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सत्यमेव जयते

UNDERGROUND URBANISM

Re-imagining the role of underground spaces for India's urban future

Resilient India - Disaster Free India

National Institute of Disaster Management (NIDM)
Ministry of Home Affairs, Government of India

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2022

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National Institute of Disaster Management (NIDM)

(Ministry of Home Affairs, Government of India)

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Underground Urbanism: Re-imagining the role of underground spaces for India's urban future

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MESSAGE

Cities and urban areas are home to more than half of the global population and this figure is predicted to increase manifold in the upcoming years. However, cities across the globe are faced with the challenge of limited land availability. Land resources play an integral role for development; where on one hand, more land for development is required, while on the other, more open spaces are required for climate and disaster resilience. Thus, it is essential to strike a balance between sustainable development and public space availability on the surface.

Facing this dichotomy, cities are now exploring the subsurface for public use like transportation, entertainment, commerce, water and sewer lines, electricity etc. Yet the value of underground spaces is largely overlooked in planning processes. It calls for planners, designers, engineers, architects, managers and innovators to come on a common platform.

I compliment all the authors and National Institute of Disaster Management (NIDM) for documenting key insights of the study while using case examples from the technology industry. I am sure that "Underground urbanism: Re-imagining the role of underground spaces for India's urban future" being published by the NIDM, Ministry of Home Affairs, Government of India will be useful to all practitioners exploring, implementing or studying science and policy-based studies for underground urbanism.

(Akhilesh Gupta)

Resilient India - Disaster Free India

ताज हसन, भा. पु. से.
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FOREWORD

Climate change and sustainable urbanisation are increasingly becoming a priority concern for policymakers and practitioners across the world. For a long time, cities have been designing, planning, and implementing strategies and solutions for a climate-resilient and sustainable urban future. In all these efforts, the focus on resilience and sustainable development has been above the ground surface.

While selected cities have explored the underground surface for a climate-resilient and sustainable future, the world beneath our feet remains largely unexplored and undervalued. This study provides valuable insights into the world of underground spaces. It highlights the role these spaces are playing and can play in climate response and sustainable development using case examples from across the world.

I compliment the authors for leading this study and publishing key findings and ways forward in this direction. This publication is most relevant in the present time and I am confident it will be very useful for professionals and policymakers across multiple disciplines working on climate change and urban sustainability.

Tajhassan

(Taj Hassan)

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PREFACE

The importance of underground spaces for human settlements have been well existing in theory as well as in practice. Various age old civilizations stand testimony to this. However, the potentials, benefits and also the challenges of developing underground settlements have not been fully explored. As the global population growth rate soars, the next level up becomes down. The limited availability on ground is pushing the planners, designers, engineers, architects, managers, and innovators to tap diverse opportunities lying deep in the subsurface.

This paper has been developed under the 'Climate Adaptive Planning for Resilience and Sustainable Development in Multi-Hazard Environment (CAP-RES)' with the support of the Department of Science and Technology (DST). It is an attempt to explore the potentials of subsurface spatial developments for human activities and habitation and tries to understand how underground urbanism can be an effective alternative to vertical and horizontal spatial development for a sustainable, resilient and inclusive future. The paper also highlights the key policy and governance challenges and opportunities for the use of underground spaces, with a particular focus on India.

(Anil K. Gupta)

ACKNOWLEDGEMENT

On June 19, 2022, the Prime Minister of India Sh. Narendra Modi inaugurated a tunnel and five underpasses as part of the Pragati Maidan Integrated Transit Corridor Project in New Delhi. Entirely funded by the Government of India, this underground project was developed with a vision to provide smooth access to the new world-class exhibition and convention center being developed at Pragati Maidan in New Delhi.

This project is part of the Prime Minister's Gati Shakti National Master Plan which aims to create and improve multimodal connectivity across India. This National Master Plan for multi-model connectivity and infrastructure development was launched on October 13, 2021, and established a digital platform to bring 16 Ministries including Railways and Roadways together for integrated planning and coordinated implementation of infrastructure connectivity projects for the movement of people, goods, and services from one mode of transport to another. As part of this National Master Plan, several new tunnels have been constructed or are in the process of design, planning, and development across India. This renewed focus on above-ground and underground tunneling has highlighted their role in improving connectivity.

However, how these tunneling and other underground efforts can help respond to climate risks and contribute to sustainable development is not fully understood. We hope and believe that this study and its insights are critically important in the context of India's commitments to climate action — as it clarifies the role underground spaces are playing for climate resilience and sustainable development, as well as the role these spaces can play for India's urban future.

This publication has been supported by the Department of Science and Technology (DST), Government of India, through the Climate Adaptive Planning for Resilience and Sustainability (CAP-RES) in multi-hazard environments. Our most sincere thanks to Mr Taj Hassan, Executive Director of NIDM, Dr. Akhilesh Gupta, Senior Advisor and Secretary, Science and Engineering Research Board (SERB), Dr. Nisha Mendiratta, Advisor and Head of Climate Change at the Department of Science and Technology, Dr. Susheela Negi, Principal Scientist of Department of Science and Technology, Government of India for their support to this study.

Our special thanks to Ms Pritha Acharya for providing technical support and coordinating the printing of this study as a Research Associate of CAP-RES and Mr S.K. Tiwari, Librarian, Mr Surendra Thakur, Consultant, I/C (HR and Admin) and the entire publication cell including Ms Karanpreet Kaur Sodhi and Ms Sonali Jain of NIDM for facilitating the study's printing and publication. We sincerely hope that the findings and recommendations of this study are useful for further research and policy action on underground urbanism and the role the world beneath our feet can play in unlocking new ideas for a sustainable future and climate resilience.

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Introduction to the CAP-RES Project

Climate Adaptive Planning for Resilience and Sustainable (CAP-RES) development in the multi-hazard environment is an umbrella project funded by the Department of Science and Technology, Government of India under the National Action Plan on Climate Change. It aims to address gap areas in capacity building to curb the challenges of climate change. The project has five thematic areas:

1. **Green growth and disaster risk reduction:** The concept of green growth promotes resource-efficient, sustainable, cleaner and more resilient growth processes while fostering economic growth and development which could be materialized through internalizing ecological cost, maximizing resource efficiency and minimizing pollution. The idea fosters Nature Based Solutions (NBS) or investments in ecological assets that can play a vital role in climate change mitigation and disaster risk reduction.

2. **Resilient agriculture systems:** Agriculture sector is one of the most disaster-affected sectors resulting in huge economic losses and livelihood disruptions. There is an immediate need for integrated disaster risk reduction strategies, strengthening the agriculture systems in the country and making them more resilient to future disasters and climate change consequences. It is imperative to quantify losses and damages in terms of production, assets, and post-harvest impact for allied sectors (crops, livestock and fisheries) and prioritise policy interventions.

3. **Public health resilience:** Unsustainable use and overexploitation of the resources and services provided by the ecosystems degrade the environment and may have disastrous consequences on human health. Effects of climate change on public health and coupled with the impact of hydro-meteorological disasters and extreme events on health, and related resources and systems, are key concerns of resilient development and disaster response preparedness.

4. **Climate proofing disaster relief and recovery:** post-disaster, response, and recovery interventions are considered to be the most crucial stages in the disaster risk management cycle. The response phase caters to the immediate needs of the affected population, providing emergency relief to protect lives, and reduce further damages and losses. The recovery phase focuses on reconstruction and rehabilitation activities for the restoration of normalcy post-disaster. Climate proofing focuses on mainstreaming environmental sustainability into development planning and it can be a solution for sustainable disaster relief and recovery needs. It is thus imperative to identify the gaps and opportunities across different sectors during response and recovery where climate-proofing measures can be mainstreamed.

5. **Environmental policy instruments in disaster risk reduction:** Policy instruments are useful in the formulation of policies and strategies and in implementing policy decisions. Development planning and disaster risk reduction have to be dealt with together with mainstreaming of disaster risk management into development policy, projects, planning, and implementation. Modern Environmental Policy Instruments Environmental Impact Assessment (EIA), Life Cycle Assessment (LCA), Risk/Vulnerability Assessment, Audits, and new tools like DIA (integrated with EIA), mitigation analysis, etc. help in mainstreaming Disaster Risk Reduction. Customization and application of EPIs would help in avoiding reinventing the wheels.

