Underground resources and sustainable development in urban areas

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Abstract: The lateral expansion and increase in population that have characterised urban growth and development patterns of the last few decades have produced cities that are often inconsistent with the principles of sustainable development. Due to the high rate of global urbanisation, problems such as greater traffic congestion, higher levels of air pollution, lack of green space, and insufficient water supplies not only affect the cities in which they occur, but extend around the world. Cities that optimize the use of the third dimension are seen as a possible path to sustainable urban form.

The urban underground possesses a large untapped potential that, if properly managed and exploited, would contribute significantly to the sustainable development of cities. The use of its four principal resources (space, water, geothermal energy and geomaterials) can be optimized to help create environmentally, socially and economically desirable urban settings. For instance: space can be used for concentrating urban infrastructure and facilities, as well as housing, parking facilities and transportation tunnels; energy from geothermal sources and thermal energy stored in the underground can be used for heating and cooling buildings, thereby reducing CO2 emissions; groundwater can be used for drinking water supply; and geomaterials from urban excavation can be used within the city to minimise long-distance conveyance.

The present research creates a methodology that helps planners consider and integrate the full potential of the urban underground within the larger context of city planning. Since the way in which the use of the urban underground varies in accordance with a city's specific natural, social and economic circumstances, this research is trans-disciplinary, incorporating both the physical and social sciences.

The methodology is tested on and refined during a case study on the city of Geneva and will be applied to other Swiss cities to provide general assessments of their underground potential.

Résumé: L'étalement spatial et l'accroissement de population qui ont caractérisé la croissance et le développement urbain des dernières décennies ont produit des villes qui sont souvent incompatibles avec les principes du développement durable. En raison du fort taux d'urbanisation, des problèmes tels que l'engorgement routier, les taux élevés de pollution atmosphérique, le manque d'espace verts ou l'insuffisance des ressources en eau, affectent non seulement les villes où ils ont lieu mais s'étendent également partout dans le monde. Aussi, l'optimisation de l'usage de la 3[ème] dimension des villes apparaît comme une solution au développement urbain durable.

Le sous-sol urbain possède un important potentiel inexploité, qui peut contribuer sensiblement au développement durable des villes s'il est exploité et géré de manière appropriée. L'utilisation des quatre principales ressources souterraines (espace, eau, énergie géothermique et géomatériaux), peut être optimisée pour créer des arrangements urbains qui soient favorable du point de vue environnemental, social et économique. L'espace peut par exemple être utilisé pour concentrer des infrastructures et des services urbains tels que, parking souterrains ou tunnels de transport ; l'énergie géothermique et l'énergie stockée dans le sous-sol peuvent être utilisées pour le chauffage et la climatisation des bâtiments, ce qui réduirait les émissions de CO2 ; l'eau souterraine peut être utilisée pour les besoins domestiques ; et les géomatériaux extraits des excavations peuvent être réutilisés dans la ville, ce qui minimise les transports sur de longues distances.

Cette recherche développe une méthodologie pour inciter les aménagistes à considérer et à intégrer l'ensemble du potentiel du sous-sol urbain dans le contexte plus large de la planification urbaine. L'utilisation du sous-sol urbain variant en fonction des caractéristiques naturelles, sociales et économiques d'une ville, cette recherche est transdisciplinaire et intègre tant les aspects naturels, techniques que sociaux.

La méthodologie développée sera finalement testée sur le cas de la ville de Genève et sera appliquée à d'autres villes suisses afin de fournir une évaluation générale de leur potentiel souterrain.

Keywords: Environmental Geology, Natural Resources, Regional Planning, Underground Installations, Urban Geosciences

INTRODUCTION

The latter part of the 20th Century has seen cities around the world undergo rapid lateral expansion. In industrialised countries, the development of individual housing and the increase in car transportation have lead to a migration from the city centre toward the periphery in residential suburbs and villages. In developing countries the urban population has exploded, in part due to rural migration, and cities have expand, most of the time without any strategic planning. The consequences, in both the industrialized and developing world of the city sprawl are an increase in traffic congestion, higher levels of air pollution, a lack of green space, and insufficient water supplies. This development is inconsistent with sustainable development. More compact cities are seen as a possible path toward sustainability (Besner 2002), particularly cities that optimize the use of the subsurface. The underground remains mostly underutilized and it can provide some new space for the city development. Some of the functions of the city (e.g. transportation, shopping, cinemas, catering facilities) could be partly transferred toward the underground. This transfer would create more space aboveground for recreation and social activities, and for the development of new green fields and residential areas. The consequences of increasing the use of the underground include more efficient use of space, better traffic mobility, and reduced noise levels that will lead to city renewal and an improved quality of life (Durmisevic 1999). Space is not the only resource of the underground: groundwater, geomaterials and geothermal energy should be optimally exploited and their potential should be preserved, in order to achieve sustainable development.

