Urban Underground Space

Sustainable Property Development in Helsinki

Helsinki

Urban Environment Publications 2018:11

Author: Ilkka Vähäaho
Urban Environment Publications 2018:11
City of Helsinki, Urban Environment Division, Soil and Bedrock Unit GEO
P.O. Box 58213, FI-00099, Helsinki, Finland
E-mail: ilkka.vahaaho@gmail.com
www.geotechnics.fi

Updated 2nd Edition, June 2018
English editing: Howard McKee and Kristoffer Westlake
Layout: Recommended Finland Oy
Cover photo: Q-Park Finlandia, Ilkka Vähäaho
Printing house: Grano Oy

ISBN 978-952-331-436-8 (paperback)
ISBN 978-952-331-437-5 (web publication)
ISSN 2489-4222 (paperback)
ISSN 2489-4230 (web publication)

Download the pictures of this publication **https://helsinki.contenthub.fi/ui/shares/w13477849/877310/fi/**

Contents

References include *former names* of the City of Helsinki's organisations, used prior to June 2017. The ***new names*** of the corresponding organisations are listed below:

City of Helsinki, Real Estate Department, Geotechnical Division
City of Helsinki, Urban Environment Division, Soil and Bedrock Unit GEO

City of Helsinki, Real Estate Department, Land Division
City of Helsinki, Urban Environment Division, Land Property Development and Plots

Helsingin Vesi
Helsinki Region Environmental Services Authority HSY

Helsingin Energia
Helen Oy

Helsinki City Planning Department
City of Helsinki, Urban Environment Division

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.

Since Budapest, the paper has been elaborated and widened to cover the development of underground space in the urban environment. After that was completed, it was time to release the first edition of this paper to a wider audience in October 2014.

This non-commercial publication has been updated and is now available as an independent online publication on the City of Helsinki's website.

In my view, the close cooperation that the City of Helsinki has established with the numerous 'partners' involved in the planning, financing and designing as well as the actual construction and maintenance of tunnels and underground spaces has perhaps been the crucial factor in 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 extremely grateful for the demanding work that so many people have done in the field of Urban Underground Space. My role during the past ten 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 and update this paper 'Urban Underground Space – Sustainable Property Development in Helsinki'. For this, I thank them all. I also want to thank my own organisation and my family for their support and patience during this process, which has lasted much longer than it should have done!

June 2018
Ilkka Vähäaho
City of Helsinki
Soil and Bedrock Unit GEO

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 311 independent municipalities as of 2018. Helsinki, the capital, is clearly the biggest city in Finland. While the average size of all the municipalities is 977 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 one particular district (Kallio) is higher than 20,000 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, 1.5 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).

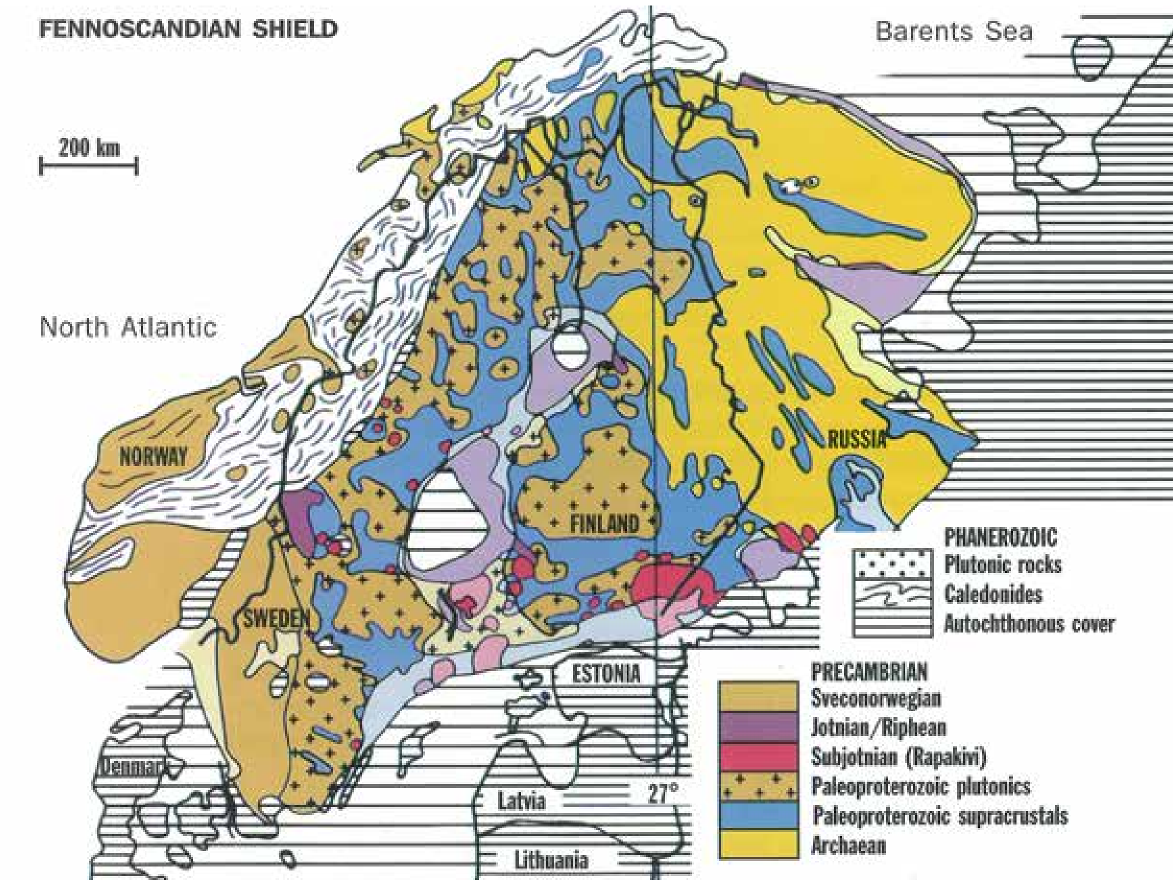


Fig. 1. Geological conditions in Finland and Scandinavia. (Image: Geological Survey of Finland)

The bedrock quality in Finland is, for the most part, ideal for tunnelling and 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 building underground spaces since the bedrock mainly consists of old Precambrian rocks (Finnish Tunnelling Association, 1997) and there are only a 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. In the 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, recrystallisation and later movements (Saraste, 1978). 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's 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/m^3 (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. However, TBMs are a probable alternative for the possible future Helsinki-Tallinn tunnel.

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 of this paper 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.

The average price per cubic metre of tunnels and underground spaces in Finland is EUR 100/m^3.

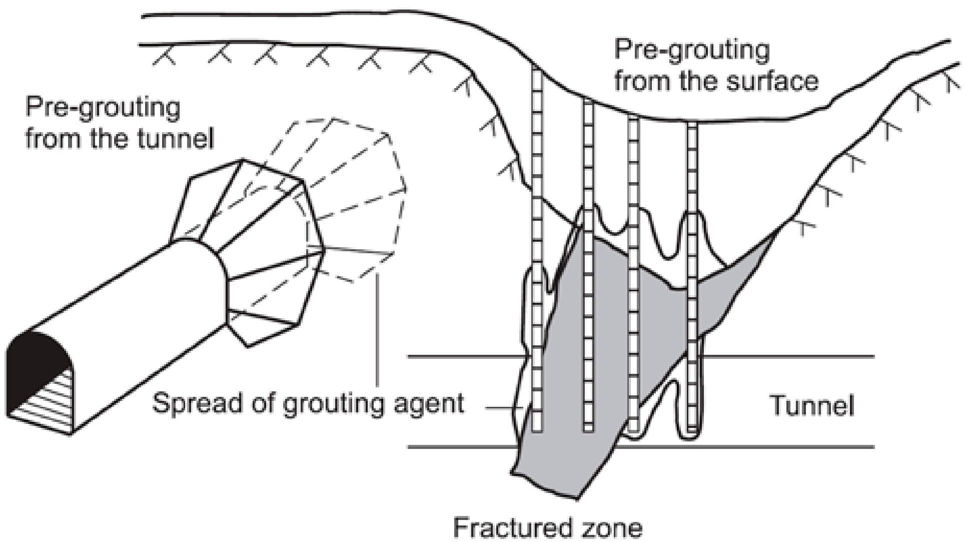


Fig. 3. Pre-grouting is crucial because of the conditions in Helsinki.
(Image: Sandvik Mining and Construction Finland)

