THE WAY TO PLAN A SUSTAINABLE "DEEP CITY": THE STRATEGIC FRAMEWORK AND ECONOMIC MODEL

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Abstract

Underground infrastructures and buildings are new urban forms. This paper will give an overview of the strategic framework for developing and managing urban underground space (UUS) development, which represents a rational iterative process going through steps of "criteria framing", "data building", "city-scale zoning", "project-scale evaluating", "decision analyzing", and "policy making". Each step will be illustrated in detail, while we will mainly focus on project evaluation by introducing new urban economic indicators, and on decision analysis by using decision criteria in scenario analysis.

Optimization of urban underground space use has to take into account social-economic demand and supply capacity of geo-space resources. Urban development land can be classified based on a zoning system mapping subsurface integrated quality, which is an indicator combining engineering constructability and development value of below-ground space. Based on this macro-zoning of UUS at a city scale, high potential land parcels can be selected or stock-taken for short-term development, while special protection area can be reserved for valuable geo-resources protection for long-term use.

An economic model is developed to perform micro-analysis for project scenario evaluation. Two economic indicators ("underground development rate" and "underground premium") will help to integrate underground options into real-estate project appraisal. The decision criteria will take into account direct and indirect costs generated along the project life cycle, developer gains and social benefits for the whole community, opportunities for synergetic resources exploitation (e.g. geothermal energy use), and risks induced by sectorial development patterns (e.g. groundwater damage). These main criteria of cost, benefit, opportunity and risk are useful for decision-makers to promote urban subsurface projects in a sustainable way. At the end, a multi-criteria decision-making process with performance indicators will be demonstrated, designed to guide strategic development and policy making.

The improvement in policy making will further change the "criteria framing" for successful underground development practices, enabling a continuous improvement cycle for underground space management in urban areas.

Keywords: urban underground resources, economic viability, strategic framework, Deep City, sustainability

1 Introduction and Purpose

1.1 Integrated management concept for urban subsurface

Cities are economic growth centers hosting nearly 50% of world population and having the capacity to provide best services for high quality of life(Programme 2009). The drawback is that these successful centers are getting more and more congested with expanding occupation of production, service, living space, public infrastructures and decreasing greenery amenities. While cities evolve from industrial to centers of services and administration, the quality of urbanism is playing an important role in city development and governance. While maintaining the basic service of infrastructures, investing in urban quality is becoming a priority among city governors. Big cities facing population immigration have to provide more living space and related services, making urban land and other resources more and more valuable and scarce. In order to enable a city to survive and to sustain economic and demographic growth, a rational management pattern of land and other resources should be at the top of urban development planning agendas. Urban sprawl is to be avoided because it leads to higher infrastructure costs (larger transport and utilities networks), as well as higher energy consumption for low-density living (enhanced use of cars)(Burchell, Administration et al. 1998). Obviously, cities are facing "limits to growth" and calling for innovative development strategies and sustainable renewal by favoring compact city patterns(Jenks, Burton et al. 1996).

Urban growth is facing two emerging problems: 1) shortage of resources, due to unsuitable exploitation processes; 2) lack of value chain to create growth, due to inappropriate policy making or insufficient capacity building. Therefore, ways to support urban growth could be resources-oriented or institution-oriented. *Resources-oriented management* focuses on the protection or optimal exploitation of basic resources (land, water, energy, materials and so on), establishing a self-sufficient society in a value-protected environment. Resources-oriented management is a development pattern giving priority to respect "supply limits of resources". On the other hand, *Institution-oriented management* focuses on value creation and revenue generation by enabling project opportunities, facilitating participation of all interest groups and implementation of constructive action plans. Institution-oriented management is another development method which gives priority to "satisfaction of people's demand". In the logic of "sustainable development", urban governance in the new era has to combine environmental protection and economic growth, that is, resources-oriented management with institution-oriented management. This integrated approach meets the needs of sustainable urban growth.

The aim of this research project is to put forward a new management methodology for urban underground space (UUS) development, taking into account the economic potential of UUS and the global benefits to urban quality of using it better. As UUS is part of urban land resources, 3D urbanism should not only manage building heights and skylines but also the space potentials below ground (Parriaux, Tacher et al. 2004; Admiraal 2006). "3D urbanism" concept is to couple resources-oriented management with institution-oriented management, integrating the supply scheme of resources with the demand scheme of human society:

- *Resources-oriented 3D urbanism* gives priority to underground resources protection (including land, water, energy and material, see Figure1)(Parriaux, Blunier et al. 2010), by identifying future resources use potential (Blunier 2009) and zoning to a "*development reservation area*". For example, reserved areas for drinking water exploitation, reserved areas for material mining, and reserved areas for deep geothermal systems. These legalized areas are placed outside of construction authorization schemes.

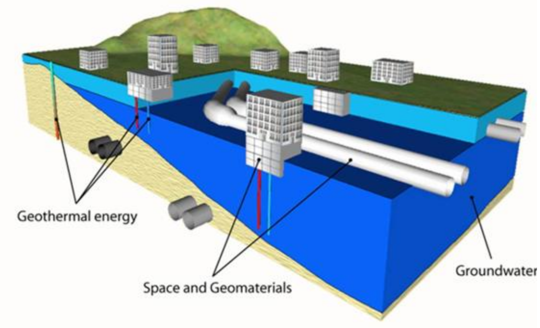


Figure 1 Deep City model with four main resources

- *Institution-oriented 3D urbanism* focuses on the social demands of development projects, located outside "development reservation areas". The aim is to find an optimal way to develop underground projects. By analyzing economic values and social values, decision criteria will be developed to balance the interests of different stakeholders in the public and private sectors. Through a multi-criteria decision-making process, project scenarios will be evaluated and compared. Feedback from the decisions will give implications on policy making, in order to adapt to development demand.