The transfer from the surface toward the subsurface is already a challenge of the present-day. Increasing amounts of the urban underground resources are being exploited, but this exploitation is done without proper planning. Since any void created in the underground could have irreversible consequences to the city, a reasoned management of the potential of the underground is necessary in order to avoid the unnecessary waste of resources.

This paper describes the potential of the urban underground to support the long-term development of the city and it shows how the current approach of underground exploitation is insufficient to reach sustainability. A new approach that considers the multiple uses of the subsurface is proposed and the expected results from this approach are exposed.

THE PRESENT SYSTEM AND ITS LIMITS

Urban underground is poorly known

The underground is not visible; its 3D characteristics and properties have to be investigated by direct and indirect methods such as borehole characterization, geophysical investigation or geological modelling. In spite of recent development and progress achieved in these techniques and methods, the knowledge of the urban subsurface remains unsatisfactory. There are several reasons that account for this. Most of the investigations in the urban underground are done only at the building scale. As a result, information is essentially site-specific, and the change of scale to provide regional information is not a simple process, as it requires compilation of data from several sources, obtained with various methods of acquisition. Moreover, data are often dispersed between several offices and their collection and collation may be time consuming. Cities have often been constructed on alluvial deposits. In this setting, the underground geology has been shaped by erosion and deposition mechanisms. As a result, the geological structures are typically laterally and vertically heterogeneous and complex, and consequently their representation may be difficult. Finally, the underground information is mostly dedicated to specialists. Most of the time, important stakeholders such as planners or the non-specialist user only have partial access to this information and don't have the ability to fully interpret and exploit it. This results in a poor knowledge of the urban underground value and an underestimation of its potential for urban development.

Urban underground is full of resources but vulnerable

The underground offers four important resources: space, groundwater, geomaterials and geothermal energy.

- Space is the more obvious resource for urban development. From the 1900's, the French architect Eugène Hénard suggested burying the urban traffic, fluids, wastes and goods in a gallery with multiple floors (Henard 1903-1906). This idea of a vertical segregation of the city was taken up by another French architect Edouard Utudjian who founded in 1937 the "International Permanent Committee of Underground Technologies and Planning". Utudjian proposed that certain modern functions of the city should be transferred to the underground in order to reduce the traffic congestion at the surface, to improve the hygiene and aesthetic of the city, and for civil protection. The functions considered by Utudjian were parking, public transportation facilities, and administrative, public and private buildings such as banks, shops or theatres (Utudjian 1952).
- The underground of many cities contains drinking water resources that supply a large proportion of the population. This groundwater forms a renewable but vulnerable resource. Sustainable development is possible only if groundwaters are maintained in quality and in quantity. Unsustainable exploitation of aquifers can lead to serious problems. An example of one such problem is from Mexico City, where the constant deficit of water balance has drastically lowered the water table, leading to ground subsidence and ecological problems (Esteller & Diaz-Delgado 2002).
- Historically, many cities were built over or very near underground quarries that provided the building materials for the construction of the city (for example, stone and gypsum quarries were built over in Paris, a practice that ceased during the 20th century). Recently, a shortage of geomaterials and the difficulties of bringing them on site have exerted a growing pressure for the use of local material. In response to this, rock and soil extracted for deep construction now have potential for their use as geomaterials.
- The underground can be used both as a source of energy and as an energy storage medium. Several technologies exist to extract geothermal energy. Deep geothermal boreholes can be very efficient, but the difficulty in identifying suitable deep aquifers restricts their widespread use. The recent advances in deep aquifer engineering are promising for the future (Baria et al. 1999; Brown et al. 1999). Subsurface geothermal systems can exploit low temperatures using heat pumps and are often feasible in urban settings, but they

should be planed at the aquifer-scale. Effective planning (which is rarely undertaken) would ensure that geothermal structures do not have a negative impact on each other and become ineffective. Heat storage is a promising technology in cities of mid-latitude. Its concept is to store excess heat in summer and reuse it in winter by heat exchange through geothermal structures such as drilling, piles or other foundation systems (Dupasquier 2000).

