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From urban underground space (UUS) to sustainable underground urbanism (SUU): Shifting the focus in urban underground scholarship

Loretta von der Tann *, Stefan Ritter, Sarah Hale, Jenny Langford, Sean Salazar

Norwegian Geotechnical Institute, Sognsveien 72, Oslo 0855, Norway

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ABSTRACT

This viewpoint argues that for sustainable urban development the relationship between the city and the ground beneath it needs increased attention. The underground volume might provide additional urban space, but it cannot be treated in the same way as above-ground space. Cross-disciplinary research and professional collaboration are needed to better understand (a) the variety of processes at play, and (b) the role of geotechnical engineers and geoscientists in working towards sustainable underground urbanism.

1. Introduction

With ongoing urbanisation, the pressure on land use is growing. Between 2012 and 2018, the annual average of newly developed land was 540 km^2 (EEA, 2019). One measure being advocated to counteract this continuous land take is the regeneration of brownfield sites (EC, 2016). This directly ties future urban development and redevelopment to the suitability of the ground present and to human ability to improve its current condition. In addition to brownfield utilisation, several aspects of urban development rely on the subsurface and our ability to change the subsurface environment. The availability of groundwater, to give an example, has often been a determining factor for the establishment of new settlements. The abstraction of groundwater for urban development can cause secondary effects such as land subsidence or saline water intrusion (Foster et al., 2011) and, in turn, have a severe impact on the built environment present.

Here we present the case that all relevant disciplines need to work towards Sustainable Underground Urbanism (SUU) practices to create a lasting conversation and better cooperation between local stakeholders, communities and geoscientists, engineers, urban planners and other affected disciplines about what the city is built on, what processes are followed from idea to implementation of projects in the subsurface and who is involved in making relevant decisions. The case for SUU is complementary to and aims to advance the current efforts of an increasing number of authors and practitioners to integrate the subsurface, or Urban Underground Space (UUS), into urban planning (e.g. Bobylev, 2009, Admiraal and Cornaro, 2018) or conceptualising the subsurface as a resource through extending the concept of ecosystem services to geosystem services (Volchko et al., 2020). SUU emphasises the variety of stakeholders and actors who influence the space, and their interaction with the functions and assets within the urban subsurface.

The authors of this commentary are geotechnical engineers and environmental geoscientists focussing on the engineering processes required to plan and execute changes of underground use, such as excavation or stabilisation of ground, abstraction or injection of materials, that appear to be rarely addressed in the wider, non-engineering literature. In literature and public perception, engineers seem to be "hidden between architects and geologists" (Brandl, 2011). However, just as land policy is intrinsically linked with land engineering (Han and Zhang, 2014), so should subsurface management and planning be linked with subsurface engineering. The role of engineers in negotiating between different stakeholders and creating lasting structures that define the relationship between the city and the ground beneath it, warrants new and increased attention.

Sustainable Underground Urbanism evolves around two main concepts or spaces: First, the ***urban underground*** in its distinction from the above ground. Second, ***sustainability*** and the role, or potential role, of the underground in working towards sustainable urban development. These ideas will be expanded upon in the sections below. Based on the positionality of the authors, particular attention will be paid to the activities and contributions of geotechnical engineers and the geoscience discipline within these concepts.

2. The urban underground

What is considered to be "underground" or "subsurface" is rarely

* Corresponding author.
E-mail address: loretta.von.der.tann@ngi.no (L. von der Tann).

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defined. One possible definition postulates that structures and volumes can be considered "underground" when changing the structure or accessing the volume would require removal of or drilling into – natural or altered – ground (von der Tann et al., 2018). Reynolds (2020) distinguishes earth covered, sunken, underground and tunnelled structures, all of which share the aforementioned characteristic. For non-structural uses such as groundwater abstraction, pore space may be accessed indirectly. A local technological intervention to do so remains necessary. As such, access is one defining characteristic of space or volume below ground that makes it fundamentally different to the above ground. The underground volume is not empty, even if it often is described as if it were – as a volume available for exploitation without consequences (Melo Zurita, 2020). Access to underground volumes and pore space is constrained not only by the ground properties and the availability of volumes not currently used, but also by a range of economic and political factors (ibid.). In addition, the built and natural environment above the volume to be accessed (Doyle et al., 2016) as well as the availability of knowledge and techniques to physically access the space or volume (von der Tann et al., 2021) play an important role.

