SUPPLY AND DEMAND OF SUBSURFACE SPACE , BETWEEN GEO- AND LAW- SCIENCES

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ABSTRACT Nature provides 2D surface space and 3D underground space; as well surface morphology as subsurface anatomy and physiology are relevant for using such spaces; that is why Geosciences are needed for any planning and building tasks, the more so when the subsurface is considered. Construction must follow different rules over and below the surface, as the shape and layout of openings may depart from those inside buildings: as an example, Nature may provide natural roofs and floors.

Subsurface use is restrained by sets of laws and regulations firstly devised for constructions over the surface. The extension of private property to the centre of the Earth, along the latin law, is today counterproductive and might be replaced by a better scheme. Just like open sea far off the coasts, the centre of the Earth ought to be at best a common property of mankind. The subsurface of a city might be a Public Private Partnership like the common parts in a condominium. Town planning must install all utilities inside common galleries. Transportation needs should make a better use of underground roads and railways. Up to now, transportation of freight and goods inside cities appears a severely underrated problem.

Geosciences are hard sciences, valid at any time and place. Law sciences are soft ones, varying from country to country, from time to time. They must adapt to a sustainable use of underground space.

KEYWORDS ***Geosciences, Law, Regulations, Sustainable development, Town planning, Underground space***

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1. 1. GEOSCIENCES

Just as surface space, subsurface space is offered by Nature. The surface supplies 2D areas, the subsurface 3D volumes. In both cases, the properties of the ground which are relevant for man activity, either farming or building, derive from morphology, anatomy, and physiology of the Earth crust, three components of Geosciences which parallel with the same categories in Life sciences. We call here “subsurface” all the space under the ground surface, a space too often underrated, underused, or even misused and sometimes wasted. Where the surface is fully occupied, as by cities, industry plants or even vital agriculture, the subsurface remains the only available space for improvements.

Though at first sight the designer may feel freer than on the surface, by lack of such constraints as gradient, sun and winds, traffic, aesthetics, etc. (Duffaut et al, 1999), the subsurface presents its own 3D landscape, we may call it “groundscape”.

1.1. Morphology Of course, the shape of the surface, morphology, is more relevant for surface construction, anatomy and physiology becoming more relevant for subsurface construction, the more for the deeper works. Morphology governs the location of surface water bodies and water courses. Any geologist knows that morphology also betrays useful indications on geological materials and structures below, what we call here anatomy.

Any civil or military architect and planner knows the weight of morphology on the location of cities and of their main buildings. Just remember Athens Acropolis, roman *oppidums*, and since then Middle Age castles on top of hills. So cities are used to adapt to reliefs, as they do to water bodies, seaside, lakeside, or riverside.

Thanks to the subsurface of hills, the first long distance railway in France (along the Seine river) did not harm Rouen. 150 years later, the Principality Monaco followed the example, by turning the track which had cut the city along the 20 m contour into a long tunnel. There are two examples of tracks inside cities, without any of the harms and pollutions from an open air track and with the station in the very heart of the city.

1.2 Anatomy The ground being opaque, just as the skin of animals and the bark of trees, the knowledge of its interior is gained from school (second hand) or from experience (autopsy). The “visible man” (or woman) is a 3D model of the main parts of human body, inside a see-through skin; bones, muscles, and all organs, together with nerves, veins and arteries may so be visualized. Most people know the location of their heart, but too many civil engineers lack any rudiments of geology! Nevertheless, they have to work like surgeons, so they must have learnt some anatomy by themselves.

Both the materials and structures of the subsurface are very variable from place to place. Every rock mass presents flaws (cherts in chalk, karstic cavities in limestones, joints in granites, faults everywhere, etc.), all of them likely to become hazards for underground works. To the engineer such flaws are far more significant than the age and true name of the formations.

In addition to natural features, the subsurface hosts manmade features, underground quarries and mine workings, tunnels & caverns (ancient or not), more so below cities.

