Underground space, the hidden face of any territory

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RESUMEN

ABSTRACT

Underground space looks to be underrated in most countries, though it makes up a real wealth, worth of being thoroughly considered by owners and developers at any scale, from the private owner to the city, and the state. It provides three functions: i) support of the surface, *ii*) mineral resources, *iii*) extra volumes for many services and activities. Such extra space is available everywhere below the surface. Many examples are given, examples of use as well as of geological and legal constraints. Even more than soil use and occupancy, subsurface use must be thoroughly planned, as it is never possible to turn back to the initial status.

1. INTRODUCTION

In most countries, the rules on City planning (urbanism) and Territory management do not take enough account of the underground space. Nevertheless it makes up a real wealth, worth of being thoroughly considered by owners and developers at any scale, from the private owner to the city, and the state. Besides i) the support of the surface, including watercourses and any structures above, the subsurface may fulfil two more valuable functions, ii) provide mineral resources, from water to oil, from building stone to gold, iii) provide extra volumes for many services and activities. Where space above ground becomes scarce and expensive, extra space is available below, with natural properties well recognised, among them preservation and storage of any goods.

Supply of underground space is given by Nature (shape of the surface, nature and structure of geological materials inside, groundwater) and its use is limited by laws and administrative rules (1), beginning with the depth limit of private property. The shape and dimensions of public and private land lots prevent a rational use of the volume below (figure 1).

Just as for surface supply, underground space supply is limited by all previous uses. Inside cities, the proliferation of embedded utilities is denounced but not yet counteracted. Outside cities, the bad results of some mining and quarrying operations have called for new rules, not yet fully enforced.

Even more than soil occupancy, subsurface use must be planned, as it is never likely to turn back to its initial status (proposals for a new law by the French Senate have not yet been approved by the government).

2. PRELIMINARIES : SUPPLY AND DEMAND OF UNDERGROUND SPACE

2.1. The three functions of the underground, explicit or implicit

The main function of the material under the surface is to support the surface and all it may have to bear, including watercourses and man constructions. The sciences and technologies of foundations, soil and rock mechanics (2), soil improvement, etc. (out of this paper) help answer this question. In addition, any previous underground work may restrict later uses of the surface: The French national railway company, SNCF, happened to sue the tenant of a quarry who had stockpiled rock aggregate above a shallow tunnel (near Modane, Savoie) when the old tunnel masonry had suffered some minor damage; the respective role of the extra load outside and the masonry ageing inside was not clear. At the time the tunnel had been bored, about 120 years before, no formal expropriation had taken place, and since this time, the quarryman did not know any constraint might limit his property rights. For lack of a formal paper on property transfer, he was not supposed to refrain from stockpiling material.

On the contrary, the rapid regional metro station Les Halles, built in the 19-sixties at the lower level of a huge open air excavation, provided columns strong enough to support whatever could be built later as well below than over the surface (just now, projects are called to replace the first «Forum des Halles» supposed to be obsolete).

Locating public works, be sewers or metros or others, under public property eliminates the need of expropriation, a troublesome procedure when private owners are many and hard to number and locate. Conversely, the scheme of public property would severely limit the width of underground stations and impose short radius turns at street intersections (figure 1). Most of ancient metro lines in Paris kept below public property, the sharp bends limiting the train speed. Recent lines (Meteor, line 14) encroach below private property for their bends and stations.

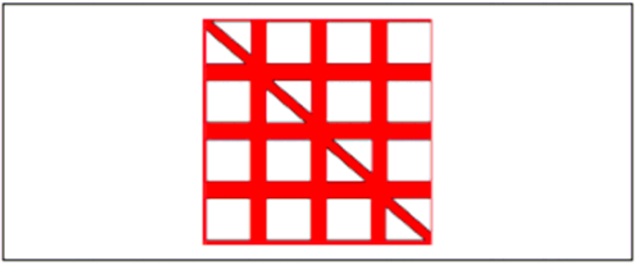

Figure 1. Basic property scheme inside a city: the public space (red) is made of narrow lanes intersecting at sharp angles between isolated private estates (1).

