مدیریت شهری

فصلنامه مدیریت شهری
(ویژه نامه لاتین)
Urban management
No.**43** Summer **2016**
107 - 120

Received *23 Sep 2015*; **Accepted** *11 Feb 2016*

Sustainable development in Urban Underground Space

Sourosh Rabanian- *Department of Architecture, Mahdishahr Branch, Islamic Azad University, Mahdishahr, Iran*
AghaFazlolah Aadal[1]- *Department of Architecture, Mahdishahr Branch, Islamic Azad University, Mahdishahr, Iran*

Abstract

During a very long period of time, civil engineers have been the only ones to be designated as the experts for underground space, while the planners and architects were the ones of the development at the surface. Cities worldwide tend to overlook an invaluable asset that lies beneath their surfaces. Most cities and urban regions are unaware of the benefits underground space use has to offer, both for climate inflicted and spatial constraints: In many cities, infrastructure development is being outpaced by population Growth. Climate change effects are requiring radical new approaches in terms of coping with for example excessive rainfall. The available space at the surface is rapidly being used up and the biggest danger is that built-up spaces are taking over the public green spaces of cities thereby threatening livability and quality of life. Urban underground space forms a societal asset, which is often unappreciated and underestimated in terms of the role it can play within dynamic city environments and associated challenges. The world-wide trend of increased urbanization creates problems for expanding and newly-developing cities alike. Population increase leads to an increased demand for reliable infrastructure, nowadays combined with a need for increased energy efficiency and a higher environmental awareness of the public. The use of underground space can help cities meet these increased demands while remaining compact, or find the space needed to include new functions in an existing city landscape. Use of Urban Underground Space (UUS) has been growing significantly in the world's biggest and wealthiest cities. UUS has been long acknowledged to be important to the urban development agenda: sustainability, resilience, livability, and creating a better urban environment in particular.

Keywords: *Underground space; urban planning; Sustainable development; subsurface governance; City resilience; urban growth.*

1. Corresponding Author, Tel:09121690702, Email Address: aadal@yahoo.com

Introduction

Although high urban density can help cities become more energy and resource efficient, urban density alone is not sufficient to obtain a high standard of living. Comparing the most densely populated cities with the most livable ones (Wikipedia, 2015; Mercer, 2015) shows there must be other factors involved. This paper proposes that an efficient and integrated use of the underground is one of these factors and gives a brief overview of the possible solutions the underground offers to improve the factors contributing to quality of live: safety, health, convenience, and comfort (UN, 1961). Indeed, UUS development can contribute a lot to urban sustainability, ranging from local renewable energy provisioning to urban space cohesiveness and aesthetics. Sustainability issues related to UUS use were raised by Carmody and Sterling (1993), Sterling (1997), Bobylev (2006, 2011), Rogers (2009), ITA-CUS (2010), and systematised by Sterling et al. (2012). Development of Urban Underground Space (UUS) can mitigate surface constraints on land acquisition, from building height limits and from landscape control (Carmody and Sterling, 1993; Golany and Ojima, 1996)[1]. The scale of UUS development constantly expands along with technological advancements (Goel et al., 2012). However, many of the current urban underground development cannot be said to be compatible with sustainable development. At present, the demand-driven "top-down" planning of Urban Underground Space (UUS) is commonly adopted worldwide (Admiraal, 2006). Urban underground is mainly considered as a space for construction. The interactions between underground space, groundwater, geo-materials and geothermal energy utilizations have not been fully considered in planning (Parriaux et al., 2004)[2]. The urban underground developments are mainly on a project basis when a need appears, which can be called a "sectorial approach" of urban underground use (Li and Li, 2013; Parriaux et al., 2004).

Measuring sustainability is an important subject, both in scholarly terms and as a policy informing tool. Lists of urban indicators or urban sustainability indicators have been adopted by many cities, countries, and international organizations to monitor progress in sustainable urban development. Sustainability is just one of the concepts that require to be informed by urban indicators; most recently the concepts of ecosystem services, resilience, smart cities have been developed and require input of urban data. Urban underground space, a place where all disciplines currently converge, is therefore better planned? Planning underground space hasn't the same meaning even today for an engineer as compared an urban planner. In fact, a lot of planning terms are used by many disciplines and they are not always consistent. During a very long period of time, civil engineers have been the sole experts of the underground space, while the planners and architects were the ones for the development at the surface. More recently, some visionary reformers and urban planners came and tried to change the situation, leading gradually all the experts of the underground toward real interdisciplinary work. Thus urban indicators become a more general notion, pertaining to developing, collecting, and analysing data from different aspects of urban life and then apply-

1.The world is increasingly an urban environment. Since 2008 more than half of the world population lives in cities and the world population are expected to increase to roughly 10 billion people over the next four decades. As the world's rural population is projected to remain stable in this period, that increase will occur in urban areas; By 2050, 70% of all people will live in cities and the world urban population will have more than doubled compared to the turn of the century (UN, 2007, 2013).

2.An urban population that is increasingly aware of the factors that improve quality of living, poses increased demands on their environment with respect to: reliable and safe transport of people and goods; dependable utilities, water distribution and sewerage systems; sustainability of the environment and limited urban sprawl; green spaces and recreational areas; reduced energy use and reduced emissions and noise levels; aesthetics and conservation of heritages; efficient use of real-estate and public space (Broere, 2012). In existing urban areas these demands pose significant challenges, as the space needed for developing new functions or relocating and improving existing ones is often not readily available. Placement of infrastructure and other facilities underground presents an opportunity to find the needed space, but it is often considered only as a last resort.

