An Integrated Planning Concept for the Emerging Underground Urbanism: Deep City Method Part 2 Case study for resource supply and project valuation

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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.

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

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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 (Figure 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:

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 (0-30m 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.

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.

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; Salisbury and Salter 1941b). 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, Chow 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, Singh 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, Burton 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 Figure 1. The built-up area surface quadrupled in less than ten years after the land reform policy (Figure 2).

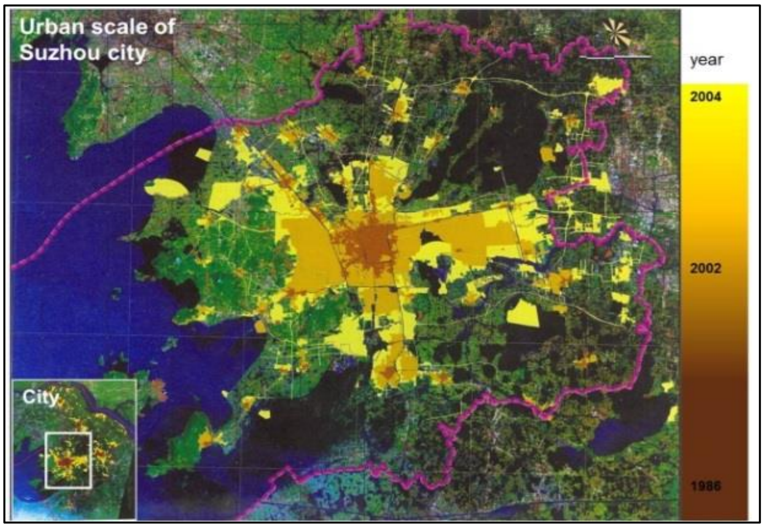


Figure 1 Spatial expansion of Suzhou city from 1986 to 2004 (from Suzhou urban planning bureau)

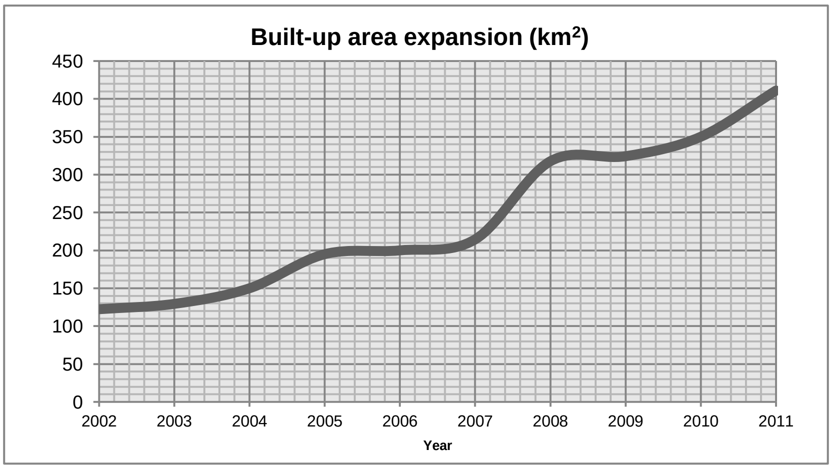


Figure 2 Suzhou city's built-up area in km^2 from 2002 to 2011 (from Suzhou statistical yearbooks)

Underground development is divided into four layers for two reasons: Firstly, shallow layers (15m, 30m) 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 30m (Nishioka, Tannaka et al. 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 (0-15m) 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.

Table 2 Inventory of underground space supply (0-30m depth) in Suzhou city's built-up area (324 km^2), Mapping showed in Appendix A

Indicators	Supply Inventory
15 meters shallow layer (3 floors)	
Good quality land	64.80 km^2
Underground space	194,400,000 m^2
30 meters sub-shallow layer (3 floors)	
Good quality land	55.08 km^2
Underground space	165,240,000 m^2
Total space supply	359,640,000 m^2
Surface density	5 (Floor area ratio)
Studied built-up area	324 km^2
Surface land release	71.93 km^2 (22%)

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.

In order to deliver a strategic plan for underground space, extensive digitized information is gathered through governmental support to formulate an urban scale potential zoning instrument. Planning the urban underground should make use of overall criteria before assigning **qualifications** to particular zones for underground urbanism. Our research group used 14 criteria to map the strategic areas to a depth of 100 meters (WU 2012), taking into account supply capacity of vulnerable underground resources and built environment demand.

The remaining section will elaborate specific measures of asset reserve inventory, district-level allocation and dynamic forecast of this pilot city. Strategic areas are selected: a new development zone in Old City district and a commercial zone in Central Business District. They have higher scores combining construction capacity and demand potentiality.

3.1. Urban regional scale underground assets inventory (quantity outlook)

Urban underground assets include buildable subsurface area, potable water aquifers, reusable mining material and geothermal energy sources. Estimation data in Table 3 comes from an internal project report. Spatial mapping for these underground resources is showed in Appendix B.

Table 3 Inventory of underground assets reserve in Suzhou city urban area (632 km^2), Mapping showed in Appendix B.

Assets of resources	Zoning rate (% of surface)	Quantity reserved	Inventory of supply capacity
Subsurface	30%	2678 million m^3	535,600,000 m^2
Drinking aquifer	10%	22 million m^3/year	[1]366,666 habitants' water supply
Reusable Material	30%	6 million tons	[2]For 2.4 million m^2 floor space
Geothermal energy[3]	12.5% (operable drilling area)	2.89 ×10^6 KW	[4]Heating space of 29,445,683 m^2, cooling space of 16,031,538 m^2.

[1] Assuming that per capita drinking water consumption is 60 m^3 per year.
[2] Assuming that 1m^2 floor space needs about 2.5 tons of soft ground material (gravel, clay, sand), here is mainly clay reused for brick production.
[3] The energy potential here is a theoretical estimation based on lab experimentation. (Borehole distance use 6m, around 2 million boreholes).
[4] Heating load is 98w/m^2, cooling load is 180 w/m^2, ground source heat pump (GSHP)'s unit power is 1321W of a 100-meters probe.

According to the municipal geological resources survey of Suzhou city, exploitable shallow geothermal source has a potential of producing 2.89 million KW of thermal energy for the building sector, representing 14 times of urban household electricity need in the year of 2009 (0.2 million KW). Despite the potential quantity of geothermal resources, the operable area in urban core is limited to 10% of land, due to spatial conflicts with existing building blocks. Development zones could have 30% of land available for ground source heat pump drillings. For the whole urban scale, only 12.5 % of land is operable for geothermal borehole drilling (potential area allocation by district is shown in Table 5).

