Urban Underground Space

Sustainable Property Development in Helsinki

City of Helsinki
Real Estate Department

© City of Helsinki

Author: Ilkka Vähäaho
City of Helsinki, Real Estate Department, Geotechnical Division
P.O. Box 2202, FI-00099, Helsinki, Finland
E-mail: ilkka.vahaaho@hel.fi
www.geotechnics.fi

October 2014

English editing: Key Image Ltd / Howard McKee

Desktop publishing: Recommended Oy / Niina Kummu

Contents

Foreword

The roots of this publication lie in a lecture I gave in 2009 at the World Tunnel Congress in Budapest, Hungary. Following this, the theme has kept me lecturing around the world, mostly in the Far East. Using the City of Helsinki, a forerunner in the field, as a prime example, I have written several papers, given numerous interviews, completed many questionnaires and helped to arrange a number of site visits in order to give inspiration and encouragement to other cities and decision makers on the possibilities of Underground Space Use.

The last time I gave a talk on Underground Space Planning in Helsinki was in 2014 in Nanjing, China. Since Budapest, the paper has been elaborated and widened to cover the development of underground space in the city. After doing so, it is now time to release the paper to a wider audience.

This non-commercial publication is now being updated continuously as an independent on-line publication on the website of the City of Helsinki geotechnics (www.geotechnics.fi).

In my view, the close cooperation that the City of Helsinki has established with the numerous 'partners' involved in planning, financing and designing as well as the actual construction and maintenance of tunnels and underground spaces has perhaps been the most important issue for sustainable underground property development. As much of this work is also carried out unofficially, trust between the parties is central, particularly when developing processes and sharing risks.

I am excessively grateful for the demanding work that so many people have done in the field of Urban Underground Space. My role during the past five years has been more like an 'ambassador' who has strived to advance the long-term sustainable use of underground space.

The countless questions, presentations and discussions with colleagues from different countries and cultures have inspired me to write this paper 'Urban Underground Space: Sustainable Property Development in Helsinki'. For this, I thank them all. I also want to thank my own organization and my family for their support and patience during this process that has lasted much longer than it should have done!

October, 2014
Ilkka Vähäaho
Head of the Geotechnical Division,
the City of Helsinki Real Estate Department

1 Introduction: Geological conditions and challenges in Helsinki - experiences and advice

1 Introduction: Geological conditions and challenges in Helsinki - experiences and advice

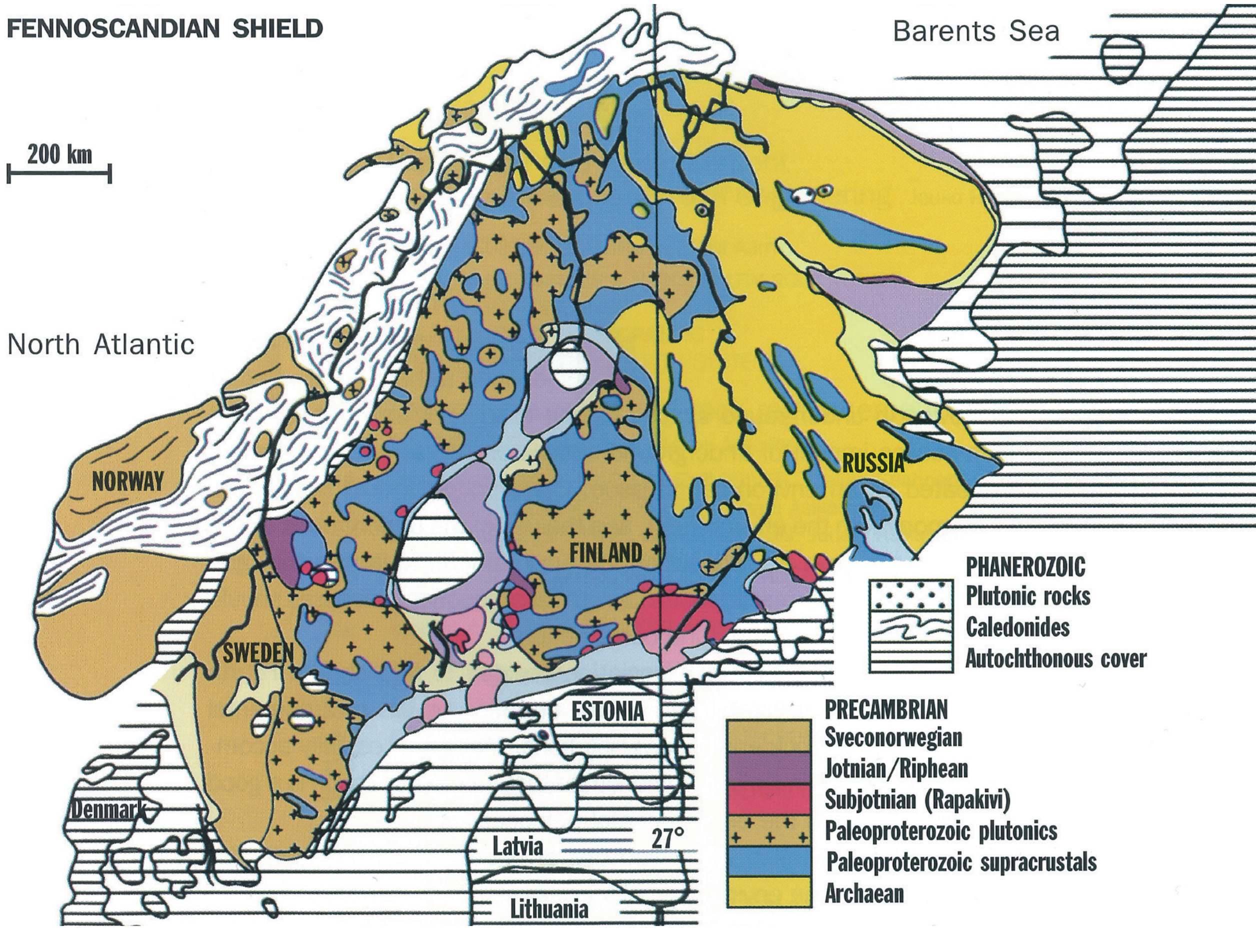
The Drill and Blast method has been proven effective in Finnish conditions. The practice of not using cast concrete lining in hard rock conditions has lowered the cost of tunnelling significantly.

Finland has 320 independent municipalities as of 2014. Helsinki, the capital, is clearly the biggest city in Finland. While the average size of all the municipalities is 950 km², the surface area of Helsinki is only 214 km² including a number of bays, peninsulas and islands. The inner city area occupies a southern peninsula where the population density in certain parts can be as high as 16,500 inhabitants per km².

The Greater Helsinki area is the world's northernmost urban area among those with a population of over one million and the city itself is the northernmost capital of a European Union (EU) member state. Altogether, 1.3 million people - or approximately one in four Finns - live in the area.

Helsinki is located in southern Finland on the coast of the Baltic Sea and has a humid continental climate. Owing to the mitigating influence of the Gulf Stream, temperatures in winter are much higher than its far northern location might suggest with an average in January and February of around −5°C (23°F). Due to its latitude, days last some six hours around the winter solstice and up to nineteen hours around the summer solstice. The average maximum temperature from June to August is around 19-21°C (66-70°F).

Fig. 1. Geological conditions in Finland and Scandinavia (Image: Geological Survey of Finland).



The bedrock quality in Finland is for the most part ideal for tunnelling and for building underground spaces.

Fig. 2. A bare uncovered rock surface 'window' in the Kluuvi underground parking hall in Helsinki (Photo: Ilkka Vähäaho).

Helsinki's landscape is quite flat - the highest natural point is only 60 metres above sea level. One third of Helsinki´s ground is clay with an average thickness of three metres and shear strength of around 10 kPa. The average depth of soil material upon bedrock is seven metres, but varies from 0 to almost 70 metres. The bedrock quality in Finland is for the most part ideal for tunnelling and for building underground spaces since the bedrock mainly consists of old Precambrian rocks (Finnish Tunnelling Association 1997) with only few places where younger sedimentary rocks exist (Fig. 1). This can be observed in Fig. 2 where a typical bare uncovered rock surface is visible. There are no sedimentary rocks in the Helsinki area; however, there are several fracture zones formed by rock block movements that cross the bedrock in the city centre (Saraste 1978). It is important to identify the locations and properties of these zones in the planning and excavation of rock constructions. At early stages of the Svecofennian Orogeny, rock deformations were ductile; later, the rock cooled down and the deformations at the topmost layers became brittle and formed faulted structures. The fault zones were subsequently fractured by weathering, hydrothermal alterations, recrystallization and later movements. Being more fragmented than surrounding areas, the fractured zones have eroded more rapidly and are seen as depressions in the topography. The fractured zones have had a great impact in defining the shoreline of Helsinki city centre (Vänskä and Raudasmaa 2005).

The fractured zones are usually under a thick layer of soil and therefore hard to examine. However, there are signs of movements on nearby rock surfaces which help to locate those zones.

The average price per cubic metre of tunnels and underground spaces in Finland is EUR 100/m3 (including excavation, rock reinforcement, grouting and underdrainage). To date, only the Drill and Blast (D&B) method has been used for rock excavations - the use of Tunnel Boring Machines (TBMs) has not been competitive in Finland so far.

In cases where pre-grouting is needed, it is always carried out since it is practically impossible and much more expensive to achieve a dry underground space later on (Fig. 3).

The reason for the low cost of tunnelling in Finland is due to the practice of not using cast concrete lining in hard rock conditions, effective D&B technology (Fig. 4) and extensive experience of working in urban areas.

The author argues that cast concrete lining was used without any good reason, for example in the Hong Kong MTR West Island Line (Fig. 5) which was under construction during September 2011. Cast concrete lining can mean up to 200% extra costs and is a waste of money in conditions where there are excellent rock materials.

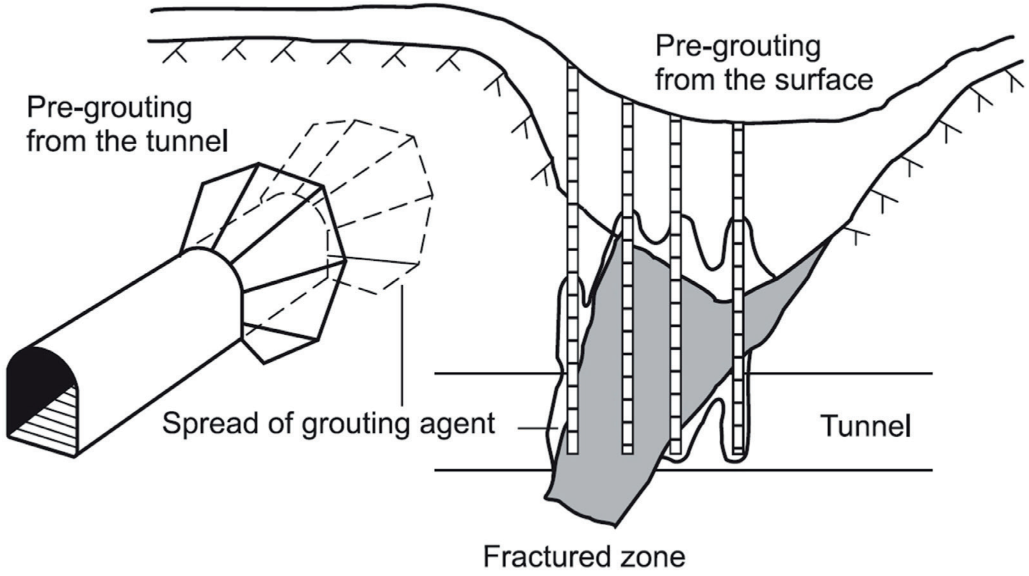


Fig. 3. Pre-grouting is most important because of the conditions in Helsinki (Image: Sandvik Mining and Construction Finland).

