INTEGRATED GOVERNANCE OF THE URBAN SUBSURFACE

- A SYSTEMS-BASED APPROACH

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Thesis Submitted for the Degree of
Doctor of Philosophy

2020

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Declaration

I, Loretta Sophie Reichsfreiin von und zu der Tann-Rathsamhausen, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis with the use of citations and references. All cited quotes of the interviewed study participants have also been marked accordingly.

Signed

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Dated

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Abstract

The ground our cities are built on has always been a constitutive part of urban life, but is only in recent decades starting to become recognised by built environment professionals and academics as an area that might require more intentional governance. While the task of doing so is usually assigned to the realm of urban planning, a major body of literature engaging with this stems from the engineering discipline. This thesis draws on systems thinking and uses London as a case study to bridge these two disciplines and confront currently engineering-centred ideas of urban underground governance.

Applying a mixed methods strategy, the thesis presents a review of planning legislation, affirming the central position of engineers and Local Planning Authorities in the current governance arrangement around London's subsurface. Overarching theoretical and strategic suggestions are drawn from a thematic analysis of interviews with tunnelling and planning professionals, designed to provide insights into discipline specific perceptions of the urban underground, with additional insights provided by a questionnaire with a broader group of practitioners.

The research shows that the spatio-material context of the ground is underrecognised when specific functions are managed within it and that despite growing engagement in the field, governance of the subsurface remains fragmented across sectors as well as temporal scales. The findings indicate that (a) an integrated data format and repository and (b) an integrated evaluation of priority for interventions in the subsurface could serve as enabling mechanisms towards a more holistic understanding of subsurface value that extends beyond purely financial assessments, and moves towards more integrated overall strategies. Reflection on ownership models, specific local contexts, early citizen engagement, and consideration of pathways are shown to be key elements of a potentially broader conversation about the role of the subsurface in cities like London today and in the future.

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Impact Statement

Urban underground planning, or the integration of the subsurface into urban planning, is a growing field in research and practice. Often attributed to the scarcity of space above ground, but also dealing with legacies such as ground contamination, municipalities in the UK, Europe and worldwide are beginning to engage with the material reality of what their city is built on.

The current thesis contributes to this field by presenting some overarching theoretical considerations as well as practitioner's voices – both underrepresented in the current literature – and the impact of the research is, for now, primarily of an academic nature. The research draws key insights from placing the current literature into the theoretical framework of systems thinking. These have already been published in collaboration with key thinkers in the field, ensuring the recognition of the presented line of thoughts in the academic context. Further publications and conference contributions arising from the research, as well as presentations at topic-related events, have opened up conversations and avenues for further thought. Through the publication of the main findings of the thesis, developed from the empirical data collected, it is hoped that these conversations will continue.

In an environment in which increasing numbers of cities are coming to recognise the necessity of better understanding the ground and geology they are built on and the effects that these, in turn, have on their prospects for future developments, the current findings will become important to practitioners in the field, allowing them to better understand the role of specific actions or conversations in the overall process towards integrated subsurface planning. The key considerations presented here will enable the development of a more reflective, holistic approach to dealing with the topic area. As such, the research opens up pathways to further research not only in the academic setting, but also in collaboration settings between academia, planning authorities and other potentially affected institutions, as well as practitioners of the various disciplines involved.

Throughout the course of the current study, the researcher collaborated with Think Deep UK and with the International Tunnelling and Underground Space Association's Committee for Underground Space (ITACUS) in order to engage practitioners in topic-related workshops. Whilst not delivering a tangible impact, the process of testing and discussing the developed line of thought with these key groups in the national and international area of subsurface planning may have shifted the focus of their activities, and will continue to do so. In this way, the theoretical considerations presented here may contribute to the international discussion about urban subsurface planning, and might also be relevant to other contexts.

Acknowledgements

The journey of a PhD is not travelled alone. Many people walk alongside, some for a moment, others for the whole path. It is these people who reminded me time and again that this path is neither a dead end nor an infinite road but rather an endeavour full of curiosity, challenge and consideration, and of personal and professional development.

Three people deserve special gratitude: my two supervisors, Brian Collins and Nicole Metje, as well as my friend and colleague Marilu Melo Zurita. Without Brian's openness and enthusiasm, I would have not embarked on this journey. Without Nicole's perseverance, patience and tireless encouragement I would not have persisted. And without Marilu's dedicated support and cheering, there is a good chance I would not have finished.

The work and collaboration with TDUK (in particular Stephanie Bricker, Liz Reynolds, Petr Salak, Christian Bocci, and Patrick Cox), ITACUS (in particular Han Admiraal and Antonia Cornaro), and the subsurface team at the municipality in Rotterdam (especially Ignace van Campenhout and Kees de Vette), helped me put my thoughts into a practical, multidisciplinary context and to gauge which questions are considered relevant in the field. I also want to thank my interview partners for their time.

The length of this whole thesis would not suffice to write down how thankful I am to all the other people who supported me throughout the years: those who have embarked on similar journeys – Paul Honeybone, Kell Jones, Colin Rose, Athanasios Kourniotis, Iwona Bisaga, Jenny McArthur and Jonathan Ward – for their advice and companionship; at CEGE, Jane Doogan's and Nicola Christie's for their pragmatic outlook; Franscesca Risetto and Fransje Hooimeijer for their positive energy; Holger Kessler of the BGS for being a sounding board to discuss two preliminary Chapters; and Lidija in Mexico for working so hard in the final weeks to help refine my English.

Thanks to all my family, who made me who I am; my parents for entrusting me with independence; Cosima for her sisterhood; Sabine for providing me space; and, in particular, thanks to Anna and her family who keep me grounded.

Thanks to all my friends, who continuously supported me throughout the years: Reka, Amanda and Matthias for always checking in at just the right moment; Linda and Fiona for making sure I get some exercise; Zareen and the 'Frognal family' for making me feel home in London; Raphael for providing continuity; Nina for endless hours of company; and all the others for just being amazing friends.

Finally, Nic, thank you for your patience and warmth and for being next to me.

I dedicate this thesis to my nieces, Tilda and Lene.

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List of Abbreviations and Acronyms

AGS	Association of Geotechnical & Geoenvironmental Specialists
AMS	Asset Management of the Subsurface
APA	Archaeological Priority Area
BAA	British Archaeological Association
BGS	British Geological Survey
BTS	British Tunnelling Society
CBA	Cost-benefit analysis
COST	Cooperation for Science and Technology
DCO	Development Consent Order
EA	Environment Agency
GCC	Glasgow City Council
GLA	Greater London Authority
ICE	Institution of Civil Engineers
ITACUS	International Tunnelling and Underground Space Association Committee on Underground Space
LPA	Local Planning Authority
MEMSA	Modular evaluation method for subsurface activities
NPPF	National Planning Policy Framework
NPPF	National Planning Practise Guidance
Ofcom	Office of Communications
Ofgem	Office of Gas and Electricity Markets
Ofwat	Water Services Regulation Authority
PAA	Policy Arrangement Approach
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
RTPI	Royal Town Planning Institute
SPD	Supplementary Planning Document
SSM	Soft Systems Methodology
SuDS	Sustainable Drainage System
TDUK	Think Deep UK
TfL	Transport for London
URA	Urban Redevelopment Authority (Singapore)
UUS	Urban underground space

1. Introduction

In the underland we have long placed that which we fear and wish to lose, and that which we love and wish to save.

Robert Macfarlane, Underland

1.1. Setting the scene

The underground has always been a metaphor for exclusion and protection, for secrets and discovery. As such, it also provides a good metaphor for research – for the uncovering of hidden layers and gaining knowledge or, at least, a better understanding of the material and social processes around us. The actual material under our feet, the underground or subsurface, has often influenced, if not constituted, where cities have been built, providing a supply of natural resources on one hand, and protection or trade routes via geomorphological features on the other (Doyle, 2010). In every city, the potential for subsurface utilisation is set by the local geology that also influences the way buildings and infrastructure are designed and built (Hunt et al., 2016).

Apart from serving as a bearing ground for urban structures, the underground also provides additional physical space for developments, storage and infrastructure, and the subsurface as a natural and site-specific system accommodates aquifers, and nurtures flora and fauna (Price et al., 2016). It can, depending on the local conditions, also serve as storage for waste or natural resources (Parker, 2004), or constitute a barrier to development, such as when the remediation of former contamination is necessary for a development to be permitted (Wassing and van der Kroog, 2006). Furthermore, the urban underground can also be claimed for new uses such as geothermal energy (Hunt et al., 2016; De Mulder et al. 2012; Parriaux et al., 2007; Sterling et al., 2012), and potentially there are other uses of the subsurface that cannot yet be foreseen.

The underground has been linked with many current themes in urban research and development, including sustainability (Hunt et al., 2011; Makana et al., 2016), resilience (Admiraal and Cornaro, 2019; Makana et al., 2016), and climate neutrality (Qiao et al., 2018). The authors of these contributions emphasise that the allocation of underground space should no longer be reactive to changes in spatial development, but should form an integral part of the latter. However, cities with a coherent planning strategy for subsurface assets and functions remain few (Sterling et al., 2012; Price et al., 2016), and the need for a strategic approach is recurrently expressed in the literature.

1.1.1. The 'urban' and 'subsurface'

To explore how better to capture the sphere of the urban subsurface – theoretically as well as practically – the two terms 'urban' and 'subsurface' require some consideration. There is no standard definition for what constitutes an 'urban' area. As a result, what is considered 'urban' can, for example, be defined in terms of a built-up area, functional area, or population density, and this differs from country to country (UN, 2014). In the UK, the Department for Environment, Food & Rural Affairs (DEFRA) classifies settlements of more than 10,000 residents as 'urban' for the purposes of statistical analysis (Bibby and Brindley, 2013). Another distinction can be made with regard to the political or administrative institutions that formulate planning policies (Newman and Thornley, 1996). The question of what kind of settlement or human dwelling should be looked at when referring to an urban scale thus needs to be considered in light of the specific question to be answered. What is to be considered 'urban' in the context of urban subsurface studies has not yet been discussed in the literature. For the purposes of the current thesis, it can be argued that London falls under the category of being a decidedly urban area.

