Re-promoting Sustainable Underground Urbanization for Developed and Developing Countries in Our Modern History

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Abstract. During recent decades of overwhelming exploration of underground resources (groundwater, geothermal energy, minerals) and underground spaces (tunnels, caverns, buildings), there has been a lack of in-depth investigation on international agenda to look at the degree of political awareness of sustainable underground development. International organizations advocating and debating the use of underground space and its innovative contribution to urban futures, have been sustained through intensive interaction through conferences and working groups. These active moves involved public and private actors from developed and developing countries, with a rapidly increasing interest to explore the various and viable usage of this natural resource – subsurface space. From 2014 to present, as an international consensus built up by a long-term advocating efforts addressed through a series of World Urban Forums, United Nations Human Settlements Program (UN-HABITAT) recognized the necessity of promoting best practices of the sustainable use of underground space for resilient urban development in modern era and for implementing the 17 Sustainable Development Goals (SDGs) of UN 2030 Agenda. This article will present a first retrospect on the modern history of research initiation and international promotional agenda for sustainable underground urbanization. Qualitative archive data analysis and city case study demonstration will be used to showcase international stakeholders’ awareness enhancement, policy promotion and universal implementation.

1. Introduction
Started from 1981, United Nations stated an urgent need to strategize a sustainable development of underground spaces beneath growing cities through its action by adopting subsurface space as part of the program financed by “United Nations Committee on Natural Resources”. The 1982 “United Nations Interregional Workshop on the Utilization of Subsurface Space” pointed out the need to investigate potential use of subsurface space in developing countries, by drawing lessons and experiences learnt from developed countries that had intensively explored the functionalities of underground spaces for transport and facilities. Subsurface development technology and technology transfer, as well as the economics of underground space projects were also key topics of this UN workshop. Financing urban development projects of transportation systems and public utilities in developing countries, was stressed with special attention to UN organizations by recognizing the increasingly importance of subsurface space projects for urban development.

Developed countries (such as Finland, Sweden, France, UK, Japan, Canada, USA, Switzerland, Australia) have been sizing up extensively the scale and depth of subsurface space for urban development with respective strategic models, while impacting the natural environment of geosphere. This research orientation targeted to urban subsurface, namely “Deep City Concept”, has been a long-term initiative started by the authors from 2009 in Swiss Federal Institute of Technology in Lausanne (Li et al., 2013b; Li, 2013). This unique experience for innovative urbanism has been transferred to developing countries (such as China, Singapore) by academic cooperation, with a more holistic view
on synergizing sustainable geological resources management (groundwater, geothermal energy, geomaterial and underground space) with resilient underground construction (Li et al., 2013a; Li et al., 2016).

International organizations advocating Underground Development for megacities in our 21st Century (Kaliampakos, 2016) and debating the use of underground space and its contribution to urban futures, have been sustained through intensive interaction through conferences and working groups. These active moves beginning from 1980s involved public and private actors from developed and developing countries, with a rapidly increasing interest to explore the various and viable usage of this multifunctional natural resource – Urban Subsurface.

1.1. In 1981: the first resolution drafted by the United Nations Committee on Natural Resources about Subsurface Potential

In 1981, United Nations Committee on Natural Resources adopted subsurface space as part of its program (Magnus Bergman, 1986). The First Draft Resolution on Utilization of Subsurface Space, was archived by UN Resolution Library with the official document number E/RES/1981/82 (ECOSOC, 1981). This first official voice for promoting the potential of subsurface space was caused by stressing concerns on population growth, urbanization speed, surface congestion, as well as availability of experiences on underground space use in many parts of the modern world. Due to limited experience and knowledge on underground utilization in this early era, general attitudes towards the use of subsurface space technology were focusing on cost issues and financing difficulties.

Basic urban services, are crucial for human settlements in developing nations. In some African cities (such as Lagos in Nigeria) with more than 10 million people and with the world’s most highest growth rates (3.79% for the period of 2010-2025) (Zhao et al., 2017), citywide sewage system is poorly organized and not controlled, causing severe urban health disasters (OBAYOMI 2011). When urban growth is above a certain threshold of development, there is little alternative to utilizing the underground. Subsurface offers an opportunity to begin with a virtually untapped resource in the developing nations. A report published by the World Economic Forum clarified the division of the developing and developed world, with a mapping shown in Figure 1 below.

![Developing / Developed World](Image)

*Figure 1 Mapping the developing and developed world (Source: from World Economic Forum 2015)*

We are facing a tremendous population explosion happening in major cities of the world, causing an ever-increasing competition for available space (urbanized land) and competition for available resources (water, food, energy). According to the World Population Prospect (United Nations, 2019): between 2019 and 2050, countries of sub-Saharan Africa could count for more than half of the growth of the world population.

