

URBAN PROBLEMS - UNDERGROUND SOLUTIONS

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World wide, we see developing nations build new infrastructure as well as developed cities rehabilitating and expanding their infrastructure to meet the demands of increased population, energy efficiency, and environmental awareness of the public. Working Group 20 of the International Tunnelling and Underground Space Association (ITA), focused on Urban Problems and Underground Solutions, has examined the current status of the use of underground space in the urban environment as it evolves with expanding cities and urban densification. This paper presents examples of the uses of underground space in cities, trends in Metro and roadway planning, and gives an overview of aspects to be considered during the decision making process, in order to optimally include underground solutions.

Use of the underground is not restricted to mega projects. This paper presents innovative uses of space for storage, local transport, water conveyance and treatment, and commercial space. Underground solutions to urban problems were in the recent past only considered if all other (above ground) solutions had been exhausted. If the underground options are considered at an earlier project stage, more optimal solutions will become possible. This overview of existing underground solutions for urban problems and the way they can help in the decision making process is intended to boost the consideration of the underground option for future projects.

Keywords: underground space, city planning, decision making, resilience

1 Introduction

The world is increasingly an urban environment. Already more than 50% of the world population lives in cities. And this number is expected to rise to 70% by 2050. As a result, existing cities are expanding and adapting to the changes in population and to the changed demands on infrastructure and facilities. In order to meet these demands and maintain or improve the quality of the city environment at the same time, engineers, city planners and decision makers need to come together and recognize that in order to reach an optimal solution, the underground option should be considered as well.

The International Tunneling and Underground Space Association (ITA) was created in 1974 with a mission to encourage the use of the subsurface for the benefit of the public, environment and sustainable development, and to promote advances in the planning, design, construction, maintenance and safety of tunnels and underground space. Working groups within ITA provide special studies and publications to address the use and construction of underground space. Working Group N°20 was formed to provide an overview of the typical challenges of urban city planning and the solutions which are offered by the use of underground space. Earlier this year, the Working Group published ITA Report N°11 'Underground Solutions for Urban Problems' that addresses this topic (Arends et al., 2012). The main goal of this report is to create awareness of the underground option in city planning.

Over time, the uses for underground structures have developed from primarily shelter to space for infrastructure and a wide range of functional facilities. The uses may be categorized into

several primary uses: Infrastructure for transit and utilities, storage, and protection of the environment. Increasingly, the public, especially in larger cities, demands a higher quality environment with respect to:

- Reliable and safe transport of people and goods,
- Water distribution and sewerage systems,
- Sustainability of the environment and containing sprawl,
- More green spaces and recreational areas,
- Reduced use of fuel, and fuel emissions,
- Noise control,
- Aesthetics,
- Efficient use of real-estate.

All of these demands call for continuous improvement of sustainable and resource efficient urban planning and development, and is and can be facilitated by the use of underground structures. Advanced underground construction technologies can provide solutions for reducing congestion and other environmental problems while contributing to energy efficiency. However one of the greater aims of underground use in an urban environment may be to free surface space for other human needs and to improve the living conditions of cities.

In order to present the underground options that exist and the problems they can solve, this paper is divided in three parts. The first section reviews typical urban problems for which use of underground space may offer a better alternative than use of the surface. The second section describes typical solutions the underground can offer such as subway systems, road tunnels, underground manufacturing space, water and sewerage transport systems and storm water relief systems. The final section illustrates the decision making progress for identifying and creating underground solutions.

2 Urban Problems

In the first decade of this century a milestone has been reached, in that more than half of the world population now lives in cities. Urbanization is occurring at an increasing rate. The urban environment cannot fully absorb the influx of people without substantial improvements in infrastructure.

Rapid urbanization has produced many urban problems such as the need for more housing, roadways, water and power distribution systems, sewerage systems, reduction of air and noise pollution and other population growth issues. Urban sprawl creates more traffic congestion and increasing travel times, loss of valuable farm land, and inequitable allocation of resources (Longman, 1998, Chen 2000).

In newly emerging mega-cities such infrastructure needs are compounded by inadequate water and power distribution systems, sewerage and treatment systems, and flood control measures. Whereas this creates problems in controlling the growth, planning and managing the city environment and providing the basic necessities, the complete absence of infrastructure also provides a unique opportunity to city planners and decision makers to select the optimal solutions from the start and consider quality of the environment, quality of life, safety, health, convenience and comfort from the start (UN, 1961).