About the second function, let's first consider surface quarries (table 1): in addition to any drawbacks from the works, such as noise, dust and heavy traffic around, they leave unaesthetic scars on hillsides and irregular holes in plains, sometimes with unstable borders. Owners are requested, since some decades only, to rehabilitate the places they leave: remove built remains, restore stability and vegetation and, where possible, find a sustainable use for the hole. In South Africa, when slides along the slopes of the Kimberley diamond open pit (known as the Big Hole) were a menace for buildings around, a drainage gallery helped control the water table and flow. In France the coal open pit near Carmaux (Tarn) has been turned to a recreation park, fitted with a bottom lake with free beaches and a skilift to serve ski and bike runs. Nowhere yet such holes have been used as ways to disenclave and serve underground space around like on figure 2).

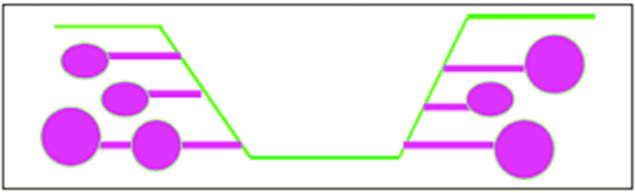

Figure 2. How to access the underground space around an open pit through horizontal adits.

Most of underground networks only host one function, railway below grade, road detour below a hill, sewer, water or gas duct, electric or phone wire, etc. On the contrary when Paris prefect Haussmann built the sewer network, he designed tubes large enough to allow for man cleaning, so they can host all public utilities (which were few at the time). For most of them, they have left since, to be independent of the tube owner). A research project has just been completed by a study group (called «Clé de Sol») in order to promote technical galleries (utilidors) under the streets, in which all kinds of networks might be located, with some room for later extensions (9).

In the same way, any underground work may be shared by some more users: transportation tunnels may host many utility networks, and even car parks could serve better their neighbours, full integration of works, transportation tunnels, car parks.

Underground storage was first emphasized at two Stockholm symposia, 1977 (4) and 1980, beginning with oil storage. Subsurface storage of explosives close to underground worksites is a classical practice. Underground location of dangerous activities could also prevent the catastrophic consequences of explosions such as the one in Toulouse on 20 September 2001 (ammonium nitrate at AZF chemical plant). Only a few nuclear power stations have been built underground in the 19sixties, rather small ones, in spite of many studies for bigger ones (and a recent project in Belgium (7)). Long before the Tchernobyl and Three Mile Island accidents, the first core melt happened in the Lucens cavern plant, in Switzerland, without any damage outside.

Just as NORAD[1] surveys the Atlantic air space from two deep underground centres (Colorado Springs, Co and North Bay, Ontario), the French Air Defence is hosted in underground centres, Taverny, close to Paris, Mont d'Or, close to Lyons (the latter having reused gypsum quarries). The Provence missile silos site has been closed and partly turned into a university laboratory: thanks to its 500 m depth, it provides low noise rooms; one of them, a steel lined cylinder 8 m ID, 28 m long, is the world best chamber for accurate magnetism measurements.

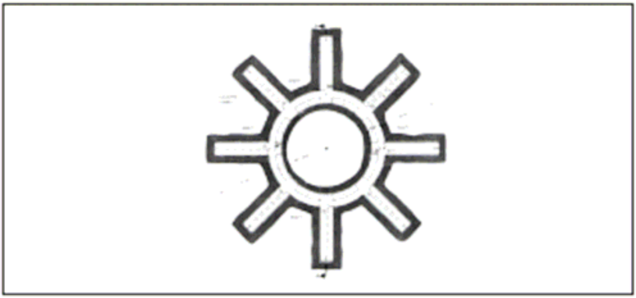

Figure 4. Map of an underground civil defence bunker designed for 600 people (8).

