Underground development: a path towards sustainable cities

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Abstract

The utilization of underground space has provided viable solutions with regards to many serious problems that modern cities are faced with. Underground development releases valuable space on the surface, improves the environmental quality and preserves the city-scape and the landscape. Lately, interest in underground space utilization in Greece is more intense than ever. This paper presents two characteristic cases from Greece’s experience. Furthermore, important issues such as the public’s considerations and land ownership are discussed.

Keywords: underground development, urban planning.

1 Introduction

Nowadays, the majority of the population of a given country lives in large urban areas, where the centre of today’s life revolves. This situation begun to take shape during the beginning of the previous century and the trend continues to our days. The concentration of many people and human activities in relatively small surface area created the need to expand in order to fulfil the demands for better living conditions. Cities begun to expand “horizontally” or “two dimensionally” and the urban sprawl consumed neighbouring “green areas”, while free surface space was evidently diminishing. We all experience the repercussions of this model of urban expansion as we bear witness to the degradation of the environmental quality, the deterioration of the living conditions, the scarcity of free space, the high land prices and other urban-related problems. At the same time, infrastructure and the industry demand all the more surface areas and as a result land prices continue to rise.
It is only lately that urban planners are beginning to realize that there is a resource practically unexploited so far, a resource with potential to alleviate the above-mentioned problems, as it has been proven in several cases, that resource is the underground space. Today underground development encompasses both the relocation of several surface land uses or activities, which are difficult, impractical, less profitable, or even environmentally undesirable to be installed on ground level, into subsurface built environments and the development of a strategic, multi-disciplinary vision about the use of space as integral part of the future physical planning and zoning [1]. Among the main advantages of the utilization of underground space are the release of space on the surface, the preservation of “sensitive” areas, such as historical city centres, archaeological sites and considerable energy savings. At the same time the installation of hazardous processes (industrial uses, hazardous waste treatment and disposal, etc.) below ground level ensures minimum risk and disturbances (visual impact, noise pollution, odours, etc.) generated by these activities [2].

One of the main interests of the Laboratory of Mining and Environmental Technology (LMET) of the National Technical University of Athens (NTUA) has been to raise public awareness regarding issues of underground development. Among the research activities of the LMET, two characteristic cases are presented and several issues related with underground development are discussed.

2 Underground development in Greece

2.1 General

The historical background of the utilization of underground space in Greece displays several contradictions. On the one hand there are records that prove that the Ancient Greeks had achieved a remarkably high level in the field of underground engineering. Their ability to construct complex mining underground works, such as shafts and adits, in difficult geological conditions such as in the case of the ancient Lavrio mines or important infrastructure works, such as the Eupalinus aqueduct on the island of Samos, gains more respect and admiration if one takes into consideration the primitive tools and limited resources available [3]. On the other hand during the following centuries underground works were considered to be a very difficult task and with only a few exceptions, underground solutions were disregarded. Therefore, apart from the Athens’ first metro line, which included an underground tunnel and was inaugurated in 1895, fact that makes it one of the oldest in Europe and the underground works undertaken by the Greek Public Power Corporation (PPC), only limited underground construction actually took place. In contrast, Greece is experiencing, today, a significant increase in the number of underground infrastructure projects. The majority of them concern transportation tunnels. Approximately 16 new tunnels with a total length of 36 km will be constructed until 2010, while more than 20 tunnels having length between 500 m and 1000 m will have been commissioned by that year [4].
However, it was only a decade ago when the underground construction for sections of the Ymittos Western Peripheral Motorway (YWPM) was regarded as an almost impossible and non-feasible prospect. The technical feasibility of the tunnels was put into question both by construction companies and governmental authorities. What is more, they argued that the construction of underground sections would result in an overwhelming cost. Subsequently, a surface alignment was chosen for the motorway that would follow the foothill of Mt. Ymittos, hence destroying a large part of one of the few remaining forests in Athens. Inevitably, the proposal was met with strong opposition from the public and a research project for the preliminary investigation of the underground solution was assigned to the LMET. The findings supported that the underground construction was a realistic, environmentally friendly solution and the construction cost would be slightly over twice the respective cost for the surface road [5]. The research project’s findings combined with the environmental benefits of an underground alternative and the intense public protests resulted in the project’s redesign, which finally included almost 6.5 km of tunnels.

The above-mentioned case marked a gradual shift among the technical world of Greece regarding the development of underground projects. Nevertheless, there still remains a challenge. The technical community has not yet realised that underground development is more than the establishment of transportation infrastructure. Thus, the part of underground development that involves the integration of several underground facilities in the modern city’s life, which perhaps is the most beneficial, has not been fully developed yet.

