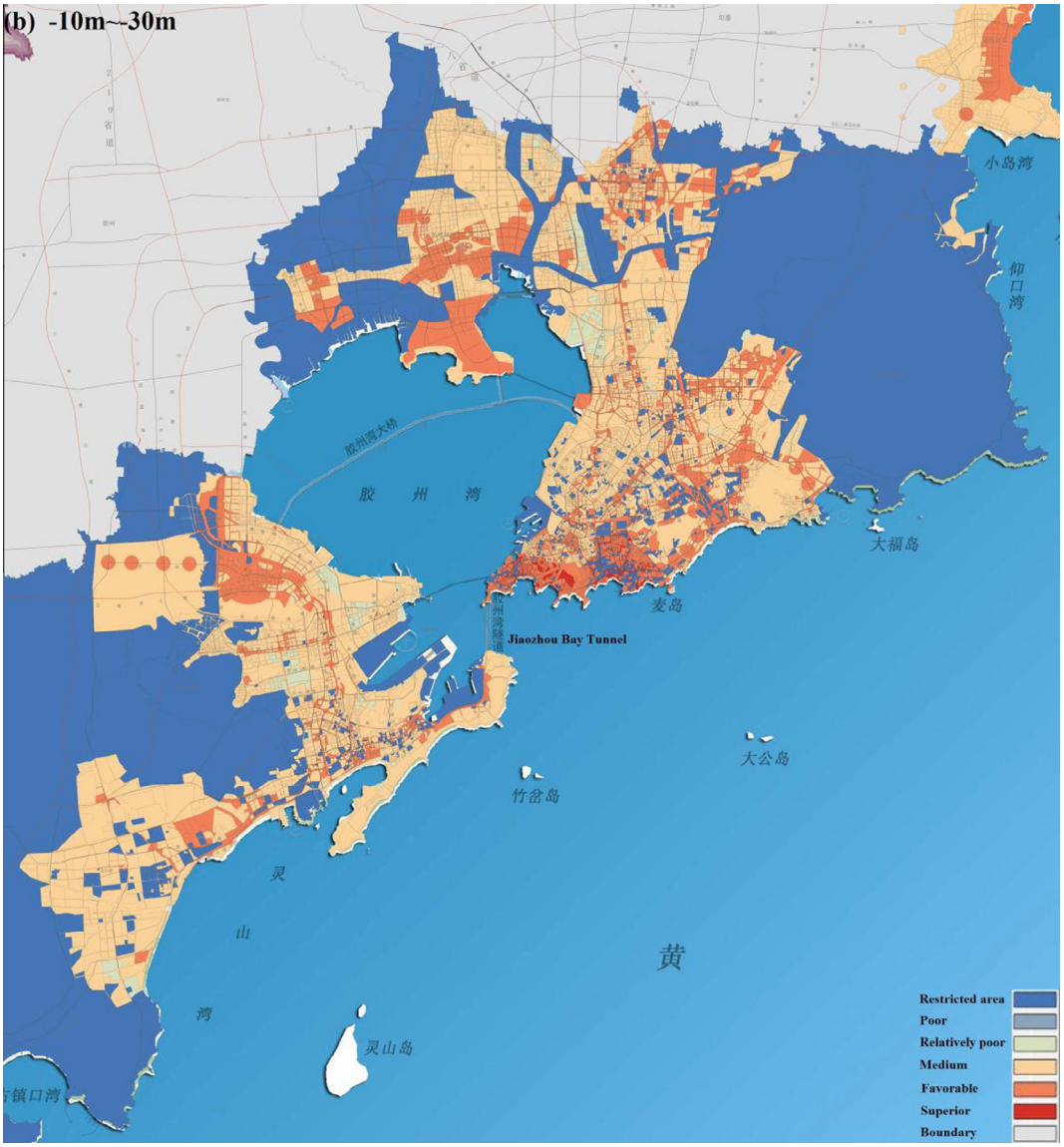

Fig. 4 (*continued*)

these problems have caused low utilization efficiency of UUS, which cannot meet the demands of three-dimensional urban development and improving the quality of urban life.

6.3. Investigation and evaluation of UUS resource in Qingdao

With the influences of the geographical environment, engineering geology, hydrogeology, land use and urban environment of Qingdao, it is necessary to investigate and evaluate its UUS resource to figure out the quantity and quality of UUS resource, which will provide important basis for future UUS planning.

Quantity and quality have considerable influences on the results of investigation and evaluation of UUS resource (Li et al., 2013). Quantity of UUS resource refers to the space volume or capacity and the quantitative index can be expressed by its space volume or floor area. In the investigation and evaluation system of master planning of UUS in Qingdao, quantity of UUS resource comprises the volume of natural reserves, the volume of potential reserves for reasonable exploitation, and the volume of potential reserves for effective utilization. Quality of UUS resource is used for comprehensively evaluating the engineering suitability and the potential value of UUS development and utilization. Since the evaluation of engineering suitability consists of geological conditions and urban construction status of surface and subsurface, and the evaluation of potential value consists of urban spatial allocation conditions and functions of surface land use, quality of UUS resource can be viewed as a comprehensive combination of subjectivity and objectivity. Evaluation system of UUS resource in Qingdao can be decomposed into three parts, that is, the evaluation of distribution and capacity of UUS resource, the evaluation of engineering suitability of UUS resource and the evaluation of comprehensive quality of UUS resource (Table 5).

