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Keynote Paper

Sustainable urbanization through underground development – towards an urban underground future

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ABSTRACT

Our globe is experiencing unprecedented growth in urban populations. The corresponding sprawl of existing urban areas and the explosion of new cities and urbanizing regions is occurring at rapid speed. Often infrastructure development cannot keep up while the resource land is being developed into urban sprawl. Efforts are going on in many cities and urbanizing regions to contain the sprawl and to densify in already built-up areas. At the same time, cities strive to create more open spaces and parks, especially in dense urban environments to improve or maintain or regain quality of life. The other side of the equation is the rise in natural hazards and the continuously increasing amount of people exposed to such. Making our cities more resilient is therefore a key necessity to avoid excessive damage through unpredictable natural disasters. The paper examines what the role of underground space is in that regard. Outlining the key elements for an effective and long-term use of the underground space, the authors present showcases, demonstrating to what extent underground facilities contribute to the sustainable development of urban areas

1. INTRODUCTION

Our globe is experiencing unprecedented growth in urban populations. The corresponding sprawl of existing urban areas and the explosion of new cities and urbanizing regions is occurring at rapid speed. The ever larger and denser concentration of population is causing further concerns. Ever larger groups of people are being exposed to natural hazards such as major storms, floods and earthquakes. The resulting need for disaster risk reduction and mitigation places additional burdens on cities and their governments. They also represent major challenges for urban and transport planners, as well as urban policy and decision makers.

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1.1 Rapid urbanization

The rapid urbanization of the world's cities and urbanizing regions can best be illustrated by the fact that by 2050 approximately 70% of the world's inhabitants (forecast to be 10 billion at that point) will live in urban areas (see Fig. 1) and UNISDR (2013). It goes without saying that this unprecedented growth is bringing up a multitude of challenges for city governments in terms of coping with urban development. But it is not just the sheer volume of urban population that is causing challenges; the density is also continuously increasing making land an ever more precious resource.

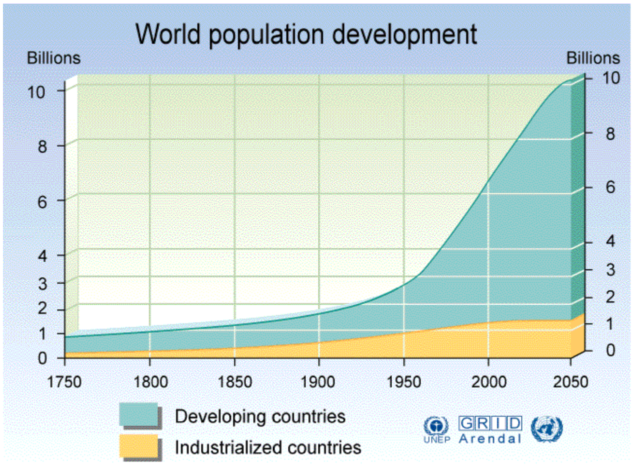

Fig. 1 World population development 1750-2050

1.2 Disaster risk reduction

The UN Office for Disaster Risk Reduction has been tasked by analysing how the world is challenged by not only natural hazards, but also by the effects of climate change and giving recommendations to affected regions around the world. One of the findings is that not only are the weird weather phenomena (extreme temperature fluctuations, floods, droughts, etc.) increasing, they are threatening more and more people as population density increases in cities.

1.3 Crowded cities – Sustainable cities of the future?

Cities are known to be places of human interaction, social and economic activity, as well as creativity. Cities are striving to accommodate growth and at the same time being places where people feel at home, in which they enjoy living, working and playing. Open public spaces play a key role in providing meeting and recreational places for people. But open green spaces also serve other purposes. They are the lungs of the city, which help filter out CO_2. Greenery also provides shelter and reduces temperatures avoiding urban heat islands. Sustainable cities are those that realize that in order to survive they need to use available spaces in a manner that helps the city meet the challenges of rapid urbanization and city resilience.

2. UNDERGROUND SPACE USE

More and more cities are looking to their underground spaces for relief as the resource land is being used up at alarming rates. Efforts are made to contain the sprawl of cities and to densify further in already built-up areas. Underground space suddenly becomes an interesting alternative leading to often very positive developments.

