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From hydro/geology to the streetscape: Evaluating urban underground resource potential

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ABSTRACT

Despite a persistent call for a greater recognition of the underground in urban planning practices, cities still tend to address underground resources only when the need arises. Historically, this has proven costly for cities that have neglected the potential synergies and conflicts between, for instance, urban aquifers and underground infrastructure systems or building foundations. For urban planning to remain in a paradigm of needs to resources risks rendering conflicts between urban underground activities irreversible and possible synergies unattainable. Researchers and practitioners from multiple disciplines argue for the many benefits of underground development—alternative renewable energy and drinking water sources, additional urban space and reusable geomaterials. Visualizing resource potential is a first step in raising awareness among planners of the capacities of the underground. Existing mapping methods tend to focus only on underground space development in contexts where the needs for the underground are already urgent and do not explicitly engage with the distribution of existing land uses. As an alternative to existing methods, this paper will present a procedure for mapping underground resource potential that incorporates four resources—space, groundwater, geothermal energy and geomaterials—developed by the Deep City project at the Swiss Federal Institute of Technology in Lausanne. San Antonio, Texas, a city with a complex relationship to an underground aquifer system but current little need and support for underground space, serves to illustrate the mapping method. Two future surface light rail and bus rapid transit lines, presented in recent planning reports, are examined in light of a latent but as yet untapped multi-resource underground potential. The paper concludes with a discussion of the applicability of the method to other cities and possible opportunities for improvement.

1. The underground as an integral part of the urban

Since the first official geological investigations in the 19th century, urban planners, architects, geologists and engineers have called for a greater inclusion of the underground in urban planning. Eugène Hénard's early 20th century vision for the Paris street of the future rethought the way urban infrastructure was situated vertically (Hénard, 1982). Édouard Utudjian's proposal in the mid-20th century for an 'underground urbanism' offered the underground as a solution to the problems of congestion and pollution of rapidly urbanizing Western cities (Utudjian, 1952). As many of the contributions to this journal's recent retrospective on its predecessor *Underground Space* attest, the relationship between the urban activities of the surface and those of the subsurface remains the source of an intense interdisciplinary focus. Urban areas experiencing population growth and investment in the construction industry, particularly in Asia, are looking toward cities whose histories are marked by over a century of management of underground resources. At the same time, population growth in urban areas, particularly in the Europe and North America, is slow and situated on historically dispersed territories. Both cases beg the question: what is the underground potential of these areas and what possible alternative urban forms can it foster?

Much of the current interest in the underground remains focused on the excavation of large volumes of space. Although space as an underground resource contributes in multiple ways to improving urban quality of life (International Tunnelling and Underground Space Association, 2012), the underground is also an important source of drinking water, geomaterials for construction or infill and geothermal energy. Experiences in cities like Paris, Mexico City and Tokyo demonstrate the problematic relationship excavation and construction practices in these cities have had with their urban aquifer, particularly where they provide a significant source of drinking water (Blunier, 2009). Unlike geomaterials

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(the extraction of which has only a limited geographical impact), groundwater extraction and pollution have consequences that can reach a much larger scale (Morris et al., 2003). At least 122 cities worldwide with a population of greater than one million obtain at least 25% of their total water consumption from groundwater (Struckmeier and Richts, 2008). This provides both a challenge and an opportunity to develop diagnostic tools that can integrate multiple resources into the evaluation of underground potential, for both urban areas whose needs for additional space are pressing and for those where the management of other resources (geothermal or groundwater) may be of greater interest in the short term. For these latter cities, short term efforts can identify and reserve volumes of underground space for future excavation.

Progress has been made in recent years in developing methods for evaluating and visualizing underground potential. The Helsinki Underground Master Plan presents existing and reserved areas for caverns and tunnels, indicating potential entry locations and depths of tunnels and spaces, overlaid by city blocks and the street network (Vähäaho, 2009). The map's objective is to manage publicly owned underground real estate, in a manner synonymous with a land preservation plan. In Hong Kong, the cavern suitability maps currently under development present locations for potential cavern development classified according to geotechnical and land use characteristics of the surrounding context (Wallace et al., 2014). Researchers in China have tested a similar method on the city of Changzhou, and reported results at the parcel level (Peng et al., 2014). Whereas the cavern suitability map is specifically focused on the development potential of specific zones, the method tested on Changzhou provides a suitability score for different layers of the underground and for each parcel in the study area. This latter strategy is interesting because it provides information on resource potential at every location in the study area.