1.2 New urban forms with underground development trend

Major use of urban subsurface can be classified into two basic functions: infrastructure networks and building space. While infrastructure networks are acting as the city engines for surviving and growing, building spaces provide complementary space resources to locate various human activities (profit-generating services such as commercial, cultural, recreational centers, which are usually windowless and widely accepted to be underground)(Nishi, Kamo et al. 1990; Durmisevic 1999; Nishida, Fabillah et al. 2007; Maire 2011).

1.2.1 Underground infrastructures

Along with the rapid development of metro systems in big cities, UUS has been exploited as part of urban land resources, providing protective space for infrastructures such as road tunnels, water systems, sewage systems, energy supply networks and cable networks (Annica 2000; Nishioka, Tannaka et al. 2007). With technological advancement on renewable energy utilization, deep geothermal systems will begin to emerge in urban area (see Figure 2).

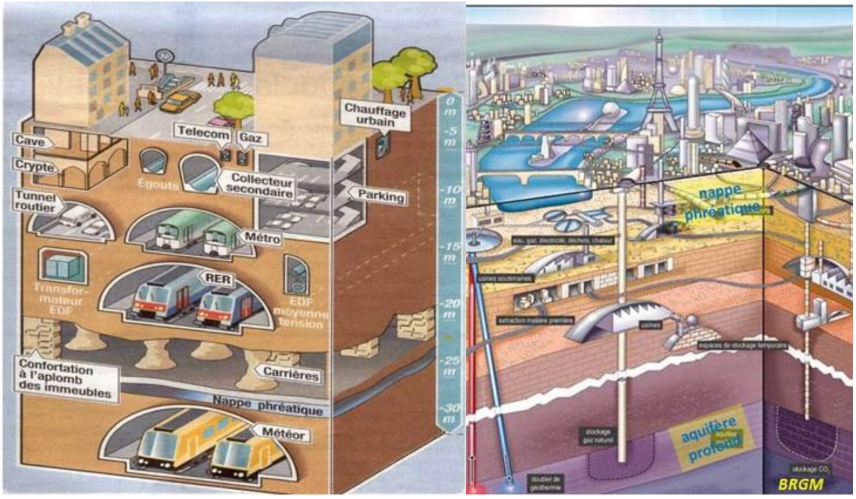


Figure 2 Underground facility functional illustration, city of Paris (Duffaut 2010)

"Underground development" trends of urban infrastructures are driven by various surface development forces:

- *Land use pressure*: the competition of buildings forces more and more facilities to be placed underground. Since they are often large scale facilities, burying them releases large area at central locations (Don V 1996; Tajima 2003). For new infrastructures it has become nearly impossible to find space over ground. The share of infrastructures placed below ground is highly related to the urban population density (Bobylev 2009).

- *Increasing land prices*: real estate property development, particularly high-rise, is creating huge opportunity costs for land reserved for public use. Moving public facilities underground helps to reduce land costs, respectively it makes it possible to sell the surface area. The price factor has contributed to the emergence of a new legal system for deep space (40m depth) in Japan (Nishioka, Tannaka et al. 2007).

- *Environmental impacts*: belowground transport systems causes less noise and less smoke than surface transport (bus, car) during operation time, reducing pollution in the city, it may also reduce road congestion (Girnau and Blennemann 1990).

1.2.2 Underground buildings

Underground commercial centers become common in central business districts. For example, subterranean shopping centers in Japan have become its major business space (Japan Tunnelling, Takasaki et al. 2000). Montreal's "indoor city" network connects subterranean commercial areas with metro stations. Its comfortable underground pedestrian network enables citizens to pass through the center freely during severe weather (Daniel J 1991; El-Geneidy, Kastelberger et al. 2011). Although cost of underground construction is higher than over ground, this is partly or fully offset by smaller surface land investment, and more commercial and service space. Several empirical researches have shown that the external benefits of these spaces could be considerable (Nishi, Tanaka et al. 2000; Lin and Lo 2008). Architects and planners are increasingly interested in UUS developments in crowded business districts as a response to increase demand for density (see Figure 3) (Carmody and Sterling 1993; von Meijenfeldt and Geluk 2003; Okuyama 2007).

Energy consumption of underground building during operation will be lower than surface building (heating and cooling consumption), due to better thermal isolation capacity (Monnikhof, Edelenbos et al. 1999; Maire 2011). This long-term benefit will encourage the future promoters to invest on underground building projects, for the reason of reducing considerable power expenses. On the other hand, more artificial light and ventilation is needed.

