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Future cities, resilient cities – The role of underground space in achieving urban resilience

Han Admiraal [a,c,*], Antonia Cornaro [b,c]

[a] Enprodes Management Consultancy BV, Marshalllaan 2, 2625 GZ Delft, the Netherlands
[b] Amberg Engineering AG, Trockenloostrasse 21, 8105 Regensdorf-Watt, Switzerland
[c] ITA Committee on Underground Space (ITACUS), International Environment House (MIE2), Chemin de Balexart 9, 1219 Châtelaine – Geneva, Switzerland

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Abstract

The need for future cities to be resilient stems from the fact that now more than ever in history, both natural and human-made hazards are threatening cities in the forms of shocks and stresses. The ability of cities to resist or restore themselves following these events is dependent on their resilience.

As we now firmly enter the Anthropocene, the geological epoch in which human activity, for the first time in history is directly influencing the Earth's systems, we need to develop resilient cities that can cope with the increase in hazards. Although climate change is one factor influencing urban resilience, it is not the only one. A lack of understanding of the subsurface can also influence a city's resilience, as can the unplanned use of its underground spaces. In planning and developing our cities of the future, a deep understanding of the geology that supports the city is required not only to be able to determine the possibilities of future use but also to determine whether there are natural processes that could threaten human existence over time. The destruction of ecosystem services through unchecked human activities could be one of these activities. In this paper, the authors will investigate how the subsurface and use of underground spaces can influence urban resilience. The role that underground spaces can play in achieving urban resilience for our future cities will be described.

Keywords: Underground space; Urban planning; Urban resilience

1 Introduction: The concept of urban resilience

Cities today are the core of human existence. Cities are where people live, work and play. As part of an irreversible trend, we are experiencing a mass migration from rural areas to our cities. More than ever, the world's cities have become areas of dense concentrations of humanity, and population forecasts show that the mass urbanization will continue rapidly. This large concentration of people in one area in combination with natural disasters and human-made hazards makes humankind more vulnerable than ever before.

Referring to Hurricane Katrina, which struck New Orleans, USA in 2005, Bloomberg and Pope (2017) write the following:

> "*All over the world there are places like New Orleans that need new approaches to cope with the reality that the future climate will be different from today's, and probably less stable. We will need a greater resilience at all scales – local, regional and global – to cope with the changes in the climate that are already occurring as we write this book.*"

* Corresponding author at: Enprodes Management Consultancy BV, Marshalllaan 2, 2625 GZ Delft, the Netherlands.
E-mail addresses: han.admiraal@enprodes.nl (H. Admiraal), acornaro@amberg.ch (A. Cornaro).

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This greater resilience Bloomberg and Pope call for in relation to climate change can be framed in a larger context as the shocks and stresses that cities will have to cope with. Urban resilience in this context is the ability of cities to absorb these shocks and stresses and to recover from them.

In 2011, the city of Sendai in Japan was struck by an earthquake and the resulting tsunami. The combined effect was disastrous and caused heavy losses of life and property. This disaster also led to the Fukushima nuclear reactor meltdown. What is most remarkable is the recovery the city made and the fact that it hosted the 2015 UN World Conference on Disaster Risk Reduction. The conference concluded with the Sendai Framework for Disaster Risk Reduction on March 18, 2015. This date was significant, since it was only four years and one week after the day disaster struck the city and the wider region. The Sendai Framework follows the Hyogo Framework from 2005. Since then, the world has faced many challenges.

> "*Over the same 10 year time frame, however, disasters have continued to exact a heavy toll and, as a result, the well-being and safety of persons, communities and countries as a whole have been affected. Over 700 thousand people have lost their lives, over 1.4 million have been injured and approximately 23 million have been made homeless as a result of disasters. Overall, more than 1.5 billion people have been affected by disasters in various ways, with women, children and people in vulnerable situations disproportionately affected. The total economic loss was more than $1.3 trillion. In addition, between 2008 and 2012, 144 million people were displaced by disasters. Disasters, many of which are exacerbated by climate change and which are increasing in frequency and intensity, significantly impede progress towards sustainable development.*" (UNISDR, 2015)

Disasters, in the context of the Sendai Framework, are natural disasters. It is important to note that climate change is affecting the frequency and intensity of natural disasters such as storms, rainfall and, consequently, landslides. In terms of vulnerability the document states:

> "*Evidence indicates that exposure of persons and assets in all countries has increased faster than vulnerability has decreased, thus generating new risks and a steady rise in disaster related losses, with a significant economic, social, health, cultural and environmental impact in the short, medium and long term, especially at the local and community levels.*" (UNISDR, 2015)

The document defines vulnerability as: "(...) *the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards*" (UNISDR, 2015).