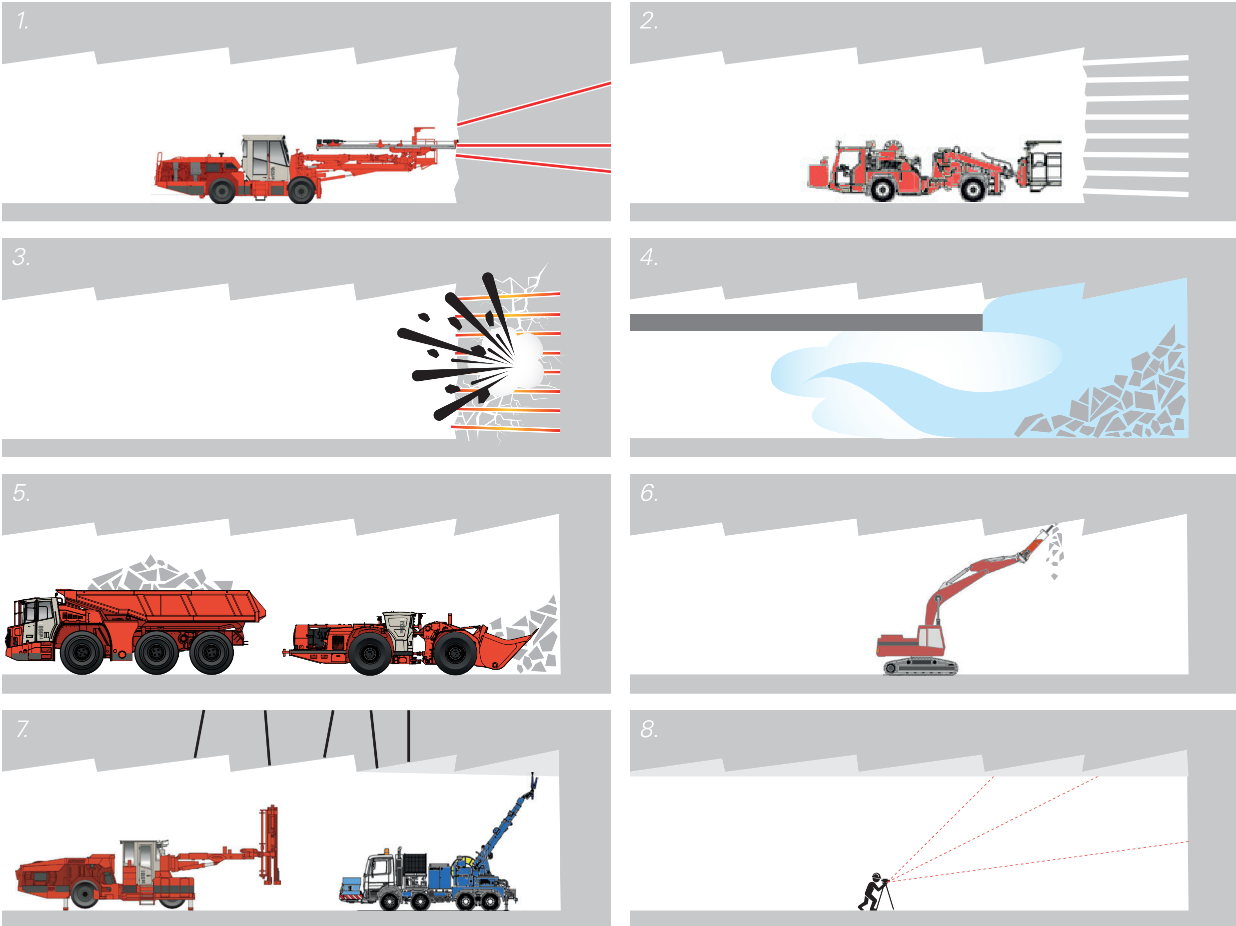


Fig. 4. Drill and Blast method cycle
1. Drilling, 2. Charging, 3. Blasting, 4. Ventilation,
5. Loading, 6.Scaling, 7 .Reinforcements, 8. Measuring
(Image: Adapted from Sandvik Mining and Construction Finland Oy).

Fig. 5. Hong Kong
MTR West Island Line,
September 2011
(Photo: Ilkka Vähäaho).

References

Finnish Tunnelling Association MTR-FTA, 1997, The Fourth Wave of Rock Construction, Environmentally Responsible Underground Design, Engineering and Application, WSOY, ISBN 951-96180-2-3, Porvoo, Finland

Saraste A., 1978, 'Kallioperäkartta' (Bedrock Map) GEO 10K, 1:10.000, City of Helsinki, Real Estate Department, Geotechnical Division

Vänskä P. and Raudasmaa P., 2005, Helsingin keskustan kallioruhjeet (Fracture zones in the bedrock of Helsinki City Centre), City of Helsinki, Real Estate Department, Geotechnical Division, Publication 89, (in Finnish with English abstract)
www.hel.fi/static/kv/Geo/Julkaisut/julkaisu-89.pdf

The History of
the Underground
Master Plan of Helsinki

2 The History of the Underground Master Plan of Helsinki

The process of drawing up the Underground Master Plan was prepared by the City Planning Department. The steps were according to the following decision-making history (Helsinki City Council, 2010) and Narvi (2012):

1980 ······ 2004

I **Since the 1980s**, the City of Helsinki has maintained an underground space allocation plan.

II **In the early 2000s**, a need arose to draw up an underground master plan for the entire city's underground facilities.

III **On 9 December 2004**, the Helsinki City Planning Committee approved a set of planning principles for preparing the Master Plan. *

2005

IV **On 4-22 April 2005**, a participation and assessment plan was presented, which indicated the content of the planning work and the wider consultation process.

V **In 2005**, an open discussion event was arranged for anyone interested; many in-depth discussions were held with different interests.

2006

VI **On 19 January 2006**, prior to drawing up the draft Master Plan, discussions were held with the relevant public authorities based on the participation and assessment plan.

2007

VII **At the start of 2007**, at the draft plan finalisation stage, representatives from the water and energy utilities 'Helsingin Vesi' (Helsinki Water company) and 'Helsingin Energia' (Helsinki Energy company) were separately consulted on the plan's content. A statement was also requested from the Helsinki Police Department, the Helsinki Military Province Headquarters, the Safety and Operational Readiness Division of the City's Administration Centre and the Helsinki City Rescue Department on whether a thematic map showing technical services could be published.

* **In accordance with the decision of 9 December 2004, the planning principles were**

1. The Master Plan will cover the whole of the city at a print scale of 1:10,000 south of Pasila and 1:20,000 elsewhere.
2. The Master Plan may have legal effect in part, but is mainly without legal consequence. The areas will be determined later (The result was that the entire Master Plan does, in fact, have legal effect. Comment by Ilkka Vähäaho).

3. Connected to the Master Plan will be an underground space allocation plan, which will support the City's underground facilities management system and the exchange of information.

4. The Master Plan will include space allocations for various facilities: transport, civil defence, sports, various installations and establishments, water and energy supply, parking, storage, waste management and similar.

5. The aim is to achieve joint use of facilities (e.g. use of civil defence facilities in normal circumstances; multi-purpose tunnel network; shared parking).

6. Current functions could be studied to see if they can be located underground if this would release land above ground or otherwise improve matters.

7. Underground spaces are to be located mainly in bedrock. Bedrock resources are to be investigated in sufficient detail.

8. Bedrock resources are to be reserved mainly for uses that are for the common good.

9. Bedrock resources below recreational areas may be used if this does not present problems for such recreation or for valued natural environments.

10. Planning will support arrangements for underground parking in new residential areas with due consideration of the potential for its implementation.

2008

VIII **In May 2007**, following its examination by the Helsinki City Planning Committee, the draft Underground Master Plan of Helsinki was distributed for comments. The aim was that in autumn 2007, the proposed Master Plan could be displayed to allow any objections to be made and distributed for comments, and that the proposed Underground Master Plan would then proceed for a decision by the City Council at the end of 2007.

IX **On 11 December 2008**, the Helsinki City Planning Committee examined the statements and views given on the draft Underground Master Plan and decided that a revised draft should be resubmitted for its consideration.

2009

X **On 17 December** 2009, following the examination by the Helsinki City Planning Committee, the proposed Underground Master Plan of Helsinki and the statements, objections, views and responses given on it were submitted for approval by the City Council.

XI **On 22 and 29 November 2010**, the City Board considered the proposal.

2010

XII **On 8 December 2010**, the City Council approved the Underground Master Plan of Helsinki (except for the reservation of the Pitkäkoski fresh water treatment plant, against which an appeal was made to the Administrative Court, but was rejected on 18 November 2011).

References

Helsinki City Council, 2010, 'Helsingin maanalaisen yleiskaavan hyväksyminen' (Approval of the Underground Master Plan), Decision number 16 (Khs 2009-237), 8 December 2010, Decision-making history from the Appendices (in Finnish) **www.hel.fi/static/helsinki/paatosasiakirjat/Kvsto2010/Esityslista21/Halke%20 2010-12-08%20Kvsto%2021%20El.html**

Narvi, S., 2012, Underground planning specialist at Helsinki City Planning Department (RET), Interview 24 September 2012

3 Key Considerations for the Use of Underground Space

3 Key Considerations for the Use of Underground Space

▼ *Fig. 6. Interior of the Temppeliaukio Church, which was designed by architects and brothers Timo and Tuomo Suomalainen and opened in 1969. It is also known as the Rock Church (Photo: Juha-Pekka Järvenpää).*

There are 10,000,000 m³ underground spaces in Helsinki for parking, sports, oil and coal storage, the metro and so on. There are also more than 400 premises, 220 km of technical tunnels, 24 km of raw water tunnels and 60 km of 'all-in-one' utility tunnels for district heating and cooling, electrical and telecommunications cables and water.

It is perhaps easier to comprehend these statistics by comparing Helsinki´s surface area and the total area of underground spaces that are in use. On average, under each 100 m² of surface area there is 1 m² of underground space. Consequently, there are still many underground resources for future needs existing within the whole city area (Vähäaho 2012).

The fundamental idea of district heating and cooling is to use local resources that otherwise would be wasted (Helsinki Energy, 2013).

Some unique examples of the use of underground spaces are shown in Figs 6 and 7. According to Suomalainen (2001), "The church hall was excavated using a certain system: first a large pit was made while leaving a layer of one or two metres unexcavated. The last few metres were then excavated very carefully while planning at the same time how to accomplish an acoustically suitable surface as well as some angles and 'rough spots' for the sake of outer appearance. The background wall of the altar was left last because it was the most important part. The final stages of the excavation went very well. As we were roaming round the hall we began to feel the strain disappear and knew then that the work would go well to the end. However, we had a shock when the foreman called us – he was really upset. The wall where the altar was to be situated had crashed down. Everything was ruined!

We told him to remove the loose pieces of rock and we would come and have a look immediately. When we arrived in the church we saw our altar. It had a really fine surface. We thought that just by placing a cross or crucifix on it, it would be perfect!

The altar is situated so that the sun shines during the service while the sun wedge comes in through the glass roof onto the altar wall."

▲ *Fig. 7 Underground Swimming Pool in Itäkeskus, which can accommodate 1,000 customers at a time and can be converted into an emergency shelter for 3,800 people if necessary (Photo: City of Helsinki Media Bank).*

Unlike in the Netherlands where underground spaces are the 'stand-alone' type, in Helsinki the existing and new underground spaces and tunnels are connected to one underground city (De Onderbouwing 2014).

Alonso (2013) discovers that "there are two Helsinkis, the city that we all know and another Helsinki underground. Many passages and facilities are 'hidden' in the underground of the city, like the Itäkeskus Swimming Hall, one of the world's nicest sport facilities".

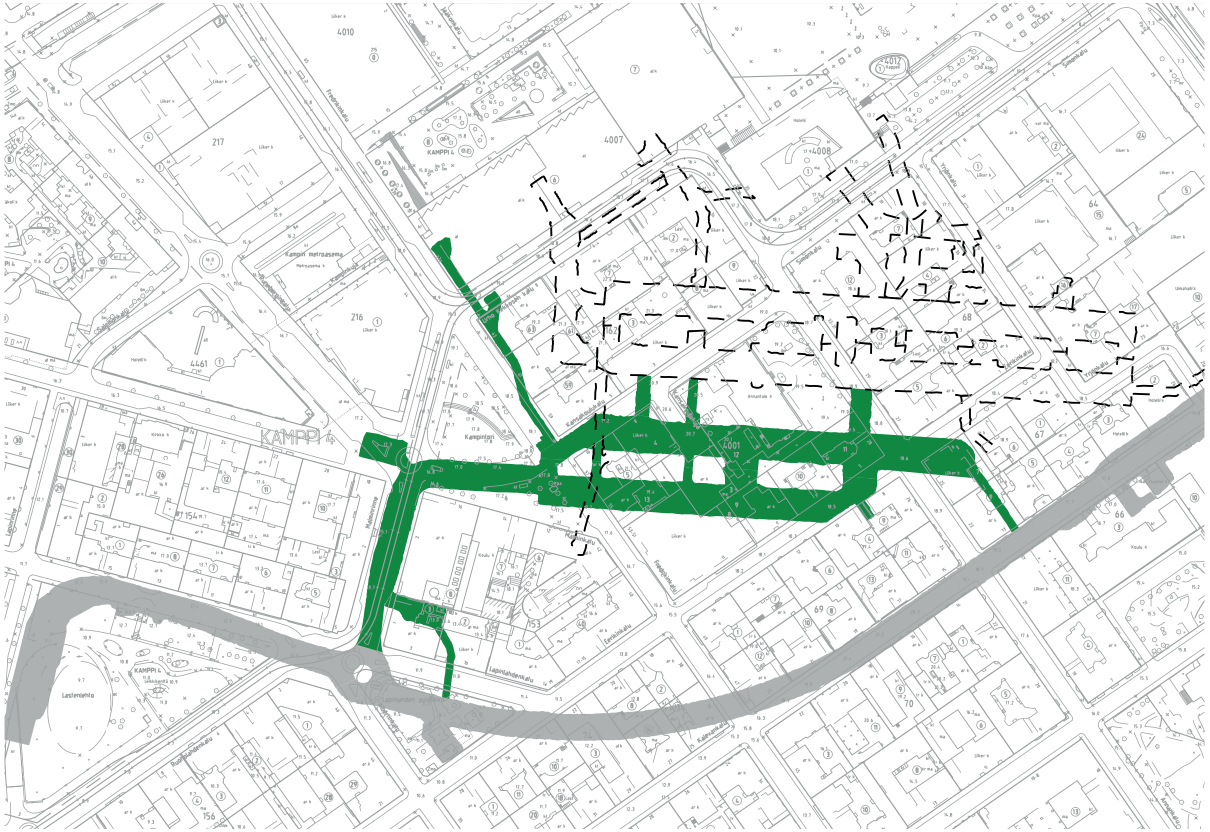
In Finland, property owners must include civil defence shelters in buildings of at least 1,200 m^2. Today, however, it is more common to have an underground defence shelter that serves some other purpose during 'normal times'. In reality, such spaces are now designed to meet the needs of normal times with 'just' strengthening for 'exceptional times'. This enables property owners to transform the swimming pool, for example, into a defence shelter quickly and economically should the need arise. The underground swimming pool in Itäkeskus (Fig. 7) has facilities on two floors and can accommodate some 1,000 customers at a time. The hall attracts some 400,000 customers a year. Quarried out of solid rock, the hall can be converted into an emergency shelter for 3,800 people if necessary.