Table 1 – Void volumes below the 106 km² Paris surface
(rough assessments, embedded pipes and wires excluded; after Duffaut, 1979)

Type of void	Volume	Height	Depth	Percent of total
Ancient quarries*	6 hm^3	2 to 4 m	10 to 25 m	7,2 %
Basement of buildings	43 hm^3	2 to 6 m	0 to 12 m	51,2 %
Metro	19 hm^3	5 to 8 m	10 to 30 m	22,6 %
Rail tunnels	1,2 hm^3	8 m	5 to 20 m	1,4 %
Road tunnels	1,2 hm^3	8 m	3 to 5 m	1,4 %
Car parks	3 m^3	0 to16 m	0 to 15 m	3,6 %
Sewers	8,4 hm^3	2 to 5 m	0 to 10 m	9,9 %
Other utilities	1,8 hm^3	2 to 3 m	0 to 15 m	2,1 %
Commercial centres	1 hm^3	3 to 12 m	0 to 10 m	1,2 %
Total volume	84 hm^3			100,0 %

* after a major part of the initial volume being refilled

Early constructions and infrastructure had to adapt to the foundation grounds through trial and error; modern town planning does more or less the same along geological formations, clay, sand or rock (the Empire State Building was built on top of a bedrock hill). Underground projects have more and more to fit geological materials and structures.

1.3. Physiology Within physiology, we mostly include groundwater pressure and flow (remember that hydrogeology focuses on yield, and happen to neglect “impervious” formations). Groundwater lowering during underground construction may be a severe drawback for buildings around on the surface; in addition many underground facilities located inside pervious formations alter the flow of groundwater, just like dams do in valleys.

We include as well stress fields, temperature and heat flow, magnetism and electricity. Stresses are the more relevant for the deeper works. They may impair or favour the stability of caverns. Heat is relevant for insulation against atmosphere temperature variations; heat flow may be tapped in geothermal plants. Magnetism and electricity play minor roles, except in specific cases.

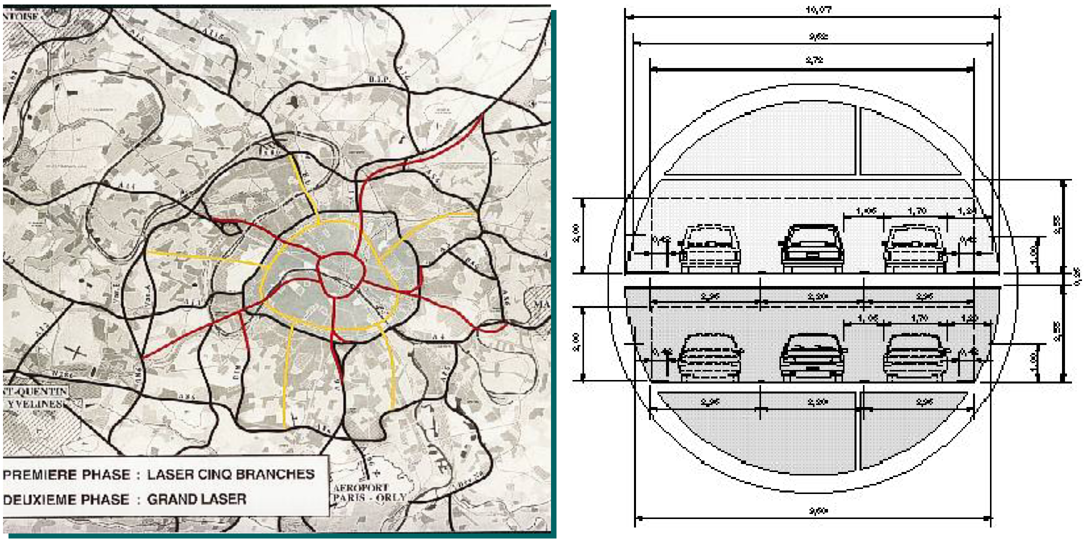
1.4. Building requirements For building over the surface, gravity asks for transferring all vertical forces downward through slender members, walls and posts, because their material, timber, masonry, concrete or steel for most of them, has to be minimised ; most constructions on the surface only require vertical support from the ground, through shallow or deep foundations. That is why surface buildings (except a few) do not depart from verticality. Under the surface, “members” are no longer slender, as their natural material is freely available, which give designers more freedom in choosing the shape of openings in a massive rock (multiple openings may be placed in the stress field like bridge piles in the river flow); not infrequently, Nature may provide natural roofs and floors.

Sometimes, the “ideal city” is designed from zero (“*Salines royales d’Arc et Senans*”, built 1775 along a design by architect Claude Nicholas Ledoux); on the contrary, a preexisting city provides an heritage, the ground, the surface spaces, either green or built, which have to be taken in account : nobody can neglect them.