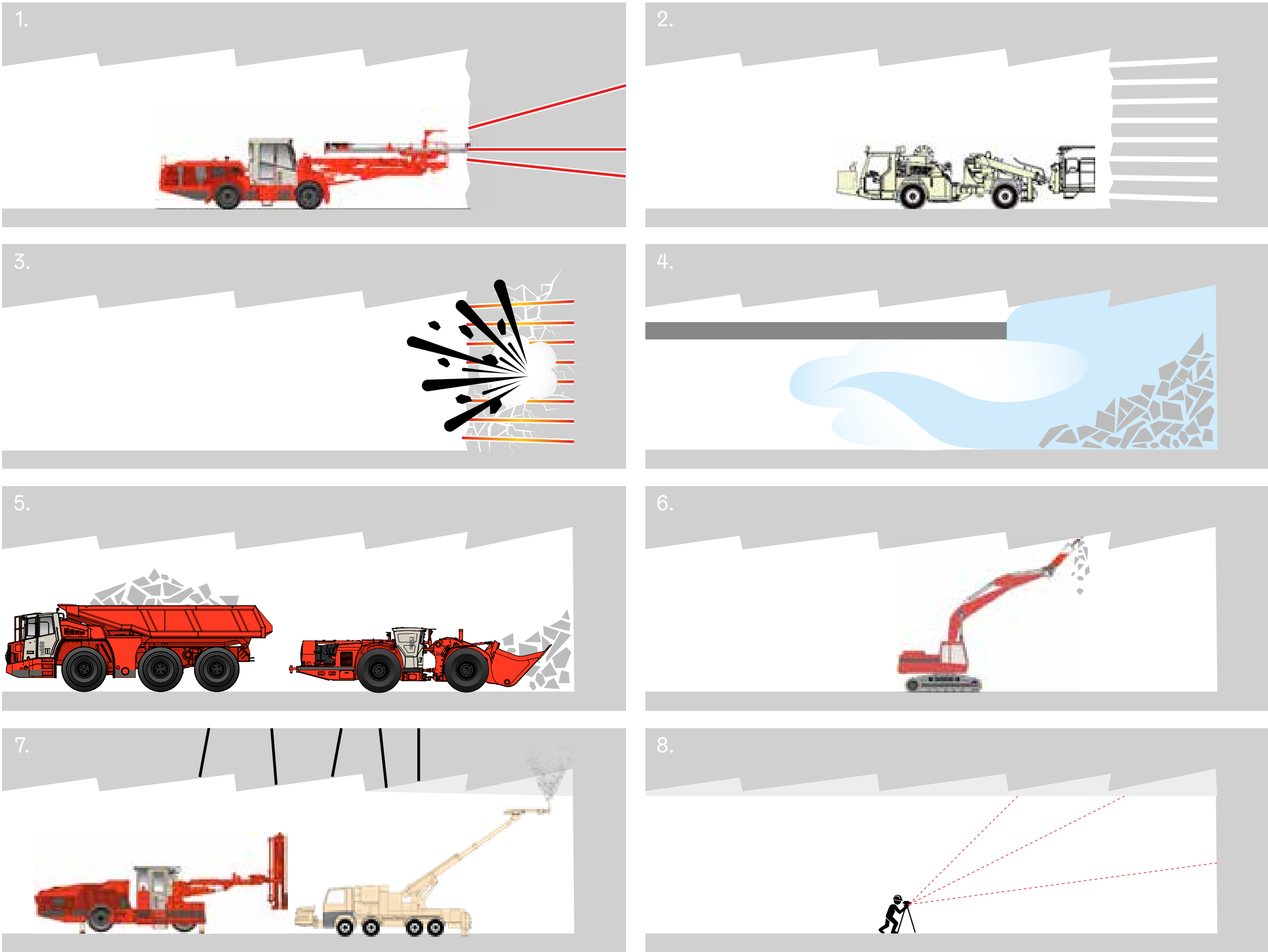


Fig. 4. Drill and Blast method cycle
1. Drilling 2. Charging 3. Blasting 4. Ventilation 5. Loading 6. Scaling 7. Reinforcements 8. Measuring.
(Image: Adapted from Sandvik Mining and Construction Finland Oy and Normet Oy)

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

2.
The History and Future of the Underground Master Plan of Helsinki

2. The History and Future 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 are outlined in the decision-making history presented below (Helsinki City Council, 2010 and Narvi, 2012):

* 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 in central Helsinki 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 did, in fact, end up having legal effect. Comment by Ilkka Vähäaho).
3. An underground space allocation plan will be connected to the Master Plan, which will support the City's underground facilities management system and the exchange of information.

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**, in 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.

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

5. The aim is to achieve joint use of facilities (e.g. the use of emergency shelters in normal circumstances, a multi-purpose tunnel network, shared parking, etc.).

6. Current functions could be studied to see if they can be located underground and 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.

2010

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

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).

2019

XIII Estimated completion date for the draft of the updated Helsinki Underground Master Plan.

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

Kivilaakso E. 2018, Unit Manager of Technical and Economic Planning at the City of Helsinki Urban Environment Division, Interview, 15 January 2018

3.
Key Considerations for the Use of Underground Space

3. Key Considerations for the Use of Underground Space

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.

Some unique examples of the use of underground spaces are shown in Figs 6 and 7. According to architect Timo 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 all the way 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 on it during the service while a ray of sunlight comes in through the glass roof onto the altar wall."

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).

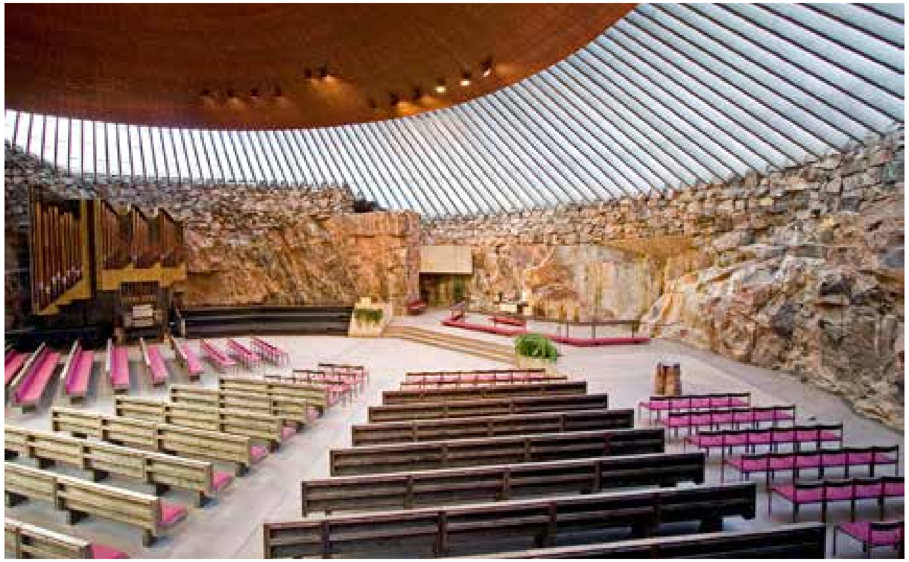


Fig. 6. Interior of the Temppeliaukio Church, which was designed by architects and brothers Timo and Tuomo Suomalainen and opened in 1969. It is also known as the Rock Church. (Photo: Juha-Pekka Järvenpää)

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 emergency shelters in buildings of at least 1,200 m^2. Today, however, it is more common to have an underground emergency shelter that serves some other purpose during 'normal times'.

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)

In reality, such spaces are now designed to meet the needs of normal times with strengthening 'just' for 'exceptional times'. This enables property owners to transform a swimming pool, for example, into an emergency 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."

The Finnish Rescue Act
Pursuant to the Finnish Rescue Act, an emergency shelter shall be built if a building has a floor area of at least 1,200 square metres and is used as a permanent dwelling or workplace or is otherwise permanently occupied. An emergency shelter shall be built for industrial, production and storage buildings and buildings used as a place of assembly if the floor area of a building is at least 1,500 square metres.

According to the proposed amendment to the Rescue Act now in circulation for opinions, "the construction of joint civil defences serving multiple buildings would be made easier by extending the maximum protective distance from 250 to 500 metres". Thus, a residential building's emergency shelter could be located a maximum of 500 metres away from the building.

21 million views of Helsinki
In 2018, TV ARTE made a five-minute programme about the emergency shelters in Finland (in French). **https://www.arte.tv/fr/videos/081158-000-A/finlande-la-vie-souterraine/**.

Underground (UG) spaces with rock surfaces in Helsinki

- Area 2,070,000 m^2
- Volume 12,700,000 m^3 (117 times greater than the Parliament House in Helsinki)
- 336 UG spaces altogether
- Helsinki's total surface area is 214 km^2, thus 1 m^2 of UG space on average per 100 m^2 of surface area (1% holes)
- Central Helsinki has 3 m^2 of UG space on average per 100 m^2 of surface area (3% holes)
- Valio Emmental Blue Label cheese e700g has on average 20% holes (Valio 2014)
- Tunnels altogether 293 km
  - 194 km of technical tunnels
  - 34 km of traffic tunnels
  - 30 km of tunnels with secondary purpose as emergency shelters
  - 14 km of parking caverns
  - 22 km of tunnels for other purposes

(Pehkonen, 2017 and Vähäaho, 2012)

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 reason 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 recorded damage occurred 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 mitigate their effects even more.

The growth in underground construction and planning, and the demand to coordinate different projects 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 ecoefficient structure (Figs. 8 and 9).

As the city structure becomes denser, more facilities suited for different purposes are being placed underground.

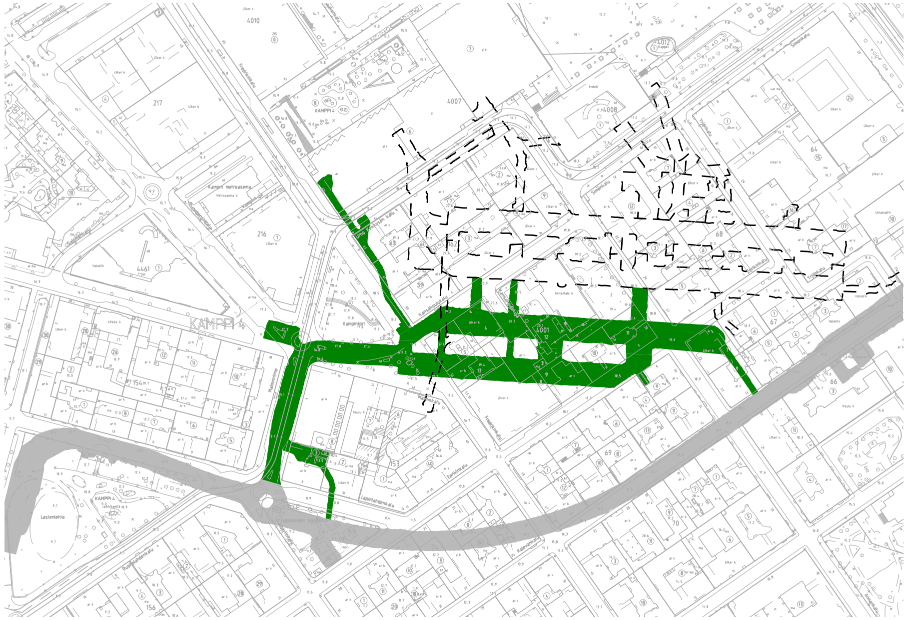
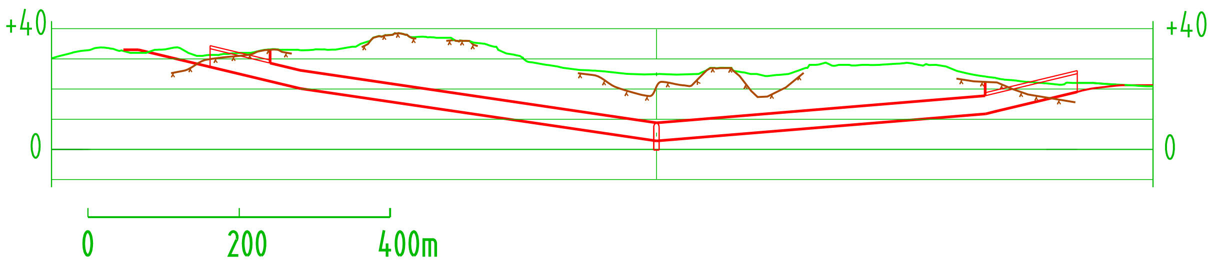
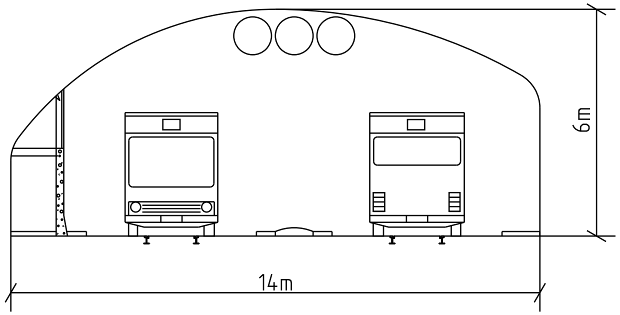


Fig. 8. Example of the development of the city structure of Helsinki where an old car park (shown with a dashed line) is connected to an extension and a new city service tunnel. (Image: Adapted from Helsingin Väylä Oy, a company owned by the City of Helsinki)

Fig. 9. The 'Jokeri 2' Central Park Tunnel was opened in 2015 for public transport connecting two residential districts. Elevations are with reference to mean sea level in metres. (Image: City of Helsinki)





Underground planning enhances the overall economic efficiency of facilities located underground and boosts the safety and use of these facilities. "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 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 more important main drivers than winter, such as the Finnish need to have open spaces even in the city centre, the excellent and long-lasting cooperation between technical units and commercial enterprises as well as the small size of Helsinki. It is among the smallest cities by area and clearly the biggest by population in Finland.