2.1 Placing surface road and rail infrastructure underground

There are many well-known examples whereby the demolishing of surface elevated highways or railways generate new life on the surface. The Boston Artery or *Big Dig* project extended the Central Business District by one third into the semi-abandoned seaport district. Salvucci (2003) states that it reduces street traffic allowing better pedestrian amenity and cleaner air. A few years after its completion it is evident that real estate prices in the now accessible Seaport District (no longer cut off by an eight-lane wide highway viaduct) are soaring, now commanding the highest rates in the City of Boston.

The currently ongoing Alaskan Way Viaduct Replacement Project in Seattle is seen to have a high impact in redeveloping the waterfront and re-establishing relationships between neighbourhoods cut off by the existing elevated highway (WSDOT, 2011). The positive effect of the underground solution can clearly be seen in Fig. 2 and Fig. 3.

Fig. 2 Alaskan Highway Seattle, USA, situation with elevated structure

Fig. 3 Alaskan Highway Seattle, USA, situation with bored tunnel

In the City of Rotterdam an elevated 19th century rail line was replaced in 1993 by a cut and cover tunnel, the Willems Railway Tunnel. The tunnel runs for 3 km below street level. Removal of the elevated rail line created an enormous space potential at the surface as can be seen from the new market hall development recently constructed on top of the railway tunnel (see Fig. 4) which was opened in 2014.

Fig. 4 The new 'Market Hall' arising in the centre of Rotterdam, the Netherlands

2.2 Freeing the surface from visual and noise blights

There are numerous noisy nuisances in cities that cause both visual and noise impediments to further urban development. In Helsinki, the 'Viikinmaki' wastewater treatment plant was placed underground (see Fig. 5). The plant processes all of Helsinki's wastewater and is one of the largest underground spaces in the world. At the surface, it allowed a 60-ha development, providing accommodation for 3,500 people (Paul et al, 2002).

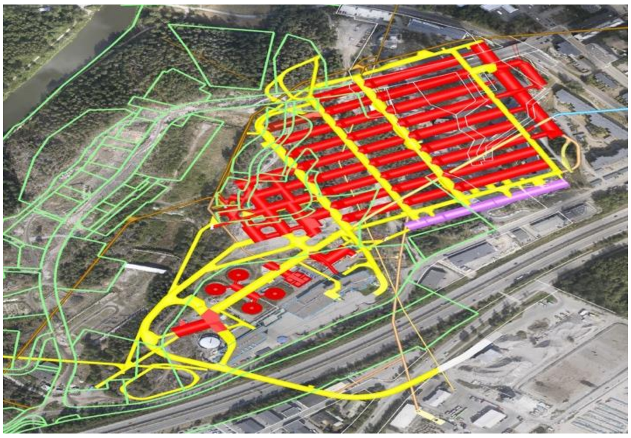

Fig. 5 'Viikinmaki' Wastewater Treatment Plant, Helsinki, Finland

2.3 Underground space as urban service layer?

The question is whether this type of development (see 2.2) actually leads to sustainable urban development and indeed to sustainable urban underground space development? Although in many respects the answer could be yes when looking at such development from a micro perspective, the answer from a more macro level could very well be no.

Experience in many countries has shown that underground space is often seen as the 'urban carpet' under which we can sweep all unwanted functions and all by-products of modern life.

Indeed, in a past architect's proposal for a redevelopment in Hong Kong the mind-set of using the underground space as urban service level was clearly illustrated. Note how in Fig. 6 the underground space is labelled 'traffic and pollution below'.

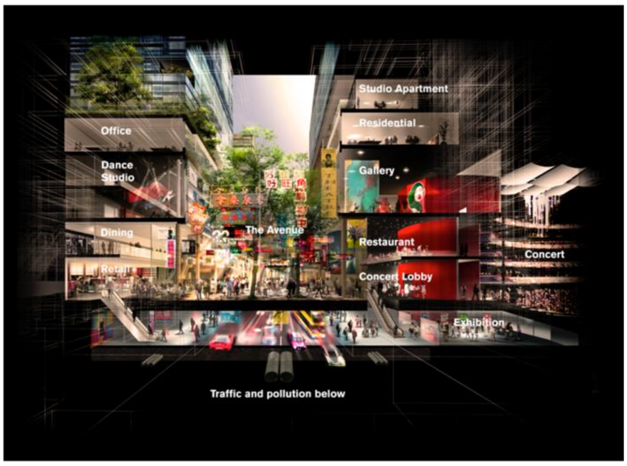

Fig. 6 Foster + Partners proposal for a 40-hectare arts district in Hong Kong

The main issue with this approach is that it leads to a mono functional use of the underground space. Also, the concept of losing pollution by placing road tunnels beneath the surface only works if extensive measures are taken to ventilate these tunnels and filter out the pollutants. Otherwise there will be extremely high concentrations at the tunnel portals to cope with and the solutions will not be sustainable.

