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Underground space planning in Helsinki

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ABSTRACT

This paper gives insight into the use of underground space in Helsinki, Finland. The city has an underground master plan (UMP) for its whole municipal area, not only for certain parts of the city. Further, the decision-making history of the UMP is described step-by-step. Some examples of underground space use in other cities are also given. The focus of this paper is on the 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 21st century; at the same time, the necessity to control construction work has also increased. The UMP 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-km 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.

1. Introduction: geological conditions and challenges in Helsinki—experiences and advice

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 km^2, the surface area of Helsinki is only 214 km^2 spreading across a number of bays and peninsulas, and encompassing a number of 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 square kilometre.

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 which might suggest with an average in January and February of around −5 °C (23 °F). Due to its latitude, days last for approximately 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).

Helsinki's landscape is quite flat—the highest natural point is only 60 m above sea level. One third of Helsinki's ground is clay with an average thickness of 3 m and shear strength of around 10 kPa. The average depth of soil material upon bedrock is 7 m, but varies from 0 to almost 70 m. The bedrock quality in Finland is for the most part ideal for tunnelling and for building underground spaces, because the bedrock mainly consists of old Precambrian rocks and 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. 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,

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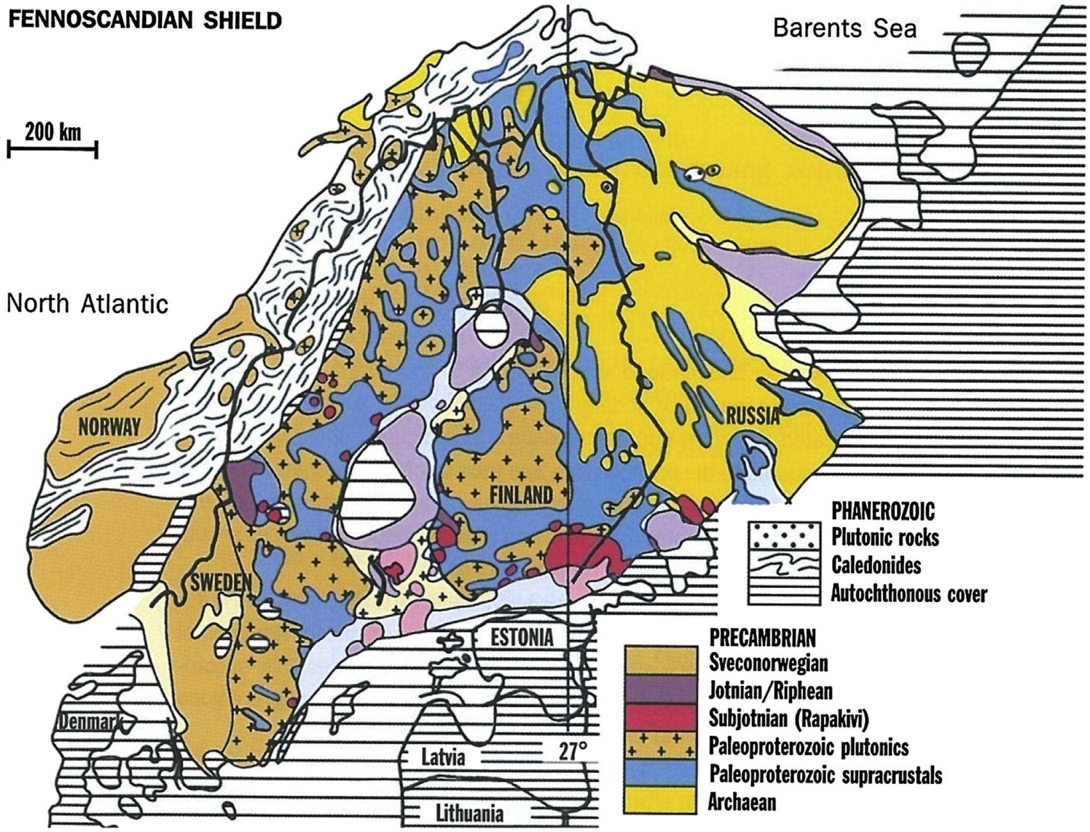

Fig. 1. Geological conditions in Finland and Scandinavia (Image: Geological Survey of Finland).

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. Being more fragmented than surrounding areas, the fracture zones have been eroded more rapidly and are seen as depressions in the topography. The fracture zones have had a great impact on defining the shoreline of Helsinki city centre (Vänskä and Raudasmaa, 2005).

The fracture zones are usually under thick layer of soil and therefore hard to be examined. However, there are signs of movements on nearby rock surfaces which help to locate the zones.

The average price of tunnels and underground spaces is 100 euros/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, and 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.

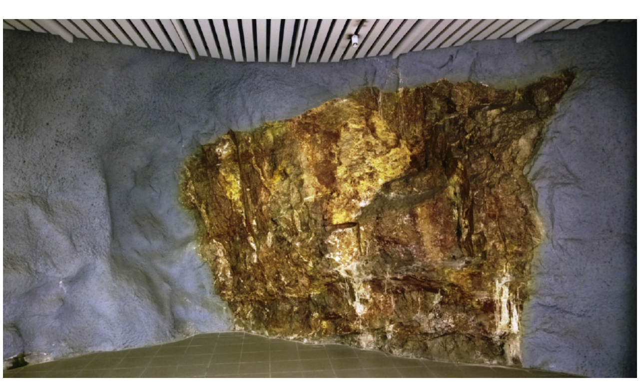

Fig. 2. A bare uncovered rock surface 'window' in the Kluuvi underground parking hall in Helsinki (Photo: Ilkka Vähäaho).