[1] North Atlantic Radar Air Defence.

At the latest World Tunnel Congress in Singapore, last May, the design of an underground bunker has been presented (figure 4). The civil defence project was intended to protect approx. 600 people, with all necessary housing facilities, together implementing flexibility and economy and allowing discussions and comparisons with feasible alternatives in regard to construction time and cost. The concept was designed in the shape of a wheel with 8 spokes in order to offer an optimum of safety for the people affected. Any military facilities could be arranged in addition. The structure consists of 4 circular shafts connected at the one end with a circular tunnel. The living quarters are installed in 8 adjacent tunnels of approx. 30 meters length, radial arranged at 45 degrees angles.

2.2. Topology: tubes, flat volumes, boxes, assemblies and networks

Single underground openings may be described in three groups along the number of dimensions:

- 1D i.e. linear volumes (cylinders or tubes, like tunnels and shafts, whatever the gradient), like the underground car park of Landsberg, Germany (figure 5).
- 2D «flat» volumes like in room and pillar mining (Banque de France safe room, Paris).
- 3D volumes (caverns or boxes, either parallelepipeds, or more rounded, spheres and ellipsoids being rather infrequent).

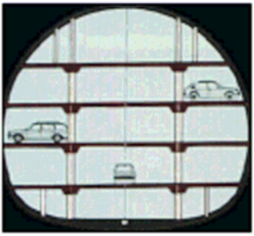

Figure 5. Cross-section of the Landsberg underground car park, Germany: 385 cars or 5,000 people civil defence shelter.

The next step in classifying underground volumes describes assemblies of simple volumes: bends of a tube, parallel tubes, branches, intersections, then networks (2D and 3D). One knows that hydraulic conduits do not turn at sharp angles, neither they branch at large angles, and they never intersect (except for low discharge sewers); railway tracks follow the same rules, the more stringent for the higher speeds; surface roadways may accept intersections, even multiple intersections and roundabouts; underground, only branches at small angles are permitted as in some underground roadways around Paris (along external Boulevards and below Les Halles garden); an underground roundabout connects three road tunnels near Tromsö, Norway).

Extending any existing volume shall deserve specific consideration: it is easy to extend the length of a tube, uneasy to enlarge its section (at Marseilles Prado-Carénage road tunnel, instead of widening an abandoned railway tunnel, its invert has been dug to provide two storeys); in most of cases it is better to bore a second tube.

Figure 6. The Bouygues 3-storey MUSE concept: an underground motorway restricted to light vehicles and mass transit in the same 10 m ID tube (designed for the Hauts-de-Seine department, immediately west of Paris, but not yet adopted).

2.3. Demand of underground volumes

Examples quoted above only are a sample of the uses the underground space can fulfil, which could fill many pages and can be found elsewhere (3-4-5-6). Here we prefer to focus on the supply side, as offered by Nature (10) and limited by laws, codes and rules (1).

2.4. About toll tunnels

Urban mobility is significantly constrained by bottlenecks and gaps in the current freeway systems, inside and around cities, most of which were designed decades ago for a different urban land-use pattern than exists today. Congestion-relief toll tunnels in downtown areas (11) appear to be economically feasible, largely or entirely from premium-price tolls paid by users. They are being developed by private consortia, operating under long-term franchises from government. Restriction of use to light vehicles only helps reduce the tunnel cross section). The best model is the LASER project designed in 1987 for Paris by GTM (Grands Travaux de Marseille); though it has been rejected by the City, by fear of the local associations, some modern examples are operated in Marseilles and Lyons, and out of France in Sydney & Melbourne, Australia, not to mention short sections e.g. underwater tunnels, as in Hong Kong. Non-stop electronic toll collection systems have given more interest to such tunnels (like on bridges). The closure of the second ring freeway under the hilly western suburbs of Paris (A 86) is by a pair of tunnels, the first of which is two-storey for light vehicles only, in each direction, the next one for all vehicles. A rival project proposed by Bouygues sited a mass transport system on a third level (figure 6).