In order to unlock the energy potential of underground to serve the long term demand of the built environment, coordination of construction land and energy preservation zones should be taken into account to promote a synergetic use of energy and space. However, geothermal drills should be only permitted outside the protected groundwater zone. Layered mapping of overall underground assets including space, water, energy is shown in Appendix B (0-100m depth).

3.2. City scale potential evaluation (quality outlook)

The indicators of construction capacity and demand potentiality are composed of 8 geotechnical criteria and 7 socio-economic criteria respectively (Table 4); Figure 3 shows the integrated quality zoning of four layers, considering that for subsurface (0-30m) demand potential is weighed higher than supply potential, for deep underground (30-100m) engineering challenge is more important than demand value (see Table 5).

This comprehensive evaluation was based on fundamental geotechnical research for soft soil construction as well as extensive data collection in planning documents. Procedure of integrated quality evaluation for Suzhou city scale is as follow:

1. Criteria selection, data collection and standard level classification: (Table 4)

Based on existing studies in subsurface evaluation from Chinese major cities of Shenzhen, Guangzhou, Shanghai and Beijing, general criteria and local specific factors were put together. From 2009 to 2011, local data from geological survey and economic statistics is collected and treated. A 3D geological model is created with an internally invented software GEOLEP3D (Cao, Li et al. 2011), showing all the critical resource layers (Appendix B) in a three dimensional way.

In order to define standards for the selected criteria, ten municipal departments were invited to give advice on resources management and infrastructure development, including departments of housing, civil defense, archeology, population, water, environment, urban planning, road, metro and energy. Those discussions helped to form a constructive framework for underground development standards, which is one of the major challenges in planning coordination (Narvi, Vihavainen et al. 1994; SHU, PENG et al. 2006).

2. Weighting criteria with questionnaires and interviews: (Table 5)

A group of local professionals in geological engineering, building construction and urban planning was interviewed and gave weights for overall criteria to indicate importance level from 1 to 9. From 2010 to 2011, numbers of joint meetings were organized by the Chinese Deep City Team with the provincial geological department and municipal land use administration, to gain updated legislative information and political guidance in order to readjust the weighting results.

3. Analytic diagnostic for supply and demand and mapping for integrated potential: (Figure 3)

Analytic Hierarchy Process (Saaty 2001) and GIS are used for data treatment and geographic mapping (Li, Zhao et al. 2012; WU 2012). The combination of information technologies helps to translate decision making criteria into zoning maps as planning instruments.

Table 4 Preference standard for the 15 criteria to evaluate urban land for underground construction

Preference standard levels	**Technical/legal basis**	**Very high**	**High**	**Moderate**	**Low**	**Very low**
Supply potential criteria:						
S1: Geo-risks (subsidence)	Monitoring center data	No risk	No risk	<5mm/a	5-10mm/a	>10mm/a
S2: Sensitive soil thickness	Borehole data	0	0-5m	5-10m	10-15m	>15m
S3: Sensitive aquifer outflow	Water well data (1st aquifer)	Absent	<50t/d	50-150t/d	150-300t/d	>300t/d
	Water well data (2nd aquifer)	Absent	<100t/d	100-1000t/d	1000-3000t/d	>3000t/d
S4: Existing foundation	Suzhou underground planning	No	No	6-10m	10-30m	>30m
S5: Archeology discovery	Suzhou city planning 2020	Absent	Absent	Absent	Present	Present
S6: Ecology protection level	Suzhou city planning 2020	Non sensitive	District level	City level	Province level	National level
S7: Topography (altitude)	Suzhou DEM model	>5.8m	4.8-5.8m	3.8-4.8m	2.8-3.8m	>2.8m
S8: Faults buffer	National standard 2010	>200m	>200m	>200m	>200m	<200m
Demand potential criteria:						
D1: Civil defense need	Civil defense planning 2020	Old city	SSIP	SSND	Xiangcheng	Wuzhong
D2: Commercial land prices	Land valuation report 2007	>26K RMB/m^2	14K-26K	6K-14K	3K-6K	<3K
D3: Residential land prices	Land valuation report 2007	>6K RMB/m^2	3K-5K	1K-3K	675-1K	<765
D4: Land use type	Suzhou land use plan 2005	Commercial	Education	Residential	Industrial	Farmland
D5: Population density	The 6th Population Census	11K-15K/km^2	2414-7860	1774-2218	1561-1667	1083-1195
D6: Transport accessibility	Suzhou city planning 2020	Metro hub	Metro station	Bus stop	Road	Other
D7: Development stage	Suzhou underground planning	1	2	3	3	4

Table 5 Criteria and weights (importance for the development) for potential zoning of underground space at four layers (0-15m-30m-50m-100m)

Criteria for supply (S) and demand (D)	**15m**	**30m**	**50m**	**100m**
Supply potential criteria:	**0.2**	**0.3**	**0.7**	**0.8**
S1: Geo-risks	0.039	0.058	**0.144**	**0.187**
S2: Soil type	0.037	0.060	**0.166**	**0.125**
S3: Hydrogeology	0.035	0.078	**0.242**	**0.274**
S4: Existing foundation	0.033	0.047	0.000	0.000
S5: Archeology	0.020	0.031	0.000	0.000
S6: Eco-sensitivity	0.018	0.027	0.078	0.091
S7: Topography	0.018	0.000	0.000	0.000
S8: Faults	0.000	0.000	0.071	**0.122**
Demand potential criteria:	**0.8**	**0.7**	**0.3**	**0.2**
D1: Civil defense need	0.066	0.058	0.025	0.017
D2: Commercial land prices	0.088	0.077	0.033	0.022
D3: Residential land prices	0.088	0.077	0.033	0.022
D4: Land use type	0.091	0.080	0.034	0.023
D5: Population density	**0.115**	**0.101**	0.043	0.029
D6: Transport accessibility	**0.174**	**0.153**	0.065	0.044
D7: Development planning stage	**0.178**	**0.155**	0.067	0.044

(Weights indicated in 0.000 means an absence of factor for corresponding layer)