2.4 Undesirable use of underground space

So, do these examples illustrate an undesirable use of underground space? In the short term this does not have to be the case. As we have seen before, freeing up surface space to make cities more liveable and loveable is a welcome development. The City of Madrid gained one million square meters of green public space by placing 56 km of the total 99 km long M30 at grade motorway in tunnels (Cornaro & Admiraal, 2012).

In the long term however the real question is whether these mono-functional and often isolated examples contribute to the sustainable development of cities? Are they a part of a vision or strategy driven by the conviction that cities need to develop in a sustainable manner and become resilient against natural hazards and the effects of climate change, in order to survive?

3. SUSTAINABLE UNDERGROUND SPACE

For underground space use to be sustainable it has to meet two basic criteria. The first is that the development itself must be shown to be sustainable in its inherent qualities. Secondly the intended use of the underground space must be shown to be sustainable.

We will illustrate this with an example. In Switzerland, a plan was developed for an underground industrial facility to produce wafer chips (see Fig. 7). It was shown that by placing the factory inside the mountain a lot of benefits could be gained. Inside the mountain there would be no vibrations. Constructing the facility on the surface would require complex foundations to cope with this aspect alone. The climate inside a cavern is constant and especially in summer requires less cooling. Overall the project also required less land acquisition compared with a project at the surface (Ruegg et al, 2013).

From this it can be concluded that the development itself can be taken to be sustainable. To develop it inside a mountain, material has to be excavated to create the required space. This material is treated and then reused as gravel for foundation layers in road projects, thereby providing a secondary use of the excavated material. Inside the mountain the facility poses no known obstacle to future developments. As such it is also sustainable in terms of future development. After ceasing operation, the spaces could be reused for all kinds of other purposes. So also from this perspective, the development is sustainable.

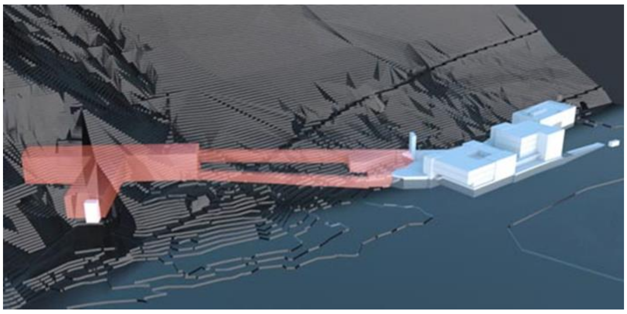

Fig. 7 ‘Waferfab’ Facility, Switzerland

Using the examples shown, the authors have developed a sustainability matrix including four sustainability criteria, which underground space projects need to meet if they are to contribute to sustainable development of cities and urbanizing regions (see Fig. 8).

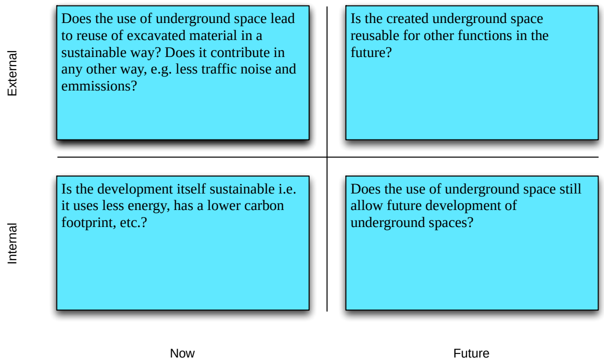

Fig. 8 Sustainability matrix (Cornaro & Admiraal, 2012)

When we look at a further example, the use of underground space for geothermal energy application (see Fig. 9), we come to a development that in itself is sustainable. Given however that these applications require vertical pipes to be driven many hundreds of meters into the underground, they could potentially block future developments in the horizontal plane. Without further consideration of the circumstances a development that in itself contributes to sustainable development, could prove to be non-sustainable by blocking future urban underground development.