In terms of the development sequence and function arrangement, the underground space resource of Qingdao can be divided into four levels in the vertical direction: shallow layer (0 to −10 m), media layer (−10 to −30 m), secondary deep layer (−30 to −50 m), and deep layer (−50 m below). According to the investigation and evaluation result, if the development depth was 100 m, the total volume of natural reserves of UUS resource in Qingdao would be about 1088.20 billion m^3, and the volume of potential reserves for reasonable exploitation would be 117.87 billion m^3. Among them, the volume of the four layers from shallow

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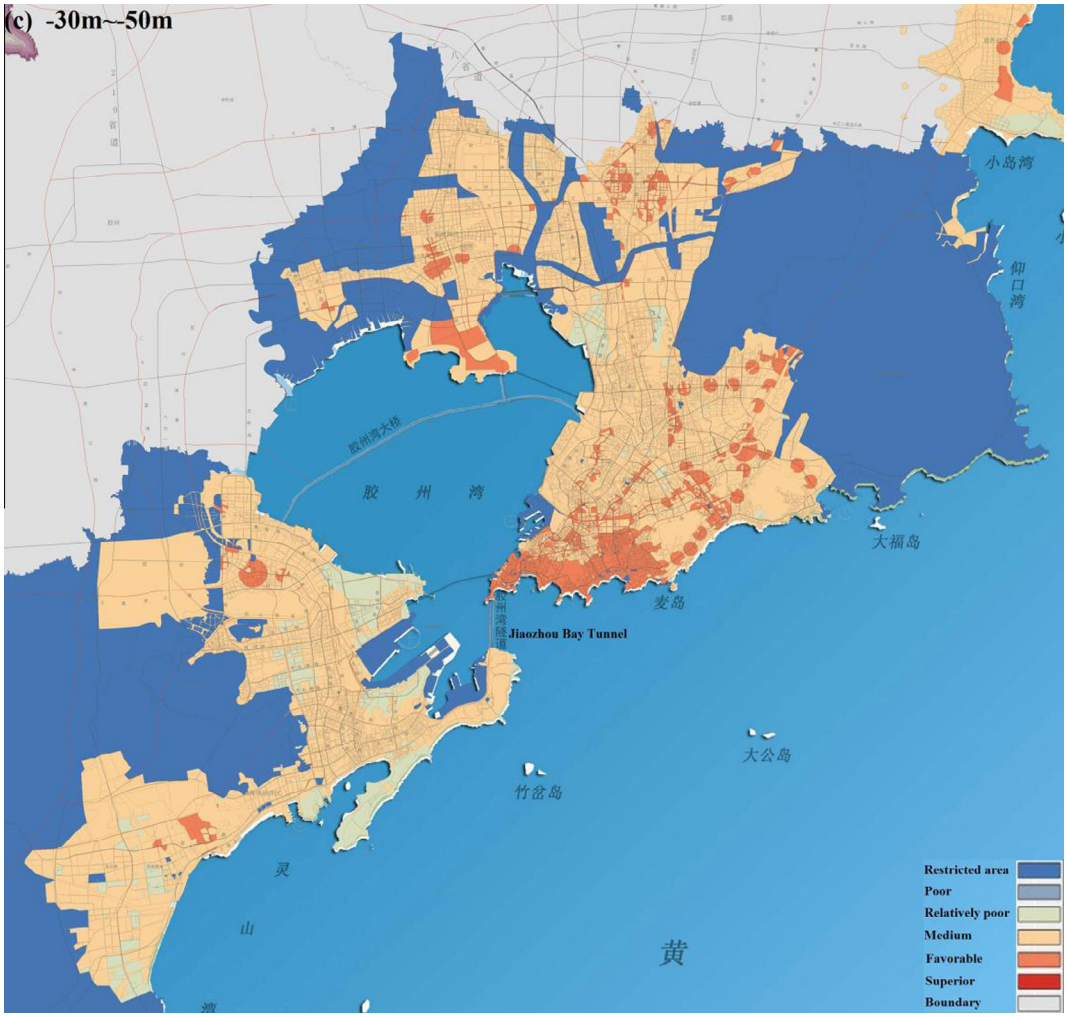

Fig. 4 (*continued*)

layer to deep layer amount to about 6.74 billion m^3 (equivalent to an floor area of 1348 km^2, hereinafter taking each floor as 5 m high), 21.38 billion m^3 (equivalent to an floor area of 4276 km^2), 25.11 billion km^3 (equivalent to an floor area of 5022 km^2), and 64.64 billion m^3 (equivalent to an floor area of 12,928 km^2) respectively.

