The Hidden Role of the Subsurface for Cities

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Abstract

The evolution of cities is directly linked to their subsurface: the local geology and hydrogeology alongside the history of human interventions are the basis for the present structure and organisation of cities and affect the prospects for future developments within and above the ground. The underground serves multiple purposes in cities including; providing stability for buildings, providing drinking water and materials, serving as a heat source or retention basin, and accommodating infrastructure and developments. In the face of growth predictions and climate change, interdependencies between urban planning objectives and the subsurface, such as placing infrastructure underground to release surface congestion, remediation of brownfields for development, or prospecting for geothermal energy, become ever more important.
This paper reviews current initiatives in industry, policy and research in the UK which aim for changes in urban subsurface management and governance. It identifies the multitude of planning topics in which the subsurface implicitly features, many of which are commonly only addressed at project level. It highlights that the wider impact of these interventions on underground space and the development of the city are not considered. Consequently, the value of the subsurface for sustainable and resilient development of cities may not be realized.

Keywords
Town & City Planning; Tunnels & Tunneling; Infrastructure Planning

Introduction

Urban dwellings heavily rely on and affect their subsurface. The availability of resources in the subsurface, in particular water, building materials and fertile land were key parameters for the initial choice of location for human settlements. Specific functions such as agriculture for food production are nowadays sourced outside of the cities themselves (Deelstra and Girardet, 2000), but the relationship between a city and its subsurface remains close. As illustrated in Figure 1, the urban subsurface today serves as historical archive, as support for surface structures, and as space for developments, transport and utility infrastructure. The local geology determines the availability of water, materials and geothermal energy, influences the form and method of construction of engineered structures (Bell, 2003) and provides ecosystem services like temperature regulation or nutrient cycling (Rawlins et al., 2015). As such, several topics addressed in the UN Habitat New Urban Agenda (UN Habitat III, n.d.), like infrastructure provision or ecosystem and resource management, implicitly build on subsurface functions. Admiraal and Cornaro, 2016, point out that use of the subsurface can contribute to seven of the 17 sustainable development goals proposed by the United Nations (UN, 2017).

In turn, humans have substantially influenced the local subsurface environment in and around cities through mining activities, levelling of ground, building up of artificial ground, or reclaiming land from the sea (Price et al., 2011). Developments (Curiel-Esparza et al., 2010), contamination of soils and groundwater (Meuser, 2010), modification of the local groundwater regimes (Foster and Hirata, 2011), or ground sealing (Scalenghe and Marsan, 2009) are just some of the human interventions that continue to have a significant effect on the formation and condition of the local geology and in turn on the feasibility of new projects. Land remediation and waste management of excavated soil, for example, are prevailing challenges.

Construction of engineered structures in the ground and other projects affecting the subsurface are commonly decided upon on a case by case basis and approved by planning authorities following a specified process. Several authors have suggested a more explicit integration of the subsurface into urban planning policies, for instance through master plans (Bobylev, 2009) or mapping of use potentials (Doyle, 2016). The recent push to make cities more resilient to extreme events increases the necessity for a shift towards whole system approaches that integrate below ground, above ground and at-grade developments (Nelson, 2016).

To understand the baseline on which a holistic approach to subsurface planning would have to build in England, this paper first outlines the persistent challenges for gathering subsurface information and reviews recent approaches to map and survey services in the shallow subsurface. A brief outline of how the subsurface is governed in the current English planning regime shows a predominance of ecological and regulatory institutions. It is demonstrated that accessibility and understanding of data about the subsurface and the embedded assets can stimulate new ideas about how to holistically plan and prepare our cities for the future. The challenges stemming from the local geology cannot be disregarded, but the perspective can be changed from seeing the subsurface as a constraint to understanding it as an opportunity to improve urban spaces.