Across these five thematic areas, CAP-RES focuses on three specific regional contexts—the Indian Himalaya Region with special reference to the North East region, the Coastal region, and the Central-western region.

Abstract

'Next level up is down' seems strange to hear, maybe even confusing at first! But it is imperative and appropriate for the present and future of human existence. Exploring the earth beneath our feet is increasingly gaining traction due to the limited land supply above ground. Utilising the often-ignored underground spaces requires planners, designers, engineers, architects, managers, and innovators to tap diverse opportunities lying deep in the subsurface—and strive for a sustainable, resilient and inclusive future. Strategic planning, design and management of the spaces beneath our feet can help us move miles ahead in our vision for a sustainable, resilient and inclusive future. But, realising this vision calls for an uphaul in our traditional master planning processes — processes that limit the use of the subsurface to urban mobility or physical infrastructure. Moving forward calls for government incentives, investments and technological development to improve the scalability and efficient use of the subsurface.

This paper thus seeks to respond to two key questions: One, what is underground urbanism, and how effective is it for a sustainable, climate-resilient and just urban future? Two, what are the characteristics of effective implementation of the underground approach?

Introduction

Underground spaces have long been associated with diverse perspectives and cultural values. In some cultures, the underground is identified as a dwelling space for demons (Admiraal & Cornaro, 2018); for several others, underground spaces have been used as a natural shelter against natural and human-made hazards. With time, these perspectives and values have changed, particularly the potential long-term value of these spaces for the future of cities.

Home to over 56% of the global population in 2020, cities are increasingly being challenged by the limited availability of land above ground. In Latin America and the Caribbean, over 81% of the population is living in urban areas—up from 41.3% in 1950 (Buchholz, 2020). Decision-makers at all levels of governance are struggling to strike a balance between sustainable development and public space availability on the surface, liveability and price control, between energy efficiency and compact development (Admiraal & Cornaro, 2018).

On one end, we need more land for development while on the other end we need more open spaces for disaster and climate resilience, strengthening drainage systems, wetland rejuvenation, pandemic response, and relief camps, to name a few. While balancing these opposing needs for land, it is also important to give the land back to nature and restore ecosystem services—as highlighted by the UN Decade on Ecorestoration that aims to “prevent, halt and reverse the degradation of ecosystems on every continent and in every ocean” (United Nations Decade on Ecosystem Restoration, 2019). It is estimated that approximately 2 billion hectares of land - an area more than three times the size of India - are degraded but can be restored back to health through sustainable land management practices (United Nations Convention to Combat Desertification, 2019).

Cities around the world have used these spaces to lay down service and sewer lines—for water, sanitation, electricity—or for parking and transport. However, the multifaceted value of underground spaces is largely overlooked in planning processes—focusing on the horizontal and vertical expansion of urban areas above the surface. This neglect of underground spaces is linked to a limited understanding of the value of underground spaces and the importance of spatial planning to effectively utilise these spaces (Admiraal & Cornaro, 2018). Even cities that are exploring the subsurface for public spaces, entertainment, commerce and pedestrian connectivity, are constrained by challenges of unknown conditions, geology, geochemistry, government regulations and legal barriers. Moreover, without a coherent city-level vision, appropriate legal, fiscal and planning instruments, the use of underground spaces for a sustainable, liveable, inclusive and resilient future would remain fragmented and chaotic.

Utilising the often-ignored underground spaces requires planners, designers, engineers, architects, managers, and innovators to tap diverse opportunities lying deep in the subsurface—and strive for a sustainable, resilient and inclusive future. Strategic planning, design, and management of the spaces beneath our feet can help us move miles ahead in our vision for a sustainable, resilient, and inclusive future. This paper highlights the values of underground spaces in the development, planning, and management of resilient and sustainable urban futures, with a key focus on India. This paper seeks to respond to three key questions:

1. What is underground urbanism, and how effective is it for a sustainable, climate-resilient, and just urban future?
2. What are the characteristics of effective implementation of the underground approach?
3. What can the Government of India do to effectively use the underground spaces for disaster risk reduction and sustainable development?

Structured into four sections, the paper illustrates examples from around the world to educate current and future decision-makers, planners, architects, designers, and engineers on key aspects of using and managing underground spaces.

1. The first section highlights historical approaches toward the diverse use of underground spaces.
2. The second section elaborates on the multifaceted value of these spaces and elaborates on key ideas to invest in underground spaces and capture value,
3. The third section highlights different uses of underground spaces from all around the world
4. The fourth section expands on key policy and governance challenges and opportunities for the use of underground spaces, with a particular focus on India

It concludes on a note advancing the use of underground spaces for connecting spaces, people, and goods that will shape and enhance the cities India needs.

Evolution of underground urbanism

In the evolution of human settlements, underground spaces have long been used for habitation and seeking shelter from hostile environments—whether climate or protection from war and displacement. In China, one of the earliest housing types existed as underground dwellings called yaodong. Dating back to at least the Qin dynasty (c. 221 B.C.), these subterranean dwellings are situated in the Loess Plateau of China—across six provinces in north-central China covering approximately 400,000 km^2. Today, these provinces are inhabited by roughly 40 million people, and outside the urban areas, more than 80% of rural residences are yaodong or their derivatives. Even in the present, new yaodong units are constructed to retain the regional architectural style. The geology of this plateau allows for easy excavation of materials and the creation of a structure that retains shape post-extraction. As an underground development, these yaodongs exist in two basic forms: one, a yaodong is created by the excavation of a large courtyard into the surface and then tunnelled sideways to create rooms; two, a yaodong is tunnelled directly into the hillside to create rooms inside a hill (Liu, et al., 2002).

Figure 1 (left to right): Aerial view of China's yaodong units; a close-up of yaodong dwelling
Images source: Getty Images (2022)

Similar underground dwellings have been found in Tunisia and are known as pit houses. These historic developments highlight the critical role of local geology in underground developments. This form of underground development has been used as a reference for modern-day developments around the world, including non-residential developments—such as the underground school of

Artez Faculty of Dance and Music in Arnhem, the Netherlands. The evolution of human settlements highlights that cave—whether carved inside hills or shaped and placed below ground level via excavation—have played and continue to play a vital role in providing shelter.

In the 19th century, the use and exploration of underground spaces expanded and were aided by engineering advances. For instance, the 41-kilometer-long Semmering Railway was built between 1848 and 1854 in some of the most difficult terrains of the Alps to connect Vienna, the capital of the Austro-Hungarian Empire, and Trieste—the Empire's port on the Adriatic. Operational even today, the railway network featured 14 tunnels or underground passageways extending over 1477 meters, 16 viaducts, over 100 stone arch bridges and 11 small iron bridges. Stations and buildings for supervisors were often built from the rock excavated during tunnelling works (UNESCO World Heritage Centre, 2022). This network is being further expanded, with a plan to build a double 27.3 kilometres long tunnel by 2026. Advent and expansion of railways in the 19th century—from 50 kilometres in 1830 to over 600,000 kilometres by 1890—was in large part possible by engineering and technological developments that could build tunnels to overcome geographic and geological limitations (Ilie, 2017). These expansive networks of railways, including underground railways, became vital conduits in developing infrastructure across continents and reducing the boundaries of travel.

With advances in tunnelling technology, more infrastructure projects were initiated and the value of underground development—as part of larger urban development—became increasingly evident. By the end of the 19th century in Paris, France, Haussman's aspiration for the future of Paris also included subsurface. He argued that subsurface should serve the purpose of taking away a society's excrement or waste in a way that no one would notice and without disturbing life on the surface. His vision to use the subsurface for supplying gas for housing and lighting helped the city gain its reputation as the City of Lights. In essence, Haussman's plans of integrating underground spaces to life over the ground led to the concept of underground spaces as an urban service layer (Webster, 1914).