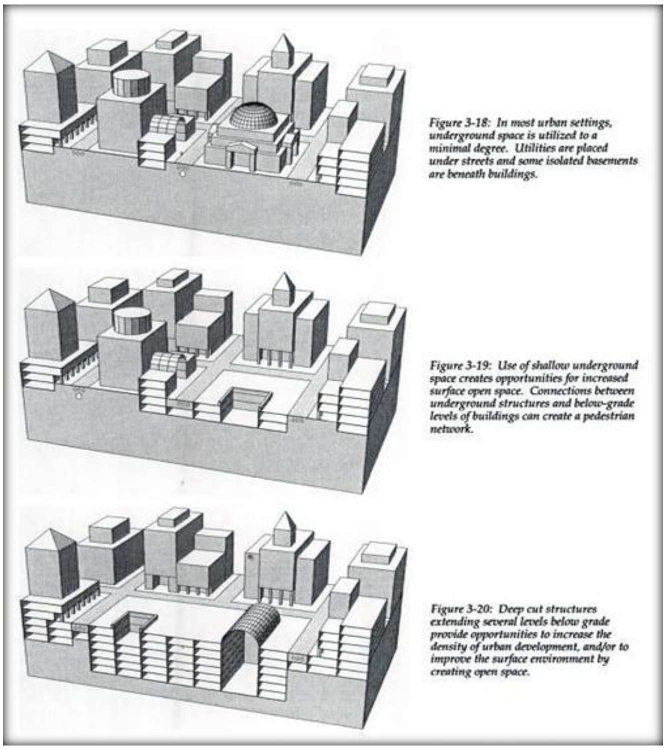


Figure 3-18: In most urban settings, underground space is utilized to a minimal degree. Utilities are placed under streets and some isolated basements are beneath buildings.

Figure 3-19: Use of shallow underground space creates opportunities for increased surface open space. Connections between underground structures and below-grade levels of buildings can create a pedestrian network.

Figure 3-20: Deep cut structures extending several levels below grade provide opportunities to increase the density of urban development, and/or to improve the surface environment by creating open space.

Figure 3 Underground building configurations in urban center (Carmody and Sterling 1993)

Since the development value of underground building space has not yet been well documented worldwide, this paper will derive project typologies related to UUS construction, which is used for urban densification to meet demand linked to economic growth, and for urban revitalization to meet the demand for quality of life.

2 The Strategic Framework for Urban Underground Space (UUS) development

2.1 A rational analytic process for sustainable development

Current development of underground space in cities is facing coordination dilemmas: on one side, public infrastructures are growing fast and going deep; congestion and disorder hinder future development (Sterling 2005); on the other side, private developers are playing a major role in property development but lack cognition of subsurface potential and comprehensive decision-making. The process proposed below (see Figure 4) is an ideal facilitating procedure to frame a comprehensive decision platform, linking public and private actors into new subsurface urbanism plans. It is also an "*underground development value chain*" combining multiple competences for creating economic growth and meeting urban space demand while optimizing the use of the underground in the city.

- Step1: accumulate critical success factors from best practices around the world and select public instrument references;
- Step2: collect local urban data for problem diagnostic and solution feasibility study;
- Step3: map the city with different levels of potential use, based on comprehensive but simple indicators;
- Step4: assess project typologies and introduce new economic indicators for project evaluation;
- Step5: lever the scenarios with multiple decision criteria, to guide project implementation;
- Step6: propose new institutional tools or legal instruments to improve the public management process.

This new strategic and operational process dedicated to urban underground development, is based on the classical theory of rational problem-solving processes (Patton and Sawicki 1993). The continuous improvement loop showed in Figure 4 helps to develop a long-term vision and planning methodology for sustainable subsurface use in urban centers. The result is an "integrated planning" tool linking multiple spatial scales (international, national, municipal, local, parcel), multiple institutional levels (political, scientific, planning, implementation) and specific planning methods and instruments.