The concept of the 'subsurface' or 'underground' is equally ambiguous. Both commonly refer to the bedrock and superficial deposits covering the earth's surface. Geotechnical engineers are concerned with the engineering behaviour of these formations. However, space that is covered over without having previously been filled with bedrock, or with superficial or man-made deposits, could also be considered to be a subsurface (see von der Tann et al., 2018b). These activities date back a long time: ancient societies all over the world have raised mounds over the graves of their ancestors. In urban areas, rivers have been covered over to shield the vicinity from the smell and diseases it may carry (e.g., Bolton, 2011). A similar idea prevails today with the covering up of existing traffic ways to shield the vicinity from noise and pollution and, at the same time, provide new open spaces. Recent examples would be the revived plans for covering a railway section in Zurich (Kälin, 2017), or a 2.2km long covering of the inner-city motorway in Hamburg (hamburg.de, n.d.). In England, the current Air Quality Strategy implemented by Highways England budgets for canopies (Highways England, 2017). These examples show that what constitutes the earth's surface is constantly changing, and that it is necessary to define a reference surface when the interface between the above and below ground is considered, and when a systematic view on what is below ground is sought. Furthermore, some authors use 'subsurface space' or 'underground space' to describe specifically underground developments, while others include all human uses of the subsurface, such as the use of groundwater or geothermal energy, within these terms. A discussion of this specific terminology is not the focus of the current thesis, and the terms 'subsurface', 'subsurface space', 'underground' and 'underground space' will be used interchangeably throughout this thesis.

1.1.2. Current situation

Historically, 'undergrounding' – putting structures underground instead of above ground – of functions in cities often goes hand in hand with protecting the urban population above ground from potential hazards or disruptions. For example, the construction of sewage systems prevented the spreading of diseases in London (Halliday, 2013), and air quality as well as noise reduction are frequently mentioned when placing structures into the underground (e.g. Delmastro, 2016; Rogers, 2009). However, every intervention in the subsurface changes ground conditions in the long-term (Sterling et al., 2012), and major underground projects not only require surface space in order to obtain access to the subsurface levels via shafts, but also permanently occupy a large underground space, which, at least partly, had previously been untouched. In the planning of these projects, the limits imposed on the future development of underground space along a tunnel alignment or project parameter, and in its vicinity, is not usually considered (Suri and Admiraal, 2015). In addition, it has been commented that in many urban areas, the piecemeal development of underground usages and the predominating 'first-come first-serve' mentality (Bobylev, 2009; Suri and Admiraal, 2015) has led to the description of the space as 'chaotic' realisation of ever more complicated underground constructions, and to a lack of safeguarded space for future activities and access to deeper levels (Rogers, 2009).

Today, the subsurface in London, as in many European cities, is described as congested with structures and utilities that have been successively added following the development of the individual technologies (Admiraal, 2006). As part of infrastructure networks, the operation of the structures, cables and pipelines placed underground are crucial for our urban society to function (Price et al., 2016). With regard to much of the infrastructure, the 'invisibility' of these services or infrastructures is accompanied by them being taken for granted (Star, 1999) and, thus, by a general lack of acknowledgement. In addition, in cities worldwide urban underground space (UUS) is increasingly being developed into shopping malls, extensions of museums or parking facilities, recreational spaces, archives, car parks or computer centres, to name just a few functions (Zhao and Cao, 2011).

1.1.3. Approach followed in the current thesis

To reconcile the promise and potential pitfalls of planning for and with the urban subsurface, and to achieve a realistic assessment of likely outcomes, the concepts applied in favour of such planning need to be examined in a critical light. Most literature about the urban subsurface sits exclusively in either the engineering domain, discussing technologies and the management of underground resources, or in the social domain, engaging with the political, historical and social aspects of the resulting spaces and infrastructures. This thesis seeks to bridge these two lines of thought by employing systems thinking as an integrative framework that has mobilised new approaches in both domains.

In the context of urban planning, systems approaches have been applied since the 1970s (McLoughin, 1969; Rittel and Webber, 1973), and are still frequently referred to. With regard to the subsurface, it has been claimed that sectoral approaches have not only led to piecemeal development, but also to a set of problems with regard to data sharing (Likhari et al., 2017), as well as during project planning and implementation. Specifically regarding elements or functions of the subsurface, construction projects have been discussed through the perspective of systems engineering (e.g., Zhou, 2014), and systems thinking as an approach aiming to understand the relevant interrelationships and interdependencies is seen as vital for water management, as evident in a recent report by the UK water regulator, Ofwat (Ofwat, 2017). As the current thesis sits in between the two disciplines of engineering and urban planning, it appeared apposite to explore whether the principles of systems thinking could guide an exploration of urban subsurface governance and the development of a holistic framework, or, at least, meaningful reflections about how to consider and compare approaches to urban subsurface management and planning. Systems thinking provides a tool that can embrace policy analysis and resource management, and allow for the inclusion of the appropriate historical perspectives when considering the issue at hand.

The current thesis thus aims to contribute to the above critical examination through an investigation of the theoretical framework of systems thinking, and an in-depth discussion of the specific setting of London. London was chosen as the case study area for the current thesis given that it is a city with a long history of underground use. Some of the oldest underground infrastructures are in London, including the first ever underground railway (see Wolmar, 2004), and the sewerage system designed by Bazalgette (see Halliday, 2013). Growth predictions imply a demand for the further development of infrastructure. At the same time, the continuous increase of housing and land prices in the city makes private underground developments feasible and has led to the construction of deep basements for residential houses, colloquially called *iceberg-buildings* (Burrows, 2018). Over the last few decades, a series of large underground infrastructure projects have been built in London, or are still underway, to extend the underground transport network and renew or upgrade services. London, therefore, provides an opportunity to study the scope of the retrospective integration of the subsurface into planning policies in a city where the subsurface is already highly developed.

The research was undertaken using a predominately qualitative mixed-methods approach, consisting of a review and analysis of research and policy documents, in-depth expert interviews, and an online questionnaire with a predominantly quantitative component. The qualitative analysis of the documents and interview transcripts aims to consider the data in an unbiased way rather than through a predefined framework, asking how the subsurface is currently represented and perceived. As such, the thesis seeks a rich description of urban underground governance and its meaning for cities with the objective of learning about the *problem situation* through understanding why certain aspects are being conceptualised as a 'problem', rather than accepting a problem as predefined and directly working towards a 'solution'. It is hoped that the in-depth discussion of the empirical data presented can provide starting points for a consideration of value and ownership, as well as of the human-nature divide that appears to be one of the main topics of our time.

1.2. Scope, aims and objectives

The management and governance of the urban subsurface, including all of the materials embedded within it and their potential utility for humans, covers a vast area of disciplines, projects, legislation and organisations. As such, the struggle towards integration applies as much to the field itself as to a research project engaging with it. The current thesis approaches this quandary from two sides: firstly, by exploring the theory of systems thinking as a way of theoretically integrating efforts in the field of study, and, secondly, by exploring the specific urban setting of London in more depth.

The research was guided by the following overarching research question:

How can systems thinking contribute to more integrated urban underground governance?

To answer this question, the following research aims and supporting objectives were set:

AIM 1

To understand the potential utility of systems thinking for the analysis of the urban subsurface through a review of literature and to define a coherent research approach towards investigating urban underground governance.

Supporting objectives

To review the literature to:

a. understand the principles of systems thinking.
b. describe the potential meaning of these principles with regard to the urban subsurface and its governance.
c. discuss if and how systems principles are reflected in the current literature about urban subsurface planning.

AIM 2

To provide a rich description of the perception of London's subsurface and the current approach to its governance as a case study, in order to improve the understanding of the current and potential importance for cities to more intentionally govern their subsurface use.

Supporting objectives

a. With regard to London, to review the current urban planning legislation and related documents in order to understand and illustrate how the subsurface is currently captured in such legislation.
b. Also regarding London, to review legislation and consultation documents for local plans and underground projects to identify the key actors contributing to the governance setup, and to understand how they are positioned.
c. To contrast the actors identified with observation notes taken in relevant settings and data from in-depth expert interviews to develop a rich picture of the stakeholder field relevant to London's subsurface.
d. To conduct and analyse in-depth interviews with practitioners to understand how the problem situation is perceived by the main actors identified.

AIM 3

To develop theoretical considerations and make strategic suggestions towards holistic and integrated governance of the urban subsurface in London and beyond.

Supporting objectives

a. To investigate how the current governance setup as well as the specific perceptions by key practitioners are reflected by a broader group of professionals, using an online questionnaire.
b. To discuss and conclude how these insights can be mobilised to contribute to an integrated conceptualisation of the urban underground as part of the urban system.

1.2.1. Limitation of research scope: systems, society and value

The current thesis focusses on today's governance arrangement in London and the key actors who are involved in the conceptualisation, design, implementation and approval of underground projects. There is an argument that the civil society and the general public should participate in planning the underground to enhance the transparency and legitimacy of decision-making processes as well as the accountability of the involved parties. The importance of community participation is increasingly recognized for construction projects in general. In the UK, public consultation is a statutory requirement for schemes of a certain size (Localism Act, 2011). However, to understand what are the best ways of promoting such participation for the system as a whole it is deemed necessary to first better understand the current arrangements and professional actors and their perspectives within the field.