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)

Helsinki City, 2009, The Helsinki Underground Master Plan, Brochure, Urban Environment Division's Technical and Economic Planning Unit
www.hel2.fi/ksv/julkaisut/esitteet/esite_2009-8_en.pdf

Mashable, Inc., 2014, Underground Cities:
The Next Frontier Might Be Underneath Your Feet,
https://mashable.com/2014/02/21/underground-cities/#BiV_AB7TsEq0

Pehkonen T., 2017, City of Helsinki Maps and Geographic Information, 5 October 2017
www.hel.fi/helsinki/en/maps-and-transport/city-maps-and-gis/geographic-information-data/

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

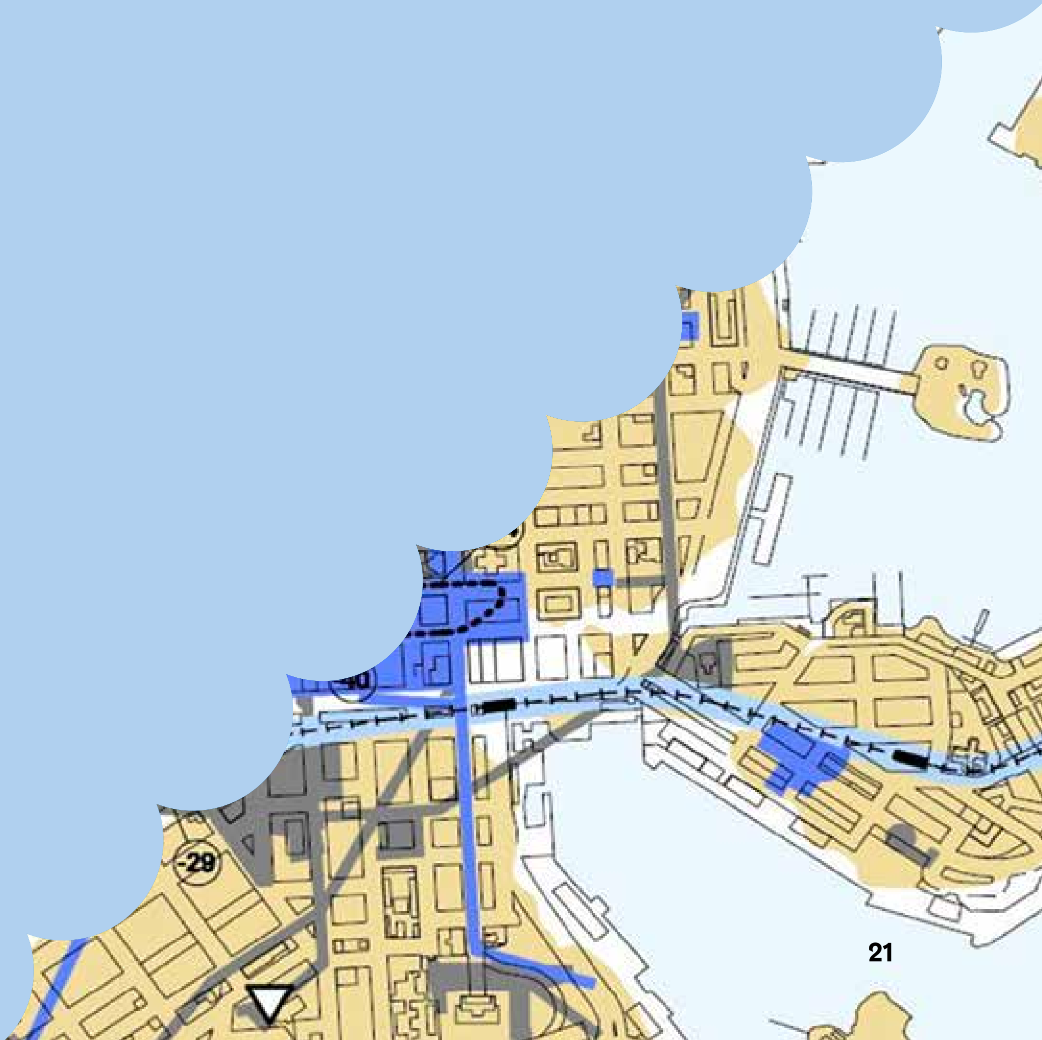
Suomalainen, T., 2001, 'Kalliosta Temppeliksi' (From Rock to a Temple). Production House Oy / YLE 2001. TV program broadcast on YLE Teema on 14 July 2014, Finland, (in Finnish).

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

Valio Emmental sinileima e700 g, 2014 (in Finnish)
https://vapa.valio.fi/VAPA/Aspx/Forms/Form.aspx?FormType=FormFeedback&UrlIdentifier=0f762c68-b5e6-4bfc-90be-246058d602c7

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

4.
Planning for the Use of Underground Space



4. Planning for the Use of Underground Space

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 shafts 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).

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 (Mail Online News, 2011) then be a model for the disputed museum venture?

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 being 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 rock resource and purpose-driven (Vähäaho, 2011a).

In 2017, the Port of Helsinki was the busiest passenger port in Europe and possibly the entire world with 12.3 million passengers. Passenger numbers continued to increase on the Helsinki-Tallinn route in particular, reflecting the development of Helsinki and Tallinn, which have close economic and social ties. Corresponding figures can't be reached anywhere else in the world, because elsewhere the important ferry connections have mainly been replaced with bridges or tunnels.

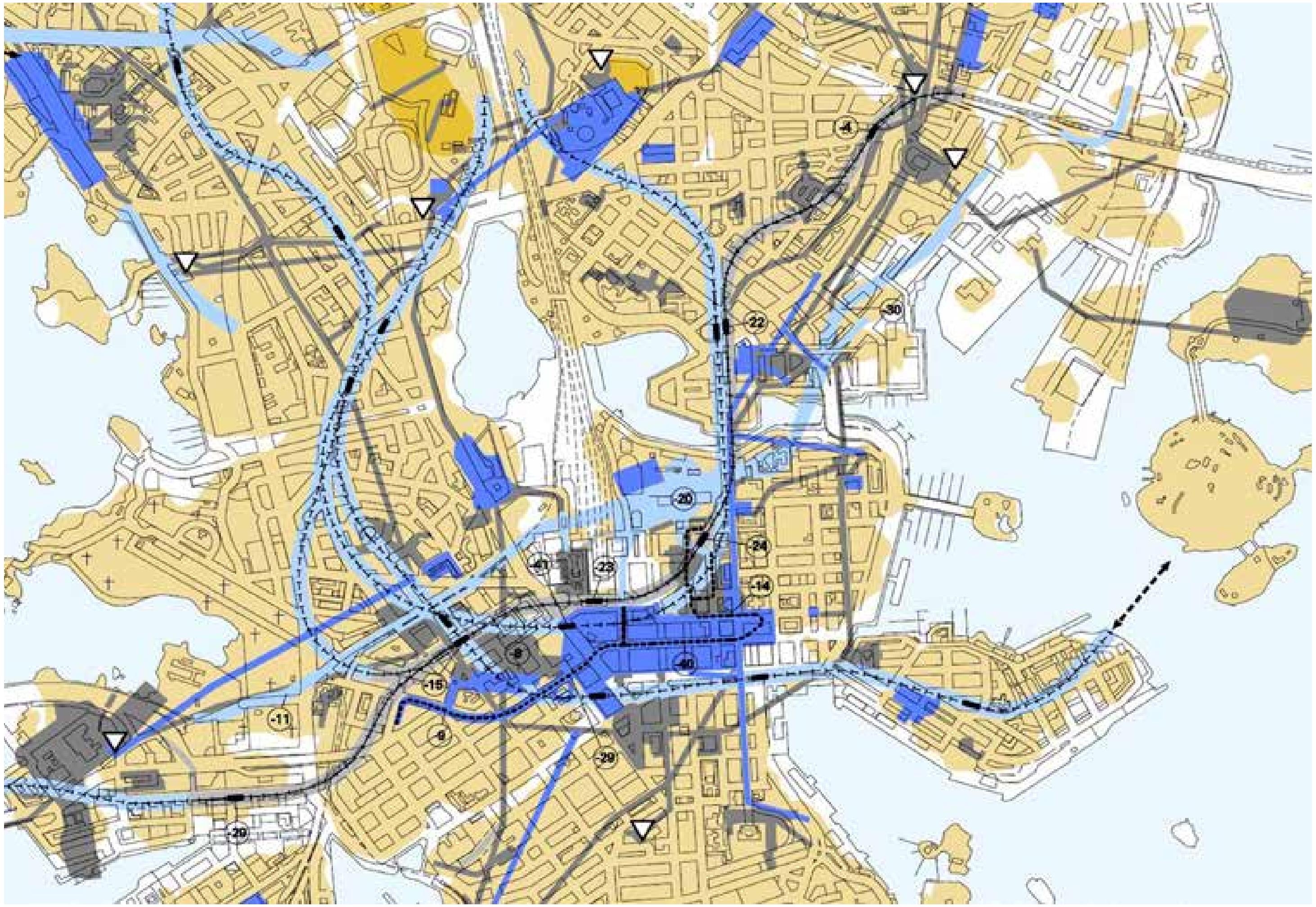
Today, the **Helsinki-Tallinn** metropolitan areas have a combined population of 2 million. In 2008, an International Ideas Competition called 'Greater Helsinki Vision 2050' was organised to visualise the future of Helsinki. The winner of the competition proposed a new, fixed connection between the capitals through an 80-kilometre subsea FinEst tunnel, which would generate huge potential for them to become a true twin city – 'Talsinki' (Vähäaho, 2016).

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. The construction of the tunnel between the capitals will be a logical step for further integration of the city spaces and 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

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



future extensionof the Rail Baltica rail link, which is a project to improve north–south connections among EU Member States (Keinänen, 2009). This project was accepted by the Council of the EU as a first priority EU project.

Moreover, according to Vesterbacka and Valtonen (2016), the FinEst Tunnel would form a unique Tri-City Helsinki-Tallinn-St. Petersburg area with a population of over 20 million. The Helsinki-Tallinn twin city might then become a major hub between Asia and Europe.

The bedrock construction conditions between Tallinn and Helsinki were discussed by Ikävalko et al. (2013). They focused on providing an overview of the geological and geotechnical properties of the construction environment, and described 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.