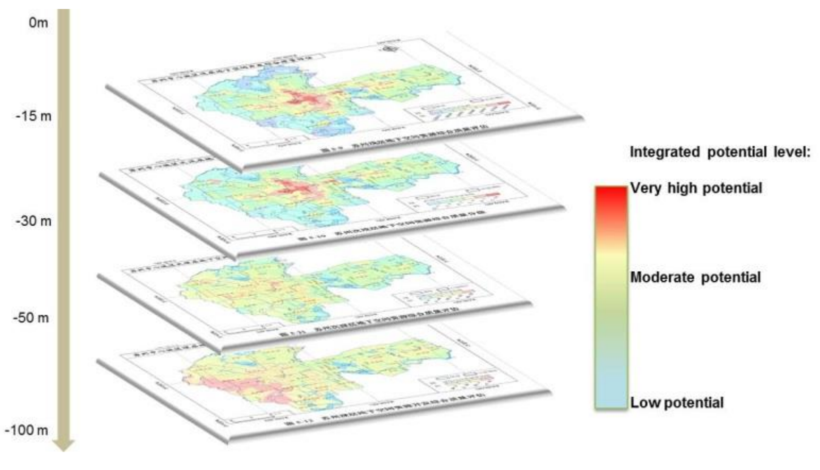


Figure 3 Integrated potential zoning for underground space (0-100m) in five urban districts in Suzhou city, maps readapted from (WU 2012)

3.3. District scale underground space supply inventory (strategic area planning)

Based on the asset quantity outlook, allocation of these assets in three districts including Old City core and two development zones is further clarified (location indicated in Figure 4), in order to identify priority targets for underground urbanism.

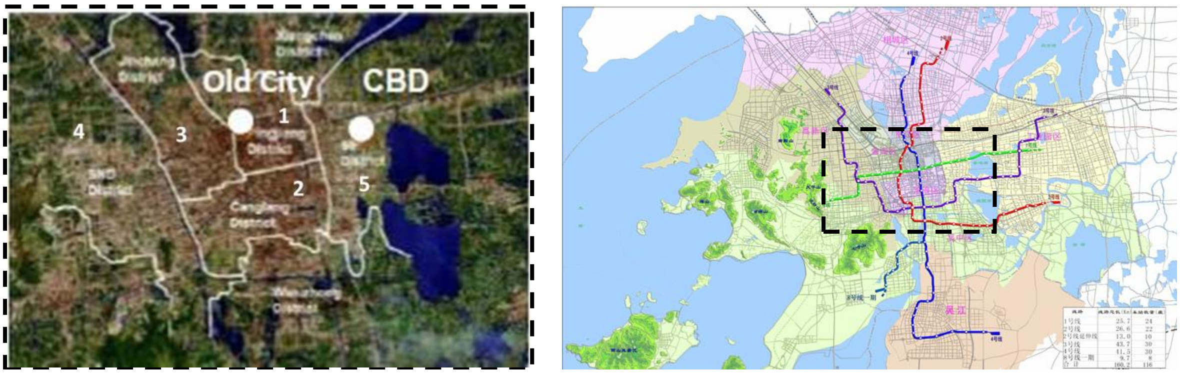


Figure 4 Location map of the five districts (Old City core: 1, 2, 3; Developing zone: 4, 5) and Metro system map (green line east-west in operation, the others in construction)

Inside the large urban boundary within 632 km^2, over 42% of land (0-100m depth extent) has high construction capacity (see the second column in Table 6). However, the highest demand zone is concentrated on 5% of urban area (see the fifth column in Table 5), which is mainly located in the Old City core (26.30 km^2 area with high demand for subsurface), the traditional administrative and cultural center with the highest land price, population density and transport accessibility. A new financial center in the city's CBD is located in the SSIP district, whose high demand potentiality calls for a timely planning for its underground asset to support economic development and urbanization.

Table 6 Quality and potential allocation of underground asset for the five districts

Urban Districts (all the units in km^2)	**Area with high capacity for space and material**	**Area with groundwater supply**	**Area with geothermal supply**	**Area with High demand potentiality**	**Area with high integrated quality**
1.Ping_Jiang (23 km^2)	2.60	11.50	2.30	12.20	13.20 (target area1)
2.Cang_Lang (26 km^2)	4.30	2.60	2.59	10.60	12.00
3.Jin_Chang (37 km^2)	10.50	0	3.10	3.50	4.10
Old City core (86 km^2)	**17.40**	**14.10**	**7.99**	**26.30**	**29.30**
4.SND[5] (258 km^2)	189.30	0	13.47	1.60	1.70
5.SSIP[6] (CBD incl.) (288 km^2)	61.10	86.40	57.14	3.10	4.40 (target area2)
Developing zone (546 km^2)	**250.40**	**86.40**	**70.61**	**4.70**	**6.10**
Total urban (632 km^2)	**268 (42%)**	**100.50**	**78.61**	**31 (5%)**	**35.40**

According to the district level asset allocation potential shown in Table 6, Ping-Jiang district and SSIP (CBD) district become two target districts for underground urbanism, given their bigger surface areas having good quality of underground asset. The supply inventories for these two districts serve as a basic estimation of using underground space to provide additional densities to existing district land area. Densification inputs showed in the tables below indicate a potential rate of underground space to

[5]SND: Suzhou New Technology District, situated to the west of old city core.
[6] SSIP: Suzhou-Singapore Industrial Park, situated to the east of old city core.

total space demand, named "underground space rate". All the underground space supply estimation is readjusted by a technological feasibility factor of 50%, due to space occupied by geotechnical support and space reserved for safety buffer.

Detailed estimation of underground space supply at district level is elaborated below:

Target Area 1: Ping-Jiang district: Underground Space's role in historical center

Underground expansion in the cultural core of Suzhou City (23 km^2) is being driven by a high population density (11,682 habitants/km^2) and building height restrictions (9 meters for residential zones and 24 meters along main avenues). Existing utilization includes underground transport, parking, pedestrian passageways and commercial spaces. Three subway lines will pass through the district, with two most important central transfer stations located beneath the district.

Land saturation is causing a relocation of all municipal administrative and social services from the central part to the northern part of the district (a 10km^2 regeneration zone planned to provide 2.35 million m^2 floor space) close to the national high speed rail station. The potential supply of underground space helps to relieve land use pressures in the center (gaining 57.61% of building footprint, see Table 7), leaving more spatial freedom for this historical center to preserve cultural and landscape capital (gardens, museums, water canals, old bridges, listed historic buildings for rehabilitation). Spatial relocation and functional adaption helps to preserve this historical city while providing better social services.