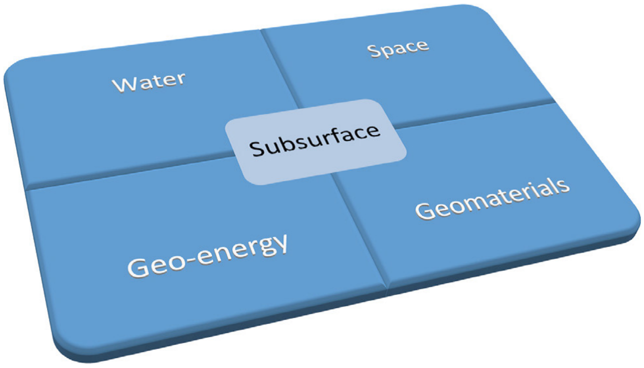


Fig 1. A model of the subsurface as comprising of four exploitable resources

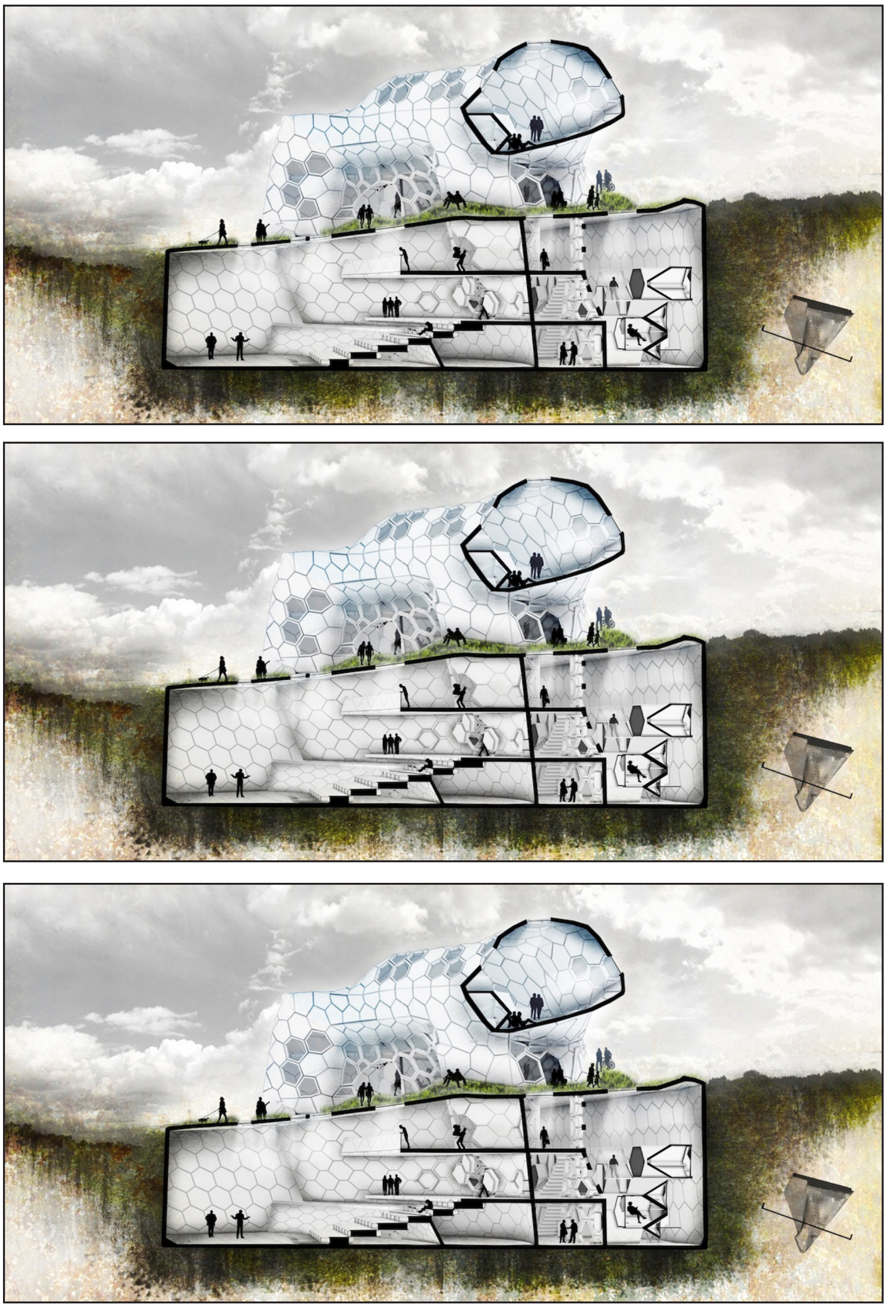


Fig 2, 3, 4. Sample of urban undergroind space; sources: athours' s archive.

فصلنامه مدیریت شهری
(ویژه نامه لاتین)
Urban Management
No.43 Summer 2016

ing this knowledge to develop a better urban environment. Value, exploitation difficulty and comprehensive quality of Underground Space Resource Urban Underground Space is a type of resource. It has its own potential, which is the available volume of exploitation.

The comprehensive quality of Underground Space Resource) is depended on its value and the exploitation difficulty. For the development of Urban Underground Space, there are some driving factors as well as limiting factors, which determine the available potential. For example:

1. High population density requires more space (Land shortage is common in many densely populated cities, e.g. 58% of Hong Kong (Hui et al., 2006) and 35% of South Korea's large cities (Son and Kim, 1998) have this issue. Population density might reflect the shortage of space and hence is a driving factor for underground development (Bobylev, 2009; Golany and Ojima, 1996)).

2. Land type, grade and real estate (or property) prices would affect the demand and commercial value of Underground Space. (Cost is much higher and hence an important consideration in UUS development. For example, in Tokyo, most of the basement type buildings are built in districts with population of more than 200,000 and land price of more than 400,000 yen/m2).

3. Subway construction is a vital driving factor and would also control the order of Underground Space development (Ground: Transit-Oriented Development (TOD2) mode; Underground: the metro network offered opportunity for nearby buildings to connect with metro stations).