The use of underground space, however, is not always linked to the excavation of the ground. In 1910, Eugène Hénard published a paper titled The Cities of the Future and proposed a radical change to the layout of city streets (Hénard, 1911). He argued that instead of placing the bottom of the road on a level with the ground, existing streets could be elevated to a level that the space below can be used as an urban service layer, and new urban areas should have additional subterranean layers to meet increasing demands on the street without disturbing traffic on the surface (The Museum of Modern Art, 1969). In

2005, Eugène's idea was used by the Office for Metropolitan Architects (OMA) for the development of Almere's city centre in the Netherlands, where a slightly curved plateau is used for car parking, services and public transportation below street level.

Much before Almere, a similar idea was used by Le Corbusier for his 1925 Project Plan Voisin for Paris where he proposed large office blocks with public spaces in between and an underground station beneath each office block—to connect the entire area via underground public transport (Boesiger, et al., 1964). Shaped by these developments, the start of the 20th century was marked by a belief that underground spaces should primarily serve as a service layer—a belief that is dominant even today.

In 1933, French-Armenian architect Édouard Utudjian founded a national group called the Groupe d'Etude et de Coordination de l'Urbanisme Souterrain (GECUS) or the Underground Urban Planning Study and Coordination Group, plus an international one called as International Permanent Committee of Underground Technologies and Planning (CPITUS). The latter organised several international congresses from 1948 to 1964. Édouard advocated for underground city planning—using the French name Urbanisme souterrain—and for looking at the subsurface for remedies and improvements to multiple challenges urban centres were facing (Duffaut, 2006). He went a step ahead of his contemporaries by not only thinking about utopian ideas but also acknowledging that underground urbanism requires planners, architects as well as artists, researchers, scientists, geologists, and technologists. He emphasised the need for cross-disciplinary collaboration and helped imagine cities in three dimensions for decision-makers and planners of urban areas (Heim de Balsac, 1985).

In 1970, the Organization for Economic Co-operation and Development (OECD), organised an Advisory Conference on Tunnelling and produced a set of recommendations on the future of tunneling and the use of underground spaces. Four key recommendations of the OECD emphasised: the need for a local agency in each country; planning for the utilisation of underground spaces; informing investment and planning decisions via cost-benefit analysis; and encouraging relevant technological advancements and research (Orski, 1970). In 1974, the International Tunnelling Association or ITA was established and several working groups started exploring non-technical aspects of underground space use.

In the 1980s, the role of underground spaces in sustainable development was further reinforced. In 1982, a United Nations conference—Subsurface space use in developing countries—took place in Sweden and identified underground spaces as an important resource for the future of cities. In 1991, the Tokyo

Declaration was adopted at the International Academic Conference on Urban Underground Space wherein the 21st century was defined as the century for human development and utilisation of underground space. This Declaration led to the establishment of Associated Research Centers for Urban Underground Space (ACUUS) in 1996—as a collaboration between research centres in the United States, Netherlands, and Japan (Zhang, 2019). In the early 2000s, ITA changed its name to International Tunneling and Underground Space Association and set up four permanent committees to address strategic issues in the field of tunnelling and underground spaces. ITACUS or ITA Committee on Underground Space was one of the four ITA Committees and was charged with the responsibility of promoting and advocating the planning and use of underground space (ITA-AITES, 2022).

In summing up, the idea to plan and manage the use of underground spaces has been around for a long time. Perspectives, ideas, and use of underground spaces have evolved but their true potential—in contributing to sustainable, resilient, inclusive, and liveable cities—is yet to be realised.

2.1 Use of urban underground space in India: Past to present

The evolution in the use of underground spaces in India has not been well documented. Documented history indicates that the earliest underground structures in India existed as dwelling pits in Kashmir around 3000 BC-500 BC—to protect against extreme cold weather of the region. Similar dwelling pits were found in Nagarjuna Konda in Andhra Pradesh state and date back to 1600 BC (Goel & Dube, 1999). Several of the earliest tunnels and underground spaces in India were built for cultural values — such as the Ellora caves in Maharashtra, from the 600-1000 BCE period, which house one of the largest rock-cut Hindu temple caves complexes in the world. Tunnels in Ellora add up to 10.8 kilometers in length (Sharma & Selby, 1989). Time and again, several underground caves and tunnels are discovered in India. Several of these were used as secret passages or escape routes in case of an enemy attack by various dynasties that ruled the land before India gained Independence in 1947.

In 2010, for instance, a secret enclosure in a 250-year-old National Library in Kolkata was found by archaeologists with the belief that the space was used as a treasure vault or torture room by the British. During the same year, a secret passageway was discovered beneath the General Post Office in Mumbai. In Delhi's Red Fort, a secret underground tunnel connects the eastern end of this Mughal heritage site with the Yamuna River. In Hyderabad's Charminar, underground tunnels and passages were built as escape routes in the event of an enemy attack (India Today Web Desk, 2015). Post-partition of India, the underground market of Palika Bazar was built by the North Delhi Municipal

Council beneath the British-built Connaught Place and opened up for operation in 1979 to allocate shops for refugees of the partition. Hosting nearly 400 shops, this underground space freed up space on the ground which is now used for public parks and cultural events (SNS, 2019).

Till the late 1990s, underground space use in India focused on hydroelectric power projects. Soon after, tunnels were planned and constructed for road and rail projects. Additionally, a few underground projects focused on the storage of petroleum products in underground rock caverns. Post-2000, several new hydropower projects, metro rail projects, inter-state rail projects, and highways have come up in the underground space—and several more are in different stages of planning and development (Goel, 2015). Despite the increasing and expanding use of underground space in India, the planning, development, and management of underground spaces have been piecemeal and dealt with on a project-to-project basis.

In India, extensive regulations and development plans exist for surface planning, development, and management, but little to no regulatory frameworks exist for the use of the subsurface. Building bye-laws and similar regulations focus on laying down public services of water, drainage, sewerage, electricity, telecommunication pipelines, metro stations, and railways, plus the construction of public and private building foundations and basements. Moreover, there is no regulation or guidelines, or standards linking public and private development underground or multipurpose use of the underground. Mapping of the underground is piecemeal and limited and guidelines on registration, ownership, and transfer of underground properties remain unclear.

Value of underground urbanism

Understanding the value of underground spaces is imperative, but impossible without understanding that this space exists as a component of the subsurface (Parriaux, et al., 2004). The latter comprises four resources: space, water, energy, and geo-materials; underground space is one of the four resources that we can identify below the surface. Most of the activities and developments are in the top subsurface layer that is at most 200 meters deep. Below the top subsurface layer, we identify the deep subsurface, which runs to 4–5 kilometre in depth at most. The presence of water, and the ability to obtain or store energy and extract geo-materials are often forgotten in the quest for space that cities undertake.

There are several ways in which the value of underground spaces and the subsurface can be determined. The subsurface acts as the foundation of life—on which cities are built. The subsurface is also used for food production, extraction of fuel, and several other resources that power industries and almost all aspects of human life. Essentially, the value of any underground space is linked to its utility. This value—plus human needs—guides the planning, use, and management of the subsurface.

Subsurface as a resource is limited in supply and regenerates slowly. The use of underground spaces thus calls for planning spaces for use and regulations to conserve ecosystem services or prevent disturbances to these services. Sustaining this balance between exploitation and conservation requires analysis of the use of the subsurface, frameworks to guide its use, as well as good knowledge of the composition of the subsurface, the ecosystem services it delivers—such as infiltrated rainwater that the subsurface purifies—and processes that assure delivery of these services.

The value of underground spaces is also linked to their utility in relieving surface congestion, connecting people and neighborhoods, protecting residents from pollution and climate risks, increasing land supply in space-constrained cities, and environmental protection. These spaces are also valued for their ability to store food safely. For centuries, farmers and civilisations have carefully analysed soil and drainage conditions to prepare pit wells and store food to minimise post-harvest loss. In China (600-900 A.D.), national grain reserves were stored in a series of underground pits beneath the present Henan Province where the low water table and loess soil allowed for underground storage. Near these ancient underground storage sites of Henan Province, new spherical-shaped structures sealed with bitumen have been built for food storage. Even today, several countries around the world are storing their food stock in underground spaces. For instance, limestone caverns under Kansas City in the United States are being used for storing grains and processed food. Underground cold storage in rocks—built in Sweden, Norway, Japan, and Finland— provides natural insulation while keeping construction costs low (Goel, et al., 2012).