Construction capacity (defined by supply potential) in the district is constrained by existing below ground structures and numerous protected building sites. However, the high level land price and social-political role of the district allows it to be one of the important targets for underground urbanism.

Table 7 Inventory of underground space supply (0-30m depth) for Target Area 1 (Ping-Jiang district)

Indicators	Planning reference (Ping-Jiang)	Space and land (Ping-Jiang)
Housing sector space demand	268,686 habitants	9,404,010 m^2 living space[7]
Commercial sector space demand	285,200 employees[8]	7,130,000 m^2 working space[9]
Built-up area	23 km^2	
Green space	40% of built-up area	9,200,000 m^2 (9 km^2)
Building footprint	60% of built-up area	13,800,000 (13.8 km^2)
Densification demand	Floor area ratio	3.0
Underground space supply (0-15m)[10]	13.20 km^2	19,800,000 m^2 (3 floors)
Densification input (current trend)	Underground space rate	1.20
Underground space supply (15-30m)	4.5 km^2	4,050,000 m^2(3 floors)
Densification input (short term trend)	Underground space rate	0.24
Building footprint release	Underground space / density	7.95 km^2 (57.61%)

Target Area 2: SSIP (CBD) district: Underground Space's role in CBD

The CBD of Suzhou city is the first in China introducing a preliminary subsurface leasing regulation. According to official data in 2009, land supply in the district decreased by 30%, while the district GDP increased by 15%. Land scarcity of the CBD zone pushes its urbanization upward to reach an average building height of 150 m and downward to depth of 20m. With the improved accessibility to rail transit (three subway stations to be serving the CBD), other uses including subterranean pedestrian ways, parking, and shopping centers are gradually planned to release more surface space for housing and office (80% of Grade-A office in the city will be located in SSIP CBD).

Due to the unfavorable soil quality, the foundation of this development zone was built artificially from earth fill to increase its elevation and to prevent flooding (Chen 2006). A cautious land development pattern is critical to maintain its role as business and financial center by providing sufficient working

[7] According to the municipal objective in 2010: per capita living space reaches 35 m^2.
[8] Adapting to international planning standard for Transit-Oriented land development: 1.24 employee per 100m^2 land near subway catchment area.
[9] Assuming that per employee working space is 25 m^2.
[10] The layer of 0-15m subjects to an effective use coefficient of 0.5, for the layer of 15-30m is 0.3 (technical limit coefficient).

space. The contribution of underground space to building densities and land savings can be seen from Table 8.

An abundant groundwater resource reserve beneath the district also helps to sustain its urbanization need in the long-term future. From 2003, groundwater exploitation in Suzhou city has been totally prohibited, due to land subsidence from over-exploitation. The groundwater level is increasing significantly, offering a potential long-term reserve for future generations under rational exploitation.

Table 8 Inventory of underground space supply (0-30m depth) for Target Area 2 (SSIP CBD district)

Indicators	Planning reference (SSIP CBD)	Space and land (SSIP CBD)
Predicted space demand	12,000,000 m^2	
Built-up area	5 km^2	
Building footprint	70% of built-up area	3.5 km^2
Densification demand	Floor area ratio	4.05
Underground space supply (0-15m)[11]	2.20 km^2	3,300,000 m^2 (3 floors)
Densification input (current trend)	Underground space rate	0.28
Underground space supply (15-30m)	0.4 km^2	360,000 m^2(3 floors)
Densification input (short term trend)	Underground space rate	0.03
Building footprint area release	Underground space / density	0.90km^2 (25.8%)

3.4. Dynamic forecast (supply and demand outlook for the future)

Dynamic supply of underground space:

The exploitable underground space asset quantity is limited due to the natural quality of land resource and legal restrictions to preserve the landscape, while the supply value of the asset in terms of high construction capacity could be variable due to the technological progress of builders and financial means of the developers.

Table 9 shows the potential supply of subsurface space based on current technological limits (e.g. engineering skills to deal with soft ground excavation). Technological innovation in the construction industry reduces capital cost (material, equipment, skills) and project duration, two of the main determinants in economic feasibility. One indicator for construction performance is the R&D expenditure of builders. It is reported that the R&D expenditure of major Chinese construction enterprises in 2003 was only 0.25% of their total revenues.

According to Global Construction Perspectives 2020[12], China is the largest construction market with 15% world market share, followed by US (14%) and Japan (9%). Chinese emerging megacities are demanding high level performance in urban construction, particularly for the cities that intend to realize underground projects. As most of them are coastal cities with challenging soft ground conditions, they will require resilient technical solutions to prevent subsidence (Zou and Li 2010).

Table 9 Urban scale (632 km^2) supply forecast of subsurface space (0-30 m depth)

LAYERS	EXPLOITABLE ASSET VOLUME	URBAN ZONE WITH HIGH RESOURCE CAPACITY	UNDERGROUND SPACE SUPPLY LIMIT
0-15m SHALLOW	1588 million m^3 (26% of total asset volume)	267.80 km^2 (44% of total urban surface)	317,600,000 m^2
15-30m SUBSHALLOW	1090 million m^3 (12% of total asset volume)	219.00 km^2 (36% of total urban surface)	218,000,000 m^2

[11] The layer of 0-15m is subject to an effective use coefficient of 0.5, the layer of 15-30m is subject to an effective use coefficient of 0.3 (technical limit). Technological evolution could increase the effective use coefficient and enable more supply quantity of underground space.
12 http://www.globalconstruction2020.com/

Dynamic demand of underground space:

Total registered building floor space in the Suzhou city in 2009 is over 230 million m^2, in a built-up zone of 324 km^2 (current average Floor Area Ratio 0.71). While housing policy is on the top agenda, land supply for commercial buildings will be cut sharply and more green surfaces will be planned by the city (objective of 40%). Densification of functional space and revitalization of public surface is calling for the contribution of the subsurface to host booming business in retail, recreation, sports and related services.

Considering that only 20% of the built-up area (65 km^2) has a high construction capacity, if technological and financial means enable Suzhou city to supply more and more underground space for urban densification, dynamic scenarios can be predicted in Table 10. For a projection demand of Level-6 densification grade, an underground space rate of 60% helps the city to continue urbanization inside its built-up area without creating sprawl effect. Considerable land savings by using underground space could reach 30%.