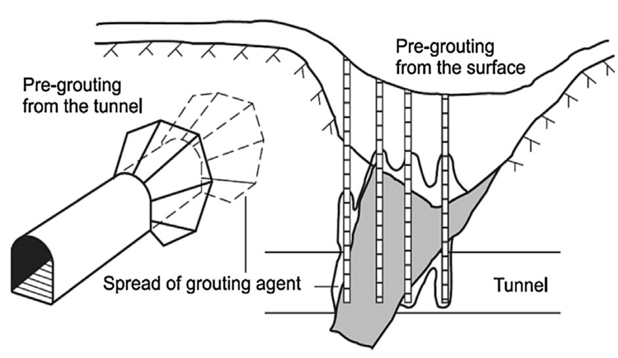

Fig. 3. Pre-grouting is most important because of the conditions in Helsinki (Image: Sandvik Mining and Construction Finland).

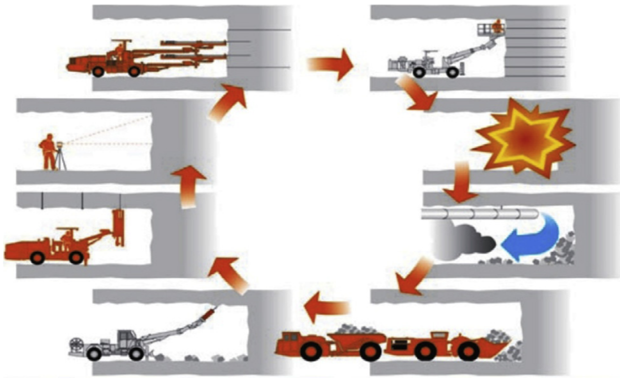

Fig. 4. D&B method cycle: drilling → charging → blasting → ventilation → loading → scaling → reinforcements → measuring (Image: Sandvik Mining and Construction Finland).

2. History of the underground master plan of Helsinki

The process of drawing up the UMP was according to the following decision-making history (Helsinki City Council, 2010) and Narvi (2012):

(1) Since the 1980s, the City of Helsinki has maintained an underground space allocation plan.
(2) In the early 2000s, a need arose to draw up a UMP for the entire city's underground facilities.
(3) On 9 December 2004, the Helsinki City Planning Committee approved a set of planning principles for preparing the UMP.
(4) 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.
(5) In 2005, an open discussion event was arranged for anyone interested; many in-depth discussions were held with different interests.
(6) 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.
(7) At the start of 2007, at the draft plan finalisation stage, representatives from the water and energy utilities Helsingin Vesi and Helsingin Energia 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.
(8) In May 2007, following its examination by the Helsinki City Planning Committee, the draft UMP 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 UMP would then proceed for decision by the City Council at the end of 2007.
(9) On 11 December 2008, the Helsinki City Planning Committee examined the statements and the views given on the draft UMP, and decided that a revised draft should be resubmitted for its consideration.
(10) On 17 December 2009, following the examination by the Helsinki City Planning Committee, the proposed UMP of Helsinki and the statements, objections, views and responses given on it were submitted for approval by the City Council.
(11) On 22 and 29 November 2010, the City Board considered the proposal.
(12) On 8 December 2010, the City Council approved the UMP 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).

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

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

(1) The UMP 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 UMP 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. Commented by Ilkka Vähäaho).
(3) Connected to the UMP will be an underground space allocation plan, which will support the City's underground facilities management system and the exchange of information.
(4) The UMP 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 which are for the public 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.

3. Key considerations for the use of underground space

There are 10,000,000 m^3 underground spaces in Helsinki (parking, sports, oil and coal storages, the metro, etc.), more than 400 premises, 220 km of technical tunnels, 24 km of raw water

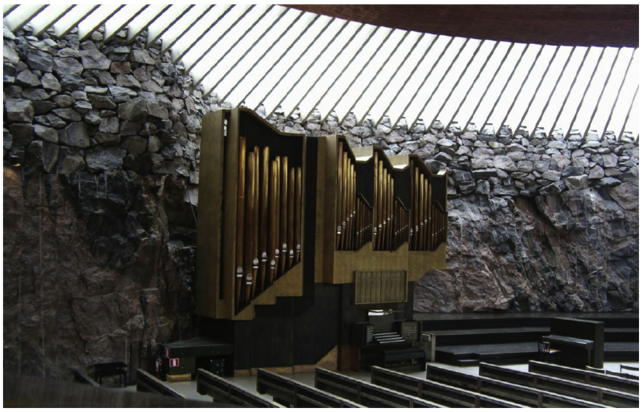

Fig. 6. Temppeliaukio Church built into solid rock (Photo: Pertsaboy).

tunnels and 60 km of 'all-in-one' utility tunnels (district heating and cooling, electrical and telecommunications cables, and water). The fundamental idea of district 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.