In this thesis, systems thinking is employed as a guiding structure. In this way of thinking, as will be elaborated on in Chapter 2, it is acknowledged that complexity arises through human agency. As such, even if the civil society is not a focus of the work reported in this thesis, the research process was accompanied by a constant reflection about the impact of different functions of the underground, and the planning for such utilisation, on communities and the wider society. For example, the researcher conducted several activities in collaboration with the municipality of Rotterdam deliberated what the public should know and how it could be informed about the underground. The data from these activities and according reflections constituted an independent body of work that requires further development and a different focus of discussion than the one pursued in the current thesis and are consequently not reported here.

Throughout the current study, the value of the underground and the functions embedded within it will be repeatedly touched upon. Whereas exploring the meaning of value in depth would have gone beyond the scope of the current work, it shall be noted that in the context of construction projects there has been a general shift from looking at benefits in the context of cost-benefit-analyses to understanding the value of a project in a broader sense. As such, a distinction is made between value as a financial term, expressed in a monetary unit or price and a more general idea of value that is multidimensional, including social, cultural, and/or environmental considerations. Such values are is context dependent and context specific. Throughout the thesis, value as a price or monetary measure will be referred to as 'financial value'. The broader understanding of subsurface value as an assignment of importance to the subsurface by individuals, organisations, communities, or society warrants further consideration and research.

1.3. Structure of the thesis

This thesis starts from the observation that, in the field of urban underground planning and management systems terminology is often used without due regard to its conceptual and theoretical background. Consequently, Chapter 2 explores what systems thinking might mean in relation to the subsurface as a system on the one hand, and subsurface management on the other. It then reviews how the recent literature fits within these considerations. Based on a general understanding of systems concepts, Chapter 3 presents the philosophical underpinning of the research, based on the critical realist paradigm, as well as the design of the research process that followed, mobilising qualitative as well as quantitative data collection.

Ultimately seeking empirical traces to further the general theoretical exploration of the field of subsurface planning, the main body of the thesis consists of three parts. Firstly, in Chapter 4, the current governance approach in the case of London is analysed through a review of policy documents and observation notes. Secondly, Chapter 5 elicits and analyses the specific perceptions of two main expert groups involved in the space: urban planners and tunnelling engineers. Finally, Chapter 6 broadens the analysis by using a questionnaire to extend the range of empirical data and relates the findings back to the theoretical framework of systems thinking. The last chapter reflects on the scope and objectives set out at the start of this thesis, and presents overall conclusions as well as pathways to further investigation. The structure of the current thesis is presented in Figure 1.1.

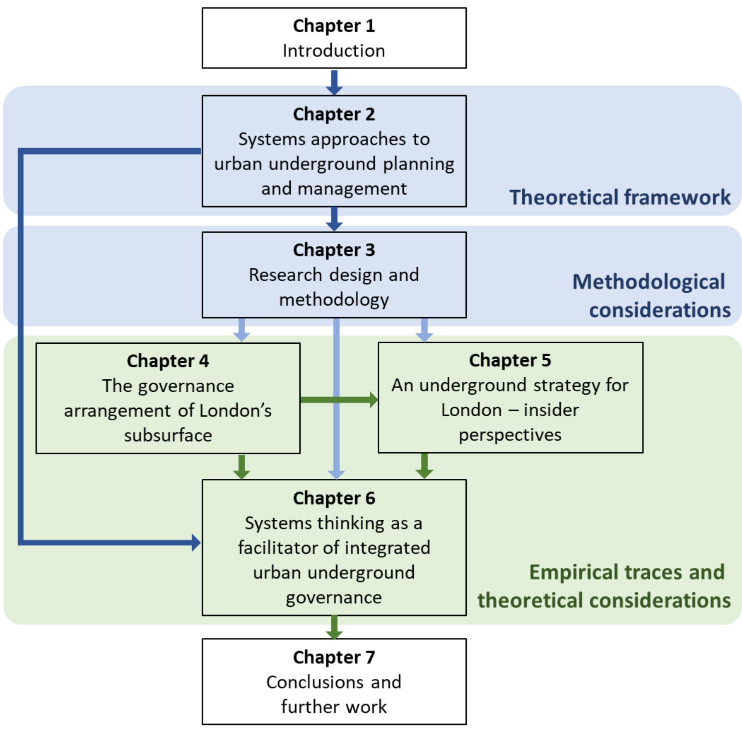

Figure 1.1: Structure of the current thesis

2. Literature review: systems approaches to urban underground space planning and management

Parts of this chapter were previously published in von der Tann et al. (2018b) (Section 2.4) and von der Tann et al. (2020), (Section 2.1 to 2.3). The sections from this chapter that are drawn from those papers have been slightly adapted and edited to suit the purposes of the current thesis, including the conversion from American to British English. All parts reproduced and, in some cases, edited here are the author's original work. The co-authors of the published papers acted as reviewers of these parts and contributed to the content in Table 2.1 and Table 2.2. The complete papers can be found in Appendix III and Appendix IV.

2.1. Introduction

As stated in the introduction to this thesis, the subsurface or underground constitutes an important part of our urban environment. Infrastructures, water, developments, natural and man-made cavities – all of these are connected to the history and economy of a specific city or urban area. More systematic approaches to planning or management of the urban underground have been demanded repeatedly for some time, alongside a more general progression towards the description and analysis of cities as systems (e.g., Moffatt and Kohler, 2008). The relevance of the subsurface for urban development in general, and for urban sustainability in particular, as well as the potential benefits that a more conscious approach to managing the subsurface could entail, are being increasingly addressed, often by tunnelling and geotechnical engineers (e.g., Bobylev, 2009; Hunt et al., 2016; Kaliampakos et al., 2016; Kishii, 2016; Nelson, 2016; Sterling et al., 2012; Zhou and Zhao, 2016).

Despite the development of urban geology as an independent discipline since the mid-eighties (De Mulder, 1996), a growing number of research projects in the area (see Assessing the Underworld, n.d.; COST sub-urban, n.d.; Mapping the Underworld, n.d.; Parriaux, 2007) and current political efforts in a range of countries that further emphasise the need to better understand the role of the subsurface with all its facets for the development of an urban area, as well as its relationship with environmental change, the main body of literature about urban underground space (UUS) planning still stems from the engineering discipline. The risks and opportunities of utilising the subsurface for different functions need to be considered in terms of this background.

This Chapter will introduce systems approaches as approaches with which to design, observe or analyse, and consequently steer systems that shift the focus of analysis and understanding of the world around us from constituent technical and controllable parts to interrelations and dependencies, and processes and changes over time, as well as to the role of human actors and society for the development and continuous renewal of sustainable technical solutions (Section 2.2). Current research into the urban underground and its role as a complex system or cluster of systems supporting the overall city is reviewed, with a reflection on how the proposed approaches for subsurface management and planning contribute to a more systemic understanding of the complexity of the human-technical-environmental system the urban underground constitutes (Section 2.3). Differences between disciplines are often established through their respective vocabulary, and the question of which terminology regarding the uses, functions, resources or services of or in the subsurface would be preferable for providing a useful tool, or at least ground for consideration among practitioners, is essential. As a way of engaging with this question, Section 2.4 reviews the different classification systems that have been proposed in the literature and that provide the basis for the discussion (Section 2.5) and establishment of research gaps (Section 2.6). A description of the method for literature selection can be found in Appendix VII.

2.2. Systems approaches and urban underground space

This section introduces principles of systems thinking and presents a theoretical perspective on what it could mean to understand the underground as a system and what systemic elements should be included in approaches for planning and management of the subsurface. This understanding provides the basis for the subsequent literature review on urban underground planning and management in the following section.

2.2.1. What is a system?

The term 'system' or 'complex system' describes an entity that consists of a number of interacting elements or parts that operate together towards a common purpose. Such an entity is commonly described according to the so called "holism principle", stating that the function of a system goes beyond that of the sum of its parts. This means that through the complex interactions of the parts of a system or sub-systems, an outcome or function will emerge that cannot entirely be explained by examining the system's elements (Richardson, 2004).

Apart from its individual elements or sub-systems, a system is defined by the boundaries between those elements (internal boundaries), as well as between the system and its surroundings (external boundaries), the interconnections and interactions between elements, and the function or purpose of the system (Meadows and Wright, 2009). The boundaries enable the attribution of specific purposes or roles to particular elements of the system. The overall function or purpose of a system is not predetermined, but will be assigned to the system in a specific moment in time by society or a particular stakeholder or stakeholder group. In other words, the purpose of a system is dynamic and depends on the position of the person or group describing it. For example, a developer may describe the main purpose of a housing development as the maximisation of revenue, while a local council may describe it as the provision of affordable housing units. Thus, the value and performance of any system will be assessed through the respective lens of a stakeholder or researcher.

Complexity arises when multiple stakeholder groups interact and open sub-systems bring about dynamic, constantly changing boundaries. In these cases, the boundaries and assignment of purpose for the whole system, sub-system or system elements are incomplete or contested, and cause-effect relationships can only be seen retrospectively, not in advance (Childs and McLeod, 2013). This can lead to conflicts when different groups have incompatible perspectives on a system's or sub-system's purpose. Chen and Crilli (2016) formulate this as follows:

> What distinguishes a complex system from a non-complex system is that we do not understand that system well enough to realise our objectives. In other words, 'complexity' is subjective; it describes the stance that is being taken towards a system. That complexity can itself be characterised in many different ways (e.g. emergence) depending on the different ways in which this shortfall in understanding is manifest (e.g. unpredictability) (p.4).

