reviewed paper

The Way to Plan a Sustainable "Deep City": From Economic and Strategic Aspects

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1 ABSTRACT

Facing the challenges of population growth, energy crisis, land pressure and environmental deterioration, modern urbanization is calling for governance innovation to facilitate flexible spatial transformations and to promote creative city redevelopment. Developing Urban subsurface as a sustainable option for renewing congested urban centers and for updating public infrastructures, should be economically viable and institutionally feasible.

Optimization of urban underground space use has to take into account social-economic demand and supply capacity of geo-space resources. A framework research is put forward, with a functional classification of subsurface project typology, as well as a zoning system of subsurface integrated quality, which includes engineering constructability and development value. Based on the macro-zoning of urban underground space (UUS) at a city scale, an economic model is developed to perform micro-analysis for specific project evaluation. The economic analysis will take into account direct and indirect costs generated along the project life cycle, business benefits and social benefits for the whole community, opportunities for synergetic resources exploitation (e.g. geothermal energy use), and risks induced by sectorial development pattern (e.g. groundwater damage). These main criteria of cost, benefit, opportunity and risk are useful for decision-makers to plan urban subsurface projects in a sustainable way. At the end, a multi-criteria decision-making process will be demonstrated, in order to guide strategic development and policy making.

2 INTRODUCTION AND PURPOSE

2.1 Urban problems and integrated solutions

Cities are economic growth centers hosting nearly 50% of world population and having the capacity to provide best services for high quality of life. These centers, in forms of different scale of metropolitans, are getting more and more congested with expanding occupation of production, service, living space, public infrastructures and decreasing greenery amenities. While the era is going from industrial style to post-industrial trend, the quality of urbanism is playing an important role in city development and governance. While maintaining the basic service of infrastructures, investing on urban quality is becoming an essential concept 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 growth, a rational management pattern of land and other resources should be on urban development planning agenda. Urban sprawl is a signal to constrain a sustainable growth, causing higher infrastructure investment to maintain the sprawling area function (larger transport and utility networks), as well as higher energy consumption for low-density living (enhanced use of cars). Obviously, cities are facing "limits to growth" and calling for innovative development strategies and sustainable renewal.

Urban growth is facing two problems: 1) shortage of resources, due to unsuitable exploitation process; 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* focus on protection and optimal exploitation of basic resources (land, water, energy, material), establishing a self-sufficient society and value-protected environment. Resources-oriented management is a development pattern giving priority to respect "supply limit of resources". On the other side, *Institution-oriented management* focus 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 the importance to "satisfaction of people's demand". Since the concept of "sustainable development" goes beyond the simple environmental protection or the sectorial economic growth, our urban governance in the new era has to combine resources-oriented management with institution-oriented management. This integrated approach meets the need of sustainable urban growth.

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2.2 New urban forms with "undergroundisation"

2.2.1 Underground infrastructures

Along with the rapid development of metro systems in big cities, urban underground space (UUS) has been exploited as part of urban land resources, providing protective space for infrastructures such as road tunnels, water system, sewage system, energy supply network and cable network. With technological advancement on renewable energy utilization, deep geothermal system will begin to emerge in urban area (Figure 1).

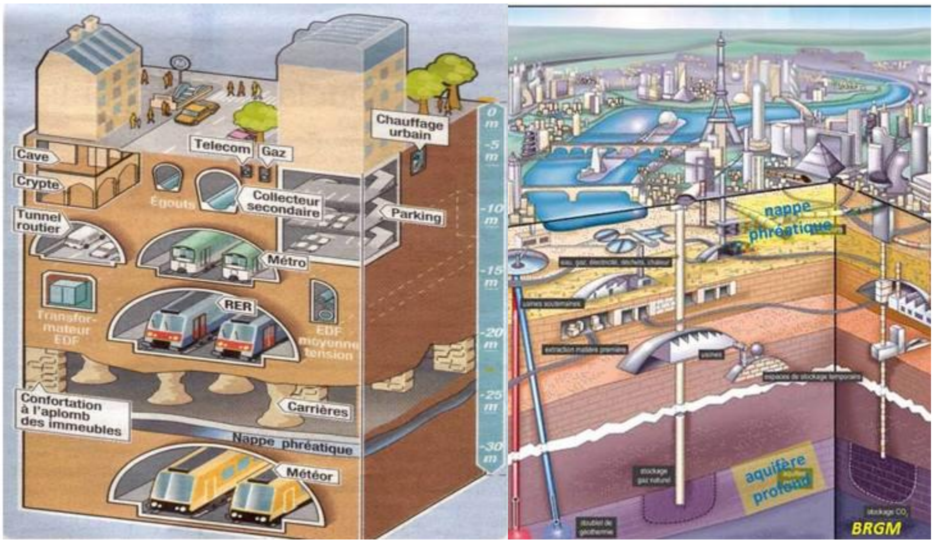


Figure 1 underground space functions illustration for the city of Paris, France (Duffaut 2010)

