Tunnelling and Underground Space Technology 38 (2013) 569–580

Contents lists available at SciVerse ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

An integrated planning concept for the emerging underground urbanism: Deep City Method Part 2 case study for resource supply and project valuation

Li HuanQing [a,*], Li XiaoZhao [b], Parriaux Aurèle [c], Thalmann Philippe [a]

[a] Swiss Federal Institute of Technology in Lausanne (EPFL), Research Group on the Economics and Management of the Environment (REME), Switzerland
[b] Nanjing University, Institute for Underground Space and Geoenvironment (IUSG), China
[c] Swiss Federal Institute of Technology in Lausanne (EPFL), Engineering and Environmental Geology Laboratory (GEOLEP), Switzerland

ARTICLE INFO

Article history:
Available online 25 May 2013

Keywords:
Underground urbanism
Deep City Method
Supply inventory
Building project valuation
Suzhou city

ABSTRACT

Four underground resources have been seen as having long-term potential to support sustainable urban development: underground space, groundwater, geomaterials and geothermal energy. Utilization of these resources proposes a new paradigm of economic development: underground urbanism. The new management approach named "Deep City Method" is put forward to aid decision-makers to integrate global potential of the urban underground into city-scale strategic planning. The research output will be presented in form of two papers each with a different focus. Part 1 aims to introduce the concept, process and initial application in Switzerland; Part 2 is devoted to show methodological insight for a new zoning policy in China and investment scenarios for project cost viability.

The Part 2 paper will demonstrate a comprehensive evaluation methodology for underground resources beneath the municipality of Suzhou in China, in order to formulate 3D land zoning. Strategic districts in Suzhou city of China are selected for feasibility outlook and policy instrument proposition. Finally, a new economic index "Underground cost efficiency premium" has been proposed to aid project developers to justify competitiveness of underground development.

1. Operational level research of Deep City Method and case study in Suzhou city

After the strategic level research described in the Part 1 paper, specific operational steps are performed and illustrated in this paper to specify the integrated planning process (Fig. 2 in Part 1 paper) and to make it adoptable and transferable to other cities around the world. A multi-scale approach is used for illustrating the operational feasibility of the Deep City Method.

- *Urban scale*: the urban context of the pilot city is analyzed. Supply and demand schemes of underground space are evaluated, simulated and mapped with an integrated potential zoning indicator. Districts having a representatively high integrated potential were identified.
- *Land parcel scale*: selected districts are analyzed with multiple criteria, including land quality, land value, and legal rights. It is at this scale that a new economic indicator "underground cost efficiency premium" is put forward, proposed as a potential specification of 3D land parcel valuation.
- *Project scale*: project scope differs to meet particular urban needs (defined here as *densification* or *revitalization*). With variation in project scope, cost (land and construction) and benefit (direct saving in land acquisition) levels vary. This variation is defined as "rate of underground development", which induces a series of changes in economic gain.

All the macro indicators (resource capacity, municipal demand level) and micro indicators (land parcel quality, land price, project scope) were aggregated into two main criteria: development potential and economic efficiency premium. Six characteristics of urban underground asset determine specific measures to be implemented for urban level operation, as listed in Table 1 below:

2. Building information platform as the first step for an integrated planning process

A comprehensive underground urbanization strategy requires a significant amount of information on the urban scale: land quality related to geological foundation, groundwater reserves, construction material and energy sources, existing built environment layout (buildings, transports, utilities, and greenery), land use plan, district level zoning rules, housing capacity, functional space demand, land parcel inventories and real estate marketability.

* Corresponding author. Tel.: +41 216939398.
E-mail addresses: Huanqing.li@epfl.ch (H. Li), lixz@nju.edu.cn (X. Li), Aurele.-parriaux@epfl.ch (A. Parriaux), Philippe.thalmann@epfl.ch (P. Thalmann).

0886-7798/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tust.2013.04.009

Table 1
Specific measures proposed by Deep City Method to manage urban underground asset.