In order to meet such goals, the various urban problems where underground solutions exist should be recognized. These include:

- Crowding and lack of space (for work and recreation),
- Traffic congestion,

- Aging infrastructure and distribution of resources,
- Environmental conditions such as noise and air pollution,
- Aesthetic qualities and image of our urban environment quality,
- Safety, security, and protection against natural disasters,
- Flooding,
- Sewage conveyance and treatment,
- Synergy effects of the above.

2.1 *Traffic congestion and travel time*

Probably the most recognized problem is the need for congestion relief in city streets. Time can be saved by using separated rail systems in order to reduce the rush hour traffic pressure. Hundreds of hours per worker per year can be saved in this way, as the cost of congestion in OECD countries is estimated to be equivalent to about 2 percent of the GDP (Godard, 2008).

But mass transit systems offer other benefits, as they tend to require less surface area than road traffic. Studies show that car traffic takes up 30 to 90 times more space than metro systems, depending the reason for the car use: work, leisure or shopping. Similarly, public road transport takes 3 to 12 times more space.

By moving from above ground car traffic to underground mass transit systems, enormous amounts of surface land can be freed up for other uses.

2.2 *Pollution and noise*

Highway noise and emissions from vehicles are recognized as pressing problems in urban areas. In order to reduce the noise impact, sound barriers may be erected, but the visual impact of such measures is major. It is often the case that residential property values near freeways are reduced due to high noise levels from automobiles and exhaust emissions. Also, there are associated health and safety issues for living close to a freeway.

Once again, moving passenger transport from cars to mass transit systems can reduce the noise and pollution impact at the local level, but also at a larger scale as mass transit systems tend to be more energy efficient and substantial energy savings can be obtained by the increased use of metro systems.

2.3 *Protection against Natural Disasters*

With concentration of population, urban areas are particularly vulnerable to failures in infrastructure due to aging of the systems or those caused by other natural forces. Growth of population not only means more people are relying on the infrastructure, but at the same time that the man-made facilities may increase the severity of the disaster. For example, urbanization means more paved area leading to more severe flooding, as well as loss of water resources recharging groundwater.

Underground construction can help here. Underground rivers can be constructed to increase run-off or divert storm water. And it should be realized that underground structures are often less prone to earthquake and many metro systems for example have suffered little or no damage in major earthquakes (Wallis, 2010).

3 Underground Solutions

Underground structures can provide shelter and storage, as they have for many centuries. Today, underground structures also help in the use of the limited and valuable space in urban areas by replacing traditionally surface facilities with tunnels, caverns and other underground spaces. The main uses of the underground are (Admiraal, 2007):

- Transport Use (with emphasis on infrastructure): Provides for transportation tunnels and underground utilities,
- Production Use: Extraction of underground resources,
- Urban Structure Use: Structure foundations and underground facilities such as shopping malls, recreational facilities, car parks and working space,
- Storage Use: Space for materials best placed underground such as hazardous materials and energy storage,
- Archive Use: Underground resources – archaeological and earth science resources and subsurface bio-diversity.

3.1 *Transport and infrastructure*

Tunnels have been used since the 19th century to provide a grade-separated space to make individual car transport and public transportation faster and independent from local traffic and natural barriers. The success of subways and road tunnels continues to be seen in the expansion of existing systems world-wide and creation of new metros as the urban populations demand more rapid transportation. Road tunnels are increasingly used to reduce the surface impacts of motorized vehicles while maintaining a habitable urban environment.

The availability of subway (metro) systems in many cities in the world has become standard since the opening of the first steam-powered underground railway in London in the 1860s. New systems are developed as cities grow. Also, heavy rail tunnels are developed to remove surface railway lines from the city surface land free up the large swaths of land traditionally occupied around railway stations.

Continually improving tunneling and excavation support technology adds to the success of urban rail systems. Advances in Tunnel Boring Machine (TBM) Technology now allows tunneling in more difficult ground conditions – even below the ground water table – with little disturbance to the surface.

Over the last few decades, many cities have constructed roadway tunnels to improve their traffic conditions and to adapt the road network to the predicted demand. At the same time the impact of traffic on the surrounding residents has been reduced. Some cities have built tunnels in “ring roads” in order to avoid vehicles traversing the downtown area. The list of large ring road tunnels and direct access tunnels increases annually, with large road tunnels completed, under construction or planned in: Paris, Munich, Madrid, Prague, Melbourne, Shanghai, Tokyo, Zurich, and other cities.