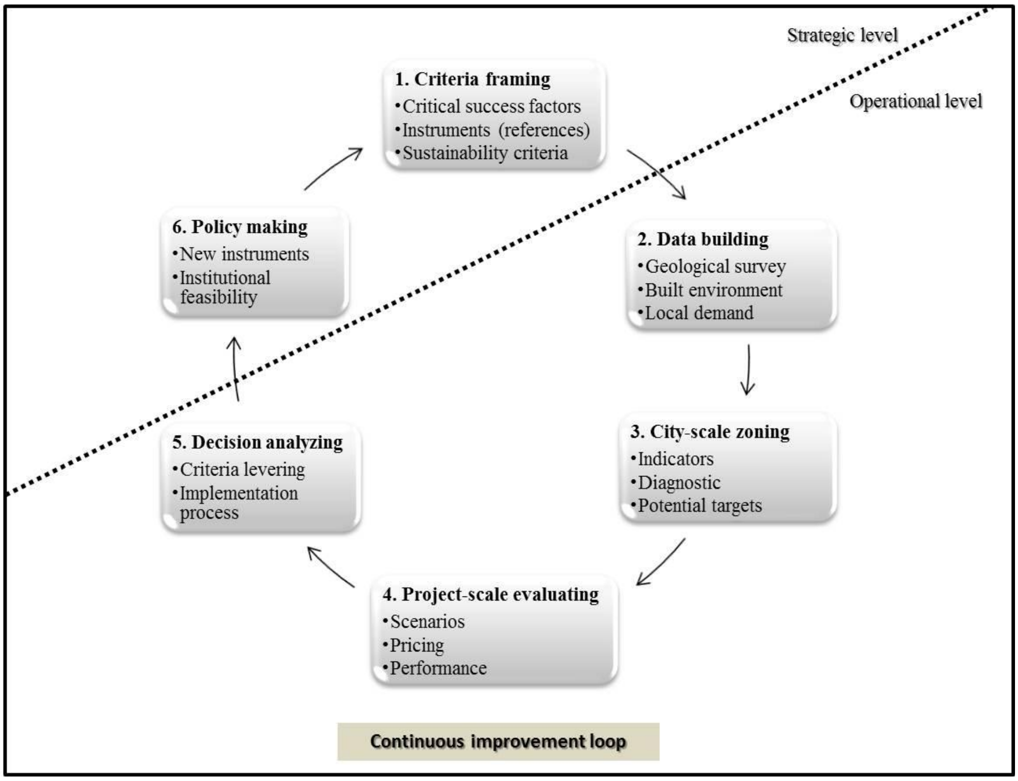


Figure 4 Iterative analytic process

The remaining of section 2 will demonstrate step1, step2 and step3 with general policy insights from five leading cities and a concrete zoning instrument case study in China, Section 3 will illustrate step4 and step5 for project assessment.

2.2 Policy analysis for five leading cities in underground space development (<u>step1, strategic level</u>)

International best practices are valuable resources for cities to learn from experience. Urban governance is evolving due to the continuous changes of the global context (Bevir 2011). Policy innovation is required in order to adapt to further development need and economic growth. Sustainable guidelines have been on the way to fully incorporate into urban development policies, making public governance face more and more challenges to resolve the global and local issues regarding limited resources, increasing economic demand, and imbalanced social interests (Desire for more floor space or more green space? Build a compact city or garden city? etc.).

Five representative cities in the world were selected for their comprehensive plans for UUS development. These cities drafted and implemented their plans to cope with land scarcity, congestion, high prices of land acquisition, deterioration of the built environment, renovation of infrastructures and regeneration of living spaces. These plans are summarized in Table 1, based on literature reviews and personal communications. It is far from exhaustive, however, it is useful to position policy preferences according to referential instruments or methods, as well as to initiate institutional collaborations to launch operational actions.

Table 1 Catalogue of successful policy references from five leading cities in underground space development

Cities	**Strategic plans**	**Milestones in Policy History**	**Capacity building with Collaboration bodies**	**Instruments and Methods**
Amsterdam	*AMFORA* (Alternative Multifunctional Underground Space Amsterdam) (Rein 2009)	• 1998 policy initiation for assessing "underground development" possibility(Monnikhof, Edelenbos et al. 1998) • 1999 policy application on Great Randstad spatial planning revision(Monnikhof, Edelenbos et al. 1999) • 2008 mainstream into Amsterdam Action Plan Healthy City	• COB (Netherlands Knowledge Center for Underground Space and Construction) • TUD (Delft University of Technology) • RPD (National Physical Planning Service) • Ministry of Housing, Spatial Planning and Environment(Edelenbos, Monnikhof et al. 1998)	• Layered land planning and Area-scale mapping • Multi-criteria decision making process(Monnikhof and Bots 2000) • Economic valuation for resources(ir. K.R. Weytingh and Roovers 2007)
Montreal	Indoor City Master plan (Boisvert 2004)	• 1960s conception and initiation • 1970s network expansion (RESO) • 1980s maturity with functions (commerce, mobility, institution, office, culture)(El-Geneidy, Kastelberger et al. 2011) • 1992 adoption of Master Plan • 2002 revision of Master Plan	• OVI (L'Observatoire de la Ville Intérieure) • University of Montreal • City Council of Montreal • Association of owners (ARQIM) • CNR (Canadian National Railway) • STM (Société de Transport)(Besner 1997)	• Public-private partnership(Boisvert 2007) • Land use rights and incentives(Besner 2007) • Layered planning and inventory (Boivin 1989; Boivin 1990)
Tokyo	Deep Space Utilization Law (Nishioka, Tannaka et al. 2007)	• 1955 construction of large volumes of underground shopping arcades • 1965 "Golden age" • 1980 regulation restriction • 1988 promotion of effective land use with subsurface • 2000 new legal system(Japan Tunnelling, Takasaki et al. 2000)	• USJ (Urban Underground Space center of Japan) • JTA(Japan Tunneling Association) • Investigation Committee for Deep Underground Space use • (MITI) Ministry of International Trade and Industry(Tetsuya 1990) • Urban Development Department • National Land Policy Institute	• Legalization of deep space (-40m public domain) • Planning method for zoning(Barles and Jardel 2005) • Numbers of building investigations and social surveys (Nishi, Kamo et al. 1990; Nishida and Uchiyama 1993; Nishida, Fabillah et al. 2007; Okuyama 2007)
Helsinki	Underground Master Plan (VÄHÄAHO 2009)	• 1955 database building (Real Estate Department 2005) • 1996 initiation of feasibility study for underground space(Rönkä, Ritola et al. 1998) • 2006 working group on 3D property cadastral system • 2009 adoption of rock space Master Plan	• Helsinki City Real Estate Department • Geotechnical division • Ministry of Environment • Land use department • Ministry of Agriculture and Forestry (3D cadaster)	• Detail mapping of existing & planned facilities and potential geo-space(Chow, Paul et al. 2002; Paul, Chow et al. 2002) • Public acquisition of land • Legalization of underground (rock) space utilization
Paris	Development Program (*Ville 10D*) (Labbé 2011)	• 1972 initiation study for underground urbanism(Utudjian 1972) • 1995 feasibility research for underground urbanism(Barles and Guillerme 1995) • 2006 policy initiation for sustainable subsurface use • 2010 action plan of "Ville 10D"	• Underground Space Committee (AFTES-COMES) • Regional Economic and Social Council • Ministry of Ecology, Energy and Sustainable Development • IREX (Institut de la Recherche appliquée et l'Expérimentation en génie civil)	• Economic valuation for subsurface use right(Barles 2000) • Integration with existing planning instruments(Barles 1999) • Sustainability indicators (M. Deffayet and d'Aloïa-Schwartzentruber 2011)