2.5. Mountain resorts

This case is environmentally-friendly as the mountain landscape may be preserved from pollution by constructions. Two cases have been studied by the author in cooperation with architects, one inside an alpine summit 1600 m over Grenoble (Pic Saint Michel) (12), the other in Peru in order to preserve the Macchu Picchu site from a growing number of visitors (13).

3. MAIN FACTORS OF THE SUPPLY OF UNDERGROUND SPACE

3.1. Integration into landscape and «groundscape»

In its rather recent environment-friendly way of thinking, man needs to look at the landscape around before any new work: two —and three— dimensional landscape, including ecology of all living species, including mankind, that is agriculture, mines, industries and cities.

Two-dimensional landscape (Physical Geography) begins with surface morphology, that is relief, hills and slopes, plateaus, plains, and surface water, rivers and lakes whatever their size. The relief may offer opportunities to locate linear infrastructures, through combinations of tunnels and bridges, as in the half-ring motorway of Funchal, Madère Island, Portugal.

Many examples were since long given by railway tracks & stations inside cities, from Rouen to Monaco; by Paris metro lines 2 & 6, as by more recent roadways and motorways (many examples around coastal cities like Nice, estuary cities like Hamburg, Germany, and fjord tip cities like Oslo, Norway; studies are launched at Geneva, Switzerland).

Three dimensional landscape is governed by Geology, and should be best named «groundscape». It must be seen first as anatomy of the ground, that is how geological materials are organised into structures; then one needs to understand its physiology, that is the whole of what happens inside, groundwater pressure and flow, heat flow, stresses, fault movements and strains. Today this anatomy has often been modified by man works and uses (subsurface utilities, mining cavities, fill hills, and reclaimed land, again as in Monaco).

The benefits of the geological environment have been studied elsewhere, for instance in reference (10).

3.2. Obstacles from property rights and other codes

Laws: In France as in some other countries, the Roman Law applies to private ownership: the owner of the surface owns the whole volume below, down to the centre of the Earth. Many other countries set a depth limit, e.g., 6 m, or sometimes any depth the surface owner can claim he needs it (6). Cities and other so-called «collectivités locales», including the State, may own private properties. But most of their estates are under a special statute: the «Domaine public» (public estate) is collectively owned by all citizens; parts of it are allocated to such or such public use (e.g., for streets, roads and railways, navigation canals, ports and airports, etc.; others are free for use (common lands, e.g., for pasture), provided equal access to all citizens is provided. Each community and each authority in charge of public services are entrusted to manage «their» public estates, always in the interest of the whole public. There is no formal mention of the property statute for the volume below the surface of public estates; authorities in charge of managing the surface play as they have the right of disposing of it, provided it be in the interest of the public.

Codes: Many laws are implemented through a number of specific Codes, say in France Code du travail, Code de l'urbanisme, etc. Except for the Mining Code, no special provision applies to the underground (even in the Urbanism code, the words underground or subsurface do not appear) and what is much worse, most of the rules inside them do not fit with underground plants of any kind. Some rules are very hard to comply with : no ERP (establishment receiving public) is permitted deeper than 6 m; no classroom or hospital bedroom is permitted underground; every working place must receive daylight and fresh air from a working window, etc. Of course, derogations have long been established for the metro stations; otherwhere, they have to be obtained before opening any new specific place; e.g. the Les Halles commercial centre (14) had to discuss for months with the Fire Brigade and other authorities in charge of hygiene and safety.

That is why, early in year 2000, Espace Souterrain and Senator Jean-Paul Hugot tried to present a new law text along which:

- The Urbanism Code shall apply together to surface and subsurface.
- A public body be created, named Agency for subsurface, to improve the knowledge and development of the subsurface of cities.

