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Multiple resources and their sustainable development in Urban Underground Space

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ABSTRACT

Traffic congestion and ground space scarcity are increasing the need to find more space in the urban underground. The demand-driven "top-down" planning of Urban Underground Space (UUS) is common worldwide. As natural resource, the endowments of UUS are different in different regions. Consideration of UUS resource endowments, which can be called "bottom-up" thinking, should be integrated into planning. The evaluation method of UUS resource and investigation results in typical cases are being presented in the paper. It is important for urban development to utilize the underground space. Meanwhile, we should also be aware that there are multiple valuable resources in urban underground. Besides space, there are also water, energy and geo-materials. The paper will discuss how to consider these different resources in urban development. There might be conflicts between the developments of different urban underground resources. The paper investigated the interactions between these developments, revealed some serious impacts and typical conflict modes. The identification of conflicts is a basis for the coordination and synergy of these developments. For sustainable development of city, it is needed to understand and scientifically evaluate the multiple urban underground resources, then holistically plan and manage the developments. Structure and properties of urban underground geological body determine the engineering conditions of UUS and resource attributes of urban underground. Since 2003, China has been conducting pilot projects of Urban Geological Investigation (UGI) programs in some large cities. The paper will also show how to consider the influence of geological conditions in urban underground resource evaluation and UUS planning.

1. Introduction

Development of Urban Underground Space (UUS) can mitigate surface constraints on land acquisition, from building height limits and from landscape control (Carmody and Sterling, 1993; Golany and Ojima, 1996). The scale of UUS development constantly expands along with technological advancements (Goel et al., 2012).

However, many of the current urban underground development cannot be said to be compatible with sustainable development. At present, the demand-driven "top-down" planning of Urban Underground Space (UUS) is commonly adopted worldwide (Admiraal, 2006). Urban underground is mainly considered as a space for construction. The interactions between underground space, groundwater, geo-materials and geothermal energy utilizations have not been fully considered in planning (Parriaux et al., 2004). The urban underground developments are mainly on a project basis when a need appears, which can be called a "sectorial approach" of urban underground use. (Li and Li, 2013; Parriaux et al., 2004). The early developments by this "sectorial approach" often formed obstacles to later developments (Cano-Hurtado and Canto-Perello, 1999). Conflicts between developments of underground space, groundwater and geothermal energy are often observed. For example, serious interactions between groundwater and metro lines have been found in Paris and Mexico City (Birkle et al., 1998; González-Morán et al., 1999).

The understanding of the resource endowments of urban underground is very poor, which is the root cause of the nonconformity to the principles of Sustainable Development.

In this paper, the concept of multiple urban underground resources and sustainable development will be introduced. Studies on evaluation methodology and investigations on typical cases will be presented.

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2. Investigation and evaluation of resource attributes of UUS

2.1. Value, exploitation difficulty and comprehensive quality of Underground Space Resource

Urban Underground Space is a type of resource. It has its own potential, which is the available volume of exploitation. The comprehensive quality of Underground Space Resource (USR[1]) is depended on its value and the exploitation difficulty.

For the development of Urban Underground Space, there are some driving factors as well as limiting factors, which determine the available potential. For example:

- High population density requires more space (Land shortage is common in many densely populated cities, e.g. 58% of Hong Kong (Hui et al., 2006) and 35% of South Korea's large cities (Son and Kim, 1998) have this issue. Population density might reflect the shortage of space and hence is a driving factor for underground development (Bobylev, 2009; Golany and Ojima, 1996)).
- Land type, grade and real estate (or property) prices would affect the demand and commercial value of Underground Space. (Cost is much higher and hence an important consideration in UUS development. For example, in Tokyo, most of the basement type buildings are built in districts with population of more than 200,000 and land price of more than 400,000 yen/m^2).
- Subway construction is a vital driving factor and would also control the order of Underground Space development (Ground: Transit-Oriented Development (TOD[2]) mode; Underground: the metro network offered opportunity for nearby buildings to connect with metro stations).
- The sites of particular interest (e.g. historical and ecological sites or places of natural beauty) should be defined, documented and protected.
- Various geological factors affect the UUS development.