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 m^2 of surface area there is 1 m^2 of underground space. Consequently, there are still many underground resources for future needs existing within the whole city area (Vähäaho, 2012).

In Finland, property owners must include civil defence shelters in buildings of at least 1200 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 1000 customers at a time. The hall has about 400,000 customers a year. Quarried out of solid rock, the hall can be converted into an emergency shelter for 3800 people if necessary.

Finns are used to have lots of green areas around them—even in urban areas. This is also 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. Although seismic risks are not a major threat in Finland (earth tremors are normally recorded up to a magnitude of 3; the biggest observed occurred on 23 June 1882 with a magnitude of 5), underground solutions would mitigate their effects even more.

As the city structure becomes denser, more facilities suitable 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 a UMP 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 UMP 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 UMP 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.

Helsinki has been the first city to develop a dedicated UMP 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-term 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.

4. Planning for the use of underground space in Finland (Helsinki, Tampere, Oulu) and Estonia (Tallinn)

Space allocations for long-term projects, such as traffic tunnels, must be maintained for future construction. The same

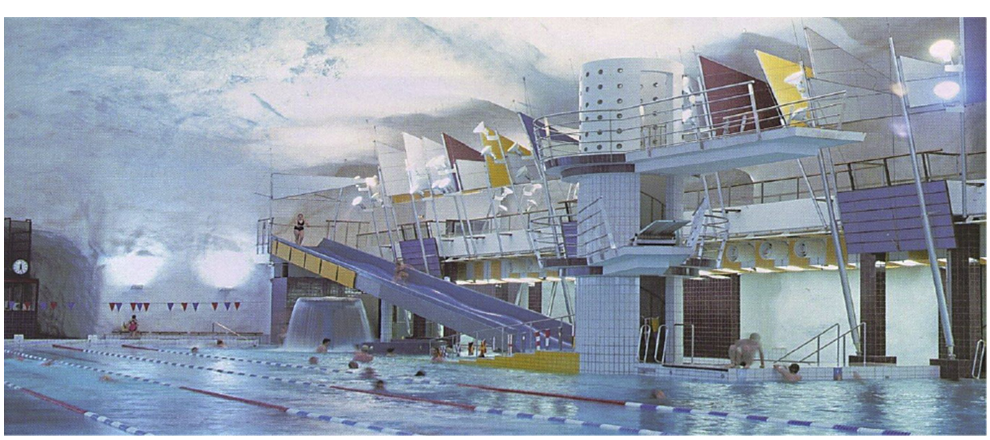

Fig. 7. Underground swimming pool in Itäkeskus, which can accommodate 1000 customers at a time and can be converted into an emergency shelter for 3800 people if necessary (Photo: Erkki Makkonen).

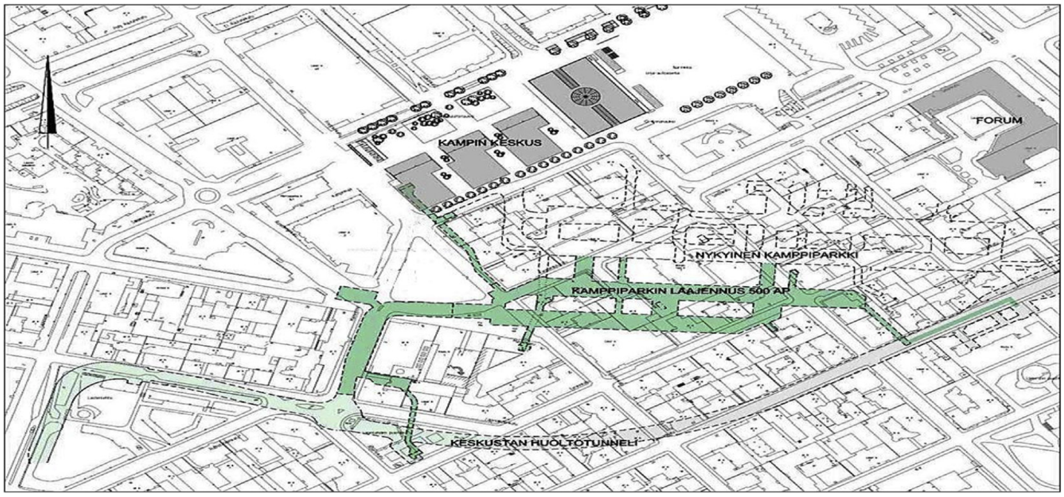

Fig. 8. Example of the development of the city structure of Helsinki where an old car park (shown with a dashed line) is connected to an extension and a new City Service Tunnel (Image: Helsingin Väylä Oy).

applies to those resources that are worth conserving for future projects. The exploitation of those resources must be carried out according to plan since excavating bedrock is a 'one-off action' (an action that can only be performed once). The UMP 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.

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 that the selection of unclassified resources is both purpose- and rock-resource driven (Vähäaho, 2011a).

