URBAN UNDERGROUND SPACE AND BENEFITS OF GOING UNDERGROUND

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INTRODUCTION

The history of civilisation continues to register a steady tide towards the urban life as the basis of its social organisation. The manifestation of this movement is a continuous growth and increasing density of population in our towns and cities, as the favourite space for the development of humanity. Naturally, this trend raises a certain number of problems which grow proportionally with the size of the city. The use of the underground space has an important role to play in solving such urban problems. But various issues must be taken into account when developing urban underground space.

THE URBAN PROBLEMS

The growth of the urban population

The pressure caused by population growth is an important factor in the deterioration of the environment, particularly with regard to the over exploitation of natural resources and to the quality of life in urban areas.
The Population Division of the UN Department of Economic and Social Affairs released in March 2004 its new estimates and projections of urban and rural populations for major areas, regions and countries of the world, large urban agglomerations and capital cities.
Here are some of the most significant statements of this report :
Over the last 50 years, the world has witnessed a dramatic growth of its urban population. The speed and the scale of this growth, especially concentrated in the less developed regions, continue to pose formidable challenges to individual countries as well as to the world community. Monitoring these developments and creating sustainable urban environments remain crucial issues on the international development agenda.
Major findings from this report are:

- *The world's urban population is estimated at 3 billion in 2003 and is expected to rise to 5 billion by 2030.*
- *It is projected that the world's population living in urban areas to exceed 50 per cent by 2007, thus marking the first time in history that the world will have more urban residents than rural residents. And the proportion of the world population that is urban is expected to rise to 61 per cent by 2030.*
- *At the rate of its current growth, the world's urban population will double in 38 years.*
- *Population growth will be particularly rapid in the urban areas of less developed regions. Almost all the growth of the world's total population between 2000 and 2030 is expected to be absorbed by the urban areas of the less developed regions.*
- *In contrast, the urban population of the more developed regions, where the process of urbanization is already advanced, is expected to increase very slowly, from 0.9 billion in 2003 (representing 74 per cent of the population), to 1 billion in 2030 (representing 82 per cent of the*

population). For the less developed regions, the corresponding figures are : 42 per cent in 2003 and 57 per cent in 2030.

- *The proportion of people living in mega-cities (urban agglomerations of 10 million persons or more) is small. In 2003, 4 per cent of the world population resided in mega-cities. About 25 per cent of the world population and one half of the urban population lived in urban settlements with fewer than 500,000 inhabitants.*

Allocating the "urban space" to the various urban functions

Towns were founded to satisfy man's needs, notably for the trading of goods. They are attractive mainly because of the wide range of opportunities they offer. They bring a large number of people together within a limited space because these people need to be close to one another to carry out their business.

Theoretically, the larger the town and the wider the range of opportunities it provides, the more attractive it will be. But in order to do business, man needs space, to live, to set up his office, to carry on his business and for other activities. The more a town grows, the more expensive and scarce urban space becomes. Growth is therefore achieved by intensifying the population density in the centre and developing the outskirts.

The law of the market forces naturally leads to a concentration of tertiary sector activities at the heart of cities, and to the classic imbalance between housing and jobs. This imbalance is precisely what makes transportation means necessary, because the distances to be covered soon become too great for walking. The number of journeys in the central area grows in line with the population density and the size of the city. The centre is clogged up, and at the same time the development of the outskirts creates new demand for "alternating migrations" towards the city centre. This is why the opportunities which a city has to offer only remain worthwhile if efficient transportation compensates for the growing travel distances.

In these conditions, one of the key issues encountered in town planning of big cities is the management of this space shortage and therefore how to prioritise the consumption of the "urban space" by the different activities. This is especially the case between, on the one hand, the "static" part of the town (meaning housing, office space, amenities and services, etc.), and on the other hand, its "dynamic" part (meaning the transport system, which facilitates an exchange between the different static elements and therefore fosters economic, social and cultural life).

The necessity of favouring economic development

Cities have always played and will continue to play a major role in the development of regional, national and international economies. They embody all the positive advantages of economies of proximity, scale and agglomeration and they play a key role in driving technological change. They represent the major concentrations of investment in infrastructure, buildings and social, cultural and educational facilities. Hence, the efficiency with which cities provide for economic activities will inevitably influence the efficiency of the economy as a whole.