As this knowledge – what is there, what to do with it and how to access it – is often provided by geotechnical engineers and geoscientists, it seems apt that a lot of the current literature on urban underground space (UUS) with a focus on infrastructure and the built environment, stems from tunnelling and related disciplines or is published in journals with said focus (e.g. Bobylev and Sterling, 2016). Many of these publications aim to shift the starting point of planning efforts: from first asking what is needed and then ***where*** it could be placed to first examining the volume available and then asking ***whether*** and ***for what*** this volume should be used or exploited. In the former approach the necessity of a function such as an infrastructure is accepted before location specific or geological constraints are evaluated. In the latter approach, the geology and legacy of urban development are assessed before planning any specific intervention, in an attempt to conceptually grasp or *fill* the volume that is underground. This is an important shift in working towards the ground being better acknowledged for what it is (not an empty volume) and what potentials it might have beyond providing space or volume for the given function. Yet the decision about what ultimately will be done will not only need to integrate both, the need for specific urban functions and the potential of the ground volume present, but also be embedded in and react to the location specific socio-economic context. As such, it is important not only to understand what is technically possible and where, but also to engage with the processes and actors that govern the formation of underground interventions and constructions.

The observation that the underground space is not initially empty (if it is not created through filling) also dictates (a) that built interventions within it are irreversible, reflected by the fact that underground space is sometimes considered a "non-renewable resource" (Bobylev, 2009), and (b) that subsurface interventions have physical effects on the surrounding built and natural environments. For example, groundwater leakage into subsurface constructions can induce subsidence which may cause settlements and damage to adjacent structures or infrastructure.

In addition to local effects, the ground also affects what and how we can build at larger scales, often across administrative boundaries. Urban floods, for instance, can be local or can span huge catchment areas and thus need to be managed as *"part of an environmental system that is larger than an incorporated city territory"* (Andjelkovic, 2001). Similarly, local stability needs to be assessed alongside larger scale effects (Cascini, 2015). Yet, geotechnical engineers and geoscientists often find themselves in a position where they react to, and enable the construction of, what has been planned above ground rather than being involved in the conversation about what should be built, how it should be built and where. Geotechnical engineers and geoscientists are rarely asked to identify or point out opportunities and challenges that the local geology presents to future development. The lack of consideration of the ground and the consequences of how the built environment is designed/engineered in urban and early stages of project planning means that the location and design of buildings and infrastructure is often not optimised for the geological situation present or planned at the optimal location. This can result in structures that are cost and material intensive, or, in other words, not sustainable. Thus, integrating the subsurface into urban planning also means involving geotechnical engineers and geoscientists into urban planning decisions. Laws and regulations that influence how and when different stakeholders and experts engage in the planning and building process of subsurface functions should be analysed and potentially revised to this aim.

3. Sustainability

With the establishment of the Sustainable Development Goals (United Nations, 2015), the Paris Climate Agreement (UNFCCC, 2015) and the Sendai Framework (UNISDR, 2015), international organisations and communities have acknowledged that, ultimately, human interventions impact climate, ecosystems and human health. These documents advocate a global view that works towards understanding these impacts and embracing the corresponding uncertainties in projects and policies.