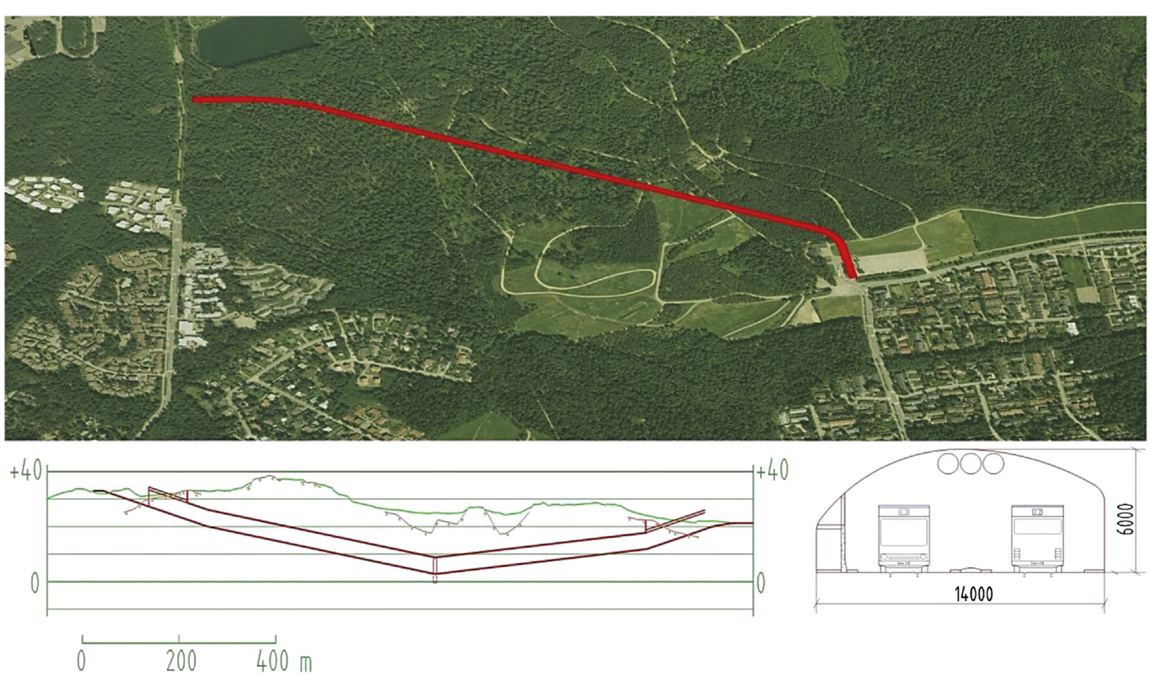

Fig. 9. The 'Jokeri 2' Central Park Tunnel Plan for Public Transport connecting two residential districts (Image: City of Helsinki). The ordinate is the elevation in metre, and the dimension of tunnel cross-section is in millimetre.

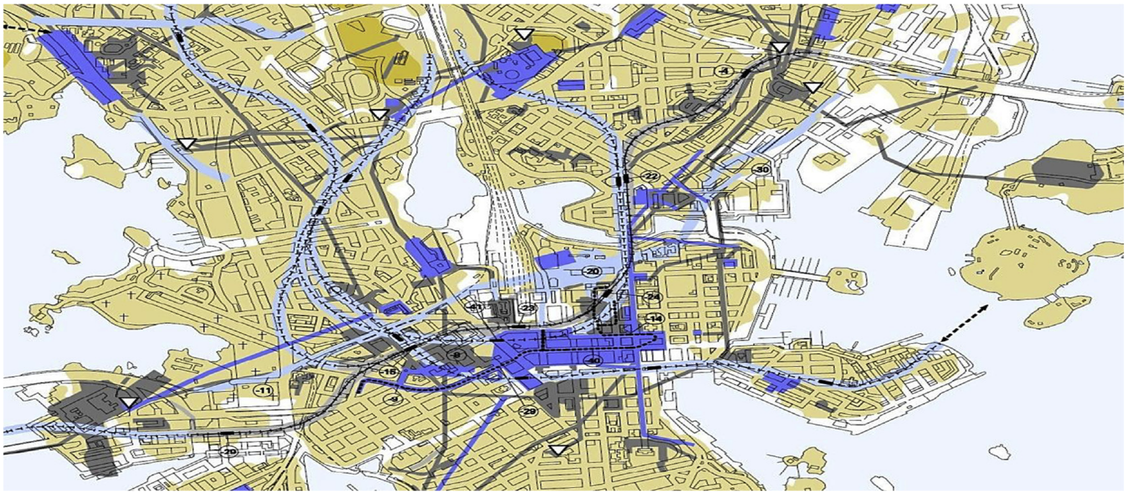

Fig. 10. Extract of the Helsinki Underground Master Plan (Image: Helsinki City Planning Department). Light blue = reserved routes for new tunnels. Dark blue = reserved for future underground spaces. Grey = existing tunnels and underground spaces. Brown = reserved for future use (not designated). Light brown = rock surface less than 10 m from ground level.

'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-km 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". Kallìala (2008) envisaged 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 km-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. 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 subsea 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.

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.

