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objections in terms of the distance between the surface and this boundary of the deep subsurface. Secondly, it would pose quite an engineering challenge given the great pressures at this depth and also the high temperatures. The thermal gradient below the surface is 25–30°C/km, which would mean that at 4 km depth we would expect temperatures in excess of 100°C. For the purposes of geothermal energy these temperatures are, however, very attractive, and Fridleifsson *et al*. (2008) have mentioned a project running down to 5 km: 'into a reservoir with supercritical hydrous fluids at 450–600°C … If this project succeeds, the power obtained from conventional geothermal fields can be increased by an order of magnitude.'

This shows that the lower boundary might be pushed further, as is the case with all kinds of human exploration. For the purposes of planning, we feel that the 'top subsurface layer' is sufficient as an object of investigation in relation to the urban fabric.

1.4.2 The subsurface resources model

Parriaux *et al*. (2004) first suggested a model of the subsurface as comprising four resources: space, water, energy and geo-materials. What makes this model interesting is that 'underground space' is but one of four resources that we can identify below the surface. The presence of water, the ability to obtain or store energy, and the ability to extract geo-materials are sometimes conveniently forgotten in the quest for space that cities undertake. This quest is real, as can be seen from a recent article in the *China Daily* (Wei, 2016):

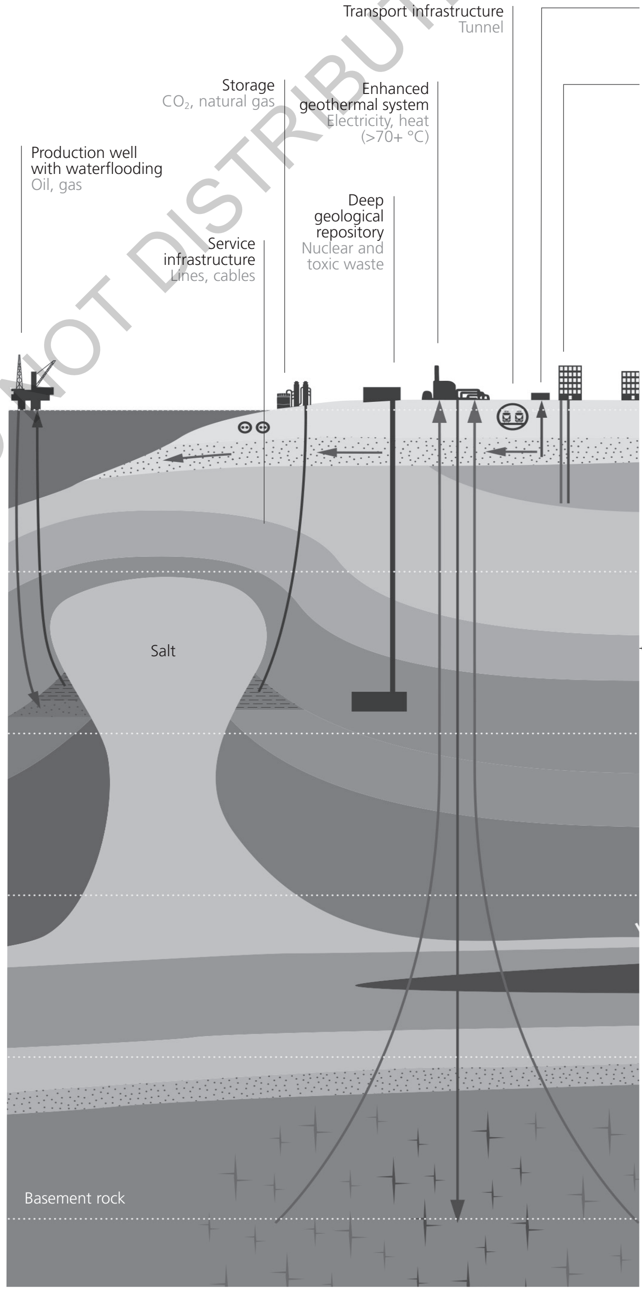

Figure 1-6 Schematic depicting the diversity of subsurface use | Courtesy of Ulrike Kastrup

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Achieving harmony between humanity and nature – urban underground sustainability