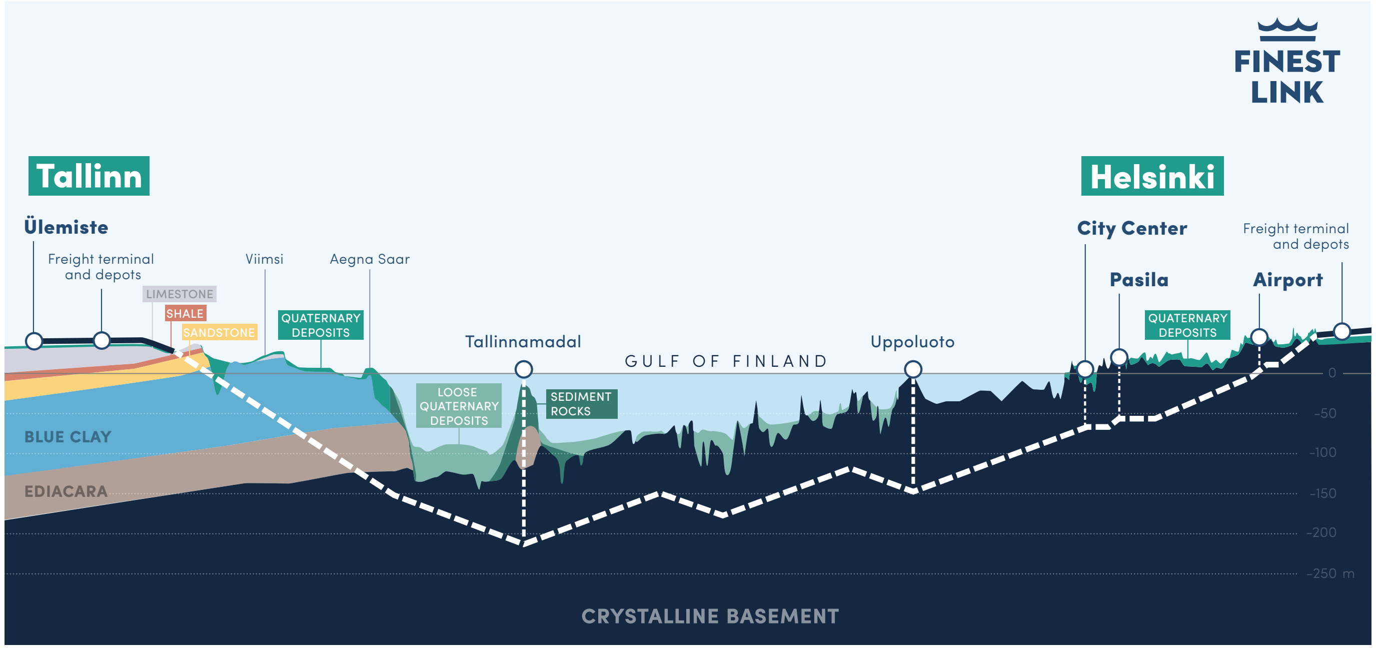


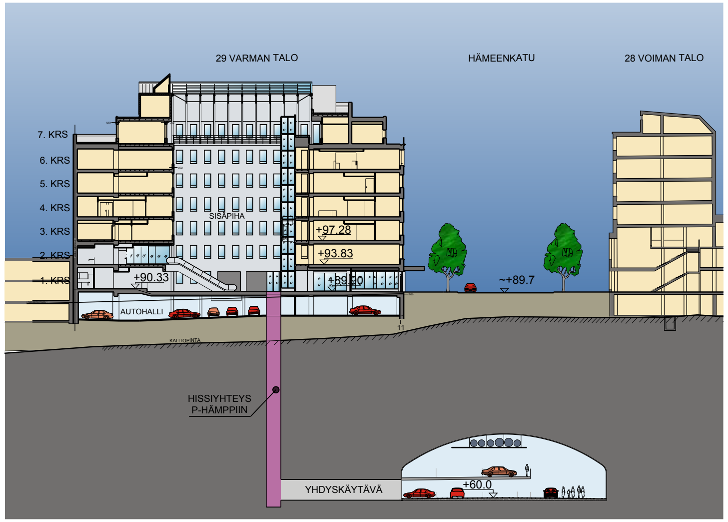
Fig. 11. A map and longitudinal section of the proposed Helsinki-Tallinn undersea tunnel. (Section image: Muotoilutoimisto Kairo Oy). Elevations are with reference to mean sea level in metres (Image: OpenStreetMap, FinEst Link, 2018)

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 limited experience of tunneling work in 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 on the Finnish area are mainly obtained based on mapping done in the coastal areas and islands. More detailed data are gathered in some undersea sewage tunnel projects. The description of the investigation and geological setting of the Estonian area is based on a report by Suuroja et al. (2012) and a new acoustic-seismic survey of the proposed railway tunnel route options between Helsinki and Tallinn, conducted by the Geological Survey of Finland's Marine Geology Unit (2017). In the reports, 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: 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). Geological data in the City of Helsinki Database (Soili) is described in detail by



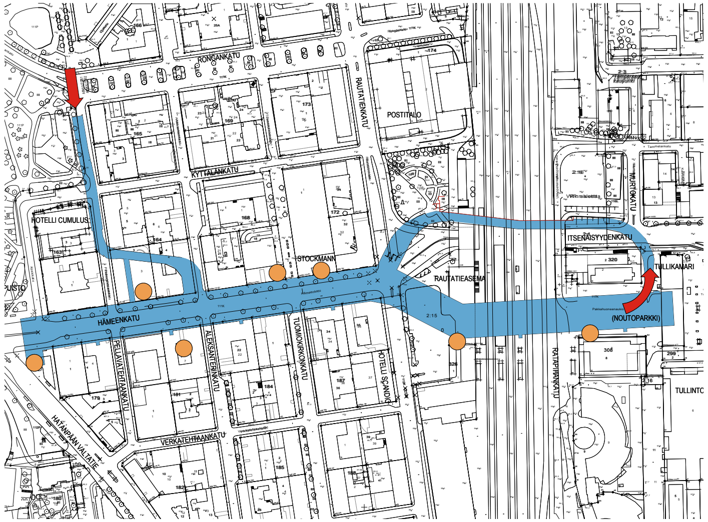


Fig. 13. Future Tampere with the Central Arena constructed over the main railway station, housing several facilities on different levels. (Image: Tampere Central Arena)

Fig. 12. The new parking solution, called 'P-Hämppi', is located below the main street in Tampere. (Image: architectural firm Aihio Arkkitehdit Oy)

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).

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. 12 and the future vision of Tampere Central Arena (2011) in Fig. 13. The new parking solution for 972 cars in Tampere received the European Parking Association (EPA) Award 2013. It has also been chosen as the best new parking house in Europe and the best indoor lighting project in Finland 2013. The planning of this parking cavern 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 cavern '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.

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. 14). 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 year-round temperature target is +15°C. The total cost is EUR 73.5 million, of 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 was completed by the end of 2015.

Fig. 14. Kivisydän (Stoneheart)
The underground parking cavern in Oulu
● lift
● car access
(Image: City of Oulu and Oulun Pysäköinti Oy)

References

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

FinEst Link, Helsinki-Tallinn, 2018, Information, statistics and research about the cities of Helsinki and Tallinn and the increasing mobility between them **www.finestlink.fi/en/**

'Greater Helsinki Vision 2050', 2008 **https://www.hel.fi/hel2/helsinginseutu/2050/en/what-is-this/greater-helsinki-vision-2050.html**

Geological Survey of Finland Marine Geology, 2017, Acoustic-seismic survey along the proposed railway tunnel route options, between Helsinki and Tallinn. 19.8.–1.11.2016, 10.01.2017/ Journal No. GTK74/03.02/2016 **http://www.finestlink.fi/wp-content/uploads/2017/02/Hki-Tallinn-2016-GTK-Report.pdf**

Hiltunen, M., 2013, 'Maanalainen Tampere on autoilijan: Pysäköinti osana kaupunkikeskustan kehittämistä' (Underground Tampere is for the driver: Parking as apart of downtown development), The Day of Underground Possibilities, MTR-FTA, 11 April 2013, Helsinki, Finland (in Finnish)

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)

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' (A Growing and Developing Capital Needs Underground Spaces) The Day of Underground Possibilities, MTR-FTA, 11 April 2013, Helsinki, Finland (in Finnish)

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**

Vesterbacka P., Valtonen K., 2016, FinEst Bay Area Program – The New Northern Silk Road
http://www.finestlink.fi/wp-content/uploads/2016/11/Peter-Vesterbacka.pdf

P-Hämppi, 2012, P-Hämppi is the first stage of Parkisto, Tampere's underground parking solution (in Finnish)
https://www.finnpark.fi/p-haemppi/

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 Deck and Arena, 2011, Tampere Central Arena is a project aiming to build a new multifunctional arena in Tampere.
https://libeskind.com/work/tampere-central-deck-and-arena-2/

Twin-City Scenario, 2013, H-TTransPlan, Helsinki-Tallinn Transport & Planning Scenarios

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

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

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 cavern (width 50 m, length 150 m, height 12 m). 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. 15). 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 presented 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 (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.

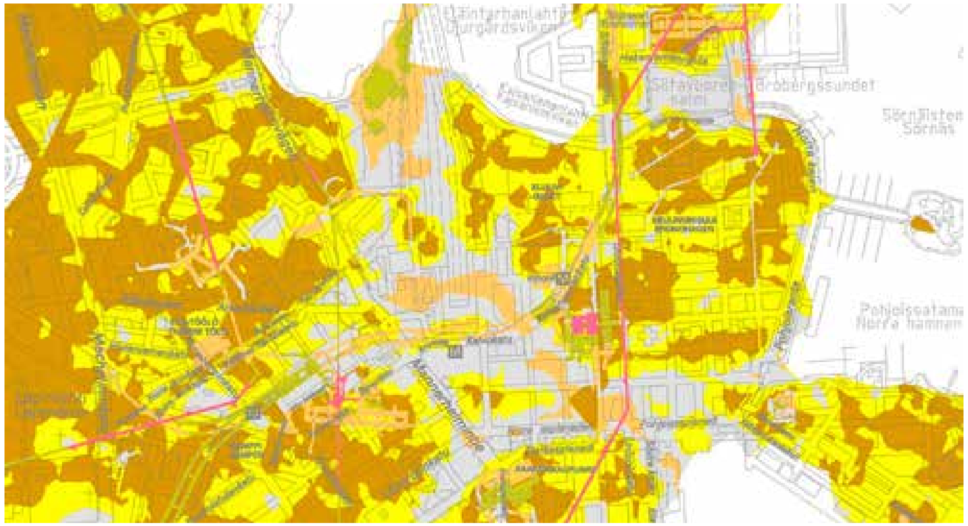
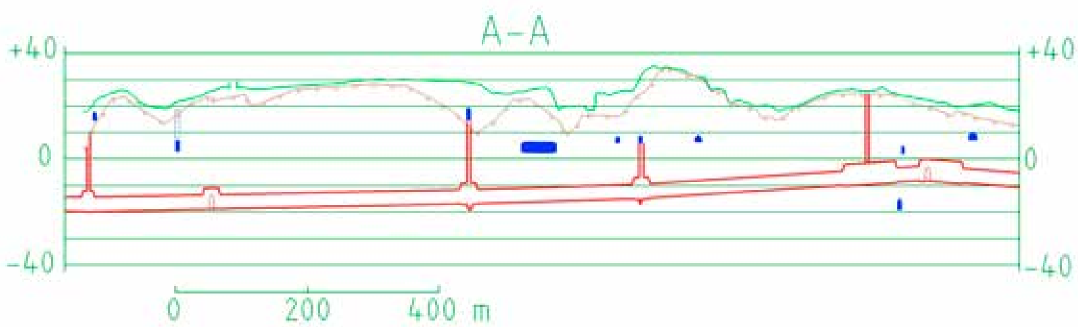


Fig. 15. Extract of the rock surface model. The deepest public underground spaces have been taken into consideration when presenting free rock resources. The estimated rock surface is based on bedrock confirmation drillings.
(Image: City of Helsinki Real Estate Department)

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 into consideration. These issues are briefly discussed in Chapter 6.

