URBAN SUSTAINABLE UNDERGROUND RESOURCES MANAGEMENT: THE "DEEP CITY" CONCEPT[i]

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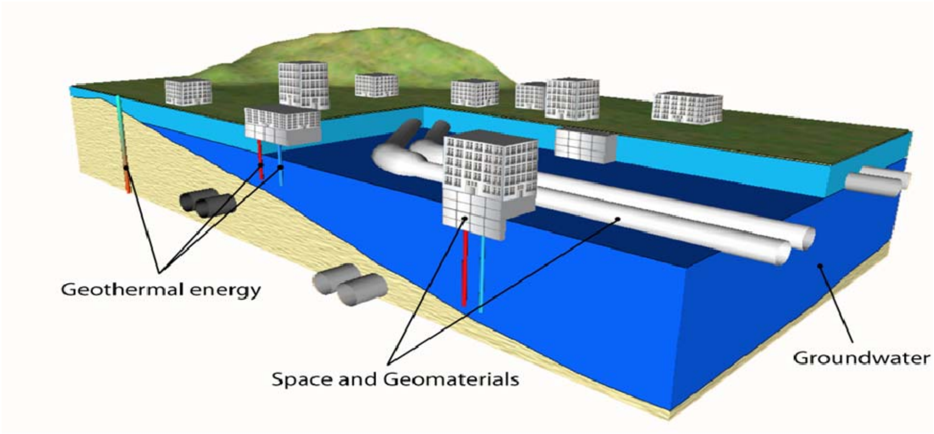
Keywords: Deep City, underground resources, subsurface economics, institutional governance

1 INTRODUCTION: THE INTERDEPENDENCY BETWEEN CITY AND SUBSURFACE

City is considered as an economic engine of the world, however, its growth is constrained by natural resources. Site selection to plan new cities about 100 years ago has been recognized the geological environment as a critical factor for long-term development. Urban geology influences urban generation and stable exploitation, by providing soil foundation for buildings, sufficient material for construction industry, secure groundwater provision for domestic and industrial need, proximate mineral sources such as oil and metal for production activities, and safe conditions against natural disasters. Unfortunately, urban subsurface territory has been always beyond our visibility until we encounter shortage of these resources and suffer geo-environmental disasters (such as earthquake, landslide, seawater intrusion and land subsidence). As a result, long-term development of cities should start by rethinking the pattern of spatial planning and resources management, especially the pattern to enable synergetic development of the city and its subsurface.

1.1 Urban Subsurface

By the year of 2050, there will be nearly half of the world population living in cities[1]. How to absorb these demographical migrations and retain their social dignity inside the advancing economic sphere are essential concerns for policy makers. Human activities and urban functions are becoming more and more diversified, which call for highly integrated usage of urban space. High-rise building is an option but not the only, below-ground level is gaining more and more attention among architects[2] and city planners. Various commercial and institutional buildings can be placed under urban surface, for the purpose of gaining more surface land and benefiting environmental advantages (noise isolation, stable temperature, energy saving, protect landscape, etc)[3]. Public infrastructures can be also placed totally underground to economize urban land supply, such as transport systems, utility networks, and storage or deposit facilities[4]. It is estimated that the possible gain offered by subsurface in urban space ranges from 5-15% for city environments, up to 100% for infrastructure areas [5]. This figure will be attractive for land administrators, who are responsible to allocate scarce land resources rationally, particularly to protect farmlands conversion for the aim to ensure national food provision security. Meanwhile, spatial planners are also attracted by the economic potential of subsurface utilization[6]. The scale of subsurface construction has been growing rapidly among world metropolises, including Paris, Tokyo, Montreal, Helsinki, Shanghai, etc. Their functional types evolve from unique infrastructure (metro, road, pipeline, shelter) to social place (shopping center, theater, museum, sports center), representing a more and more lively dimension of subsurface territory. Along with the increasing housing provision to absorb urban population, related social services become indispensable to form livable neighborhoods. Rational exploitation of underground space will play an important role for urban growth.



1.2 Underground Resources

Besides space resources, subsurface is a rich territory possessing other valuable natural resources to support urban life [7].

1) Groundwater: as many cities rely on groundwater for domestic drinking need, its local conservation of quantity and quality represents huge economic savings from long-distance water conveyance and excessive treatment. Facing population increase, this issue becomes a priority within social welfare sphere. Most of the groundwater beneath construction area is polluted, while natural recharge and dissimilation take time. To avoid suffering from future water crisis, protection of these resources should be on the nearest political agendas.