Therefore, the concept of urban resilience addresses the vulnerability of communities in terms of identifying the risks, mitigating them, preparing for risk events and ensuring a rapid recovery after the event has occurred. As we saw above, the risks can be defined as the shocks and stresses that cities increasingly face.

2 Threatening shocks and stresses

Hajer and Dassen (2014), in their book on smarter cities, write about 'urban metabolism', and Renner (2018) speaks about the 'urban being'. Both concepts illustrate the way urban planners are trying to comprehend the city and try to look at urban life holistically. The Rockefeller Foundation 100 Resilient Cities organization uses the same approach when looking at resilience. According to them, "(...) *building urban resilience requires looking at a city holistically: understanding the systems that make up the city and the interdependencies and risks they may face.*" (100 Resilient Cities, 2018). This in itself is a massive challenge that will vary across cities. Hajer and Dassen (2014) talk in this respect about reconnecting the biophysical and social domains. It is our contention that this should also include the subsurface, as we will expand on in the following paragraph.

The 100 Resilient Cities organization offers an insight into what kind of stresses and shocks we are talking about. They see stresses as chronic, slow-moving disasters that threaten the fabric of a city. Shocks are far more acute events that threaten the city (Hajer and Dassen, 2014). Table 1 provides an overview of what they consider as stresses and shocks.

To further analyze and understand urban resilience, the 100 Resilient Cities organization also created a 'City Resilience Framework', which describes four dimensions that can act as a lens through which the city can be examined. Each dimension consists of three drivers, which relate to actions cities can take to become more resilient. The four dimensions are the following: (1) Health & Well-being, (2) Economy & Society, (3) Infrastructure & Environment, and (4) Leadership & Strategy. If we look closer at Infrastructure & Environment, the three drivers are: Provide and Enhance Protective Natural and Man-Made Assets, Ensure Continuity of Critical Services, and Provide Reliable Communication and Mobility (see Fig. 1) (Hajer and Dassen, 2014).

In the paragraph about underground spaces, we will take a further look at these drivers to show how the subsurface can contribute to urban resilience. Before we come to

Table 1
Chronic stresses and acute shocks. Taken from 100 Resilient Cities (2018).

Chronic stresses	Acute shocks
• High unemployment • Overtaxed or inefficient public transportation systems • Endemic violence • Chronic food and water shortages	• Earthquakes • Floods • Disease outbreaks • Terrorist attacks

- **Provide and Enhance Protective Natural and Man-Made Assets**

Maintain protective natural and man-made assets that reduce the physical vulnerability of city systems. This includes natural systems like wetlands, mangroves and sand dunes or built infrastructure like sea walls or levees.

- **Ensure Continuity of Critical Services**

Actively manage and enhance natural and man-made resources. This includes designing physical infrastructure such as roads and bridges to withstand floods so that people can evacuate, as well as ecosystem management for flood risk management. It also includes emergency response plans and contingency plans that may coordinate airports to function so that relief can be lifted in and out during a crisis.

- **Provide Reliable Communication and Mobility**

Provide a free flow of people, information, and goods. This includes information and communication networks as well as physical movement through a multimodal transport system.

Fig. 1. Infrastructure and Environment - drivers for urban resilience. Courtesy of 100 Resilient Cities (2018).

that topic, we need to further explore the dynamics of the subsurface and human intervention.

3 Geology: Friend or foe?

When considering the subsurface below a city from an urban planning point of view, we need to consider something that is difficult to comprehend: we must think in terms of volume, rather than area. One of the reasons for this is that rather than dealing with ‘air’, we need to deal with ‘geology’ below the surface. Due to the unique characteristics of the subsurface, we need to extract materials in a way that humans have been doing for centuries in order to create space. Although caves are the archetypical human shelter below the surface, mines, consisting of shafts and galleries, are the archetype for human extraction and exploitation of the subsurface. As such, the subsurface provides goods, which are nonrenewable materials, ranging from coal to copper and from oil to gas. At the same time, we need to consider that for certain geologies the subsurface can contain biodiversity; through natural processes and cycles it delivers ecosystem services to support life on the surface. The ability for the soil to grow crops and that for rainwater to infiltrate and naturally be filtered to drinking water are just two examples of this (Admiraal & Cornaro, 2018).