This quote implies that through learning about systems, over time, complexities can be understood and managed to such a degree that the system comes to be no longer perceived as complex. Complexity can thus be seen as defined by the perspective and knowledge of the person describing a system, as well as by the temporal, functional and spatial boundaries this person defines. Since they are by definition not – or not yet – fully understood, complex systems exhibit unexpected or emergent behaviours. These features of a system that have not previously been observed appear on the macro- or system level through interactions and the unplanned or unforeseen organisation of the system's components (Goldstein, 1999). As previously mentioned, emergent behaviours cannot be fully explained through a description of the system's components, and can lead to either unanticipated and potentially catastrophic failures or to robust new patterns (Chen and Crilly, 2016). Systems approaches aim at early recognition and management of the former, and encouragement and exploitation of the latter.

2.2.2. Systems approaches

The described properties and characteristics defining a system correspond to what are called systems approaches. In general, systems approaches that are based on systems thinking employ methodologies that facilitate better understanding of a system's elements, the interactions between them, and the relationship between the system and its environment (Cooper et al., 1971). Such approaches aim to prevent conflicts between different stakeholders through early recognition of interactions between the various system elements, as well as the interaction between the system in question and the social, economic and environmental systems within which it is embedded or nested. Systems approaches acknowledge that the exact problem definition of a particular issue is subjective to a group or culture, and forms part of the process rather than being predetermined and fixed. Consequently, systems approaches aim to optimise the outcome of unforeseeable system behaviours through continuous learning. Feedback loops and learning cycles are thus key components of the methodologies applied.

In the technical sphere, the notion of systems still mainly refers to the technical systems themselves. Consequently, methodologies that are based on systems thinking in this sphere deal with the design of technical systems as well as with the process used to implement and monitor them over their life-cycle. Design is here understood as the arrangement of elements to create a complete entity that has a specified purpose, or aims towards a specific outcome. Here, the purpose or outcome is equivalent to the fulfilment of a specified function, such as to enable the flow of a specific amount of water from A to B. In this technical understanding, systems of governance or cultural settings are analysed as external to the system that is being designed. Methodologies such as the systems engineering of complex projects (see e.g. Ziv et al., 2019) that were developed as a method to deal with engineering challenges spanning multiple engineering disciplines (Ryan, 2008), but that are well defined in their scope, fall into this category.

Beyond the traditional technical disciplines and tasks, a different set of systems methodologies have been deployed in the field of engineering, the main intention of which is not *design*, but *observation*, and potentially the *steering* of systems – often systems pertaining to the management and governance of a specific task in a specific setting. As such, systems thinking is more than an engineering approach, and can be seen as a philosophy for solving problems through joined-up integrative thinking. Technical systems in this understanding are described as embedded or nested in wider systems of governance, cultural settings, and the natural environment. These systems are already present and cannot be designed from scratch. However, they influence, and are themselves influenced by, the designed technical systems and other human interventions and decisions. Boundaries here are often more difficult to define, and the empirical testing and controlling of variables to identify causal mechanisms is not possible.

Systems thinking in itself is complex, and various definitions of systems can be found (see, for example, Arnold and Wade, 2015). However, a few key elements can be extracted that are characteristic of methodologies or tools applied in systems approaches:

a. The *purpose* of an intervention or element is integrated in the purpose definition of the system as a whole. This also allows for purpose and value definitions beyond the neoclassical idea of value generation.
b. The analysis of system elements is *integrated* across traditionally drawn *boundaries*. These can be temporal, spatial, administrative or sectoral, to name a few. The focus of analysis and interventions shifts from hierarchies between the elements to networks and interactions, and from the definition of parts and their boundaries to process observation and management (Simutis et al., 1973). This integration also implies that different perspectives and levels of functionality are perceived as equally important (see Blockley, 2010). For a specific problem, the analysis of the given system's boundaries is key, as they not only define the problem space but are also necessary for system optimisation.
c. It is acknowledged that the system is *dynamic and will exhibit unexpected behaviours*. The approaches thus entail:
    i. **Future thinking:** The near and distant future are considered. There is a push towards exploration and experimentation rather than only empirically derived rules to inform planning. The focus shifts from prediction to preparedness.
    ii. **The empowerment and inclusion of stakeholders** to recognise and exploit favourable emergent behaviours rather than to control the system as a whole, as it is accepted that the latter is not entirely possible.
    iii. **Continuous learning:** The system's evolution is understood as a loop rather than linear (Figure 2.1). These loops or circles entail the definition and redefinition of the problem or purpose, as well as time and the mechanisms used to monitor and evaluate the impact of the interventions undertaken. To do so, the system has to be analysed and a *baseline has to be established* against which an evaluation can take place.

Rather than claiming comprehensiveness, these points summarise what are considered to be the most important aspects for the issue at hand, and shall serve as a basis for the discussion below. Not all approaches cover all these aspects, and tools are needed for all stages and at all levels of analysis, modelling, decision making, implementation and monitoring. Priorities have to be set for each individual situation and topic dealt with.

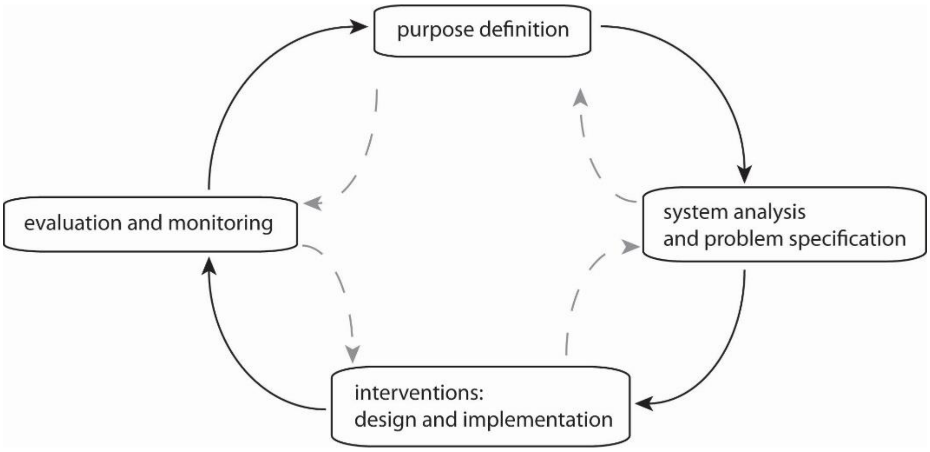

Figure 2.1: Illustration of a characteristic process-loop in system approaches

Note: Some approaches do not mention the purpose definition separately and separate out other aspects.

2.2.3. The urban subsurface as a system

The previous sections explained how systems are described and how that relates to the methodologies and tools applied in what are called systems approaches. On that basis, the current section discusses if the subsurface either as a whole, or in parts, can be seen as a system, and if or in which cases a systems perspective for the subsurface may be helpful.

Following the holism principle, if a unified purpose is to be assigned, the notion of whether the urban subsurface itself can be seen as a system can be questioned, as can whether the appropriate unit of analysis should, rather, be the city as a whole, with the subsurface then construed as a sub-system or set of sub-systems (von der Tann et al., 2016). In this context, there are various systems at play, of which the geological system and the water system, commonly perceived as 'natural' despite anthropogenic influences, and the embedded, man-made infrastructure systems are probably the most prevalent. Each infrastructure sector can be analysed as a system, with building or development projects seen as complex socio-technical systems in their own right (Zhou, 2014).

The number of systems and use potentials present in the same subsurface volume lead not only to questions of integration in order to avoid use conflicts (see, for example, Bartel and Janssen, 2016a), but also the question of how to take a decision about which functions to prioritise in cases where different uses would be feasible in the same volume. Thus, while it might be difficult to assign one specific purpose to the whole of the subsurface, the high number of interconnections between components, actors, and the continuous evolution of the space as a result of human activities in the context of urban development, coupled with an inherent unpredictability, provide a rationale for adopting the notion of a complex adaptive system (McPhearson et al., 2016; Rinaldi et al., 2001). The notion of feedback loops challenges practitioners and policy makers to recognise the mutual effects of the local geology and subsurface legacy on the future development of the city, and vice versa (von der Tann et al., 2016). In this continuously changing and evolving space, each engineering project or other intervention alters the system in some way, and every subsequent intervention may have to react to the new state. What a new state will entail is never fully predictable and engineers will always aspire to contribute to the improvement of the whole (Simon, 1996). What is considered to be an improvement, however, is embedded in individual and cultural values. This observation, in turn, strengthens the case for the value education in engineering curricula that has gained momentum in recent years (see, for example, Coyle et al., 2006; Rugarcia et al., 2000).

The evolution of systems understanding and analysis is – at least in cities with growing population and densities – paralleled by an increased density of utilizations of underground space that need to be managed in conjunction, supporting the call for a systems approach to underground space management. This management need gets allocated to the urban planning discipline, building on the conception of urban planning as the discipline responsible for the spatial distribution of human activities. To provide an overview, Table 2.1 relates the developments in urban subsurface use with the prevalent understanding of planning and dimensions of systems analyses. The information provided here illustrates that the newly emerging focus on underground space in cities can be correlated with the increasing complexity of urban systems – and thus how cities are planned and analysed – generally reacting to global challenges like population growth and climate change. It also indicates that a more systemic approach to the urban subsurface is, indeed, needed, in particular when competing space claims are present.

2.2.4. Systems approaches for the urban subsurface

A systems approach to urban underground or subsurface management requires an awareness of a multitude of perspectives and scales, as well as the interdependencies between those and the tools to examine them. A pluralist approach to research including methods, tools and perspectives seems advisable, as a single approach necessarily entails a limited view of the problem being looked at (von der Tann et al., 2016). A brief discussion of the main aspects outlined in Section 2.2.2 is provided here, before recent contributions in the literature are presented in Section 2.3.