In addition to these resources, it is important to consider the heritage value of the underground. Subsurface work can present a great danger to the archaeological patrimony, and to preserve this, it should be considered in the planning stages of developing the underground.

To understand the relationship between the underground resources, we should consider the geological and hydrogeological conditions of the site. Underground resources are strongly interrelated; the exploitation of one resource may impact on another. Cities have often been developed on alluvial plains. In this geological configuration, construction may be difficult. In particular, groundwater resources are often important, but vulnerable to surface and subsurface contamination. Additionally, unsustainable groundwater exploitation may lead to the compaction of the alluvium leading to land subsidence phenomena.

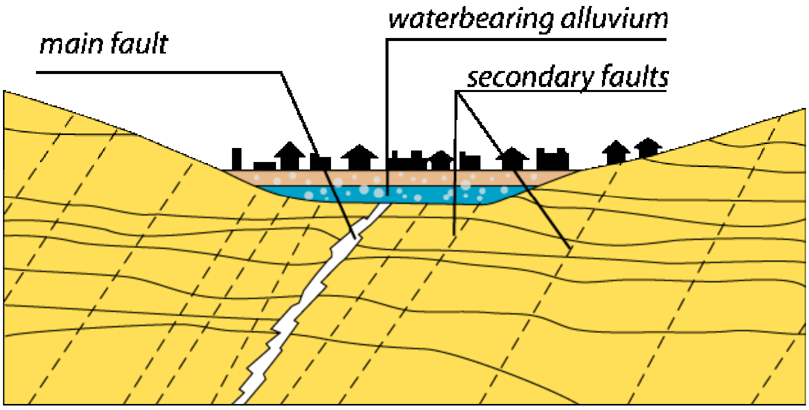

Figure 1. The typical geological and hydrogeological setting of a city. The underground below valleys is often the location of a major fault zone, making the rock very weak. In some cases, the faults are still tectonically active. The alluvial deposits, completely saturated by groundwater, are very unstable for underground structures. During an earthquake, they result in increased damages to buildings (Parriaux 2004)

The effect of the exploitation of an underground resource on another may be negative (i.e. the utilization of a resource hinders the use of another resource) or positive (i.e. the use of a resource improves the potential use of another or creates new opportunities to optimize its use).

- The negative effect is illustrated by Figure 2, which shows the interaction of the space utilization (here for tunnel construction) with the groundwater flow. Depending upon the vertical localisation of the tunnel, the flow of the groundwater table may be disturbed by creating barrier or pathway effects. This disturbance may hinder a future utilization of the groundwater for example for drinking water supply.
- The positive effect is illustrated by Figure 3. The construction of piles for foundations through the saturated alluvium creates an opportunity for geothermal exploitation in order to heat or cool the constructed building.

The urban underground potential is underestimated

The potential for urban underground development remains mostly unexploited and underestimated in urban areas. Several reasons account to this, including a lack of knowledge of the urban underground, and that its potential is not assessed in terms of its four main resources. Additionally, multiple uses of the underground are still out of the practice.

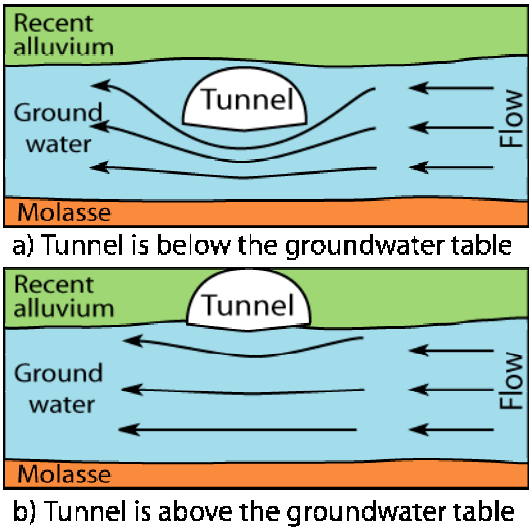

Figure 2. Interaction between space utilization for tunnel construction and aquifer. Depending upon the position of the tunnel, the effect on the aquifer may be important a) or not b).