Mashable Inc. (2014) reports that "The 20th century was inarguably the era of the skyscraper. Cities across the world, out of necessity and sheer showmanship, expanded up, up, up. But the 21st century is seeing a new trend of going underground instead. Urban areas such as Helsinki and Paris are looking to expand below the surface for resource, retail and travel purposes."

Finns are used to having lots of green areas around them - even in urban areas. This is a good reason for using underground space as a resource for those functions that do not need to be on the surface. Safety is also a major aspect for using underground space instead of building infrastructures on the surface. Earth tremors in Finland are normally recorded up to a magnitude of 3. Probably the greatest damage was to the church in Paltamo, which was badly damaged in the 1626 earthquake that had a calculated magnitude of 4-5 (University of Helsinki - Institute of Seismology 2006). Although seismic risks are not a major threat in Finland, underground solutions would mitigate their effects even more.

As the city structure becomes denser, more facilities suited for different purposes are being placed underground. There is also a growing demand to connect underground premises to each other to form coherent and interrelated complexes. The growth in underground construction and planning, and the demand to coordinate different projects have led to a requirement to prepare an underground master plan for Helsinki. Having legal status, the plan also reinforces the systematic nature and quality of underground construction and the exchange of information related to it. The Underground Master Plan is a general plan that allows the control of the locations and space allocations of new, large significant underground rock facilities and traffic tunnels, and their interconnections (Helsinki City 2009). The Helsinki Underground Master Plan is administrated by the Helsinki City Planning Department. The Real Estate Department's Geotechnical Division qualified the areas and elevation levels in Helsinki that are suitable for the construction of large, hall-like spaces. Underground resources play an extremely important and central role in the development of the city structure of Helsinki and the adjoining areas, helping to create a more unified and eco-efficient structure (Figs. 8 and 9).

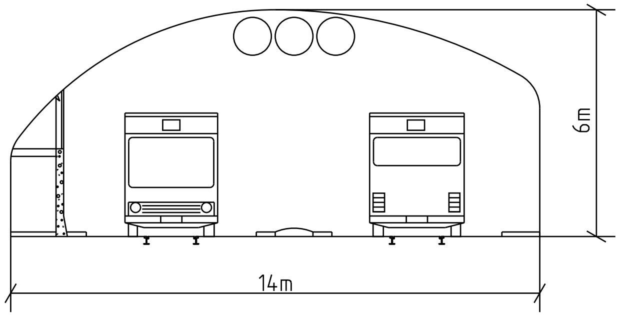
Underground planning enhances the overall economy efficiency of facilities located underground and boosts the safety of these facilities and their use. "In simple terms, underground facilities can be thought of as providing the ultimate 'green roof'. Facilities placed fully underground (once constructed) do not impact the surface aesthetic

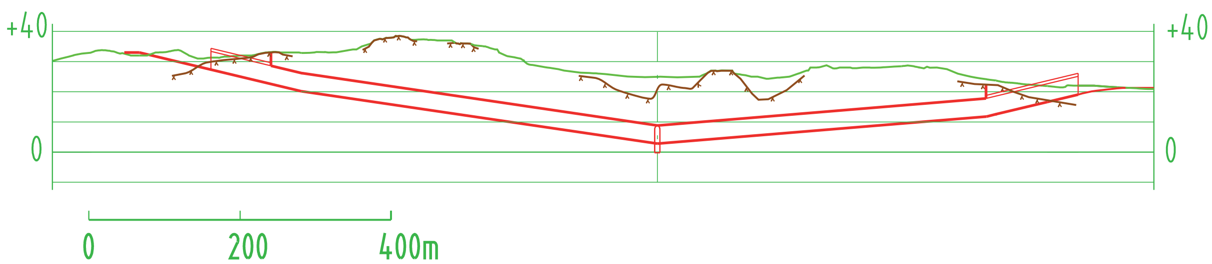


▲ *Fig. 8. Example of the Development of the City Structure of Helsinki where an old car park (shown with a dashed line) is connected to an extension and a new City Service Tunnel (Image: Adapted from Helsingin Väylä Oy, a company owned by the City of Helsinki).*

and can provide natural ground surfaces and flora that maintain the natural ecological exchanges of thermal radiation, convection and moisture exchange” (Sterling et al. 2012).

Helsinki has developed a dedicated Underground Master Plan for its whole municipal area, not only for certain parts of the city. It has been claimed by some non-Finnish experts that the favourable characteristics of the bedrock and the very severe winter climate conditions have been the main drivers for this development. While rock material is one of them, there are other main drivers heading the list over winter, such as the Finnish need to have open spaces even in the city centre, the excellent and long-lasting cooperation between technical departments and commercial enterprises as well as the small size of Helsinki. It is among the smallest by area and clearly the biggest by population in Finland.





► *Fig. 9. The ‘Jokeri 2’ Central Park Tunnel Plan for Public Transport connecting two residential districts. Elevations are with reference to mean sea level in metres (Image: City of Helsinki).*

References

Alonso R., 2013, Helsinki underground city ('Helsinki ciudad subterranean'), 'Itäkeskus' Swimming Hall, Video (subtitled in English)
www.youtube.com/watch?v=mf7_NDQ0ek4&feature=player_embedded

De Onderbouwing, #18, May 2014, Publication of the Dutch Underground Space Association Nederlands Kenniscentrum voor Ondergronds Bouwen en Ondergronds Ruimtegebruik (COB), Helsinki Zwemmen in een schuilkelder (Helsinki Swimming in a shelter), p. 10 (in Dutch)
www.cob.nl/fileadmin/user_upload/Documenten/PDF/De_Onderbouwing/Onderbouwing18-mei2014-web.pdf
The complete article on the COB-website
www.cob.nl/verdieping/verdieping-mei2014/orde/zwemmen-in-een-schuilkelder.html

Helsinki City, 2009, The Helsinki Underground Master Plan, Brochure, Helsinki City Planning Department
www.hel2.fi/ksv/julkaisut/esitteet/esite_2009-8_en.pdf

Helsinki Energy, Annual Report 2013, District Heating and District Cooling
www.helen.fi/en/Annual-Report/Annual-Report-2013/A-Year-in-Helen-Group/The-business-year/District-Heating-and-District-Cooling/

Mashable, Inc., 2014, Underground Cities: The Next Frontier Might Be Underneath Your Feet,
http://mashable.com/2014/02/21/underground-cities/

Sterling, R., Admiraal, H., Bobylev, N., Parker, H., Godard, J.P., Vähäaho, I., Rogers, C.D.F., Shi, X., Hanamura T. 2012, Sustainability Issues for Underground Space in Urban Areas. *Proceedings of the ICE - Urban Design and Planning*, Volume 165, Issue 4, December 2012, Thomas Telford Ltd., pp. 241-254, DOI: 10.1680/udap.10.00020

Suomalainen, T., 2001, 'Kalliosta Temppeliksi' (From Rock to a Temple). Production House Oy / YLE 2001. TV program broadcast on YLE Teema on 14 July 2014, Finland, (in Finnish).

University of Helsinki - Institute of Seismology, 2006
www.helsinki.fi/geo/seismo/english/observation/index.html

Vähäaho I., 2012, Keynote lecture, 0-land_use: Underground resources and master plan in Helsinki, *Proceedings of the 13th World Conference of the Associated research Centers for the Urban Underground Space*, Advances in Underground Space Development, 7-9 November 2012, Singapore, pp. 31-44
www.isrm.net/conferencias/detalhes2.php?id=3063&show=conf

4 Planning for the Use of Underground Space in Finland (Helsinki, Tampere, Oulu), Estonia (Tallinn) and Russia (Saint Petersburg)

4 Planning for the Use of Underground Space in Finland (Helsinki, Tampere, Oulu), Estonia (Tallinn) and Russia (Saint Petersburg)

Space allocations for long-term projects, such as traffic tunnels, must be maintained for future construction. The same applies to those resources that are worth conserving for future projects.

The exploitation of such resources must be carried out according to plan since excavating bedrock is a 'one-off action' (an action that can only be performed once). Underground master planning in **Helsinki** today is a significant part of the land-use planning process (Fig. 10).

When planning and carrying out new construction projects, it is important to ensure that the space reservations for public long-term projects, such as tunnels and ducts for traffic and technical maintenance, are retained for future construction. Similarly, the use of the valuable and unique rock and ground must be practical and exploited without wasting any future resources (Kivilaakso 2013).

The City of Helsinki has also reserved rock resources for unclassified future use for the construction of as yet unnamed underground facilities. The aim is to identify good sites for functions that are suitable for locating underground, and which would also reduce the pressures on the city centre's rock resources. The suitability of rock areas for different purposes will be studied when preparing town plans. There are now some 40 unnamed rock resource reservations without a designated purpose with an average area of 0.3 km^2. Unnamed reservations have a total area of almost 14 km^2, representing 6.4% of the land area of Helsinki. When selecting these resources, the survey took into account their accessibility; the present and planned ground-level uses of these areas; traffic connections; land ownership; and possible recreational, landscape and environmental protection values so the selection of unclassified resources is both purpose- and rock-resource driven (Vähäaho 2011a).

'Greater Helsinki Vision 2050' (2008) was the name of an International Ideas Competition to visualise the future twin city, **Helsinki-Tallinn** (with a population today of 1.7 million). The winner of the competition also proposed a new, fixed connection between the capitals by an 80-kilometre subsea tunnel, which would generate huge potential for them to become a true twin city – 'Talsinki'!

According to the Twin-City Scenario (2013), "By 2030, the twin city will be formed as a closely integrated joint labour area". Kalliala (2008) envisages future living in the northern metropolitan twin city. The differences in the quality of social services in Helsinki and Tallinn will diminish significantly. 'Talsinki' will become a major development centre in northern Europe capable of competing with Stockholm and Copenhagen and organising the Olympic Games. The construction of the tunnel between the capitals will seem as a logical step for further integration of city space and the surrounding regions.

Both capital areas have grown enormously over the last 20 years. The 80 kilometre-wide Gulf of Finland separates the cities and restricts the movement of people and goods. The envisaged tunnel would be a possible future extension of the Rail Baltica rail link, which is a project to improve north–south connections among EU Member States (Keinänen 2009). This project has already been accepted by the Council of the EU as a first priority EU project.

The bedrock construction conditions between Tallinn and Helsinki were discussed by Ikävalko et al. (2013). Its focus was to provide an overview of the geological and geotechnical properties of the construction environment, and to describe the possible difficulties in building the world's longest undersea tunnel. The information is based on a cooperation project between the City of Helsinki, the Geological Survey of Finland and the Geological Survey of Estonia.