Table 10 Built-up area (324 km^2) demand forecast of underground space for urban densification

DENSIFICATION GRADE (= FAR)	1	2	3	4	5	6
Built-up area (km^2)	324	324	324	324	324	324
Building footprint (km^2) 50%	162	162	162	162	162	162
Total space demand (million m^2)	162	324	486	648	810	972
Underground space rate (%)	10%	20%	30%	40%	50%	60%
Underground space demand (million m^2)	16.20	64.80	145.80	259.20	405.00	583.20
Release in building footprint (km^2)	16.20	32.40	48.60	64.80	81.00	97.20
Potential land savings (%)	5%	10%	15%	20%	25%	30%

4. Economic efficiency assessment and project marketability as the third step for an integrated planning process

The value of underground space is firstly linked to its surface economic context (land price, density, transport accessibility, livability, and affordability of users) and also is linked to its subsurface executability (construction cost, skilled builders, and materials). Most of the subterranean space beneath the city is used for large scale functional space (subway station, commercial center, museum, theater, sports center, conference hall, art storage, archeological reserve, parking, logistic center, industrial storage, etc.). The use of underground buildings can also be small scale habitable space (basements beneath houses for library, swimming pool, wine cave, parking, storage, etc.)(McCarthy and Kilgour 2011). This article will use floor space scale to represent different uses of the underground, because the project scope in terms of floor space determines economic viability level, which is measured by surface economic context and subsurface executability.

In this section, two main economic indicators (land price and construction cost) will be applied to measure a project's economic viability: land price on the market will represent surface economic context, and construction cost will represent subsurface executability. These two main investment cost components of building projects are generally sharing around 70% of overall capital costs. In order to reveal competitiveness of underground building projects, a new index is put forward by the authors, named "Underground cost efficiency premium": proportion of total investment cost (land and construction) of a building that can be saved by burying part of it. We can obtain a series of investment scenarios by varying the burying rate (underground space rate varies from 0% to 100%).

A breakeven cost analysis is also illustrated, to justify a viable level of underground space rate in building projects according to different levels of land quality and land price. Similar analysis has been done previously by (Carmody and Sterling 1993) who evaluated competitiveness of underground facility to surface facility in terms of capital costs, indicating a favorable cost efficiency of underground facility construction in high priced land parcels with limited density authorization.

4.1. Indicator 1: Land price in the city

According to statistics of land price evolution in 46 American metropolitan areas[13], the land cost share in housing projects has increased by 20% from 1984 to 2008, with land price having increased by 490% during 22 years. In Chinese emerging urban land markets, housing land price in the city has been going through an incremental rate of 125%, while commercial land price was observed with a 100% incremental rate, during a 12-year period starting from its national land reform in the year of 2000 until now[14]. This value increase is often more crucial in the Old City core than in development zones outside the city center. Evidence could be found for the above mentioned districts in Suzhou city: Ping-Jiang Old city district's commercial land price is 59,435 CNY/m^2 (9527 USD/ m^2)[15]; CBD's commercial land price is 20,085 CNY/m^2 (3219 USD/ m^2).

Land acquisition right is managed by various building codes such as Floor Area Ratio (FAR) or building height, building footprint (built-up density), greenery rate, leasehold duration[16], land use, etc. All these codes have significant impacts on project implementation. In the current context, general fixed codes include land use (commercial, housing, education or industrial use), building footprint (50% for commercial land and 20% for housing land), greenery rate (40%), leasehold duration (40 years for commercial land and 70 years for housing land). Floor Area Ratio or building height could be flexible according to specific need (high-rise building projects), but generally it is also subjected to strict regulations (e.g. building height limits to 24m in Geneva's old city district and 9m in Suzhou's old city district). Although current regulations don't embrace underground space into the FAR calculation, unlimited extension below the ground is not a wise plan, which will be explained by Indicator 2 below.

4.2. Indicator 2: Construction cost of underground space

According to these 46 American metropolitan areas, the observation of house building costs showed an increase over 130% in 22 years. Material price keeps climbing (cement, concrete, aggregate, steel), with a percentage recorded in Switzerland as 48% (1998-2008). Technology in the construction industry is giving impetus to scale up the performance of developers in terms of bringing efficient equipment, shortening project duration and forming skilled builders (Newton, Hampson et al. 2009). Underground construction especially tunneling technology is one of the important areas of continued innovations in this industry (Sterling 1992). However, underground buildings still have higher construction costs compared to surface buildings. Savings in operational costs in terms of life-cycle energy consumption were quantified for an underground commercial center in Switzerland (Maire 2011). Compared to the Swiss "Minergie" standard eco-building, this underground commercial center can help to reduce emission of 1.5 kg CO^2 per square meters per year.

Construction cost is determined by land quality, which is illustrated in section 3 using the constructability indicator. The analysis below will consider three quality levels: good, moderate and bad land quality with corresponding cost coefficients.

4.3. 3D Land Valuation with viability index: Underground Premium (land parcel scale)

Estimation of an "Underground cost efficiency premium" index will be applied on 3 project scopes (house project, shopping mall project and mixed-use complex project), using three indicators (land price, subsurface quality and underground space rate). For each project scope, nine scenarios combining subsurface quality and surface land price will be evaluated and compared to the baseline scenario. The baseline scenario is conventional surface building with an underground space rate of 0% and a cost coefficient of 1. Table 11 displays the reference data for the project scopes. All the price references are from Suzhou city Land Use Bureau and Construction Statistics Bureau.

[13] http://www.lincolninst.edu/subcenters/land-values/metro-area-land-prices.asp
[14] Urban land price report, China Ministry of Land Resources http://www.mlr.gov.cn
[15] http://www.szgtj.gov.cn (1 USD = 6.23 CNY)
[16] Leasehold is a common practice in Chinese land market, while most of developed countries applied freehold in land trading.