2) Geomaterial: excavated material should be recycled and reused as an input for construction industry. As reported from the city of Geneva, most of the excavated material during civil works is not recycled and generated large pressure for landfills. Paradoxically, the shortage of construction material is urgent due to limited quarries exploitation. Municipal initiatives have to be launched in order to sensitize contractors and project owners, in terms of reducing landfills, increasing recycling and promoting material valorization[1].

3) Geothermal energy: shallow ground source is a clean and renewable energy, which is developed widely in European countries like Sweden, Austria and Switzerland[8]. Facing the trend of reducing the share of fossil fuels utilization due to its threat to climate change, geothermal energy exploitation will be an economically attractive option for domestic heating and cooling, which represents 40% of urban power demand.

To illustrate the underground management issues, section 2 will focus on the planning and management framework of urban underground space, drawing through economic implications and institutional concerns of subsurface development; section 3 will focus on integrated governance of urban underground resources for sustainable urban growth.

2 PLANNING AND MANAGEMENT FRAMEWORK OF URBAN UNDERGROUND SPACE USE: FROM ECONOMIC AND INSTITUTIONAL POINT OF VIEW

Considering that the planification of urban underground space refers to multiple environmental factors, broad socio-economic factors and different institutional factors, a framework for planning practices should be comprehensive and pragmatic to involve all the stakeholders into decision-making process. This section is divided into 3 sub-sections: stakeholder and regulation analysis, economic assessment, administrative procedure and management strategies.

[1] Project ECOMAT-GENEVA: http://etat.geneve.ch/dt/environnement/ecomat/ecomat-829.html

2.1 Stakeholder and regulation analysis

In order to succeed an underground construction project, no matter for large scale government-invested ones or smaller private-invested ones, different components as "hardware" and "software" are to be necessarily integrated. The "hardware" includes land disposition, feasible technology, available financial capital, labour qualification and operation bodies, while the "software" here includes regulatory guidelines, legal permission and management tools. Government as a city owner is playing a leading role through all the major urban transformation projects. Intra-governmental interests upon different hierarchies determine their regulatory patterns and mental modes. Structure of the institutional network and related regulations is showed on table 1.

Table 1 stakeholder structure and regulations

Stakeholder parties	Main objectives	Related regulations
Economic Planning Commission	• Promotion of urban economic growth by delivering approval for potential projects to qualified developers.	Macro-economic plan, National Economic agenda, Public finance plan, Investment regulations, etc.
Land Management Department	• Allocation of land resources, emphasizing on farmland protection. • Management of property rights under land transaction and registration system.	Law of Land Administration, Civil Code on property rights, Regulation on Land property market, etc.
Urban Planning Department	• Promotion of spatial growth by allocating urban functions (commercial, industrial, residential, public space) on designated area. • Establishment of detail planning and design guidelines for construction projects to ensure quality.	Law on spatial planning, Urban Planning standards and guidelines, etc.
Urban Construction Department	• Management of construction works by establishing operational guidelines for civil engineering. • Standardization of urban construction project management for contractors and owners.	Law on urban construction, Building standards, Building energy consumption standards, Law on Fire Protection and Security, etc.
Real Estate and Housing Department	• Management of real properties by establishing obligations and rights.	Real Estate Law, etc.
Urban Infrastructure Department	• Provision of public facilities, including transport system, water and sewage system, energy utility, and communication networks. • Standardization of public infrastructure project design to ensure social benefits.	Law on urban infrastructure, Regulations on concessions for public infrastructures, etc.
Environmental Protection Department	• Control environmental impact assessment for construction projects. • Promotion of natural resources protection by imposing related standards according to natural carrying capacities.	Law on Environmental Protection, Law on Waste Management, Regulations on Environmental Impact Assessment, etc.
Civil Defense Department	• Provision of basic shelters and evacuations during disaster and emergency.	Law on civil defense, etc.

Similar to conventional surface construction projects, subsurface development should go through all related management bodies within municipal institutional structure, for the aim to avoid conflicts with existing infrastructures and buildings, as well as to avoid incompatibility with natural environment. Since during the latest decades, more and more countries are trying to establish planning laws on underground space development, the regulatory framework should be enlarged to a broader extend. Harmonizing the intra-governmental interests within the framework could help to facilitate construction projects and promote sustainable subsurface exploitation.