Gathering Subsurface Information

A necessary basis for subsurface planning is a sound understanding of the local geological and hydrogeological conditions as well as a record of the spatial and temporal distribution of existing and future planned activities. Despite the constant advancement of mapping and visualisation tools like GIS or BIM, the depth-related data to feed into these models remain disperse. Whilst surface geological mapping is undertaken systematically at a national level, information about the variation in geological and geotechnical properties with depth is often only retrieved via individual exploration or construction schemes. The volume, distribution and quality of data arising from these sites determines the extent to which this disparate data can be amalgamated into a consistent geological model. Data acquisition and management is described as particularly challenging in urban settings where these data are highly inhomogeneous and a large number of data types describing the natural and anthropogenic subsurface persist (Watson et al., 2017). The various formats for borehole logs from site investigations usually do not include details about quality and uncertainty (Tegtmeier et al., 2013) and the data are not commonly shared with a wider community.

To enable harmonization and re-use of geological and geotechnical data, in the UK the Association for Geotechnical and Geoenvironmental Specialists (AGS) already in 1992 launched a new data format (AGS Format) comprising the manifold industry requirements (AGS, n.d.). In parallel, the British Geological Survey (BGS) collated a National Geotechnical Properties Database which largely builds on voluntary data deposition by private and public institutions (BGS, n.d.) and provides controlled access to the data, predominately for the geotechnical and engineering community. As of 2012, the BGS in collaboration with Glasgow City Council developed ‘Accessing Subsurface Knowledge’ (ASK), a network of private and public institutions to improve ingestion and data reporting into the database (Bonsor, 2017). The AGS format has been widely accepted in the industry (Bland, 2014) and some national stakeholders now include AGS data donation to the BGS national data repository as a requirement of framework contracts (Bonsor, 2017).

Establishing a similar process for data about buried infrastructure appears to be much more difficult. The exact location and condition of utility lines and cables is often unknown (Thomas et al., 2009) and the available data have to be obtained separately for each site from a multitude of infrastructure owners and utility providers, making planning of new structures in the vicinity of these services becomes more and more challenging. At the same time, many assets date back to Victorian times, and maintenance requirements are increasing (Costello et al., 2007). Because long trenches in busy urban areas are unfeasible, utility companies begin to develop deep tunnels when large sections of their shallow assets need replacement. The London Power Tunnels (see www.londonpowertunnels.co.uk) are one example of this development.

The need to reduce traffic disruption and the associated costs due to streetworks (Goodwin, 2005) and at the same time facilitate access to services has led to a range of industrial, political and academic initiatives in recent years; London and Kent introduced lane rental schemes to incentivise more efficient and collaborative execution of streetworks (DfT, 2015). Extensive research was carried out on the development of a multi-sensor approach to detect the position and assess the condition of underground assets without excavating (MtU, 2012). In April 2017, the British Standard Institution launched a Publicly Available Specification (PAS) setting out processes of gathering, recording and sharing of asset data (BSI, 2017). PAS256 followed PAS128 for underground utility detection, verification and location (BSI, 2014) and defines a standardized data protocol to enable data sharing similar to the AGS Format for geotechnical data. The application of PAS256 is not mandatory but it is anticipated that the prospect of easier data exchange between infrastructure owners will encourage its adoption with large projects leading the way (Phull, 2017).

Even if a standardized data format would be accepted, there remains a lack of a central data repository and, although it is encouraging owners to move to a digital format, PAS256 (BSI, 2017) does not cover integration of the old, paper based records. One initiative to mention in this context is the 'London Infrastructure Map' initialised by the Greater London Authority in 2015 (Figure 2). The map visualises data from utilities, boroughs and developers and aims to improve infrastructure planning and delivery (London Assembly, 2016). Despite the general concept being supported by the infrastructure companies, concerns about data confidentiality and security delayed the process (McMunnigall 2017, personal communication).