The question is whether we know sufficiently how these systems work and what the effect of human interventions is on these systems, as was discussed by Sterling and Nelson (2013). To illustrate this point, we can look at the extraction of natural gas from onshore facilities in the northeastern part of the Netherlands. The ‘Groningen’ gas field has for over 50 years not only provided the Netherlands with fuel to heat homes and to cook, it has also contributed to the gross national product as an export product. That was the cause until the earth in that region started to move and it was realized that the earth tremors and earthquakes hitting the region were caused by the extraction of gas from deep below the surface. Although minor in magnitude compared with earthquakes in other countries, there was substantial damage caused to buildings that were not designed to withstand these forces of nature (Admiraal & Cornaro, 2018). The public outcry led to a political decision to reduce gas extraction to zero within a couple of years, requiring the country to look for an alternative. After the Tōhoku earthquake, the decision was made in Germany in the same way to close its nuclear power stations; this step required looking for alternative, renewable ways to produce energy.

It was the well-known former secretary-general of the United Nations, Ban Ki-Moon (2012), who pointed out that humankind was entering the Anthropocene. For the first time in the history of this planet, human activity was influencing and altering the earth’s natural processes. When looking at the subsurface for energy, storage or physical space uses, an in-depth knowledge is required of the geology to ascertain whether human interventions will disturb the ecosystem in a way that could be detrimental to urban life.

When looking at urban resilience we need to consider past human interventions. Mining, for example, poses a potential risk as it can cause sink holes due to the collapse of galleries. These collapses could threaten the city as a chronic stress.

Does this mean, from an urban resilience perspective, we should not be looking at the subsurface? In our opinion that is not the case. We do need to take a balanced approach and extend both our sustainable development principles and our urban resilience objectives downwards to include the geology below our cities and urbanized regions.

4 Underground spaces

How can underground spaces contribute to urban resilience? This issue has been previously explored by Sterling and Nelson (2013), Bobylev, Hunt, Jefferson, and Rogers (2013) and Hunt, Makana, Jefferson, and Rogers (2016). To further explore this question, we will take one dimension of the City Resilience Framework, Infrastructure and Environment, and the three drivers that determine a city's resilience within that dimension.

4.1 Provide and enhance protective natural and man-made assets

This driver is about protecting those protective natural human-made assets that reduce the physical vulnerability of city systems (100 Resilient Cities, 2018). One way to investigate this point is by considering the urban heat island effect. We know that built-up areas heat up more than rural areas due to the prominence of concrete and asphalt. We also know that in certain terrains cool winds from surrounding hills can help to reduce the urban heat island effect. High-rise buildings can seriously impact this natural effect. By considering creating underground spaces, the need for more space can be fulfilled while at the same time maintaining this natural flow of air throughout the city. Another example is the way in which natural sand dunes protect the Netherlands from the sea. In the city of Katwijk, the dunes were used to create an underground car park, maintaining the natural sea defense and creating more space (see Fig. 2).

4.2 Ensure continuity of critical services

One of the threats of climate change is to have more frequent highly intensive precipitation. This precipitation poses a problem for cities without urban drainage. For those cities that have drainage systems, the capacity is often such that not all rainfall runoff can be dealt with, resulting in flooding. In Rotterdam, in the Netherlands, an underground car park was combined with a water retention basin. In this way the underground space created was used for both the storage of cars and water, independently of each other. When canals and sewer levels become critical, a controlled overflow to the basin can be created. After levels recede, the basin is pumped out using the urban drainage system. In Tokyo, Japan, the same concept was used to create an enormous underground 'temple'. The sole purpose is to store rain water to prevent flooding of the city (see Fig. 3). What has not yet been attempted is to combine this mitigation of an acute shock with the alleviation of a chronic stress, i.e., combating water shortages by reusing the rain water that is caught in these storage basins to prevent flooding (Admiraal & Cornaro, 2018).

Another example is the way that underground infrastructures are a lot less susceptible to earthquakes. This has been proven in multiple earthquake events. In this sense, underground transport systems could serve not just for transporting people; they could also be used as a disaster relief system, helping a city to recover after an earthquake event.