Our specialties are 'all-in-one' utility tunnels for district heating and cooling, electrical and telecommunications cables and water. 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. 16 and 17). The fundamental idea of district heating and cooling is to use local resources that would otherwise be wasted (Helsinki Energy, 2013).

The City of Helsinki has about 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. 16. Typical utility tunnel.
(Photo: JormaVilkman)

Fig. 17. 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).

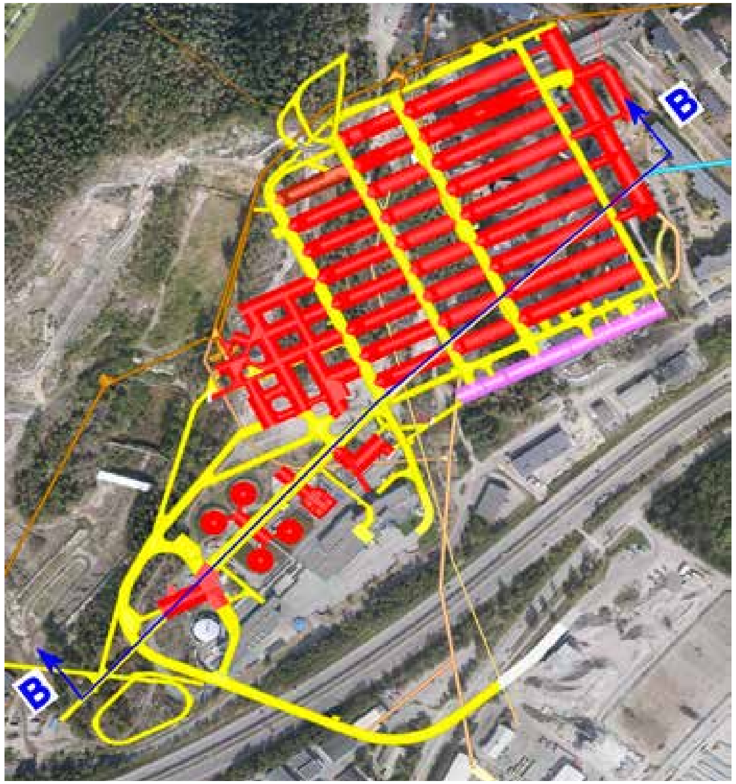
Raw water for the Helsinki region comes from Lake Päijänne via a rock tunnel measuring 120 km (Laitakari and Pokki, 1979).

- 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 Helsinki 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. 18). 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. 19 and 20). 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.

Fig. 18. The 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)



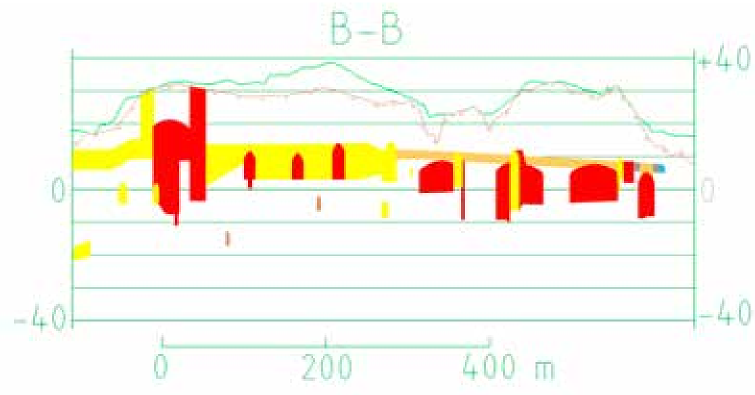


Fig. 19. An aerial view of the Viikinmäki wastewater treatment plant.
(Image: City of Helsinki)

Fig. 20. 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)

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 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 have 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 utilised.
- 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.
- 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

Helsinki Energy, Annual Report 2013, District Heating and District Cooling **https://www.helen.fi/en/annual-report/annual-report-2013/a-year-in-helen-group/the-business-year/district-heating-and-district-cooling/**

Laitakari I. and Pokki E., 1979, Summary: Geological observations from the Päijänne Tunnel, construction phase 1, Hl. 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
https://about.ita-aites.org/wg-committees/itacus/downloads/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. A lot more attention has been paid to underground architecture as well as the reuse of underground spaces no longer used for their original purpose.

Helsinki consists of 214 km^2 of land and 500 km^2 of sea. The City of Helsinki owns 63% of the land area of Helsinki as of 2017 (Fig. 21). "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 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 increasingly 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.

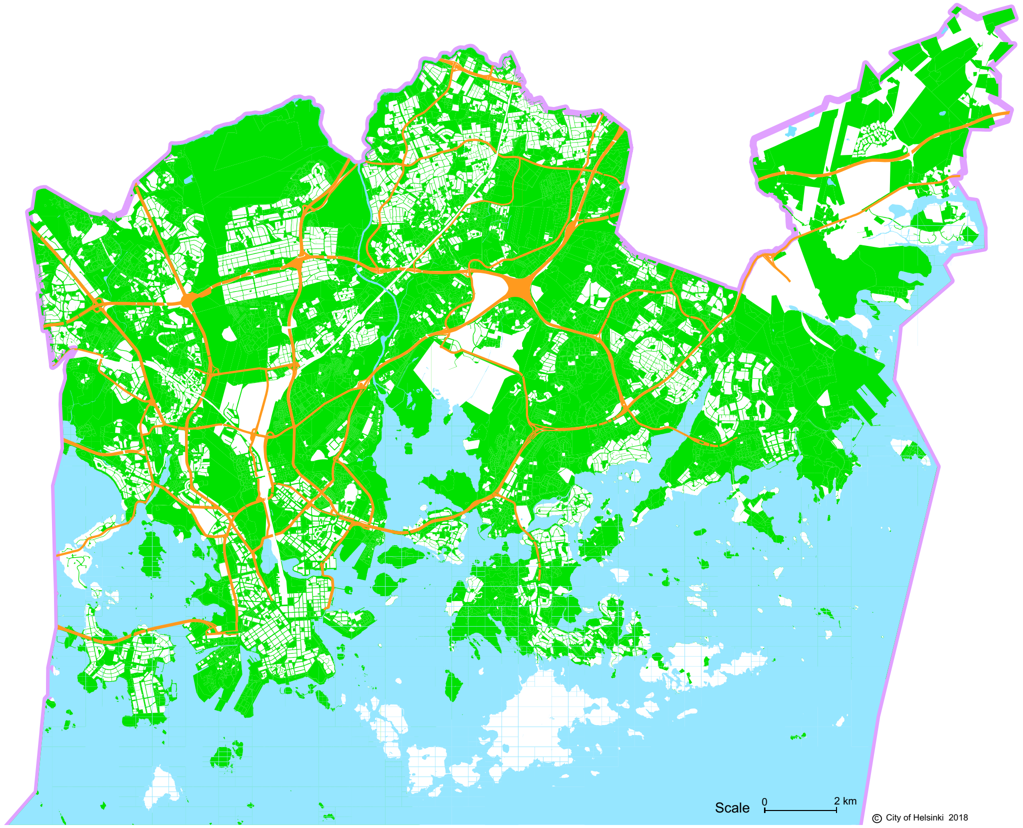


Fig. 21. Map of Helsinki. The green coloured areas are land owned by the City of Helsinki; white coloured areas are owned by others. (Image: City of Helsinki, Land Property Development and Plots)

The deepest underground spaces in Helsinki are situated about 100 m below sea level.

Fig. 22 Downtown Singapore in 2004 (Photo: Ilkka Vähäaho) and Helsinki Market square (Photo: City of Helsinki Media Bank).

Buildings in Helsinki are mainly quite low with skyscrapers only being built in some special areas. The historic inner city (as seen in Fig. 22) is therefore remarkably different from the centre of Singapore, for instance. Helsinki can be classified by the term 'downrise city' (using underground resources effectively) while Singapore, in turn, is a 'high-rise city', which was fashionable in the 1900s. The deepest underground spaces in Helsinki are situated about 100 m below sea level. Nevertheless, underground resources may also be found in the inner city in the future, if needed.

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

A good example of making use of land property resources several times is the Katri Vala Park situated in the city centre (Fig. 23). Nowadays, there are four totally independent underground activities under the park. 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 (similar to sustainable use of underground space) adopted by Sterling et al. (2010).