An international example addressing the challenge of subsurface data collection and management is the baseline underground register established in 2015 in the Netherlands. The 'Basisregistratie Ondergrond' (BRO) consolidates geological and exploration data as well as data about mining activities and the associated structural assets (BRO, 2017a). However, to create new legislation focussing on the subsurface as an entity in its own right proved too complex and structural assets in the shallow subsurface like underground car parks, basements, tunnels or cables and pipelines, will not be covered in the BRO. These structures will instead be integrated in another of a total of 12 baseline registers that are being created by the Netherlands' Government and will provide open source data for future decision making (BRO, 2017b). With these registers the Netherlands implement regulation stemming from the EU- INPSIRE programme that aim to create a spatial data infrastructure for EU environmental policies and policies or activities potentially having an impact on the environment (European Commission, n.d.).

The described initiatives focus on mapping and evaluation of existing assets and ground conditions that build on bottom up involvement of the affected industries. A step change in regard to data sharing will be necessary to oversee the current situation, allow analysis of interdependencies between present and future interventions and evaluate the practicability of tapping into the potential for future developments or activities in the subsurface. Also potential data gaps should be assessed, as which data is recorded in the first place remains driven by geological research requirements and project specific site investigations and does not react to specific needs of other domains like, for instance, urban planning.

The Subsurface in Current UK Planning Regulations

If baseline data is one cornerstone for subsurface planning, understanding of the current governance regime is another. Many of the services and functions that are occupying subsurface space are in some way covered in current UK environmental and planning policy and legislation. However, the detail to which they are considered and the level on which they are regulated differ widely. For example, much of the environmental regulation stems from EU directives, but policies around basement development, if any, only exist at local level. Whilst a presumption exists that land ownership extends into the subsurface (HM Land Registry, 2015), a range of statutory rights and legal agreements facilitate the presence of infrastructure in the subsurface (see Darroch et al., 2016). In addition, ownership and safeguarding of minerals can significantly influence planning decisions for developments above and below ground.

Despite urban policy not being an EU responsibility, the European Commission over the last decade emphasized the urban dimension (European Commission, 2011, 2017). However, the responsibility for spatial planning remains with the Member States. In the UK, the land use planning system in all four countries (devolved regions) is ‘plan-led’, meaning that formal development plans on local and regional levels set out policies which serve as a framework for decision-making about planning applications. Each local authority prepares its own local planning policies following the guidelines set out in national and potentially regional legislation (House of Commons, 2015). European regulation and regulation stemming from European directives serve as material consideration for local planning decisions.

A selection of directives that cover subsurface related topics and – without being exhaustive - the most recent and relevant transposition documents in England are given in Table 1. Many of these mainly environmental topics in England are included in the National Planning Policy Guidance (NPPG), and therewith acknowledged as primary concern for planning, see Table 2. Alongside the National Planning Policy Framework the NPPG sets out the major guidelines for local planning authorities in England to prepare their Local Plans. Similar legislation and guidance has been issued in the other three UK countries.

Further to the regulation originating from EU directives, as well as the national and regional policies, local authorities can emphasise specific planning topics or include additional aspects in their Local Plans. Some of these are directly concerned with subsurface space use. For instance, mainly as reaction to citizen's complaints about mega basement extensions (Reynolds and Reynolds, 2015), five London Boroughs developed supplementary planning documents or specific policies on basement developments. Another example is the City of London, where the use of 'pipe subways', accessible tunnels in which several utilities can be fitted and which eliminate the need for repeated excavation (Hunt et al., 2014), is mandatory wherever feasible (City of London, 2013).

There are other topics covered in the Local Plans that imply intensified use of underground space without stating it explicitly. The promotion of high rise buildings, for example, often entails deep foundations, and protection of open space or efforts to recover open space might incentivise construction of underground developments. Also the general intention to densify as a reaction to housing needs could incentivise the development of underground space for facilities that do not rely on daylight as well as increase the demands for underground infrastructure. Beyond the process of gaining planning approval by a local authority, the use of underground space for major infrastructure projects can be approved on a national level through specific acts of parliament (e.g. Crossrail Act 2008; Channel Tunnel Act 1987) or more recently through the National Significant Infrastructure scheme that was introduced with the Planning Act 2008.