Table 11 Reference of project scopes, land price and construction cost coefficient

Project	Scope 1	Scope 2	Scope 3
Space use	House	Shopping mall	Mixed-use Complex
Floor space (m^2)	300	20,000	100,000
FAR	1	5	8
Building footprint (50%) (m^2)	150	2000	6250
Baseline scenario			
Construction cost (CNY/ m^2)	1577	2517	1826
Total construction cost (CNY)	0.47 Million	50 Million	182 Million
Indicators			
Surface land price CNY/ m^2	(Low) 1855 (Medium) 5565 (High) 6905	(L) 2800 (M) 12080 (H) 59435	(L) 2800 (M) 12080 (H) 59435
Subsurface quality Cost coefficient	(Good) 1.33 (Moderate) 2.66 (Bad) 5.32	(G) 1.33 (M) 2.66 (B) 5.32	(G) 1.33 (M) 2.66 (B) 5.32

4.3.1. Project scope 1: house (villa)

Building a house with basement on a land parcel with bad geological quality will bring negative gain for the owners; the land with moderate to high subsurface quality will probably bring a positive premium to the owners, depending on the land price level. Table 12 shows underground premium of certain investment scenarios. Highlighted numbers represent positive premium. Figure 5 shows the breakeven construction cost coefficient of underground scenarios to baseline scenario. It is indicated that for the current housing price level, if the belowground option costs no more than 3.06 times higher than the surface option in construction works, the capital costs can still breakeven. While quality of housing becomes one of the vital household investments, an individual house is desired more and more by Chinese middle class citizens. Observation on local real estate market indicated an increasing activity in the villa market in recent years. Our justifications imply that a rational underground space rate contributes to a cost cutting in house building, with the conditions of suitable subsoil quality.

Table 12 Underground cost efficiency premium (%) of referential house project scope

Underground space rate (10%)	Good quality	Moderate quality	Bad quality
Low land price	1.63%	-6.75%	-23.50%
Medium land price	5.19%	0.38%	-9.24%
High land price	5.83%	1.66%	-6.68%

Underground space rate (50%)	Good quality	Moderate quality	Bad quality
Low land price	8.13%	-33.75%	-117.49%
Medium land price	25.94%	1.89%	-46.22%
High land price	29.15%	8.30%	-33.40%

Underground space rate (100%)	Good quality	Moderate quality	Bad quality
Low land price	16.25%	-67.49%	-234.98%
Medium land price	51.89%	3.78%	-92.45%
High land price	58.30%	16.60%	-66.81%

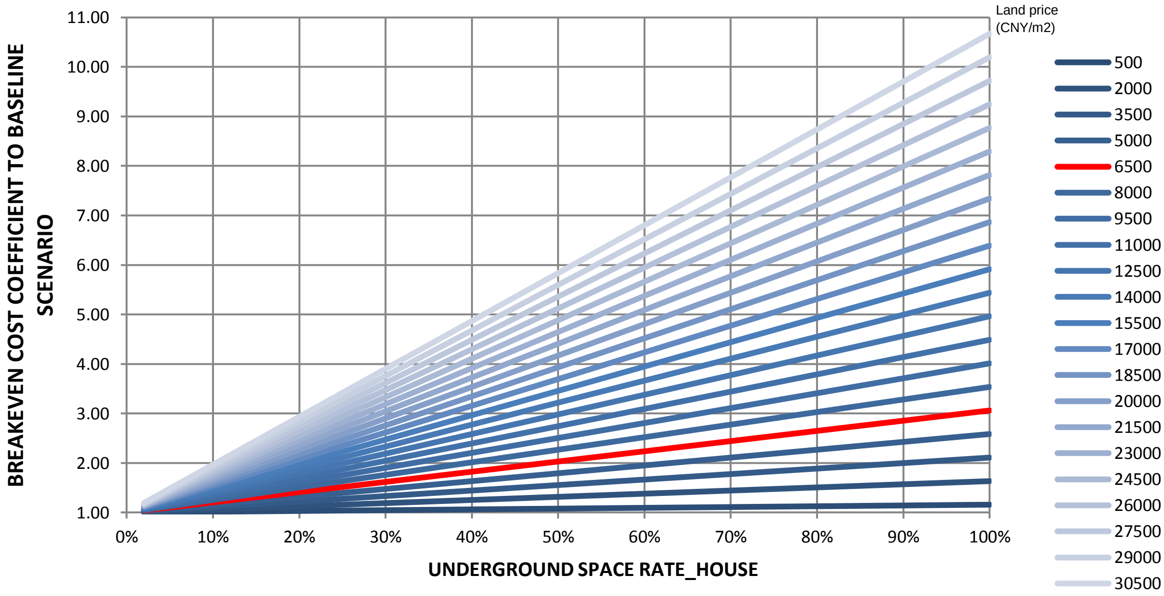


Figure 5 Breakeven cost coefficient of underground project to surface project (house)

4.3.2. Project scope 2: Shopping mall

The viability requirement of a shopping mall project scope is even stricter (see Table 13), limiting for moderate to high quality land with above medium level commercial land price. According to Figure 6, in the current commercial land market, construction investment of underground shopping malls should below the 3.38 times of baseline option. Figure 6 also indicates that: for different quality of land parcels (cost coefficient), the optimal underground space rate is determined by land price on the market. In general context of Suzhou urban area, subsurface cost coefficient is around 3 times to surface construction costs, meaning that the parcels with the highest commercial land price can attain a maximum underground development rate of 89%.

Table 13 Underground cost efficiency premium (%) of referential shopping mall project scope

Underground space rate (10%)	Good quality	Moderate quality	Bad quality
Low land price	-1.97%	-13.94%	-37.87%
Medium land price	1.01%	-7.97%	-25.95%
High land price	6.04%	2.09%	-5.83%

Underground space rate (50%)	Good quality	Moderate quality	Bad quality
Low land price	-9.84%	-69.69%	-189.37%
Medium land price	5.07%	-39.87%	-129.74%
High land price	30.22%	10.43%	-29.14%

Underground space rate (100%)	Good quality	Moderate quality	Bad quality
Low land price	-19.69%	-139.37%	-378.74%
Medium land price	10.13%	-79.74%	-259.47%
High land price	60.43%	20.86%	-58.27%