1.2. In 1982: the first report released by the United Nations Sustainable Development Journal about Subsurface Functions

In 1982, the “United Nations Interregional Workshop on the Utilization of Subsurface Space” was convened in Stockholm during October 24th to 29th. This workshop pointed out the need to investigate potential use of subsurface space in developing countries, by drawing lessons and experiences learnt from developed countries that had intensively explored the functionalities of underground spaces for transport and municipal facilities.

Subsurface planning and technology transfer, as well as the economics of underground space projects were also key topics of this UN workshop. Financing urban development projects of
transportation systems and public utilities in developing countries, was stressed with special attention to UN organizations by recognizing the increasingly importance of subsurface space projects for urban development.

For summarizing the outcome of this UN workshop, United Nations Sustainable Development Journal “Natural Resources Forum” published an article titled “Utilization of Subsurface Space in Developing Countries” by Mr. Tajammal H. Hashmi, Technical Adviser of the Public Works Section of the Water Resources Branch in the Division of Natural Resources and Energy, TCD, United Nations (Hashmi, 1983). This workshop led a very first move to bridge inter-regional discussions on the potential usage, functional design & technology transfer, as well as planning, financial & technological discussions.

1.3. In 1983: the first resolution adopted by the United Nations Economic and Social Council about Subsurface Planning

In 1983, official adoption of the Resolution on Utilization of Subsurface Space by The UN, Economic and Social Council (during the 40th plenary meeting, 28 July 1983), symbolized the international consensus for subsurface space as valuable natural resources (ECOSOC, 1983). During the United Nations Development Program (UNDP) Governing Council Thirtieth session (June 1983, New York), Department of Technical Co-operation for Development (DTCD) addressed the important of administering sub-surface space for water supply.

Infrastructures is considered as a catalyst for the prosperity of African Cities (Arimah, 2017), enabling climate change risk management by preparing drainage for flooding (Steynor et al., 2020; Filho et al., 2018), and facilitating Resiliency planning for megacities emerged in Africa (Spaliviero et al., 2020). Disaster prevention and sheltering facilities should be also incorporated into urban planning process, by allocating safety evacuation space for emergency incidents (such as floods, earthquake, fire accident) and reserving secured sheltering centers for severe events (such as epidemics, plague, turmoil).

1.4. In 2004: the first statement released by the United Nations Economic and Social Council about Underground Storage

In 2004, UN Economic and Social Council released a statement on “Resources mobilization and enabling environment for poverty eradication in the context of the implementation of the Programme of Action for the Least Developed Countries for the Decade 2001-2010 (Association, 2004). In this UN Statement (E/2004/NGO/14), targeted to help the Least Developed Countries (LDC), it was suggested to apply underground construction in rural communities for storing food, water and other products and equipment, to provide good and safe environment. Indicated by the statement, using underground space in the LDC as one of the best and least expensive ways to improve the quality of life in the least developed countries, there are several benefits for local communities: employment of local labour and demand of limited outside resources. Beside large scale underground tunnels and infrastructures built extensively in developed nations, earth-sheltered construction and underground storage were proposed to be part of the development program for the least developed countries.

1.5. In 2008: the first International Year of Planet Earth proclaimed by UNESCO about earth science and subsurface

In 2008, United Nations Educational, Scientific and Culture Organization (UNESCO) – Earth Science Division, jointly initiated the International Year of Planet Earth (IYPE) with the International Union of Geological Sciences (IUGS). Earth science (climate, oceans, megacities, earth and life), geological resources management (groundwater, soils, deep earth, geohazards, resources issues), and human health (medical geology) are key themes supported by the 2008 IYPE for a global launch to enhance research effort and to raise political concerns. Focusing on earth and health, this exceptional international initiative brought up an united effort contributed by multidisciplinary communities including geoscientists, engineers, sociologists, economists, legislators and medical scientists. Progressing technologies including transport and storage engineering in the shallow subsurface of cities and mineral exploration in the deep earth, allowed the increasing demand of subsurface space for modern urbanization. Therefore, an urgent call was launched by 2008 IYPE to raise geo-environmental awareness and to reduce negative impacts of advanced geoengineering to the nature and human being.
1.6. In 2014: the first world urban campaign on sustainable development of underground space promoted by UN-HABITAT