Quality evaluation of UUS resource in Qingdao is processed on the software platform of ArcGIS (a geographic information system (GIS) for working with maps and geographic information). As shown in Fig. 3, comprehensive quality of UUS in Qingdao consists of two themes: engineering suitability and potential development value. And themes and sub-themes are constituted by items and sub-items, including topography and geomorphology, geotechnical characteristics, hydrogeology, field stability, surface construction status, underground construction status, spatial location, rail transit network, population distribution, surface land use, and economic conditions, and the corresponding representative indexes adopted in the evaluation of UUS resource in Qingdao to describe these items and sub-items are slope gradient, weighted compression modulus, water outflow from single well, distance to geological faults, influence depth of surface buildings, influence depth of underground buildings, grade of spatial location, distance to rail transit lines and stations, population density, function classification of surface land use, and market price of real estate. Each box in Fig. 3 represents a raster map layer in ArcGIS. Data of items and sub-items in white boxes can be obtained directly from the database of ArcGIS, which is established in the investigation stage. And the value of raster map layer in white boxes ranges from 0 to 1, and is obtained from the normalization of the representative index of an item or a sub-item. The value of raster map layer in orange boxes is the overlaying result of lower level map layers. The overlaying is processed by methods of analytic hierarchy process or fuzzy set theory, represented as "A" and "F" above the arrows in Fig. 3 respectively. Analytic hierarchy process is used to identify the weight of overlaid lower level map layers, and fuzzy set theory is used to take the minimum value of each raster in overlaid lower level map layers. After all the overlaying process, the map layer of comprehensive quality is presented with values of 0–1, which can be classified into 6 categories to express the quality of UUS resource more intuitively. The comprehensive quality evaluations of the four layers are shown in Fig. 4.

6.4. Demand forecast of UUS development in Qingdao

6.4.1. Forecast of functional demands

Prior to functional demand forecast of UUS, function and other development characteristics of UUS in various stages of UUS development process are concluded from the experience of UUS development at home and abroad (Wang and Peng, 2014). Then, current status of UUS use in Qingdao is checked and compared with the development experience mentioned previously, and the stage of UUS development process that Qingdao should be at pre-

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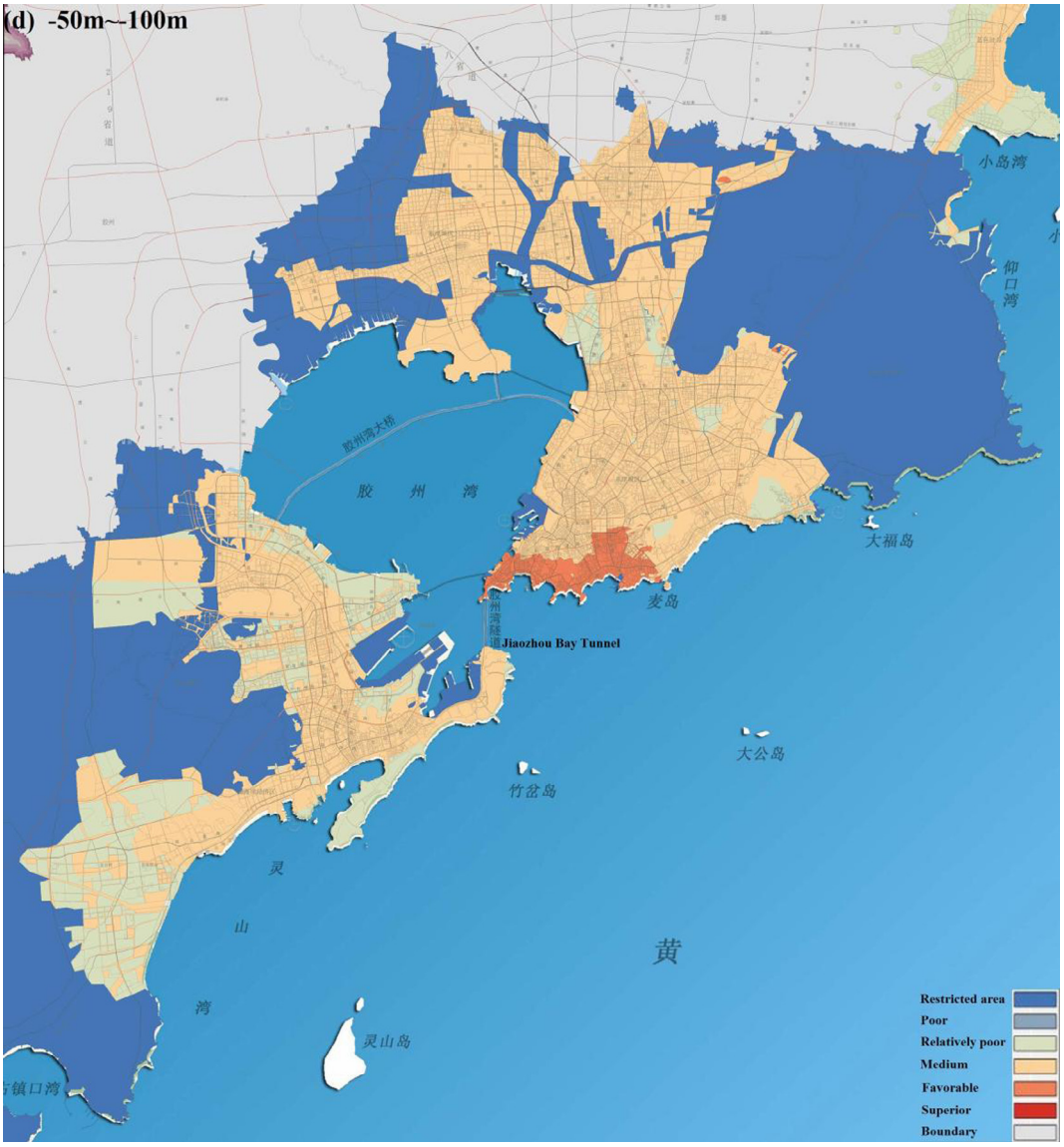

Fig. 4 (*continued*)

sent is identified. Finally, on the grounds of analysis result, forecast of functional demands for UUS development in Qingdao in various planning periods is achieved, as shown in Table 6.