2.3 Case study for zoning instrument (step3, operational level)

Public instruments such as zoning are common policy in urban planning systems. Leading cities have tried to map the regional suitability of underground construction, using technical parameters and spatial maps. Along with technological advancements in field survey and data treatment, the process of urban diagnostic has been facilitated. Scientific outputs (engineering geology, civil engineering, geography, urban economics, and social science) from step2 in the strategic framework could be well incorporated into planning practices under operational initiation of public policy.

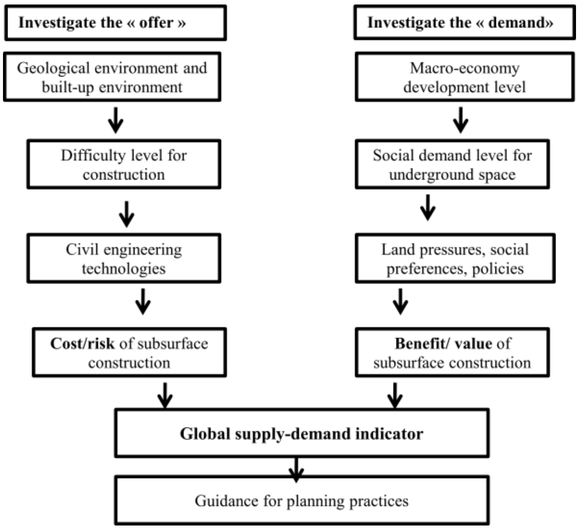
A case study used by the international collaboration project Deep City is demonstrated here. It is based on the context of a large Chinese city, Suzhou (East Yangtze region, urban population of 4 million, urban density of 2500 hab./km^2), which launched a regional-wide scientific survey to investigate the suitability of underground space construction(Cao, Li et al. 2011). The main goals are to alleviate urban congestion and pollution and to protect its central historic area. Detailed parameter weightings and mappings can be found in (Li, Parriaux et al. 2011). The output of mapping for macro-zoning is further used for project-scale evaluation with micro-analysis (economic feasibility and acceptability of specific project type) in Section 3.

- Macro-zoning system for land valuation (city- scale)

Urban projects are developed in response to economic attraction and social demand. For real estate projects, locating on high price land indicates higher property price for commercialization, if construction prices remain the same. However, if we take into account the economic potential of UUS, the existing land value distribution will be different. Underground land quality determines construction costs, which implies that, a parcel of high surface value can have lower value for "underground development", due to bad quality for excavation engineering. On the other hand an abandoned industrial land with low land price can be exploited by developers for its good soil quality, to build underground parking or subterranean logistic centers and create a green park above. This generates revenues for the land owner and good renewal environment for the community. Similar case can be seen in Helsinki(Ilkka 2011), a waste water treatment plant under a new residential area. Two indicators (supply and demand) will be integrated through multi-criteria evaluation to map the appropriateness of urban land parcels (see Table 2).

This macro-zoning system aims to classify the urban land into several development levels: high potential, moderate potential and low potential (See Figure 5). *High potential areas (blue-colored)* can be short-term development targets, using the underground to create more urban growth; *moderate potential areas (yellow-colored)* can be reserved for long-term exploitation; *low potential areas (brown-colored)* are prohibited zones due to sensitive condition or highly protected resource reservation (e.g. groundwater, material, heat source, mining). With future demand dynamics, distribution and mapping of these zones can vary and they can be re-affected.

Table 2 indicator building for macro-zoning of UUS



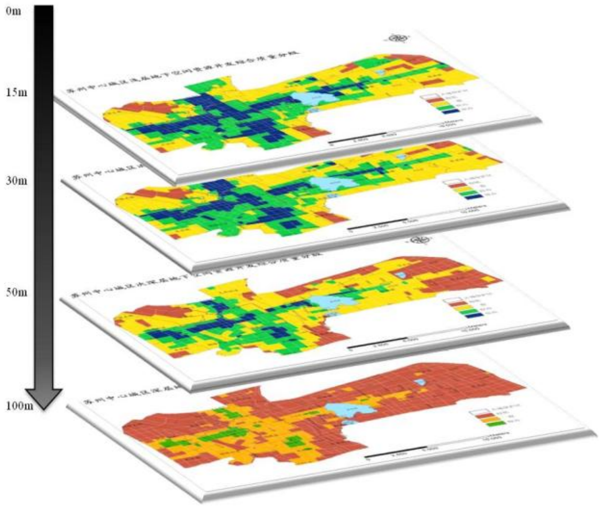


Figure 5 macro-zoning results, layered approach (Suzhou city, 0m-15m-30m-50m-100m depth)