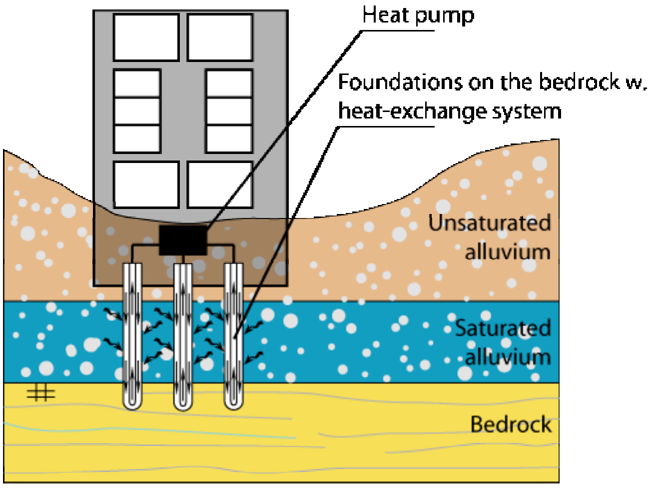

Figure 3. The need for pile foundations through the saturated part of the aquifer is an opportunity for geothermal structures

Non-technical reasons can also explain the reluctance to develop the subsurface. Underground developments are often considered to be more costly than the developments at surface, and therefore they are chosen only when there is no possibility of developing aboveground. The gross cost of construction has been constantly decreasing in the last decades (Chow et al. 2002). Even so, it is often more expensive to build underground than above, if we only consider construction costs. But if the cost of land with the exploitation costs are considered, underground projects are often competitive with projects in surface (Monnikhof et al. 1999). A reasonable comparison of both underground and surface development options can be gained by comparing the cost of the entire life cycle of the infrastructure (i.e. construction, exploitation, removal/destruction) along with the cost of the environmental impact. Unfortunately these costs are difficult to assess and they are in most cases not taken into account.

Since underground infrastructures have no surface expression, the underground lacks opportunities for building architecture, and consequently it suffers from a poor public perception (Duffaut & Labbé 2002); most people do not like to go underground. The result of this poor perception of the underground by public and professionals is that it remains mostly dedicated to utilities such as transportation, underground car parks or for storage. Recent projects such as the Louvre Museum in Paris or the Bilbao metro, have gone some way to proving that underground projects can be challenging for architects and result in attractive spaces (Von Meiss & Radu 2004).

The urban underground is poorly planned

In order to avoid an irreversible waste of resources in the development of the urban underground, the full resource potential should be investigated before any exploitation is realized. Often, no planning of the urban underground is done, and the subsurface is developed with a piecemeal approach which one particular need or project. This approach is here termed ‘sectorial’, since it considers sectorial needs one at a time (Figure 4). At time T1, a need for transportation infrastructure is identified; this need can be covered by an underground construction in a way that seems to be sustainable since the three objectives of sustainable development are considered. But at time T2, when another need, e.g. drinking water, is identified, the project cannot be realized since the metro line that has been constructed previously hinders it. If the global potential of the underground had been estimated before any construction took place, resources could have been maximised. The metro project could have been modified in order to take care of the potential value of the underground for drinking water. This could only be achieved through a planning mechanism of the urban subsurface that considered the potential of multiple uses.