6.4.2. Forecast of development volume demands

The forecast of development volume demand is an important procedure of master planning of UUS, because one of the basic objectives of UUS planning is to reasonably predict the development volume of underground space for a city in the planning period. At present, many scholars at home and abroad have developed some methods about the prediction of UUS demand (He et al., 2012), and according to experiences of master planning of UUS across China in recent years, current prediction methods can be summarized as the methods on the basis of ecological demand, comprehensive classification, function demand, land use intensity, and comprehensive demand, etc.

Master planning of UUS in Qingdao adopts the prediction methods based on comprehensive demand, function demand and land use intensity respectively to forecast the development volume demand (Tables 7 and 8). Through comparing the calculation results of the aforementioned three prediction methods, it can be concluded that the overall demand of UUS in key planning areas of Qingdao is 29.4–33.09 million m^2 during the period 2011–2020, and the overall demand in the administrative region of Qingdao is 30.676–35.219 million m^2. According to the investigation result on current situation of underground space of Qingdao, during the period 2011–2012, the development volume of underground space in Qingdao is 5.325 million m^2. Therefore, the overall demand of underground space in key planning areas is 24.075–27.765 million m^2 and the overall demand of the administrative region of Qingdao is 25.351–29.894 million m^2.

6.5. Overall layout planning of UUS in Qingdao

Under the Master Plan of Qingdao City (2011–2020), planning structure of urban public centers in Qingdao can be concluded as three urban centers and five sub-centers integrated by multi-level urban public service facility network. In detail, three urban centers refer to Qingdao (the east coast), Huangdao (the west coast), and Hongdao (the north coast); five sub-centers refer to

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Table 6
Functional demands of UUS development in various planning periods in Qingdao.

Planning periods	Planning areas	Functional demands
Short term (before 2015)	Key planning areas (Huangdao District, Shibei District, Shinan District, Chengyang District, Licang District and Laoshan District)	UUS development should take the construction of rail transit system as an opportunity for achieving the objectives of expanding the capacity of urban infrastructure and improving the infrastructure system, and take the rail transit stations as core areas in the urban centers and sub urban centers where the following underground functional facilities should arranged: rail transit facilities, parking facilities, underground pedestrian underpasses, underground commercial facilities, underground public service facilities, etc.
	Four peripheral areas (county-level cities) (Pingdu, Laixi, Jimo and Jiaozhou)	The objective of UUS development is to ease the contradiction of large urban population, city scale and relatively backward urban infrastructure, to improve urban infrastructure system and to expand the capacity of urban infrastructure. Main contents of underground space development include underground parking, underground storage, underground pipeline, civil air defense facilities, etc.
Medium term (before 2020)	Key planning areas (Huangdao District, Shibei District, Shinan District, Chengyang District, Licang District and Laoshan District)	The objective of this period is to further deepen the functional positioning of short-term for relieving the tense situation of urban land use and achieving the three-dimensional coordinated urban development. The key point is to utilize pedestrian paths to expand outward in important urban nodes and transfer hubs of the rail transit. Main functional facilities include rail transit facilities, parking facilities, underground streets, underground public service facilities, underground culture, recreation and sports facilities, underground electric substation, underground garbage disposal facilities, underground storage and underground disaster prevention, etc.
	Four peripheral areas (county-level cities) (Pingdu, Laixi, Jimo and Jiaozhou)	After achieving the objectives of short term, key points of this period is to intensify UUS development and add more functions based on the short-term development contents, including underground streets, underground culture, recreation and sports facilities, underground electric substation, utility tunnel, disaster prevention facilities, etc.
Long term (before 2030)	Key planning areas (Huangdao District, Shibei District, Shinan District, Chengyang District, Licang District and Laoshan District)	In this period, underground railway system will be basically formed and regulations and management of space along rail transit lines and underground stations combining urban renewal will be strengthened. In addition to intensifying the connections between underground functional space in important urban nodes and large rail transit stations, it is also necessary to improve the internal environment, safety and atmosphere of humanism in underground public space. Main development depth in this period should focus within −30 m. In addition to the function types of medium term, UUS development should enhance the interconnections of public service facilities in important areas, and focus on the underground constructions of municipal wastewater treatment, garbage disposal, electric substation facilities and other infrastructures, and the construction of utility tunnels in downtown areas
	Four peripheral areas (county-level cities) (Pingdu, Laixi, Jimo and Jiaozhou)	In the urban center and large transportation hubs areas, underground public space of underground commerce and public services are arranged to further enhance the underground construction of urban infrastructure
Future (after 2030)	The objective of future vision is to realize the sustainable development of urban economy, environment and resources, and keep deepening the objectives of short term and long term. UUS development of this period should show a deep, three-dimensional and comprehensive trend. Vertical development will reach the depth below −30 m. Besides the aforementioned function types, it also should includes underground logistics, underground research, underground rivers, underground roads, underground railways, underground storage, etc.	