Despite significant qualitative values of underground spaces, their monetary valuation is far from mature and often poses a challenge for decision-makers. Assigning money value to these spaces is tough because the subsurface is a complex system made of several layers and its ownership is not always clear or demarcated in legislative frameworks. Difficulties in determining monetary value and initial high construction costs of underground structures— sually 2-10 times that of surface structures—often lead to decision-making processes favouring conventional surface development over underground projects (Qiao, et al., 2017).

Attempts have been made to calculate underground space value—using direct costs, indirect costs, and benefits—associated with exploitation and utilisation. In this calculation, direct costs include land use fees, construction costs, energy consumption costs, and operation and maintenance costs; indirect costs include environmental impact and governance costs; and benefits of underground space use can be direct or indirect social, economic, and environmental benefits. The net value of underground space utilisation is calculated as total benefits minus total costs and reflects new value creation as compared to original land use (Zhu, et al., 2009). Once constructed and operational, these underground developments contribute significantly to the value of surrounding real estate and public spaces. More often than not decision-makers however look at the pure construction cost and don't assess the other above-mentioned factors. Cities should start to appraise projects on a social cost-benefit basis as was done in Athens for Attiko Metro.

3.1 Investing in underground spaces

Solutions, including those for the subsurface, should never be judged based on cost alone. They should be justified and appraised by the multifaceted value they create over time. Apart from value creation, investments in solutions for our common future—including underground projects—should be guided by value capture and opportunities for private investors to invest in the underground space.

The value capture mechanism aims to rectify unfair and inefficient profits accrued by private landowners from public investments and decisions—such as new rail line meant to improve accessibility for residents and businesses, rather than increase the land value or business revenue of surroundings—by taxing some of the increased revenue or land value and allocating them towards initial costs of infrastructure provision. For urban areas, there are three key variants of value capture—tax increment financing, transit value capture, and value capture via planning processes.

Transit value capture is a project-based approach—used in Hong Kong and Japan—that often packages a new railway line development with a new town development. Tax incremental financing is used in the United States to fund urban renewal and new transit projects. A portion of the increase in business revenue or rents—in areas where the urban renewal or new transit project will occur—is collected via property tax and then allocated to repay project debt. One way to value capture via planning processes is to levy charges on the first property transaction, i.e. land sale. Another is to add a charge to existing contributions paid by developers (Gurran & Lawler, 2016).

There are several ways in which investments for underground projects can be sourced and a new value can be captured. Similarly, there is a multitude of strategies for using the subsurface. Some of these include the creation of public spaces, converting grey zones into green zones, creation of pedestrian networks and rapid transit systems, storing data centres, and food production.

3.1.1 Creation of an underground city

In Montreal, an underground city—referred to as La Ville souterraine in French— known as RÉSO is one of the largest underground complexes in the world composed of a series of interconnected spaces beneath the downtown area. Spread over an area of 12 square kilometers, RÉSO has 33 kilometers of tunnels connecting and comprising shopping malls, hotels, banks, offices, condos, apartments, museums, universities, seven metro stations, two commuter train stations, a regional bus terminal, an arena and an amphitheatre. It is connected to the above-ground Montreal city by more than 190 exterior access points and is closely integrated with the city's entirely underground rapid transit system. On an average day, over half a million people use RÉSO, and each of these 190 access points is linked to one of the 60 residential or commercial complexes—representing 80% of all office space and 35% of all commercial space in downtown Montreal (Montreal Underground City, 2022).

Construction of this underground city began in 1962 with the construction of the Place Ville-Marie office tower and underground shopping mall that were built to cover railway tracks that were aesthetically unpleasing. Between 1984 and 1992, the underground city expanded with the construction of three major interlinked shopping centres. Throughout the 1990s, trade centres were added to the underground city. In 2003, the redevelopment of Quartier International de Montreal consolidated several segments of the underground city by establishing continuous pedestrian pathways. In 2004, the city was rebranded and renamed RÉSO (Domanska, 2011).

For most citizens of Montreal, RÉSO serves the purpose of a large shopping complex and a refuge from harsh winters. The city however promotes this underground city as a tourist attraction and an urban planning marvel. Montreal's RÉSO is an example of how cities suffering from extreme weather conditions can create an underground city to adapt to changing climate. It also highlights the role of regulations in underground space use—as the Municipality of Montreal had already acquired land on which surface development took place, and subsequently led to the creation of the Underground City.

In the case of India, one of the earliest underground developments was a shopping arcade that was unveiled in the late 1970s—in the heart of New Delhi and next to Connaught Place and Janpath. Till the 1990s, it was one of the most popular market places for Delhi and boasted more than 300 shops. Built-in record time of one year, that too during the political instability brought upon during the Emergency, Palika was Delhi's first air-conditioned public space—and underground. Several pieces of evidence indicate that more than the diversity of shops, the real draw for Palika was the air-conditioning where people could seek respite during a hot summer day or seek shelter from heavy rainfall during the monsoon period. While this underground public space in the heart of the city has lost its charm and is affected by decay, there are several possibilities to transform this underground space into a place—with the right vision and investments (D'Mello, 2016).

3.1.2 Underground networks

Tunnels are often associated with underground networks. They vary in length, diameter, form, and accessibility. For instance, most subsurface cables and pipe networks—though owned by public companies for public use—are not accessible to the general public, but only to the owners or operators of the network. Underground networks that are publicly accessible are known by a variety of names across the world—such as the 'Tube', the 'Underground', the 'Subway', the 'Metro' or by abbreviations such as mass rapid transport.

Figure 2 (left to right): London Underground station and underground pedestrian pathways linking stations and different parts of London, while also providing space for advertisement campaigns
Images by Mahak Agrawal (2019)

The origin of the word 'metro' lies in the London Underground Metropolitan Line, the oldest mass rapid transport system in the world that commenced operations in 1863 and transformed the city (Figure 2). After London, other cities started developing their versions, including Istanbul, Budapest, Glasgow, Vienna, Boston, and Paris (Admiraal & Cornaro, 2018). Development and expansion of these underground transport networks set a precedent for successful use of the subsurface in a way that supports a city.

The expansive cities we see and know today would not exist without these mass transit systems situated beneath our feet. For instance, New York City's subway system (Figure 2) opened up in 1904 (Metropolitan Transportation Authority, 2013). Today, with a track length of roughly 1,400 kilometres, this underground network reported 1-2 million daily rides on any given day of January 2022 (Metropolitan Transportation Authority, 2022). Delhi's metro system, now in its third phase of expansion, has approximately 80 kilometres of underground tunnels and 31 underground stations that were laid from 2012-2017 without much disruption to the hustle and bustle of the city above the surface. In the third phase, the construction of 54 kilometres of underground tunnels and 35 underground stations will be more than the 48-kilometre length of tunnels and 31 underground stations constructed as part of phase 1 and 2 (Dayal, 2017).

The success and expansion of these underground networks come with a few concerns as well. For instance, the growth of the London Underground has led to the laying down of each new line deeper than the one before. The new Elizabeth Line reaches a depth of roughly 40 metres below the surface (Hobson, 2018). In Kyiv, Ukraine, select stations of the underground metro system lie as deep as 105.5 meters below the surface owing to geological conditions—and carry 1.3 million people every day (Baker, 2019). Access, egress, transporting and maintaining the temperature at these depths is a challenge.

Without strategic planning, these underground networks need ever-deeper placements for the future. It is thus imperative that policies and regulations respond to not just local interests but also regional and national interests to prevent future blocking of much-needed development. Until this occurs, it is a case of staking a claim and grabbing the space while possible.