(Though many approved this proposal, the government rejected it for the time, probably because such a text would need approval from many ministries, which could delay the whole law).

3.3. Some international approaches

The first rules established towards use and planning of underground space were established in Scandinavia, about 1976 (15). Among countries and cities which followed were Kansas City and Minneapolis, USA, Montreal and Toronto, Canada, Tokyo and Nagoya, Japan.

Italy: In 1996, the association Quarta dimensione, lead by Pietro Lunardi, listed five principles favouring the underground alternative:

i) As works escape any climatic hazards, the costs and delays are minimized.
ii) The cost of land is reduced.
iii) The surface disruption is minimized.
iv) Underground structures need less maintenance, whatever the climate.
v) Heating and cooling of any premises are cheaper, thanks to natural insulation.

Then the Law on saving the environmental equilibriums was complemented to give priority to the underground alternative on two points:

i) The choice of a surface alternative must be expressly justified.
ii) Any citizen may propose uses of underground space, private or public.

Japan: The first proposal of the government, to set a 50 m depth limit for private ownership, was rejected by the parliament. Then a concept of deep underground space was established, its extension being defined along the building foundations and the geology:

i) Below buildings with basements, some of them extending to 40 m depth, this figure is the limit.
ii) Below buildings on piles, the integrity of the layer on which piles rest must be preserved, and the limit is 10 m below the foot of the piles.

Along the today technological level, the underground space in Japan is supposed usable to 100 m depth, in spite of poor alluvium geology and pervasive groundwater (the same geotechnical conditions paved the way for the tight slurry and earth-balanced pressure TBMs which may now tackle the worst conditions worldwide (including the Channel Tunnel).

3.4. The Singapore World Tunnel Congress

In spite of its title, «Underground Space for Sustainable Urban Development», very few papers in Singapore last spring tackled true underground urbanism examples or concepts. The reference (8) comes from this meeting. Just as this one, many national and international conferences since a few decades invoke the benefits of using the underground space, but most of them do not go farther than the design and construction methods and fail to give consideration to true city planning. There is no real attempt to integrate the uses of the underground into the conventional surface planning of cities. For instance, multifunction galleries are only operated in a very few cities.

4. CONCLUSIONS

Urban design expert Gideon S. Golany of Pennsylvania State University was one of those calling for making increased use of the land beneath urban areas. He told American City and County meeting in 1992 «Cities everywhere have grown beyond the point of manageability, and their inhabitants now pay an invisible social and economic price,». Based in part on his study of underground construction in Japan, Golany called for the transfer below ground of most, if not all, urban transportation facilities to below ground, metros, high-speed rail, and motorways.

After Scandinavia, after the USA, after Japan and Korea, after the Netherlands, Switzerland has expressed a wide interest in underground use and architecture through a collective book (16) titled «Vingt mille lieux sous les terres» instead of «Vingt mille lieues sous les mers», a paraphrase of the Jules Verne story of Captain Nemo and his famous Nautilus submarine.

Up to now, few countries have developed bodies of laws governing all the possible uses of underground space. It is clear that every underground work has to be authorized and registered ; every hole must be traced on an official map. A number of underground works need to have their surroundings protected. And mostly, the sites able to accommodate very large openings (17) shall be searched for inventory, be classified, and be preserved (4).

Geosciences are hard sciences, valid at any time and place. Law sciences are soft ones, with wide differences from country to country, and from time to time; they have to adapt to new concepts; the sooner the better. City sciences must be a mix of geosciences, social sciences and engineering sciences as appear in the works of Sabine Barles, coauthor of a short and comprehensive book «L'urbanisme souterrain» (18).

Just as is the surface, the whole subsurface is a part of terrestrial environment, providing support for buildings and structures, providing water and minerals, and offering extra room for many services and activities. As there is no way to go back to the initial «virgin» state, a global long term assessment is essential ; this way, underground city planning asserts oneself as a contribution to sustainable development provided it be managed in a sustainable way.

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