Licang, Laoshan, Chengyang, Zhongshan Road and Huanghe Road; public service facilities refer to four municipal-level business districts, and 18 distinctive business districts. According to the Urban Rail Transit Network Planning of Qingdao, there will be a network of nine urban rail transit lines and four rail transit express lines, with an operating route length of 500 km in 2030.

Based on 13 rail transit routes, 31 key development areas of UUS have been planned and will form a complete integrated network of underground space (Fig. 5). The 31 key development areas are allocated on the grounds of aforementioned planning structure of urban public centers, of which 9 areas are planned as municipal-level key development areas, and 22 areas are planned as development-zone-level key development areas. In detail, the 9 municipal-level key development areas are central business district (CBD) of Shinan District, CBD of Shibei District, central culture and commercial district of Licang District, new financial center of Laoshan District, high-tech science and technology innovation center in Gaoxin District, business conference center in west coast, business center of Renmin Road, west coast economic zone CBD and blue silicon valley core center, and the 22 development-zone-level key development areas mainly comprise central business districts, urban business districts and district-level urban important areas.

6.6. Important function systems planning of UUS in Qingdao

6.6.1. Planning of underground traffic system

Planning of underground traffic system planning is the most important function system planning of UUS planning, not only because solving urban traffic problems is a major concern for UUS development, but also because underground traffic system, especially underground rail transit network provides significant basis for the planning of overall layout, morphology, underground public service system and key development areas of UUS. Planning of urban underground traffic system generally includes four parts: rail transit system, underground road system, underground parking system and underground pedestrian system.

6.6.1.1. Rail transit system. In the future, Qingdao rail transit is composed of 19 lines of 829.5 km. Among them, there are 9 express lines with a length of 475.8 km, and 10 metro lines with a length of 353.7 km. Around 2020, line 1, line 2, line 3, line 4, and line 6

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Table 7
Development volume forecast of UUS development in Qingdao.

Forecasting methods	Brief introduction of methods	Forecasting results
Forecasting method based on comprehensive demand	This method need to classify various kinds of land use in planning areas, then calculate the demand volume of each kind of land use in planning period based on development needs, and finally work out the overall demand of all kinds of land uses in planning areas	In the period from 2011 to 2020, the development increment of underground space in key planning areas is 29.87 million m^2 and the overall demand of underground space in the administrative region of Qingdao is from 31.15 million to 32.00 million m^2
Forecasting method based on function demand	This method need to divide UUS use into different function types roughly and classify each type into detailed terms, then forecast the amount of each type on the grounds of functional demand of each item, and finally work out the overall planning demand of underground space	As shown in Table 8, underground space Qingdao is divided into four functional types, including rail transit & underground station, underground parking, underground public service facilities and underground space below residential areas. Taking underground public service facilities as example, detailed terms can be classified into underground commercial streets, underground urban complex and general underground commercial nodes
Forecasting method based on land use intensity	Demand of urban underground space is influenced significantly by surface planning and construction factors, e.g., location of land use, floor area ratio, and planning capacity. Based on this analysis, this method classifies construction land in urban planning areas into different development levels, identify the new underground space volume in all development levels based on certain land use intensity of underground space, and finally obtain the overall demand of urban underground space	In period from 2011 to 2020, the demands of underground space in key planning areas, the four peripheral county-level cities and the administrative region respectively are 29.40 million m^2, 4.368 million m^2 and 33.77 million m^2

Table 8
Development volume forecast based on function demand in key planning areas of Qingdao (2011–2020).

Functional items	Sub-items	Demand (million m^2)	Notes
Underground traffic facilities	Subway tunnels and stations	3.70	Running tunnels with a length of 127.6 km; 96 stations
	Underground public parking lot	2.40	60,000 underground parking berthes, each covering an area of 40 m^2
	Underground pedestrian traffic system	0.30	About 30 pedestrian networks, each covering an area of 10,000 m^2
	Underground motorways	0.40	About 20 km in planning period, around 20 m^2 per meter
Underground public service facilities	Underground complex	3.90	A total of 39 complexes, each covering an area of 100,000 m^2
	Underground commercial streets	0.60	A total of 12 streets, each covering an area of 50,000 m^2
	General commercial nodes	1.38	A total of 46 nodes, each covering an area of 30,000 m^2
	Other space	0.40	Accounting for 5% of surface public service space
Underground municipal facilities	Utility tunnels	1.91	Utility tunnels with a length of 44 km, around 40 m^2 per meter; cable pipe utility tunnels with a length of 30 km, around 5 m^2 per meter
	Underground heating stations	0.50	A total of 10 stations, each covering an area of 50,000 m^2
	Underground sewage treatment plants	0.10	Maidao sewage treatment plant phase II&III projects
Underground space below residential areas	–	17.50	In 2020, per capita residential land will reach about 35 m^2; population will increase by 1.25 million in the period from 2010 to 2020; average floor area ratio will reach 2.0; proportion of underground space developed below residential areas will reach 20% of surface floor areas
Total		33.09	–

will be opened in succession, which will form the basic framework of rail transit network in Qingdao (Fig. 6). At that time, external traffic between urban center and peripheral areas, and internal travel among outer areas will be more convenient. Furthermore, the proportion of rail transit in traffic system will be increased, and this will bring a big impact on travelers' choice of travel mode.