In a number of US cities, for example, Boston, Seattle, and San Francisco, urban road tunnels are used or considered in order to replace the elevated highways, mainly constructed in the 1950s and 60s. Such giant elevated structures through downtown areas are now seen as unsightly, noisy, possibly unsafe, and provide only limited access to areas adjacent to the freeway. The original decision to build such structures only focused on direct construction costs. In order to avoid such unfavorable situations again, decision makers should include real-estate impacts, structural life span, and long-term sustainability when making such choices.

3.2 *Drinking water storage and distribution*

Access to unpolluted freshwater is a critical issue for human survival. Several methods to deliver and to process drinking water are used today. Stored freshwater from dams is distributed both by open channel or through pressure pipelines. Water from lakes and barrages, or water from deep lying aquifers, is also used for the production of drinking water. What these systems have in common, is that the water needs to be stored, treated, and distributed, which requires a large network of basins, pipelines and pumping stations.

Underground cisterns have been in use for over 2000 years. Today cisterns can also be outfitted with filters or other water purification methods when the water is meant for consumption. Such underground cisterns offer additional protection of the water against air pollution and make the water supply more secure.

3.3 *Storm water relief and combined sewer outfalls*

Handling the effects of storm floods is proving to be an increasing problem for cities as, along with development, paved areas increase and infiltration into the ground is reduced. Other reasons for this increasing problem are the conversion of former retention areas adjacent to stream courses into populated or economically used land, and more intense storms attributed to climate change.

To cope with the unfavorable effects of flooding, the options include:

- recreating natural storage areas,
- improvement of the drainage capacity using pipelines or tunnels,
- creation of temporary storage capacities (above and below ground), such that storm and sewer water may be treated before being discharged into natural waterways,
- combinations of the above utilizing underground space multi purpose systems.

One of the most interesting projects with respect to multiple purpose systems is the SMART Tunnel project, (Stormwater Management and Road Tunnel). The objectives of this tunnel, which is situated in Kuala Lumpur, Malaysia, is to solve both the problem of flash floods and traffic jams during rush hour. The 9.7 km long SMART Tunnel, put into operation in May 2007, consists of three separate sections. During normal conditions, a 3 km long section of the upper two decks is used for vehicular traffic, whereas the base section of the tunnel is used for the transportation of water from a basin in the northeast to a reservoir in the southeast. In case of an increase in storm water due to a major storm incident, all three sections of the tunnel with a diameter of 13.2 m can be used for water storage and transport. The necessity for closure of the tunnel for traffic is expected to happen once or twice a year. By combining these two functions, Kuala Lumpur saves money and space compared to building two separate systems.

3.4 *Energy storage and distribution in underground networks*

The distribution of fossil fuels and electric energy requires a sophisticated network of infrastructure. The availability of these resources must be guaranteed at all times for urban areas. Underground options include district heating, geothermal energy, thermal heating, hydropower, and fossil fuel distribution.

District heating is a system for distributing heat using steam (vapor) or water – via a thermally isolated network of underground pipes in densely populated areas. The heat is generated in a centralized location and is predominantly used for residential heating. The heat is often obtained from a cogeneration plant burning fossil fuels or increasingly from biomass. Geothermal heating and central solar heating also may be used.

Geothermal energy results from the use of the underground as a heat or cold source or as a thermal reservoir. It is well suited for many applications due to the available large volume and the constant natural temperature level. Geothermal energy from the underground is obtained via underground heat exchangers or by pumping groundwater. Apart from heating, heat pump systems can also be used for space cooling.

The underground can also be used as a thermal reservoir for heating and cooling. Heat from other sources, which would otherwise be lost can be stored and used later. By the same principle, environmental cold can also be stored for later cooling applications. Underground thermal energy storage is especially suitable for storing larger quantities of heat or cold over longer periods of time. Many major new office blocks are making economical use of these new developments, thereby minimizing the use of underground pipe systems for long distance energy transport.

Underground reservoirs are an important method of storing various gases. Three principal types are used: depleted gas reservoirs, aquifer reservoirs and salt cavern reservoirs. From such storage the gas can be extracted when needed, in order to deal with rapid changes in demand during the day and night, or variations in the demand through warmer and colder periods of the year. Similarly, oil can be stored in underground cavities, from which it can be discharged into road tankers or pipelines. The use of underground caverns frees up the large surface area normally occupied by oil depots.

Along similar lines, Helsinki, Finland, moved the storage of coal from surface to underground caverns. This move freed up valuable space at the surface for other uses and allowed a nearby residential development to proceed without the hindrance that in the past the surface storage of coal caused.