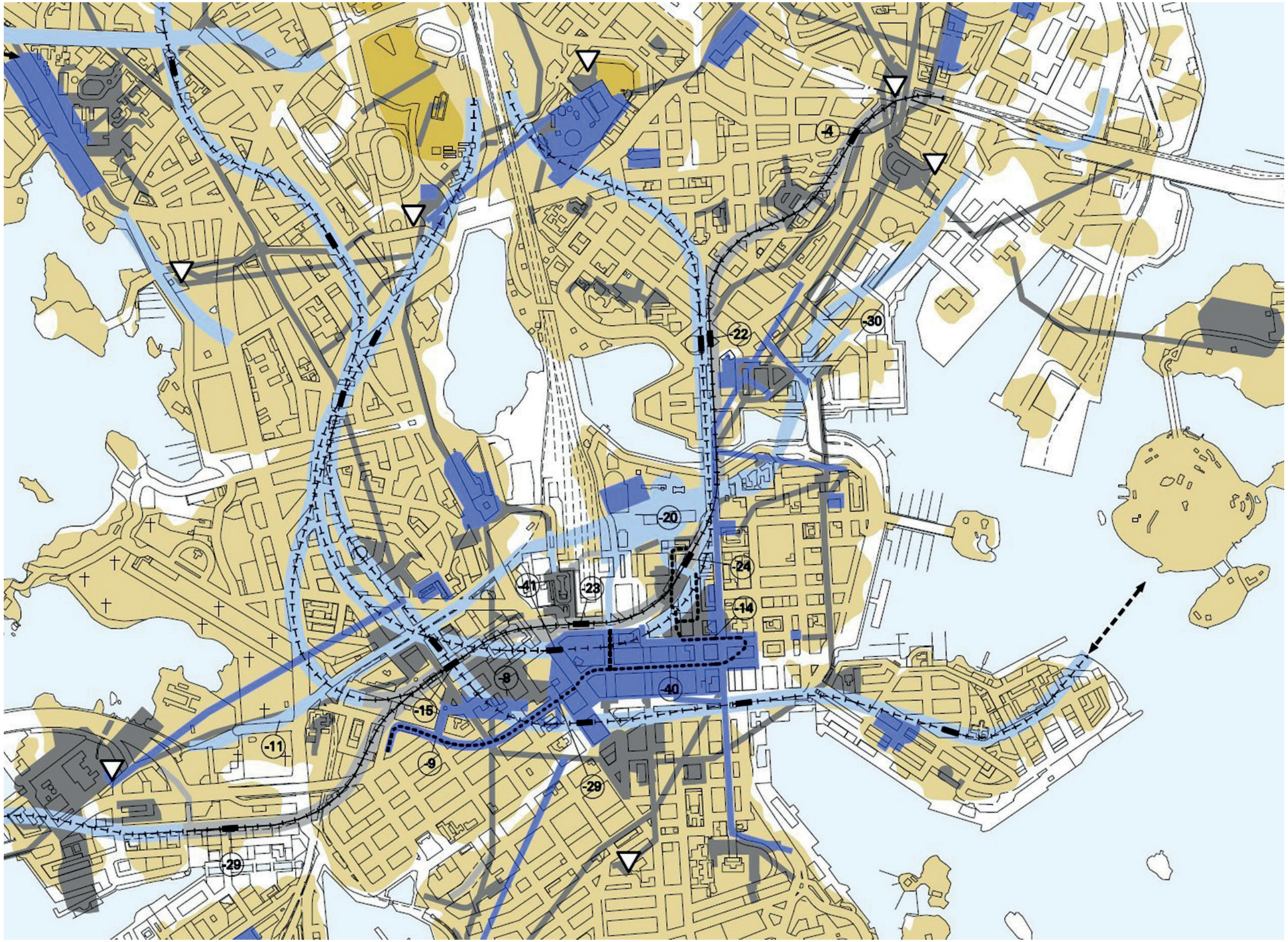
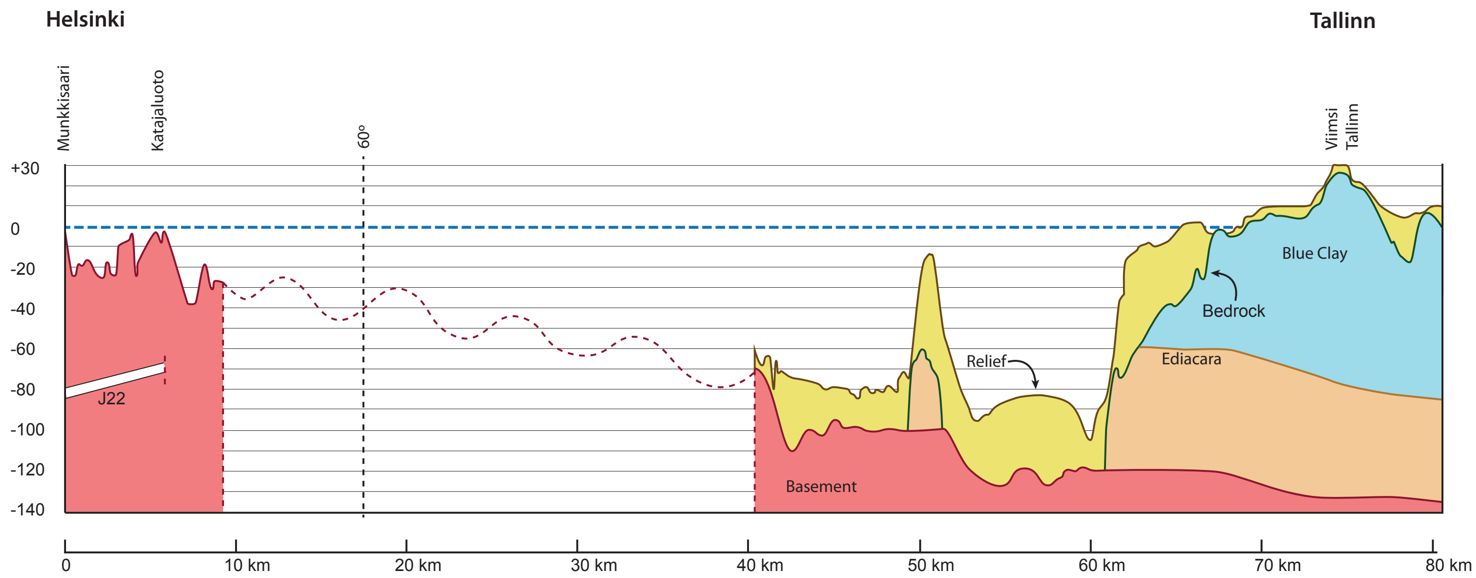


Fig. 10. Extract of the Helsinki Underground (UG) Master Plan (Image: Helsinki City Planning Department).

- Reserved routes for new tunnels
- Reserved for future UG spaces
- Existing tunnels and UG spaces
- Reserved for future use (not designated)
- Rock surface less than 10 metres from ground level

► *Fig. 11. A longitudinal section through the Gulf of Finland from Helsinki to Tallinn according to the constructed 3D model. J22 is the cleaned wastewater outlet tunnel which was built in the 1980s and extends from the Viikinmäki wastewater treatment plant. The tunnel measures 17 km, of which 8 km is in the sea area. Elevations are with reference to mean sea level in metres (Image: Geological Survey of Finland).*

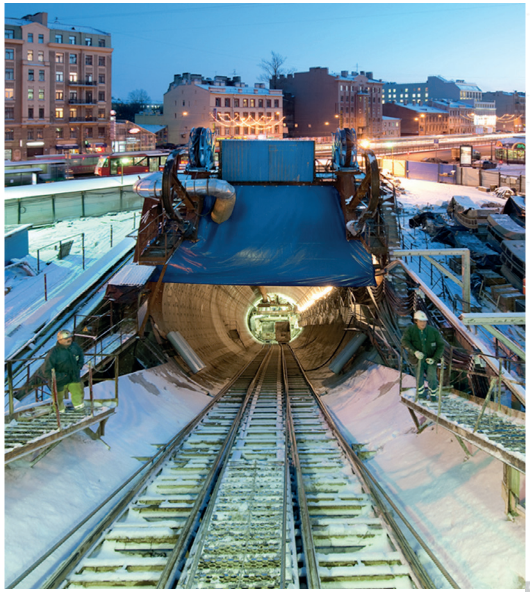


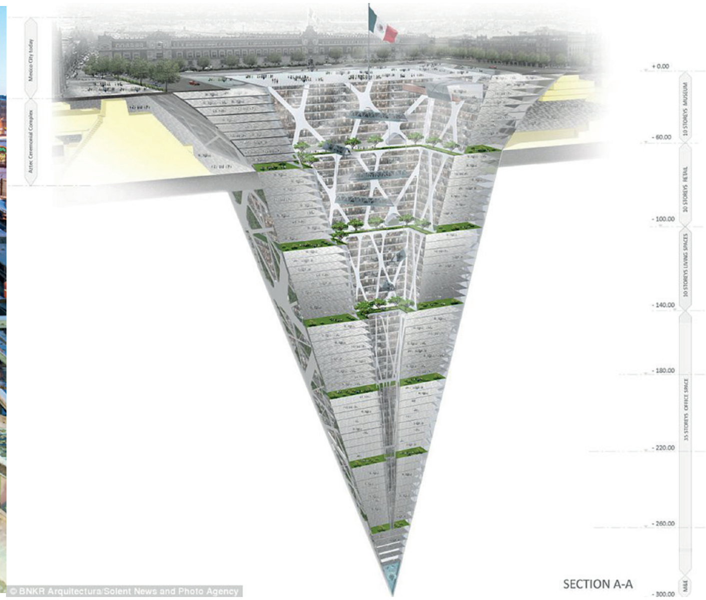
The tunnel area is located at the border between the East European Platform and the Fennoscandian Shield. In the Helsinki area, the exposed old Precambrian hard bedrock is overlain with a thin layer of loose Quaternary sediments. Near Tallinn, the old crystalline basement meets the 1.2 billion-year younger sedimentary rocks. The tunnelling project will be challenging, especially in the area of its southern end due to the limited experience of the conditions near the interface between these two formations.

The possible methods for tunnelling are D&B techniques, specific to hard rock conditions such as in Finland, and the use of TMBs as an alternative at the Estonian site.

Geological data of the Finnish area are mainly obtained based on mapping made in the coastal areas and islands. More detailed data are gathered in some undersea sewage tunnel projects. The description of investigation and geological setting of the Estonian area is based on the report by Suuroja et al. (2012). In the work, the data were collected from different databases of a predetermined area within the Estonian Exclusive Economic Zone. On the basis of the data, a three-dimensional (3D) model of the main geological units was constructed and an explanation of the physical properties of the soil and bedrock units was given.

The geological longitudinal section consists of two principal elements in the platform area: the Precambrian crystalline basement and sedimentary layers. The crystalline basement contains younger formations of the Subjotnian rapakivi granites and remnants of Jotnian sediments and diabases. The whole crystalline basement has been eroded quite flat over long-lasting continental erosion and dips gently to the south below Ediacaran rocks at a depth of 130-140 metres below sea level near the coast of Estonia (Fig. 11). In the sea area there is still a 30 km stump without any geological data in the City of Helsinki Database (Soili). Soili is introduced in detail by Vähäaho (1999), Anttikoski et al. (2002) and Vähäaho et al. (2011). Mapping and geotechnical data management in urban areas at the European level is discussed by Vähäaho (2007).





▲ *Fig. 12. The first ever inclined tunnel construction at an angle of 30 degrees with TBM in Saint Petersburg (Photo: Herrenknecht AG).*

◀ *Fig. 13. Underground vision from Mexico City - an 'Earth-Scraper' - in the case where space is needed yet heritage does not allow skyscrapers (Image: Mail Online News, 2011).*

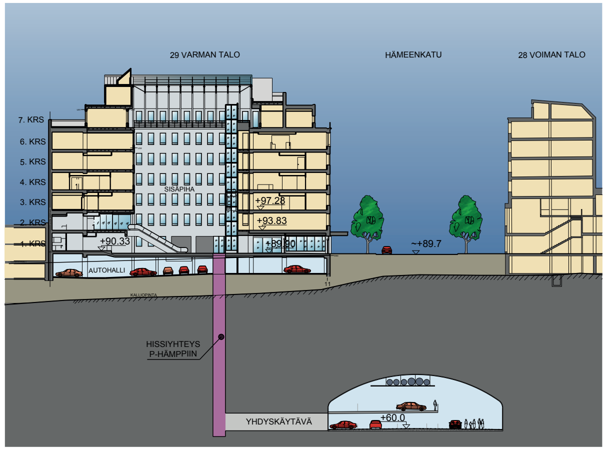
The Quaternary sediments on the Estonian side are water-saturated loose and soft deposits, and thus pose a challenge for tunnelling. In buried valleys, the Quaternary sediment thickness may reach up to 150 metres. It is a construction environment that has to be avoided due to high groundwater pressures as should the rocks of the Ordovician system. The blue clay stratum, however, is a steady aquitard and is a good environment for tunnelling. The Ediacaran water-saturated silt and sandstones, reaching up to 60 metres in thickness and an important source of water supply for both Tallinn and its surroundings, poses a significant challenge for tunnelling. The crystalline basement consisting of very hard solid rocks is a firm and protected environment for the tunnel constructions. Many surveys need to be carried out in order to locate the bedrock surface, a process that will begin with seismo-acoustic sounding during the first phase and by drilling during the second. Weakness zones will also need to be located. As the project is still at the consideration stage, the main conflicts surround the fundamental question of the need for the tunnel. The first step to be taken is a competition for a pre-feasibility study of the Helsinki-Tallinn fixed link arranged by the North Estonian Harju County Government et al. (2014).