Pressures on the urban environment

The qualities and attractiveness of the cities are not only determined by the fulfilment of the material economic needs of their citizens, but also by the social and environmental conditions which prevail. Environmental conditions in urban areas are a source of critical concern, since urban populations are particularly exposed to the combined effects of air and water pollution, problems of waste disposal and derelict land, noise and congestion. Furthermore, these problems, which are worsening in many cities, are often accompanied by a lack of open space and greenery and, in certain cases, a decay of the built environment. These issues are not restricted to any particular city size, age, or type; nor are they specific to cities of a particular country. The urban environmental problems exist in all countries, although they are a cause for variable degrees of concern, from acute and immediate to minor and local.

Impacts on global environment

Large cities all over the world may be seen as a threat to the environment because of the large supply streams they are creating. Cities may also be seen as a threat to sustainable global development in that they produce huge amounts of non-recyclable waste and pollution which must be absorbed back into the ecosystem, causing problems which range from local to global in scale. The environmental problems being generated by cities are, therefore, substantial, and increasing.

THE RELATIONSHIP BETWEEN THE CITY AND ITS UNDERGROUND SPACE

Not all cities have the same potential for using their underground space. Obviously, any city is provided with an underground usable space, in the same way as any plot of private land. However, it is well known that there are factors which favour and others which detract from its use, independently of the financing capabilities of the urban community.
The city's underground space comprises three main parts :

- the immediate underground level or "sub-surface", the use of which is directly influenced by the requirements of the city. We could refer to this as a sort of "all purpose" underground level. Very frequently, this level corresponds to ground with loose soils, alluvial deposits or backfill. However, the quality of the ground is not a deciding factor when considering how the sub-surface should be used. Its use is essentially dictated by urban constraints and is directly related to the purpose for which we use the surface level;
- the deep level or "underground", for which the quality, i.e. its aptitude for underground structures, is the deciding factor when determining its use. Obviously, this so-called quality is essentially related to the geology and hydrogeology, which for the most part dictate the degree of difficulty and consequently the cost of building underground structures;
- the reliefs, which provide us with space with some clear advantages, because in general, the rocks which make up such areas are of superior quality and they are mostly out of ground water. Above all, they have the distinct advantage of being at an accessible level, while access to underground can only be achieved by way of slopes, shafts or stairs.

There are other factors, which also play a part in the choice of what purpose underground space in cities should be used for. In particular, we should look at the following:

- the case of new towns or new districts, which provide a unique opportunity to organise and plan how underground space should be used and where temporary or provisional measures may be taken, facilitating the building of underground structures later on, or for a reduced cost;
- the existence of wide avenues and unbuilt open spaces, which can help reduce some of the construction constraints (open air work, the ability to maintain traffic flow during work, ...).

BENEFITS RESULTING FROM THE USE OF THE URBAN UNDERGROUND SPACE

Examples exist around the world of almost all kinds of facilities that have been placed underground. But public perception of potential uses and related benefits is in fact very limited.
The benefits offered by underground structures are directly based on certain specific qualities of underground space. First of all, the underground constitutes a "space", able to accommodate activities which it is difficult, impossible or unacceptable to locate on the surface. It offers a natural protection to whatever is placed underground. The containment created by underground structures has the advantage of protecting the surface environment from the risks and disturbances inherent in certain activities. And last, but probably not least, thanks to the natural visual screen created by the geological medium, everything installed underground is discrete. This faculty can therefore be

exploited particularly to hide unattractive technical facilities, and thereby to resolve certain aesthetic problems.

Benefits as regards land use and location problems

In many cases, underground space use results from a lack of surface space or location problems.

- The use of underground space allows a facility to be built in a location where a surface facility is not possible, either because of lack of space or because building a surface facility in that location is not acceptable to the community. There are many types of facilities that are best or necessarily placed underground because their physical presence on the surface is unwanted, for example: public utilities, storage of less-desirable materials, and car parks.
- The underground solution also allows one to build in close proximity to existing facilities or on otherwise unbuildable sites, thus offering better services to the users.
- Underground space use helps provide safe, environmentally sound, fast, and unobtrusive urban mass transit systems;
- Also, there is often the need to separate conflicting transport activities. Grade separation of corridors is often desired and placing one corridor underground generally impacts far less on the existing community.
- Several levels of transport facilities can be brought together in important city transport hubs, thus providing easy connections among them.
- Underground car parks and shopping malls leave room for recreation areas and playgrounds above ground;

Benefits as regards isolation

The ground is massive and opaque and provides a variety of advantages in terms of isolation.