Also from traditional cables, pipes and other building elements and materials placed underground, we know what spatial conflicts can arise (see Fig. 9) through non-use and neglect in the long term. The Deep City Project has been researching this issue in order to find a methodology for decision-making on the use of the underground space (Li et al, 2012).

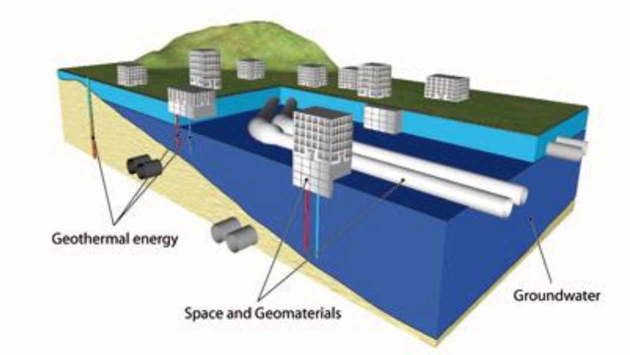

Fig. 9 The ‘Deep City’ model showing various uses of the underground

Based on the above the authors propose that sustainable development of underground space cannot be achieved without a decision-making framework to ensure this development contributes to a sustainable urban underground future as a whole.

4. URBAN UNDERGROUND SPACE FRAMEWORK

When considering an underground space decision-making framework, the following aspects need to be included: (1) vision & strategy, (2) planning and (3) management.

4.1 Vision and strategy

A vision and strategy on the use of urban underground space requires us to look further than the ad hoc incidental use that is now often achieved.
As can be seen from the above examples, freeing up surface space by placing urban infrastructure underground is in itself a much-needed land pressure relief valve. It does however not automatically lead to sustainable solutions.

One of the major differences between surface and underground development is that public spaces need to be purposely created underground (Bélanger, 2007). Examples are known of underground cinemas and underground car parks being developed at different time scales but placed next to each other. As no one thought about connecting these developments, citizens need to leave their cars underground, travel to the surface and walk to the cinema, only to then travel below the surface again.

So, any vision and strategy on urban underground space should include how connections underground will be created in order to establish a new urban underground fabric, such as the underground cities or '*villes souterraines'* of Montreal and Toronto) When the RATP, the Paris Transport Authority invited architects to come up with new ideas for metro stations, one idea evolved around the opening up of the underground metro station to create a multi modal transport hub with various functions (RATP, 2012). It is this strategy that should also be considered when looking at the long term of urban underground space development. By integrating the underground spaces into the surface fabric, the underground becomes an integral part of that fabric. It no longer is a stand-alone mono functional development; it starts to become part of the liveable and loveable city that is so important to us as urban residents. In many new Asian intermodal developments of this kind, consisting of integrated design of underground and surface development, is commonly practiced.

A further strategy is required to address the issue of city resilience against natural hazards and the effects of climate change. Cities need to cope with earthquakes. Cities need to cope with excessive rainfall. Cities need to cope with excessive flooding. Cities need to cope with major storms. Providing resilience through integrated urban underground development is possible as can be seen from the next example.

When plans were being developed for creating an underground car park in Rotterdam's Museum Quarter, this was combined with creating a large water retention basin to store excess water during flash rainfall in the city. When the city's street become in danger of flooding or the canals start overflowing, some 10.000 m^3 can be redirected and stored in the retention basin inside the facility. After water levels in the city reside, the stored water inside the facility is pumped out and fed off in the traditional manner. The facility also provides 1,150 public car parking spaces (see Fig. 10).

Fig. 10 ‘Museum Park’ Public Car Park Rotterdam, the Netherlands

4.2 Planning

The vision and strategy developed by a city should provide a solid basis to proceed on. Planning is required to take this a step further by ensuring that urban underground spaces become part of cities’ master plans as was done by the City of Helsinki. Similar plans are now being envisioned for Singapore and Hong Kong.

With land at a premium the biggest challenge urban planners face is what to fit in how and where. In relation to underground space this challenge becomes a puzzle. To illustrate this, take the concept of the skyscraper. The skyscraper is a universal solution for providing high density within a small surface footprint. From an engineering perspective challenging, but creatable in most circumstances.

Now invert this concept into an ‘Earthscraper’. Recently proposed by young architects in Mexico City (see Fig. 11), but already illustrated and propagated as earthquake proof structure in Japan in journals going back to the 1930’s (Depthscraper, 1931).