The transport of fossil fuels, freshwater, sewage and electric energy through underground pipelines and cables was strongly developed in the 19th century. Pipeline transport has proved to be an economical way to move pressurized liquids and gases over long distances, and typically has lower cost per unit and higher capacity than other means of transport. To guarantee consumers the distribution of fresh water, gas, district heating as well as electricity and telecommunication in cities, pipeline and cable systems may use more complex underground solutions, for example, bundling all components in service ducts or tunnels. Such utility tunnels or utilidors lower the underground space required by the individual cable systems and at the same time improve the reliability of the system, allowing for easy inspection and maintenance.

3.5 Underground shopping, cultural and amusement facilities

The charm of a city centre is closely related with the existence of leisure time facilities and public green spaces. Urban centers for shopping, entertainment, dining and social events are seen as key for “quality of life” in urban areas. These factors attract people to stay and live in the city centre areas. Due to limited space in downtown areas, some cities have expanded their cultural facilities into the underground.

Remarkable examples include the Philharmonics in Cologne, Germany, where performances are below the earth’s surface right next to the world-heritage site of the Gothic Cathedral. Graz, the capital of the federal state of Styria in Austria accommodates an event hall chiseled into a

mountain below the castle («Dom im Berg»). The facility is used for multiple events and offers a volume of 6,700 m³. The world's largest arena excavated in rock can be found in Gjøvik, Norway. The Gjøvik Olympic Hall was one of the sites of the Lillehammer Winter Olympics Games in 1994 and houses up to 6,000 visitors. The hall is today used for sport and cultural events. The Louvre in Paris, France, and the extension of the Rijksmuseum in Amsterdam, The Netherlands, both possess underground exhibition space.

Throughout the world, many major underground shopping malls in combination with restaurants, cafés, and cinemas open their doors daily. The first large center, the so called «Underground City», was constructed in Montreal, Canada. Later, cities like Seoul, Beijing, Moscow, Toronto, Tokyo, Singapore and others adopted this concept.

3.6 *Underground parking*

An underground parking garage is a building or part of a building, which is designed specifically for automobile parking situated below the ground surface. It is usually accessed via a ramp on the street floor level and consists of one or more parking levels. In many cities in the world, it is now standard to use the underground space in central areas for parking garages instead of a high rise car park.

Further reduction in underground space needs may be realized by automatic multi-story car parking garages. These provide lower building costs per parking slot, as they typically require less building volume and less ground area than a conventional facility with the same capacity.

3.7 *Underground housing and offices*

Humans generally prefer to live and work under the influence of sunlight and fresh air. Nevertheless, due to extreme climatic conditions, and limited resources for heating and cooling, some places require underground housing solutions. In other instances, lack of surface space has meant looking for additional space to be placed underground – especially when the existing building may have historic designations or significant appearance.

The underground can be extremely suitable for manufacturing, laboratories or scientific facilities. Such facilities can be constructed in the underground for obvious standard reasons like safety, fire protection, protection from severe weather, reduced noise and vibration, energy savings, and other special reasons such as shielding of the surface from radiation.

4 *Decision Making Process*

The decision making process involved in the planning, funding and construction of major infrastructure across the globe is dependent on many factors, most importantly:

- Financing and funding aspects,
- Designated function of the facility,
- Type and jurisdiction of owner,
- Market sector (transportation, water, utilities, other),
- Legal and administrative process,
- Authority granted to the lead agency,
- Number and role of every stakeholder,

- Owner status: public or private.

How the process and factors are managed within individual countries, as well as within localities, varies markedly, but the principal steps involved in remain:

- Recognition of the purpose and need for the infrastructure for concept justification and development,
- Planning and preliminary engineering: to define scope, feasibility, and preliminary budget definition,
- Implementation: including strategies for project delivery, procurement, packaging, engineering, cost estimate, financing strategies,
- Implementation and Construction: including contract terms and definitions of roles, risk allocation and sharing strategies, and construction approaches.

Decision-making is involved throughout the process at key milestones and may be as simple as a review and comment of a draft planning or engineering document, to the assessment of project risks and their allocation among project partners, to the ultimate project funding and approval. Projects and managers must evolve with the project over time to satisfy the constraints and apply adaptive management strategies to assist in progressing the program and helping the decision makers.