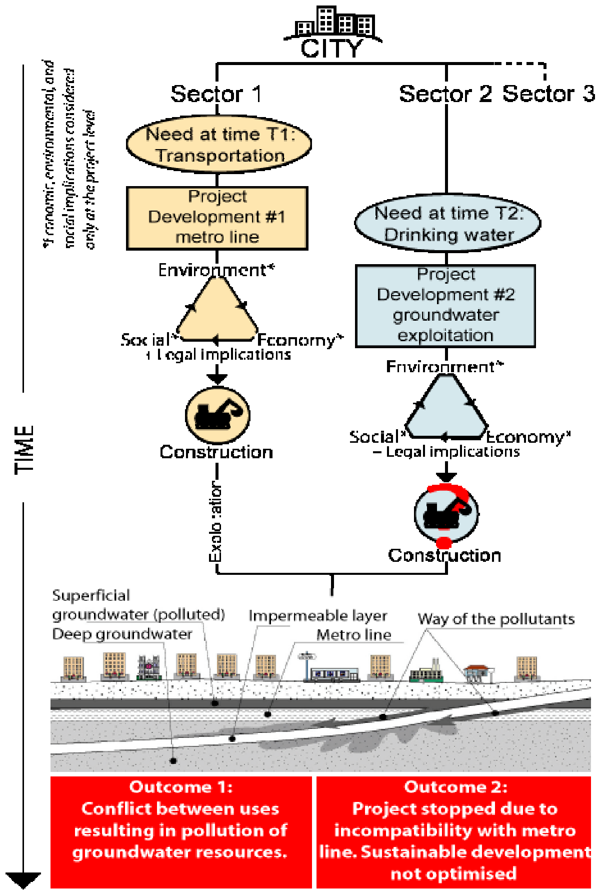

Figure 4. Simplified representation of the sectorial approach, example of the competition between space (metro line) and groundwater exploitation

STATE OF SCIENCE

The concept of urban underground planning is not new; in the 1950's, Edouard Utudjian was already pleading for a planning of the subsurface (Utudjian 1952). More recently, it has been the subject of numerous government, industry and academic studies.

Since the 1990's, the International Tunnelling Association (ITA) through the Working Group 4 *Subsurface Planning* has coordinated several studies in its member nations.

In 1990, the legal and administrative issues where assessed in the ITA's member countries through a questionnaire (Barker 1991). This questionnaire investigated problems of the limits of the surface property, the exploitation of natural and mineral resources, the ownership and the right to develop subsurface space, the requirements for permits, the application of surface land-use regulations, the environmental controls and the restriction associated with surface and subsurface structures. This survey indicated that in numerous countries, underground development was not specifically taken into account in the evolution of legal and administrative issues. The example of the application of surface land-use regulations is interesting; in most countries, land-use zoning was extend to the subsurface, independently of its specific characteristics; in countries where this is not the case, no specific regulations for the subsurface exist. Following the Barker (1991) study, a policy statement was issued by the ITA (ITA Working group 4 1991). It plead for "national and local policies … to provide guidelines, criteria and classifications for assessing appropriate uses of underground space, identifying geologic conditions, defining priority uses and resolving potential utilization conflicts". It proposed to use site reservation as an application tool.

In 1994, the International Tunnelling Association (ITA) developed some general considerations for assessing the advantages of underground space for structures (Godard & Sterling 1995). These are based on the answers to a series of questions regarding, for instance, the qualities offered by the underground space, stakeholder benefits, economic and environmental advantages, and the definition of direct and indirect advantages as well as disadvantages.

A Finnish study on *Underground Space in Land Use Planning* was launched in 1994 and completed in 1996 following an assessment by a committee appointed by the Finnish Ministry of the Environment that current legislation and planning procedures were unsatisfactory for underground development purposes. In addition to reviewing the current situation in underground planning and development needs in Finland's largest cities, it analysed current uses of underground facilities and possibilities for future uses and needs. A basic method of classifying the building potential of rock areas was created, and other factors such as environmental impact assessment and costs (particularly in comparison with equivalent costs of aboveground space) were examined. Finally it sought to draft a proposal concerning planning at different levels and permit procedures for developing underground space (Rönka et al. 1998)

In 1995 and 1996, The Warren Centre for Advanced Engineering at the University of Sydney conducted an extensive multi-disciplinary study on the potential of underground space to create and maintain more liveable cities (Sterling 1997). The *Underground Space Project* was driven by three principle concerns: a) a purely piecemeal approach to the use of the underground does not optimise its potential present and future benefits; b) there are many opportunities beyond the most obvious urban underground uses; and c) underground construction technologies and geological constraints are not understood well enough by decision makers to enable them to make appropriate decisions. The research identified a number of issues, conclusions and recommendations regarding: strategic issues and special opportunities; environmental implications; planning the underground; transport; financing; legal issues; geotechnical aspects; underground construction technology; and research and development.

Delft University of Technology and the Centre for Underground Construction conducted a national *Strategic Study on the Utilization of Underground Space* to examine the potential for subsurface space use, considered most applicable in the dense provinces comprising the Randstad (Edelenbos et al. 1998; Monnikhof et al. 1998; Monnikhof et al. 1999). The study included the development of a methodology for strategic decision-making with the objectives of: a) determining the functions that are the most suitable to being constructed underground; b) ascertaining the areas with a high potential for the use of underground space; and c) identifying which developments would encourage or frustrate the use of underground space. A wide array of variables was considered including the societal aspects of underground use, potential gains in space for different urban environments, and limiting conditions such as effects on groundwater. Policy measures for provinces were formulated and recommendations made.