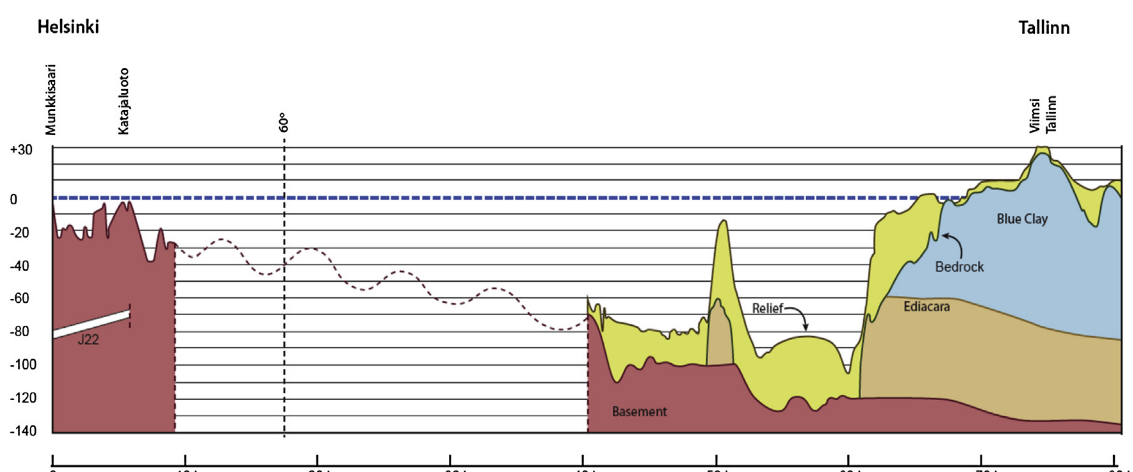

Fig. 11. A longitudinal section through the Gulf of Finland from Helsinki to Tallinn according to the constructed 3D model. The ordinate is the elevation in metre. J22 is the cleaned wastewater outlet tunnel which was built in the 1980s and extends from the Viikinmäki wastewater treatment plant. The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

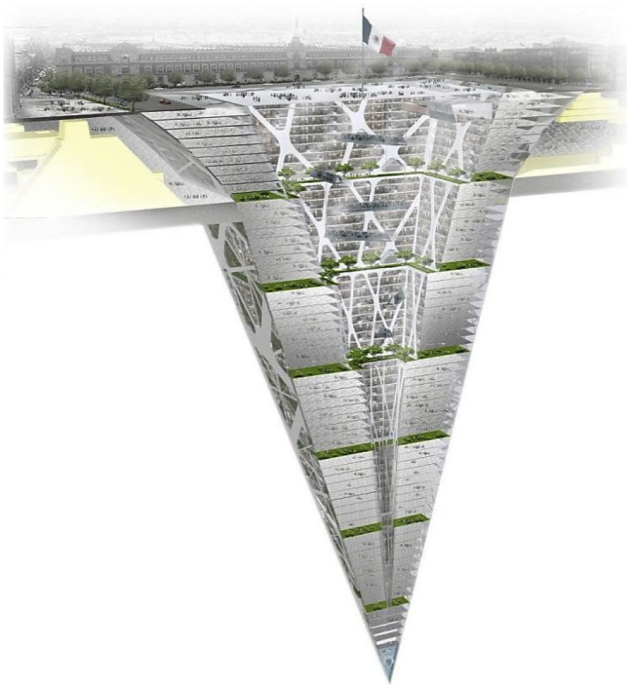

Fig. 12. Underground vision from Mexico City, an 'Earth-Scraper', in the case where space is needed yet heritage does not allow skyscrapers (Mail Online News, 2011).

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 subsea 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 m below sea level near the coast of Estonia (Fig. 11). In the sea area there is still 30 km stump without any geological data in the City of Helsinki Database (Soili).

The Quaternary sediments on the Estonian side are water-saturated loose and soft deposits, and thus pose a challenge to tunnelling. In buried valleys, the Quaternary sediment thickness may reach up to 150 m. It is a construction environment that has to be avoided due to high groundwater pressures as should be 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 m in thickness and an important source of water supply for both Tallinn and its surroundings, poses a significant challenge to 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

Fig. 14. Future Tampere with the central 'Arena' constructed over the main railway station housing several facilities on different levels (Image: Tampereen Keskusareena Oy).

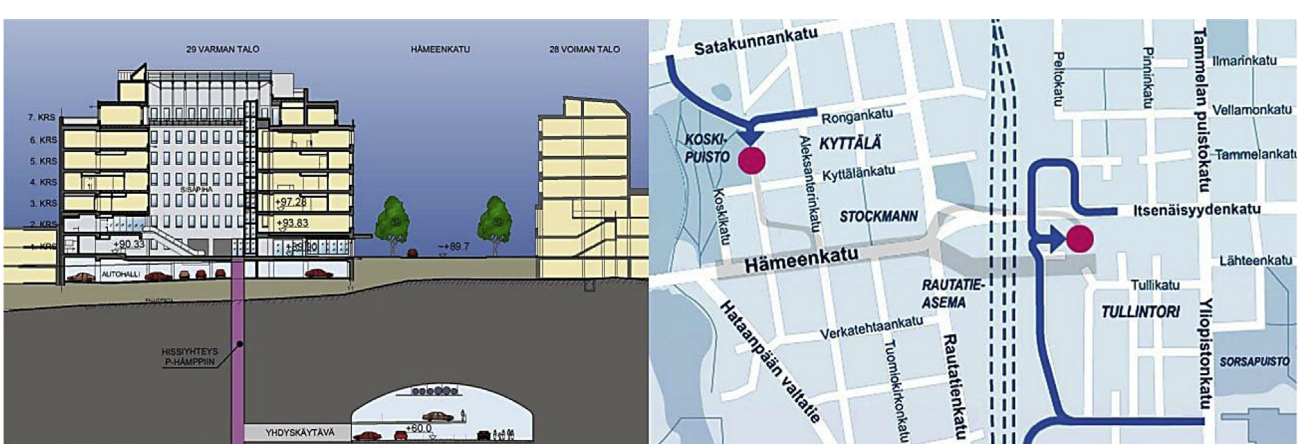

Fig. 13. The new parking solution, P-Hämppi, is located below the main street in Tampere (Image: Aihio Arkkitehdit Oy).