Resonating with the more general observation of geotechnical engineering not being widely recognised by society (Towhata, 2019; Pathmanandavel and MacRobert, 2020), the role of the (geotechnical) engineer in the context of the sustainability transition is not sufficiently defined (Fragaszy et al., 2011). Yet, climate change effects on the environment and, in turn, on the ground and its properties require careful consideration when planning and maintaining infrastructures and buildings. For instance, changes in temperature which can induce freeze-thaw cycles can lead to differential settlements and local loss of soil structure (Vardon, 2014). Moreover, changes in precipitation patterns can have an impact on land stability via an alteration of soil properties when precipitation increases, or via a loss of vegetation due to extended periods of drought, and sequential events could result in increased overall risk (Roberts, 2020). To manage these risks, cross-disciplinary efforts are required, combining knowledge about, for instance, meteorology, hydrology, hydrogeology and geotechnical engineering. Consideration of the ground on multiple spatial scales, as mentioned previously, will only become more relevant and the ground-related effects of a changing climate on the existing building stock need to be constantly reviewed.

For cities to adapt to, and mitigate the effects of, climate change, the ground must be accounted for at all planning levels and integrated with water and flood management (SGI, 2017a). Adaptive capacity can be built on a structural – or engineered – level (Basu et al., 2015), but it also involves social and economic considerations that determine a communities' ability to react to and cope with unexpected and potentially hazardous events. Consequently, risks and opportunities arising from the ground beneath our cities need to be understood and communicated at the institutional level, including necessary adjustments in regulation, and this understanding must be conveyed to citizens at the community level. The geotechnical engineering and geoscience communities possess the relevant expertise to support this understanding but also need to develop the required communication skills (Stewart, 2017).

As a provider of environmental, economic and social security via the construction of infrastructure and creation of jobs, the construction sector has both the potential and duty to become more sustainable. The construction sector is accountable for 38% of the global energy related carbon emissions, 10% of which are related to indirect value chain emissions such as material manufacturing and construction processes (UNEP, 2020). In cities, it has been estimated that 16% of carbon emissions could be cut, solely by using more sustainable materials (Coalition for Urban Transitions, 2019). As a response, the built environment is often one of the focus areas in cities' efforts to become climate neutral. Civil engineers design, build and maintain infrastructure and buildings and consequently have a role to play in the reduction of global carbon emissions. Energy and resources used for foundations and groundworks are significant (Song et al., 2020) and likely account for a substantial part of the environmental impact of buildings (BRE, 2016) thus the contribution of geotechnical engineers to more sustainable efforts should not be neglected.

Several authors have stated that different uses of the urban underground could contribute to achieving the 17 Sustainable Development Goals (SDG) and associated targets set out in the United Nations Agenda 2030 (e.g. Norrman et al., 2020; Paraskevopoulou et al., 2019; Qiao, 2019). These publications emphasise the ultimate outcome of using the subsurface, rather than the engineering asset or intervention needed to achieve such outcome. This increased attention to the ultimate purpose of engineering interventions is aligned with the idea of a systems approach, as expressed in a recently published report by the Institute of Civil Engineers (ICE), in which engineers and infrastructure owners are challenged to "think outcome, not edifice" (ICE, 2020). Activities carried out by the geotechnical and geoscience communities such as mapping of risks, developing new technologies and supporting and guiding municipalities and other administrative bodies contribute to that aim (SGI, 2017b). Careful and conscious engineering as well as coordination between different potential subsurface uses are necessary to ensure that the specific interventions lead to the desired outcomes, and at the same time do not hinder other potentials for urban development. Institutions and actors working towards and planning for sustainable urban development need to be able to assess these technical aspects, put them into a wider context, and weigh them against a wider range of socio-political considerations. Sustainable (re)development itself is a process, not a product, and "proper planning" of the potential underground uses (Norrman et al., 2020) including better understanding of the underlying governance mechanisms is needed.

4. Towards sustainable underground urbanism

The ground in cities is often a "complex of natural and anthropogenic deposits, formed by geological deposition and erosion processes and of historic and modern city development processes such as excavations and infilling" (NGU, 2015). Urban geologists have raised awareness and cities have now begun to realise their dependence on the ground they are built on, and the opportunities arising from it. Extending the concept of land and land-use from a two-dimensional understanding of area to a three-dimensional understanding of volume, the underground has been called "the final frontier" of urban development (Admiraal and Cornaro, 2018). In human geography, "vertical" (Harris, 2015) and "volumetric" (McNeill, 2019) urbanism, both of which necessarily include underground structures, have emerged as areas of enquiry.