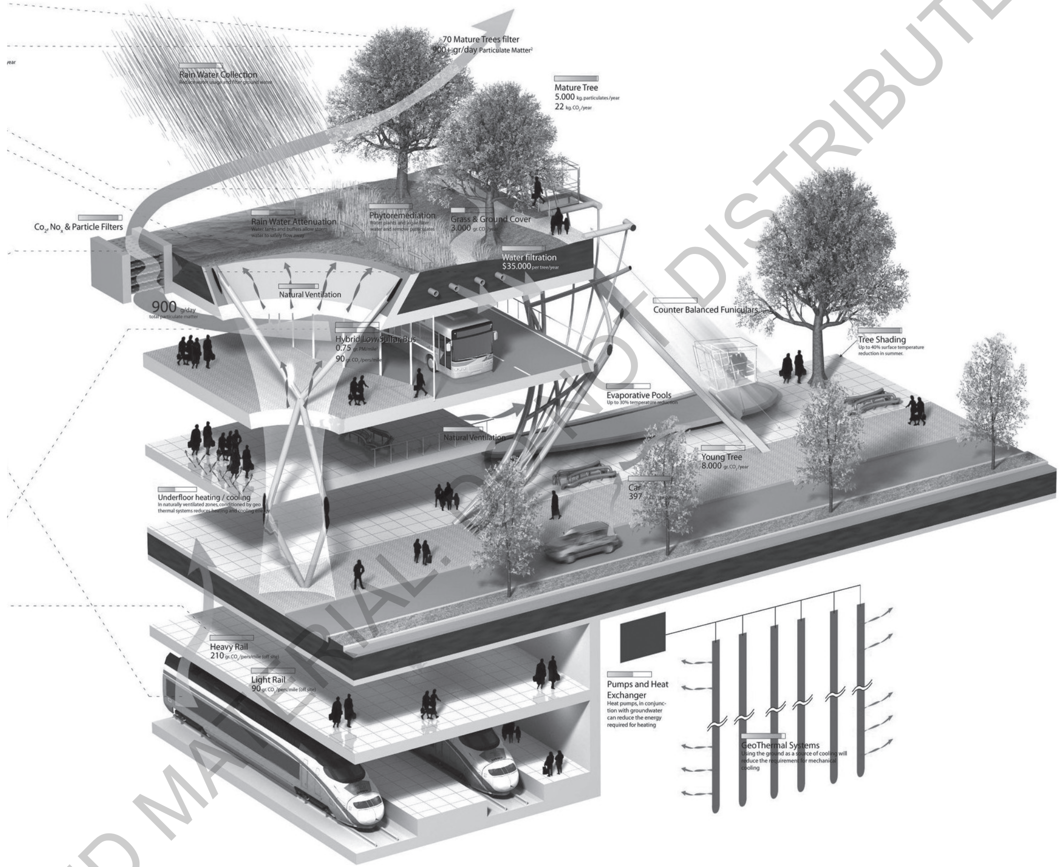

Figure 2-3 Sustainability design of the Transbay Transit Center in San Francisco | Courtesy of Except Integrated Sustainability, Utrecht, the Netherlands, reproduced under CC BY 2.0

which created enough concrete waste to fill 28 Olympic-size swimming pools. All the waste will be recycled. The project also reduces storm water runoff through the use of grey water storage tanks (Transbay Program, 2017). The potable water use of the Transit Center will be reduced by half, saving nearly 6 million litres of potable water (Urban Fabrick, 2015).

Apart from complying fully with the five principles, this case study also shows how the development contributes to enhancing ecosystem services in the city. An example of an underground development that achieves this as well is the Croton Water Filtration Plant in the Bronx, New York City. The development consists of an underground facility that is topped by a green area consisting of a golf driving range (Brown, 2014). Interestingly, New York made its case for this facility through the valuation of ecosystem services: using nature's ability to filter and decontaminate water. The development also contributes aesthetic and recreational benefits

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The relationship between the surface and subsurface has always been of interest to architects. Looking at the first designs of metro entrances, for example Hector Guimard's entrance for the Paris Métropolitain (Figure 4.5), these seem to have always marked the entrance to life below the surface through stairs or escalators. Even modern-day Metro entrances still use this concept, where the M or U logo serves as the primary indicator for the point of access to the underground. However, at the turn of the 21st century this idea began to change, as can be seen from the design of Kongens Nytorv Station on the Copenhagen Metro, which opened in 2002 (Figure 4.6). This design allowed for a more open transition, emphasising lines of sight with the surface. In a way, it followed the lead given by the design of British architect Lord Norman Foster for Canary Wharf Underground Station (Figure 4.7). His design integrated the surface and subsurface in a way that opened up the subsurface and at the same time connected it with the surface. Exiting the underground at Canary Wharf and standing on the escalators

Figure 4-5 Hector Guimard's original Art Nouveau entrance of the Paris Metro in Abbesses station | Courtesy of Steve Cadman, reproduced under CC BY-SA 2.0