In support of this perception, LMET has undertaken research efforts focusing on the design of underground plans that will promote sustainable solutions compatible to the Greek conditions. The studies thoroughly cover all aspects of the underground endeavour, such as the excavation and support design, safety measures, mechanical installations, market research, living environment and finally the financial appraisal of the project as a whole. The concept behind each project is to study the specifications and requirements of specific activities on the surface and then try to transform the underground space in an ideal working environment, in compliance with all necessary standards.

With a view to displaying the true potential of underground development in Greece two selected cases of underground development in urban areas are presented hereinafter. Apart from these cases, there is a number of other ongoing promising projects, such as the underground car parks in the internal hills of Athens using the room-and-pillar method, the development of underground repositories for hazardous waste disposal, etc.

### 2.2 Underground logistics warehouses

According to a recent market research, the demand for modern storage facilities in the wider area of Athens is high. However, the construction of new logistic facilities is a very difficult issue, as it has to overcome serious obstacles concerning the scarcity of unified free land and its high cost.

On the other hand, the development of underground storage facilities can provide feasible solutions. Underground space that would have all the necessary
features to host such activities can be created using the “room-and-pillar” mining method, as it has been thoroughly investigated [6, 7]. Furthermore, the evaluation concerning the establishment of underground logistic centres in Attica has demonstrated very promising results [8]. The site selected for the development of the underground storage facility is located in the south-eastern parts of Mt. Ymittos, near the Mesogeia region. The underground space will be converted into a state-of-the-art underground warehousing-logistics centre that would be as ergonomic, efficient and functional as a relevant surface facility.

The necessary modifications include the installation of utility networks (electricity, water supply, ventilation, lighting, communication network, safety arrangements, etc.) and the creation of the cross-docks. Taking into account the specifications set for the storage area, a square-patterned room-and-pillar layout was used, having a height of 11 m. The width of both the rooms and the pillars are 11 m, yielding about 62,000 m$^2$ of free space to be utilized and approximately 1.8 million tn of very good quality limestone that can be sold as aggregates. Calculations estimate the total construction cost for this underground storage facility at 94 €/m$^2$, which is significantly less than the respective cost for a typical surface facility in the same area, taking into consideration the average land price.

2.3 Underground oil storage facility

The tank farm in the Perama district near Piraeus is vital for the supply of refined oil products to the greater area of Athens. In these facilities, covering an area of about 30 ha, 175,000 m$^3$ of various oil products are stored in 102 steel tanks. The placement of the facilities within the urban fabric, just a few meters from the houses, has resulted not only in harmful environmental impacts but also in serious threats to public safety.

In search for a feasible solution to the growing problems and disputes the relocation of the tanks to another surface area has been investigated. This solution confronts two serious obstacles, the protests of the neighbouring communities and the land cost. Approximately 500 ha are required for the establishment of the tank farm, costing, with moderate assumptions, around €12.5 million.

Table 1: Comparative cost analysis between the surface and underground relocation of the Perama tank farm.

<table>
<thead>
<tr>
<th>Cost categories</th>
<th>Underground (10^3 €)</th>
<th>Surface (10^3 €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Cost</td>
<td>1,000</td>
<td>12,630</td>
</tr>
<tr>
<td>Civil Works</td>
<td>26,840</td>
<td>17,400</td>
</tr>
<tr>
<td>Mechanical Installations</td>
<td>18,300</td>
<td>21,480</td>
</tr>
<tr>
<td>Piping</td>
<td>2,000</td>
<td>16,140</td>
</tr>
<tr>
<td>Contingencies</td>
<td>7,140</td>
<td>10,150</td>
</tr>
<tr>
<td>Total</td>
<td>55,280</td>
<td>77,800</td>
</tr>
</tbody>
</table>
A possible alternative can be the relocation of the tank farm to an underground oil storage complex constructed in the same region [9, 10]. The project suggests the construction of 5 storage caverns with a total capacity of 200,000 m³. The limestone bedrock is of good quality and can sustain such type of excavations without encountering significant difficulties. Without overlooking the financial benefits of the project, the main advantages lie in the environmental superiority compared to any surface alternative. The initial estimations of the cost of the project [11], including all surface installations (e.g. truck loading stations), piping and coastal facilities range at about € 55 million, almost 30% lower than the initial surface relocation alternative (Table 1).

