Investigating the Feasibility of Underground Construction for Urban Development Projects

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ABSTRACT

The abstract outlines a study conducted within the Deep City project at the Swiss Federal Institute of Technology in Lausanne (EPFL), focusing on the mapping method developed and applied to San Antonio, Texas. The study addresses the common tendency in urban growth to overlook the underground until surface alternatives are exhausted, leading to conflicts and missed opportunities. The challenge lies in how underground potentials are assessed, often fragmented across disciplines and administrative divisions. The paper introduces an innovative mapping strategy, the production of interaction maps, alongside resource potential maps. San Antonio serves as a case study due to its lack of major underground infrastructure and limited support for short-term underground development. By mapping the combined potentiality of underground resources, the study aims to provide a compass for interdisciplinary discussions, positioning the urban underground as a source of opportunity rather than an afterthought. The research situates itself within broader theoretical and philosophical contexts, emphasizing the importance of holistic approaches to urban planning and development.

Keyword: - *Urban underground; mapping; potentiality; geology; urban planning; sustainable development*

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1. Introduction

The introduction sets the stage for exploring the mapping of the urban underground, highlighting its historical neglect in urban planning models and the emergence of alternative paradigms. Traditionally, urban planning models have focused on surface features, neglecting the underground, which has been symbolically associated with death or seen as an obstacle to be overcome for aboveground urban systems. Early proponents of urban underground integration, such as Eugène Hénard and Édouard Utudjian, viewed geology and geography merely as barriers to be addressed through technological advancements.

The shift towards ecological models of urban planning, influenced by thinkers like Ian McHarg, emphasized the integration of natural processes and constraints, including geological factors, into city design. However, even within this framework, the underground was primarily considered as a constraint for surface planning rather than as a resource to be explored. The mechanistic view of cities as organisms, with a focus on balanced flows of energy and materials, further reinforced this perspective, leading to a needs-driven approach where resources are managed based on predetermined demands. In contrast, the Deep City project proposes an alternative paradigm where the assessment of underground resources precedes the identification of needs. This approach reframes the underground not as a stabilizing force within an optimized system but as a source of novelty and evolution. Drawing from information theory, it recognizes the importance of both existing information within the system and the potential inherent in yet-to-be-interpreted data, or "negentropy." Existing maps of the urban underground typically follow a needs-driven and sectoral approach, focusing on specific resources or addressing underground space without considering its multiple potentials. Examples from cities like Helsinki, Hong Kong, and Qingdao illustrate this trend, where underground planning is largely space-oriented and lacks consideration of the broader range of underground resources. The introduction argues for a shift towards a more holistic understanding of the urban underground, one that recognizes its multifaceted potentials and incorporates them into masterplans and urban development strategies. Overall, the introduction provides a comprehensive overview of the historical context and current challenges in mapping the urban underground, setting the stage for the methodology and findings presented in the subsequent sections of the paper.