Despite the overlapping focus on the underground by several disciplines, the expertise and agency of geotechnical engineers and geoscientists rarely appear in literature about urban underground space. Engineering literature is characterised by results and models arising from construction projects, rather than the activities of the engineers themselves. Apart from a few often quoted examples such as Helsinki (Vähäaho, 2014) or Singapore (Zhou and Zhao, 2016), policy initiatives to integrate the subsurface into urban planning as yet appear to mostly focus on urban geology, water and data management (e.g. COST sub-urban network, http://sub-urban.squarespace.com). Urban studies have rarely engaged with the work of engineers directly, possibly because engineering is seen as applied science rather than an activity in its own right (Björkman and Harris, 2018). This might also be the case for geotechnical engineers or engineering of underground functions. Just as the underground appears to be a "forgotten" space in studying the urban environment and ecosystem services (Bricker et al., 2017), so the work of engineers seems to be somewhat hidden when looking at the development of urban space. This is concerning given the described relevance of geotechnical engineering and the geosciences for more sustainable underground development, including the creation and management of underground uses as well as for mitigating potential ground related threats to human safety and health.

The technical knowledge held by geotechnical engineers and geoscientists needs to be communicated in a way that enables planners and decision makers to conduct holistic assessments. In this context, technological developments such as Geographic Information System (GIS) maps and Building Information Modeling (BIM) that can advance particular disciplines, should be critically assessed. They should be assessed with regards to how well they work as communication tools between different actors and disciplines, as well as with regards to the power structures the measurement and visualisation of volumes might establish or reinforce (Bridge, 2013).

Thinking about both underground urbanism and engineering, a shift of focus is thus needed to look beyond specific underground assets, such as tunnels or foundations, and interventions such as for groundwater abstraction or geo-energy. A renewed focus should involve not only looking at the expected outcomes that engineers contribute to, but also acknowledging and analysing the processes during planning and implementation, and how the use of UUS, and the actors involved, are regulated. Sustainable underground urbanism (SUU) is a proposition to work in a multi-disciplinary setting towards better understanding of the contributions different disciplines – including geoscientists and geotechnical engineers – make or could make to sustainable urban (re) development and ultimately the lived experience of cities.

5. Conclusion

The current commentary suggests Sustainable Underground Urbanism as a concept to work towards multidisciplinary efforts to integrate the understanding of relevant processes, requirements for and effects of underground interventions into urban research, as well as engineering practise. The underground, the structures embedded within it as well as the risks and potentials the natural and man-made grounds implicate, influence the prospects for sustainable urban development and thus needs to be appropriately acknowledged in urban sustainability guidelines and policies. The commentary shows how geotechnical engineers and their work need to become more visible and better embedded into policies and regulations to maximise the contribution of geotechnical engineering and the geosciences in working towards a sustainable urban future. These disciplines hold knowledge about technical aspects that arguably need to be better integrated into the - non-technical - processes of decision making. Whilst the role and contribution of other disciplines were not covered in this commentary, the commitment of all relevant disciplines to work across disciplinary boundaries is crucial to achieve the goal of more sustainable urban development. Considerations about the underground will need to be included into these efforts to prevent unintended events in the future, and SUU is a suggestion to bring the multitude of current efforts in academia and practice together under one umbrella. With cities increasingly focusing on sustainability, there is an opportunity to work towards sustainable underground urbanism that should not be overlooked.

CRediT authorship contribution statement

Loretta von der Tann: Conceptualization, Writing - original draft preparation. **Stefan Ritter:** Project administration, Conceptualization, Writing - review & editing. **Sarah Hale:** Conceptualization, Writing - review & editing. **Jenny Langford, Sean Salazar:** Writing - review & editing.

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