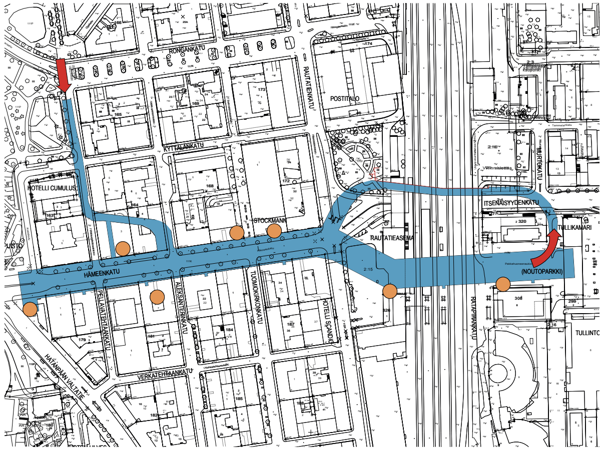
An escalator shaft in **Saint Petersburg** was built during 2009-2012 into a soft and challenging ground to service the Obwodny Canal station located at a depth of 60 metres - Saint Petersburg is the most northern megacity in the world and its metro system is one of the deepest. The station was not put into service for a long time due to the problems associated with building the escalator accesses. The major challenge during the TBM tunnelling of the 105-metre-long escalator shaft was its 30-degree gradient. The first ever inclined tunnel construction at an angle of 30 degrees with TBM was introduced to Finnish tunnelling specialists in Saint Petersburg by Sergei Alpatov (2013) from the Association of Underground Builders in Russia. The solution was an Earth Pressure Balance (EPB) Shield with a diameter of 10.69 metres designed and developed by Herrenknecht AG. This new technology for constructing inclined tunnels in soft ground might also be one option for the possible Tallinn station in Estonia.

Vanjoki (2012), an individual multi-contributor and former member of Nokia Group's Executive Board, suggests that if the Guggenheim museum comes to Helsinki it will have to be built underground. Would the Earth-Scraper presented in Fig. 13 (Mail Online News 2011) then be a model for the disputed museum venture? The State of Finland will, in turn, participate in the architectural competition of the venture should the museum be built of wood - an interesting challenge. In any case, the general opinion has to be favourable for the new museum.

According to Hiltunen (2013), **Tampere**, the third most populated city in Finland and the biggest inland city in the Nordic countries, has already started a new era in the use of underground space. The new parking solution is presented in Fig. 14 and the future vision of Tampere Central Arena (2011) in Fig. 15.

The new parking solution for 972 cars in Tampere received the European Parking Association (EPA) Award 2013. It has also been nominated the best new parking house in Europe and the best indoor lighting project in Finland 2013. The planning of this parking cave started in 2007 and building permission was received in 2009, the building period was 2009-2012 and the costs were EUR 75 million. The parking cave 'P-Hämppi' (2012) lies beneath Tampere's city centre and is 600 m long, 30 m wide and 12 m high. It has two (two-way) entrances for cars and 14 elevators at 7 different locations.





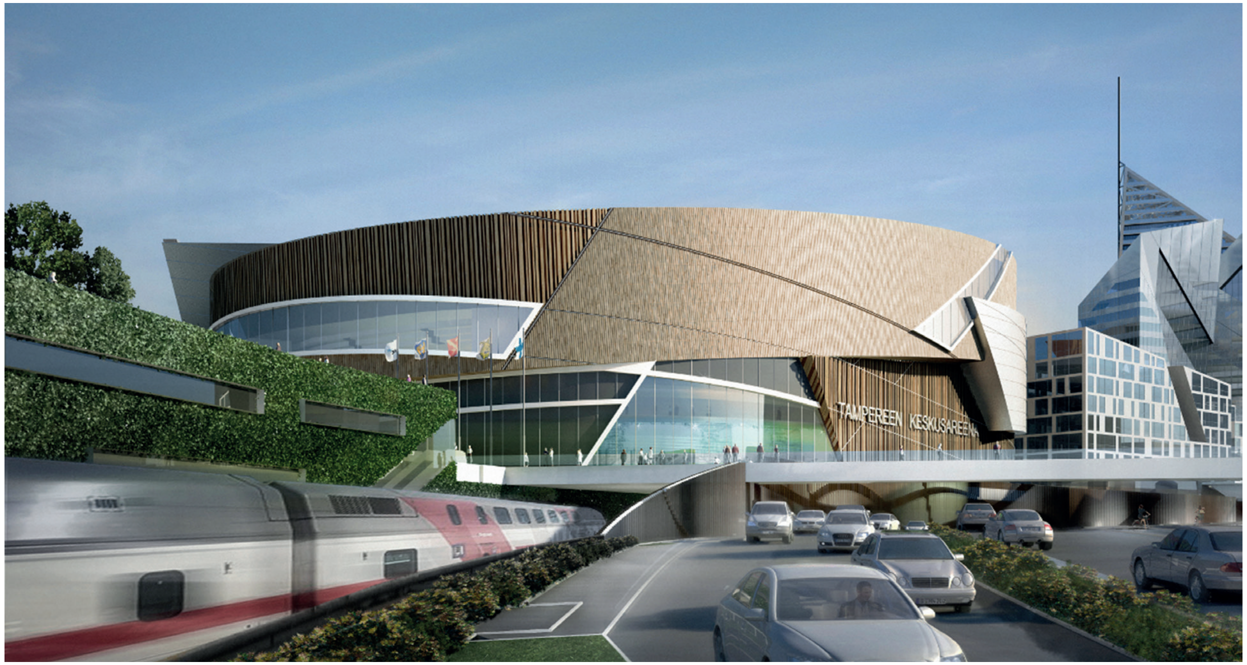
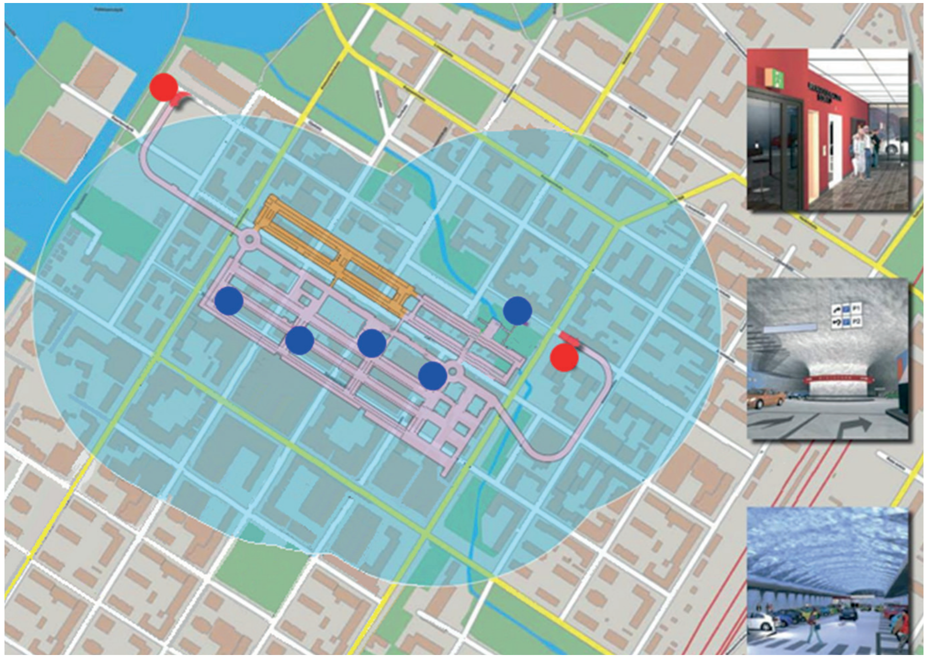


Fig. 14. The new parking solution, called 'P-Hämppi', is located below the main street in Tampere (Image: architectural firm Aihio Arkkitehdit Oy).

Fig. 15. Future Tampere with the Central Arena constructed over the main railway station housing several facilities on different levels (Image: Tampere Central Arena).



▲ *Fig. 16. Kivisydän (Stoneheart)*
The underground parking cavern in Oulu
● *lift*
● *car access*
(Image: City of Oulu and Oulun Pysäköinti Oy).

Oulu, the capital city of northern Finland, has also started to 'go underground' (Vähäaho 2013). The vitality of the old market place and the central city area is ensured by means of modern and convenient underground parking facilities together with commercial and public services (Fig. 16). The name of the new parking cavern is 'Kivisydän', translated as Stoneheart. Its current capacity is 900 parking lots but can be extended up to 1,500. It can also be converted into an emergency shelter for 3,000 people if necessary. There are seven accesses for cars and 21 customer lifts (giving entry either to the streets or the nearby buildings). The temperature target is +15°C year around. The total cost is EUR 73.5 million, from which some 60% is covered by compulsory parking lots (zoning related) and the remainder (40%) by a loan taken out by a company owned by the City of Oulu (Isoherranen and Manninen 2014). Underground car parking makes it possible to develop the city centre blocks and park areas, and to expand the Rotuaari pedestrian area. Transferring service traffic underground will also considerably improve the activity, cosiness and safety of the expanding pedestrian area in the city centre. In all, it was an extensive project - the City of Oulu started to study underground parking in 1998 with the first call for bids in 2009. Construction work started in June 2012 and should be completed by the end 2015.

References

Alpatov S., 2013, Site visit to Saint Petersburg Metro construction for the Finnish Tunnelling Association, 3 September 2013

Anttikoski U., Korpi J., Raudasmaa P., Vähäaho I., 2002, Geotechnical Database of Helsinki in City Planning Process, *Proceedings of the 2nd Int. Conference on Soil Structure Interaction in Urban Civil Engineering*, Zurich, Switzerland, 2002, pp. 317-322

'Greater Helsinki Vision 2050', 2008
www.helsinginseutu.fi/hki/HS/The%20Region%20of%20Helsinki/News/Newsarchive?id=16538&office=HS&lang=en&period=2008&path

Harju County Government, City of Helsinki, City of Tallinn, 2014, Invitation to tender for a pre-feasibility study of Helsinki-Tallinn fixed link. 3 April 2014

Hiltunen, M., 2013, 'Maanalainen Tampere on autoilijan: Pysäköinti osana kaupunkikeskustan kehittämistä' (Underground Tampere is for driver: Parking as a part of downtown development), The Day of Underground Possibilities, MTR-FTA, 11 April 2013, Helsinki, Finland (in Finnish)
www.getunderground.fi/getfile.ashx?cid=205375&cc=3&refid=20

Ikävalko, O., Vähäaho, I. and Suuroja, S., 2013. Soil and bedrock conditions to be expected in Tallinn – Helsinki tunnel construction. Strait Crossings 2013. June 16-19, Bergen, Norway, pp. 790-799
www.vegvesen.no/Fag/Publikasjoner/Publikasjoner/Statens+vegvesens+rapporter/_attachment/514239?_ts=140a4ee85f0&fast_title=svv+rapport+231.pdf

Isoherranen J., Manninen L., 2014, Oulun keskusta saa kivisydämen (City Centre of Oulu is getting a Stoneheart), Kuntatekniikka 4/2014, KL-Kustannus Oy (in Finnish)
http://lehti.kuntatekniikka.fi/

Kalliala M., 2008, Talsinki Island, A 21st Century Pragmatic Utopia, Master´s Thesis in Architecture, Helsinki University of Technology

Keinänen O., 2009, From fantasy to vision: towards planning of Helsinki-Tallinn railway tunnel, *Proceedings of Get Underground – Underground Space Seminar / Rock Engineering Seminar*, Finnish Tunnelling Association MTR-FTA / Finnish National Group of ISRM, 4-5 November 2009, Helsinki, Finland, pp. 61-68

Kivilaakso E., 2013, 'Kasvava ja kehittyvä pääkaupunki tarvitsee maanalaisia tiloja' (Growing and Developing the Capital Needs of Underground Spaces) The Day of Underground Possibilities, MTR-FTA, 11 April 2013, Helsinki, Finland (in Finnish)
www.getunderground.fi/getfile.ashx?cid=205375&cc=3&refid=21

Mail Online News, 2011, Introducing the earth-scraper, 12 October
www.dailymail.co.uk/news/article-2048395/Earth-scraper-Architects-design-65-storey-building-300-metres-ground.html

P-Hämppi, 2012, P-Hämppi is the first stage of Parkisto, Tampere's underground parking solution
www.finnpark.fi/parkisto/briefly-in-english/