Table 2.1: Evolution of subsurface use in relation to urban planning principles

	Past	Present	Future
City location	Choice of settlement location depending on availability of resources and ease of construction	Fixed through history Geomorphology changed through human interventions	Fixed through history Geomorphology changed through human interventions New cities in arbitrarily chosen locations
Uses of the shallow subsurface (today's 'streetscape')	Bearing capacity Plant roots Building material Drainage Basements	Bearing capacity Plant roots Utility infrastructure Shallow tunnels Basements and developments Man-made ground Ecosystem service provision pushed deeper down or out of the city	Fully managed space More functions and services Underground: - waste management - freight - housing Sustainable Drainage Systems (SuDS) to recreate drainage Reintegration of ecosystem services into urban space
Uses of the deeper subsurface	Groundwater wells Mining (industrialisation)	Groundwater wells Geothermal energy Mining legacy – cavities Deeper tunnels (transport, sewers, other uses)	Higher number of deep tunnels (transport and other uses) Storage capacities 'Right of non-use' might be discussed
City relation to the subsurface	Subsurface as basis for city location Resources like wood, building materials, fertile land and water, as well as ease of building, all connect to the subsurface	Subsurface (grown and man-made soil) mainly understood as a given constraint that has to be dealt with for project realisation Existing assets and services in the subsurface vital for the city	Subsurface part of the starting point of planning considerations/integrated in overarching spatial plans or analyses Subsurface as opportunity
Driver/purpose of building cities/ planning	Survival, fulfilment of basic needs	Health and well-being of citizens Growth Climate change Sustainability	In addition to present drivers: Flexibility Adaptability Preparation for as yet unknown changes
Planning dimensions	Not a defined discipline	2D to 3D	3D to 4D
System understanding	Engineered systems: focus on technical (engineering) solutions to well bounded problems People as predictable input in the system (e.g. demand)	Nested systems System of systems Various systems embedded in the ground still largely considered separately	Complex adaptive systems, city as ecosystem Systems constantly changing Strong focus on people to understand and meet present-day challenges

2.2.4.1. Purpose definition

Planning for underground space should examine the visions, missions and goals of the overall system within which it exists. This system can be the transport system, the water system, or the urban system as a whole. For a systems approach, it is important that the purpose of an element, task or problem be linked to its position in the overall system. Engineering tasks, such as the design and implementation of a tunnel, might have the purpose of improving the transport system whilst minimising the impact on the existing built environment. The transport system itself, in turn, might have the purpose of increasing the ratio of public to private transport for environmental reasons, to boost the urban economy, or to counteract inequality. Which of these is the main objective in a specific moment in time and consequently guides planning and design decisions is a fundamental systems choice, and it is important to keep that in mind.

2.2.4.2. Integration and boundaries

The integration of, for example, perspectives, scales and disciplines is core to systems thinking, and the challenge of broadening analyses and the ambition to integrate the various systems at play in the subsurface as well as the corresponding stakeholders is ubiquitous in the literature. In a sense, the whole question of urban underground space planning and management concerns the integration of this spatial volume into urban planning considerations and the analyses of urban areas. Embedded in this way of thinking is the intention to integrate a variety of processes and perspectives across apparent boundaries if a comprehensive approach is sought. Table 2.2 provides a list of the dimensions of integration that could be considered.

The notion of integration across various boundaries goes hand in hand with the definition and analysis of these boundaries, in general as well as for a specific task. In order to analyse a system, boundaries are often treated as temporarily stabilised, meaning that they were 'created and agreed on by groups and individual actors over a long period of time' (Kerosuo, 2006, quoted in van Broekhoven et al., 2015, p.1007). In this context, it is important to recognise that apart from the constraining effects of boundaries that motivate the move towards integration, boundaries can also have enabling effects because they reduce complexity, enable professional specialisation, and generally provide structure (van Broekhoven et al., 2015). For example, the purpose definition as well as the goals set can constitute enabling or constraining boundaries, depending on the context. This recognition is helpful to accept in that, while aiming for a systems approach, it is not only impossible but also unnecessary to integrate everything.

Table 2.2: Dimensions of integration

Conceptual integration
Integration of human, technical and environmental systems Integration of scientific and practical understanding of the role and corresponding processes of underground space planning Integration of stakeholder views
Spatial and territorial integration
Integration of local geological setting with city visions and urban planning objectives Integration of spatial scales and corresponding interests, e.g., local, regional, national Integration of above and below ground governance and design Spatial integration of various space claims on underground space – physical integration of the embedded systems
Sectoral integration
Integration between the different infrastructure sectors occupying underground space Integration of public policy domains in a specific area, e.g., infrastructure, environment, mining
Process integration
Integration of overarching visions and objectives with specific interventions Integration of project planning and project implementation Integration across political election cycles Integration of maintenance and reviewing cycles across different industries (different functions and assets evolving at different time scales or intervals)
Data integration
Integration of various data sources and their understanding, and the corresponding analysis and processing tools

In the context of the subsurface and the attempt to capture its role, as well as the challenges and opportunities it provides, other boundaries that require careful consideration and definition are the actual spatial boundaries between different uses, as well as the areas of responsibility of the relevant authorities. This can be complicated as the uses are not necessarily exclusive and territorial boundaries can be fluid. For example, the same space can be used for bearing load and groundwater flow, and the boundary for a catchment area might not be equivalent to that of the local boroughs in the city looked at. The boundary analysis provides the baseline for project evaluation and decision taking. This bridging from 'soft', holistic parameters and processes to 'hard', tangible projects that permanently change the built environment remains a major challenge.

With regard to the planning and management of underground functions, the local geological and geographical setting, as well as the legacy of structures and human interventions in the ground and the legal and regulatory system, constitute the major boundaries that are usually accepted as a starting point or baseline for planning specific interventions.

2.2.4.3. *Emergence and continuous learning*

Whilst it can be accepted that boundaries have to be analysed as temporarily stabilised for specific tasks or purposes, the aspect of process integration is related to the notion that the behaviour of the urban – and, with it, the underground – system is not fully predictable, and that the aim of systems thinking is to recognise and capture the emerging behaviours and situations in time to make meaningful adjustments. In other words, emergent and unpredicted systems behaviours should be met by an effort to continuously adapt and learn. The previously referred to 'first come – first served' approach (Chapter 1, Section 1.1.2) to the allocation of space in the subsurface causes discontent because, in hindsight, it appears that subsurface use was not tackled systematically but in a piecemeal fashion. On the other hand, was it possible to predict the increasing number of networks that would be embedded into the subsurface over time? While this problem was recognised by some at an early stage (e.g., Webster, 1914), this recognition did not lead to any significant change in practice. Likewise, could planners and engineers have foreseen (when they planned city layouts) that personal transport in cities would increase to the level that it has, and that it may now potentially decrease again due to climate and public health considerations?

There exists a range of examples of the way in which the subsurface, or elements of it, are managed today clearly being an effect of previous interventions or historical developments. This path-dependency becomes apparent in that any structure can create an impediment for future developments or impose increased management needs on a subsurface related sector. For example, damaged sewage pipes can act as drains or recharge the groundwater table, depending on the hydraulic gradient (Boukhemacha et al., 2015). Re-sealing the pipes changes the groundwater levels again, which can, in turn, affect individual citizens, such as when groundwater seeps into basements that had previously been considered dry (Sterling et al., 2005).

Systems approaches to managing the subsurface should analyse location-specific past events, describe the relevant path-dependencies, and apply future methodologies in order to maximise the potential to recognise, change and adapt existing strategies and projects.

2.3. Current thinking in a systems context

In recent years, the understanding of using underground space in urban areas as an opportunity to tackle major challenges of urban planning, as well as its role as part of the natural environment that cannot be controlled but needs to be sustained, has led to a series of academic contributions as well as research reports arising from international projects. This section reviews this literature, applying the principles introduced in the previous section to structure the literature as well as to critically reflect on how systemic the adopted positions and proposed strategies or tools are.

To accept the local geology, in addition to the legal and institutional framework, not only as a boundary but as a starting point for urban planning and planning decisions is here understood to be a necessary condition for a systemic approach to underground planning and/or management, challenging the predominant process in which subsurface assessments and interventions often follow demands and objectives set for the allocation of uses at the surface level (Admiraal and Cornaro, 2018). Similarly, the strategies and tools developed in the context of underground planning or management need to take into account how change and learning can be integrated into the proposed processes, and to foster understanding of and cooperation across traditionally separate disciplines and stakeholders.

A lot of what is summarised in the following sections also applies to underground space outside urbanised areas; while the latter are of equal importance and manifest similar issues, the uses discussed or present often occupy much larger volumes and deeper layers of the subsurface and are, in contrast to those in urban areas, uses that could not be located above ground instead. However, the higher density of people, assets and information in urban areas makes a considerable difference to the definition and analysis of boundaries, and thus the following review and discussion are focused on urban settings.

2.3.1. Boundaries: geological setting and physical legacy

As previously mentioned, the acceptance of the geology as the baseline or starting point for any activity or intervention in the subsurface marks a change of perspective towards a more systemic approach. A criticism of the observation that geology is often related to construction costs and project risk, but seldom considered in the planning stage – for example, planners propose and set tunnel alignments and engineers only later deal with the geological risk (Barton, 2009) – is inherent to this acceptance, and has been emphasised in the recently completed research project, COST sub-urban (COST sub-urban, n.d.). An understanding of the local geology and hydrogeology, in combination with careful consideration of the human legacy present, not only enables a definition of the influence zones of different potential functions or the mapping of potentials to support planning and avoid conflicts (such as, for example, those proposed by Kahnt et al. (2015) and Doyle (2016), see Section 2.3.3.6), but also the determination of the availability of materials and water, as well as the predisposition to natural hazards such as flooding and earthquakes.