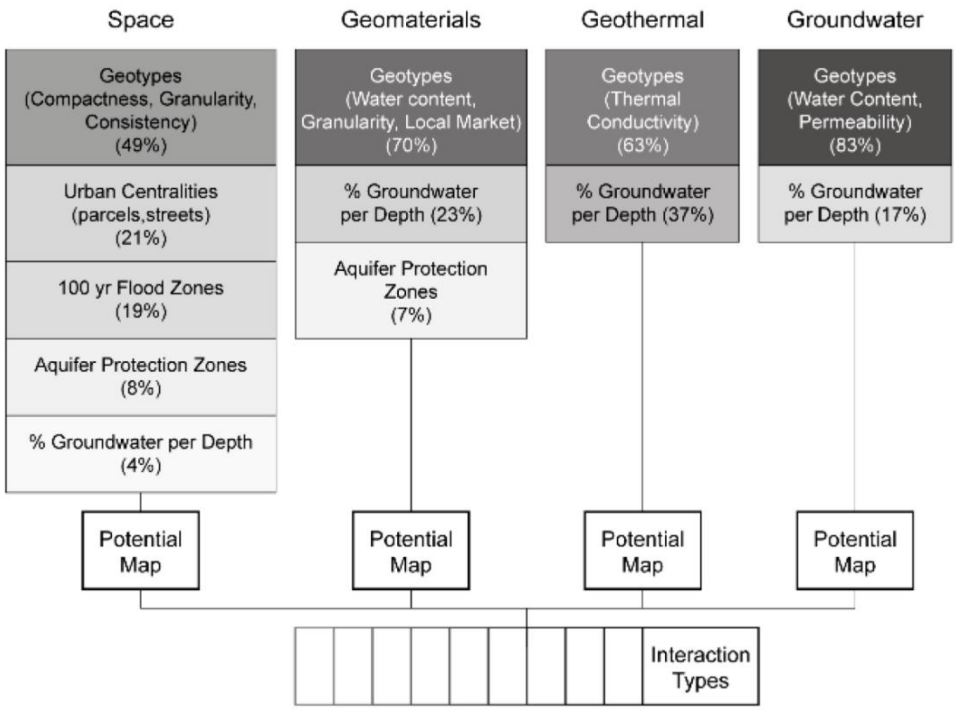

Figure 3. Aggregation hierarchy for the separate resource potentials and their interactions.

The process of aggregating relative scales resulting from pairwise comparisons into resource-specific scales involves several steps, as illustrated in Figure 3. Initially, all vector data are converted into a raster dataset with a resolution of 50 by 50 meters in our GIS model. This conversion allows for a consistent spatial representation across the entire region of interest, which, in this case, is at the county level. By using a grid format, the analysis is detached from political or topographical boundaries, providing a uniform spatial unit for assessment. Once the vector data are transformed into a grid, the potentiality for each cell is calculated based on the aggregated relative scores derived from pairwise comparisons. These scores range between zero and one, or can be presented as percentages (ranging from zero to 100), enabling comparisons across different resources. This normalization process ensures that the potentiality values are standardized and comparable, regardless of the specific characteristics of each resource. In contrast to our previous work, where a single map visualized the potentials of four underground resources, this paper introduces a multi-use approach that prioritizes the development of multiple resources in one location, irrespective of risk attitudes. This strategy diverges from conventional approaches that often focus on singular resource utilization. Examples from previous research highlight both positive, such as geothermal energy-collecting building foundations, and negative, like aquifer-polluting geothermal conduits, manifestations of this multi-use approach. The interactions between construction, excavation, and geothermal energy, as opposed to those involving groundwater, suggest different potentialities and involve distinct stakeholders. To construct interaction maps, we propose characterizing locations based on the extent of overlap in potential and combining extraction (geomaterials) and construction (space) potentialities due to their interconnectedness in transformation activities. This results in eight combinations of potentialities, including scenarios where no interaction is presupposed, such as when only geothermal potential scores highly. Utilizing ArcGIS 10.3, a similarity index for each of the 1,301,102 locations in Bexar County's 50 by 50-meter grid was calculated using these eight resource potential combinations.

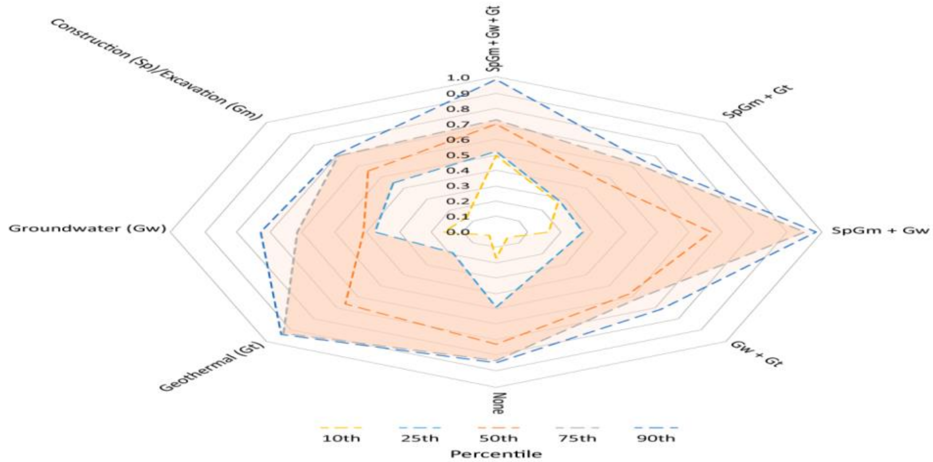

Figure 4. Distribution of the degree of similarity to interaction types, presented as percentiles.