Note that the objective towards the respective activities in the subsurface is not uniform. Whereas for groundwater management the main objective is protection and a balanced use of the water resource, flood management can require the provision of subsurface space for retention purposes. Policies on renewable energy, high rise buildings, open spaces as well as decisions about major infrastructure schemes explicitly encourage or determine the utilization of subsurface space. The latter are of particular interest as they might bring about an increase in subsurface structures and thus irreversible modifications to the subsurface resource.

It becomes apparent that the current governance of subsurface space in England is largely sectoral and project centred rather than based on the premise to control all activities in a given volume. The planning system in the UK provides a framework for mediation of different interests when deciding about planning applications in which the listed guidance documents serve as material considerations. However, each aspect is addressed separately and the interdependencies dealt with in a particular application are restricted to already existing or planned activities in the project vicinity. The effect of the individual regulations on plan making from the outset seems to be limited.

New Approaches for Integrated Subsurface Planning

The brief summary of relevant English regulation related to subsurface planning highlights that there is considerable scope for improvement. In recent years the topic of conflicting space claims in the subsurface and as a consequence of the question if and how the use of subsurface space should be regulated appeared on the policy agenda in a range of countries including Norway, Sweden, Finland, China and Japan (Sterling et al., 2012). The 2015 revision of the spatial planning law in Switzerland calls for sustainable use of the subsurface (RPG, 2015) and research commissioned by the Federal Environment Agency in Germany concluded that the application of existing planning instruments to underground space would be possible and should be established to manage current and prevent future use conflicts (Bartel and Jansen, 2016).

The importance of the subsurface for urban development has also been addressed in major research projects; At least two volumes of the UN Atlas of Urban Geology focused on the interface to urban planning (United Nations 2001, 2003) and 2013-2017 the BGS chaired a research action supported by the European Cooperation in the field of Scientific and Technical Research (COST) that addressed the question of how information and knowledge about the subsurface can benefit urban decision makers. ‘COST sub-urban’ involved a variety of municipalities and geological surveys and was not focused on academic institutions (http://sub-urban.squarespace.com).

In the UK, the City of Glasgow was actively involved in the COST action and itself takes a progressive stance: The new City Development Plan, adopted on 29 March 2017, explicitly touches on the subsurface in that it includes geodiversity in its policy on the natural environment and committed Glasgow City Council (GCC) to address subsurface infrastructure as well as ground source heat in a supplementary guidance document on resource management (GCC, 2017a, 2017b).

The development of the City of Glasgow is closely linked to its subsurface environment, not least through the legacy of mining and heavy industry that throughout the last centuries have caused substantial modifications to the ground surface. Many parts of the city are underlain by shallow abandoned mine workings which still cause settlements due to local collapses (Whitbread et al., 2016). To improve the knowledge of the distribution and depth of these mine workings and enable the regeneration of the associated areas in the city, the British Geological Survey (BGS) in 2002-2003 initiated the development of a three-dimensional geological model of the area (Whitbread et al., 2016, Campbell et al., 2010). The model also improved the understanding of groundwater flow and the location of flooding in Glasgow (Bonsor et al., 2013). Continuing collaboration between GCC and the BGS as well as knowledge exchange with other European Cities through the COST network mentioned above, enabled Glasgow City Council to facilitate a growing awareness of policy makers of the value of the subsurface environment and the information about it (Whitbread et al., 2016, Bonsor, 2017). GCC now explicitly uses subsurface information in their planning processes to better understand correlations and synergies between subsurface properties and other planning aspects like connectivity or access to open space. In this context, they also explore possibilities to tap into potentials of utilising subsurface resources to regenerate above ground areas or make council assets cost neutral (Dick, 2017). GCC and the BGS are now working with other councils in order to widely publicise this new approach and share their experience (BGS, 2017).