With regard to systemic integration, these functions and potentials are traditionally looked at independently, and the influences they have on each other are only analysed for specific interactions (for example, the risk of a water pipe bursting and the associated flooding for tube tunnels). Kahnt et al. (2015) list the geochemical, geomechanical, geohydrological and geothermal influences of different uses on the surrounding geology, and distinguish between local conflicts when two or more uses would occupy the same volume and conflicts that can occur inside and across layers or geological formations. Matrices of competing space claims can be found in several reports (for example ARL, 2012; Le Guenan and Gravaus, 2016). These evaluations are based on technical and geological knowledge rather than being scenario specific; they are also based on current knowledge and thus their relevance for decision making might change with evolving technologies or city visions.

The necessity of understanding the geology, and the legacy and influence of human interventions – that is, constructions as well as contamination, man-made ground, or altered water flows – as a baseline rather than as part of the environment to be analysed in the context of specific tasks or projects, is expressed throughout the literature, and governmental initiatives indicate a change of paradigm. As a consequence, tools and strategies for data collection, management and modelling are being developed. The ensuing challenges mainly concern data management and provision, as well as the interpretation of the data and models to identify potentials, conflicts or threads (Schokker et al., 2016; Watson et al., 2017).

2.3.2. Boundaries: legal and institutional settings

Similar to the geology, the legal environment, coupled with the relevant institutions, arguably constitutes a local baseline or starting point for the planning and management of the subsurface. Whereas the tools for data collection and modelling are of a technical nature and transferrable between locations, conditions for data management and sharing are determined by the legal and cultural environment, and thus differ from country to country as well as among cities. The legal and institutional environment is diverse and includes planning law as well as other areas of law that relate to subsurface management, such as mining, water, energy, infrastructure, or environmental protection (see, for example, von der Tann et al., 2018a). In addition, the local governance regime, and evaluation of it, strongly depends on the visions and development objectives set in local, regional and national socio-economic strategies, and is embedded in the local culture. These strategies need to be considered as they influence strategic decisions such as the prioritisation of specific functions over others.

A comprehensive overview of legal aspects would go beyond the scope of this chapter, but the question of ownership and registration of subsurface space is recurrent and shall briefly be mentioned. Commonly, countries' laws tend to distinguish between the space and its content, such as mineral resources or archaeological findings (Sandberg, 2003). Who owns the land and who has a right to use it, and the resources it contains, are not necessarily linked. For example, whilst the land (or volume) is often owned by the surface land owner, the minerals may be owned by the state, who would also be the authority that gives consent for exploitation (De Mulder et al., 2012). Utility companies do not usually own the space where their pipes and cables are laid, but they do own the assets and have a right to use the space (typically, by law, in public rights-of-way and by easement across private land). In many countries, the law stipulates that who owns the surface also owns the subsurface 'to the middle' of the earth, thus arguably preventing, or at least complicating, the adoption of more systemic approaches to space allocation. In a few countries, the ownership of land is restricted to a specific depth or specific functions. In the currently prevailing understanding of ownership, the possibility of establishing different ownership models relies on the development of 3D cadastres, as for example discussed by Kim and Heo (2017) for the case of Korea. The current efforts to establish a masterplan for Singapore (see von der Tann et al., 2020) show the significance of having coherent datasets about the geology and existing underground assets (Section 2.3.1), as well as establishing coherent ownership and use models.

2.3.3. Approaches for planning and management: strategies and tools

Whilst the understanding of geology and legal settings as a baseline appears self-evident in a systems approach, a second underlying assumption in the literature might be less obvious: the allocation of the task for better management of the subsurface and all its diverse uses to the urban planning discipline or, vice versa, that the realm of urban planning should involve the subsurface, or at least build awareness of the subsurface and its importance for the city. If planning is defined as the institutionalised 'process through which a vision, actions, and means for implementation are produced that shape and frame what a place is and may become' (Albrechts, 2004, p. 747), this directly connects the idea of the subsurface with place making and, therefore, with the surface and how people use the urban space, increasing the complexity of the problem area.

2.3.3.1. Strategies: masterplans

Masterplans have been mentioned as a desirable tool or strategy for subsurface management by various authors. They have, in particular, been promoted by Bobylev (2009), and authors often refer to the cases of Helsinki (Bartel and Janssen, 2016a; Price et al., 2016; Sterling et al., 2012) or Montreal (Delmastro et al., 2016; Durmisevic, 1999) when suggesting that masterplans for underground space or including underground space are needed. The Helsinki underground masterplan sets out the allocation of underground space for a variety of public and private developments for the whole city; its establishment was practicable due to the fact that the bedrock under Helsinki is well suited for tunnelling (Vähäaho, 2014). Montreal developed an extensive pedestrian network underground (Boivin, 1991), the main driver being described as the severely cold climate in winter as well as the strategic aim to create a compact city with combined transport systems (Durmisevic, 1999). Other cities that are frequently mentioned in this context are Singapore (Zhou and Zhao, 2016) and Hong Kong, for both of which the scarcity of land is described as a main reason for exploring and managing underground development opportunities (e.g., Delmastro et al., 2016; Price et al., 2016; Sterling et al., 2012). Zhao et al. (2016) list eleven Chinese cities that in some way integrate underground space in their masterplans.

In general, the term 'masterplan' can be associated with a variety of meanings. With reference to the example of Helsinki, Delmastro et al. (2016) describe masterplans as documents guiding the allocation of space specifically for construction, integrating a map of existing and future facilities, safeguarded volumes and routes, as well as technical requirements. They emphasise that both long term underground masterplans as well as sectoral plans for transportation, leisure and commerce, and technical systems are needed. Similarly, Zhao et al. (2016) describe masterplans for underground space as 'planning for systematic development and utilization of subsurface space in urban areas' (p. 292), with a focus on the arrangement of underground structures. Underlying this idea are zoning plans which reflect a specific understanding of planning as present in some, but not all, national planning systems (see Newman and Thornley, 1996). Bobylev (2009), by contrast, writes about masterplans that go beyond the allocation of engineered structural interventions alone, being strategic documents that specify design principles and concepts to guide change and development in a city as a whole. These are different to zoning plans, as previously described, as well as to site development masterplans that deal 'with a specific property development proposition' (Bell, 2005, p. 85). In particular, Bobylev (2009) emphasises the importance of sustainability considerations in these documents and describes how a consideration of the subsurface, including all of its potential functions rather than only engineered structural interventions, can contribute to achieving these goals. The actions necessary to achieve an integration of the subsurface, as laid out in these high-level planning documents, are summarised in Bobylev (2009) as follows:

a. Understanding the baseline (geological model, three-dimensional mapping)
b. Prospective planning (establishing needs, risks and benefits for potential uses)
c. Assessment and analysis (vulnerability, scenarios, weighting of different uses)
d. Decision-making (integrated assessment, analysis of potential conflicts, priority setting).

While this list includes many aspects of systems approaches as summarised in Section 2.2.2, review, monitoring or learning are not mentioned in Bobylev (2009). Scenarios are mentioned as being directed at specific selected solutions rather than serving the development of the city as a whole, and cost-benefit-analysis is listed as the prime tool in the context of identifying the need for underground structures and developments. As a tool, masterplans were criticised in the 1970s as being too static, and the question was raised as to whether they could answer impending questions in a timely manner. Cooper et al. (1971) pointed out that a masterplan 'can be regarded as one form of systems approach' (p. 401), but added for further consideration that this might 'rest on a methodology and an associated point of view which are not adequate for dealing with an increasingly complex and dynamically changing urban scene' (p. 401). Since then, however, views have changed, and the term is now used for a variety of strategic documents. For example, Amirtahmasebi et al. (2016) emphasise that a masterplan has to be understood as a 'dynamic long-term planning document that provides a conceptual layout to guide future growth and development' (p. 18), and that it is important to be able to change the plan based on changing conditions. Consequently, whether master planning can be referred to as a systems approach – with the masterplan as the corresponding tool – cannot be answered generically, but depends on the specific masterplan and how it is designed, established and monitored.

2.3.3.2. Strategies: circular process approaches

Rather than focusing on the resulting plan and what it should entail, the Deep City Project, as first described by Parriaux et al. (2007) and further elaborated on by Li et al. (2013a, 2013b) and Doyle (2016), introduces a process for the development and ongoing improvement of a strategic plan for the sustainable management of what they call underground resources. The process emphasises the role of the four resources of groundwater, geothermal energy, geomaterials and space for urban development, and gives prominence to the idea of combined use of the same volume for various functions. Li et al. (2013a) describe a general process of plan-making in two strategic (policy making and criteria framing) and four operational steps (data collection, mapping of resource and development potentials, project evaluation and decision analysis), where policy making is the last step and leads back to a revision of the criteria set in order to evaluate the success of the overall process. Apart from the circularity, the approach also emphasises stakeholder involvement at various steps of criteria framing and indicator weighting. In that sense, the general vision of the particular city looked at is taken into account, and it is accepted that not every city might need an underground-specific plan. Li et al. (2013a) develop an 'applicability score' – a method of assessing whether a particular city requires management of the underground, building on estimates of supply and demand of the four resources, and considering driving forces as well as a classification of the available information. In the Deep City method, the collection and analysis of the data previously described as forming the physical baseline is part of the circular process, and it is thus accepted that technology and data needs might change. However, the categorisation of the contribution of the subsurface to the urban physical environment in terms of the four resources remains unquestioned.