"Undergroundisation" trend of urban infrastructures is driven by various surface development forces:

- *Land use pressure:* the unbalanced allocation of construction land and facility land forces more and more facilities to be placed underground, since they are often large scale facilities, being underground can release more freedom over ground (Don V 1996; Tajima 2003). The "undergroundisation" volume is highly related to the urban population density causing increasing demand for land, as show in Figure 2.

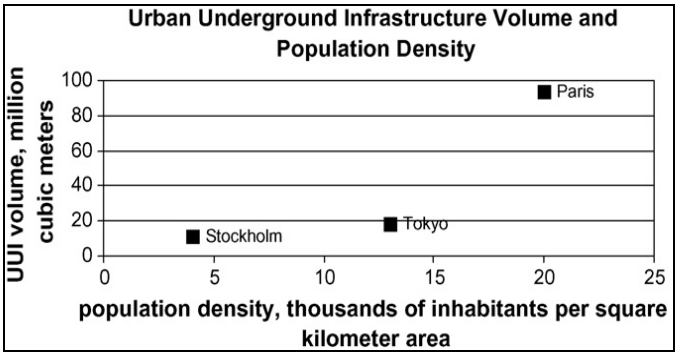


Figure 2 Relationship between population densities in urban areas and volumes of Urban Underground Infrastructures (UUI) (Bobylev 2009)

- *Increasing land prices:* real estate property development is creating huge cash flow in cities and making less and less land available for public use. Moving public facilities underground helps to reduce the land costs, sometimes even no land costs for deep facilities (Figure 3). The price factor has also contributed to the emergence of new legal system for deep space (50m depth) in Japan (Nishioka, Tannaka et al. 2007).

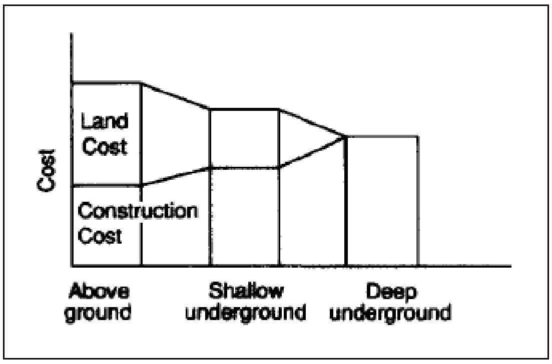


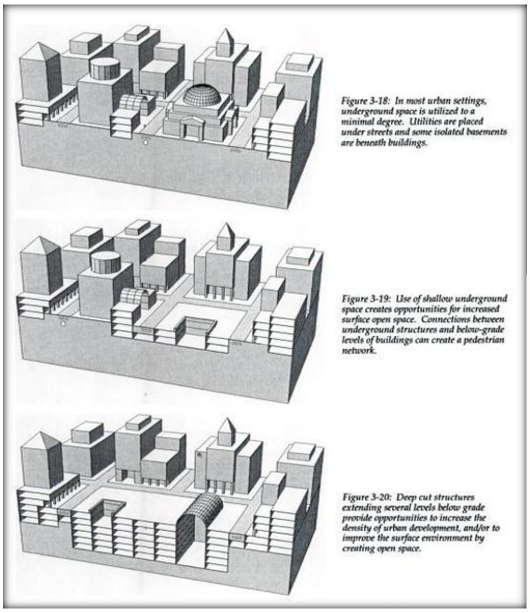
Figure 3 Comparative land and construction costs of above-ground, shallow underground and deep underground facility, Japan.(Tetsuya 1990)

- *Environmental impacts:* due to high isolation capacity in the subsurface, belowground transport system causes less noise and less smoke than surface transport (bus, car) during its operation time, reducing pollutions in the city (Girnau and Blennemann 1990)