4. The sites of particular interest (e.g. historical and ecological sites or places of natural beauty) should be defined, documented and protected.

Underground planning enhances the overall economy efficiency of facilities located underground and boosts the safety of these facilities and their use. "In simple terms, underground facilities can be thought of as providing the ultimate 'green roof'. Facilities placed fully underground (once constructed) do not impact the surface aesthetic and can provide natural ground surfaces and flora that maintain the natural ecological exchanges of thermal radiation, convection and moisture exchange" (Sterling et al., 2012).In spite of acknowledgement of UUS importance to the concepts and urban issues highlighted by use of urban indicators (e.g. sustainability, resilience), this subject has not made it yet into routine urban indicator lists. The importance of UUS as an urban activity sector is on a par with long established urban sectors as transport (widely used indicator: motorisation rate), land use and planning (widely used indicator: built stock density), environment (widely used indicators: air pollution, water quality)[1].

Urban underground solutions

UUS can be defined as a space beneath urban areas that has the potential to provide direct services to a city (e.g. groundwater supply or geothermal energy). UUS encompasses natural geological formations of rocks and soils, anthropogenically altered soils and manmade structures, as well as caverns of various origins. When considering liveability there are four basic UUS resources: space, materials, water, and energy (Parriaux et al., 2007), each of which has different degrees of renewability dependent upon the way and/ or rate they have been exploited (Sterling et al., 2012). Many dense urban environments face problems due to lacking infrastructure for transit, distribution of resources, goods and services. When paired with the demands listed above, these problems can be elaborated to include: traffic conges-

1.As populations grow in dense urban city centres, so too does the demand for space and natural resources. An option to combat this problem, all too often, has been to build denser and taller buildings in addition to transporting an ever-increasing abundance of resources (e.g. raw materials, water, energy and food) into the city whilst moving waste back out. This has major implications for liveable cities (LC), which in future policy terms might be considered to include aspects of (i) wellbeing, (ii) resource security (i.e. 'one planet' living) and (iii) carbon reduction (now enshrined in international law). An option that has been overlooked, and one which could add significantly to this LC agenda, is wider adoption of urban underground space (UUS).

Index type		Indices
I – Natural geological condition factors	Regional tectonic stability and seismic geologic condition	Fault activity Seismic intensity Construction site classification
	Topography and geomorphology	Geomorphic unit
	Geotechnical engineering properties	Properties and thickness of soft soil Liquefaction index of sandy soil Thickness of liquefiable soil layer
	Hydrogeology condition	Aquifer characteristics and distribution Yield of single well Corrosiveness of groundwater Watery faults in bed rock
	Geological hazards	Karst area Goaf area Ground fissure
II – Urban existing facilities and various protection demand factors		Protection of existing underground structures Building height limit Distribution of underground pipelines Heritage conservation Sensitivity of ecological space
III – Socio-economic factors		Population density Traffic location Benchmark land price Land usage type

▲ Table 2. Global development and urbanisation related concepts and Urban Underground Space (UUS).

tion; poor environmental conditions due to noise and air pollution; lack of safety, security, and protection against natural disasters and flooding; crowding and lack of space for work and recreation; restrictions when preserving aesthetic qualities and (cultural) heritages of the urban environment; aging infrastructure for distribution of resources, sewage conveyance and treatment; and combination effects of the above.

The undeservingly marginal role of UUS in urban sustainability and resilience discourse is reflected by the fact that the UUS topic has not made it yet into executive summaries of the most known policy documents related to urban development, i.e. United Nations Human Settlements Programmed State of Cities Reports (UN Habitat, 2006, 2013a); United Nations Environment Programmed Geo Outlook (UNEP, 2012); The World Bank Annual

Reports and Urbanization Reviews (World Bank, 2012); Organization for Economic Co-operation and Development Infrastructure Outlooks (OECD, 2006, 2008). However, the progress regarding mainstreaming UUS into urban agendas has been made. The United Nations Secretary General's formal address to the International Tunneling Association conference in Bangkok in 2006 highlighted UUS relevance to global development and urban sustainability agendas (UN, 2012b). Famous architect Norman Foster highlighted the strategic importance of UUS as well: "one of the greatest challenges facing mankind is to achieve higher density while at the same time improving urban existence. The underground has enormous potential for realizing spatial benefits" (Foster, 2011).

Underground space in cities

By 2009, in excess of half of the global population was living in cities (Besner, 2002; Parker, 2004). Moreover, the projected growth in urban centers in developed nations is expected to increase to 700,000 km2 by 2030 (from 300,000 km2 in the year 2000), with

Similar increases in emerging nations (from 250,000 km2 in 2000, to 820,000 km2 by 2030 – Angel et al., 2005). According to Godard (2004), the manifestation of this continuous growth will increase densities in our towns and cities, because they are a preferred space for development. Fig. 1 indicates that urban populations are increasing globally and it is reported that global physical city area expansion (276% by year 2030) will take place at a much higher rate than global population growth (66% by 2030 – Sterling et al., 2012). The pursuit of additional space in large urban areas is a global phenomenon as urban sprawl is restricted and buildings reach ever-increasing heights at considerable cost. This is accompanied by a number of challenges associated with provision of infrastructure, which grows proportionately with the size of the city (Hunt and Rogers, 2005; Rogers and Hunt, 2006; Hunt et al., 2009; Admiraal, 2010) and impacts liveability therein.

UUS functions in the role of a dynamic medium through which anthropological systems and ecosystem services interact and impact each other. Recognition that this interdependency exists is vital to understanding sustainability (as it pertains to civil engineering) in respect of how it impacts on urban systems' functionality. A burgeoning consensus points to the fact that future urban interventions that progress development and 'livability' for humankind, and readily embrace the principles of sustainability and resilience, must be considered at the planning and design stages of any infrastructure construction project (Godard, 2004; Jefferson et al., 2006; Braithwaite, 2007; Simpson and Tatsuoka, 2008; Hunt et al., 2008; Rogers, 2009; Rogers et al., 2012).