By employing this approach, we obtain resource-specific potentiality maps that depict the relative suitability of each location within the study area for the development of a particular resource. These maps serve as valuable decision-making tools for planners and stakeholders, allowing them to identify areas with high potential for specific resource utilization and prioritize their allocation of resources and efforts accordingly. Moreover, the use of a grid-based raster dataset facilitates spatial analysis and visualization, enabling stakeholders to assess patterns and trends across the entire study area. This comprehensive view enhances understanding of the spatial distribution of resource potentialities and supports informed decision-making in the planning and management of underground resources. Overall, the process of aggregating relative scales into resource-specific scales through the conversion of vector data into a grid raster dataset enables systematic analysis and visualization of resource potentialities at a consistent spatial scale. This approach enhances the effectiveness of decision-making processes by providing stakeholders with standardized, comparable, and spatially explicit information for guiding the sustainable utilization and management of underground resources.ormalizing these values and plotting them according to percentiles elucidates the dominant potentials across the county. Interactions involving space, geomaterials, groundwater, and geothermal energy, as well as those between space, geomaterials, and groundwater, emerge as the most prevalent throughout the territory, with similarity scores in the 90th percentile ranging between 0.9 and 1.0. Notably, interactions encompassing all three potentialities exhibit the highest degree of urgency, with nearly all values falling between 0.5 and 1.0. Conversely, interactions involving space, geomaterials, and groundwater, along with geothermal potential alone (without interaction), exhibit a broader range of middle values. This indicates that only approximately half of the locations in the study area demonstrate a strong degree of similarity to these specific combinations. Overall, these findings underscore the complexity of underground resource interactions and highlight the need for comprehensive planning approaches that consider multiple resource potentials simultaneously to address the diverse needs of stakeholders and maximize the benefits of underground development.

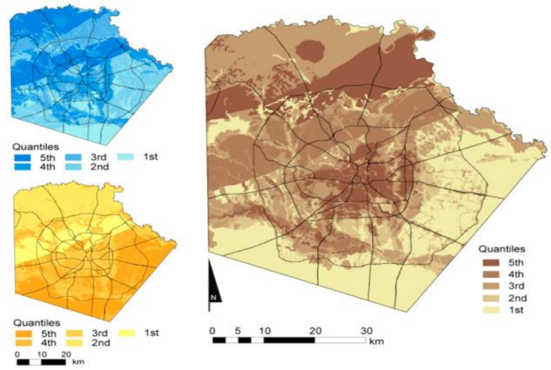

Figure 5. Maps of the degree of similarity to two different types of interaction

The significance of the interaction maps' values is heavily influenced by their spatial relationship to current or projected settlement areas. For example, in the central downtown area and the northern half of Bexar County, particularly over limestone formations, the interaction potential between the three resources—construction, excavation activities, and groundwater extraction—is notably high. This indicates fertile ground for integrated development projects that capitalize on multiple underground resources simultaneously. Conversely, in regions characterized by quaternary riverbeds and mixed marl and limestone formations, interactions between construction and excavation activities, as well as groundwater extraction, are more prevalent. These areas present opportunities for strategic planning of construction projects and groundwater management initiatives, considering their geological characteristics.