2.2.2 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 city's "indoor city" network connects subterranean commercial area with metro stations, its comfortable underground pedestrian network enable citizens to pass through the center freely during severe weather (Daniel J 1991; El-Geneidy, Kastelberger et al. 2011). Although the construction cost for construction subterranean space is higher than the surface building, it can offset a great part of surface land investment, creating more commercial and service space while saving land occupation costs. Revealed by several empirical researches, external benefits of these spaces could be considerable (Nishi, Tanaka et al. 2000; Lin and Lo 2008). Driven by increasing urban demand, "undergroundisation" process of buildings in business districts is illustrated by architects and planners (Figure 3).

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.



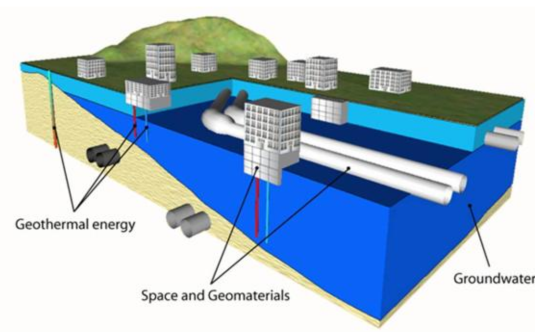


Figure 3 Underground space configurations in urban center (Carmody and Sterling 1993). Figure 4 "Deep City" model (Parriaux, Blunier et al. 2010

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2.3 Subsurface development integrated with surface city growth

The aim of this research project is to put forward a new management methodology for urban underground space (UUS) development, taking into account its economic potential and its global benefits to urban quality. As subsurface is part of urban land resources, a new approach of “3D land use” is the primary idea of implementing 3D urban projects. “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 is to give priority to underground resources protection (including land, water, energy and material Figure 4), by identifying future resources use potential and zoning to a “development reservation area”. For example, reserved area for drinking water exploitation, reserved area for material mining, and reserved area for deep geothermal system. These legalized areas are out of construction authorization scheme.

Institution-oriented 3D urbanism is to focus on social demand of development projects, located outside “development reservation area”. The aim is to find an optimal way to develop underground projects. By analyzing economic values and social values, decision indicators will be developed to lever the interests of different stakeholders in public sector and private sector. Through multi-criteria decision making process, project scenarios will be evaluated and assessed for their performances. Feedback from the decisions will give implications on policy making, in order to adapt the development demand.

3 CONCEPT AND METHODOLOGICAL DEMONSTRATION

3.1 Interdisciplinary basis

(a) Information gap:

Subsurface environment is known by geologists and civil engineers, whose knowledge and experience give supports to resources mining and underground construction. However, there is a gap between geological sciences with modern underground construction practices. Examples can be seen from tunneling accidents due to insufficient geological survey (Paul, Chow et al. 2002). Information and expertise regarding risk management are also critical factors to succeed larges underground projects such as subway construction (Degn Eskesen, Tengborg et al. 2004). “3D urbanism” requires a new representation of urban territory with a three-dimensional form, in order to visualize real potentials and clear development visions for deep urbanization.

(b) Capacity building:

Different from conventional urban planning, subsurface urbanization needs a profound understanding of deep environment and an integrated approach linked to surface development demand. In another word, capacity of urban planning is supposed to extend to a “3D urban planning” level, by engaging the competences of environmental management, economic planning, and infrastructure construction bodies. The action plan of surface-subsurface codevelopment can be materialized into existing Master Planning practice by introducing strategic procedures (Bobylev 2009).

(c) Urban land market restructuring:

The value of underground in cities has not yet been incorporated into the existing land market system, for the reason that the quality of these exploitable deep spaces is unknown among city governors and land owners. Their future value for complementary land development can not be forecasted without holistic research of resources’ supply capacity (relatively static) and urbanization’s demand context (variable along time).

(d) Business scenario analysis:

Existing best practices for underground space development can be collected to form an urban case catalogue, to show success factors and to give future improvements. Urban underground projects can be divided into typologies as: typology by depth (shallow independent use project; deep public use project) and typology by aim (“exclusive type”, e.g. metro, utility; “density type”, e.g. multi-use building; “revital type”, e.g. building under parks). Business cases could be simulated and analyzed, using performance evaluation.