Traffic congestion

Probably the most recognized problem is the need for congestion relief in city streets. Time can be saved by using separated rail systems in order to reduce the rush hour traffic pressure. Hundreds of hours per worker per year can be saved in this way, as the cost of

Congestion in OECD countries is estimated to be equivalent to about 2 percent of the GDP (Godard, 2008). But mass transit systems offer other benefits, as they tend to require less surface area than road traffic. Studies show that car traffic takes up 30 to 90 times more space than metro systems. Similarly, public road transport takes 3 to 12 times more space (Thewes et al., 2012). By moving from above ground car traffic to underground mass transit systems, enormous amounts of surface land can be freed up for other uses.

Pollution and noise

Highway noise and emissions from vehicles are recognized as pressing problems in urban areas. In order to reduce the noise impact, sound barriers may be erected, but the visual impact of such measures is major. It is often the case that residential property values near freeways are reduced due to high noise levels from cars and exhaust emissions. Also, there

A concept and reference to the Urban Underground Space (UUS) research	Summary of major Urban Underground Space (UUS) relevant issues
Sustainability (Sterling et al., 2012)	1. Rational use of UUS resources; 2. Rational land use; 3. Combating urban sprawl and compact city; 4. Geothermal energy (deep) and shallow subsurface heat exchange); 5. Urban infrastructure efficiency (transport, water, others)
Resilience (Sterling and Nelson, 2013; Bobylev et al., 2013; Makana et al., 2016)	1. Urban natural and artificial disasters preparedness; 2. Emergency response and civil defence facilities; 3. Mitigation of city scale adverse environmental impacts (e.g. urban heat island effect); 4. Critical infrastructure reliability
Climate change adaptation and mitigation (Bobylev, 2009b, 2013)	1. Urban networks energy efficiency (mitigation); 2. Stable temperature mode benefits while locating urban functions underground (mitigation); 3. Enabling urban compactness (mitigation); 4. Underground infrastructure facilities for urban climate change adaptation; 5. Adaptation of urban underground infrastructure to climate change (reflecting changes in water balance, extreme temperatures)
Smart city (Bobylev, 2014)	1. Greater use of information and communication technologies to enable more efficient use of existing urban; 2. underground infrastructure facilities (e.g. water sewers)
Liveable city (Hunt et al., 2016)	1. Compact and high quality public spaces; 2. Enhancing urban green and recreational areas by putting infrastructure underground
Compact city (Bobylev, 2009a; Wende et al., 2010)	1. Densification; 2. Quality of life and the environment; 3. Proximity
"0-land use" (Vahaaho, 2013)	1.A concept of "0-land use" is an idealistic approach to urban growth and development using just underground-space;

▲ Table 2. Global development and urbanisation related concepts and Urban Underground Space (UUS).

are associated health and safety issues for living close to a freeway. Once again, moving passenger transport from cars to mass transit systems can reduce the noise and pollution impact at the local level, but also at a larger scale as mass transit systems tend to be more energy efficient and substantial energy savings can be obtained by the increased use of metro systems.

Protection against natural disasters

With concentration of population, urban areas are particularly vulnerable to failures in infrastructure due to ageing of the systems or those caused by other natural forces. Growth of population not only means more people are relying on the infrastructure, but at the same time that the man-made facilities may increase the severity of the disaster. For example, urbanization means more paved area leading to more severe flooding, as well as loss of water resources recharging groundwater.

Lack of space and preservation of heritage and environment

Most of the underground examples above are not intended for a long-term human presence. This stems from the human preference to live, work and recreate above ground. Historically, underground structures were primarily intended for shelter or served as entry and connection points for mass transit systems. Over

مدیریت شهری
فصلنامه مدیریت شهری
(ویژه نامه لاتین)
Urban Management
No.43 Summer 2016

Fig 5. Access to UUS retail space and provision of light in the Bullring, Birmingham, UK.