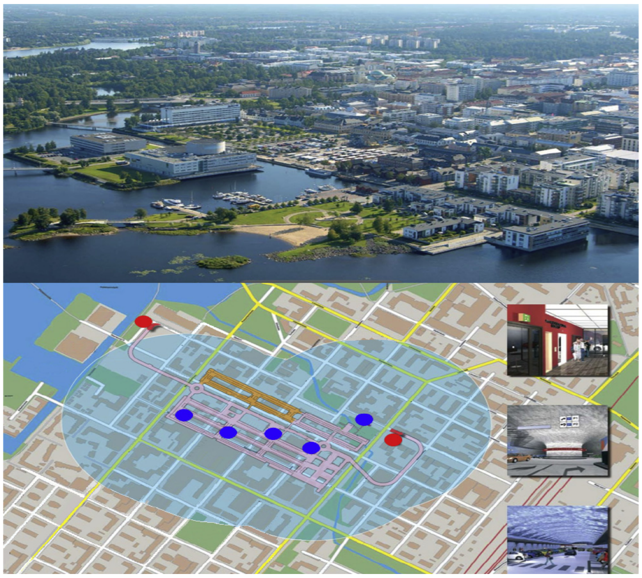

Fig. 15. Kivisydän (Rock Heart). The underground parking cave in Oulu. Blue circle = lift. Red circle = car access. (Image: City of Oulu and Oulun Pysäköinti Oy).

fixed link arranged by the North Estonian Harju County Government et al. (2014).

Vanjoki (2012), an individual multi-contributor and former member of Nokia Group's Executive Board, suggested that if the Guggenheim museum comes to Helsinki it will have to be built underground. Would the solution presented in Fig. 12 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. Furthermore, 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. 13 and the future vision of Tampere Central Arena (2011) in Fig. 14.

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 75 million euros. 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.

Oulu, the capital city of northern Finland, has also started to 'go underground'. 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. 15).

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 (50 m in width, 150 m in length, and 12 m in height). The model of the bedrock is based on base map data for exposed rock and land surface elevations; point data were obtained using drill borings (Fig. 16). The survey also took into account local weakness zones and rock resources that have already been put to use.

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 construction of underground facilities. Outside the city centre, the survey found 55 rock areas that are sufficient in size to accommodate large underground

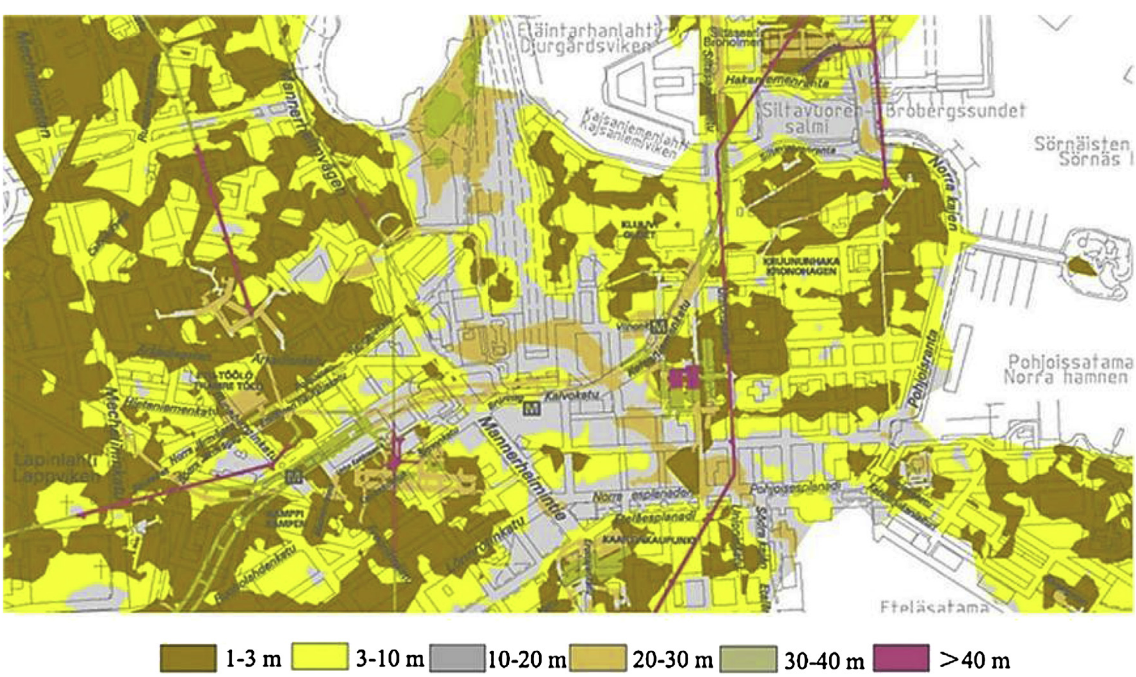

Fig. 16. An extract of the rock surface model (Image: City of Helsinki Real Estate Department). Deepest public underground spaces have been taken into consideration when presenting free rock resources. Estimated rock surface is based on bedrock confirmation drilling.