Suuroja, S., Suuroja, K., Ploom, K., Kask, A. and Soosal, H., 2012, Tallinn – Helsinki -tunnel soil- and bedrock construction conditions, Compilation of a geological database for the possible Tallinn-Helsinki tunnel area (in Estonian EEZ), Geological Survey of Estonia, Department of Geophysics, Marine and Environmental Geology, Department of Geological mapping, Tallinn, Estonia

Tampere Central Arena, 2011, Tampere Central Arena is a project aiming to build a new multifunctional arena in Tampere.
www.tampereenkeskusareena.fi

Twin-City Scenario, 2013, H-TTransPlan, Helsinki-Tallinn Transport & Planning Scenarios
www.euregio-heltal.org/httransplan/questionnaire/scenario-2-twin-city/

Vähäaho I., 1999, Helsinki Geotechnical Database, Soil-structure interaction in urban planning, European co-operation in the field of scientific and technical research COST Action C7, Workshop in Thessaloniki, 1-2 October 1999
www.bygg.ntnu.no/geo/costc7/web00/proceedings/Thessaloniki/Docs/prn_ps/vahhgd.pdf

Vähäaho I., 2007, "Review of mapping and geotechnical data management in urban areas", Discussion Session 6.2, *Proceedings of the Fourteenth European Conference on Soil Mechanics and Geotechnical Engineering in Madrid, Spain, ECSMGE 2007, Volume 3*, pp. 565-573

Vähäaho I., Korpi J., Satola I., Van Alboom G., Vergauwen I., 2011, Geotechnical and geological data management in urban underground areas, *Proceedings of the World Tunnel Congress WTC-2011*, Helsinki, Finland (extended abstract)

Vähäaho I., 2011a, Keynote lecture, Helsinki Experience with Master Planning for Use of Underground Space, *Proceedings of the Joint HKIE-HKIP Conference on Planning and Development of Underground Space*, The Hong Kong Institution of Engineers and The Hong Kong Institute of Planners, 23-24 September 2011, Hong Kong, pp. 1-9
www.hkie.org.hk/hkiehkip/cavern.html

Vähäaho I., 2013, Plenary Lecture, Use of underground space in Finland, *Proceedings of 2nd Nordic Rock Mechanics Symposium*, Gothenburg, Sweden, pp. 35-49

Vanjoki A., 2012, STT-Lehtikuva (Finland's leading news- and picture agency), News in Finnish 29 April 2012, (in Finnish)
www.hs.fi/kotimaa/Vanjoki+louhisi+Guggenheimin+maan+alle/a1305558837220

5

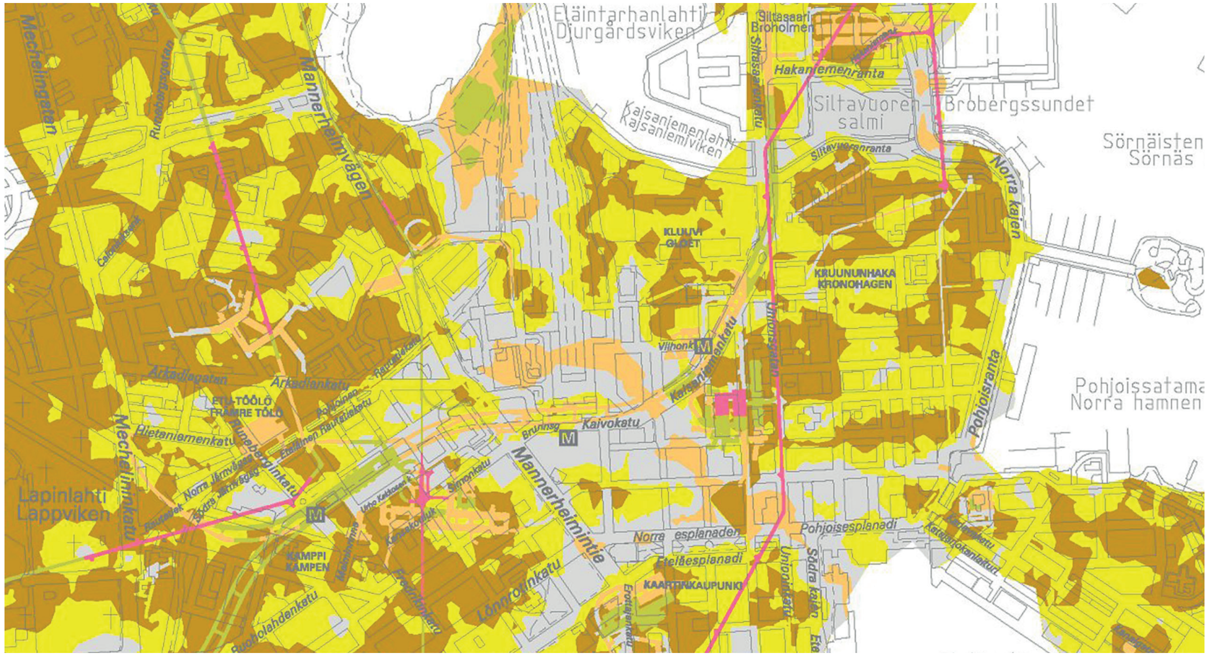
Geotechnical Engineering for Underground Space Development

5 Geotechnical Engineering for Underground Space Development

An initial survey examined those areas and elevation levels in Helsinki that are suitable for the construction of large, hall-like spaces.

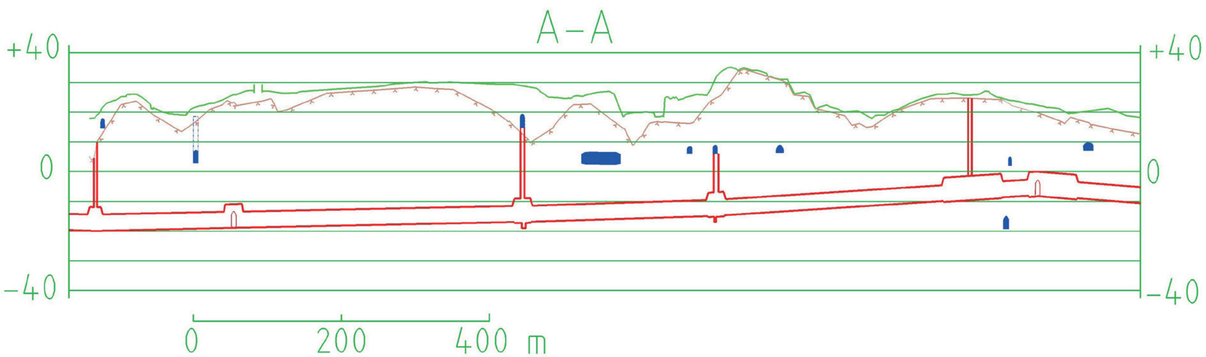
A model based on rock surface data was used by applying a standard-sized measurement cave (width 50m, length 150m, height 12m). The model of the bedrock is based on base map data for exposed rock and land surface elevations; point data were obtained using drill machine borings (Fig. 17). The survey also took into account local weakness zones and rock resources that have already been put to use. In 2009, the Underground Master Plan of Helsinki was displayed for the first time to a large international audience at the World Tunnel Congress in Budapest, Hungary (Vähäaho 2009a), and after that repeatedly around the world. The last time it was presented was in 2014 in Nanjing, China (Vähäaho 2014).

In general, it can be said that the bedrock in Helsinki and Finland is not far below the ground surface, and that there are many reasonable and safe locations suitable for the construction of underground facilities (Vähäaho 2009b). Outside the city centre, the survey found 55 rock areas that are sufficient in size to accommodate large underground facilities near major traffic arteries.



▲ *Fig. 17. Extract of the Rock Surface Model. The deepest public underground spaces have been taken into consideration when presenting free rock resources. The estimated rock surface is based on bedrock confirmation drillings (Image: City of Helsinki Real Estate Department).*

1–3 m
3–10 m
10–20 m
20-30 m
30–40 m
> 40 m



In many areas, future underground projects can make use of entrances to existing underground facilities – these are marked with triangles on the Master Plan map (Fig. 10).

It is worth mentioning that while geothermal energy from bedrock is also a noticeable resource, there are some safety, legal and economical issues that should be taken in consideration. These issues are briefly discussed in Chapter 6.

Underground facilities for municipal and other technical services (energy, water supply and telecommunications) are, by nature, large-scale closed networks. These facilities comprise a number of different functions together with the utility tunnels connecting them. The utility tunnels are located at such a depth that space reservations for them do not have a significant effect on other underground facilities (Figs. 18 and 19).

The City of Helsinki has more than 200 km of technical maintenance tunnels, 60 km of which are utility tunnels used by a number of operators. The tunnels, built in Helsinki since 1977, accommodate transmission lines and pipes for district heating, district cooling, electricity and water supply systems, as well as a large number of different cable links.

▼ *Fig. 18. Typical utility tunnel (Photo: Jorma Vilkman).*

◀ *Fig. 19. Longitudinal Section of the Newest Utility Tunnel Contract showing the principle of locating the utility tunnels at such depths that there are rock resources also for future needs. Dark blue represents existing tunnels and underground spaces. Elevations are with reference to mean sea level in metres (Image: City of Helsinki Real Estate Department).*

The Geotechnical Division of the City of Helsinki's Real Estate Department has been the main designer responsible for the preliminary and construction-phase planning required for the rock construction of the utility tunnels, the underground wastewater treatment plant and the treated wastewater discharge tunnel. The facilities designed by the Geotechnical Division include tunnel lines, halls, vertical shafts and the necessary access tunnels (Satola and Riipinen 2011).

Raw water for the Helsinki region comes from Lake Päijänne via a rock tunnel measuring 120 km (Laitakari and Pokki 1979).

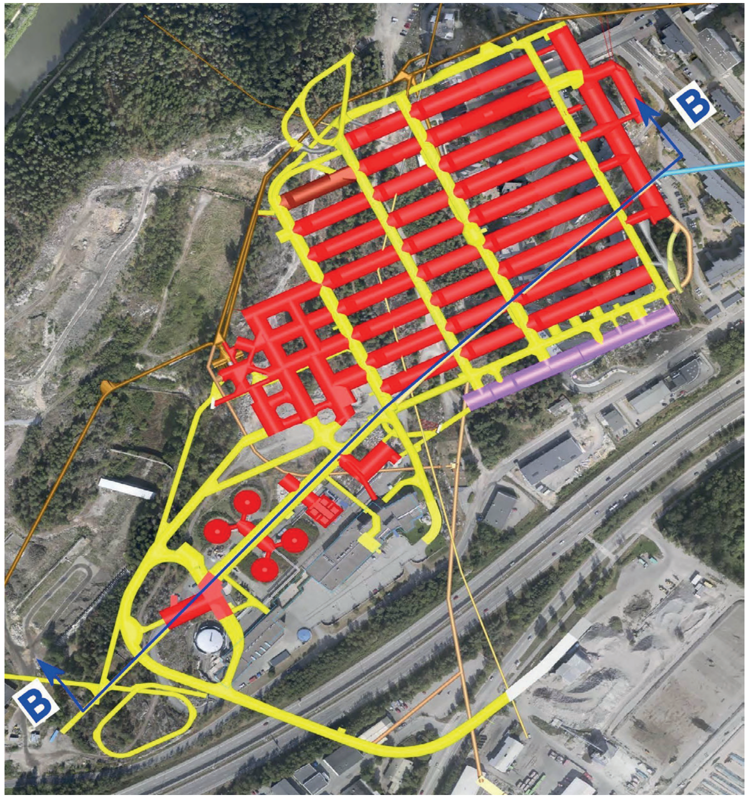
- Medium water level of Lake Päijänne MW = +78.3
- Highest water level in the Helsinki Metropolitan Area HW = +42.0
- Water capacity of the Päijänne tunnel = 9-11 (m^3/s)

Its main investor and designer was the metropolitan area Water Company PSV. Thanks to the good quality of water reserves and the constant low temperature during transport in the deep tunnel (average 40 metres below ground level), there is just a small amount of bacteria in the raw water and thus only minimal processing is required before use. Tunnel construction started in 1972 and was completed in 1982 at a cost of some EUR 200 million (adjusted for inflation in 2014). The original tunnel design was based on minimum reinforcement. In 1999, a small part of the tunnel was repaired due to rock falls (Fig. 20). In 2001 and 2008, the tunnel underwent an extensive renovation - it was bolted and shotcreted in two sections to prevent cave-ins.