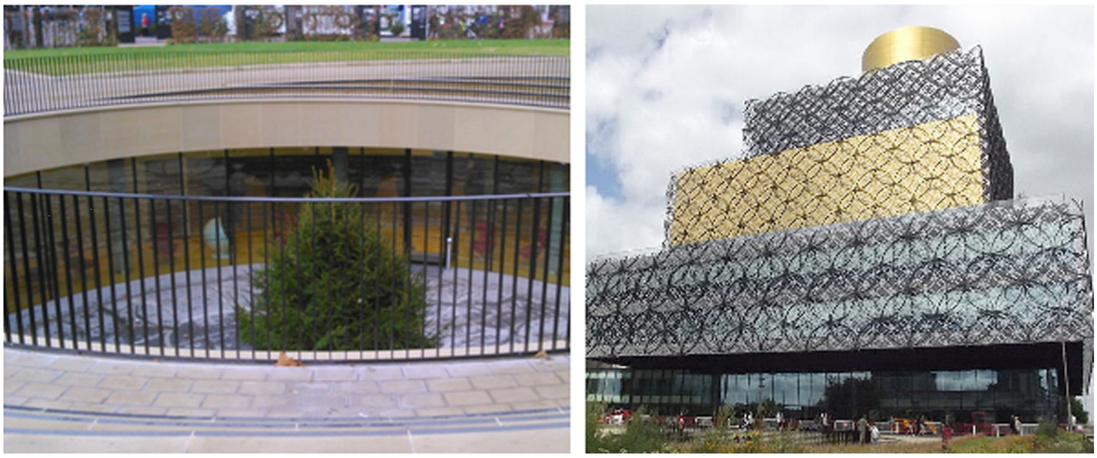


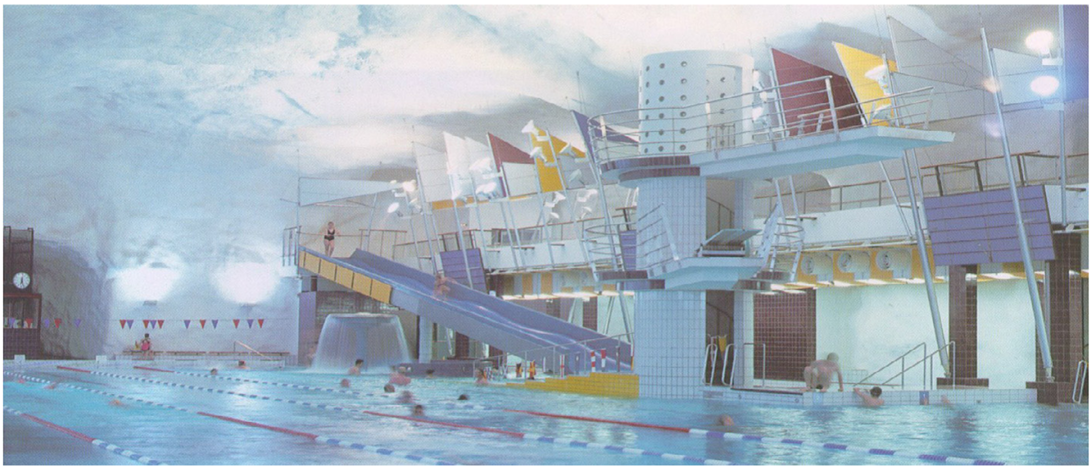
Fig 6. Access to UUS educational space and provision of light in the new library, Birmingham, UK.

مدیریت شهری
فصلنامه مدیریت شهری
(ویژه نامه لاتین)
Urban Management
No.43 Summer 2016

time, a wider range of functional facilities has taken up underground residence, but often still with a short intended stay for individuals below ground. Mostly the aim was to free surface space for other human needs and to improve the living conditions of cities. Examples such as underground car parks, shopping malls or underground storage facilities have been documented by Thewes et al. (2012). Recently, the aim is more and more to not only keep surface space free and to create new space and functions, but to do so in a manner that preserves existing buildings and cultural heritages. This is especially true for public functions housed in historic monuments.

Conclusion

Urban Underground Space (UUS) use has been growing significantly in the world's biggest and wealthiest cities. Arguably, the main driving factors of this growth were lack of surface space and a need for a better environment, including abatement of motor traffic and pollution problems. Generalising, we can suggest that awareness of the urban sustainability agenda and a need to make cities more liveable have been growing concurrently with intensification of UUS development. Underground development is an important tool in developing and reshaping urban areas to meet the challenges of the future. Placement of infrastructure and other facilities underground presents an opportunity for realizing new functions in urban areas without destroying heritages or negatively impacting the surface environment, and at the same time brings opportunities for longterm improvements in the



▲ Fig 7. Underground swimming pool in Itäkeskus, which can accommodate 1000 customers at a time and can be converted into an emergency shelter for 3800 people ifnecessary. Photo: Erkki Makkonen.

▲ Fig 8. Artist impression of the Lowline underground park. Image courtesy of: RAAD Studio, New York.

مدیریت شهری
فصلنامه مدیریت شهری
(ویژه نامه لاتین)
Urban Management
No.43 Summer 2016

environmental impact of cities and more efficient use of space and resources. These benefits are there for existing, redeveloping cities, but can be implemented for newly developing cities more easily and more cost effectively, for even greater benefits.

Refrencess

Chow, F., Paul, T., Vahaaho, I., Sellberg, B., & Lemos, L. (2002). Hidden aspects of urban planning: utilisation of underground space. In: Paper Presented at the Proc. 2nd Int. Conference on Soil Structure Interaction in Urban Civil Engineering.

Duffaut, P., 1977. Site reservation policies for large underground openings. In: Subsurface Space: Rockstore, vol. 77, pp. 10.

Duffaut, P., Labbé, M., 2008. Contribution du sous-sol à la vie urbaine, exemple du Val-de-Marne. Tunnels et ouvrages souterrains (209), 383–389.

Evans, D., Stephenson, M., Shaw, R., 2009. The present and future use of 'land' below ground. Land Use Policy 26, S302–S316.

Fairhurst, C., 1976. Going Under to Stay on Top. Pergamon Press, New York.

Fiksel, J., 2006. Sustainability and resilience: toward a systems approach. Sustain.: Sci. Pract. Policy 2 (2), 14–21.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T., Rockström, J., 2010. Resilience thinking: integrating resilience, adaptability and transformability. Ecol. Soc. 15 (4), 20.

Abraham, K., 2008. Smart tunnel the unique dual purpose solution for Kuala Lumpur. In: Enlightened Underground, Centrum Ondergronds Bouwen.