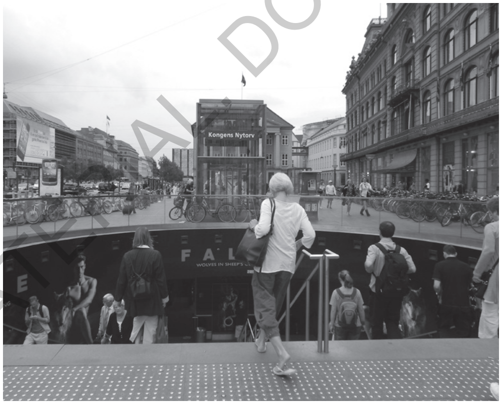

Figure 4-6 Entrance to Kongens Nytorv Station on the Copenhagen Metro | Courtesy of Patrick Nouhailler, reproduced under CC BY-SA 3.0

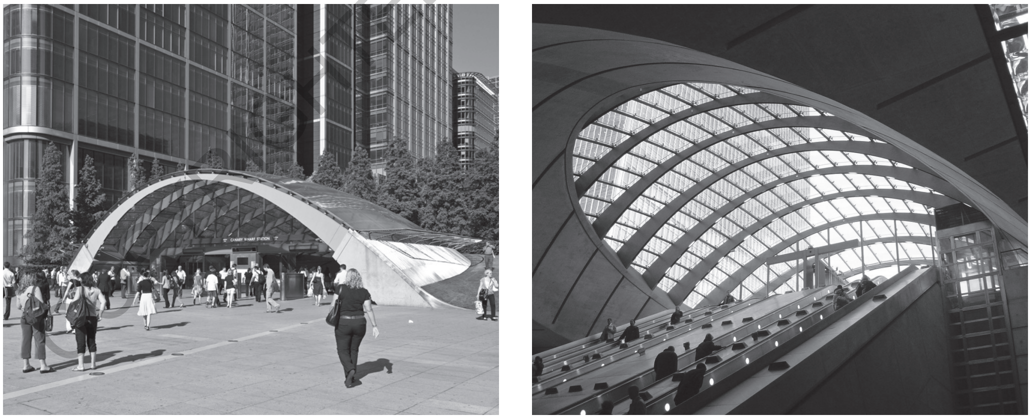

Figure 4-7 Canary Wharf Underground station | Photo left by David Ilff. License CC-BY-SA-3.0

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preservation of the built environment is the paramount ambition. It preserves the iconic presence of the city square and the existing hierarchy of the buildings that surround it. It is an inverted pyramid with a central void to allow all habitable spaces to enjoy natural lighting and ventilation. To conserve the numerous activities that take place on the city square year round (concerts, political manifestations, open-air exhibitions, cultural gatherings, military parades …), the massive hole will be covered with a glass floor that allows the life of the Earthscraper to blend with everything happening on top.

What the earthscraper so pointedly illustrates is the difference between constructing beneath and above the surface. Where the skyscraper is a universally accepted and applied concept, building the earthscraper requires specific conditions. High-rise buildings depend on the subsurface for their foundation. When it comes to buildings below the surface, a certain complexity arises. Firstly, the subsurface itself plays a role, as it exerts forces on the building. This can be soil pressure, or pressure caused by groundwater – which plays an important role too. The local geology becomes the most important determinant in deciding on the construction of an earthscraper. The groundwater table determines how deep we can reach. Where in some locations the water table can be 25 m or more below the surface, in other areas, such as deltaic regions, the water table can be as little as 1 m below the surface. Looking back at Section 4.1, the use of underground space in London utilises the local geology, the London Clay. In deltaic regions, such as the Netherlands, the presence of groundwater limits the depth of construction.