A survey of these and other in-country studies by Working Group No. 4 of the ITA identifies the key issues regarding underground planning. The three most pressing concerns are the maintenance of groundwater levels, the protection of environmentally and historically valuable ground, and the development of methods to map the presence of existing underground facilities and geological conditions. Other concerns include the valuation of economic, environmental and social costs. For instance, the reduction of underground costs by the shadow price of released land on the surface; the communities' valuation of the disadvantages of conventional construction in terms of environmental degradation; and in the case of transportation, the achieved social and economic savings through reduced surface transport. Legal issues also figure prominently. Although many countries, like Switzerland, have a clear legal framework for aboveground urban planning, this is not the case for below ground activities. The obstacles presented by land-ownership issues must also be addressed. Finally, urban planning should also incorporate geological conditions and their distribution with the anticipated need for future underground facilities (ITA Working group 4 2000).

A common point in all of these studies is that they have been developed mostly for the use of one resource, i.e. space. Groundwater has often been mentioned but only as a limitation to underground construction and not in itself as a resource; geomaterial and geothermal energy are rarely mentioned.

Some recent works have been completed in GEOLEP (EPFL) to evaluate the potential influence of one resource on another. Two of these works, which highlight the importance of the consideration of multiple uses of the urban underground, are relevant to this study:

- A study that aimed at determining the location of potential zones for geothermal structures, conducted in the city of Geneva. This study focussed on the potential effect of structures on groundwater (Joliquin 2002).
- An evaluation on the effect of the construction of a metro line on groundwater aquifers at Geneva. Through geological and numerical flow modelling, this study helped to define an alternative approach that minimised the impact of the development on the integrity of the aquifer (Parriaux et al. 2004).

TOWARD MULTIPLE USES OF THE URBAN UNDERGROUND

The present project has been motivated by the fact that sustainable development of the urban underground can be achieved only with an approach that combines its multiple uses at the planning stage. It aims to develop a methodology that will help planners consider and integrate the full potential of the urban underground within city planning, in a so called concept of "3D land planning".

A pure technical approach to this problem would be unsatisfactory since underground development can only be realized if it is socially and politically acceptable, economically viable and legally possible. Therefore, the development of the methodology is essentially trans-disciplinary work. In the first phase of this development, two main themes of research have been identified:

- Geological and environmental compatibility of multiuse underground resources.
- Social sciences inquiry of the acceptability of underground development.

These themes have been selected because they are perceived to be the greatest limitation for sustainable underground development. Since very little research has been realized to explain the effect of any resource use on another, the optimization of the potential use of the underground is currently not carried out. Until now, only space has been considered for urban underground development, even though it has been extensively reported that underground suffers from a poor attractiveness. Strategies to improve the social perception toward subsurface have to be developed to better understand this situation.

This study promotes a holistic approach of underground space planning. The experiences of sectorial approach, however insufficient to achieve sustainable development, are the groundwork for this study; they will be studied extensively in order to inform "lessons from the past".

At this stage, a multi-use approach has been proposed in the Figure 5, which shows how the different research themes are integrated. Finally, the developed methodology will be validated, using the city of Geneva as an example.