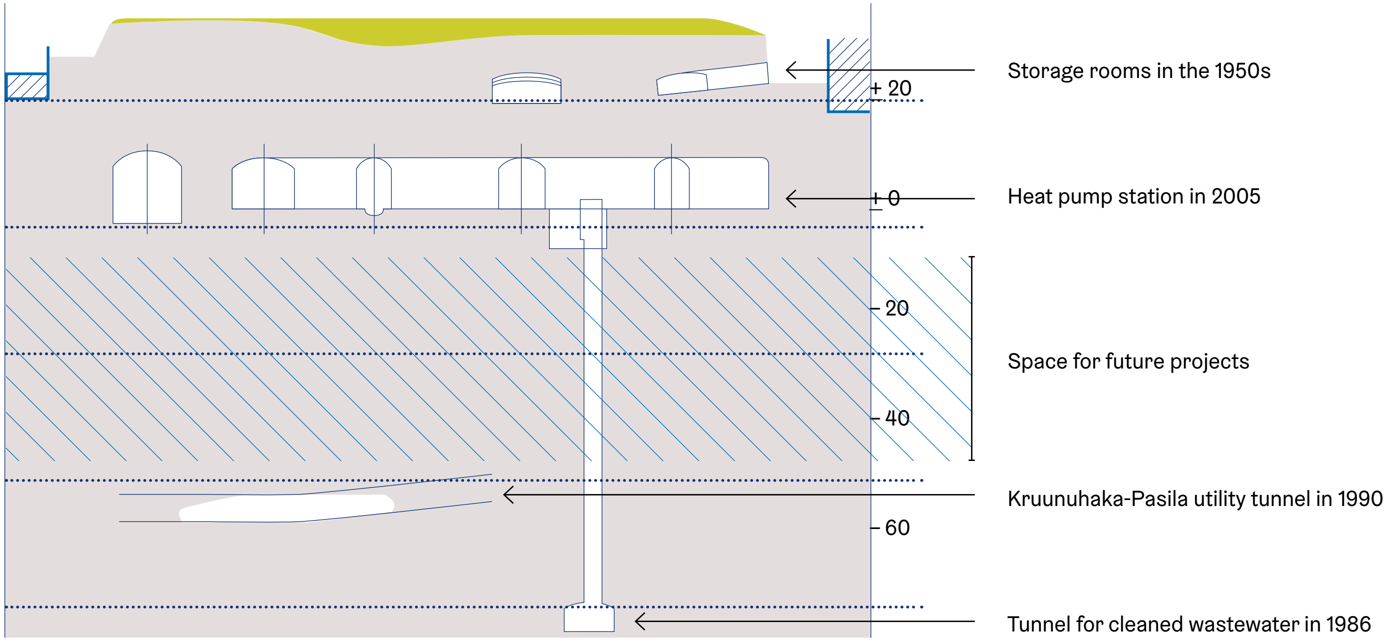


Fig. 23. Example of 0-land-use: Katri Vala Park in Helsinki. (Image: City of Helsinki)

So far, the cadastral system in Finland has been two-dimensional, but the new 3D cadastral system is going to come into effect on the first of August 2018. Finnish legislation is not precise about the extent of landownership – not upwards or downwards. There is a difference between the right to use property and the ownership of land. The lower boundary of the right to use 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 add multiple underground levels to their buildings, they must have a building permit; on the other hand, the right to build a deep cellar must be in accordance with zoning. The question is not about land ownership 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 limit of six metres is a practical measure for building one, or a maximum of two cellars below ground level. This six-metre limit is not part of Finnish legislation, but 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 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. 24).

Deep boreholes to harness ground heat are becoming more common, even in city centres.

Fig. 24. The cold water reservoir for district cooling in Helsinki's city centre was built between 50–90 metres from ground level because of the lack of free underground space. (Photo: Helen Oy)

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-governmental 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.

The use of geothermal energy in Finland is restricted to the utilisation of ground heat with heat pumps. This is due to geological conditions, as Finland is part of the Fennoscandian Shield (Kukkonen, 2000). We call this type of energy 'ground heat' but actually the energy resource we use is heat from bedrock, nowadays up to some 300 metres deep.

Deep boreholes to harness ground heat are becoming more common even in city centres. Typically, these boreholes are 150–300 metres deep. There are 3,710 boreholes for ground heat in Helsinki as of June 2018 and the number is rising by about 30 every month. It means that there is an average of one deep borehole every 240 metres. In spite of claims made by 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. An 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 in only 24 countries (Fridleifsson et al., 2009).

Underground Architecture

More and more attention is being paid to the attractiveness of underground spaces these days (Vähäaho, 2016). This is evident, for example, in the interior and other design of parking facilities and the accessways leading to them (Fig. 25).

The planning of underground spaces located in bedrock gives architects an opportunity to utilise the living and versatile rock surface. Structural engineers need to understand and know how to dimension the underground space as a rock-framed, self-supporting structure. The outcome is not only cheaper than a concrete-framed space, but at least in the opinion of the author of this paper, also far more beautiful (Fig. 26).

Architectural attraction leads underground

The space in the city centre is getting increasingly cramped, and there are not many free spots for building above ground. This issue was up for discussion at the Amos Anderson Art Museum when its future was being considered. A new idea was born, which concerned acquiring more space below ground as well as connecting Lasipalatsi (one of the most iconic buildings in Helsinki) and the museum to form a whole (Fig 27). The project was named Amos Rex and the museum was reopened in 2018 after the renovations and construction had been completed. Museum Director Kai Kartio says that expanding museums below ground is not very unusual on a global scale. "In our case, the unusual part is how it was planned. Amos Rex is turning into an architectural attraction," Kartio says. The location underground is not something that is emphasised at Amos Rex, quite the opposite. The transition from Lasipalatsi Square to underground is unnoticeable, and natural light is channelled into the building. Kartio is pleased with the fact that the underground facilities made it possible for Amos Rex to be built in the centre of Helsinki (Helsinki New Horizons, 2018).

Fig. 25. Accessways built in the 2010s to the parking facilities in the Helsinki downtown area. (Photos: Ilkka Vähäaho)

Fig. 26. A typical underground space with self-supporting bedrock. (Photo: Ilkka Vähäaho)

Fig. 27. The new Amos Rex Art Museum under Lasipalatsi Square. (Image: Asmo Jaaksi JKMM Architects)

Fig. 28. The flood level measured in 2005 and modelled flood levels in 2020, 2050 and 2100 in front of the Presidential Palace next to Helsinki Market square.

Climate Change

Underground spaces are, in principle, much more prepared for climate change than spaces above ground. However, regarding underground spaces, one matter is of critical importance. Namely, in the planning stage it is important to consider the possibility of various floods and to be prepared, in particular, for safe threshold heights with accesses and other routes connecting the space to the ground surface. For example, at the Hakaniemi metro station, which opened in Helsinki in the early 1970s, the lowest threshold height of the entrance leading to the station is at the level of +2.7 (N2000), but according to new studies based on measurements, flooding sea water could reach the level of +3.4 (N2000) in this area by 2100 (City of Helsinki Soil and Bedrock Unit, 2016). These days, an accurate forecast of an approaching flood can be obtained approximately 2 days in advance. Adapting to climate change is a long-term process (Fig. 28). The impact of climate change must be taken seriously by ensuring, for example, that future flood levels will not reach the level of the entrances and shafts leading to underground spaces.

According to the Finnish Meteorological Institute (Pellikka et al., 2018) “Coastal planning requires detailed knowledge of future flooding risks, and effective planning must consider both short-term sea level variations and the long-term trend. We calculate distributions that combine short- and long-term effects to provide estimates of flood probabilities in 2050 and 2100 on the Finnish coast of the Baltic Sea. Our distributions of short-term sea level variations are based on 46 years (1971–2016) of observations from the 13 Finnish tide gauges. The long-term scenarios of mean sea level combine postglacial land uplift, regionally adjusted scenarios of global sea level rise, and the effect of changes in the wind climate. The results predict that flooding risks will clearly increase by 2100 in the Gulf of Finland and the Bothnian Sea, while only a small increase or no change compared to present-day conditions is expected in the Bothnian Bay, where the land uplift is stronger.”

Reuse of Obsolete Underground Spaces

Underground agriculture
Pyhäjärven Callio is an underground success. The Pyhäsalmi Mine, located in the town of Pyhäjärvi, Finland, is one of the deepest known mines in Europe, reaching 1,445 metres underground. Once mining ends, a globally unique multidisciplinary operating environment, Callio, will emerge. The mine and the surrounding brownfield area offer a diverse range of opportunities for success both for new, innovative projects and established operators seeking new horizons (Callio, 2018).

One of the new applications after the end of the mining activities is underground agriculture. At the moment, cultivation tests are being carried out in the mine at a depth of 660 metres (Fig. 29). As cultivation space is running out globally, gardens isolated from the open air have aroused great interest around the world. A second potato crop is now being grown in the mine. Program Director Sakari Nokela from Callio, who is responsible for developing further use for the Pyhäsalmi Mine, enthusiastically tells us that there could be five Lapland summers a year in the underground conditions.

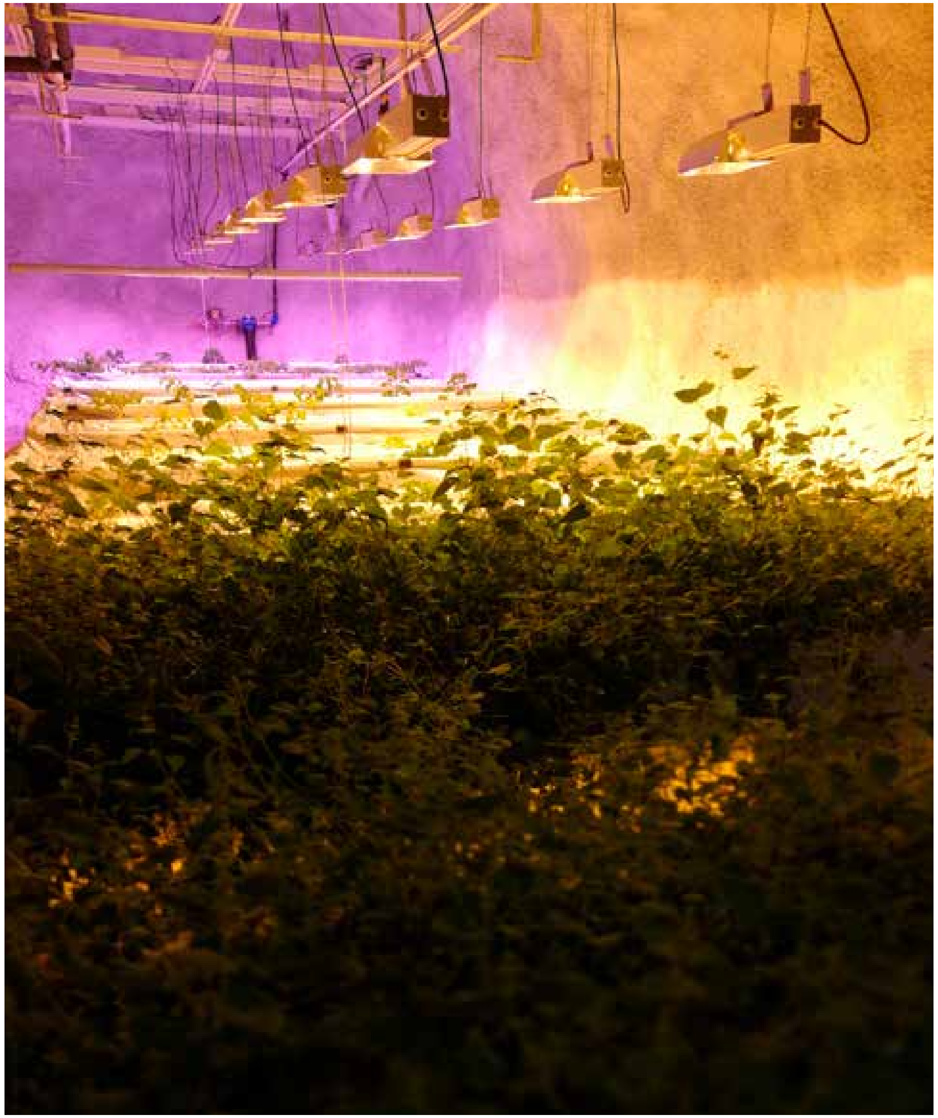


Fig. 29. Growing nettles at a depth of 660 metres in the Pyhäsalmi mine.
(Photo: Sakari Nokela)