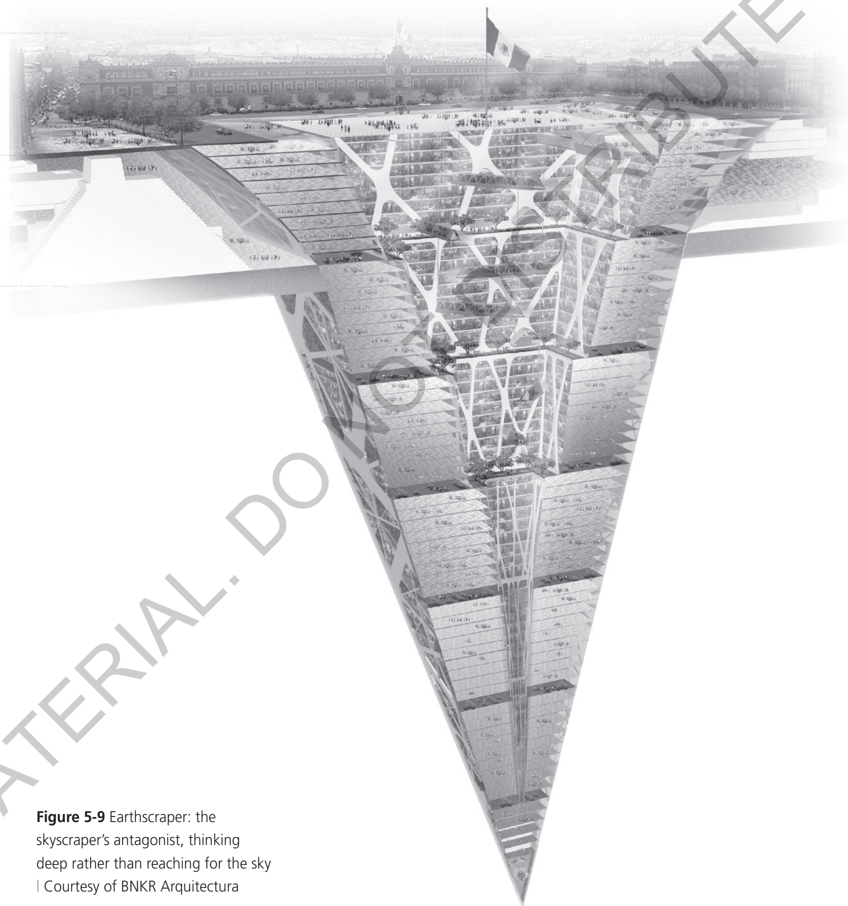

Figure 5-9 Earthscraper: the skyscraper's antagonist, thinking deep rather than reaching for the sky | Courtesy of BNKR Arquitectura

Secondly, we need to ask ourselves what the effect will be of an intervention on the regenerative ecosystem services that the subsoil delivers (see Section 2.3). Apart from this concern, we also need to address the environmental impact of the volume of material that will be generated by the project. A project on the scale of an earthscraper could potentially

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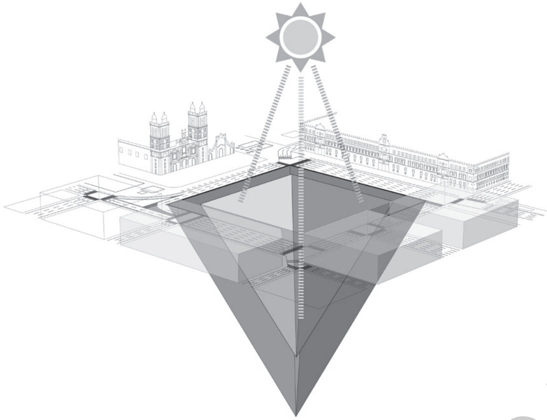

Figure 7-7 Ensuring maximum daylight entry for the earthscraper concept | Courtesy of BNKR Arquitectura

Figure 7-8 Ensuring maximum daylight for plant growth using fibre optics to bring daylight underground | Courtesy of Zerae123, reproduced under CC BY-SA 4.0

to bring daylight into a former underground tramway depot in New York. The Lowline project aims at turning this terminal into an underground park, providing much-needed green public space to the Lower Eastside. Daylight is essential to achieving this, to stimulate plant growth beneath the surface. One of the founding fathers of the project, James Ramsey, a former NASA engineer, found a solution based on satellite technology to bring daylight into an entirely enclosed space. The Lowline Lab demonstrated the proof-of-concept from February 2015 to February 2017, when a mock-up was created to show and study the feasibility of the plan (Lowline, 2017) (Figure 7.8):

> Co-Founder James Ramsey, his team at Raad Studio, and Korea-based technology company Sunportal designed and installed optical devices which track the sun throughout the sky every minute of every day, optimizing the amount of natural sunlight we were able to capture. The sunlight was then distributed into the warehouse through a series of protective tubes, directing full spectrum light into a central distribution point. A solar canopy, designed and constructed by engineer Ed Jacobs, then spread out the sunlight across the space, modulating and tempering the sunlight, providing light critical to sustain the plant life below.

What is intriguing in the technology used above is that both through design and use of fibre optics, the same objective can be achieved. Daylight can penetrate spaces where it cannot enter naturally. This could ultimately prove to be a breakthrough technology when used in underground space design.

Artificial lighting will also play the same role underground as it does above ground. When there is no daylight, artificial lighting is needed to create the right atmosphere for the environment, whether the purpose of that environment is transit, shopping, recreation, working or living. Modern LED technologies

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