Fig. 17. Typical utility tunnel (Photo: Jorma Vilkman).

facilities near major traffic arteries. In many areas, future underground projects can make use of entrances to existing underground facilities – these are marked with triangles on the UMP map. It is worth mentioning that thermal energy from the bedrock is also a noticeable resource.

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. 17 and 18).

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 in 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.

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 waste water 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.

Raw water for the Helsinki region comes from Lake Päijänne via a rock tunnel with a length of 120 km (Laitakari and Pokki, 1979). The medium water level of Lake Päijänne is +78.3 m, the highest water level in the Helsinki Metropolitan Area is +42.0 m, and the water capacity of the Päijänne tunnel is 9–11 m^3/s.

Its main investor and designer were 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 m 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 about 200 million euros (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. 19). In 2001 and 2008, the tunnel underwent an extensive renovation – it was bolted and shotcreted in two sections to prevent cave-ins.

Fig. 19. Tunnel from Lake Päijänne was repaired for the first time in 1999. The reinforcement method used here is an exception and only used in case of severe collapse. Some parts were bolted and shotcreted while most parts were still without any reinforcement (Photo: Mannelin).

Wastewater treatment is carried out centrally at the Viikinmäki underground wastewater treatment plant (Figs. 20 and 21). 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 approximately 180 million euros, 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 3500 inhabitants is above the tunnels. There are also various 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:

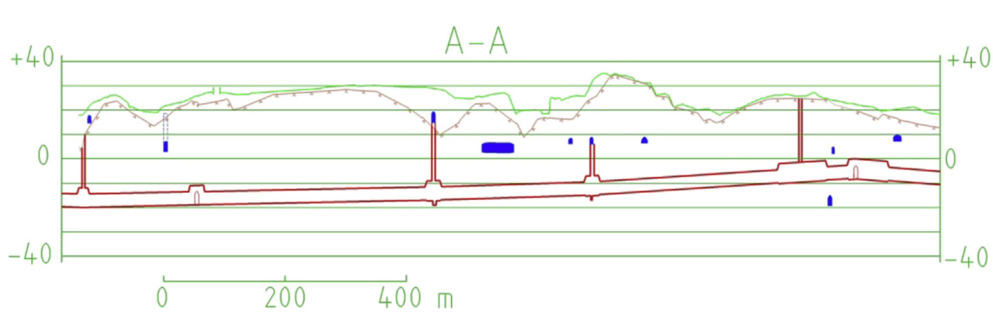

Fig. 18. Longitudinal section of the newest utility tunnel contract showing the principle of locating the utility tunnels at such depths that there are rock resources also for future needs (Image: City of Helsinki Real Estate Department). The ordinate is the elevation in metre. Dark blue represents existing tunnels and underground spaces.

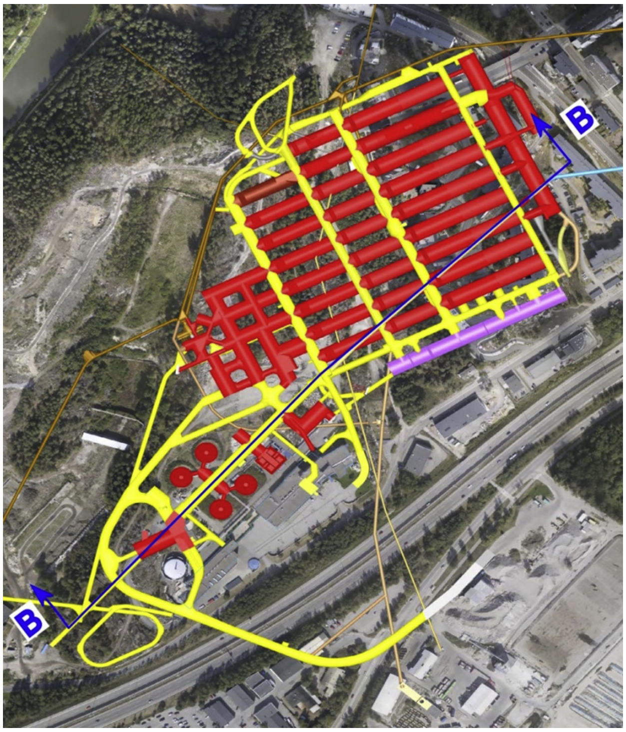

Fig. 20. An aerial view of the Viikinmäki wastewater treatment plant (Image: City of Helsinki Real Estate Department).

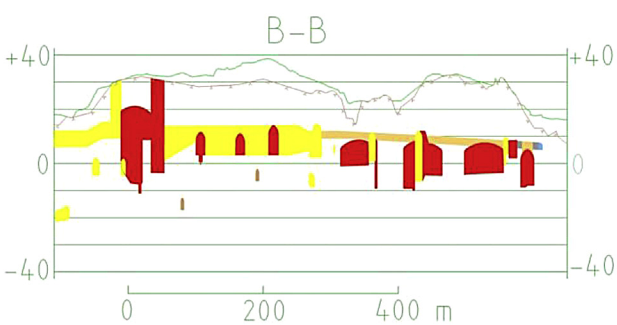

Fig. 21. Longitudinal section of the Viikinmäki wastewater treatment plant (Image: City of Helsinki Real Estate Department). The ordinate is the elevation in metre. Red colour represents the actual treatment basins, yellow colour represent other underground spaces.