Asset Management of the Subsurface (AMS), a method still under development, described by Maring and Blauw (2018), also distinguishes between the strategic and operational level. Instead of focusing on the subsurface as a manageable space and building on a pre-defined set of categories, Maring and Blauw (2018) suggest understanding all structures not only in the ground, but also the ground itself and the services it provides, as assets, and to apply methods of asset management. The definition and importance of these assets can change with the challenge in question. The strategic step in this method is described as an evaluation of how the subsurface can contribute to the achievement of a city's visions and objectives. By doing so, the method emphasises that how the subsurface may or may not optimally be used is not independent of overarching policy ambitions. The three other steps are: (1) preparation of an asset management plan; (2) implementation; and (3) maintenance and evaluation. Basing their approach in a framework that is already applied in practice (asset management), Maring and Blauw (2018) aim to reduce the threshold of the acceptance of the need to integrate the subsurface in a variety of municipal considerations. However, they also point out the challenges of implementing the necessary adjustments to the standard asset management approach in order to enable the consideration and maintenance of functions rather than objects, alongside the change in time-spans that would need to be taken into account.

2.3.3.3. Strategies: decision support system for social acceptance

Building on the theory of decision making, particularly multi-criteria analysis and decision approaches rather than planning theory, van Os et al. (2017, 2016) explicitly describe a decision support system for planning decisions regarding subsurface activities. The modular evaluation method for subsurface activities (MEMSA) is focused on the social acceptance of the various activities possible and on the dimensions of the decision-making process, with the aim of shifting the focus away from pure profitability considerations to the integration of the community through transparency and participation. In a first step, MEMSA builds on an evaluation of potentials and their relationship to concurrent or sequential uses in a specific geological volume. Importantly, this also includes the options of doing nothing now, or even never doing anything. Consequently, project acceptance is scored separately in three categories: market acceptance (investment behaviour, risk perception), social political acceptance (contribution to policy objectives), and community acceptance, which scores are then combined in a final ranking.

Given that MEMSA is directed more at large scale, deep subsurface activities, van Os et al. (2017) emphasise that for successful project implementation, policy goals need to be re-evaluated on a regular basis 'to account for timing discrepancies between the realization of activities and policy deadlines, because this discrepancy can have a large impact on the necessity and therefore acceptance of subsurface activity' (p. 97).

No other, similarly comprehensive approach to weighing the different potential functions in a specific location could be found in the reviewed literature. However, multi-criteria decision making approaches that rank possible alternatives by assessing a range of parameters, including stakeholder views and cost-benefit considerations (Kabir et al., 2013), have been applied to subsurface related functions (see, for example, van Os et al., 2016).

2.3.3.4. Tools: stakeholder engagement

In their technique, System Exploration of the Subsurface, Hooimeijer and Maring (2018) provide a method for knowledge exchange between practitioners focusing on a specific project area. Their aim is to unify the perception of the surface and the subsurface, and ultimately integrate the subsurface into established urban design processes. The authors distinguish between four categories of subsurface use with the intention of integrating a large range of ecosystem services into a limited number of categories deemed useful for the urban design process: civil constructions, energy, water and soil. Hooimeijer and Maring (2018) understand their approach to be based on systems thinking and complexity theory, dealing with 'inherent unexpected behaviour of agents' (p. 4). The tool itself consists of a matrix with subsurface use categories on the X-axis, and what the authors define as *layers of planning* on the Y-axis (people, metabolism, public space, infrastructure and subsurface). The tool is used in workshops with groups of specialists to explore the influences and interdependencies of these categories in each of the planning layers. Even if emergent properties of the system itself are not studied, the method supports knowledge exchange and provides a thinking framework in which unknown synergies or problems can emerge, in addition to facilitating the alignment of the overall project objectives and integration of further steps.

2.3.3.5. Tools: potential maps

For the second operational step of the Deep City approach (see Section 2.3.3.2), Li et al. (2013a, 2013b) and Doyle (2016) present maps of potentials specifically for construction (Li et al., 2013b), and for the four resources (Doyle, 2016). Li et al. (2013b) develop evaluation criteria for different depths and explore their relative importance for the evaluation of resource demand and supply, in cooperation with local professionals. Doyle (2016) extends and refines the method for evaluating and mapping potentials, with the aim of shifting the understanding of the subsurface from a resource or place that can satisfy urban needs to a potential that can be explored in the process of urban planning (Doyle et al., 2016). Doyle (2016) points out that the generation of these maps involves primary data gathering as well as the assignment of resource related characteristics to the geological formations present. In a second step, surface data are included to assess the suitability of actual resource exploitation and inform the planning process.

Potential or suitability maps have also been used in other contexts. Hooimejer and Maring (2018) introduce a kind of potential map in which, rather than showing what could be used in the area looked at, for a specific area or site they overlay different information layers which illustrate the impact of subsurface assets on the surface. These maps are intended as an interactive tool or design guideline for an urban designer, and focus on comparatively small areas rather than the city as a whole. Wassing and van der Krogt (2006) developed a set of suitability maps to assess the suitability of an area for building a specific kind of development. The maps are based on geotechnical, geochemical and geohydrological properties of the ground which are, in a second stage, weighted according to how they would influence future scenarios. The authors mention that the weighting is 'somewhat arbitrary and subjective' (p. 3), and that the relevance of geological as well as socioeconomic aspects will rely on the perception of the respective planner and project they have in mind.

Potential maps appear to be a valid tool for communicating information traditionally held in the technical disciplines to the planning and design disciplines. However, it is important to be aware that such maps are based on a previous definition of what 'potentials' are deemed to be, i.e., a decision as to what is being mapped. Suitability maps for specific sites or areas respond to specific demands, or are created as support tools for specific decisions. All of these tools produce an additional set of information to allow an intuitive use of technical subsurface information in the planning or design process.

2.3.3.6. Tools: scenarios

As can be seen with the potential and suitability maps described, there have been attempts to look at what the ground could provide (supply), and those which focus/start from looking at the need (demand). While the latter rely on methodologies to predict or foresee the future, the former attempts can change depending on urban development and climate change, and thus require constant updating. In planning strategies, both supply and demand need to be balanced, with an outline as to how these will be determined.

Different to forecasting, scenario approaches aim to provide a set of possible futures which can be compared and assessed so as to inform decisions. They can be applied at different scales and with different focuses. In the context of subsurface planning, as previously described, Wassing and van der Krogt (2006) use scenarios to assess the relative importance of different geological parameters for specific developments. Hooimejier et al. (2017) design subsurface related 'provoking scenarios' – extreme design solutions to current planning tasks – and challenge groups of practitioners in workshops to concretise these scenarios in an explorative manner in order to create a feasible vision for a city area. Rather than providing a concrete solution to a specific task, here, the possibilities and relationships are explored and cross-disciplinary conversations are fostered. Rogers (2018) presents an assessment approach for engineering interventions in cities, whereby a) the aspirations that the city and its citizens associated with the intervention are tested through the development of contrasting of future visions; b) interventions are tested in the current situation as well as in the context of four extreme future scenarios; and c) alternative business models are assessed for implementation. While this approach does not focus on subsurface interventions, it is particularly relevant in view of the longevity of these interventions.

2.3.3.7. Valuation

Commonly, engineering interventions in the subsurface are assessed using cost-benefit-analyses (CBA). In these analyses, and particularly in the case of underground infrastructure, it has proven difficult to equally account for the initial capital cost and the long term social and environmental benefits (ITA, 2004). No explicit market for underground space exists and, consequently, other ways of assessing its value are needed (Pasqual and Riera, 2005; Qiao et al., 2019).

The problem of value capture for projects or services whose values cannot simply be translated into monetary units is not unique to subsurface space management. De Groot (2006), for example, developed a method for the comparative analysis and valuation of different land use functions, and new terms like social value (e.g., Frischmann, 2012) or social return on investment (e.g., Lingane and Olsen, 2004) have gained importance for a variety of decisions regarding the built environment.

Related to the urban subsurface, Coogan (1979) developed a valuation scheme for subsurface developments including nine parameters: need, scarcity, substitutability, duration of change resulting from use, rate of change once the use has begun, primary impact on the surrounding area, secondary impacts on the latter, revocability of the decision for a particular use once the commitment is made, and the need for an orderly decision on use prior to commitment. In terms of more specific functions, Lim et al. (2016) evaluate the public value of soil remediation in Korea, and Matthews et al. (2015) assess the social cost of pipeline infrastructure by presenting case studies in the US and Belgium. Maring and Blauw (2018) recommend referring to methods that have been applied to ecosystem service valuations, and provide an overview over these methods. Applying one of these techniques, namely the replacement/restoration cost method, Qiao et al. (2019) present an analysis of socio-environmental losses derived from using urban underground space. Their approach is interesting insofar as it is the only study explicitly acknowledging that any subsurface intervention comes with a loss of other potential functions.

Instead of assigning monetary value equivalents, multi-criteria decision frameworks aim towards the integration of CBAs with other relevant criteria for project or intervention decisions (Kabir et al., 2013) (see also Section 2.3.3.3). Whilst these approaches support specific project decisions, a more general understanding of the value of the subsurface to various aspects of urban life – including, for example, precautionary measures to protect against natural disasters – and systemic approaches that are able to assist with the evaluation of different options for specific projects or locations as well as overarching planning objectives, have yet to evolve (Bricker et al., 2019).

2.3.3.8. Benchmarking and comparison

As mentioned in the introduction to the current section (2.3.3), there appears to be an underlying assumption in the literature about integrating the underground or subsurface into urban planning strategies. These strategies are often informed by urban indicators that can be used for comparison purposes between cities as well as for longitudinal studies by measuring the development of indicators over time. The subsurface is not currently covered by the established indicator schemes (Bobylev, 2016). Bobylev (2016) proposes a list of underground space related indicators for inclusion, including whether regional planning is taking into account the geological and hydrogeological setting and quantitative measures of underground space use. Admiraal and Cornaro (2018) emphasise that underground space functions contribute, or can contribute, to seven of the 16 sustainable development goals set by the United Nations (UN General Assembly, 2015). However, the correlation of these indicators with other indicators for overarching objectives like sustainability or resilience could not be shown, and thus requires further investigation.