- The underground provides isolation from all types of climates. The temperature within the soil or rock offers a moderate and uniform thermal environment compared with the extremes of surface temperatures. These moderate temperatures and the slow response of the large thermal mass of the earth provide a wide range of energy savings and offer advantages in terms of preservation of objects or products stored within the structure. For example, food preservation is enhanced by the moderate and constant underground temperature conditions and the ability to maintain a sealed environment.
- Underground structures are naturally protected from severe weather (hurricanes, tornadoes, thunderstorms, and other natural phenomena). Underground structures can also resist structural damage due to floodwaters, although special isolation provisions are necessary to prevent flooding of the structure itself.
- Moreover, underground structures have several intrinsic advantages in resisting earthquake motions; they are less affected by the surface seismic waves, as it has been noted notably on the occasion of the Kobe earthquake in 1995, and previously in San Francisco and in Mexico City. The structural oscillation effects are limited, since they are constrained to move with the ground motion. Besides, as they are designed to support important ground loads, they often can better resist earthquake loadings.
- Small amounts of earth cover are very effective at protecting from the transmission of airborne noise. Similarly, if the vibration sources are at or near the ground surface, levels of vibration will diminish rapidly with depth below ground and distance of the source.
- As with noise and vibration, the earth provides protection by absorbing the shock and vibrational energy of an explosion. In cases of explosion, radioactive fallout, and industrial accident, underground structures can be valuable emergency shelter facilities, if provided with the ability to exclude or filter contaminated outside air.
- The principal security advantage for underground facilities is that access points are generally limited and easily secured.

- Multipurpose service tunnels are less vulnerable to external conditions than surface installations and will cause only insignificant disturbance above ground when installed equipments are repaired or maintained.
- The containment created by underground structures is very important for protecting the surface from the nuisances and dangers generated by some facilities like hazardous material storage and hazardous processes. Examples include the storage of nuclear waste far from human activity and possibly even hazardous industrial plants such as nuclear reactors.

Benefits as regards environmental preservation

The ground also provides a variety of advantages in terms of protection of the environment. These are notably important aspects in designing facilities with a low environmental impact.

- A fully or partially underground structure has less visual impact than an equivalent surface structure. This may be important to hide unattractive technical facilities in sensitive locations or when industrial facilities must be sited adjacent to residential areas.
- The increasing requirement for all utility services to be placed underground stems essentially from visual impact considerations and concerns about protection against the elements.
- In some cases, underground structures help preserve natural vegetation. Less damage is thus inflicted on the local and global ecological cycle.
- Traffic tunnels clear vehicles from surface streets, traffic noise is reduced, air becomes less polluted and the surface street area may partially be used for other purposes
- Underground car parks and shopping malls leave room for recreation areas and playgrounds above ground;

Benefits as regards topography

- In hilly or mountainous areas, tunnels improves or makes feasible various transport options such as roads, railways, canals, etc. Tunnels are also an important option in river, straits and harbour crossings.
- Generally speaking, underground space use offers many advantages regarding the layout of facilities and infrastructures. These advantages derive essentially from the freedom (within geological, cost, and land ownership limitations) to plan a facility in three dimensions and from the removal of physical barriers on the land.
- Tunnels are also an important option in river and harbour crossings;

HOW TO GET MORE BENEFITS FROM THE USE OF THE URBAN UNDERGROUND SPACE ?

This part gives a general overview of the various problems to be taken into account when developing urban underground space.

Safety, psychological and health aspects

Human beings have never spontaneously and probably never eagerly taken refuge underground; they have used this space to protect themselves. This natural reluctance remains valid today, and many people claim to have feelings of apprehension and even anxiety when they descend into a subway or an underground car park.

So, human needs and human values should always be the main criteria when looking for underground technical solutions and systems. When discussing the underground location to people and planners, health, safety and psychological aspects should be given a high priority to avoid unneeded negative views on the utilisation of underground facilities. It is therefore necessary to take steps in order to create sanitary and pleasant, but also safe, conditions for their use.