3 Economic model and decision-making for underground building projects

3.1 New indicators for planning and appraisal practices (step4)

3.1.1 « Underground development Rate[1] » for space measurement

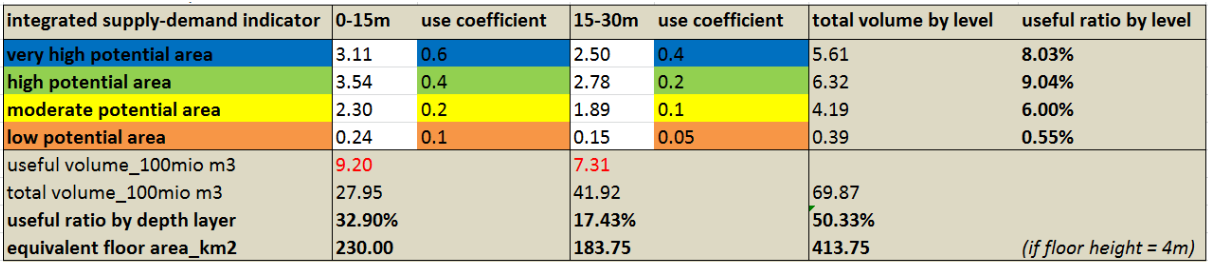
Density is commonly measured by the FAR[2]. Regulation on FAR can influence land consumption, related to projected population increase and living quality (Bertraud 2007). Using underground space to densify the city without overpassing building height limits, should be estimated quantitatively to understand and forecast its exploitation potential (Bobylev 2010). Urban subsurface is a non-renewable resource, meaning its exploitation will reach a limit. Multiplied by engineering constraint factors, the usable quantity/volume could be reduced (the use coefficient will be influenced by technical progress). The demand for densification has also a limit; excessive densities will reduce quality of life (O'Sullivan 2009). Combining the factors of resource supply capacity and land/space demand should guide planners about how to develop the underground in a careful way.

- Case study: Forecasting exploitation quantity of UUS along with urban growth

The central city area of Suzhou covers 280km², including a famous historic town, a CBD and a new development district. Current state of deep development reaches 15m below the surface, and short-term growth of its UUS is supposed to extend to the depth of 30m below ground level. With contribution of underground densification, the city can afford more future construction space without causing urban sprawl.

- *Status of 3D land use supply*: For the 30m deep urban land, total effective constructible floor space is about 413km², designing sub-floor heights of 4m for better architectural effect (See Table 3)

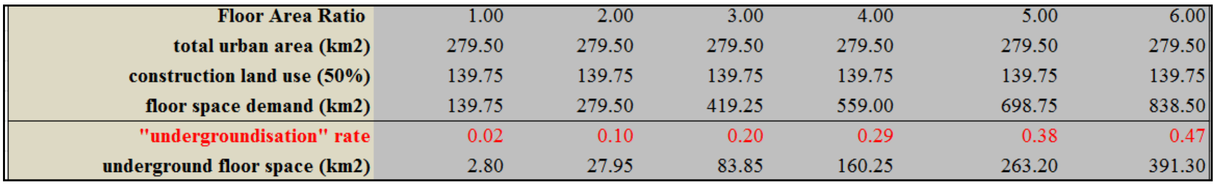
Table 3 Supply forecasting for UUS in the short-term (to 30m depth)



integrated supply-demand indicator	0-15m	use coefficient	15-30m	use coefficient	total volume by level	useful ratio by level
very high potential area	3.11	0.6	2.50	0.4	5.61	**8.03%**
high potential area	3.54	0.4	2.78	0.2	6.32	**9.04%**
moderate potential area	2.30	0.2	1.89	0.1	4.19	**6.00%**
low potential area	0.24	0.1	0.15	0.05	0.39	**0.55%**
useful volume_100mio m3	9.20		7.31			
total volume_100mio m3	27.95		41.92		69.87	
useful ratio by depth layer	**32.90%**		**17.43%**		**50.33%**	
equivalent floor area_km2	**230.00**		**183.75**		**413.75**	*(if floor height = 4m)*

- *Variation of 3D land use demand*: burying deeper helps to alleviate land use pressure by high-density development. Under proximate simulation, for attaining a density level of 6, a 47% "underground development" share needs to place nearly 400km² floor area below ground (Table 4).Compared to the supply quantity of 413km², this demand can be met.

Table 4 Demand forecasting for UUS in short-term, densification trend



Floor Area Ratio	1.00	2.00	3.00	4.00	5.00	6.00
total urban area (km2)	279.50	279.50	279.50	279.50	279.50	279.50
construction land use (50%)	139.75	139.75	139.75	139.75	139.75	139.75
floor space demand (km2)	139.75	279.50	419.25	559.00	698.75	838.50
"undergroundisation" rate	0.02	0.10	0.20	0.29	0.38	0.47
underground floor space (km2)	2.80	27.95	83.85	160.25	263.20	391.30

This new indicator can be integrated into conventional urbanism regulation, creating records for subsurface use quantity and enabling continuous monitoring and measurement of underground development. Further research can continue to simulate the dynamics of underground development with economic growth scenarios or technological progress stages for long-term development. If the indicator can be legalized by public policy, an instrumental advancement could be generated, connecting subsurface use to the surface planning (step6).

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[1] "Underground development" rate = total underground floor space/total urban construction floor space.

[2] Floor area ratio = floor space area / land area.