(1) There is a reliable energy supply via the network with multiple links (allowing alternative routes if necessary).
(2) 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.
(3) Costs are shared between several users.
(4) Land is released for other construction purposes.
(5) The city's appearance and image are improved as the number of overhead lines can be reduced.
(6) Construction work carried out on underground pipes and lines has significantly fewer disadvantages than similar work carried out at the street level.
(7) Blast stones resulting from the construction of the tunnels can be utilised.
(8) Pipes and lines in tunnels require less maintenance—they are easier to be maintained than pipes and lines buried under streets, and the tunnel routes are shorter than those of conventional solutions.
(9) Any breakages in pipes, lines and cables do not pose a great danger to the public.
(10) Tunnels are a safer option against vandalism.

6. Non-geotechnical engineering for underground space development

Helsinki consists of 214 km^2 of land and 500 km^2 of sea (Fig. 22). The City of Helsinki owns 62% of the land area of Helsinki (Helsinki City, 2013).

According to the Real Estate Department's Land Division, 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.

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 6 m − a conventional Finnish cellar. If landowners want to build multiple underground levels to their buildings, they must have a building permit. 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 the master planning, town planning and finally by building permits. The figure of 6 m is a practical measure for building one (maximum two) cellar below ground level. This 6-m figure is not laid down in Finnish legislation; rather, it is more of a tradition in Helsinki. If more space is needed, a permit is required. Most buildings with deep cellars (more than 6 m) are located in the city centre. Efforts have been made to guide the use of underground resources outside 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 m and 90 m from ground level. **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 when it is a (Local) Government Underground project. In non-government projects, such as private car parks, a contract is drawn up between the construction company and the landowner even though 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 m 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

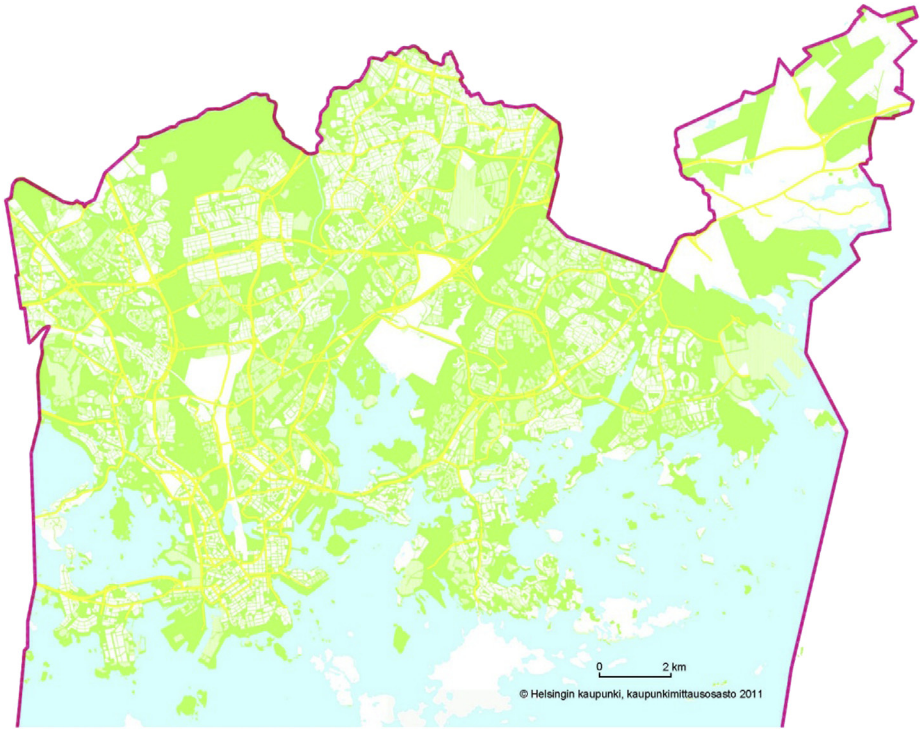

Fig. 22. Map of Helsinki. The green areas are land owned by the City of Helsinki; white areas are owned by others (Image: City of Helsinki Real Estate Department).

underground activities could then be safely located close to each other (Vähäaho, 2011b).

7. Conclusions

The UMP for 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.

There are several benefits of locating technical networks in bedrock: a reliable energy supply via a network with multiple links; the optimisation 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.

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 km-wide Gulf of Finland separates the cities and restricts 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 the EU Member States.

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 at http://www.ita-aites.org.

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 at http://kartta.hel.fi/?setlanguage=en.

Technical services and large-scale utility tunnel networks in bedrock as well as geotechnical and geological data management are described in more detail at http://www.hel.fi/hki/Kv/en/Geotechnics/CaseBank.

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

News in English about the Helsinki-Tallinn Rail Tunnel can be found at http://www.getunderground.fi/web/page.aspx?refid=62.

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.

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