Protection of the underground environment

Underground space is part of the environment and must also be protected.
Experience has shown that underground space is often used as a location for less noble activities or for storing waste generated by human activity. Nevertheless, it is important to be fully aware that underground space is part of the urban environment, and as such, it deserves certain respect too.
The vulnerability of the underground environment applies to the geological medium as such and to water tables, as well as to the space it represents in itself:

- The use of underground space is irreversible. Unlike constructions above-ground, which can be demolished and rebuilt differently, underground works cannot be demolished. This irreversible aspect of using underground space is a major consideration when developing this space and explains its specificity. It is therefore important to avoid "consuming" it in an uncontrolled and unplanned manner.
- The vulnerability of ground water tables is the most characteristic aspect of the fragility of underground space. Any use of underground space that affects formations located below the ground water level can have an impact on the quality of underground water tables or their flow, or on both.
- Any underground excavation has effects on the surrounding geological environment, whose natural constraints are inevitably altered. The geological environment is permanently marked by developments made in it, and there is no way of re-establishing its initial conditions. Moreover, if this phenomenon of "decompression" is not controlled, it can have harmful consequences for the stability of adjacent structures.
- The underground space sometimes holds archeological treasures which are now systematically protected. This aspect of protecting heritage must in no case be neglected, and this constraint must be taken into account in the schedule of the projects, notably in order to allow for archeological excavations. In this respect, it should also be recognized that construction of underground works have revealed some major archeological sites.

Relations between underground structures and the ground surface

All underground structures must have some junctions with the ground surface. But developing structures that require such junctions, and especially determining the location of their outlets at ground level, is particularly difficult, especially in urban areas. This issue must not be neglected, as it often represents a major difficulty in designing, building, and even operating underground works.
Consider a few examples :

- Transitional structures between aerial and underground sections are one type of junction structure between underground works and the surface. Special attention must be paid to the handling of these transitional zones and their environmental impact, primarily because of the disruptive effect created by the specific structures involved. In addition, their aesthetics and their integration into the site must always be handled very carefully. With road tunnels, these problems of aesthetics and integration combine with that of the pollution created by the release of exhaust fumes at the tunnel portals.
- Accesses to underground works are another type of junction construction. The difficulties in implementing such works, especially in an urban area, are well known. Yet such structures are a major part of the design of these projects. Consequently, they must be carefully studied and evaluated from the earliest stages of the design process.
- Another type of junction between underground and surface works are outlets of technical structures, which are sometimes called "ancillary works", but which are absolutely indispensable to the operation of underground facilities. One of the most characteristic examples of this type of structure are ventilation units. These can pose serious problems regarding location, due to the pollution and the disturbances they engender in their vicinity in terms of noise, atmospheric pollution, air speed, and aesthetics.

Construction techniques

No use of the underground space can be envisaged without efficient and reliable construction techniques. This is especially true in built-up areas, where careful precautions must be taken for avoiding damages to the surrounding structures and special measures have to be taken to reduce the effects on urban life during the construction phase. Underground works in urban areas often necessitate much more elaborate construction techniques. To varying extents, this has long been (and in many cases remains) an obstacle to adopting underground solutions.
The fact remains nonetheless that considerable progress has been made over the past 30 or 40 years in the area of underground construction methods, which helps to overcome such hesitations :

- The phenomena of ground decompression, which cause damage to adjacent constructions, are increasingly well controlled.
- The cost and duration of underground construction continue to decrease relative to aboveground construction.
- Technology improvements have led to high levels of safety in underground civil engineering projects.
- Furthermore, a new generation of tunnelling machines with pressure - balanced shields (slurry or earth pressure) are helping to expand the possibilities for mechanization of an ever increasing number of applications.
- Progress has also been made in cut and cover construction methods, especially in the area of ground support (slurry or precast walls, grouting, anchorage). But the efficiency of these construction methods is significantly reduced by the constraints resulting from underground congestion due to the presence of numerous utility networks and the more and more severe environmental requirements, such as, for example, maintaining trees during the construction phase. In addition, they are encountering growing resistance from local inhabitants, because of the disturbances and nuisances caused by major excavations undertaken in often very congested areas.

Any further actions and efforts encouraging and / or contributing to advances in tunnelling techniques should be encouraged. A lot has been already done in this respect, especially by the Tunnelling Associations, but this action must continue with the strong support of the authorities at the different levels of the community (local, regional, national and international).