6.6.1.2. Underground road system. In 2002, Comprehensive Traffic and Transportation Planning of Qingdao City forecasted the possible traffic flow between the west coast (Huangdao) and urban area of Qingdao. To facilitate the communication across Jiaozhou Bay and alleviate future traffic congestion, the "one bridge and one tunnel across Jiaozhou Bay" and more than one cross-sea tunnel are planned. On June 30, 2011, Jiaozhou Bay Bridge and the Jiaozhou Bay Tunnel were officially opened to traffic, ending the period of disconnection between Qingdao and Huangdao. Jiaozhou Bay Bridge whose total length is 26.48 km, is the starting section of G22 highway (from Qingdao to Lanzhou, Gansu province), and also an important component of highway network in Shandong province. Jiaozhou Bay Tunnel whose total length is 7800 m is the important channel between Xue Jiadao at the south to Tuandao at the north, through Jiaozhou Bay mouth. At present, Jiaozhou Bay Bridge and Jiaozhou Bay Tunnel are both in good condition, carrying 15,000 vehicles and 26,000 vehicles per day on average respectively. In terms of improving road network structure, there is one more tunnel planned between Jiaozhou Bay Bridge and Jiaozhou Bay Tunnel in the future. It will make it more convenient for passagers of north central Huangdao, Sino-German Eco-Park, China, Japan and South Korea Economic Zone and the International Ecological Wisdom City to communicate with Qingdao. At the same time, the development of urban underground road system is also appropriately planned (Fig. 7).

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6.6.1.3. Underground parking system. Underground parking ratio is determined on the basis of urban location and its land use function. According to the current land use classification, underground parking lots will be mainly built under planned residential lands, office spaces in planned urban centers and commercial centers, and redevelopment areas such as old towns, urban village area, and so on. In urban centers of east coast and in the residential lands, office spaces and commercial lands of west coast, underground parking ratio is planned to reach more than 90%. As for other areas, underground parking ratio is also well determined, considering the requirements of underground parking allocation and the future parking demand. Meanwhile, sites of underground public parking lots are preliminarily selected. According to this plan, there will be 188 underground parking lots in key planning areas, providing more than 60,000 parking berths.

6.6.1.4. Underground pedestrian system. Underground pedestrian system refers to the underground passage network intended for pedestrians, which connect rail transit station, underground mall, underground plaza, sunken plaza, and other facilities. As important components of underground pedestrian system, underground streets, underground plazas and sunken plazas are three kinds of key planning items. In essence, underground street is a kind of traffic facilities instead of commercial facilities, featuring a large-scale underground complex with shops, restaurants and other commercial facilities alongside walkways, while interconnecting with basements of public buildings, or the rail transit stations. Sunken plazas should be planned when elevation difference between underground space and surface space need to be dealt with by an open-air transitional space. Underground plaza is a closed space in the intersection of underground pedestrian passages, which plays an important role in underground pedestrian system with regard to functions of traffic hub, direction indicator, distribution of pedestrians and disaster prevention. Underground pedestrian system of Qingdao makes the most of existing and planned rail transit stations, civil air defense projects, and underground commercial spaces. According to the plan, there will be 26 underpasses integrated with rail transit stations, 10 underground streets integrated with rail transit stations, civil air defense projects and underground commercial spaces, and 13 underpasses located

Fig. 5. Overall layout planning of UUS in Qingdao.

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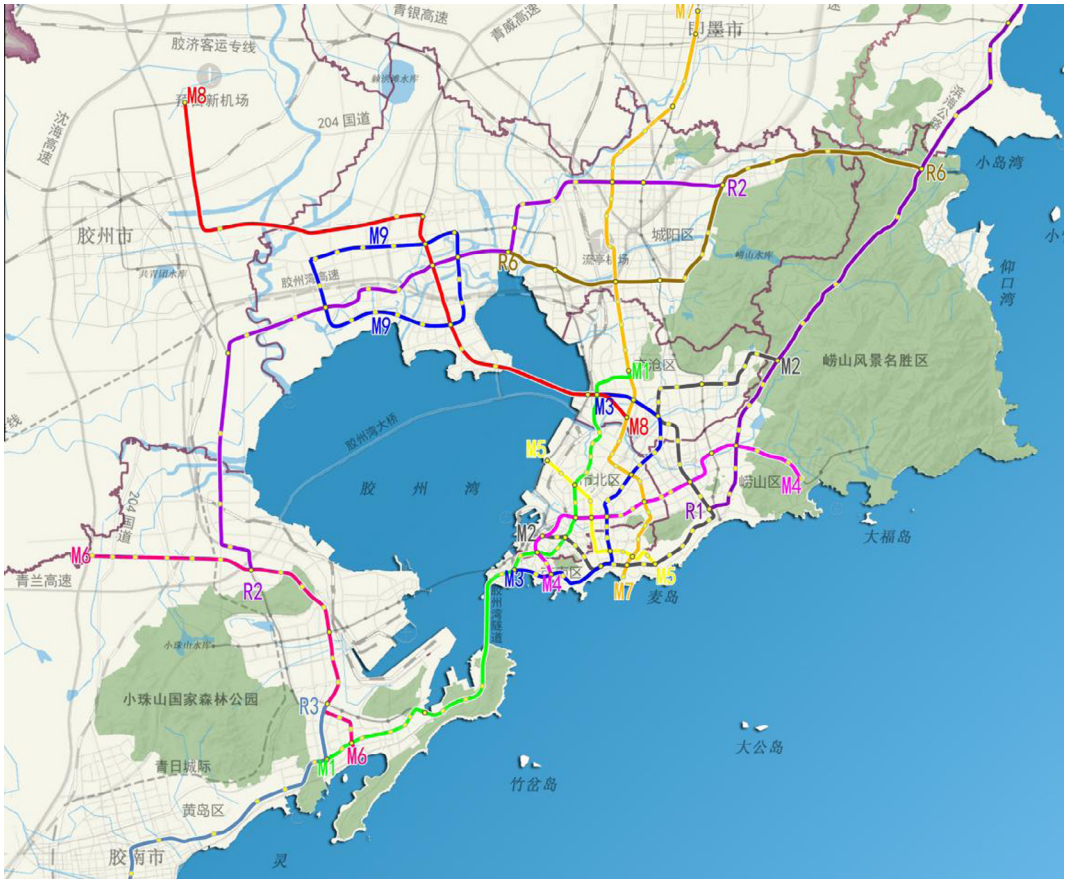