As the regulation and governance of subsurface space, the functions it embeds, and services it provides is fragmented, initiatives like the one taken by Glasgow City Council largely rely on the initiative of individuals in the respective institutions. There is currently a focus on acquisition and sharing of data. These data provide a useful tool for current projects as well as a necessary basis for a contingent governance framework. Whilst the growing demand for space drives the development of such frameworks in particular places like Singapore and Hong Kong, integration of the subsurface into urban development strategies is likely to become more pivotal with cities developing resilience strategies. As a response to climate change effects, uses like flood retention capacities, storage capacities, local energy sourcing, and potentially underground housing can be expected to become more important. These considerations also affect smaller cities in which aspects of underground developments as result of growing densities and land prices are less relevant. For example, Rotterdam and Arnhem in the Netherlands have started the process of integrating the subsurface into urban planning motivated through the need of sustainable development and urban resilience.

The City of Glasgow and other European cities herald the start of a mind shift by encouraging the use of information about the subsurface to guide new planning policies. They show that understanding the subsurface and well communicated engineering knowledge can change perception of place and generate new ideas about the cities development prospects.
The role of engineers in this context is to learn from existing projects and to develop metrics that capture and convey the meaning and complexity of the urban subsurface as well as the embedded infrastructure systems (Nelson, 2016). Ultimately, a holistic approach to subsurface planning and governance will integration of data acquisition and management, legislation and governance, as well as expert knowledge.

Conclusions

This paper reviewed a number of initiatives, both in the UK and overseas, that aim to acknowledge the role of the subsurface for cities and improve availability and utilisation of subsurface data. Pressures from climate change and urban growth will lead to intensified use of the urban subsurface and reinforce the need for a more organised response to potentially conflicting space claims. It was indicated that contemporary legislation and planning might be applicable but only if a sufficient data base is available and existing interactions and potential conflicts are understood. The paper showed that acquiring the data itself is already an enormous task. While the subsurface and according governance is changing, see Glasgow as an example, there is still a long way to go before a holistic, multi-level approach towards the subsurface, covering environmental, structural, and geological aspects of underground space is realized.

The subsurface starts to be included in the search for discrete spatial or energy solutions but it became apparent that engineers need to consider the effects of human interventions not only on the geology or hydrology but also on existing structures as well as the ecosystem services the subsurface provides. Communication of the associated risks and opportunities to the various actors involved in decision making about what can or cannot be done below the surface is key in order to ensure that the value of the subsurface is not diminished.

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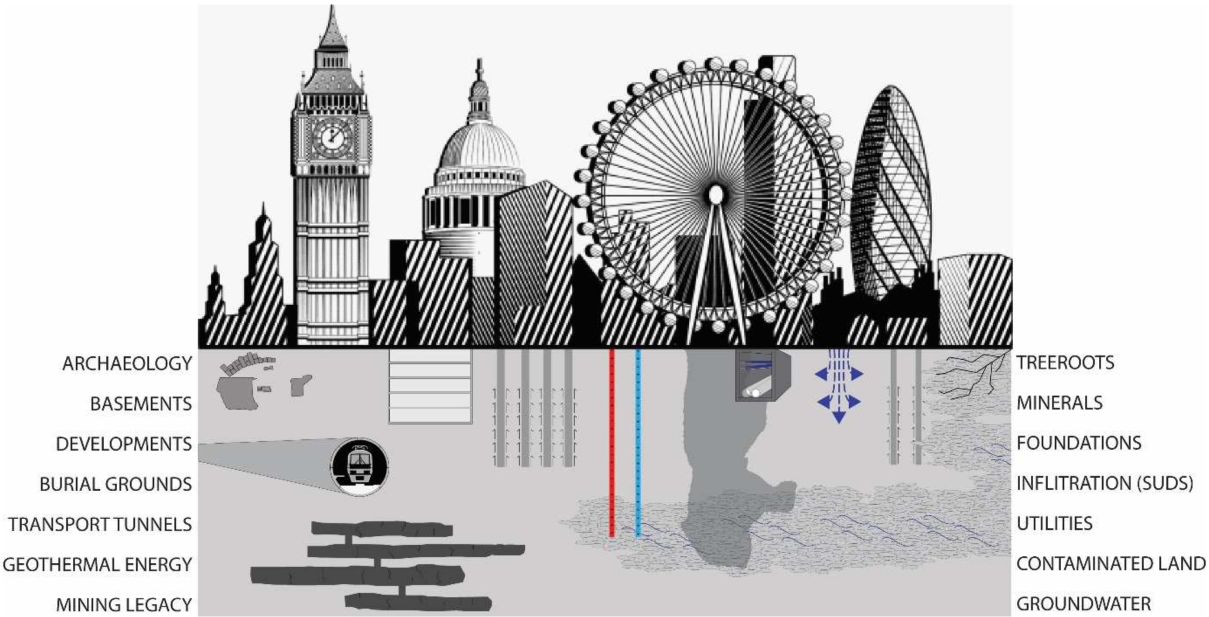