2.2 Economic assessment

Developing Urban subsurface as a sustainable option for renewing congested urban centers and for updating public infrastructures, should be economically viable. Optimization of underground space use has to take into account social-economic demand and possible supply of geo-space resources.

2.2.1 Demand side – commercial value of subsurface:

Because underground construction technologies keep advancing, construction cost as an important part of initial investment is decreasing. However, for urban planning practices, the pattern and quantity of using underground space is not perfectly aligned with engineering innovation. Other dynamic determinants have to be integrated into the comprehensive economic assessment, such as the needs and preferences of the users on spatial and environmental concerns, as well as energy concerns.

According to different construction motivations, below-ground development can be classified into three typologies:

1) (conventional type) Infrastructures naturally placed underground:

Examples: water and sewage utility, civil defense shelter, geothermal probes;

2) (congestion type) Public infrastructures placed underground due to surface congestion:

Examples: subway, road tunnel, pedestrian network;

3) (optional type) Public and private constructions that are better placed underground due to miscellaneous preferences (such as physical appearance, landscape protection, sound isolation, stable temperature, seamless structure):

Examples: parking, shopping center, energy storage and utility, food storage, merchandise deposit, cultural place, sports center, conference room, scientific laboratory.

To forecast the demand for these underground types, a series of urban indicators (showed on table 2) could provide insight implications:

Table 2 socio-economic index system

Indices
Urban density
Land prices
Population growth rate
Employment growth rate
Land use pressure
Social sensitivity to urban aesthetics
Political sensitivity to energy saving

Construction cost is also an important determinant for project decisions. Underground construction is more costly than surface construction, due to additional soil foundation structures and geo-engineering risks. However, compared to the boosting land prices in central urban area, the share of construction cost becomes small in the total project investment. Cities will go over different levels of social economic scenario, from strong economic growth, to average economic growth, then down to weak economic growth. Investment concerns differ during these transitions, with abundant capital input and the highest quality output during strong economic growth period.

A more profound study for these factors could help city planners to understand which types of underground development are needed based on specific conditions, and to decide optimal subsurface quantity allocation to meet these needs and preferences.

2.2.2 Supply side – constructability of subsurface:

Since underground space is an integral part of geo-environment, its development is constrained by natural conditions and exiting built environment. Geological survey provides useful information for land administrators to evaluate potential quality and quantity of underground space to be urbanized.

While demand evaluation reveals the commercial value and social need of subsurface development in urban area, supply evaluation will provide land administrators a vision of subsurface land management. The potential to construct can be visualized on 3D model to know the layer and volume of excavatable soil or rock. To synthesize the geological and geotechnical information into understandable indicators for non-experts, our study put forward two main categories to qualify and quantify the physical potential of subsurface land[2].

1) Qualitative indicator - Difficulty degree:
   It is determined by natural conditions, taking into account geological, hydrogeological, and geotechnical factors, possible difficulty degree index system is show on table 3:

Table 3 Difficulty degree evaluation system

	Indices	Depth (m)
Regional stability and seismic geologic condition	Fault activity	0-100
	Seismic intensity	
	Site classification for construction	0-20
Topography and geomorphology	Geomorphic unit	0-100
Geotechnical engineering properties	Properties and thickness of soft soil	0-30
	Liquefaction index of sandy soil	0-20
	Thickness of liquefaction soil layer	0-20
Hydrogeology condition	Aquifer characteristics and distribution	0-100
	Inflow of single well	
	Groundwater causticity	
	Watery faults in bed rock	
Geological hazards	Karst area	0-100
	Goaf area	
	Ground fissure	

2) Quantitative indicator - Potential volume:
   It is determined by existing built environment constraints and urbanism regulations, possible potential volume index system is showed on table 4:

Table 4 potential volume evaluation system

Indices	depth (m)
Protection area per capita	0-100
Protection level of architectural area	0-100
Building height limit	0-100
Distribution of underground pipelines	0-10
Heritage conservation	0-100
Sensitivity of ecological protection area	0-100

Based on these two categories, further research work will be carried on to formulate comprehensive multi-criteria evaluation coupling Analytic Hierarchy Process and GIS tools to demonstrate constructability potential with 2D and 3D visualization on selected urban area.

Having a good understanding of excavatable urban area is critical for sustainable exploitation. While urban planners could designate functional type and scale of subsurface development, land resources managers could identify potential urban zones and layers to allocate subsurface land disposition for developers. This coordinated process enables rational exploitation of urban underground space, respecting the sustainable management principal of "from resources to need".