1.5. First conclusions The geography of any city supplies hindrances as well as benefits: the rock hill bearing the citadel of Salzburg provides a good example of a very favourable site, the subsoil of Tokyo, though far less welcoming did not prevent the use of subsurface space. Japanese engineers had to invent novel TBMs to tackle their waterlogged soft soils.

What Milan first devised and what Paris has refused, is a motorway below the city. Boston did this now, turning a huge viaduct which had cut the city in two parts since decades into a big tunnel. Melbourne et Sydney are doing the same, though only as isolated sections, like in Marseilles and Toulon). Madrid is thinking about it, with an underground ring, connecting all radial motorways and serving immense car parks. No doubt this project derives from the LASER concept, devised 1987 by contractor GTM (Grands Travaux de Marseille), but refused by the Mayor of Paris (figure 1).

In France, underground car parks are becoming the rule inside many city centres; a lot of them are enlarged over the years (as in Lyons Part-Dieu rail station). Few car parks are designed for busses, and none of them for trucks, except below some commercial buildings (Paris-Bercy, Monaco-Fonvieille). Also, few urban traffic tunnels are open to trucks, even though this traffic is the more disturbing. Freight transport has too long been neglected behind people transport. Car traffic is not the sole problem, many (if not most of) utilities and facilities needed by today (and tomorrow) cities may be also put underground, leaving open spaces for greenery.



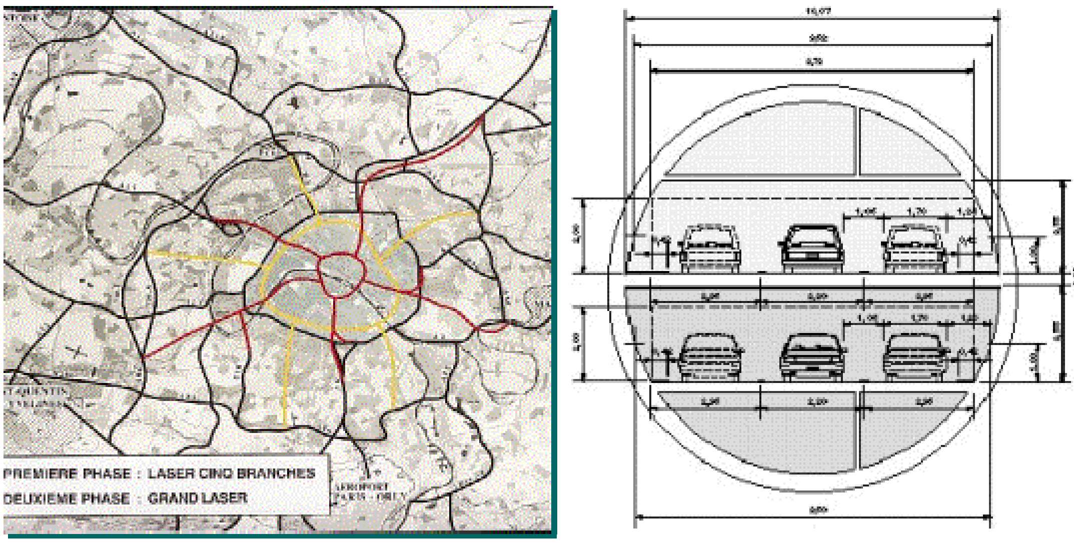


Figure 1: Sketch map of LASER network and cross section of the tube (after GTM)

There are underground spaces everywhere, easier to access under hills, more difficult under water: under a flat ground, we need to go down, under hills we may enter at level. Some cities enjoy a solid bedrock, some more deplore a waterlogged soft soil. Without any doubt, engineering can do everything, but neither at low cost, nor without any hazard ; it is up to policymakers to obtain from the public the choices between what must be preserved and what to be done.

Far more than on the surface, the weight of geosciences is dominant under the surface, as long ago wrote Francis Bacon (1620) *“non, nisi parendo, vincitur (Natura)”,* "Nature, to be mastered, must be obeyed”, and later Albert Caquot : “*les qualités de la matière sont les données premières et essentielles…, les formes ne sont que les résultantes de ces données premières”*, “Qualities of matter are the first and essential data …, shapes only are the results of those prime data” (Kérisel, 2001).

2. 2. LAWS & CODES

It is not enough to convince the people and policymakers that underground solutions may be both useful and satisfactory; over the psychological ones, the main obstacles derive from unsuited laws and regulations:

First, a private property right without depth limit is nonsense.