It is important at the outset of a project that the program requirements are clearly defined, the constraints identified to facilitate the early planning and preliminary engineering stages and that the information is provided to justify or disqualify the project to the managers and ultimately the political leaders. Distribution, discussion, and transparency of project information to all stakeholders throughout the life of the project is key to unfettered implementation. In the absence of information, stakeholders are left to speculate and frequently this can result in inadvertent dissemination of misinformation.

It is also important at the outset of the project for the managers to have a clear sense of the entire organisational network including the constituent stakeholders to understand the communications network and information needs to assist each of the decision makers.

History shows that the best information and the best prices are not often what is used in the public discourse leading up to public decisions about infrastructure alternatives. In an urban environment the answers should be clear but the transitional edge cities and suburban areas are gray areas where the debate to go underground is often waged, loudly by stakeholders. Voices of the proponents and opponents may not be those of the designers or the estimators, but of the stakeholders representatives, who frequently present information that is unclear, confusing or misleading while the industry stands frustrated on the sidelines.

Even in the absence of misinformation, the decision about whether to solve urban problems with underground solutions is usually complex. It depends on a large number of aspects which should all be taken into account including:

- Social - aspects concerning people and their preferences,
- Safety and security issues,
- Aesthetic needs – visual and architectural impacts of the solution,
- Ecological impacts – those aspects concerning the environment,
- Legal issues – including regulatory and zoning aspects,
- Economic and cost considerations,
- Technical – related to the possible construction techniques and risks involved.

The focus during the decision making process may be somewhat less concerned with technical details and more on strategic aspects of urban planning, may they be of social, economical, ecological or aesthetic background. Nevertheless, the technical aspects cannot be discounted

from any discussion of underground construction. A general perception exists that the risks in underground construction are higher than those of other construction methods and that, partly through the higher risk and uncertainty involved, the direct building costs of any underground solution will be substantially higher.

4.1 Social factors

In the decision making process, a combination of factors drive the decision to go underground – or not – and depending on the weight that various factors are given, different solutions can be reached. Examples of the various social factors that should be weighed are :

- Construction impacts and other temporary conditions affecting the community,
- Structures dividing a community;
- Development potential of the area;
- Other uses of the same space, for example for recreation,
- Noise, vibration and other impact on
- the environment.

Underground solutions often offer better development options. Well planned subway systems, road tunnels, underground parking, and underground cultural facilities, for example, allow more effective use of the area above ground. This maximizes the prospects for intensification of land use where accessibility is at a premium and it offers the prospect of development gain. These potential benefits depend upon effective planning to be realized in practice.

4.2 Safety and security

Although underground facilities can be seen in a negative light when safety and security are considered, in most cases they are better protected from external threats and natural hazards than surface facilities. On the other hand they do need more attention with regard to fires and other internal risks during their design and operation. If properly managed, however, these risks can remain comparable to that of surface and elevated structures.

When natural hazards such as earthquakes are considered, underground facilities are most often better protected without additional measures than their surface counterparts. The lower levels of ground motion away from the ground surface and the constraining effect from the surrounding soil contributes to the safety and stability in this case. With the development of seismic codes, subways are now considered very safe in earthquakes. As an examples in 2010 in the 8.8 magnitude earthquake in Chile, surface roads and public transport suffered extensive damage, but the Santiago metro system was virtually undamaged.

4.3 Aesthetics

The visual and aesthetic impact is often the major quoted reason for deciding to relocate infrastructure to the underground. Compared to above ground solutions, like elevated structures, an underground structure would not impact on the visual image and character of the environment. This may be important to hide unattractive technical facilities in sensitive locations or when industrial facilities must be sited adjacent to residential areas.

This might also be important for the preservation of natural landscapes. The increasing

requirement for all utility services to be placed underground stems essentially from visual impact considerations and concerns about protection against the elements.

4.4 *Ecological and environmental aspects*

Underground space utilization can help solve environmental and resource dilemmas in several ways. Underground facilities are typically energy efficient in their own right. The natural insulation provided by the soil regulates the temperature within the construction and thereby reduces the need for heating or cooling, lowering the energy consumption when compared to surface constructions. Over time the higher cost of construction may be compensated for by savings in power and the alternative use of the surface.

More importantly, by using underground space, higher urban densities can be supported with less impact on the local environment. In addition to the obvious benefit of preserving green space and agricultural land, higher urban density can lower fuel resource consumption by containing sprawl. Underground development will be an important tool in reshaping our urban areas to meet the challenges of the future without destroying their heritage or worsening their surface environment. (Esaki, 2005)

4.5 *Decision making process and legal aspects*

Various legal aspects can influence the decision making process for underground solutions. Underground solutions will leave the surface area open for other uses, allowing for multiple use of land in densely developed areas. This intensive use of land can ease the decision making process, as it allows multiple functions to be combined in the same area. In this way, it is often possible to conform to zoning plans and solve urban problems at the same time and in the same location.