Fig. 6. Planning of rail transit system in Qingdao (2030).

below traffic arteries or other areas that suffer from traffic congestion.

6.6.2. Planning of underground public service system

Underground public space is closely related to urban life. With the development of urban underground space, underground public space has gradually become another major concern of the underground space system. Underground public service system is a comprehensive service system comprising underground commercial, underground public spaces (such as spaces of office, recreation, sports, health care, education, and research) and large-scale underground complexes, which can provide people with a variety of services. Planning of underground public service system has a close relation with surface public service planning, traffic system of surface and subsurface, and other special functional requirements. For example, function of underground public service space should coordinate with that of surface space, and development volume of underground public service space should take into account of the demand of functional development, transportation, civil air defense, and humanization space.

The planning of underground public service system in Qingdao puts emphasis on public service capacity of underground space, improvement of surface environment and integrity of underground public space network. According to the plan, 31 key development areas of public service are planned, which consist of 40 underground complexes, 47 underground malls, 10 underground commercial streets, 44 underground recreational spaces and 59 underground business spaces, and ultimately a multi-purpose underground public service network will be completed for further development of Qingdao (Figs. 8 and 9).

6.7. Discussions about the master planning of UUS in Qingdao

(1) Master planning of UUS in Qingdao is carried out on the grounds of theories and methods discussed in Sections 4 and 5, which in turn demonstrates that the related theories and methods are feasible regarding the practice of master planning of UUS in China.

(2) The great changes in urban fabric of Qingdao, which principally result from the strategic requirements formulated in the Master Plan of Qingdao City (2011–2020), and the construction of Jiaozhou Bay subsea tunnel, rail transit line 2 and line 3, and Blue Silicon Valley line, has led to the compilation of master planning of UUS. And the master planning will play a significant part in sustainable development and maximizing the efficiency of underground infrastructures in urban areas (Sterling et al., 2012). However, it is pretty difficult to assess and demonstrate the benefits that will be brought by the planning of UUS in terms of monetary value during the decision-making process (Sterling, 1996), especially in the master planning stage. Nevertheless, the benefits of UUS development can still be expressed with qualitative terms. First of all, in most of the case of old urban areas in Qingdao, underground solution is the only option for decision-makers to choose when it comes to the planning like rail transit system and road interchanges, due to the limited space that is densely covered by surface buildings. Secondly, as the land price of urban areas in Qingdao grows rapidly, the unfavorable point of higher construction cost compared to surface solutions can be made up by the large amount of space released through the development of UUS. For example, as shown in Table 8, UUS of public service

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Fig. 7. Planning of underground road system in Qingdao.

facility is planned with a total amount of 6.28 million m^2, if the land price is taken based on the standard of Shinan District in 2013, that is, the land price per floor area is taken as \$1070.32 (6800 yuan)/m^2 (at that time, the benchmark land price is \$2140.64 (13,600 yuan)/m^2, and the standard floor area ratio is 2), then the total value created by UUS development will reach \$6.72 billion. Thirdly, social and environmental benefits brought by UUS development, often known as latent benefits or externalities, are the key turning point that makes underground solutions favorable when compared to surface solutions, but also the most complicated part to monetize, and relevant methods for the monetization of social and environment benefits need to be further studied.