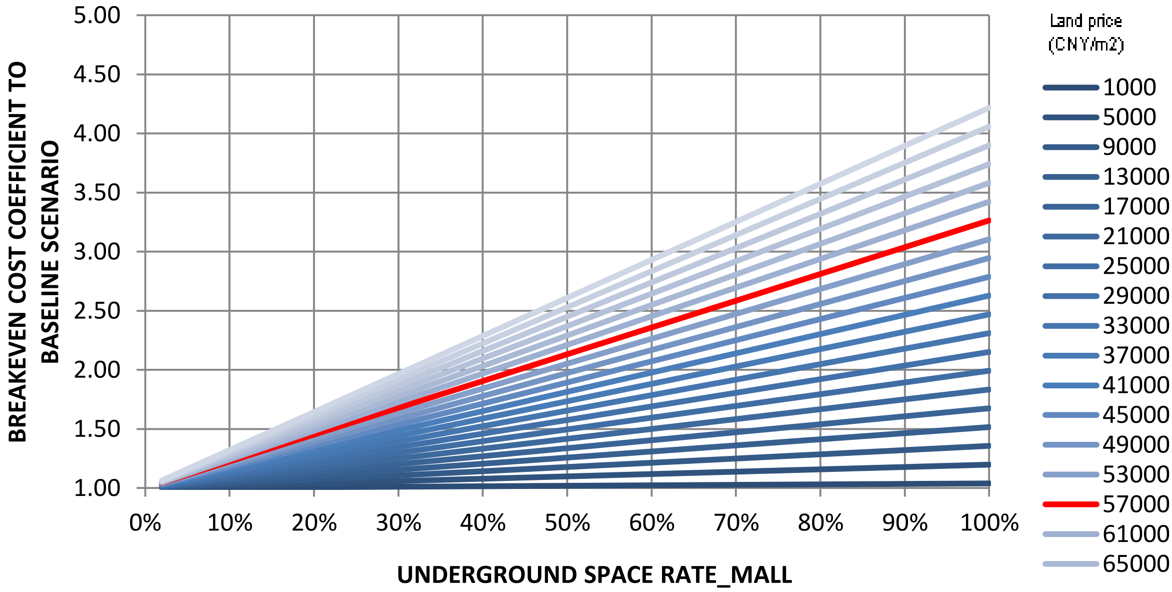


Figure 6 Breakeven cost coefficient of underground project to surface project (shopping mall)

4.3.3. Project scope 3: mixed-use urban complex (office, housing, transport, recreation)

This is one of the most common development patterns of underground space in metropolitan areas, which serve to connect the subway transport hub with commercial activities nearby. Examples can be found in megacities like Montreal, Tokyo, Paris, Shanghai, Beijing, etc. Higher land prices make the capital investment more feasible facing unfavorable land conditions, which might require stronger foundations, relocation of existing utility lines, compensation for nearby users, etc. Observations show that underground space rate is increasing for this kind of project scope, due to growing pressures of land acquisition in urban centers and due to more severe green space regulation codes in city planning. The zero land use pattern with 100% underground space rate helps the city to densify land development through three dimensional restructuring, as well as to revitalize the city by saving more building footprint and releasing more walkable surface. An ambitious project in Suzhou city's CBD will bury its mixed use complex with retail and transport functions beneath the business center. This decision could be justified from Table 14 below, giving a viability level of 12.34% (a monetary gain with 100% underground space rate, on moderate quality land).(Fig.7)

Table 14 Underground cost efficiency premium (%) of referential mixed use complex project scope

Underground rate (10%)	Good quality	Moderate quality	Bad quality
Low land price	-2.14%	-14.27%	-38.55%
Medium land price	0.59%	-8.82%	-27.64%
High land price	5.62%	1.23%	-7.53%

Underground rate (50%)	Good quality	Moderate quality	Bad quality
Low land price	-10.68%	-71.37%	-192.74%
Medium land price	2.95%	-44.09%	-138.19%
High land price	28.08%	6.17%	-37.66%

Underground rate (100%)	Good quality	Moderate quality	Bad quality
Low land price	-21.37%	-142.74%	-385.47%
Medium land price	5.91%	-88.19%	-276.38%
High land price	56.17%	12.34%	-75.33%

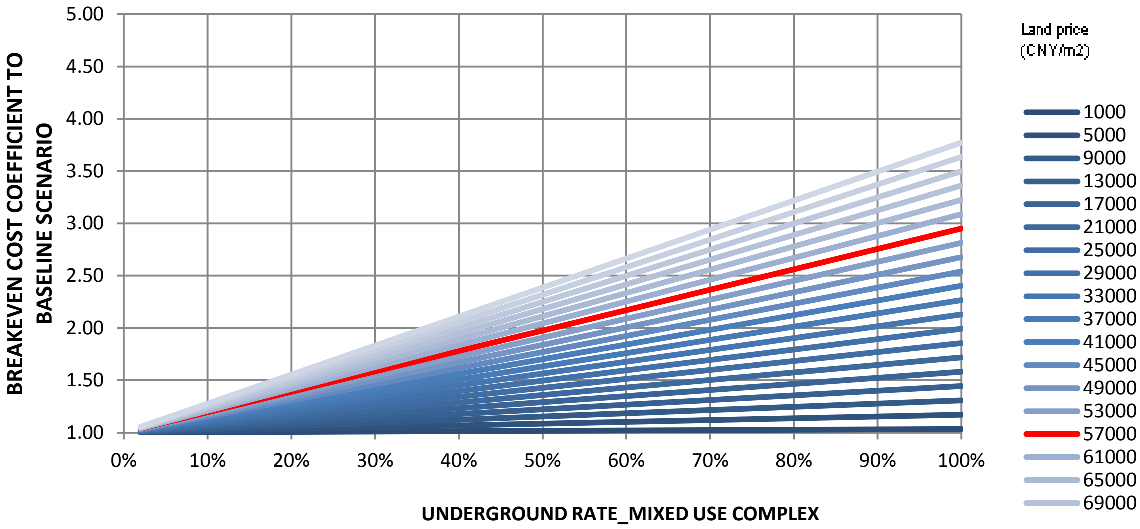


Figure 7 Breakeven cost coefficient of underground project to surface project (mixed-use complex)

5. Implications and further research for project decision-making

The aim of introducing this simple economic index is to reveal the viability level of different project scopes projected in different urban zones. Since land asset allocation by municipalities is facing a dilemma between land supply coordination (housing land, commercial land, mixed development land) and urban demand growth (more floor space for living, working, commuting and relaxing), a rational approach of using underground space could be vital to relieve the dilemma. However, misusing a subsurface land portion can be harmful, not only to the geological environment, but also to the investment side. Applying this index based on asset potential (price and quality) can avoid project risks such as over budget, unforeseen damages, and claims from other users. Considering that high quality subsurface is scarce at an urban scale, a first level selection of land parcels is critical for city governors in order to protect the asset and develop a resilient 3D city.

Project level economic appraisal should also take into account the value of other underground resources beside space: material excavated for on-site material production, integration of GSHP in the building site using the geothermal energy beneath the surface, and protected aquifer for future drinking water supply (a water capture well station). Integration of these elements into project appraisal will be further studied through an ongoing research agenda, in order to integrate the Deep City method into green building standards.

6. Conclusion

We have demonstrated operational steps of the integrated planning process for underground urbanism, including comprehensive underground asset supply assessment at the urban scale, in-depth investigation of strategic districts, dynamic forecast of supply and demand potential of underground space, and project appraisal of specific underground space users.