Figure 3 (left to right): New York City's subway stations and pedestrian pathways linking underground stations to the surface level
Images by Mahak Agrawal (2021)

3.1.3 Underground space as an innovation testing facility

Underground spaces are also being used as testing grounds for innovation. In 1970, a mining engineer Dr Rudolf Amberg founded a by now 5.5-kilometres long Hagerbach Test Gallery in Switzerland as a research and development facility for tunnel blasting and construction. Presently, specialists and industry representatives from all over the world use the facilities of tunnels, caverns, experimental fields, laboratories and seminar rooms to conduct research, prototype development, test underground farming and data centres, real scale trials and several other events (VersuchsStollen Hagerbach, 2022).

With the increasing use of internet and cloud services, the need for data centres and associated global infrastructure is also increasing. These centres are usually energy-intensive and require cooling round the clock. In Helsinki, Finland an empty second world war bomb shelter meant to protect city officials in the event of a Russian attack—beneath the Orthodox Uspenski Cathedral—has been given a new lease of life by a Finnish IT company Academica (Schwartz, 2009). The latter has installed a 2-megawatt data server in this former bomb shelter and sources water from nearby harbour to cool servers. Rather than returning the hot water to the sea, it is pumped into the city's district heating system to provide heat for around 500 homes for a city that often has temperatures of-20oC. After the extraction of heat, the water is recycled back to cool the servers again and the company estimates a cost-saving of roughly £140,000 a year from each of these data centres (Vela, 2010).

Figure 4 (clockwise from top left to bottom left): Multipurpose use of Hagerbach Test Gallery for underground farming, passageway, conference hall and underground data center.
Images by Antonia Cornaro (2022)

Helsinki's underground data centre exhibits how an ecological approach can be applied to reduce energy consumption and associated emissions, use the space for multiple purposes, deliver social and economic benefits to nearby communities, and adapt to changing climate conditions (Brown, 2014). For a city with nearly 320 kilometres of tunnels and an underground master plan, the subterranean provides mobility and safety in harsh winter conditions, as well as underground attractions—such as a museum, a church, a go-kart track, a hockey rink, and emergency shelters (Hunt, 2021).

3.1.4 Food production

An underground space without natural light has long been used for food storage, but it seems an unlikely place to harvest crops. Yet, investments for food production in underground spaces is increasing in select parts of the world. In London, for instance, an underground farm called Growing Underground is cultivating micro greens and salad leaves for the city using hydroponic technology and LED lighting powered by renewable energy. Situated 33 meters below London, this farm claims to use less space and 70% less water than a conventional farm on the surface. This farm has been developed in one of the eight British government-built bomb shelters—situated below the streets of Clapham in southwest London—during the Second World War with the potential to safeguard from future risks of radiation or air strikes, etc (Broom, 2021).

Initiated in 2015 by the Zero Carbon Farms company, Growing Underground is spread over a hectare of underground space and uses a soil-free and pesticide-free approach—plus a team of engineers and data scientists to optimise energy use and crop performance—to produce up to 60 harvests a year. Instead of soil, micro herbs and salad leaves are grown on recycled carpets and supplied to food retailers, local people and businesses (Zero Carbon Farms Ltd., 2022). Growing Underground aims to produce over 60 tonnes of produce annually by 2022 from 528 square metres of space (Walsh, 2021).

Since 2019, tech start-up called Farm8 has been using the operational underground Sangdo Station in Seoul, South Korea for urban organic farming. Using hydroponic trays—for the growth of leafy shoots, sprouts and microgreens—and automated technology systems to regulate temperature, humidity and carbon dioxide levels, this underground farm produces approximately 30 to 40 kilograms of vegetables per day (Hosokawa, 2020). The harvest is sold as ingredients for adjacent cafes and the product that is unsuitable for cafe consumption is sold to the outside restaurants (Moon, 2020). Called Metro Farms, Farm8 is collaborating with Seoul Metro and Seoul Metropolitan Government to explore and expand innovative methods of food production in other subway stations of Seoul—by using locations away from ticket gates that are often unused by retailers (Kim, 2021).

In Switzerland, the Swiss Center of Applied Underground Technologies (SCAUT) is also testing underground green farming using aquaponic systems, wherein water from fishponds is fed to a hydroponic system and recirculated back to the aquaculture system (SCAUT Association, 2021). In essence, investments in underground spaces for food production is an idea that can be replicated in several parts of the world as a new way of providing food security and nutrition. While these farms may not be able to produce staple crops of wheat, rice, maize, or animal protein, yet their utility in reducing burgeoning urban food demand and using 70-90% less water than traditional farming methods cannot be ignored. These underground farms exhibit an opportunity to transform agriculture and improve food security—at the backdrop of increasing food demand and decreasing arable land.

In Stockholm, an underground space situated beneath a 26-floor office tower has been given a new lease of life. Once used as an archive for newspapers it is now used for urban farming where farmers won't pay rent and rather their farm pays for itself in heat. Known as Plantagon CityFarm, this underground farm began production in 2018 and grows food in vertical towers under LED lights. The heat from these lights is sent by farm operators to a heat storage system for the office building and used to keep the offices warm during the winter while saving 700,000-kilowatt-hours of energy a year. The cost of the latter is estimated to be three times the rent the previous tenant of the basement was paying. A third of the food produced in this space is sold to people working in the offices above ground and two restaurants in the building. Another third of the produce is sold to nearby grocery stores and another third is sold in an on-site store in the high-rise office building (Peters, 2017).

To sum it up, the planning, design and architecture for use of underground spaces are closely linked to scale. The scale and purpose of use—in addition to policies and regulations incentivising or adding barriers to the use—differ across geographies and guide priority challenges and opportunities that need to be addressed.These examples highlight only a few of the many options by which investing in underground space can help free up space on the ground and help cities move towards a sustainable, resilient, inclusive and liveable future.

Good practices of urban underground space

Urban underground spaces have been used across the world for wide purposes, particularly urban mobility and commercial recreation facilities like shopping complexes. A few cities are also using the urban underground for food production, the establishment of data centres, disaster risk reduction, to name a few. In this section, a few good practices of urban underground space use are elaborated.

4.1 Case study 1: UNDER: Geosystem services underneath for sustainable communities and improved spatial planning practices in Sweden[1]

The project "UNDER: Geosystem services underneath for sustainable communities and improved spatial planning practices in Sweden," with funding from Formas, the Swedish Research Council for Sustainable Development, is a current initiative – led by Chalmers University of Technology, in partnership with Lund University, Malmö University, the University of New South Wales, The Geological Survey of Sweden, the City of Göteborg and other local municipal governments–to support/develop improved underground urban planning practices in Swedish cities.

The project is based around the concept of "geosystem services (GS)" which has been defined as the benefits that humans derive from the subsurface by Van Ree and Van Beukering (2016)[2]. This includes the use of the subsurface as a medium to build and construct in and on; groundwater, energy and material extraction; for the storing of e.g., water, energy and carbon dioxide; habitat

[1]This case study is co-authored by Marilu Melo Zurita, Paula Lindgren, Emrik Lundin Frisk, Lorena Melgaço, Fredrik Mossmark, Jenny Norrman, Olof Taromi Sandström, Tore Söderqvist, Victoria Svahn, Yevheniya Volchko. Dr Marilu Melo Zurita is a Senior Lecturer in Human Geography in the Faculty of Arts, Design and Architecture at the University of New South Wales. Dr Paula Lindgren is a State Geologist and Project manager at the Geological Survey of Sweden. Emrik Lundin Frisk is a PhD student in the Engineering Geology research group. He works with developing thematic representations that can support subsurface planning, Chalmers University of Technology. Dr Lorena Melgaço is an Associate Senior Lecturer in Architecture and Urbanism in the Department of Human Geography at Lund University. Dr Fredrik Mossmark is a hydrogeologist and research coordinator sustainable infrastructure at the Geological Survey of Sweden. Dr Jenny Norrman is a Professor in the Division of Geology and Geotechnics, she works in the research group Engineering Geology at the Chalmers University of Technology. Dr Olof Taromi Sandström is a Sustainability Strategist at the Geological Survey of Sweden. Dr Tore Söderqvist is associate professor of economics at the Stockholm School of Economics and researcher at Holmboe & Skarp AB. Dr Victoria Svahn is a Geotechnical specialist at the City of Gothenburg, Sweden. Dr Yevheniya Volchko is a researcher in the Division of Geology and Geotechnics, she works in the research group Engineering Geology at the Chalmers University of Technology.