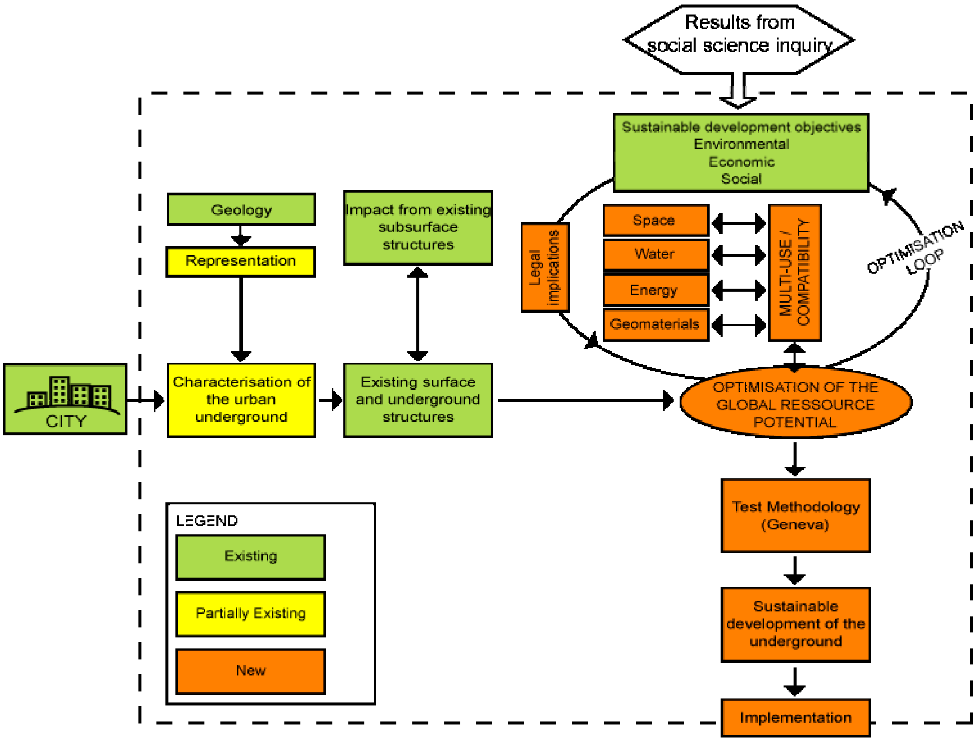

Figure 5. Multiuse of the urban underground for sustainable development

EXPECTED RESULTS

The final result of this work will be a methodology of urban underground planning, "3D land planning", adapted to the context of Swiss cities. To establish this methodology, four categories are expected; they are explained below.

Lessons learnt from the experiences of various cities

Until now, Switzerland has had limited urban underground development, mainly because it has been urbanized in a sprawling way. As a result, land has become scarce; environmental pressure has grown and there is a serious need to shift from the private car to public transportation. Therefore, in the future we can expect cities to become more compact coupled with a more extensive use of the subsurface. For example, the pre-project of the master plan of the Vaud canton is promoting the attractiveness of urban centres and more compact cities (Service d'aménagement du territoire VD 2004).

Other cities around the world make more use of their underground, for instance for population density or climatic reasons. This study will help to understand the variables that have shaped these underground developments, may they be historic, economic, environmental or social. It will assess the conflicts that have occurred in such developments, and also the success and the opportunities for sustainable development that have been created.

The following cities are of particular interest:

- Montreal: from the 1950's and the first metro lines, Montreal has developed important underground infrastructures such as a metro line, pedestrian ways and shopping centres. Montreal now possesses the most important underground urban infrastructure in the world. The development of Montreal underground city has been extensively studied by the "observatoire de la ville intérieure" in Montreal.
- Paris: two major developments have shaped the French capital city's underground; the sewer system, a entirely walk-through duct unitary system which was designed by the engineer Belgrand in the 1850's, and the Metropolitan; whose construction, started in 1896. Major buildings such as Les Halles have also had important influence in the underground. These developments and the growing needs for drinking water have had significant impact on the management of groundwater in Paris (Parriaux et al. 2004).
- Mexico City and Tokyo are the most important metropolis in the world, and as such they have put great pressure on their underground. Their developments have been subjected to different conditions, making them interesting, contrasting examples.

- Helsinki has made extensive use of its underground, mainly because the bedrock is near the surface and the characteristics of the soil in surface are not favourable for construction. Helsinki has experienced underground planning, based on geological conditions for construction and site reservation policy.

3D representation of the underground

Sustainable development can only be reached if full consideration is given to all existing and potential resources and uses. This requires the acquisition and maintenance of relevant information on underground resources and uses, and the availability of modelling, analysis and cross-checking methods and tools. Solutions need to be sought from the fields of geological modelling and Geographical Information Systems (GIS) (Figure 6). Important advancements have developed in both these fields and mature tools are available on the market, but the integration of geological modelling within GIS is still in its infancy. The future geoinformation management tools of the land planner should integrate underground information. It should enable storage, management, validation, analyse and synthesis of large quantity of data.