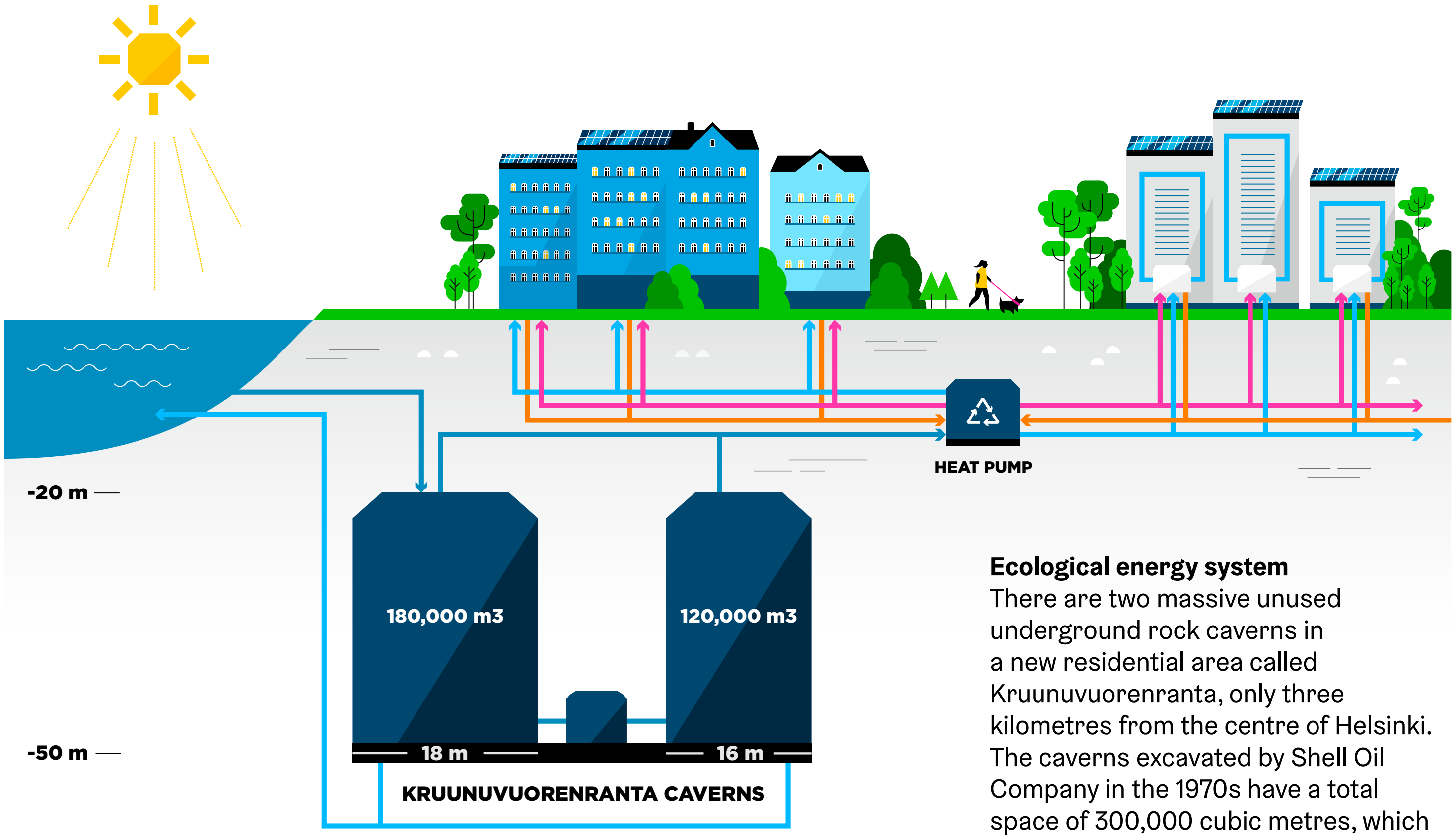


Fig. 30. Obsolete oil reservoirs located three kilometres from the centre of Helsinki will be reused as part of the energy system of an ecological suburb by utilising sea water heated by the sun. (Image: Helen Oy)

Ecological energy system

There are two massive unused underground rock caverns in a new residential area called Kruunuvuorenranta, only three kilometres from the centre of Helsinki. The caverns excavated by Shell Oil Company in the 1970s have a total space of 300,000 cubic metres, which is roughly three times the size of The Parliament House in Helsinki (Yle News, 2018). There are plans to create a seasonal energy storage solution as part of the energy system of this ecological suburb, in which sea water heated by sunlight and the recycled heat of the residential buildings would be utilised in a new way. The rock caverns located underneath Kruunuvuorenranta, one of which was formerly used as an emergency storage space for oil, would be used in the project. The bottom of the caverns are located approximately 50 metres below sea level. The energy solution designed by Helen Oy is based on a model in which the heating and cooling of buildings is implemented using heat pumps. In the summer the caverns would be filled up with surface sea water from the nearby coastal area and used as a source of energy for the heat pumps during the cold season. In other words, the stored water acts as a source of energy for the heat pumps. In all its simplicity the project is quite smart, according to Mr. Jouni Kivirinne, Development Manager at Helen Oy (Fig. 30).

References

Callio, 2018, Callio – Mine for Business
https://callio.info/

City of Helsinki, Soil and Bedrock Unit, 2016, Safe levels for construction in coastal areas of Helsinki in 2020, 2050 and 2100 (Turvalliset rakentamiskorkeudet Helsingin rannoilla vuosina 2020, 2050 ja 2100), in Finnish with English abstract.

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 New Horizons, 2018, Karting, Latin dance and technology – a second city underground
https://www.hel.fi/uutiset/en/kaupunginkanslia/a-second-city-underground

Kukkonen I., 2000, Geothermal Energy in Finland, Proceedings World Geothermal Congress 2000, Kyushu-Tohoku, Japan, 28 May-10 June 2000,
https://www.researchgate.net/publication/266073223_GEOTHERMAL_ENERGY_IN_FINLAND

Pellikka H., Leijala U., Johansson M., Leinonen K., Kahma K., 2018, Future probabilities of coastal floods in Finland, Continental Shelf Research 157 pp. 32–42, Elsevier Ltd, Available online 21 February 2018

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

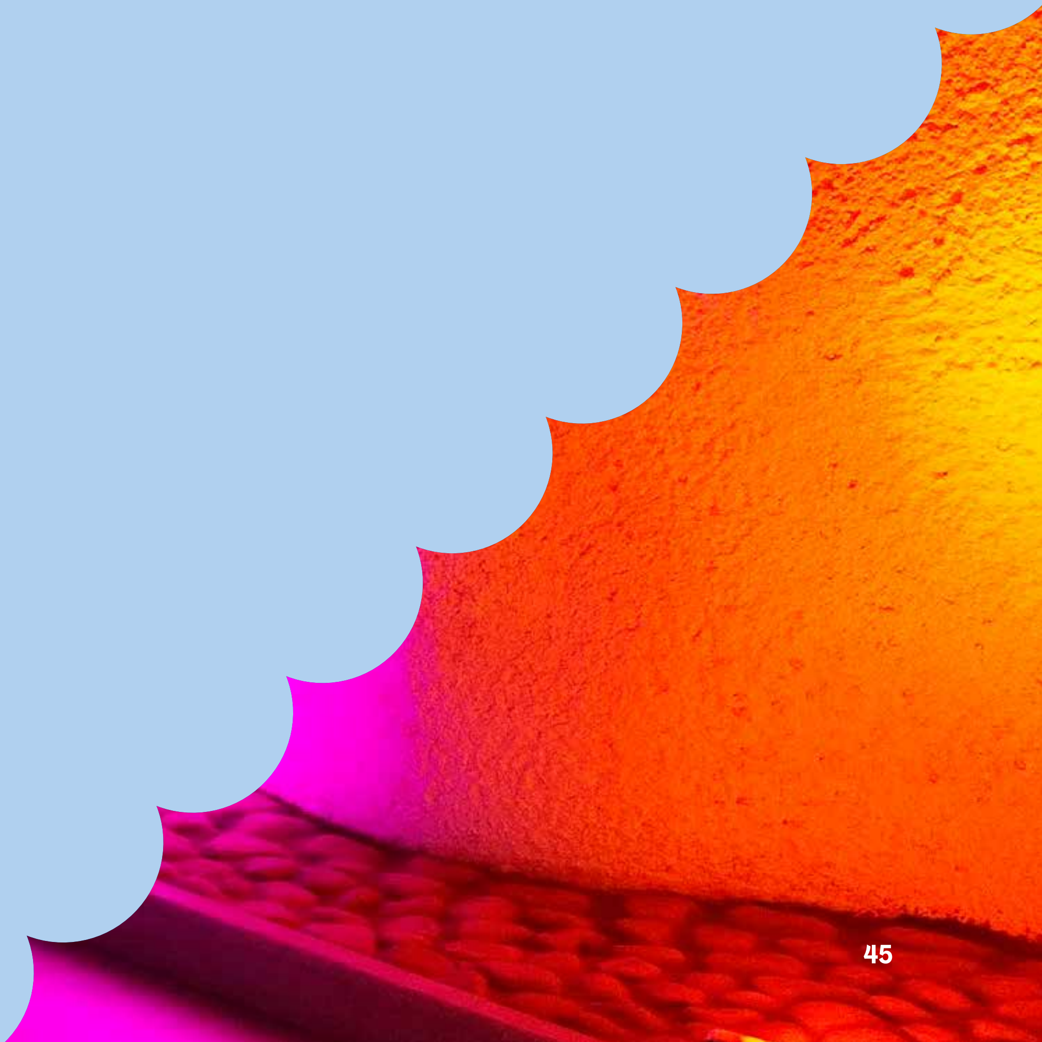
Vähäaho I., 2011b, Workshop on “Use of Underground Space in Hong Kong” for the Hong Kong Government’s engineers and city planners, 26 September 2011, Hong Kong

Vähäaho I., 2016, Geology and Development for Urban Underground Space in Helsinki and Tallinn, Lectures for studio course at Aalto University, School of Art, Design and Architecture, Department of Architecture

Yle News, 2018, Kruunuvuorenrannan luolat täytetään merivedellä, joka lämmittää kolmanneksen alueen asunnoista – ”yksinkertaisuudessaan viisas hanke”,
https://yle.fi/uutiset/3-10036485?origin=rss

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
https://www.hel.fi/static/kv/maata-nakyvissa.pdf

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 being 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 more important main drivers than winter, such as the Finnish need to have open spaces even in the city centre, the excellent and long-lasting cooperation between technical units and commercial enterprises as well as the small size of Helsinki. It is among the smallest cities 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 technicalnetworks 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 utilised; 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.