4.3 Provide reliable communication and mobility

In regard to providing a 'free flow of people, information and goods' (100 Resilient Cities, 2018), using the subsurface for this purpose is evident. Mass rapid transport systems in such cities as London, Paris, New York and Moscow demonstrate this point daily. At the same time, extensive use of the subsurface for pipelines and communication cables ensure the continuity of communications and vital supplies irrespective of the circumstances aboveground. Being below the surface makes these systems independent from exogenic forces, such as storms. For a long time, cities have been using the subsurface to create an urban service layer. A good example is the city of Prague, which has a 90 km long network of tunnels serving the city, carrying gas pipes, steam pipes, water mains, high and low voltage cables, telecommunication cables and special networks connecting individual companies (Barták, Sourek, & Karlicek, 2007) as shown in Fig. 4.

A modern-day example of taking this concept further is the utility tunnel incorporated into Gujarat International Finance Tec-City. The tunnel beneath the city measures 7.6 m × 6.2 m and runs for 15 km. The tunnel will carry (a) 50 million liters per day of treated water, (b)

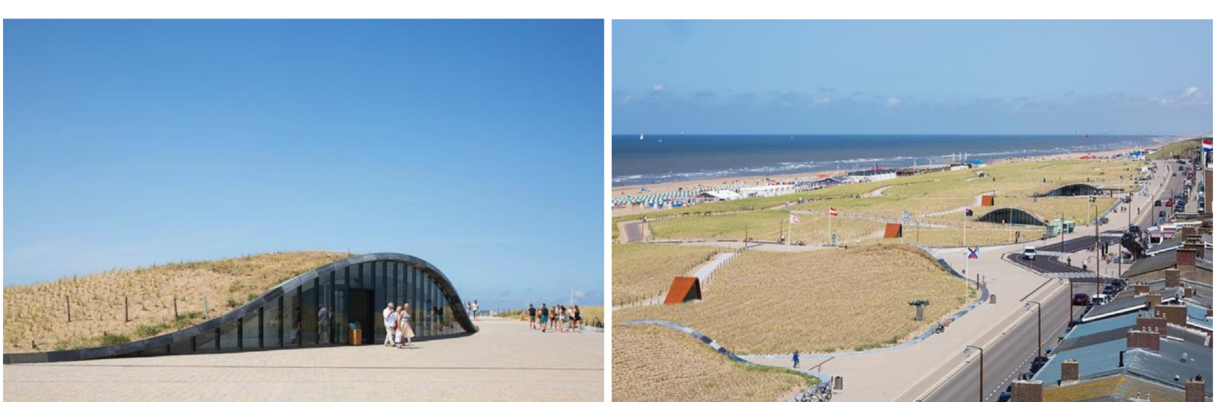

Fig. 2. Underground car park under sand dunes, acting as natural sea defenses. Courtesy: BNA Beste Gebouw van het Jaar.

Fig. 3. The temple water storage basin beneath Tokyo. Courtesy of Amano Jun-ichi, reproduced under CC BY 3.0.

Fig. 4. Prague, Czech Republic, utility tunnel. Courtesy of Honza Groh, reproduced under CC BY 3.0.

200 000 tons of cooling water, (c) 750 megawatts of power supply, and (d) 280 million tons of solid waste (Bentley, 2018).

To end this discussion, we would like to quote from our own work:

"*It's a historical fact that humanity started with two basic concepts for habitation: the cave and the tent. Throughout history, humans have been building tents on the surface and continue to do so. We may well find that the chronic stresses and acute shocks that cities face going into the* *future require us to start building more caves. In the end, forces at the surface might become such that tents can no longer withstand them, and caves will provide the resilient habitats for humanity to survive.*" (Admiraal & Cornaro, 2018)

5 Conclusions

Urban resilience is an important concept for cities to consider in addition to sustainable development. Urban resilience requires a holistic approach to identify the systems and processes that define the urban metabolism of the urban being.

The subsurface beneath our cities can in many ways be vital in supporting the city, from literally being the foundation, to mitigating climate change effects and providing new underground spaces to further enhance our cities. The subsurface could prove vital in allowing cities to recover after an acute shock and in dealing with chronic stresses.

We have shown that contemporary underground spaces can increase urban resilience in the field of infrastructure and environment. We have no doubt that this holds true in other areas as well.

To establish what the role of the subsurface can be, in-depth knowledge is required of both the geology and of the historical and contemporary uses. This knowledge is the key to determining what threats the subsurface can pose in terms of stresses and shocks, or in what way the subsurface, through sustainable and thought-out underground spaces, can help alleviate these stresses and ensure a rapid recovery.

Whatever shape our cities take into the future, the need to consider the subsurface and the creation of underground spaces is clear. This holds true whether it is to develop sustainably, to adapt to climate change, to create urban resilience or to be a part of the quest to create livable and loveable cities that are inclusive for their citizens.

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