3 Some important issues

3.1 Underground development and the environmental benefits

As a general rule the economic feasibility of underground works is judged on the grounds of the comparison between underground construction cost and surface construction cost plus the land cost. However, this comparison reflects only a part of the truth. It has been already mentioned that underground development offers certain environmental and social advantages. Therefore, in order to provide an answer regarding the social benefits of underground solutions, it is necessary to evaluate all the benefits and costs, including the so-called externalities. In other words, underground solutions should be assessed on the grounds of social cost-benefit analysis, using bottom-up approaches and environmental valuation methods. Although there are difficulties in environmental valuation, internationally the use of environmental economics in project appraisal has significantly increased, since it results in better decisions [12, 13].

Towards this direction, both primary research, based on revealed (e.g. Travel Cost and Hedonic Pricing) and preference methods (Contingent Valuation), as well as Benefit Transfer studies have been conducted. Empirical evidences show that the scarcity of free space, the need to protect existing green areas from further degradation and the will to enhance living conditions in modern urban centres tend to increase the cost-effectiveness of underground development and, consequently, the net social benefits.

To illustrate the above with an example let us consider the case of an underground parking facility. This plan allows for a corresponding increase of free space in the surface, which could be reforested. According to a recent research [13], it was estimated that an urban park of 20,000 m² in a densely populated region of Athens affects the dwelling prices at a range between 1 – 4 blocks. Within this zone, a dwelling attracts, on average, a premium of 14% up to 31%. More specific, given that the average unit price of an apartment, in the case examined, was about 1.320 €/m², the value of the green space capitalized in property prices of the surrounding dwellings ranged between 185 up to 409 €/m². It is apparent that one should compare the construction cost of an underground facility with the cost of building it aboveground, plus the cost of purchasing the
land, plus the benefits created by the green area. If the value of non-market goods and services of the environment are taken into account, the result would be that in many cases an underground solution would be justified not only on the basis of environmental and social criteria but also on strict financial grounds.

3.2 Underground development and land ownership

Among the principal issues that hinder the promotion of underground development in many countries including Greece are the legal matters and in particular land ownership. Since the roman times, it has been accepted by most western laws that the “the owner of the surface also owns to the sky and to the depths” [14]. However, laws that control land ownership vary among countries, resulting in a state of uncertainty regarding the ownership of subsurface.

According to a survey carried out by ITA three main systems have been adopted [15]:

- Unlimited ownership to the centre of the earth
- As far as reasonable interest exists
- Only to a limited depth.

Some countries, having recognised the need to revise their legislation in terms of land ownership, have already started investigating three-dimensional delimited real estate. For example Oslo (Norway), has already adopted the three-dimensional real estate model [14]. In Japan the State owns the subsurface below 50m, the so-called “deep underground”. In the case of the city of Montreal [16] it is widely accepted that the development of the underground city of Montreal would have not been accomplished, unless urban planners had decided to stratify the property rights both vertical and horizontal, etc. On the contrary, in Finland the landowner’s right to the underground space is unlimited [1].

The latter condition stands for Greece. With the exception of the exploitation of certain mineral resources, the owner of the land is also the owner of the subsurface. Hence, the issue of who owns the underground space with respect to non-mining activities, especially in urban areas, where several conflicts exist between private and public interests, remains so far unsolved and the need to revise the Greek legislation, regarding land ownership, is more pressing than ever.

3.3 Public’s common misconceptions

Currently, the public’s perception of underground space is far from modern reality. Common prejudices and misconceptions usually prevail and more often than not an underground space is described as a dark, humid and claustrophobic environment. However, modern underground workplaces have nothing in common with this picture. They are supported with good lighting, sufficient fresh air, controlled climate and well-designed, safe and high-quality interior environment.

Undoubtedly public perception towards underground places plays a critical role and it should be taken into consideration. Accordingly, in order to
familiarize the public and the end-users with the modern underground solutions, state-of-the-art 3D visualization and virtual reality techniques have been employed. The results so far underline the fact that visual scene simulation is essential in persuading non-experts. Furthermore, 3D visual representation of underground spaces could alleviate, to a certain extent, the psychological reservations regarding going underground.

4 Conclusions

Undoubtedly the underground space will be intensively exploited in the future. The growing environmental concern and the principles of sustainable development force urban planners towards the utilization of underground space. Accordingly, unwanted or polluting activities and facilities should be placed underground, releasing, in that way, valuable surface space and improving environmental conditions and the quality of life.

Underground development can change the scenery regarding major problems of modern urban centres. Nevertheless, in order to achieve this goal, certain issues affecting the underground’s ease of use, such as the ownership rights and the public’s hesitations, as well as to some critical issues that affect the final decision, e.g. externalities should be addressed.

References