7. Conclusions

Underground space, as an important part of urban land space resources, has been increasingly applied to effectively solve the urban problems of disaster prevention, municipal transportation, energy, environmental protection, and land scarcity in the process of urban development. It is an important way to realize compact and ecological low carbon city, and to achieve energy saving, environment friendly and scientific development. Through selecting and analyzing the master planning UUS in Qingdao, this paper first investigated the current problems of UUS development and utilization in China, then analyzed the planning methods and general thoughts of overall underground space layout, and finally reached the following conclusions:

(1) Given that UUS cannot be rehabilitated once it has been assigned to a specific use, UUS planning should be of sustainability, which means future use of UUS should be secured and reserved while current needs being satisfied. It is also conducive to the economies of scale regarding UUS and integration of the urban space environment, which can finally maximize the direct and latent benefit of urban land use.
(2) These are the urgent issues to solve for China as regards further understanding the strategic importance and characteristics of UUS planning, developing the content and methods of UUS planning, and establishing and improving related legal and rule system. Master planning of UUS is a systematic arrangement of future UUS uses and its fundamental social function is to provide guidance for the management of UUS development. It is also the prerequisite for reasonable development and utilization of UUS and one of the important means of achieving strategic objectives of the community and government.
(3) Contents of master planning of UUS should reflect the requirements of urban master planning as well as zoning planning, take into account of natural, economic, social and technological factors, and should include UUS development strategy, evaluation of UUS resource, prediction of demands, overall layout and special planning of multiple functional facility systems.
(4) Based on urban characteristics and dimensions, overall layout of UUS should be in accordance with the requirements of urban master planning with regard to policies, strategies, and relative function, form and scale of surface construction.

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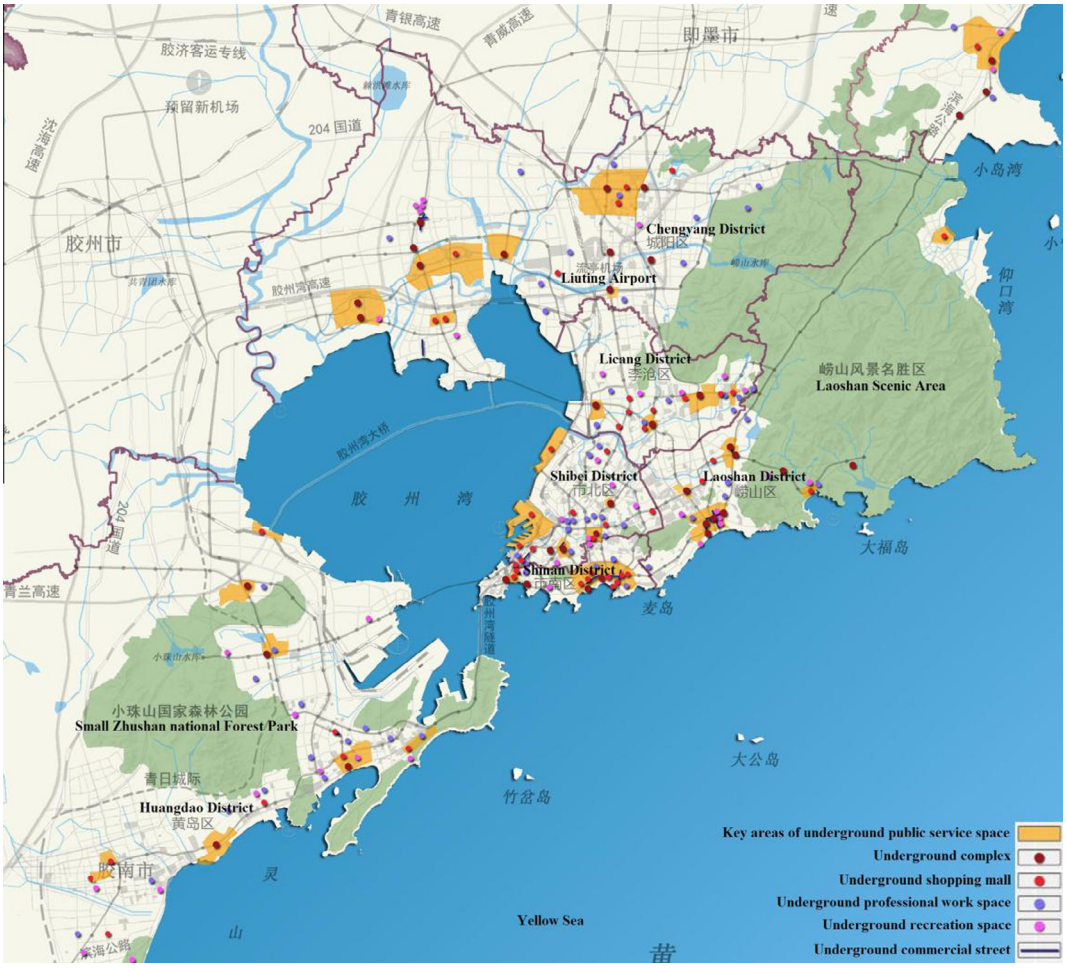

Fig. 8. Planning of underground public service system in Qingdao.

Fig. 9. Representative planning of underground public space in key areas of Qingdao.

Generally, overall layout of UUS will play a guiding role of development direction in overall arrangement and interrelation of UUS, and provide guidance for detailed planning and planning regulations.

(5) Qingdao is as an eastern coastal city of China with its unique geographical characteristics. In order to further enhancing the development of UUS in Qingdao and grasp the golden opportunity of current rail transit construction and urban

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renewal, researches on development and utilization of UUS in Qingdao are, to some extent, indispensable. Master planning of UUS will play an active role in the reasonable and systematic exploitation and development of UUS resource in Qingdao, in the integration of surface and underground development, and in solving urban problems such as space shortage and traffic congestion.

In conclusion, the achievements of the paper include both the current advanced research achievement in the planning of UUS in China and the typical practical planning case. The authors expect to make contributions to underground space development and utilization with experts and scholars in the world.

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