2.3 Administration procedure and management strategies:

After catching a global view of economic factors and institutional factors, pragmatic management procedure could be formulated to guide

[2] Based on the ongoing research project "Deep City China" collaborated with Nanjing Institute of Underground Space and Geo-environment (IUSG-Nanjing University). Geological condition of the research site is dominated by alluvial soft soil deposit.

governors and developers the way to optimize underground space and property development.

1) Initiate general guidelines by legislation bodies to sensitize rational subsurface development based on economic principals and geo-environmental protection goals.

2) Establish a professional committee coupled with Land Resources Management Department, Environmental Protection Department and Civil Defense Department, working out quality and quantity potential mapping of exploitable subsurface land, which will be added to conventional inventory of land cadastral register system. It serves as a basis for subsurface land appraisal.

3) Launch a multi-disciplinary research committee involved by Urban Planning Department, Urban Infrastructure Department, Urban Construction Department and Economic Planning Commission, working out a socio-economic demand forecast for underground infrastructure and construction types, which will fill the subsurface land system with commercial values.

4) Monitor and control urban underground space development, regulate the behavior of property developers, provide professional training modules to developers for knowledge improvement.

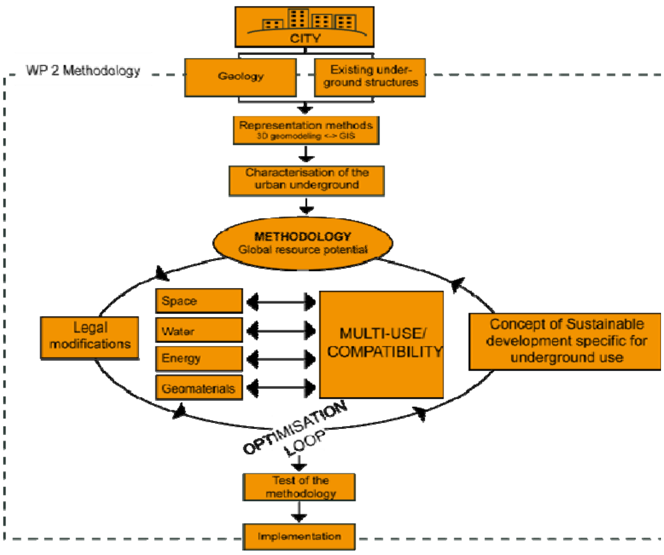
5) Dynamic management, taking into account new scientific knowledge, technologies, new environmental boundary conditions, security measures and socio-economic evolution.

3 INTEGRATED GOVERNANCE OF UNDERGROUND RESOURCES TO ATTAIN THE GOAL OF SUSTAINABILITY

This section emphasizes environmental protection planning and energy planning in the process of developing urban subsurface. Because this research direction has been not much mentioned in the previous development decades, it is necessary to embody the opportunity of going underground into the whole sustainable city transformation practice.

As presented in section 1.2 about urban underground resources (groundwater, geomaterial and geothermal energy), it exists a natural environmental network beneath our urban land. Each of these resources possesses countable value supporting urban life. Placing infrastructures and constructions underground challenges the natural state of these resources, causing feedback effects among underground agents, including the agents in built environment and geological environment. To have a comprehensive view of these feedback interactions enables urban governors and project owners to encourage synergetic exploitation (such as combine basement and foundation construction with energetic geostructures[3]), as well as to avoid the conflicts generated from incompatible exploitation (such as damaging drinkable groundwater during tunnel excavation).

The concept of “Deep City” was put forward in the framework of Swiss national research program NRP54 “Sustainable development in the built environment”. This project named “Underground resources and sustainable development in urban areas” developed a management methodology to optimize multiple exploitation of these underground resources in city perimeters, with detailed case study for the city of Geneva for methodological validations. Methodological scheme with multi-use approach to manage urban underground resources is showed below:



[3] Energy geostructures: http://lms.epfl.ch/energy-geostructures

In order to enlarge the applicability of this concept to much larger cities around the world, an ongoing project named “Deep City China” was launched with Nanjing Institute of Underground Space and Geo-environment. This comparative research between Swiss and Chinese contexts in terms of urban underground resources management, will focus on economic assessment of subsurface develop for selected urban areas in Yangtze River Region, and will investigate the feasibility of administrative and regulatory implementation. To guide the national application of the concept, territorial underground typology will be classified to customize urban management and resources governance.

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[i] This work was supported by the Sino Swiss Science and Technology Cooperation (SSSTC).