In 2014, the United Nations Human Settlements Program (UN-HABITAT) recognized the necessity of promoting best practices of the sustainable use of underground space for urban development. This international consensus led by UN-HABITAT and ACUUS (Associated research Centers for the Urban Underground Space), was built up by a long-term advocating efforts addressed through a series of World Urban Forum†† and Urban Thinkers Campus‡‡, contributing by NGOs, industries, universities, authorities and the general public. In 2014, the first Urban Thinkers Campus (UTC) inaugurated in Italy by UN-HABITAT, was contributed by an Urban Lab session titled “Advanced Local Energy Planning and Underground Space”§§. In 2019, the second UTC was organized in China with the theme “Collaborative Exploration and Sustainable Development of Underground Space: NUA, Drivers of Change and Geosciences”***. Smart city planning with better quality basic services and energy infrastructures, with integrated strategy combining surface land use with vertical functions, and with transformative restructuring enabled by geosciences related technologies and innovations, has been emphasized on the discussion platforms of these two successful Urban Thinkers Campuses.

Underground space, defined as a valuable land resource for livable cities (Sterling, 1997; Hunt et al., 2016) and resilient metropolitan areas (Bélanger, 2016; Makana et al., 2016), is calling for integrated master planning action (von der Tann et al., 2019) and localized solutions (Delmastro et al., 2016b), in which the role of geothermal energy planning for low-carbon cities and the role of groundwater exploration for drinking use should contribute with higher attention from the public and policy makers. In 2016, UN-HABITAT adopted the manifesto “The City We Need” (TCWN 2.0)††† that stated the necessity of planned underground infrastructure development as “Drivers of Change” for “Governance and Partnerships”, for “Planning and Design” and for “Land, Housing and Services”.

Best practices of urban planning and architectural design in African cities (Dos Santos and Mota, 2019), took into account the unique climate conditions and cultural characters. While master planning should incorporate the use underground space for metropolitans, local residential and farming plans can also develop climate adapted underground ventilation system, underground water drainage, and underground irrigation technology. Contemporary subterranean architecture design with geodiversity and topography is named Groundscapes (Perrault, 2016). As shown in Figure 2, there are numerous functions in the subsurface at different layers deep to 4000 meters (Volchko et al., 2020), which deserve an universal subsurface planning with advanced knowledge on geosystem qualities. As deep natural assets and geo-capitals for cities, underground space can be considered as new urban planning horizons and technology frontiers for the resilient and inclusive future of African cities.

Figure 2 Multiple functions of the subsurface deep to 4000m (left), Groundscape architecture at shallow subsurface (Ewha Womans University) (middle), Norwegian underground seed bank for securing global food future (right)

2. A concept of “Deep Growth Africa” for improving resilient urban habitat in 2030

Subterranean construction technologies have been broadly developed from the mining sector in Africa. These engineering technologies could be transferred to urban engineering market to provide more public service functions such as drainage tunnels, water supply networks, energy storage facilities, food storages and waste handling works in the subsurface.

2.1. Potential underground space functions for “Deep Growth Africa”
In many overcrowded urban areas (such as slums) and over risky residential zones (such as earthquake and flooding zones), underground utility system may be the only option for providing viable basis of energy supply, water supply and communication supply. Manmade and natural disasters can not be avoided at short term, but innovative solutions with advanced thinking for urban planning can be implemented immediately.

According to World Health Organization, locating public utility pipes underground can offer advantages for cities in terms of environmental protection (by isolating noise, odor, air and water pollution), as well as economic viability (such as gravity-functioning sewer network and water distribution system). In addition, future design and construction of multi-utility tunnels was promoted by overcoming institutional and cost constraints, considering its important contribution to megacities such as London, Paris and Tokyo, according to the “Global Guide To Sewers” (Halliday, 2019). Health concerns such as malaria are threatening survival rights of the rising population in Africa, public sewer system should a “must” for urban planning authorities responsible for creating legitimate livelihood for the fragile habitat.

2.2. Geo-space resources for “Deep Growth Africa”

Information on the explorable earth materials and usable geological resources, is vital for sustainable management enabled by spatial mapping of resources, quantity statistics of reserves and security monitoring of exploration. **For planning different types of underground food storage in Africa:** 1) Clayed soil is suitable for shallow depth (10 meters) underground grain storage (Valls et al., 2015), which should be mapped combined with population density index for locating future grain storage projects; 2) Rock based geological area can be potential sites for large food storage cavern, which will need higher capital investment than shallow grain storage facilities. Large scale food storage cavern should be planned closed to international trading ports and dense urban area (such as the planned harbor terminal underground grain storage project in Egypt in the 1980s), in order to maximum capital return and social benefits to habitat.