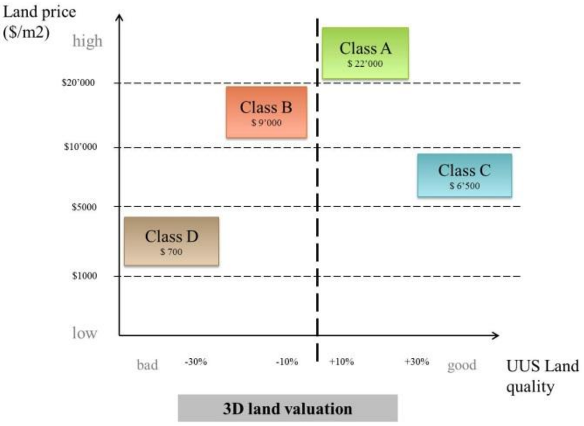
3.1.2 « Underground Premium » for 3D land pricing

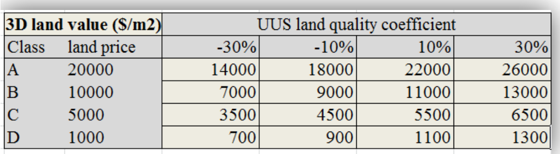
Academic contributions on underground space pricing have been focusing on methods to evaluate "subsurface land value" for underground infrastructures expropriation costs (Riera and Pasqual 1992; Barles 2000; Pasqual and Riera 2005) and for underground commercial space leasehold price in business districts (Wang, Yang et al. 1995; Wang and Cheng 2006; Chen 2010). For example, along with national policy initiations(Shu, Peng et al. 2006) to cope with increasing use of urban subsurface in China, several Chinese real estate researchers have developed methods to calculate the "*correction coefficient for subsurface use rights*" by different underground floors (Tang and Yang 2011). The aim is to serve the future policy of "*underground space use right certificates*" assigned to underground building developers with a reduced tax compared to surface land use right(Wang, Cao et al. 2009). Planning regulation will affect land parcels specific market values, linked to the permitted density (FAR), authorized use (facility, industrial, commercial, residential), infrastructure level (utility, transport, and services), etc. While a planning policy is being formulated for urban underground space, a *3D land valuation* process should also emerge into policy making practices.

Although researchers pointed out that there will be a subsurface land market in the future due to the increased use of UUS (Barles and Guillerme 1995; Pasqual and Riera 2005), this solution is not a simple administrative tool but it involves lots of legal issues and fiscal feasibility uncertainties. Since the legal context of land property rights differs among countries(Michael 1991), there is not yet a universal solution to deal with subsurface property rights. Some cities initiated a specific depth limit of ownership for underground public infrastructures (e.g. Helsinki and Tokyo in Table 1). For underground building projects, workable valuation methods have to align with existing surface land regulations and adapt to existing market rules. The authors put forward a new indicator named "*underground premium*", in order to integrate the subsurface value into existing land prices. The projected potential of underground space will be embedded into land market values, linked to "permitted underground development rate" (see section 3.1.1) and authorized use (facility, industrial, commercial, recreational, cultural), etc. A positive premium stands for profitable "*underground development rate*" due to lower construction costs or lower facility relocation costs (See Figure 6).

The structure of macro-zoning (see section 2.3) favors the rational selection of priority development zones to become investment targets. As different land use types have different underground use value, with commercial land and mixed use land having higher development potentials for "underground development". The tradable land parcels on the market can be restructured according to their land price and their exploitable underground potential, a *re-pricing coefficient* "*underground premium*" can be created to lever the integrated value variation. This land value restructuring helps to incorporate the economic potential of using underground space into market land price. It gives implication to the land owners about how to develop an underground property project in a rational way.

In high potential areas in general, land parcels to be developed can have different interpretations of real value. The potential subsurface development can be incorporated into existing land prices with premiums reflecting the differences of subsurface economic returns. Low "UUS quality" indicates higher construction costs for underground space. Decisions on land acquisition can combine UUS quality indicator with business potential of the location, developers can also adapt the real estate project plans to the 3D land value class (Figure 6).





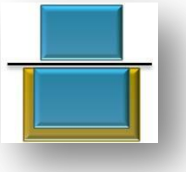
3D land value ($/m2)		UUS land quality coefficient			
Class	land price	-30%	-10%	10%	30%
A	20000	14000	18000	22000	26000
B	10000	7000	9000	11000	13000
C	5000	3500	4500	5500	6500
D	1000	700	900	1100	1300