(e) Policy-making:

Urban policy aims to facilitate good development practices. Understanding interactions between public sector and private sector help to reformulate positive instruments and to improve the existing governance mechanism. Underground urbanism should be initiated through public sector by introducing instruments promoting development synergies; independent underground projects could grow from the policy framework by applying sustainable investment scenarios (e.g. densification or revitalization).In addition, these interactions enable the policy-makers to go around the management improvement loop (Table 1), making demand dynamics incorporate into the contextual big picture.

3.2 Process-oriented management system

Current development of underground space in cities is facing coordination dilemmas: on one side, public infrastructures are growing fast and going deep, congestions and disorder hinder future development (Sterling 2005); on the other side, private developers play a major role in property development but lack of cognition of subsurface potential and comprehensive decision-making. The process proposed below (Table 1) is an ideal facilitating procedure to frame a comprehensive decision platform, linking public and private sectors into new subsurface urbanism plans. It is also an “undergroundisation value chain” to reorganize multi-disciplinary functions for creating economic growth, meeting urban demand while optimizing the use of underground space in the city.

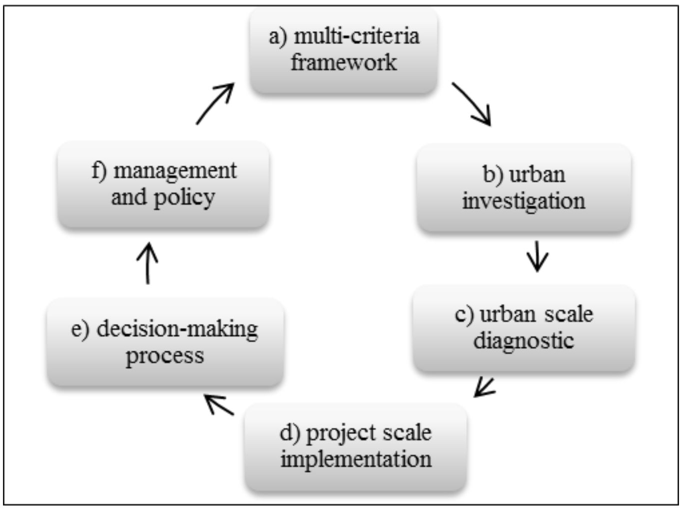

Table 1 Analysis improvement loop of research steps

3.3 New management methodology for subsurface urbanism

3.3.1 Macro-criteria system for land valuation (at urban scale)

Urban projects are developed based on 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 urban underground space (UUS), the existing land value distribution will be different. Underground land quality determines construction costs, meaning that, a parcel of high price land can have lower value for “undergroundisation”, due to bad quality for excavation engineering. For abandoned industrial land with low land price, it can be exploited by developers for its good soil quality, who built underground parkings or subterranean logistic centers with creation of a green park above, bring revenues for the land owner and good renewal environment for the community. Two macro-indexes (supply and demand) will be integrated through multi-criteria evaluation to map the different levels of urban land parcels (Table2). Detailed procedure with a considerable number of parametrs can be found in another paper of the author (Li, Parriaux et al. 2011).

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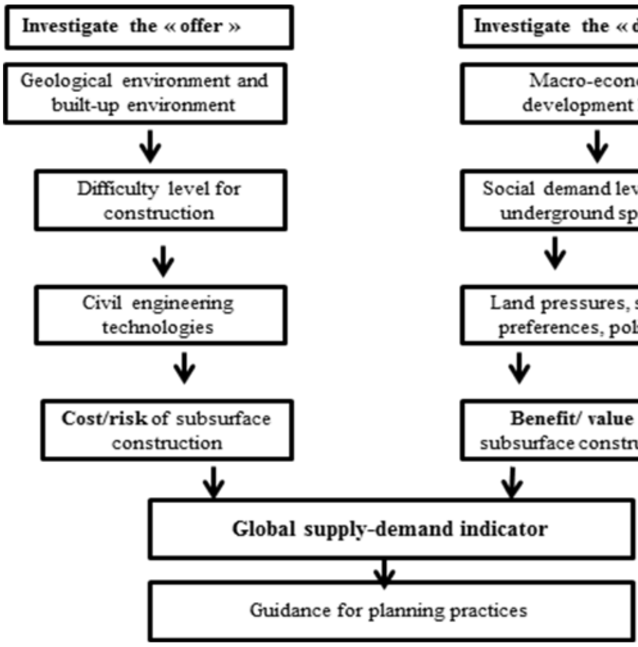


Table 2 Multi-criteria (macro-index) framework for UUS potential evaluation

This macro-zoning system is to classify the urban land into development levels: high potential, moderate potential and low potential. *High potential area* can be short-term development target, using underground to create more urban growth; *moderate potential area* can be reserved for long-term exploitation land resource; *low potential area* is prohibited zone due to sensitive condition or highly protected resource reservation (e.g. water, mine). With future demand dynamics, distribution and mapping of these zones can vary and can be re-affected.