Second, regulations on construction and city planning only consider shapes and volumes over the surface; setting limits on density (soil occupancy coefficient, French COS) increases the weight of all infrastructures and utilities .

Third, as has been done one century ago for skyscrapers (French IGH, great height buildings), codes on hygiene and safety for workers as well as for general public need to be adapted to subsurface "moderate depth" buildings (rather than great depth).

It is well known that Law only follows use, sometimes after too much delay. Novel regulations are necessary to relieve the blocks on subsurface use; more than 25 years ago, Kansas City established specific rules in order to favour the use of subsurface; more recently the government of Italy issued a law demanding a thorough study of an underground alternative for every urban project, to be compared to the surface one.

2.1. Property In the countries following the latin law on real estate, the owner of the surface owns a pyramid like volume extending from the center of the Earth to the infinite ("from the hell to the heavens"). We must have the courage of recognizing that this concept today is both stupid and inefficient: never has any owner claimed the right to go so deep, none today can prohibit the use of his aerial space by crafts and satellites. Over the surface, only some rights of view and privacy remain. Below the surface, such problems do not matter.

French law permits a surface owner to sell a part of his subsurface volume. In case of superposition, the lower owner has to provide permanent support for owners above. Since the project of Les Halles underground complex, in Paris center, even superposition of public and private estates became likely.

There is no private property on the sea; the full power of States extends offshore to a 12 miles limit; farther the state has reduced powers and responsibility, up to 200 miles; and farther the sea is a common heritage of mankind. This model looks relevant; depth limits may be assigned to private property (say 10 m), to the city (say 100 m) and to the State (5 or 10 km). Deeper volumes are common heritage.

As the shapes of public and private volumes below a city place stringent limits on the use of their subsurface, it could be more efficient to consider the whole of this space as a common property of public authorities and private owners, just as the foundations, walls and roofs of multi owners buildings or the gardens of condominiums. The PPP concept (Public Private Partnership) appears as the ideal solution for an efficient use of underground space.

2.2. Density (soil occupancy) Depending of how underground floors are counted, the COS (coefficient of soil occupancy) may severely restrict the private use of subsurface. The rule aims at limiting the density of population, and the ratio of free space between buildings, but it limits the services available. Underground services do not increase the population, neither encroach on the free space.

2.3. Expropriation While many states keep the property of minerals and fuels, some of them lack the power of using space below private estates; they have to buy the volume needed below from the owner of the surface (at a cost depending on the depth). Japan has tried to limit the private property to about 50 m, up to now without success.

2.4. Insurance of risks Just like for surgery, the tendency now is to go to court to solve any dispute between the owner, his engineers and his contractors. Such practice costs lots of money and time (that is additional money). The cost of insurance against tunneling hazards being heavier and heavier, few bureaus and companies will afford them and many will withdraw from such businesses. The “image” of subsurface works and plants suffers from such extra costs and delays.

2.5. Hygiene and safety Codes and Regulations No school classroom or hospital bed is permitted in France below ground level. Any daylong working place must have a direct view to the outer space and a window opening to the outer air (with due exceptions for metro workers). Such regulations ignore the capacities of modern technologies (air conditioning, air filtration, lighting, etc.)

For any establishment receiving people (French ERP, say shops, cinemas, sport halls, meeting rooms, etc) only one underground level is permitted, the deepest floor being six meters below grade. Special rules apply to railway and metro stations, and to big complexes, like Paris Les Halles, only permitted after due discussion with the Fire brigade, which required wide ways out, easy access for firemen, smoke control and automatic fire proof partitions. Such requirements are reinforced along the years ; what was authorized twenty years ago when Les Halles have been designed and built could not be permitted now.

3. 3. CITY (AND LAND) PLANNING

3.1 As city maps and land registers are 2D, planning authorities ignore the subsurface.

To become sustainable, a city has to keep compatible together with Nature, its environment, and with People, its inhabitants and users. In order to increase the services offered to the inhabitants of cities, the use of underground space is more and more recognized as the sole answer (Duffaut & Labbé, 2002). Not any city will achieve sustainability without the help of its subsurface space.

All cities lack space, the more so for the densest and most populated cities. Dense cities allow inhabitants to walk for most of their needs (the city as a pedestrian space); they save an extra length of all utility and transportation networks, streets and tracks, sewers, any ducts and wires; they save space for Nature, together inside and outside.