More and more attention is being paid to the attractiveness of underground spaces these days. The planning of underground spaces located in bedrock gives architects an opportunity to utilise the living and versatile rock surface. Structural engineers need to understand and know how to dimension the underground space as a rock framed, self-supporting structure. The outcome is not only cheaper than a concrete framed space, but at least in the opinion of the author of this paper, also far more beautiful.

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. Moreover, the FinEst Tunnel would form a unique Tri-City Helsinki-Tallinn-St. Petersburg area with a population of over 20 million. The Helsinki-Tallinn twin city might then become a major hub between Asia and Europe.

8.
Further information

8. 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
https://www.youtube.com/watch?v=munQwhSdUn8

City of Helsinki, Underground master plan, Materials and further information
https://www.hel.fi/helsinki/en/housing/planning/current/underground-master-plan

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

The Finnish Geotechnical Society SGY and the Finnish Tunnelling Association MTR-FTA maintain the websites for professionals who actively participate in ground and tunnelling engineering
https://sgy.fi/
https://mtry.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
http://www.cost.eu/COST_Actions/tud/C7

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

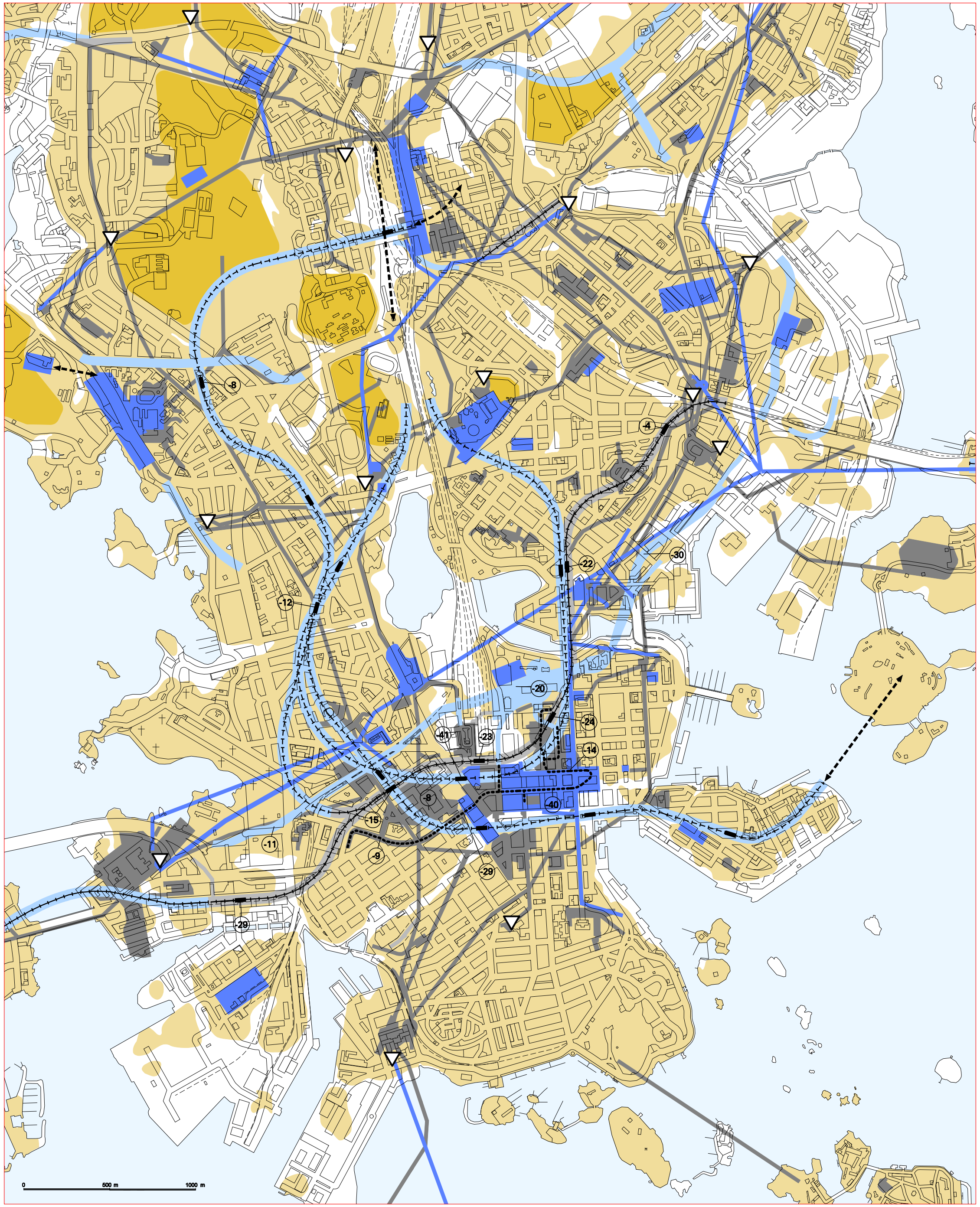
Underground Swimming Pool in Itäkeskus
https://www.hel.fi/helsinki/en/culture/sports/indoor/swimming/itakeskus-swimming-hall

Viikinmäki' underground wastewater treatment plant
https://www.hsy.fi/en/experts/water-services/wastewater-treatment-plants/viikinmaki/Pages/default.aspx

Yle News Report: Helsinki-Tallinn tunnel would cost 16 billion euros, journey time 30 minutes, tickets 18 euros each way
https://yle.fi/uutiset/osasto/news/report_helsinki-tallinn_tunnel_would_cost_16_billion_euros_journey_time_30_minutes_tickets_18_euros_each_way/10063161

Conflict of interest

The author of this paper 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.



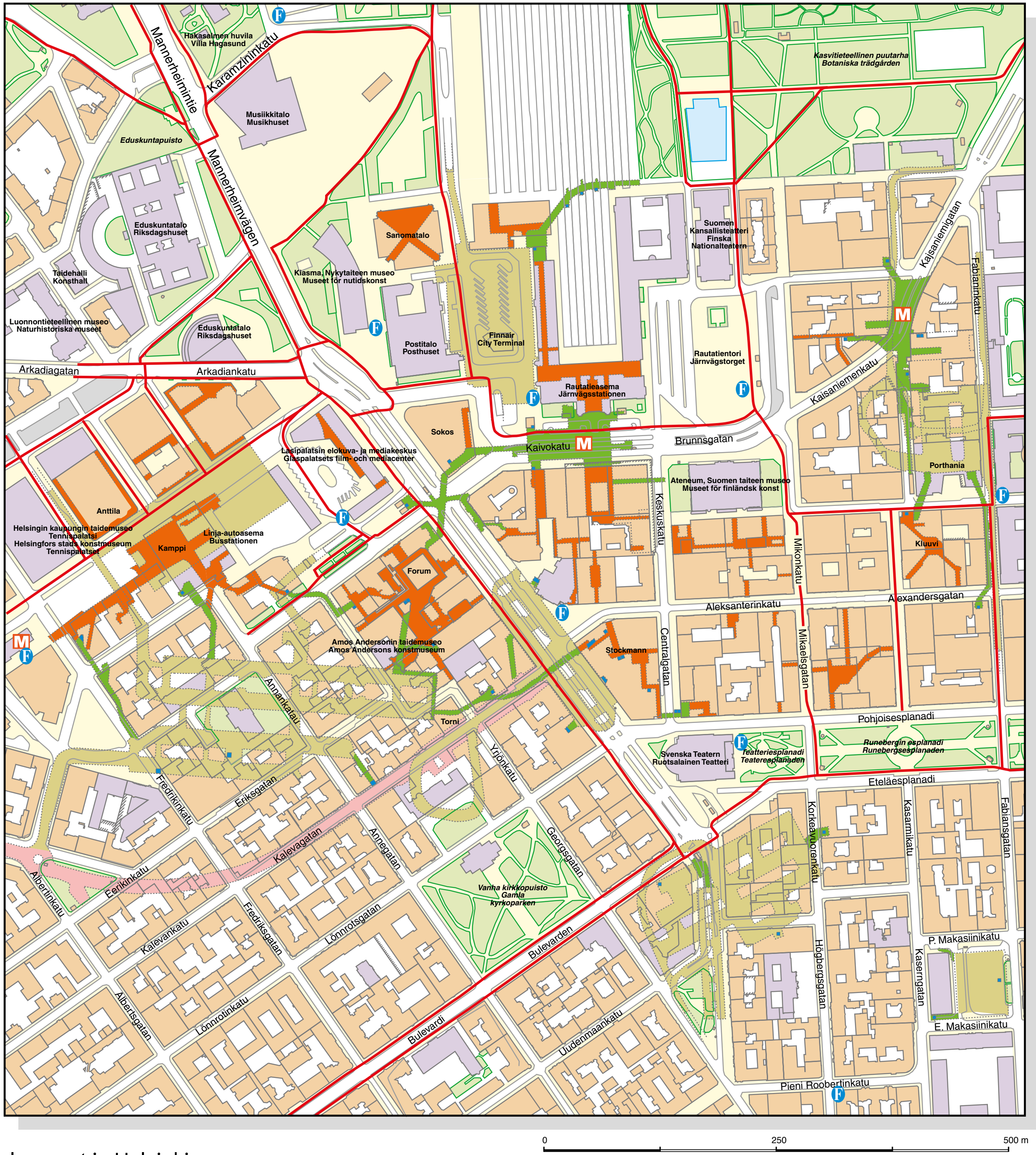
Extract of the Helsinki Underground (UG) Master Plan.

(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

Pedestrian precincts
Pedestrian subways
Parking halls

- Pedestrian precinct
- Connection in block
- Pedestrian subway
- Underground parking
- Green area
- Public building
- Metro station
- Lift
- Bike lane
- City biking park



About the author

Photo: Kai Jaskari

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

He has 41 years of experience in foundation and rock engineering at the City of Helsinki and has been the Head of Geotechnics since 1997.
www.geotechnics.fi

He is a member of the Advisory Board of the ITA Committee on Underground Space ITACUS.
https://about.ita-aites.org/wg-committees/222-root/committees/itacus

Mr. 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.
https://sgy.fi/
https://mtry.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, with some remarks on underground space around the world. The city has an underground master plan for its whole municipal area, not only for certain parts of the city. Later in the text, 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 has taken 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 through 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. Moreover, the Helsinki-Tallinn twin city may become a major hub between Asia and Europe.

Keywords:
Land-use planning, underground resources, master plan, sustainability, urban development, 3D cadastral system, geological data, land ownership, underground architecture and agriculture

www.geotechnics.fi

Helsinki