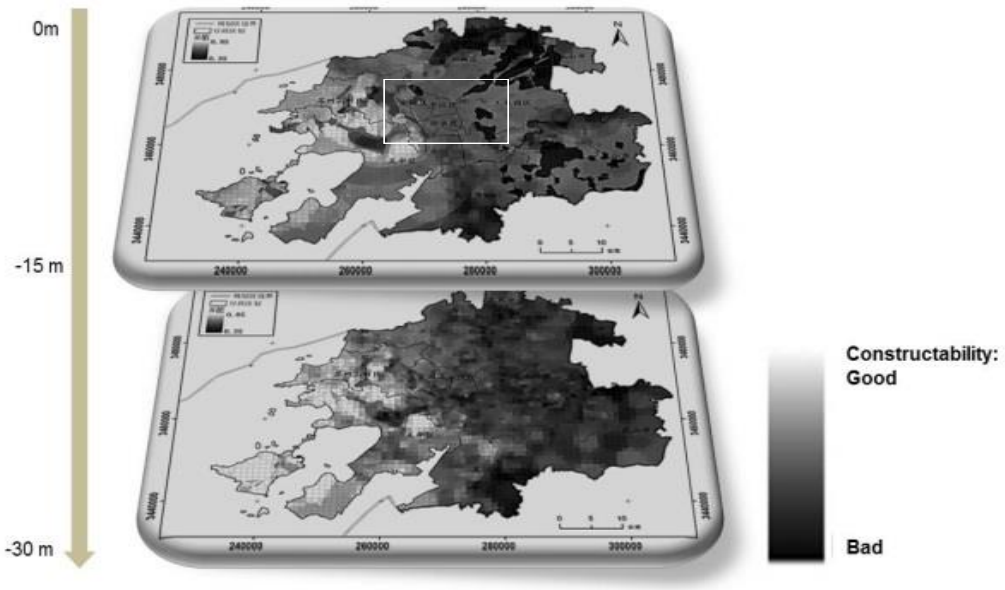
A sound development agenda for the urban subsurface should be based on the strong estimation for its potential supply, which helps to ensure a sustainable exploitation process and to avoid overexploitation. To make sure that exploitation will only take place on the high quality zones, governmental intervention should be enhanced to fix planning standards of underground assets qualification (Table 4). Stage of underground development depends on demand level, which varies among districts and economic zones. Coordination of supply and demand planning is essential for underground urbanism.

This paper gave a first attempt to compare capital costs between surface building and underground building, according to function, dimension, construction cost, land cost, underground space rate and subsurface quality. Cost efficiency level was estimated for various project scenarios. Economic benefits of using underground space are from reducing building footprint and reducing land acquisition costs, while ensuring floor space demand to be maintained. Over-cost can be avoided by rationalizing the development quantity of underground space according to land quality and land price.

Because underground urbanism is a new planning subject, global thinking and local actions should be integrated into planning decisions. The emerging trend of underground asset management should be addressed amidst metropolitan's strategic visions, which should be followed by multi-institutional operations to implement resources prospection, allocation, valuation and long-term supervision.

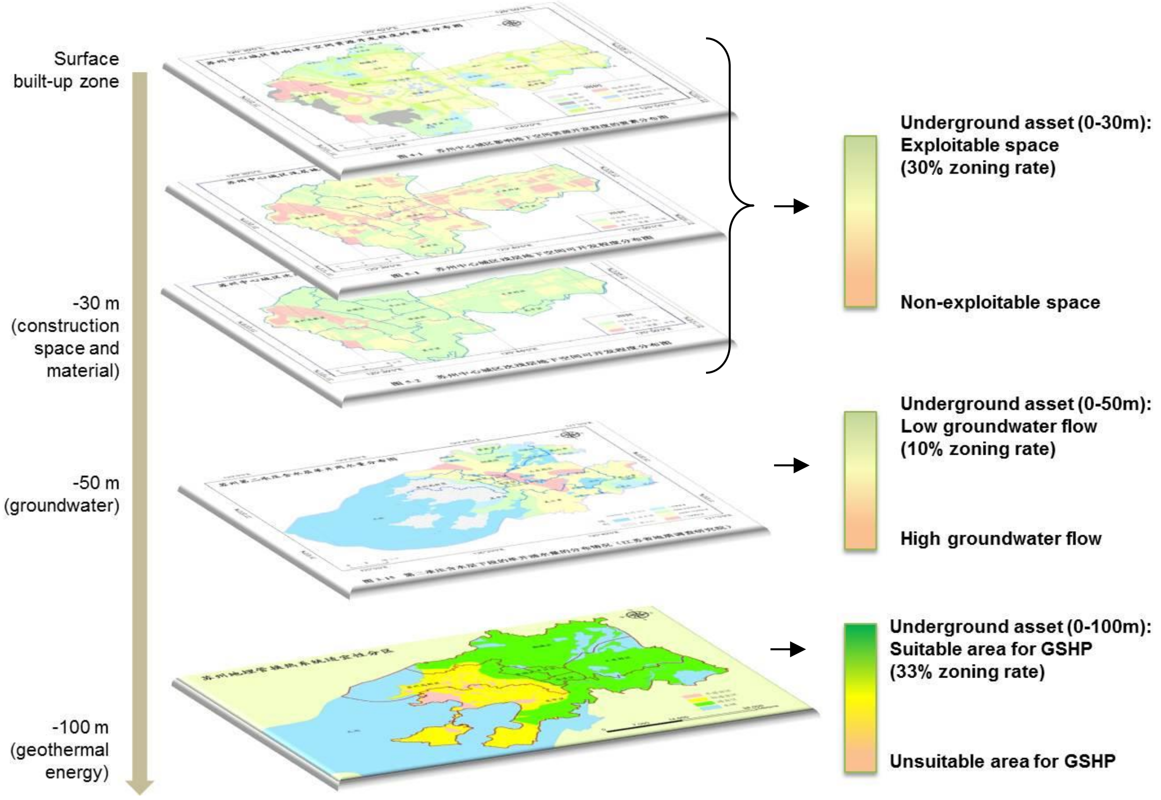
Appendix A.

Mapping the subsurface potential of construction quality in Suzhou city area, from (Cao 2012)



Appendix B.

Mapping potential layers for Suzhou city's underground assets (space, material, water and energy)



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