The size and shape of single estates is a strong limitation to an efficient use of the subsurface of cities: most of private parcels are rather small, preventing cheap excavation into the subsurface. On the contrary, the public domain is made of rather narrow street surfaces, interconnected at right angles in the best case, a very bad shape for uses other than utilities servicing buildings on either side (figure 2): the sketch of a “future street” by Hénard, 1903, has been quoted many times as the first attempt of rationalization.

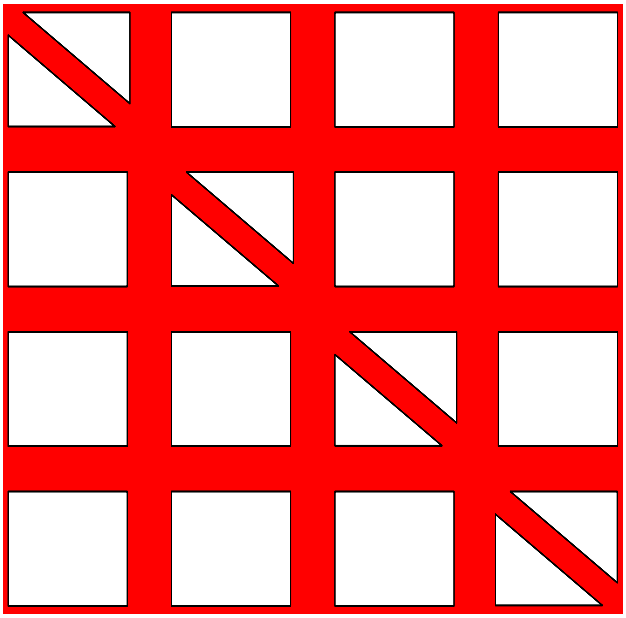
The value of the subsurface space has for long been ignored ; it is well known that every goods or estates, left free of charge, will be wasted, sooner or later. The same occurs for air, but less and less for water, which costs more and more every year in developed countries.

Never occupy a free surface without thinking what could be located below. Inside Paris such parks as Bercy and Citroën have benefited wide areas liberated by warehouses and factories.

Unfortunately, both opportunities of locating services below have been missed. The last area the subsurface of which remains free in Paris (apart from a few tunnel crossings) is the river area, a site exceptional by its continuity through the whole city (Labbé, 1997).

Every activity, rail station, market, etc., which began occupying a modest area, will happen to grow later. If no space has been reserved around, the solution is to add extra floors on the same base. When city planning prohibits any extra height, those floors will be under grade: so most of Paris rail stations have been provided of an underground level of tracks and platforms. When the Rungis MIN (*Marché d'intérêt national*, National wholesale market) will need extra buildings, the best way could be a deeper level, benefiting together from vertical liaisons with the corresponding surface warehouses, and level liaisons with rail tracks in the Seine valley (this market, built in the sixties close to Orly airport to replace the ancient Halles market, is not connected with the SNCF tracks!).

Figure 2: Basic property scheme inside a city: the public space (white) is made of narrow lanes between private estates (coloured)



3.2. Transportation All in all, planning the use of subsurface may derive from the design of the main function, underground transportation.

Classical city planning begins with the design of streets and squares. Streets are open to any kind of traffic, from pedestrians to the biggest trucks, including baby carriages, cycles, and public busses. Their subsurface hosts utility networks, wires and pipes, sewers and metros. Primarily interested in monuments and facades, city planners and architects now try to provide fair conditions of circulation for cars (the most of vehicles); either they restrict their use (toll in London, high cost of parking in many cities, restriction of the surface of streets in Paris, etc). In the densest zones of many cities, nothing may be added otherwise than underground (Sterling, 1997); underground roads appear to be as the only sustainable answer.

The capital city Moskow is launching the world's first combined vehicle and metro tunnel, 1,5 km in length, to be completed in about four years. The design is a twin deck structure with road traffic running in the upper section and the metro trains in the lower one (World Tunnelling, July-Aug. 2003, p 223). Ten years ago, such a design had been presented by contractor Bouygues to the *Conseil général* of the Hauts de Seine department, just west of Paris, as a more than 15 km network serving the whole area. Unfortunately not enough money was raised to begin the works (MUSE project).

Though freight transport has been the first reason for underground tracks below city centers (first Paris metro project, linking the central market, Les Halles, to the rail stations built close to the limits of the city; Chicago galleries network, 66 km at 12 m depth below the streets), this problem seems now forgotten; as the number and size of trucks increase everyday, it seems to become the first priority in today megapolises.