Asset features	Measures	Facts revealed from Suzhou city case study
1. Scarcity	Asset reserve inventory	In the total reserve of urban underground space, effective usable volume is limited to 30% for shallow construction land (0–30 m depth), reduced by existing below ground structures and foundations, legal protection limits and technical achievable limits. The inventory has to also take into account water, energy and material resources below the city
2. Diversity	Allocation by districts	Quality of underground resources varies among districts, requiring different district level planning approaches for underground urbanism
3. Variability	Dynamic forecast	The effective use volume can be increased due to technological advancement and financial ability, meanwhile helping to adapt to gradual demand growth
4. Vulnerability	Global cost estimation	As certain assets become more vulnerable during operation period (land subsidence, water pollution), opportunity cost will increase. Synergetic exploitation plans help to internalize this cost.
5. Irreversibility	Resilient solutions	The use type of underground space should be resilient and adaptable to future development trends, such as aging populations, industrial restructuring, and life style changes
6. Profitability	Project appraisal	Due to high capital costs, the benefit of using underground should be justified based on market value of floor spaces and price of resources

The quality of information can influence project implementation. While a good understanding of the urban underground depends on substantial geological investigation, the land management institution should add administrative issues to the resources survey. Previous geological surveys have been concentrated on mineral resources prospection (metal, gold, oil, gas, coal, rare earth, etc.), which were driven by their increasing value as primary material supply (Salisbury and Salter, 1941a,b). An accurate estimation of underground mineral resources helps to project future exploitation according to technological level and human demand. The same principle is applied in urban subsurface development (Paul et al., 2002), which requires a comprehensive knowledge basis for understanding the truth of natural assets beneath the cities.

Technological advancement enabled our deep vision of using the subsurface, including prospection methods and construction techniques. Innovations in tunnel design and construction process have been helping reduce costs and time of project execution (Sterling, 1992; Brierley and Drake, 1995; Beer, 2010; Goel et al., 2012). Contribution of geothermal exploitation for heat and power generation has been increasing since 2010 (OECD/IEA, 2011), while capital cost is expected to decrease by 2020 (OECD/IEA, 2010). Challenges for using subsurface and energy resources are linked to higher investment costs and development risks such as subsidence. Substantial R&D input should be promoted for accurate resources potential prospection and for upgrading related equipment.

A resilient city needs urban services to adapt to human demands in the context of population growth or de-growth. For the new megacities around the world, intensification of urban demands in housing, working, commuting and networking can be relieved by using underground infrastructures for providing services (utility, transport and civil protection) and spaces (commercial and residential). Infrastructure planning should be coordinated with land use planning, in order to serve the right place with the right resources in an economically viable way (Kivell, 1993; Jenks et al., 1996; Jenks and Jones, 2010).

3. Potential zoning for large urban scale and underground asset development forecast as the second step for an integrated planning process

A pilot study with a large urban scale reveals important implications for emerging urban agglomerations and metropolitan areas around the world, in terms of flexible underground development. The city of Suzhou in China's Yangtze Delta Economic zone was chosen to represent emerging metropolitan areas in China, as one of the Chinese cities to have grown significantly in the past 15 years. It is one of the pilot cities in the national program of urban geological information platform building, supported by the State Land Use Institution in China.

The evolution of developed areas in Suzhou is shown in Fig. 1. The built-up area surface quadrupled in less than 10 years after the land reform policy (Fig. 2).

Underground development is divided into four layers for two reasons: Firstly, shallow layers (15 m, 30 m) are usually used for different basements of buildings, where additional land acquisition is unfeasible on the surface; large linear public infrastructures occupy deeper layers below 30 m (Nishioka and Tannaka, 2007). Secondly, technological investment is different for shallow and deep underground: the cut-and-cover excavation method works for the shallow subsurface while deep underground projects (subway, tunnel, and large utility lines) requires high level tunneling technologies. In its local context of China, the subsurface construction costs around 3000 CNY/m^2 and deep tunneling costs above 100 million CNY/km.

According to a constructability evaluation by colleagues at the Chinese Deep City research group (Cao, 2012), approximately 20% of built-up area in the urban zone has good constructability for shallow underground projects (0–15 m) with a lower percentage for the deeper layer (Table 2, Appendix A). Based on the estimation of underground space supply potential shown below, using underground space can help to save nearly 22% of current built-up area, which could contribute to a significant savings in future land acquisition and in financing additional infrastructures to urbanize the sprawling surface.

Despite the scarcity of high quality land for underground space construction in the city center, the rich groundwater reserve, geothermal energy potential and high urbanization demand score the city as an applicable target for underground urbanism. With the foreseen demographical growth of Suzhou city, the ability to provide sufficient living space and adapted public infrastructures is essential for its social-economic development. Its rapid development allows the city to be the first second-tier level municipality operating metro lines, adapting to its growing demand (3.46 million urban habitants, with a density of 11,596 inhabitants/km^2).

The buildable underground space offers a potential per capita land use increment of 20.79 m^2 and a capacity to provide more urban amenities on the surface. The neglected potable water aquifers can relieve the city's water supply deficiency, which is one of the hindering factors (others include energy source and quarry material) for its growing economy relying on exogenous resources supply (Suzhou, 2003). In order to unlock this resource potential and to confront the limits to growth, urban underground asset management is urgent and critical.