In the project of Investigation on Underground Space Resource (USR) in Suzhou city, all these factors have been surveyed and integrated into the digital model (as shown in Fig. 1).

Suzhou is a developed city as well as a famous historical city, located in the delta of the Yangtze River, close to Shanghai. The investigation on urban geology and underground resources was sponsored by the Ministry of Land and Resources of China and the Government of Jiangsu Province.

Fig. 2 shows the preliminary evaluation results of Underground Space Resource (USR) in Suzhou city. The higher value and lower exploitation difficulty imply that USR is the higher comprehensive quality.

2.2. Index system for evaluation of Underground Space Resources (USR)

As discussed in Section 2.1, the attributes of USR depend on three types of factor:

- Natural geological conditions;
- Existing facilities and various protection demands;
- Socio-economic factors.

Specific indices depend on specific local conditions. Table 1 shows the main indices employed for evaluation of Underground Space Resources (USR) in Suzhou.

Suzhou is located in the delta of Yangtze River. Regional tectonic stability is affected by active faults in bedrocks. In the western tectonic denudation hilly zones, there are karst and goaf areas. The eastern alluvial plain areas provide unfavorable conditions for underground works due to the thick quaternary deposits (200–300 m) and a groundwater level too close to the surface. Excessive exploitation of groundwater in the buried ancient Yangtze River channel has induced serious land subsidence and ground fissures. Due to the above geological settings (Wu et al., 2013), the geological condition indices listed in Table 1 influence the difficulty of UUS development.

Various protection requirements might restrict the development of UUS or increase its difficulty. Suzhou was originally built in 514 B.C. and entitled "Cultural and Historic City" by the State Council. There are 34 cultural relics under state-level protection. Over 60 classical gardens are protected and 9 of them are listed in the Catalog of World Cultural Heritage. In the ancient city zone in the middle part of the city, there are building height restrictions. These protection requirements should be carefully investigated and employed as evaluation indices as well.

To determine the index system and weight, AHP[3] (Analytic hierarchy process) has been employed.

In different depth ranges, indices and weights may differ.

3. Multiple resources in urban underground and conflicts between their exploitations

3.1. Multiple Resources in Urban Underground (MRUU[4]) and timeliness of exploitation

Urban underground not only contains space for construction, but also groundwater, geothermal energy and geo-materials, which are all fundamental resources for sustainable development of cities.

3.1.1. Groundwater resource

Groundwater is the main water supply source in many cities in the world. In China, the total groundwater extraction accounts for about 1/3 of the total urban water supply. 71% of cities exploit groundwater as a source of water supply. In 27 cities of northern China, the proportion of groundwater utilization reaches 87%. In many European countries, the use of groundwater also exceeds 70% of the total water consumption, especially for the use of domestic drinking water.

Even though surface water is the main supply of drinking water in some cities, groundwater also needs to be carefully investigated and protected. Surface water is vulnerable. When it is polluted or deteriorated, groundwater can be used as an emergency supply. Therefore, groundwater is a strategic reserve for city.

3.1.2. Shallow geothermal energy

Geothermal energy in urban shallow ground is a ubiquitous renewable resource. Over a certain depth (10–20 m), the ground temperature is no longer changed with surface air temperature changes. Through ground source heat pumps (GSHP[5]), the shallow geothermal energy can be used for the heating and cooling of buildings. The number of geothermal installations has been rising continuously for the past 15 years (Bayer et al., 2012; Hähnlein et al., 2010; Lund et al., 2011; Rybach and Eugster, 2010; Sanner et al., 2003).

[1] USR means Underground Space Resource.
[2] TOD means Transit-Oriented Development.
[3] AHP means Analytic Hierarchy Process.
[4] MRUU means Multiple Resources in Urban Underground.
[5] GSHP means Ground Source Heat Pumps.

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