Figure 1. The multitude of human uses and their legacy in the urban subsurface (not to scale, geological features are not shown). Skyline reprinted with permission of Neil Watson, www.neil-watson.co.uk

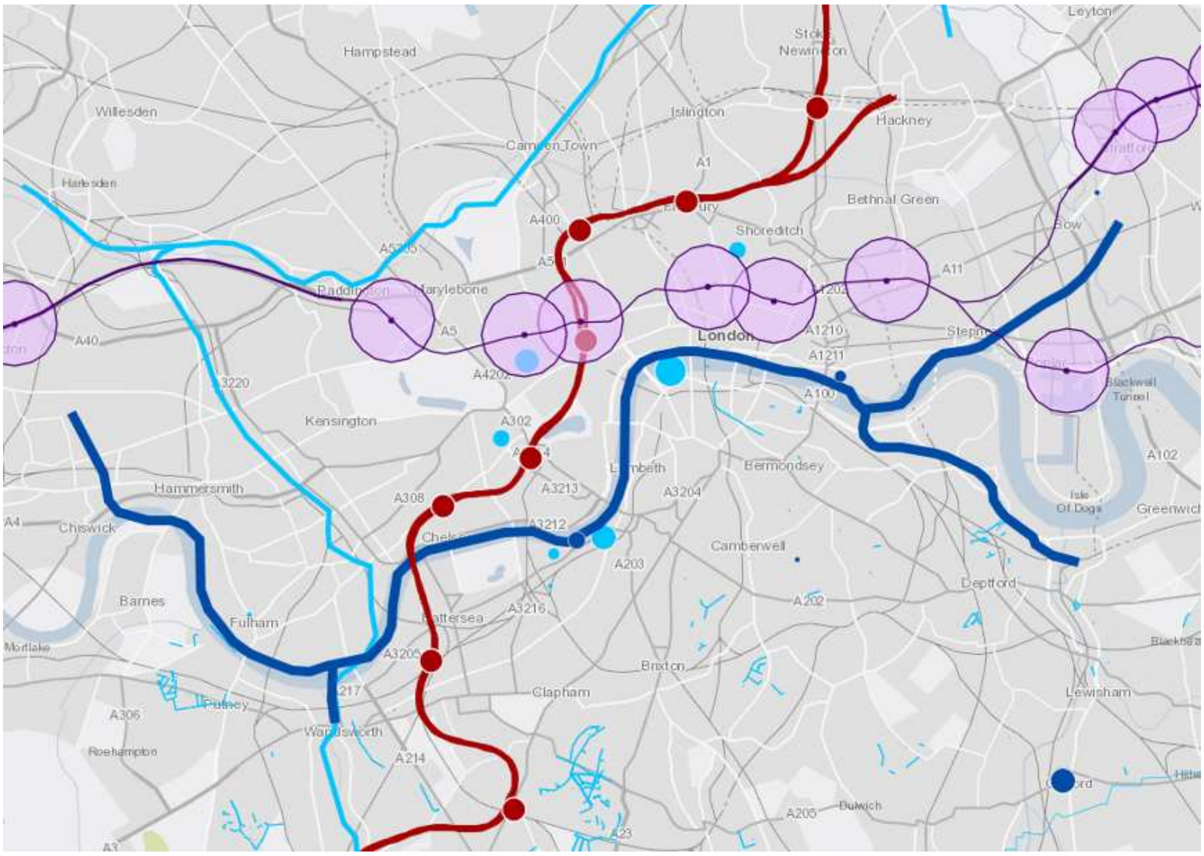

Figure 2.