[2]There are other interpretations and definitions of what Geosystem Services encapsulate as well. See e.g. Gray (2011).

provision for ecosystems and support for surface life; as well as serving as an archive of cultural and geological heritage (Van Ree and Van Beukering 2016). Geosystem services have the potential to be utilised as a means to improve urban liveability, sustainability, and development outcomes (Admiraal & Cornaro, 2016; Norrman et al. 2016; Volchko et al 2020). Problematically, however, in most (if not all) urban and national contexts the various (geosystem) services provided by the urban underground are not considered holistically throughout planning processes. Instead, the underground is often shaped by a “first-come-first-served principle” (Volchko et al 2020; Norrman et al. 2021), whereby uses proposed by those actors first gaining access to a subsurface (and its resources) are often approved without thorough consideration of competing or complementary subsurface uses. Such an approach hinders a sustainable management of the subsurface and its resources and compromises inter- and intra-generational equity (Volchko et al 2020; Norrman et al. 2021).

The UNDER project has been established to address this issue. The overall goal of the project is to develop a framework for systematic and structured consideration of geosystem services in Swedish planning practices The research is expected to contribute to transformative steps towards sustainable cities and communities. To achieve this goal, the project aims to 1) advance the use of the theoretical concept of GS in spatial planning; 2) identify methods to assess societal values derived from GS; 3) engage with specific urban case studies in Sweden to inform current governance practices; and 4) create a participative learning environment in which participants can gain new insights and new experiences. The project is case study driven, working closely with local municipalities, to ensure its impacts are grounded in contemporary urban policies.

The UNDER project is nascent and commenced in late 2021, it will continue until 2025 and will involve the development of specific geosystem services planning tools. The project's design nevertheless was informed by a pilot project in 2020 which involved four workshops across different locations in Sweden enquiring the key themes that need to be addressed in relation to geosystem services and urban planning. The themes and ideas from the workshops included: 1) the need for a central organisation that contains a full database (including sensitive information) about what is (and what is planned for) urban underground; 2) the need for the publics to be more involved in the decision-making process for underground urban development; 3) the need for local municipalities to have a more critical role in shaping projects due to their close engagement and communication with citizens; 4) that geosystem services can be positive (e.g. resources for development) but may also give rise to negative effects (risks) when not properly dealt with in the planning process (e.g. soil subsidence) and this needs to be taken into consideration in planning tools; and 5) the need for opportunities for multi-functional underground infrastructure, such as combined tunnels that are used in parallel for traffic, stormwater management, storage of food, amongst others. Overall, the workshops identified the need for a multidisciplinary approach to engage with geosystem services. To be able to better account for the subsurface in planning and to better manage subsurface resources, an increased understanding and better communication are needed between disciplines, as well as between practitioners and researchers (Svahn et al 2021). The research team for this project is therefore a multi-trans-disciplinary group of scholars and practitioners of the underground and its values for humans and their environments.

4.2 Case study 2: Underground farming in Europe

Currently examples of underground farming are being developed, implemented and preferably used mainly in developed countries to produce greens and specific vegetables to achieve a more sustainable production in agriculture by using hydroponics or aquaponics. However, a primary reason for underground farming is to end hunger, achieve food security and improve nutrition. The underground space ensures sustainable food production systems by using hydroponics or aquaponics as well as is independent to climate change, extreme weather, earthquakes, flooding and other geohazards maintaining this a suitable ecosystem. Examples of underground farming located in Europe are illustrated in Figure 5.

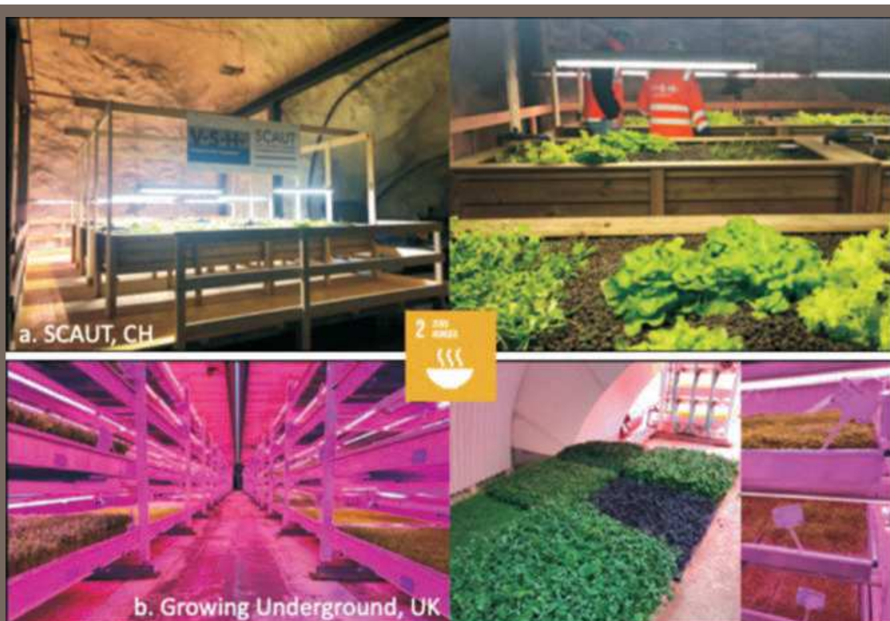

Figure 5: Examples of Underground Farming: a) SCAUT in Switzerland and b) Growing Underground in the UK. (Images by Dr. Chrysothemis Paraskevopoulou, 2021).

4.3 Case study 3: Utilising mine water for geothermal energy in the United Kingdom

Underground space is inherently an energy resource related to geothermal (Paraskevopoulou et al. 2019). Existing caverns or abandoned mines can be used as aquifers for heat recovery or storage (renewable sources of energy). The latter directly contributes in reducing the need of carbon-based energy and achieving lower CO_2 emissions for heating and cooling as highlighted in Paraskevopoulou et al. 2019 and is aligned with the SDG 7 on Clean and Affordable Energy.

With the ongoing reality of the climate crisis now impossible to ignore, decarbonizing our energy supply is vital (Connolly et al. in press). A key energy sector to consider is space heating, which can sometimes be overlooked in broader discussions surrounding decarbonization. In the UK according to the Department of Energy (Palmer and Cooper, 2013), 18% of the UK's energy usage is taken up by space heating. The UK is currently aiming to reach Net Zero carbon emissions by 2050, proposing a plan that all new homes post-2025 to be built without fossil fuel heating systems. The latter benefits fuel poor households whose income would sit below the official poverty line if income is spent on the amount of energy needed for heating (Leeds Observatory, 2021). One such potential source of heat is shallow geothermal energy that can be used to target Net Zero and contribute to sustainability (Paraskevopoulou et al. 2019).

Shallow geothermal is a low enthalpy method capable of generating useable space heating from groundwater at temperatures as low as 10°C, compared to traditional high enthalpy geothermal energy, which requires groundwater temperatures of over 100°C to generate power or temperatures above 50°C for direct heating (Ng et al. 2019, Farr et al. 2020). One example of shallow geothermal energy uses the flooded water in abandoned coal mines as its heat source and is commonly referred to as mine water geothermal (Adams et al. 2019; Stephenson et al. 2019).