Site investigations

For all sub-surface construction, it is particularly important to predict the properties of the ground, because misjudgements can have serious consequences for a project as regards completion dates and additionnal costs. Geological surveys are therefore vital and include the development of systems for the mapping of geological, hydrological and seismologic conditions, and to make up plans for preinvestigations (seismic and other geophysical measurements, core drilling and determination of physical properties of rock).
In the same way, when planning an underground structure, it is important to have reliable information concerning the location and the features of the existing underground structures, facilities and public utilities, in order to be able to determine the most suitable location of the planned structure, the most appropriate construction methods and the precautions to be taken towards the works in the vicinity.
Thus, actions towards a better knowledge and representation of the geological medium and of the existing underground structures should be conducted and encouraged by urban authorities. And it is to be noticed that the use of computerized systems (CAD), by helping making 3-dimensional plans, is of a great use in this respect.

Economical considerations

Costs remain a major barrier to the development of the urban sub-surface space. Despite important progress in knowledge and in construction methods, construction costs of underground structures are still considered to be higher than those of above ground constructions.
Nevertheless, the cost and duration of underground construction continue to decrease compared to aboveground construction. But higher design standards and environmental mitigation costs offset much of the impacts of the improvements in underground construction. Besides, these technological improvements have led to high levels of safety in underground works.
Information about the impact of progress on safety, risks and costs should be better publicized in the design, planning and decision-making communities.

Assessment of the projects

The assessment of underground space use is strongly related to the community valuation of drawbacks of aerial structures in terms of environmental degradation. Unfortunately, most of the numerous advantages of underground structures, especially those concerning the protection of the environment, cannot be assessed in terms of monetary value. On the other hand, the construction costs of underground structures are generally higher than those of building in the open air. So, underground structures are in some ways "penalized" when compared to open air constructions. Moreover, in long term use, underground constructions can prove more economic, e.g. with regard energy savings. The value of surface land, insofar as it can be used for other purposes thanks to underground structures, must also be taken into account.
As a consequence, the decision making process concerning the realization of an underground structure (especially when it is compared to an aerial solution) should not only refer to the construction costs, but should take into account the various advantages offered by the underground alternative, particularly those related to the effects on the environment.

FROM SUB-SURFACE USE TOWARDS SUB-SURFACE DEVELOPMENT

Cities that are capable of functioning both in social and hygienic terms form the prerequisite for a decent life in built-up areas.
Giulio Carlo Argan, an urban architect and former prefect to the city of Rome, stated: "*The aim of town planning is not to design a city of the future (the ideal city, built for an ideal society, made up of ideal individuals), but to administer a patrimony in the common interest with not only a value in economic terms but also with a duly recognised historical, aesthetic, moral, cultural and individual value, which remains lodged in the sub-conscious mind*".
Therefore, it appears that one of the primary aims of town planning is to reconcile, with the greatest degree of harmony, the location of amenities which satisfy diverse urban functions, and to ensure easy access to them, while preserving the quality of the urban environment.
As explained before, underground space has an important role to play in this respect, whether it be in the reduction of pollution or noise nuisance, the efficient use of space, economic development, the preservation of the living environment, public health or safety. In these fields, it offers numerous advantages. This assertion is held valid when we observe that one of the principal motivation for building the infrastructures underground is most often to be found in the "rejection" of the above-ground solutions.
Putting these solutions into operation depends largely on the efficiency of construction techniques. In this respect, we can never emphasize enough the importance of the role of the various parties involved in the building of underground structures (developers, owners, engineers and entrepreneurs), who promote or actually undertake work to achieve such developments.
Yet, experience shows that, however essential it may be, the progress in techniques is not in itself sufficient to put a better use of underground space in cities into practice. All the users of underground space in cities have noticed that the occupation of this space is, in fact, done in a

quite disorganised manner. In many respects, it is the "first come, first served" rule which applies here.
It is therefore important that local authorities control the use of the underground space of their cities through appropriate laws and regulations. The major aim of these laws and regulations should be to achieve the best possible use of the urban underground space in connection to the surface town planning, in the interest of the whole urban community. Thus, it would be desirable if underground space use was taken into account when drawing up large scale outline plans for cities and when making major policy decisions in town planning. In this way its intended use could be recorded in documents dealing with urbanisation at both local and regional level. This need has already been focused by some forerunners for a long time. But any definitive solution can probably not be implemented in the short term, because of the complexity of the related problems. The tunnelling industry is willing to continue to contribute to research and practical solutions which are directed at a more coherent policy for making the best use of underground space.

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