Angel, S., Parent, J., Civco, D.L., Blei, A., Potere,

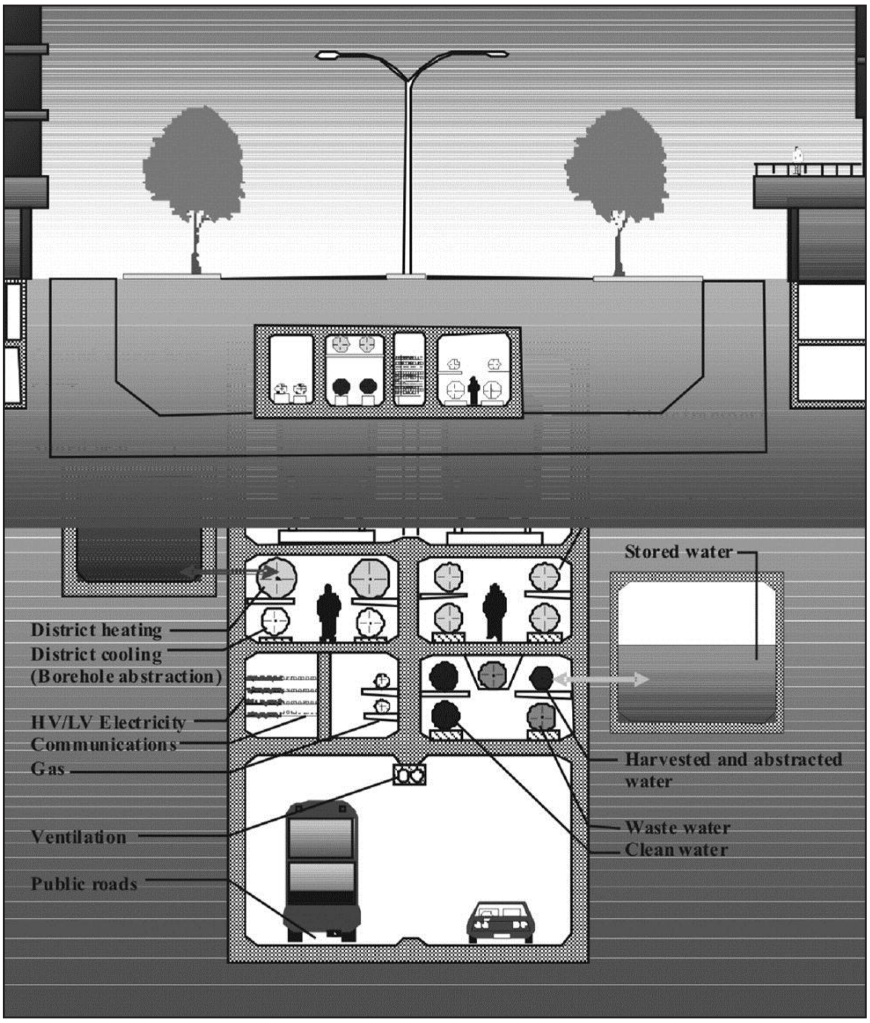


Fig 9 & 10. Sample of urban ground space; source: authors' s archive.

مدیریت شهری
فصلنامه مدیریت شهری
(ویژه نامه لاتین)
Urban Management
No.43 Summer 2016

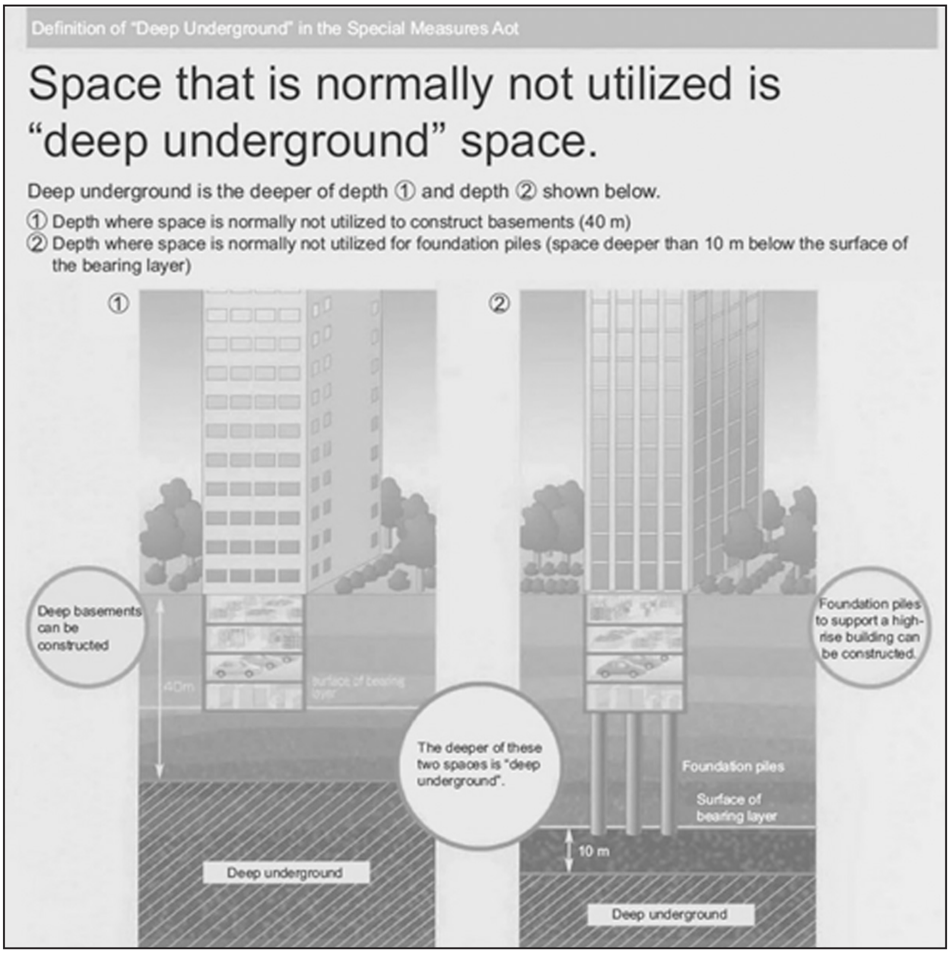


Fig 11. Illustration of 'deep' underground space in the Underground Special Measures Act in Japan (Sterling et al., 2012)..