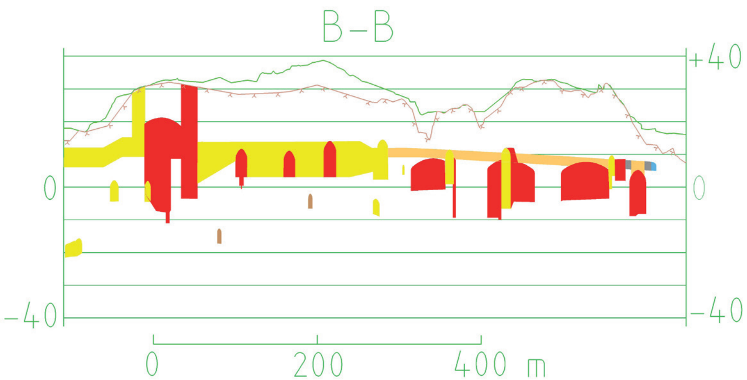
Wastewater treatment is carried out centrally at the Viikinmäki underground wastewater treatment plant (Figs. 21 and 22). The wastewater arrives at the plant via an extensive tunnel network. The treated wastewater is then discharged into the sea via a rock tunnel whose discharge outlet is some 8 km off the coast. The tunnels in the treatment plant have a capacity of 1.2 million m^3.

The Viikinmäki wastewater treatment plant is the central plant for treating wastewater from six towns and cities. The plant, located less than 10 km from the centre of Helsinki, treats 280,000 m^3 of wastewater from about 750,000 inhabitants daily. Completed at a cost of

▲ *Fig. 20. Tunnel from Lake Päijänne was repaired for the first time in 1999. The reinforcement method used here is an exception and only used in cases of severe collapse. Some parts were bolted and shotcreted while most parts are still without any reinforcement (Photo: Foto Mannelin Oy).*



◄ *Fig. 21. An aerial view of the Viikinmäki wastewater treatment plant (Image: City of Helsinki Real Estate Department).*



◄ *Fig. 22. Longitudinal section of the Viikinmäki wastewater treatment plant.*

actual treatment basins

other underground spaces

Elevations are with reference to mean sea level in metres (Image: City of Helsinki Real Estate Department).

approximately EUR 200 million (Fred 2014), the plant began operating in 1994. It replaced more than 10 smaller treatment plants, all above ground, thus allowing these sites to be zoned for more valuable uses. The construction of the underground plant took place simultaneously with the construction of ground-level infrastructures and residential buildings. The Viikinmäki residential area with 3,500 inhabitants is above the tunnels. There are also plenty of zoned ground-level areas for future residential blocks and the possible expansion of the underground wastewater treatment plant in the same Viikinmäki hill area.

Technical services and utility tunnels in Helsinki are reliable and optimise large-scale networks in the bedrock that list several advantages:

- there is a reliable energy supply via the network with multiple links (allowing alternative routes if necessary);
- the optimisation of energy generation with major transmission networks, i.e. power needs, is met by generating energy using the cheapest source at any one time;
- costs are shared between several users;
- land is released for other construction purposes;
- the city's appearance and image are improved as the number of overhead lines can be reduced;
- construction work carried out on underground pipes and lines has significantly fewer disadvantages than similar work carried out at the street level;
- blast stones resulting from the construction of the tunnels can be utilized;
- pipes and lines in tunnels require less maintenance - they are easier to maintain than pipes and lines buried under streets, and the tunnel routes are shorter than those of conventional solutions;
- any breakages in pipes, lines and cables do not pose a great danger to the public; and
- tunnels are a safer option against vandalism.

References

Fred T., 2014, Seminar Presentation on 10th June 2014 at the Viikinmäki 20 Years Anniversary, Helsinki, Finland

Laitakari I. and Pokki E., 1979, Summary: Geological observations from the Päijänne Tunnel, construction phase 1, HI. Koski – Asikkala, Geological Survey of Finland, Report of investigation no. 37
http://tupa.gtk.fi/julkaisu/tutkimusraportti/tr_037.pdf

Satola I., Riipinen M., 2011, Technical services and utility tunnels in Helsinki, Proceedings of the World Tunnel Congress WTC-2011, Helsinki, Finland (extended abstract)

Vähäaho I., 2009a, Underground Master Plan of Helsinki, the World Tunnel Congress WTC-2009, Open Session, Budapest, Hungary
www.ita-aites.org/en/component/k2/571-underground-master-plan-of-helsinki

Vähäaho I., 2009b, Underground resources of Helsinki, Proceedings of Get Underground – Underground Space Seminar / Rock Engineering Seminar, Finnish Tunnelling Association MTR-FTA / Finnish National Group of ISRM, 4-5 November 2009, Helsinki, Finland, pp. 53-60

Vähäaho I., 2014, Underground space planning in Helsinki, *Journal of Rock Mechanics and Geotechnical Engineering*, DOI: 10.1016/j.jrmge.2014.05.005
www.sciencedirect.com/science/article/pii/S1674775514000699

6 Non-geotechnical Engineering for Underground Space Development

6 Non-geotechnical Engineering for Underground Space Development

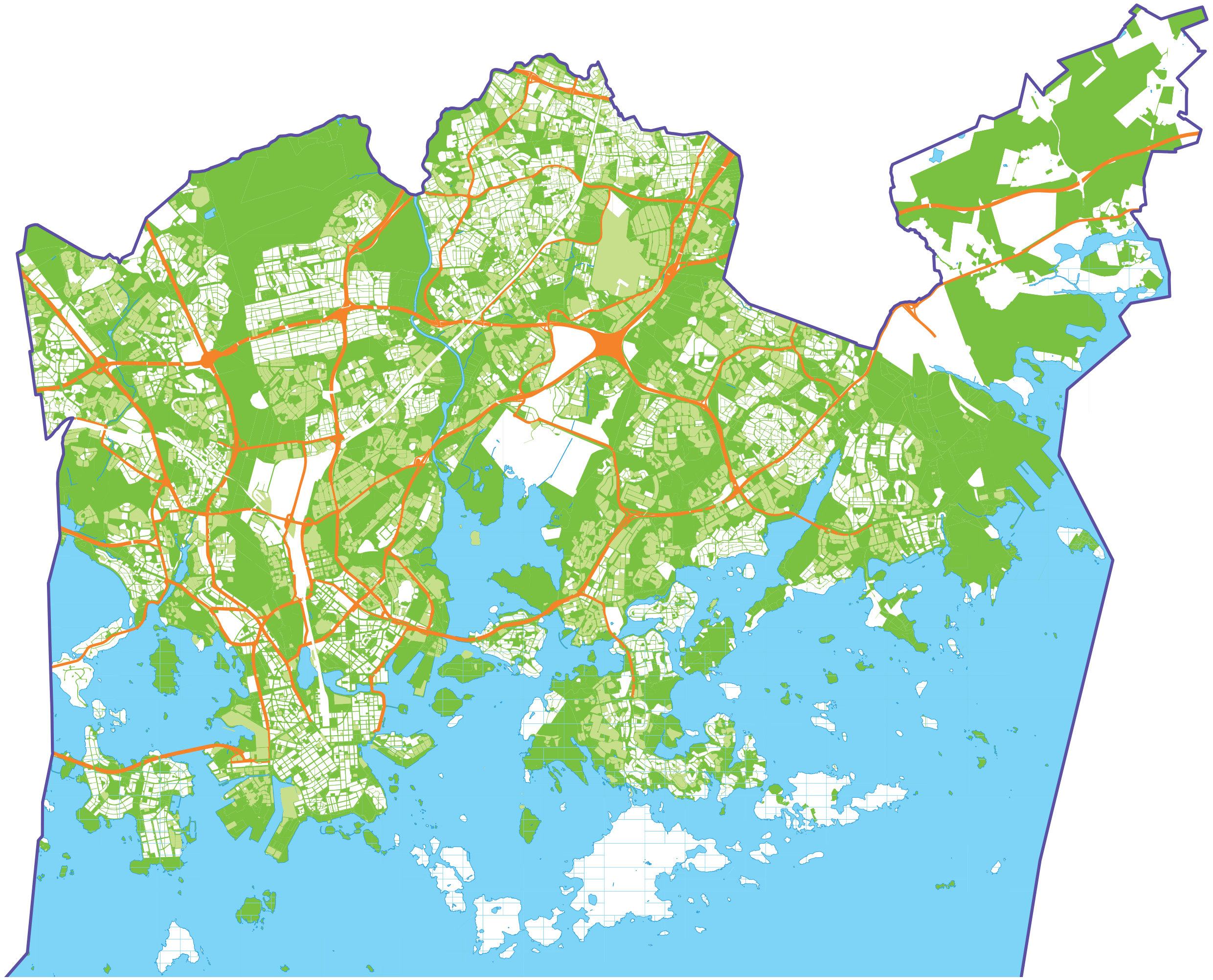
In Helsinki, diverse functions have been placed underground. As the underground network has grown, efforts have been made to ensure its sustainable expansion.

Helsinki consists of 214 km^2 of land and 500 km^2 of sea (Fig. 23). The City of Helsinki owns 62% of the land area of Helsinki (Helsinki City 2013).

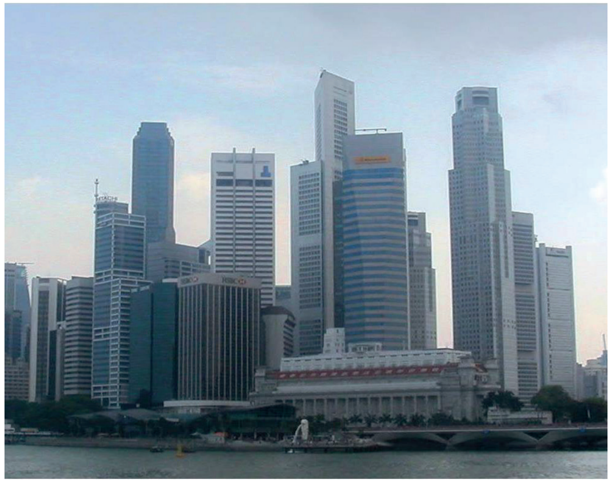
"The city has acquired land with a long-term and goal-oriented focus, and has favoured rental when conveying its land. After the major incorporation of 1946, land acquisition has mainly been used to facilitate city planning." (Yrjänä 2013)

According to the Real Estate Department´s Land Division (Haaparinne 2011), the city tries to buy the needed land areas as greenfield land (viz. undeveloped land either used for agriculture, landscape design or left to naturally evolve) before city planning (zoning). As greenfield land is becoming scarce, the city, despite previous strategies, is today more and more facing redevelopment of brownfields (previously used for industrial purposes), especially when developing waterfront areas. It is also easier to develop underground resources under one's own real estate than under somebody else's property.

Fig. 23. Map of Helsinki. The green areas are land owned by the City of Helsinki; white areas are owned by others (Image: City of Helsinki Real Estate Department).



The deepest underground space in Helsinki is situated only about 100 m below sea level.



▲ *Fig. 24. Helsinki Market square (Photo: City of Helsinki Media Bank). Downtown Singapore in 2004 (Photo: Ilkka Vähäaho).*

Buildings in Helsinki are mainly quite low with skyscrapers only being built in some special areas. The historic inner city (as seen in Fig. 24) is therefore remarkably different from the centre of Singapore, for instance. Helsinki can be classified by the term ´down-rise city´ (= using underground resources effectively) while Singapore, in turn, is a ´high-rise city', which was fashionable in the 1900s. The deepest underground space in Helsinki is situated only about 100 m below sea level – a far cry from the ´Earth-Scraper´ building culture shown in Fig. 13. Nevertheless, underground resources may also be found in the inner city in the future, if needed.

The comparison cities (Helsinki/Singapore) are similar from the underground building point of view as they both have favourable rock resources. In Helsinki, however, significantly more and diverse functions have been placed underground. The reasons why the underground dimension is utilized so open-mindedly in Finland, and in particular in Helsinki, are discussed in Chapters 1 and 3.

A good example of land property resources made use of several times is the Katri Vala Park situated in the city centre (Fig. 25). Nowadays, there are four underground activities under the park totally independent from each other. The possibility to build one more space between the existing underground 'floors' is currently being investigated. The Katri Vala Park is also an example of the concept called 0-land_use (~ sustainable use of underground space) adopted by Sterling et al. (2010).