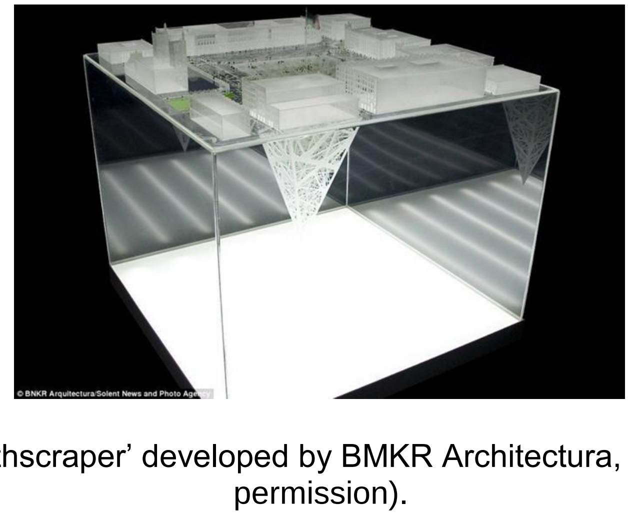

Fig. 11 The ‘Earthscraper’ developed by BMKR Architectura, Mexico (with kind permission).

Is this from an engineering perspective a universally creatable structure? The answer is no. Although engineers will take up many challenges, the concept of the 'Earthscraper' will not work everywhere. The geology of underground space has its limitations in terms of what we can achieve. In soft soils with high water tables, water pressure is often taken as the limiting factor. In hard rock, the stability and the type of rock could prove to be limiting factors. A study in Singapore shows areas, which have a high potential for underground space development

Most of these areas lie outside urban areas, posing interesting questions and challenges for city planners (see Fig. 12).

Planning the underground space cannot be achieved without looking at surface development. It can also not be achieved without a dialogue between planners and engineers identifying areas in which development could be feasible. That same spatial dialogue is also required to establish whether uses can be combined in such a way that are more beneficial to society than stand-alone developments (Cornaro & Admiraal, 2012).

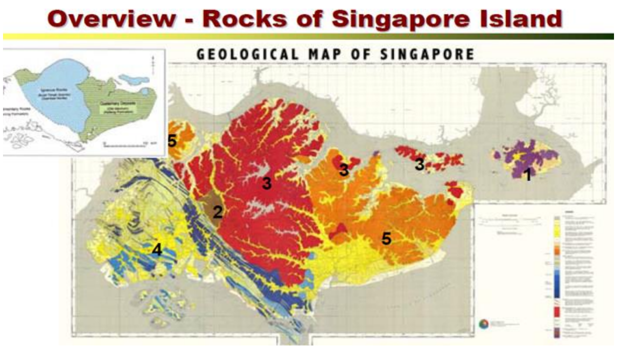

Fig. 12 Geological Map of Singapore

A multi-functional tunnel that emits clean air into the city and provides energy for the surrounding community is not far away from prototyping. Reason enough for planners to start considering this together with the engineers to see how this can provide value for our cities.

4.3 Management

Once cities start to use their underground space, this space needs to be managed. Management of the underground space is needed to ensure that future generations will still be able to use it. As such it is essential to know what is happening in the subsurface beneath the city.

One of the reasons is to prevent for example boreholes for geo-energy applications running into existing underground structures. Another reason is, as is being practiced by the City of Helsinki, to safeguard areas that have been identified for possible future uses. The Deep City Project stresses that sometimes areas beneath cities such as water aquifers should be maintained without any further human interference (Parriaux et al, 2002)

Planning and active management of a city's underground space can greatly enhance the understanding of both planners and engineers of those spaces and create numerous possibilities. It forms an integral part of sustainable development of underground space. It is vital for an urban underground future.

5. CONCLUSIONS

The use of underground space can come about by sheer necessity to free up surface space. It can happen through public or private initiative. Whatever the reason for its development, in itself its use does not lead to sustainable development of underground space.

A framework is needed to ensure the sustainable development of underground space. The authors have shown that this framework requires the development of a vision & strategy, planning and management.

The authors also emphasize that development in the context of this framework can only happen through dialogue with all stakeholders involved. Without planners and engineers sharing information in the early stages of underground development chances are that autonomous development will cause serious impediments to future development and use.

The authors see a clear need for the effective and long-term use of underground space in making our cities more resilient, more liveable and more sustainable.

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