From the start of the industrial revolution in the mid to late 18th century, the high demand for coal led to a drastic increase in mining production, particularly around industrial centres. The extent of these workings varies between cities but often represents a significant volume. However, although the concept of mine water geothermal has been executed successfully in multiple pilot schemes internationally (UK, Banks et al. 2019, Heerlen Netherlands, Verhoeven et al. 2014), very few large-scale schemes have been implemented on a city-wide scale. As a result, there is little knowledge of the overall heat potential available on such a scale. Connolly et al. (in press) assess the extent and thermal potential of abandoned mine workings across the Greater Leeds area to determine whether the implementation of mine water geothermal schemes is a) feasible, b) advantageous in terms of greener energy and overall social benefits to poor fuel households that are aligned with Net Zero goals and c) can be constrained using currently available data, providing both a baseline for future geothermal developments in Leeds area but also a methodology that can be adopted to explore similar geo-energy opportunities in the UK.

With 17% of Leeds households experiencing fuel poverty in 2019 according to Leeds Observatory (2021) and the increasing need to decarbonise space heating to help mitigate the worst of the effects of the climate crisis, assessing the feasibility of mine water geothermal schemes in Leeds is an important task. It should be highlighted that it had not been considered in detail before Connolly et al. (in press). The results of the study (Connoly et al. in press) are shown in Figure 6.

The results show that Leeds has significant potential for implementing mine water geothermal schemes, specifically in the southeast, due to the high volume of workings in the area. Optimistic calculations of thermal energy potential show that the magnitude available could provide energy for all poor fuel households in Leeds or up to 70% of all households. However, the degree to which this potential can be utilised is almost certainly less than calculated, as not all workings are likely to be fully flooded. Regardless, the estimates are helpful as they provide a good sense of the magnitude of potential and an upper limit to what can be achieved within Leeds.

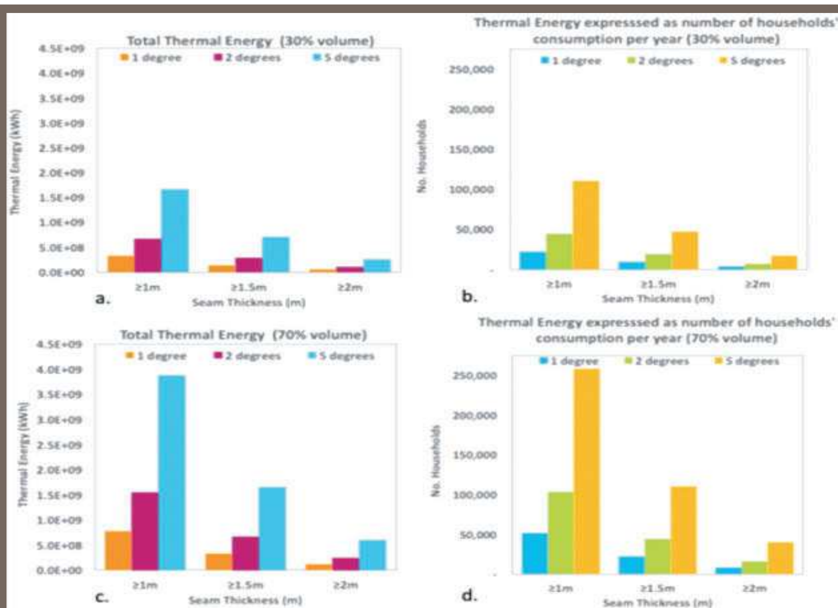

Figure 6: Thermal Energy potential of seams thicker than 1 metre expressed in kWh, number of households, and percentage of fuel poor households in Leeds. a-b = 30% coal extraction, c-d= 70% coal extraction (from Connolly et al. in press).

A model for sustainable development of urban underground spaces

The rationale for using underground space, for a long time, was driven by the argument that using this space was in itself sustainable. For instance, tunnel construction reduces distances and thereby fuel consumption and associated emissions. While the argument cannot be faulted, it only acknowledges one of the many reasons for using the subsurface.

The model (indicated in Figure 7) for sustainable underground development—proposed by Admiraal and Cornaro in 2018—appraises the sustainability of an underground space development while providing a framework for development to urban planners, designers, and architects (Admiraal & Cornaro, 2018). It provides four-point criteria for urban underground developments that preserve the past, enhances the present and respects the future. Failure to meet one criterion automatically deems a project as unsustainable.

The first criterion of the model determines the suitability of the subsurface for human intervention. In terms of geology, geochemistry and spatial planning, it seeks to assess the suitability of the subsurface for a proposed development. For instance, using brown field sites could result in the excavation of highly polluted or toxic soils that would be best left alone or require specific treatment which may come at a high cost. In terms of spatial planning, consider the impact of the proposed development on soil quality, groundwater, environment above the surface, etc.

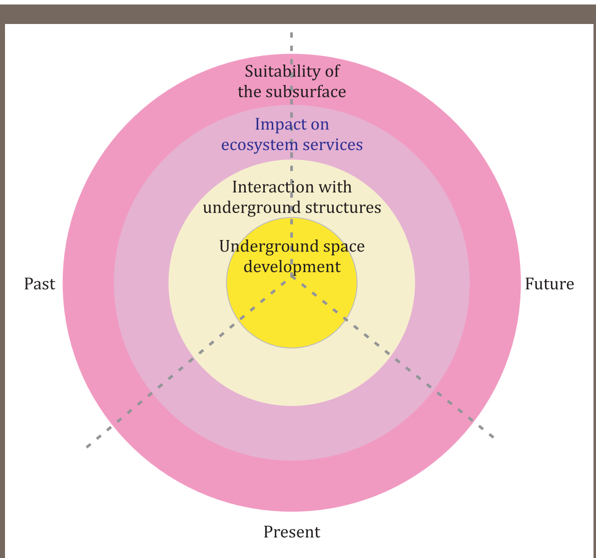

Figure 7: A model for appraising underground development
Source: Admiraal & Cornaro, 2018

The second criterion examines the proposed development's impact on ecosystem services—and processes supporting these services—below the surface. It is tough to however appraise this as knowledge of these processes and the timescale at which they occur is limited and can change significantly in 50-100 years. The third criterion focuses on acknowledging existing underground structures— including disused structures from the past and planned developments in the future—and the impact they could have on future alignments of underground infrastructure. For instance, if one development runs in a horizontal plane and another in a vertical plane, it could pose conflicts and even prevent future developments. It is, however, not always easy to envision future use of the urban underground space with 100% certainty. One solution in this respect is to think in three dimensions and to layer the subsurface.

Typically, urban utilities can be found in the shallow subsurface in the first layer, running to about 1.5 metres. Further development is dependent on the geology, and the occurrence of groundwater can severely limit it. Allocation of uses to underground space can be achieved in three dimensions through zoning in the horizontal plane and layering in the vertical plane. The fourth criterion focuses on the appraisal of the underground development itself. Few indicators for this appraisal include climate adaptation measures, delivery of social and economic benefits to surrounding communities, reduction in energy use and greenhouse gas emissions, and mixed-use of underground space.

But the model has its limitations—like any other model. It cannot acknowledge and respond to all the details of complex subsurface. Nonetheless, the model is a step forward in providing a framework for sustainable underground development. It brings together geological, ecological, planning and environmental considerations—to develop more ecological infrastructure. It also highlights that to determine the sustainability of development, it is not sufficient to just look at the capacity of the development itself; advancing underground development requires a holistic approach to harmonising humanity and nature.

Challenges and opportunities for effective use of urban underground in India

Investments to capture the value of underground spaces need to be guided by an integrated planning approach and government regulations. The latter two provide opportunities for use of underground spaces but often pose challenges too.

6.1 Spatial planning and policies

In spatial policies and other strategic plans, underground spaces are often overlooked due to a lack of awareness and understanding by policymakers, decision-makers and planners—on how these spaces can assist in achieving policy goals and contribute to achieving sustainable development goals (SDGs). Post-acknowledgement, cross-disciplinary and cross-policy collaboration is needed to ensure cities take full advantage of the multitude of opportunities that lie below the surface.

Geology is critically important in planning underground space. It can limit the depth of development and at the same time provide favourable conditions for underground space use. For instance, the London Underground uses the non-permeability of clay to prevent the ingress of water. With years of use, however, the heat released by underground tunnels has dried the soil. In addition, the sheer volume of underground service lines, including water pipes, are rapidly filling up the usable layer of the subsurface—thereby decreasing opportunities for future use of the layer.