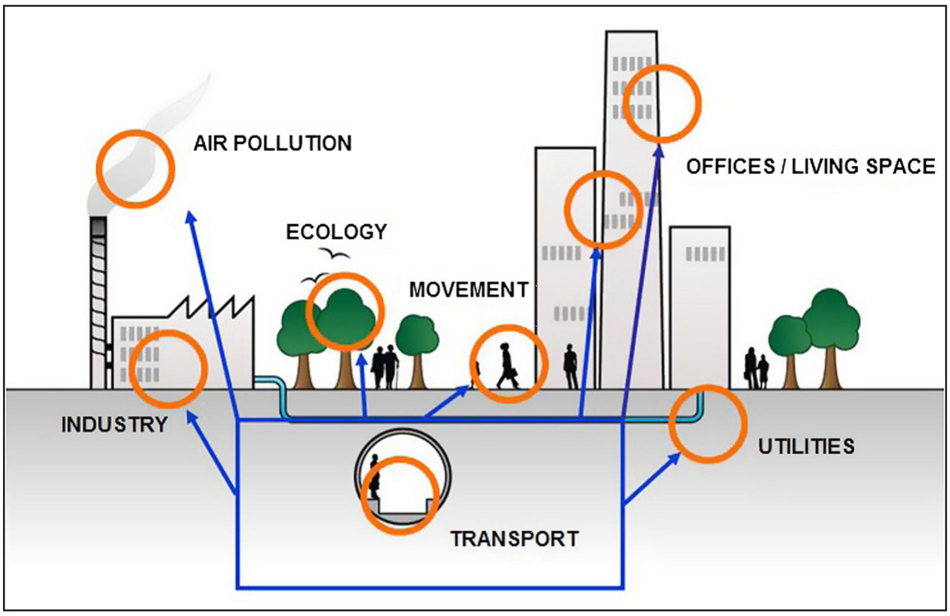


Fig 12. Different dimensions of urban sustainability and resilience that UUS impacts within the urban landscape (adapted from Lombardi et al., 2012).

مدیریت شهری
فصلنامه مدیریت شهری
(ویژه نامه لاتین)
Urban Management
No.43 Summer 2016

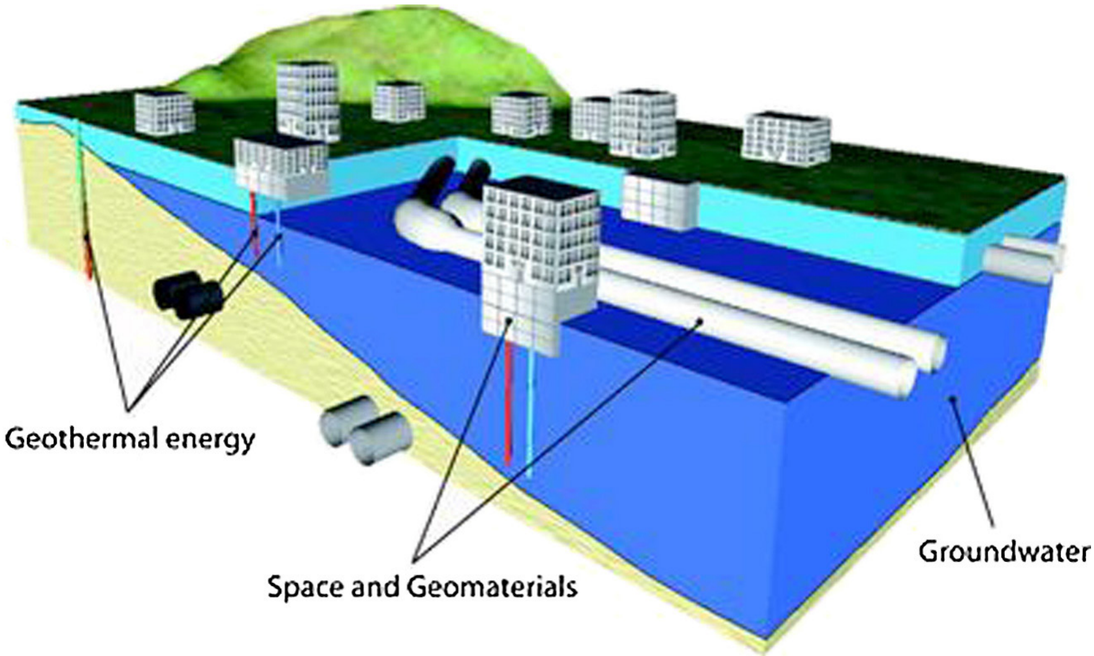


Fig 13. The four main resources of the urban underground (Parriaux et al., 2006).