The cadastral system in Finland is still two-dimensional, although a 3D cadastral system is currently being developed. Finnish legislation is not precise about the extent of landownership - not upwards or downwards. The work for a 3D cadastral system in Finland is on-going and should be completed by 2016. There is a difference between the right to use the property and ownership of the land. The lower boundary of the right to use the property has been limited to the depth where it can be technically utilised; in practice, this means a depth of six metres – a conventional Finnish cellar. If landowners want to build multiple underground levels to their buildings, they must have a building permit; on the other hand, the right to build deep cellar must be in accordance with the zoning. The question is not about the ownership of the land but about the right to use land for building purposes. This is mainly controlled by master planning, zoning (town planning) and finally by building permits. The figure of six metres is a practical measure for building one - maximum two - cellars below ground level. This six-metre figure is not part of the Finnish legislation - it is rather, a Helsinki practice. If more space is needed a permit is required. Most buildings with deep cellars (more than six metres) are located in the city centre. Efforts have been

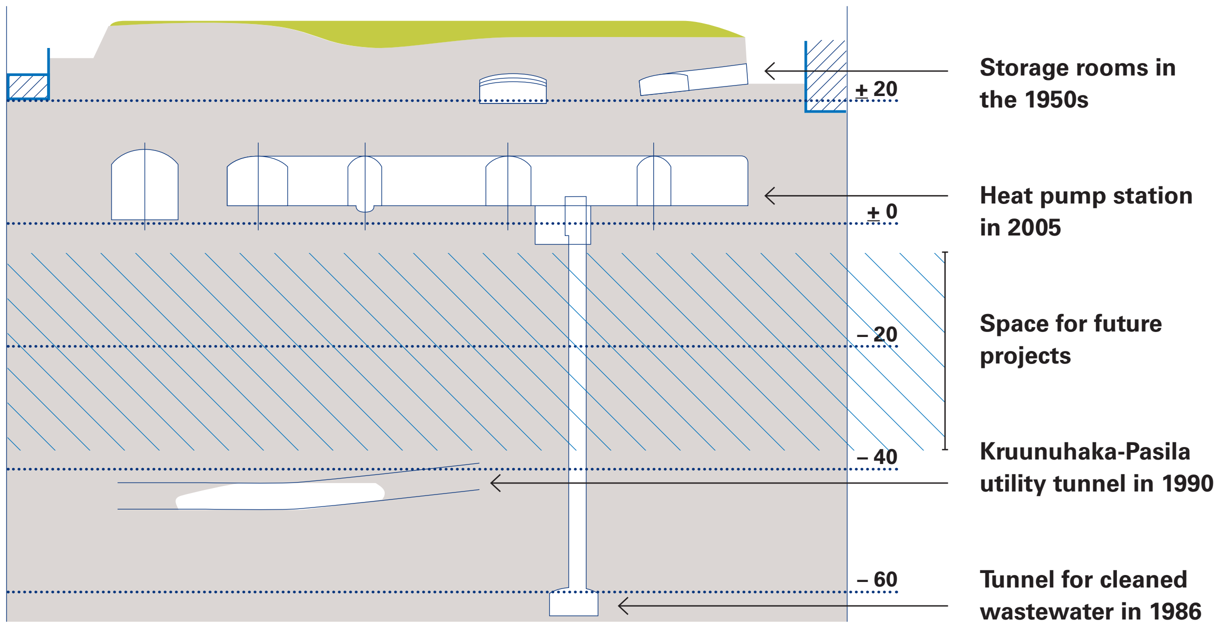


Fig. 25. Example of 0-land_use: Katri Vala Park in Helsinki (Image: City of Helsinki Real Estate Department).

▲ *Fig. 26. Cold water reservoir for district cooling in Helsinki city centre was built between 50-90 metres from ground level because of the lack of free underground space (Photo: Helsingin Energia).*

made to guide the use of underground resources outside the city centre. As many deep cellars, underground spaces and tunnels already exist in the centre of Helsinki, the new underground cold water reservoir for district cooling was excavated between 50-90 metres from ground level (Fig. 26). **Although all underground space below the surface of real estate owners' land belongs to them, they may only restrict its use or get compensation if the space to be used is harmful or it causes some loss to the owner.** This is mainly the case in (Local) Government Underground projects. In non-government projects, such as private car parks, a (servitude) agreement is drawn up between the construction company and the landowner even when the company is not paying for the use of the underground space.

Deep boreholes to harness geothermal energy are becoming more common even in city centres. Typically, these boreholes are 150 metres deep. In spite of the claims of contractors, these boreholes do not normally go in the desired direction. The City of Helsinki has taken some measurements along the whole length of some boreholes to determine their actual location. It was found that boreholes can be inclined even tens of metres from the ground-level position. As a result, boreholes that were meant to be drilled vertically under one plot ended up in another plot or even under the neighbouring city block. In reality, deep boreholes are detrimental to underground space construction since the exact position of the holes is uncertain. The obligation to measure these deep holes along their whole length would considerably improve the situation. Several underground activities could then be safely located close to each other (Vähäaho 2011b).

Geothermal heating is in use in 70 countries (Geothermal Energy Association, 2010), while geothermal electricity generation is used only in 24 (Fridleifsson et al. 2009). The author prefers concentrated power plants for geothermal energy instead of one borehole for each detached house system, arguably a more environmental and economical solution.

References

Fridleifsson I., Bertani R., Huenges E., Lund J., Ragnarsson A., Rybach L., 2008, The possible role and contribution of geothermal energy to the mitigation of climate change, IPCC Scoping Meeting on Renewable Energy Sources, Luebeck, Germany, pp. 59–80, retrieved 2009
www.ipcc.ch/pdf/supporting-material/proc-renewables-lubeck.pdf

Geothermal Energy Association, 2010, Geothermal Energy: International Market Update May 2010, pp. 4-6
www.geo-energy.org/pdf/reports/GEA_International_Market_Report_Final_May_2010.pdf

Haaparinne P., 2011, Land acquisition specialist at the City of Helsinki Real Estate Department, Interview 19 August 2011

Helsinki City, 2013, Building Helsinki, Leaflet of the Helsinki City Real Estate Department
www.hel.fi/static/kv/BuildingHelsinki.pdf

Sterling R., Admiraal H., Bobylev N., Parker H., Godard J.-P., Vähäaho I., Rogers C., Shi X., Hanamura T., 2010, “0-Land use through sustainable use of underground space”, *Proceedings of Euregional conference, Sustainable Building, Towards 0-impact building and environment, SB 10 Western Europe,* Maastricht, Hesden-Zolder, Aachen, Liége, 11-13 October 2010, pp. 112-113

Vähäaho I., 2011b, Workshop on “Use of Underground Space in Hong Kong” for the Hong Kong Government’s engineers and city planners, 26 September 2011, Hong Kong

Yrjänä J., 2013, ’Maata näkyvissä. Helsingin maanhankinnan viisi vuosisataa’ (Helsinki´s Five Centuries of Land Acquisition), Edita Publishing Oy, ISBN 978-951-37-6450-0, in Finnish with an English Summary, pp. 235-237
http://netmarket.edita.fi/cgi-bin/netmarket/webprog/item/page.htm?itemCode1=37-6450-0&RowNum=4

7 Conclusion

7 Conclusion

Underground space is a resource for those functions that do not need to be on the surface. The Underground Master Plan of Helsinki shows both existing and future underground spaces and tunnels, as well as existing vital access links to the underground.

It also includes rock resources reserved for the construction of as yet unnamed underground facilities, with the aim of identifying good locations for functions suitable for locating underground, and which would also reduce the pressures on the city centre's rock resources.

It has been claimed by some non-Finnish experts that the favourable characteristics of the bedrock and the very severe winter climate conditions have been the main drivers for the underground development. While rock material is one of them, there are other main drivers heading the list over winter, such as the Finnish need to have open spaces even in the city centre, the excellent and long-lasting cooperation between technical departments and commercial enterprises as well as the small size of Helsinki. It is among the smallest by area and clearly the biggest by population in Finland. Real estate owners may restrict the use of underground space under their lot or get compensation only if the space to be used is harmful or it causes some loss to the owners.

There are several benefits of locating technical networks in bedrock: a reliable energy supply via a network with multiple links; the optimization of energy generation; expenses are shared by several users; land is released for other construction purposes; the city's appearance and image are improved as the number of overhead lines can be reduced; construction work carried out on underground pipes and lines has significantly fewer disadvantages than similar work carried out at street level; blast stones and construction aggregates resulting from excavating the tunnels can be utilized; pipes and lines in tunnels require less maintenance; tunnel routes are shorter than those of conventional solutions; any breakages in pipes, lines and cables do not pose a great danger to the public; and tunnels are a safer option against vandalism.

In cases where pre-grouting is needed, it is always carried out since it is practically impossible and much more expensive to achieve a dry underground space later on. The reason for the low cost of tunnelling in Finland is due to the practice of not using cast concrete lining in hard rock conditions, effective D&B technology and extensive experience of working in urban areas.

The capital areas of Helsinki and Tallinn have grown enormously during the last 20 years. The 80 kilometre-wide Gulf of Finland separates the cities and restricts the movement of people and goods. A tunnel between Tallinn and Helsinki would be an extension of the Rail Baltica rail link, a project to improve north–south connections between EU Member States.

8 Further Information

Further Information

Further information and international examples of the use of underground space is given by the International Tunnelling and Underground Space Association ITA
www.ita-aites.org/

Helsinki's underground master plan, February 14, 2011, CNN's Richard Quest takes a look at the development of Helsinki's vast underground and eco friendly programme
http://edition.cnn.com/video/data/2.0/video/world/2011/02/14/qmb.fc.helsinki.underground.cnn.html

City of Helsinki, City Planning Department, 'Helsingin maanalainen yleiskaava' (Helsinki's underground master plan), Materials and further information (in Finnish)
http://www.hel.fi/hel2/ksv/Aineistot/maanalainen/Maanalaisen_yleiskaavan_selostus.pdf

Helsinki City Geographic Information system web service offers detailed and accurate information on the Helsinki City region by various maps, aerial photography, geotechnical and geological information as well as city and traffic plans and real estate information
http://kartta.hel.fi/?setlanguage=en

Helsinki experience with master planning for use of underground space, Technical services and large-scale utility tunnel networks in bedrock as well as Geotechnical and geological data management are described in more detail
www.geotechnics.fi > CaseBank

The Finnish Geotechnical Society SGY and the Finnish Tunnelling Association MTR-FTA maintain the website for professionals who actively participate in ground and tunnelling engineering
www.getunderground.fi

Endorsed by the European Council of Town Planners, the report - Hidden aspects of urban planning: surface and underground development - is an essential reading for planners, architects and developers and the geotechnical engineer interacting with these professions
http://books.google.fi/books?hl=fi&id=fUtUAAAAMAAJ&focus=searchwithinvolume&q=

Soil-structure interaction in urban civil engineering, COST Action C7
www.bygg.ntnu.no/geo/costc7/web00/

News in English about the Helsinki – Tallinn Rail Tunnel
www.getunderground.fi/web/page.aspx?refid=62

'Temppeliaukio' Church built into solid rock
www.temppeliaukio.fi/english/

Underground Swimming Pool in Itäkeskus
www.hel.fi/hki/liv/en/sports+facilities/swimming+halls/it_keskus+swimming+hall

Viikinmäki' underground wastewater treatment plant
www.hsy.fi/en/waterservices/wastewater_treatment/Pages/viikinmaki.aspx

Conflict of interest

The author wishes to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

About the author

Ilkka Vähäaho graduated as a Civil Engineer from the Technical University of Helsinki, Finland in 1979.

He has 37 years experience at the City of Helsinki and since 1997 as the Head of Real Estate Department - Geotechnical Division.
www.geotechnics.fi

He is also a member of the Steering Board of the ITA Committee on Underground Space ITACUS.
www.ita-aites.org/en/wg-committees/committees/itacus

Ilkka Vähäaho has been engaged in the work of numerous National and European Standards and has a strong engagement in the Finnish Geotechnical Society SGY and the Finnish Tunnelling Association MTR-FTA.
www.getunderground.fi

He is currently the Chairman of the SGY Ground Improvement Committee, the MTR-FTA International Activity Group and a 'Global Perspective Ambassador' of ITACUS to promote the usefulness of Underground Resources.

THIS PUBLICATION gives insight into the development of underground space in Helsinki. The city has an underground master plan for its whole municipal area, not only for certain parts of the city. Further, the decision-making history of the underground master plan is described step-by-step. Some examples of underground space use in other cities are also given. The focus of this paper is on sustainability issues related to urban underground space use, including its contribution to an environmentally sustainable and aesthetically acceptable landscape, anticipated structural longevity and maintaining the opportunity for urban development by future generations. Underground planning enhances overall safety and economy efficiency.

The need for underground space use in city areas has grown rapidly since the turn of the 21st century; at the same time, the necessity to control construction work has also increased. The Underground Master Plan of Helsinki reserves designated space for public and private utilities in various underground areas of bedrock over the long term. The plan also provides the framework for managing and controlling the city's underground construction work and allows suitable locations to be allocated for underground facilities.

Tampere, the third most populated city in Finland and the biggest inland city in the Nordic countries, is also a good example of a city that is taking steps to utilise underground resources. Oulu, the capital city of northern Finland, has also started to 'go underground'.

An example of the possibility to combine two cities by an 80-kilometre subsea tunnel is also discussed. A new fixed link would generate huge potential for the capital areas of Finland and Estonia to become a real Helsinki-Tallinn twin city.

Keywords: *Land use planning, underground resources, master plan, sustainability, urban development, 3D cadastral system, geological data, D&B method, ownership of the land*

www.geotechnics.fi