Although information concerning groundwater or geomaterials factors into the classification of suitability, the maps presented above only focus on potential for the construction of underground space. Potential, understood as "latent qualities or abilities" (Oxford University Press, 2015), is presented in Helsinki as either built, planned or reserved, in Hong Kong on a 5-point scale from 'not suitable' to 'high suitability', and on a similar 4-point scale for the Chinese researchers. While these scales help communicate results quickly to decision-makers, the mapping method itself does not provide for competing but equally possible potentials—for instance, the parallel development of geothermal (for heating and cooling systems) or the risk of groundwater pollution. The evaluation of underground potential that takes into consideration multiple resources will need to account for the potential conflicts and synergies between uses.

Furthermore, for all the importance placed on creating new urban spaces underground, the degree to which surface urban activities factor into underground space potential suggests that additional progress can still be made. Urban theory is increasingly arguing for a more relational approach to urbanism, meaning the potential of the existing urban fabric (its forms and functions) depends upon the relationships between land uses and the overall structure of the transport network, rather than as a set of static land uses dispersed over a passive transport infrastructure (Hillier, 2007). For example, the underground potential of a park is dependent not only on the geotechnical properties of the ground beneath it, but also on the strategic location of each surface entry point for potential clientele. Centrality is an important metric for underground space, because certain activities require being central to capture potential clientele (like commercial spaces) or being central for the easy distribution of goods or materials. A storage facility or water treatment center slated for development in a location outside of existing networks would require restructuring the network of which they are a part (roads, distribution pipes, etc.). The evaluation of underground space potential can benefit from an integration of such network properties of the urban fabric.

This paper presents a mapping method for evaluating the underground potential of an urban area for four resources (space, geothermal energy, groundwater and geomaterials) with a particular focus on the role of the surface urban morphology. This method is an extension of the one developed by the Deep City project at the Swiss Federal Institute of Technology in Lausanne (EPFL) since 2005 (Li et al., 2013b; Parriaux et al., 2004) and constitutes a portion the author's doctoral work in architecture and urban planning, conducted under the supervision of a professor of geology and a professor of economics. The following section will present the scope, aims and main applications of the Deep City project, providing a brief overview of the mapping method and the contributions of the author. Then, a case study of San Antonio, Texas, will present each step of the calculation of the maps from data collection to interpretation in the context of the city's current transportation plans. San Antonio is an interesting case in that it has a relatively complex relationship to its urban aquifer, which is the main source of drinking water for the region, but has no plans and very little political or economic support for developing underground spaces, either isolated (e.g. underground parking) or as part of a network system (e.g. public transport). The conclusion will return to the initial questions posed in the introduction and discuss future directions for the research.

2. Deep City: from resources to needs

The Laboratory of Engineering and Environmental Geology (GEOLEP) at the EPFL received funding from the Swiss National Research Foundation in 2005 to launch the Deep City project, which sought to respond to the tendency for the urban underground to be managed on a project-by-project basis with often disastrous or risk-laden effects on other uses both on the surface and subsurface (Parriaux et al., 2010; Piguet et al., 2011). The underground is addressed as a strategy to increase urban compactness, increase walkability and the accessibility of urban activities. It is an alternative to building upwards, with the objective of concentrating urban activities above and below the street level at lower surface densities. For this reason, the project has been particularly interested in urban activities like food and retail, which are often located in the underground in pedestrian passages or metro stations or in underground conditions with only electric or zenithal lighting (e.g. malls, cinemas, theaters). The project is now hosted by the Laboratory for Environmental and Urban Economics (LEURE), following the retirement of the principal researcher who nevertheless remains an active contributor to Deep City.

The mapping method (Fig. 1) has evolved significantly through case studies of Geneva, Switzerland, (Parriaux et al., 2010; Piguet et al., 2011) and Suzhou, China (Li et al., 2013a,b). First, geological data either as formations or boreholes is compiled in a GIS software package. The author's contribution incorporates information on the distribution of the built environment (as buildings, parcels, or streets) into the GIS model. When possible, information concerning the buildings or parcels (resident population, jobs or activity) is included, but depends on the format in which such data is compiled. The second step classifies the geological formations into families of characteristics and evaluates the relative suitability of each family for each of the four resources, either using expert interviews or scientific evidence. The built environment is analyzed according to a series of centrality metrics, which in turn are given each a relative weight using pairwise judgments based on evidence in the scientific literature. The application of the method to San

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