Spatial planning for underground space needs to consider whether the development below the surface can continue on a first come first served basis or whether a form of planning and management guides it. In Singapore, for instance, the intent to blend underground spaces into policy and planning started with an appeal by the prime minister—highlighting that space on the surface was rapidly running out and while land reclamation could solve part of the problem, underground space provides a new development direction (Government of Singapore, 2009).

In 2007, two years before the appeal, a task force was set up to develop an underground masterplan for Singapore. In 2010, using underground space was given strategic importance by the Singapore Economic Strategies Committee. In the first attempt to develop a master plan, the outcome was government agencies acknowledging the potential of underground space and identifying knowledge and information gaps on the subject (Zhou & Zhao, 2016). In 2015, the Government introduced new legislation for amendment of the State Lands Bill and Land Acquisition Bill—to facilitate long-term planning and development of underground spaces by the government (Ministry of Law Singapore, 2015). More importantly, the use of underground space became the default for future utility and infrastructure developments and compelled government agencies to justify cases of not using underground space. While a comprehensive planning methodology has yet to be adopted by Singapore, the determination being shown by this city-state is extraordinary. There are several other examples where underground spaces are being mainstreamed into spatial planning policies.

In India, acknowledging the value and use of underground spaces as more than a service layer is urgent. Planning policies and tools, such as a legally-notified master plan document, need to first and foremost acknowledge the value of underground spaces. Next, mapping the resource, ownership and useability of underground spaces is needed. Subsequently, zoning regulations and planning guidelines need to define possible uses these spaces can be used for — in line with a city's development vision — improving resilience, inclusivity and liveability of cities.

An urban planner is a key to orchestrating the spatial dialogue and achieving results via planning processes. Whether this requires sophisticated 3D modelling with a high volume of subsurface data or can it be tackled in other ways—using and analysing the available information, and producing maps that detail the opportunities that exist below the urban surface—differs across geographies and with the scale of potential use. A bottleneck has been found to be the preparation of various data sources of the subsurface strata by geologists that are not legible or comprehendible to urban planners and policymakers (Admiraal & Cornaro 2018).

6.2 Governance and legal challenges

Everyone is, and probably never will be, enthusiastic about the idea of using underground space—particularly in India. People have preconceived notions and governance and legal challenges—including regulatory controls governing land ownership, liability, building codes and government oversight—does little to change these notions. Governmental oversight of the subsurface is needed to regulate the use of underground space and protect ecosystem services.

Gathering data and knowledge for a better understanding is an ongoing dynamic process, and needs to be part of the oversight mechanism. It requires cooperation and coordination between different levels and departments of government, as the typical approach towards above-surface development does not work for underground development.

Land ownership, and its focus on ownership of surface land, pose another issue. Air rights and the creation of condominiums are ways in which shared ownership of a plot of land upwards is limited and regulated. The same practice extended downwards for the subsurface does not exist, but as the awareness and appreciation of the subsurface grow, it is becoming an emergency that a new legal approach may be required for the subsurface. For instance, property laws in Japan restricted even compulsory acquisition due to high compensation linked to high land value. Revised legislation limits the depth of land ownership to 40 metres below a basement or 10 metres below foundation piles, and the space beneath this is deemed available for use in the public interest (Admiraal & Cornaro, 2016).

To develop the underground—either through public law or civil law—exceptions to the general rule must be created. The legal power to expropriate land to take over its ownership on behalf of public interest is an example. Exercised by public bodies, rules and conditions for compulsory acquisition has to be laid down in law. In most legal systems, solving land ownership issues is possible with either negotiation or public acquisition. In whatever way the use of subsurface is achieved, some form of agreement and compensation is needed.

Another way that underground spaces can be developed is through private negotiations and reaching agreements on the right of way. This is usually adopted in situations where one party holds the land ownership and allows the use of the subsurface beneath the land under specific conditions and compensation. The compensation is connected with land value prices or easement costs. Also, it implies that apart from legal instruments for settling easement and rights of way, instruments are needed for the appraisal of easement costs.

Building codes also pose a challenge to the use and development of underground spaces. Whether adequate guidance is developed is linked to the local state of underground space use. In geographies, where underground development has never taken place and is not expected in the foreseeable future, local or national building codes will not contain any specific requirements. In developing these codes it is important to acknowledge that constructing below the surface is not just about creating space for various uses. It is also about extracting materials from the Earth. Thus, any future development, either partially or entirely below the surface, needs to be developed in harmony with nature.

In most countries, some degree of regulation and control exists to prevent unwanted and unnecessary damage to the environment. Environmental legislation usually requires an environmental impact assessment for a certain category of projects—particularly large infrastructure projects. A typical office building, even if it includes a large basement, usually falls outside this category. This omission raises the question of whether, in the case of the subsurface, the depth to which an activity extends itself should be the determinant for whether or not an environmental assessment is needed. Even though these assessments are important for making strategic decisions, controls that regulate water quantity and quality, extraction of mineral resources, extraction or storage of energy, and use of the subsurface for storage of carbon dioxide are needed as well.

Conclusion

Urban underground space is only one of four resources that constitute the subsurface. The subsurface is limited in its size in terms of human activity but has diverse possibilities of use—from the reuse of abandoned structures to producing food below the surface to mitigating climate change and using groundwater for heating and cooling homes. These spaces have an interesting relationship with urban resilience. On one hand, the subsurface can itself contribute to shocks and stresses, such as earthquakes. On the other hand, these spaces could serve as key mitigation assets.

An urban underground future is possible if a public participatory planning process is followed and balances the requirements of the city we need with the opportunities that the subsurface has to offer. Planning the urban subsurface, however, requires not just the balancing of requirements and opportunities—but also asks urban planners, urban designers, and architects to work together in shaping a new urban tissue beneath our cities. The key to this is creating connectivity below the surface comparable and compatible with city streets and public spaces.

Cross-disciplinary collaboration is required between those who know about shaping our cities and those with knowledge about the subsurface—to come up with multiuse solutions as using the subsurface on a first-come, first-served basis is detrimental to its sustainable development. Human interventions and acknowledgment of limited space below the surface date back to the 19^{th} century. Yet, infrastructure development has varied little over centuries—from the basic concept of roads and railways. Planners and developers of new infrastructure for the present and future need to rethink the development in harmonisation with nature and explore new ways of financing.

Sustainable urban underground development can help cities to become more resilient, inclusive and liveable while contributing to the quality of life, delivering health benefits, and providing more green public spaces. In this context, the model for determining sustainable urban underground development provides a holistic four-step approach for appraising the sustainability of these developments that preserve the past, enhance the present and respect the future.

In essence, the idea to plan and manage the use of the subsurface has been around for a long time. The use of the subsurface, however, has evolved below many modern cities. It has evolved to focus on the use of the subsurface as a spatial relief valve—freeing up vital space on the surface for alternate use. In the foreseeable future, planning the use of underground spaces for a sustainable, resilient, liveable, and inclusive city will become inevitable—to avoid future chaos and limitations on city development. It will require a cross-disciplinary integrated urban planning where public policies and urban planning acknowledge the existence of underground space and plan its use with the development of the surface.

It is important to acknowledge that urban underground development does not compete with the surface, rather it complements it and, in some ways, even completes it. The underground needs to create spaces that are liveable, attractive, safe, and appealing to the general public.

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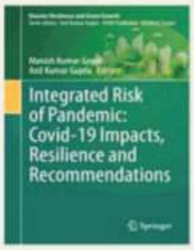

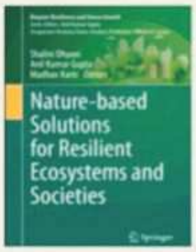


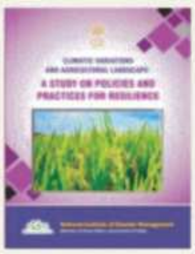




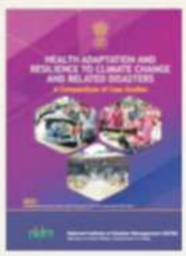



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