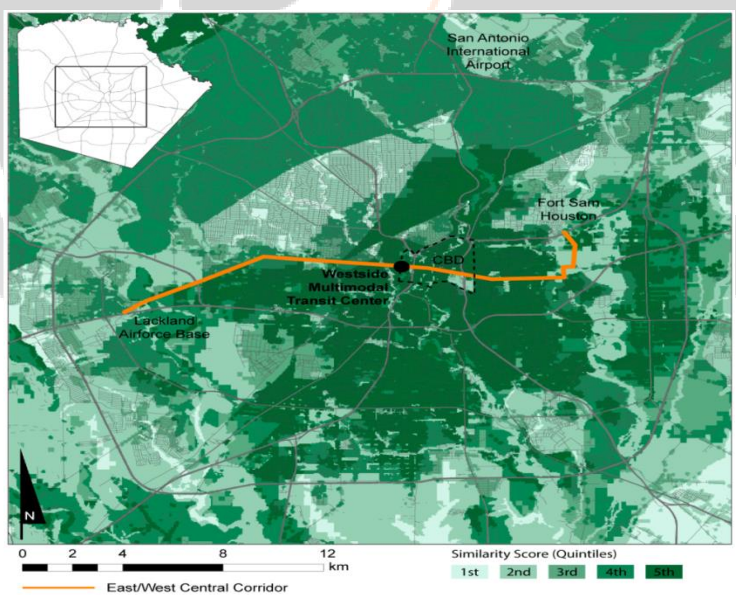

Figure 6. The Westside Multimodal Transition Center

In the southern half of the county, where clay and sand formations dominate, geothermal energy emerges as a promising single-use resource. However, the interaction with other geological affordances appears to be less pronounced in these areas. Nonetheless, in locally central parcels where space development potential is higher, there is a slight increase in similarity to the single-use geothermal category, suggesting opportunities for integrated development projects that incorporate geothermal energy alongside other underground resources. Overall, these observations underscore the importance of spatial context in interpreting the significance of interaction map values. By analyzing the distribution of interactions across different geological formations relative to settlement areas, planners and designers can identify strategic locations for integrated development projects that maximize the synergies between various underground resources, contributing to more sustainable and resilient urban development.

Deep City project serves as a practical illustration of how interaction maps can be applied to inform decision-making in underground development projects. In this particular study, researchers focused on analyzing the underground potential of future public transit hubs outlined in the 2035 Long Range Comprehensive Transportation Plan, with a specific emphasis on the Westside Multimodal Transit Center (WMTC). The WMTC, envisioned as a crucial transit hub connecting regional and local rail services, was undergoing aboveground development at the time of analysis. Through the application of order-weighted averaging (OWA) and the analytic hierarchy process (AHP), the researchers conducted an evaluation of the underground potential of the WMTC. The findings indicated a medium to low overall potential, with the highest potentials identified for underground construction, primarily due to its urban centrality, followed by geothermal and groundwater potential.

2. Conclusion

The interaction maps presented in the paper serve as navigational tools for planners and urban designers during the preliminary stages of master planning, particularly in the strategic phase. Analogous to a compass, these maps offer guidance without prescribing a specific direction, encouraging consideration of the urban volume's diverse uses and potentials. They are especially valuable in multidisciplinary design charrettes or competitions, where participants are tasked with envisioning innovative multi-use scenarios that stretch the boundaries of urban space. By establishing the "conditions for the emergence of new realities," these maps facilitate creative exploration and push the envelope of urban design possibilities. The challenge lies in bridging the gap between urban planners, designers, and various disciplines whose expertise contributes to the creative process. Following the visioning phase or design competitions, specific objectives can be formulated, and missing data can be added or updated to inform multicriteria decision-making. For instance, in the case of public transit corridors in San Antonio, strategic placement of surface lines over areas of high underground potential can lay the groundwork for future underground development, even if current circumstances do not permit immediate implementation. To operationalize interaction maps effectively, certain conditions must be met. Firstly, data collection should be cross-departmental yet centrally controlled, with all project information feeding into the city's GIS database. Secondly, while data may be centralized, the responsibility for evaluating underground potential should be distributed among relevant stakeholders, with geologists serving as custodians of the maps. Additionally, sustainable management of underground resources necessitates considering all four resources—geological, hydrological, biological, and energetic—regardless of their current significance.

3. References

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