Snapshot of the London Infrastructure Map (https://maps.london.gov.uk/ima/) showing future investments in the water and energy sector (dark and light blue, respectively) as well as Crossrail 1 (purple) and the safeguarded route for Crossrail 2 (red).

Table 1. EU Directives affecting Governance of the Urban Subsurface (selection by author)

Year	EU directive*	Topics relevant for the Urban Subsurface	Main effective transposition in England
1991/ 1998	Urban Waste Water Treatment Directive (EC 1991, EC 1998)	Waste water treatment including prevention of leakage of collecting systems	The Urban Waste Water Treatment (England and Wales) Regulations 1994 The Urban Waste Water Treatment (England and Wales) (Amendment) Regulations 2003
2000	EU Water Framework Directive (EC 2000)	Surface water Groundwater Groundwater dependent ecosystems	The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017
2001	Strategic Environmental Assessment Directive (EC 2001)	Incorporates environmental considerations in strategic planning, including land use planning	The Environmental Assessment of Plans and Programmes Regulations 2004
2006	Extractive Waste Directive (EC 2006a)	Management of geological materials that are considered waste	The Environmental Permitting (England and Wales) Regulations 2010
2006	Groundwater Directive (EC 2006b)	Protection of groundwater	Groundwater Regulations 2009 Groundwater (Water Framework Directive) (England) Direction 2016 (DEFRA, 2016)
2007	Infrastructure for Spatial Information in the European Community (INSPIRE) Directive (EC 2007a)	Requires to improve access to and sharing of spatial data	The INSPIRE Regulations 2009 The INSPIRE (Amendment) Regulations 2012
2007	Flood Directive (EC 2007b)	Assessment and management of flood risks	The Flood Risk Regulation 2009
2008	Waste Framework Directive (EC, 2008)	Disposal of excavated soil	The Waste Regulations (England and Wales) 2011
2009	Renewable Energy Directive (EC, 2009)	Legally binding targets for the share of renewable energy sources (20%) Definition of 'geothermal energy'	i.a. The Renewables Obligation Order 2015
2011/ 2014	Environmental Impact Assessment Directive (EC 2011, EC 2014)	Principles for environmental impact assessment of projects including the description of effects on: - cultural heritage (archaeology) - soil and water	The Town and Country Planning (Environmental Impact Assessment) Regulations 2017 The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017

*only main directive and major amendments of directives listed.

Table 2. National Planning Policy Guidance relevant for the Urban Subsurface (DCLG, 2016, selection by author)

National Planning Policy Guidance	Topics relevant for the Urban Subsurface
Air Quality	Green infrastructure Modes of transport with low impact on air quality
Climate Change	Renewable energy technologies Sustainable transport Availability of water and water infrastructure Flood risk
Conserving and enhancing the historic environment	Archaeological sites Undesignated buried remains of archaeological interest
Environmental Impact Assessment	Effects on soil and water Archaeological heritage Effects of the use of natural resources
Flood Risk and coastal change	All kinds of flood risks including surface and groundwater flooding Sustainable drainage systems.
Land affected by contamination	Planning duties with regards to land contamination and its possible effects
Land stability	Planning duties with regards to land instabilities.
Minerals	Safeguarding and extraction of mineral resources.
Natural Environment	Protection of ecosystems, in particular soil
Tree preservation Orders and trees in conservation areas	Protection of trees including tree roots
Waste	Landfill and excavation waste.
Water supply, wastewater and water quality	Identification of suitable sites for new or enhanced infrastructure