Apart from zoning, laws and legal restrictions do exist in many legalities that prohibit building under existing structures that are not publicly owned. Such laws can severely limit the possibilities for underground solutions and will need to be considered during the decision making phase. Although in many cases buildings or lands can be expropriated, this will add additional cost to the underground solution, which has to be weighed against the benefits of mixed land use, for example.

On the other hand, when expropriation is impossible or severely restricted, both above ground and underground solutions are limited, and extending public transport and services will soon become next to impossible. In Japan for instance the uncontrolled rapid expansion of underground space use combined with limited expropriation possibilities led to a situation where metro extensions below publicly owned land had become too restrictive due to extensive urban growth. To open up future expansion possibilities government passed the Deep Underground Utilization Act in 2001 that basically expropriates all ground 40 m below the surface (MLIT, 2001). This is just one instance where the political process drives which underground constructions are possible.

4.6 *Economics*

The fact that the initial capital cost of underground projects is often significantly higher than for elevated or above-ground solutions in most cases ultimately leads to the less expensive option. However, selection of an alternative only on the basis of initial capital cost may be misleading and in many cases precludes the realization of very substantial long-term benefits.

Considering that underground solutions have long-term benefits like lower life cycle costs due to longer durability when compared to above-ground projects, the underground alternative can return more benefits during its life time. Therefore, the true cost of an underground solution should be evaluated, not in terms of initial capital cost, but in terms of life cycle costs, benefits considering the longer service life underground solutions as well as their contribution to the environment and sustainability. In order to achieve this goal, a long-range cost-benefit analysis, where the initial capital is only a part of the total financial commitment, has to be performed (Parker and Reilly, 2008). In such an analysis, a consideration of all direct and indirect costs is necessary. The cost-benefit analysis should include the life cycle cost analysis, considering the construction costs, costs of operation, maintenance costs, disposal costs, surface use and land cost. as well as an analysis of benefits.

4.7 Technical aspects

As this paper focuses on the decision making process much more than the construction process, technical aspects of underground construction are not listed in detail. In order to decide whether to build underground or above ground a feasibility study comprising all boundary conditions and all available construction methods should be made. In this feasibility study different construction methods would be considered. The fact that a large number of different underground construction methods are available, as well as a multitude of underground solutions, reveals the innovative aspect of underground construction.

5 Conclusions

Worldwide, there is an increasing need for new infrastructure as cities expand, redevelop and rehabilitate their existing infrastructure, in order to meet demands of increased population and an increased awareness of the general public for the quality of their surroundings. In many cases this leads cities to expand outwards, with lower urban density further away from the city centre, in order to find the required space.

If, however, underground space is included when looking for solutions to urban problems, higher urban densities can be supported, leading to more compact cities with a lower impact on the local environment. In addition to the obvious benefit of preserving green space and agricultural land, there is strong evidence that higher urban density can lower fuel and resource consumption. Underground development will be an important tool in reshaping our urban areas to meet the challenges of the future without destroying their heritage or worsening their surface environment (Esaki, 2005).

In order to efficiently include underground solutions in the decision making process, it is important to realize the current possibilities of underground construction and the problems that can be solved in this way. Urban problems that may be solved through the use of underground space include:

- Crowding and lack of space (for work and recreation),
- Traffic congestion,
- Aging infrastructure and distribution of resources,
- Aesthetic qualities and image of the urban environment,
- Safety, security, and protection against natural disasters,

- Flooding,
- Environmental conditions such as noise and air pollution,
- Sewage conveyance and treatment,
- Synergy effects of the above.

Underground solutions that address one or more of these topics include:

- Road and rail tunnels,
- Parking,
- Drinking water storage and production,
- Storm water relief,
- Energy and goods distribution,
- Short and long term storage,
- Recreational facilities, leisure and shopping,
- Office space and housing.

Such solutions have been highlighted in this paper.

In order to reach an optimal solution to urban problems, these underground options should be considered throughout the decision making process. This often proves problematic, as the underground option may seem more expensive at first glance. Therefore, when considering or comparing underground solutions, point of attention such as the impact on environmental quality, aesthetic issues, social and legal influences, reduction in travel times, energy saving and possible increase in property values should all be considered in the comparison.

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