Results of case study: central city of Suzhou, Yangtze region, China (Figure 5, blue color for high potential area)

The structure of macro-zoning favors rational selection of priority development zone to be investment target. As different land use type has different underground use value, commercial land and mixed use land having higher development potential for "undergroundisation". The tradable land parcels on the market can be restructured according to their land price and their exploitable underground potential, a coefficient can be created to lever the integrated value variation (explained in session 2.3.2).

This land value restructuring helps to incorporate the economic potential of using underground space into market land price, and gives implication to the land owners about how to develop an underground property project in a rational way.

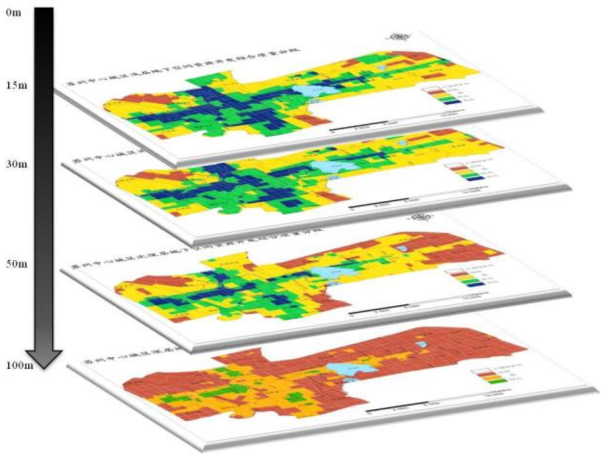


Figure 5 macro-zoning of UUS, layered approach (Deep City project in China (Li, Parriaux et al. 2011))

Analysis of case study: Forecasting exploitation of urban underground space (UUS) along with urban growth

Evaluation of central city area 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*, 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 height of 4m for better architectural effect (Ernst von Meijenfeldt 2003). (Table 3)

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)*

Table 3 forecasting the exploitable UUS supply in short-term, development to 30m below

Variation of 3D land use demand: densification helps to rebuild a compact city (Jenks, Burton et al. 1996), a density index (floor area ratio [1]) can represent this urban trend. Step-forward "undergroundisation [2]" helps to alleviate land use pressure by high-density development. Under proximate simulation, by attaining density level of 6, a 47% "undergroundisation" share needs to place nearly 400km2 construction spaces below surface(Table 4).Compared to the supply quantity of 413km2, this demand can be met.

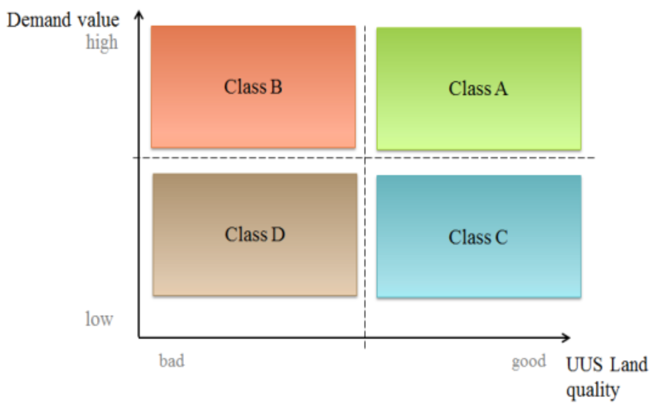
Floor Area Ratio	1.00	2.00	3.00	4.00	5.00	6.00
total urban area (km2)	279.50	279.50	279.50	279.50	279.50	279.50
construction land use (50%)	139.75	139.75	139.75	139.75	139.75	139.75
floor space demand (km2)	139.75	279.50	419.25	559.00	698.75	838.50
"undergroundisation" rate	0.02	0.10	0.20	0.29	0.38	0.47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