Geomodelling tools have made extensive use of direct and indirect characterization methods (borehole, geophysics techniques) and of geostatistical extrapolation. They allow a representation of the underground within a 3D framework and allow an estimation of the accuracy of derived models (example: Thierry et al. 2002), but they are still very limited in their capability to perform complex spatial analysis and to represent non-geological data. A positive element of GIS is that they use well-defined topological models and they fully integrate topological, metrics or attributive queries. 2D GIS are extensively used for surface land planning, a use in which 3D systems are becoming more and more relevant. Recent research has been published on 3D cadastres (Billen & Zlatanova 2003; Tse & Gold 2003), particularly in developing 3D topological interconnectivity models. 3D GIS are a novel tool in the scope of land planning, and in the future it is probable that they will supplant 2D systems.

The combination of geomodelling with GIS has also been studied (An & Yin 2002). These technologies are immature and there is still a scientific and instrumental gap between 3D object (vector) models and 3D continuity models for underground fields and resources.

This study will develop a concept of urban underground resources and space representation. Essential input will also come from the social inquiries since the 3D representation is expected to help improve the public knowledge and perception of the urban subsurface.

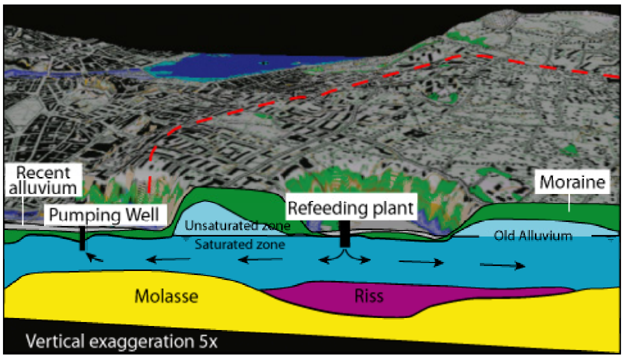

Figure 6. Linking the geological data representation and analysis of geomodelling systems with the possibility to represent non-geological data and to perform complex spatial analysis of GIS, will help to improve the use of the urban underground and its public perception.

Multiple uses of underground space

In our perception, the subsurface should be optimally exploited not only in terms of space (as it is usually considered) but in terms of its four main resources. Therefore, future research has to define the potential use(s) of the urban underground and to define and evaluate the effects of one use upon another, considered spatially and temporally. The research will help to address the following three main issues:

- What are the potential uses of the urban underground and under what conditions are they possible? This question will help to define the affectation that the urban underground could have, based upon measurable conditions such as geological and environmental parameters, surface and underground utilization or legal-economical conditions. It will also help to inform when underground uses are not compatible.
- How to evaluate effect of a potential use upon another? Effects are time and space dependent; that is to say that an activity at a given space may affect another in a different space and time. Therefore, the effect of the underground use should be assessed with models. Most of the flows in the underground (for example thermal flow or pollutants) are driven by the groundwater; therefore this evaluation will be based upon hydrogeological modelling.
- What is an undesirable effect? Any use of the underground will affect its neighbourhood; the no-effect objective is not achievable. One of the important goals of this study will be to estimate desirable target values. Target values must be evaluated considering legal framework, environmental effect, use effect, but also economic efficiency and social acceptability.

Social sciences inquiry tools to help cities assess acceptability criteria

Poor public perception has often been presented as a limitation for underground development, but it has not been assessed from the perspective of social sciences. This study will evaluate the opinion of the population regarding activities, facilities and infrastructures that should go underground. It will also evaluate the perception of the underground and more particularly the circumstances and conditions under which the underground is well or poorly conceived. The evaluation will be based upon a questionnaire of stated preferences and in-depth interviews.

The social investigations results will have two related functions:

- It will help to define conditions for the urban underground development in order to adapt the utilization of the underground resources to public appreciation.
- It will be possible to develop strategies to improve the public appreciation based upon a better understanding of the reasons for poor or good public perception.

CONCLUSION

More extensive use of the urban underground can help cities reach the goal of sustainable development, but only under the condition of long term planning. Planning of the urban underground should be done considering the four resources of the subsurface, space, water, energy and materials. This project will develop new results in terms of multiple use of the underground and integrate it in a 3D-land planning methodology. A holistic approach is promoted that does not only consider the geological and environmental effect but also the economic efficiency and the social acceptability of underground development. As a result, cities will be able to make more extensive use of their urban underground without compromising the use of their resources for the future generations.

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