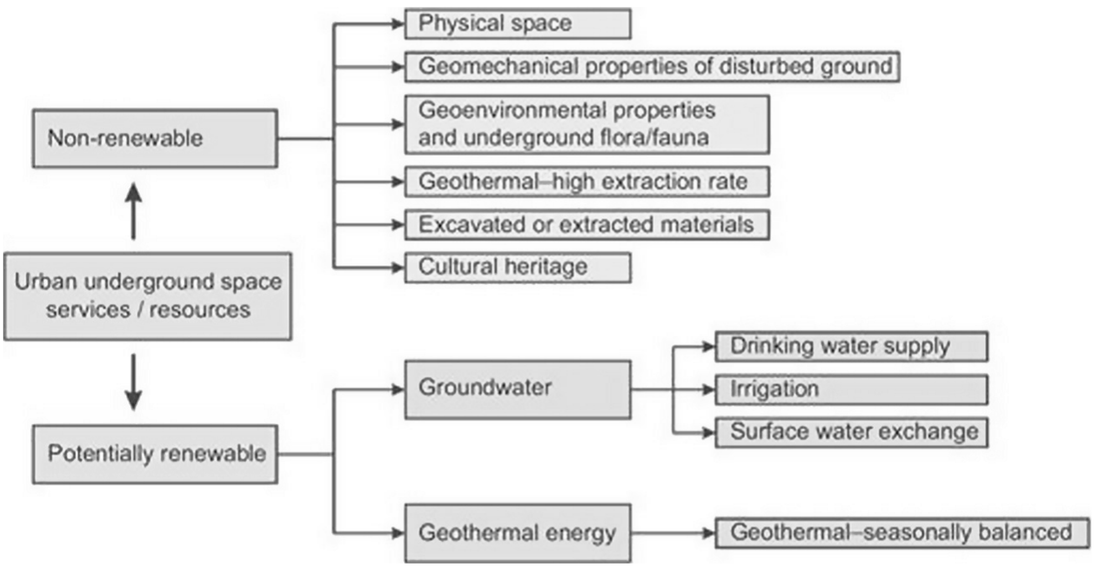


Fig 14. Renewable and non-renewable underground resources (Bobylev, 2009).

D., 2011. The dimensions of global urban expansion: estimates and projections for all countries, 2000–2050. Prog. Plan. 75, 53–107.

Arnáiz, M., Bueno, P., 2009. Madrid: a global example of the development of safe and efficient underground urban road and rail infrastructures. Mod. Tunnell. Technol. 4, 002.

Bobylev, N., 2009. Mainstreaming sustainable development into a city's master plan: a case of urban underground space use. Land Use Policy 26, 1128–1137.

Bosch, J., Broere, W., 2011. The urgent need for physical planning of the underground in the Netherlands. In: Särkkä, P. (Ed.), Proceedings WTC2011

Underground Spaces in the Service of a Sustainable Society, pp. 150–151.
Angel, S., Sheppard, S.C., Civco, D.L., 2005. The Dynamics of Global Urban Expansion. World Bank, Washington, DC.
Anttikoski, U., Grön, V., Halme, A., Juhola, M., Palmu, M., i Parkkamäki, O., Tuisku, T.,
Äyräväinen, O., 1989. Subsurface public assembly spaces in Finland. Tunn. Undergr. Space Technol. 4 (1), 17–22, ISSN 0886-7798.
Bobylev, N., 2006. Strategic environmental assessment of urban underground infrastructure development policies. Tunn. Undergr. Space Technol. 21 (3–4), 469–479.
Carmody, J., Sterling, R., 1993. Underground Space Design: A Guide to Subsurface Utilization and Design for People in Underground Spaces. Van Nostrand Reinhold, New York, January 1993.
Castanheira, G., Bragança, L., 2014. The evolution of the sustainability assessment tool SBToolPT: from buildings to the built environment. Sci. World J. 62 (4), 1(2356–6140).
CRISP Project, 1999. A European Thematic Network on Construction and City Related Sustainability Indicators. Final Report.
Cui, J., Allan, A., Taylor, M., Lin, D., 2013. Underground pedestrian systems development in cities: influencing factors and implications. Tunn. Undergr. Space Technol. 35, 152–160.
Ronka, K., Ritola, J., Rauhala, K., 1998. Underground space in land-use planning. Tunn. Undergr. Space Technol. 13 (1), 39–49.
Shen, L.Y., Ochoa, J.J., Shah, M.N., Zhang, X., 2011. The application of urban sustainability indicators – a comparison between various practices. Habitat Int. 35 (2011), 17–29.
Shi, X.D., 2006. Review and Vista of Beijing Underground Space Utilization. Planning and Construction of Beijing. Beijing Planning Review, Beijing, pp. 32–40.
Sterling, R., Nelson, P., 2013. City resiliency an underground space use. In: Zhou, Cai, Sterling (Eds.), Advances in Underground Space Development, Copyright 2013 by The Society for Rock Mechanics & Engineering Geology (Singapore). Published by Research Publishing. pp. 56–14. ISBN: 978-981-07-3756-6.
Vahaaho, I, 2013. 0-Land use: underground resources and master plan in Helsinki. In: Zhou, Cai, Sterling (Eds.), Advances in Underground Space Development, Copyright 2013 by The Society for Rock Mechanics & Engineering Geology (Singapore). Published by Research Publishing. pp. 56–14. ISBN: 978-981-07-3756-6.
Wende, W., Huelsmann, W., Marty, M., Penn-Bressel, G., Bobylev, N., 2010. Climate protection and compact urban structures in spatial planning and local construction plans in Germany. Land Use Policy 27 (3), 864–868.
UN, 1961. An Interim Report on the International Definition and Measurement of Levels of Living. Technical Report Ecn.3/270/Rev.1-E.CN.5/353, United Nations (UN).
UN, 2007. World Population Prospects: The 2007 Revision. Technical Report. United Nations, Department of Economic and Social Affairs, Population Division.
UN, 2013. World Population Prospects: The 2012 Revision. Technical Report ESA/P/ WP.228. United Nations, Department of Economic and Social Affairs, Population
Division.
Jenks, M., Burgess, R., 2000. Compact Cities: Sustainable Urban Forms for Developing Countries. Taylor & Francis.
Li, H.Q., Parriaux, A., Thalmann, P., Li, X.Z., 2013. An integrated planning concept for the emerging underground urbanism: deep city method part 1 concept, process and application. Tunnell. Undergr. Space Technol. 38, 559–568.
Longman, P.J., 1998. Who Pays for Sprawl, Hidden Subsidies Fuel the Growth of the Suburban Fringe. US News and World Report 27.
Helsinki City Council, 2010. Helsingin maanalaisen yleiskaavan hyväksyminen' (Approval of the Underground Master Plan), Decision number 16 (Khs 2009– 237), 8 December 2010, Decision-making history from the Appendices
Helsinki City, 2013. Building Helsinki, Leaflet of the Helsinki City Real Estate Department. <www.hel.fi/static/kv/BuildingHelsinki.pdf>.