Figure 6 3D land valuation

3.2 Scenario analysis to choose the right project at the right place (step5)

3.2.1 Underground building project typologies in a "Deep City"

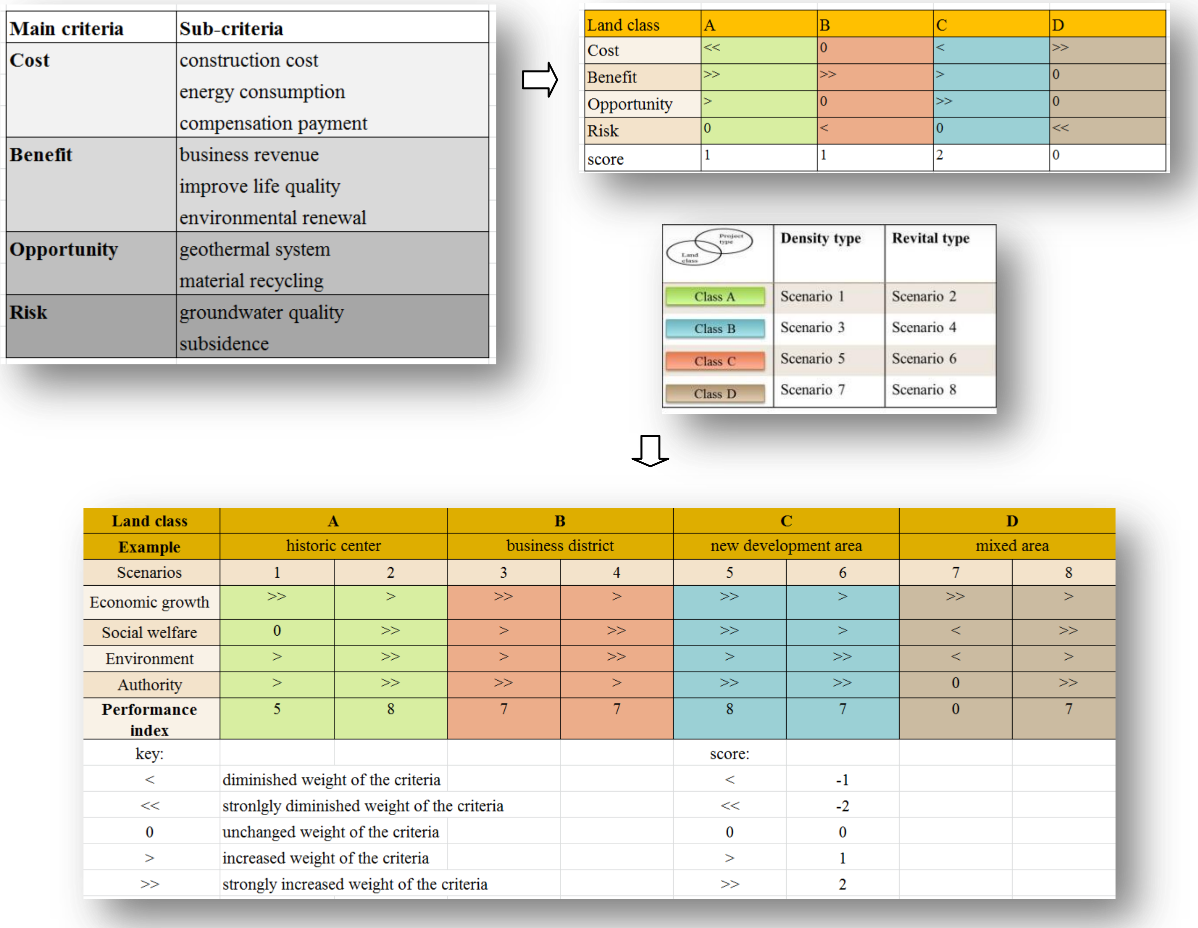
- *"Density type"* (compact city concept): With building height limits in certain urban centers such as historic areas or high land prices in prestigious business districts, underground densification can generate more commercial floor space without causing legal conflicts, as for example Place Ville-Marie in Montreal (Besner 1997). Pedestrian space can follow the underground densification trend by connecting building points and subway stations to the whole "indoor city network"(Bélanger 2007; Boisvert 2007).



- *"Revital type"* (garden city concept): With construction restrictions on public open spaces or greenfield zones, underground revitalization can release walkable surface and greeneries for public enjoyment as for example in the Paris Les-Halles complex (Duffaut 2005), Arnhem art school (Bodegraven 2008), Sapporo shopping center (Golany and Ojima 1996) and Amsterdam below-canal city (Rein 2009).

3.2.2 Preliminary Multi-Criteria Decision Analysis (MCDA)

Step1: define decision criteria (cost, benefit, opportunity, risk) and sustainability performance indicators (contribution to economic growth, social welfare, natural environment and the authority); (See Figure 7)
Step2: weight the criteria for underground projects on different land classes (ABCD), to know the priorities;
Step3: evaluate different project scenarios, using performance indicators to lever the acceptability of 8 scenarios.



Main criteria	Sub-criteria
Cost	construction cost energy consumption compensation payment
Benefit	business revenue improve life quality environmental renewal
Opportunity	geothermal system material recycling
Risk	groundwater quality subsidence

Land class	A	B	C	D
Cost	<<	0	<	>>
Benefit	>>	>>	>	0
Opportunity	>	0	>>	0
Risk	0	<	0	<<
score	1	1	2	0

Land class / Project type	**Density type**	**Revital type**
Class A	Scenario 1	Scenario 2
Class B	Scenario 3	Scenario 4
Class C	Scenario 5	Scenario 6
Class D	Scenario 7	Scenario 8

Land class	**A**		**B**		**C**		**D**	
Example	historic center		business district		new development area		mixed area	
Scenarios	1	2	3	4	5	6	7	8
Economic growth	>>	>	>>	>	>>	>	>>	>
Social welfare	0	>>	>	>>	>>	>	<	>>
Environment	>	>>	>	>>	>	>>	<	>
Authority	>	>>	>>	>	>>	>>	0	>>
Performance index	5	8	7	7	8	7	0	7
key:					score:			
<	diminished weight of the criteria				<	-1		
<<	stronlgly diminished weight of the criteria				<<	-2		
0	unchanged weight of the criteria				0	0		
>	increased weight of the criteria				>	1		
>>	strongly increased weight of the criteria				>>	2		

Figure 7 step1-criteria definition, step2-weighting, step3-project scenario analysis

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