Table 4 forecasting the UUS demand in short-term, density development for a compact city

3.3.2 Micro-analysis with business scenarios (at project scale)

The careful diagnostic at urban scale leads to identify high potential area for priority development planning of underground space. Further economic analysis can be performed based on land valuation and project assessment:

Step 1 Land valuation:



Class	A	B	C	D
Land price	10'000	10'000	5'000	5'000
UUS quality	+(10%)	-(10%)	+(10%)	-(10%)
included value	11'000	9'000	5'500	4'500

Figure 6 integrated land valuation approach

[1] Floor area ratio = floor space area / land area.
[2] "Undergroundisation" rate = total underground floor space/total urban construction floor space.

For high potential area in general, their land parcels to be developed can have different interpretation of real value. The hidden value of developing subsurface can be incorporated into existing land price (here is about commercial land or mixed use land), with a coefficient/premium to reveal the differences of integrated value. Low "UUS land 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 land value class (Figure 5). With regulated building height, a deep commercial center in the CBD should be built on land class A rather than B, whose subsurface maybe congested, inducing compensation in utility relocation.

Step 2 Project scenarios:

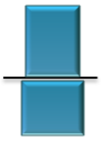
Land class / Project type	Density type 	Revital type 
Class A	Scenario 1	Scenario 2
Class B	Scenario 3	Scenario 4
Class C	Scenario 5	Scenario 6
Class D	Scenario 7	Scenario 8

Table 5 Project scenario analysis scheme

The research scheme will only focus on underground building in urban area, as its project viability has not been well researched in academic world, although its value to renovate urban centers has been documented (Barles and Jardel 2005; Maire 2011). A sustainable city is an efficient compact city and a livable city. Development of underground buildings can bring density gains or revitalization benefits. Therefore, two project scenarios can be assessed: "density type": multi-use combined building; "revital type": underground building under open space (Table 5). A cross-analysis can be performed by coupling the project type with the land class, assessing advantages and disadvantages of each scenario and levering facilitating and constraining factors. Project performance indicators include cost, benefit, opportunity and risk.

Step 3 Performance assessments:

Example is showed below to lever project viability of scenario 1, 2 and 3: (Table 6, Figure 7)

This decision-maker (environment authority) considers Scenario 2 (a revitalization type built on land class A) as the best alternative, because of a need to renew urban environment (benefit) and to protect groundwater quality (risk). Decisions of all the other stakeholders can be assessed, in order to reveal the challenges and synergies, guiding new development strategies.

Performance indicator	Criteria
Cost	• Construction • Energy consumption • Compensation payment
Benefit	• Business revenue • Environment renewal • Social welfare
Opportunity	• Geothermal system • Material recycling
Risk	• Groundwater quality

Table 6 Criteria for performance assessment

Alternative Rankings

Graphic	Alternatives	Total	Normal	Ideal	Ranking
	1Scenario: density type on land A	0.2643	0.4043	0.7823	2
	2Scenario: revital type on land A	0.3379	0.5168	1.0000	1
	3Scenario: density type on land B	-0.0516	-0.0789	-0.1526	3

How the alternatives fed forward

1Scenario: density type on land A	Total Priority	Rank
1.Benefits	0.1534	2
2.Opportunities	0.1750	2
3.Costs	0.1479	2
4.Risks	0.0605	2

2Scenario: revital type on land A	Total Priority	Rank
1.Benefits	0.1932	1
2.Opportunities	0.1427	3
3.Costs	0.0773	3
4.Risks	0.0575	3

3Scenario: density type on land B	Total Priority	Rank
1.Benefits	0.1534	3
2.Opportunities	0.1823	1
3.Costs	0.2748	1
4.Risks	0.3820	1

Figure 7 Part of the full report (by Super Decisions)

4 CONCLUSION

Rethinking the urban growth innovation by introducing sustainable concepts is current policy trend (Programme 2009). During this renovation process, social capital and natural capital have to be well integrated. The research concept and methodology put forward in the project "Deep City" tried to demonstrate a freedom for urban growth and resources consumption. Through case studies and international discussions, this third-dimension freedom could serve the future society within a participative platform, for learning, collaborating, investigating, discovering, improving and contributing. The decision platform enables a smooth process of urban restructuring, upgrading, transforming, renewing and sustaining.

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