3.3. Utilities As most of municipal utilities are managed as concessions, each of the companies likes to have his own site, as a refilled trench under the street or pavement; all of them have better their wires and pipes embedded in the Earth than benefiting a place in a common gallery. What may have been satisfactory for 3 or 4 networks, has become foolish when their number is over 15. In France, after 4 years of work, the research project team "*Clé de sol*" will provide a practical guide for city officers and planners by 2004 (www.cledesol.org).

3.4. Rehabilitation Closure of industrial sites leaves unsolved important problems of polluted ground and waters (surface- and groundwater); in addition, closure of underground mines leaves problems of subsided zones, and the more, brings delayed hazards of sinkholes: Lorraine iron ore mines, closed during the late seventies, were permitted to be refilled by water in the nineties: soon after that, sudden subsidence destroyed lots of houses in 3 or 4 little towns. The government is beginning to define new concepts for the control of the landscape, both in cities and the countryside (*Directives territoriales d'aménagement*).

3.5. Subsurface management The French Geological Service, BRGM, recently chose a new motto "*Géosciences pour une Terre durable*" (for a sustainable Earth). Its knowledge of and expertise in Geosciences makes it able to work on all themes involved, from natural hazards to any pollutions from human activities (figure 3). Mineral and water resources are among its main fields of activity, either research, measurements and monitoring. An early paper by Duffaut & coll. (1980-1981) was a forerunner of this commitment.

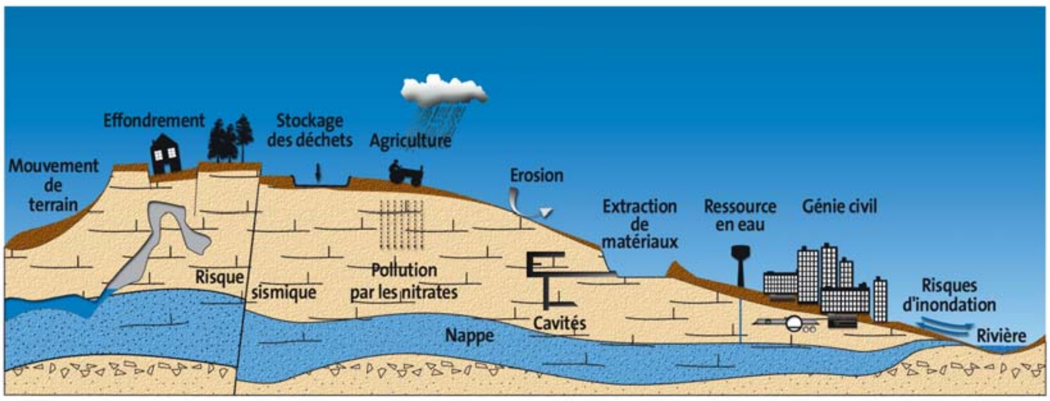


Figure 3: General scheme of interactions between natural subsurface and man activities, agriculture, extraction, construction, pollution, etc. (courtesy of BRGM, from booklet "Pour une Terre durable", *Towards a sustainable Earth, 2003)*

4. CONCLUSIONS

"Is Underground Space an option ?" asks Tris Thomas, Tunnels & Tunnelling International, Editorial, July 2003); and he gives his answer:

"The question is not: can the country afford to build it; but: can it afford not to ?".

Sustainable development of cities worldwide will require more and more underground infrastructure and facilities.

Subsurface is structured by Geology; as streets and buildings hide all natural crops, rock no longer daylight inside most of cities (Legget, 1973). Most of branches of Geology play a role in the groundscape around underground works and buildings. Given the low level of knowledge among city planners and civil engineers, they need to be given courses on engineering geology, intended towards underground works and efficient uses of underground space.

Subsurface use is restrained by property Laws and by a lot of Codes and Regulations (building codes, health codes, working regulations, etc) which have been developed long ago without consideration of subsurface use and have not yet been updated to fit its new uses (the same occurred before with skyscrapers).

Laws and regulations might be the main obstacles to an efficient use of underground space; as soon as 1968, former Director of Reconstruction in France after WW2, and former president ISSMG, Jean Kérisel wrote: *« A l'ère des mitoyennetés verticales doit succéder une vaste copropriété du tréfonds »* (after the time of vertical property limits, must come a vast co-property of the depths).

Geosciences are hard sciences, which are 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; unfortunately they do not adapt quickly enough.

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