2.3. Groundwater for drinking water resources for “Deep Growth Africa”

While we are facing drinking water scarcity in Africa, groundwater potential in Africa has been rarely documented for its contribution to urbanization due to lack of resources survey. British Geological Survey (Bonsor and MacDonald, 2011) reported groundwater availability (aquifer thickness) and groundwater access (depth to aquifer), two important indicators to assess groundwater potential in Africa. Under this estimation, **nearly 50% of African cities can have easy access to groundwater (depth less than 25 meters),** with a vast territorial potential of having high volume of groundwater resources (aquifer thickness more than 100 meters).

Published by the Nature journal (Rockström and Falkenmark, 2015), groundwater harvesting technology for farming has been proven in the world and should be promoted for sub-Saharan African cities. This represents an untapped potential in Africa (Molden, 2013) to boost urban agriculture sector by using water stored and produced in the underground. Zoning policy can be formulated to reserve groundwater sufficient regions for urban agriculture planning, based on investigation and evaluation of groundwater aquifer productivity shown in Figure 3. This very first geological resources estimation came from a project supported by British Geological Survey (Bonsor and MacDonald, 2011), which could provide guidance for a better groundwater planning solution.

![Figure 3: Groundwater quantity mapping for Africa. Blue area as high potential (from British Geological Survey 2011)](image-url)
2.4. Geothermal energy and Food storage for “Deep Growth Africa”

In addition to richness in groundwater resource, Africa has the potential to provide 9000MV of power generation capacity from hot water and steam based geothermal resources, according to the estimation published by (Aretouyap et al., 2016). Currently, African countries exploit different types of direct geothermal use, for example, usages for space heating, greenhouse heating, fish farming, bathing and swimming had the highest shares of installed capacity, according to local investigations in Africa (Simiyu, 2010; Teklemariam, 2008). Indirect geothermal energy exploitation for electricity generation in Africa is also investigated in the recent decades (Simiyu, 2010; Teklemariam, 2008).

Renewable energy storage is important for long-term supply of clean energy for Future Africa. Most importantly, according to a recent research on “Smart Economy in Smart African Cities” (Mboup and Oyelaran-Oyeyinka, 2019), 82% of climate financing target for African cities is related to the energy sector, taking into account its expanding electricity grid infrastructure as infrastructure readiness for increasing energy supply in Africa.

Food can be accessed by all people only if a complete supply chain of food production (agriculture), food storage (warehousing) and food distribution (transportation) is well designed and planned. In Africa, since urban agriculture is major economic activity for inclusive growth, supporting storage facilities and distribution infrastructures should be in place for all people in African cities. United Nations Progress Report of Subsurface Space in 1986 has raised the importance of underground storage development (to keep food storage losses to a minimum) for developing countries (Magnus Bergman, 1986), with technologies and feasible planning as shown in Figure 4.

According to FAO (Food and Agriculture Organization of the United Nations), post-harvest food losses are big concerned in developing countries due to insufficient storage technologies handling from agricultural production sites to harbor terminals. Developing countries in Africa need inexpensive storage facilities for holding large volume of raw and process food products, due to the limited conditions of cold storage and effective transportation. In reality, rural African area stored 80% of grain locally, which requires efficient storage techniques for its rural agricultural industry. In an Egyptian underground grain storage project design with rock caverns, the cost level was considered to equal that of building a surface storage facility.

Figure 4 Underground food storage system and connection to food transportation (from UN Progress Report 1986)

3. Conclusion

Political awareness of subsurface potential in the developing world, is still lack of significant attention despite the high quality development of underground infrastructures in the developed world. This experience sharing and technology transfer process, will take around 20 years based on the case of China, the country ranking the highest number of metro systems and common utility tunnels in the world by learning from the developed world. Various movements including workshops, conferences, resolution establishments, progress reporting, financing initiations and technology transfer are critical to advance this fast developing industry of underground space development. From natural resources management to urban planning, the role of subsurface space is playing as evolving and sustaining solution for the developed world and the incoming developing cities. Based on the international consensus built up by United Nations from 1981, regional platforms in Europe, North America and Asia are raising particular awareness through respective agendas in academic, industrial and political domains.

This article traced back critical moments and resolutions on the path of international consensus building on promoting sustainable use of subsurface space in cities and human settlements. The scientific enhance and political awareness should be well connected to foster common strategic
direction and operational action in this special field of urban innovation, considering that underground space is a unique natural resources providing multiple functions for urban transportation, public utilities, energy & water facilities, freight infrastructure and more frontier innovations. Historical steps were taken with universal efforts contributed by stakeholders at different hierarchies. Next steps will be oriented towards the application of underground space solutions in developing nations such as African cities.

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