Indicators provide one way of benchmarking the development of a city in a specific topic area, and comparison with other cities can provide valuable insights for policy makers. For the development of the masterplan for Singapore, the Urban Redevelopment Authority of Singapore commissioned a benchmark study about underground developments (Urban Redevelopment Authority (URA), 2018) to learn about underground planning efforts worldwide. The already mentioned COST action (COST sub-urban, n.d.) supported short-term missions through which two cities could engage in direct exchange about specific subsurface related topics. However, while several publications cite specific aspects of underground related aspects of the planning regime (e.g., Li et al., 2013a) or specific parameters (e.g., Bobylev, 2016) for several cities, in-depth comparisons between two or more cities are lacking in the literature.

2.3.3.9. Summary

The strategies and tools discussed here present processes or methods to enable decisions, either regarding what the accessible ground volume should be best used for, how to resolve a present problem affecting subsurface use in a holistic manner, or how involving the subsurface can help overarching strategic aims. In each of these, a classification of use-categories is applied that consequently feeds into a management strategy, and a series of consecutive steps necessary to achieving the set objective is described. A few elements stand out that appear in several or all of the described frameworks or methods, and can be linked to the elements of systems approaches summarised in Section 2.2.2, as follows:

a. The main objectives are the spatial allocation of structures as well as raising awareness of services the ground provides, for some of which the limits of the spatial location is less clear (**purpose**).
b. Three-dimensional mapping of geology and present assets is necessary to serve as a baseline for models and decisions (**baseline**).

c. Subsurface use is classified in categories such as services, resources and resource potentials or assets, and a link between the geological formation and the chosen classification is established to assess the potential for allocation (**integration**).
d. Scenario analysis is applied to understand and compare different possible pathways. Other future methodologies are not explicitly mentioned (**future thinking**).
e. The described processes involve continuous learning and are depicted as circular rather than linear (**continuous learning**).

Despite the fact that some of the reviewed approaches work with stakeholders, this appears to be mostly for the purposes of integration and the understanding of boundaries, and it stands out that none of the approaches discuss empowerment and inclusivity. As has been mentioned, in most of the reviewed approaches there is an underlying assumption that the realm of urban or spatial planning should be extended to involve the subsurface, or at least be made aware of the subsurface and its importance for the city. However, as will be shown in the next section, the classification of use-categories mainly stems from the realm of natural and environmental resources or services. To gain a better understanding of the rationale behind these assumptions, the following section reviews the various approaches to subsurface categorisation that do exist, but are rarely explicitly discussed in the literature.

2.4. Categories of subsurface use

To express the importance of the various uses of the urban subsurface for human life, authors use different terms to distinguish between categories of use or spatial delineation that can subsequently be described, evaluated, harnessed, or discounted. From the perspective of systems thinking, the terminology used defines the distinction between the elements of a system (internal boundaries) and their role in the system itself (von Bertalanffy, 1968), and thus plays an important part in the discussion of any system considered. On a more practical level, classification systems can, for example, build the basis for the creation of datasets (see Frith et al., 2017; Fu and Cohn, 2008). Even if not mentioned explicitly, the necessity of establishing a classification system is inherent in much of the literature about urban underground space (UUS). Following a brief introduction to classification in general, categorisations of the subsurface as proposed in the literature will be reviewed in the subsequent sections.

2.4.1. Classification – background and principles

Shared terminology is the basis for the communication of knowledge, and the need to ensure the consistency of conceptual frameworks within any discipline or field of knowledge leads to a degree of formalisation (Bjelland, 2004). It is a 'necessary step to develop a science' (Ostrom, 1998). In this process, individually held mental concepts become concretised (Ahlqvist, 2008; Bjelland, 2004). Thus, a negotiated classification system will embody the worldview of the people involved in its generation (Bjelland, 2004) and, as such, any classification can only represent a limited reflection of the social or natural world (Bowker and Star, 2000). As has been pointed out in Sections 2.2.1 and 2.2.2, the acknowledgement of different viewpoints and worldviews is central to systems approaches. Discussing terminology and classification should be an integral part of new approaches, as the establishment of a classification system always carries the risk of silencing another point of view (Manakos and Braun, 2014). While it has been posited that "to classify is human" (Bowker and Star, 2000, p. 1), and offers a way of facilitating the communication of knowledge between a range of individuals (Bjelland, 2004), it is important to be aware of the former limitation. In addition, classification systems can be difficult to change once established and may thus not be suitable for, or even constitute a barrier to, change (Ahlqvist, 2008).

Classification has been defined as 'a spatial, temporal, or spatio-temporal segmentation of the world' (Bowker and Star, 2000, p. 10), whereby a classification system consists of categories into which the described world or entities can be divided. These categories, their definition and delineation provide the basis for analyses as well as communication. An ideal classification system has three main properties (Bowker and Star, 2000; Duhamel, 2009). First, it is complete, meaning that no element in the described entity exists that cannot be assigned a category. Second, no overlap between categories exists; thus, in an ideal system, each element would only be assigned to one category and this assignment would be unambiguous. Lastly, the ideal system builds on consistent rules and principles for the identification and naming of categories as well as for the exclusion or inclusion of objects.

Whilst it might not be possible to meet the requirements of an ideal classification system (Bowker and Star, 2000) and overcome the limitations described, these points provide a background for discussing the classifications proposed in the literature and the ontological and semantical diversity needed for the analysis and management of strategies for the urban subsurface.

2.4.2. Categories in land-use planning

Given that the need to manage the subsurface more systematically is often discussed as a need to integrate the subsurface into planning efforts (see Section 2.3.3) (Bobylev, 2009; Parriaux et al., 2007; Sterling et al., 2012), it seems imperative to consider the way in which land uses are categorised and how that relates to subsurface uses. In the context of land use planning, a distinction is made between land cover and land use, the former describing the material – the observed, biophysical surface – and the latter describing the function, that is, the human use of and impact on that surface (Lambin and Geist, 2006). It should be noted that in this categorisation existing constructions are understood as land cover, whereas specifications such as 'residential' define a land use (Young, 2000). Whereas the definition of land cover is usually restricted to the surface, land uses can extend above and below the surface if the geographical location is the same. For uses that extend across wider areas below the surface, such as deep mining, only their impact at ground level is recorded as land use (Duhamel, 2009; Harrison, 2006).

There is no singular internationally agreed classification system for land use (FAO, 2005); however, classification techniques – i.e., the classification system itself combined with the technology or method used to survey and map land use – have attracted a considerable amount of research (see, for example, review in Congalton et al., 2014). Established classification systems, such as that defined for the National Land Use Database in the UK (Harrison, 2006), are shaped by their specific purpose and build on underlying value systems (Duhamel, 2009). Consequently, while multiple systems exist, the setting of clear principles for the naming, identification and elicitation of the purpose or justification of specific classes and categories, as well as how they are organised, appear to be part of the classification process.

2.4.3. Classification of subsurface volumes

A similar distinction to the one made between land use and land cover can be applied to subsurface space or volumes, which is already implicit in the literature, but not usually referred to in this way. On one hand, there exist descriptions of the subsurface content, describing the materiality and properties of the subsurface volume at a given moment in time. This is largely equivalent to the geology, for which established classification schemes exist. However, whereas in non-urbanised areas the geology and assigned properties constitute the subsurface content, in urban areas, particularly at shallow levels, man-made assets can occupy a major proportion of the volume available (see also Chapter 4, Section 4.3). On the other hand, the literature describes subsurface uses or functions, categorising the ways in which humans utilise subsurface volumes. This distinction is similar to what Coogan proposed in 1979 when he distinguished between physical aspects (particle dependent space and particle independent space) and artificial space (man-made, transparticulate, need specific) on the one hand, and uses (where subsurface space is useful for humans) of natural and artificial space on the other hand (Coogan, 1979).

Table 2.3 provides an overview of the categories of subsurface space use proposed in the literature. Classifications by depth, which can be a method of assigning different depths to the appropriate level of administration (van Campenhout et al., 2016) or, respectively, of allocating specific uses to specific depths (Zhang et al., 2017), are not listed.

In the top columns, function or activity are used as overarching terms, which are here accepted as equivalent to use. What stands out here is that a lot of authors apply *use* or *function* to refer to developed space only, that is, man-made structures and converted natural cavities, and functions that are or could be developed in these structures. The majority of these functions could also be placed on the surface, with the corresponding categorisation systems being comparable to use classes in the UK planning system, particularly if utilities are not included. As listed in Table 2.3, De Mulder et al. (2012) integrate the functions of subsurface developments with the natural geology functions or services, like storage and bearing capacity. Bartel and Janssen (2016a) as well as van der Gun et al. (2016) shift the focus entirely to these natural functions. Bartel and Janssen (2016a) propose a classification that takes the direction and finality of material movement from or into the subsurface into account, whereas van der Gun et al. (2016) distinguish between extraction and use, and focus on the interactions of functions with groundwater which, in their opinion, is particularly vulnerable to pollution and depletion. These examples show that the classification systems in the literature differ considerably with regard to detail and depend on the particular purpose of study. However, in order to constitute complete classification systems, it is necessary to introduce an extra category of no use, referring to temporary preservation for future use or complete exclusion of use (see Section 2.3.3.3, van Os et al., 2016).

Another set of classifications listed in Table 2.3 aim to cover the whole of the subsurface volume and refer to the resources or services that the subsurface is seen to provide by a range of authors. The concept of underground space as a resource was brought into awareness by the UN Committee on Natural Resources in 1983. A resolution requested the Secretary to examine the issue (United Nations, 1983) and, subsequently, a progress report was prepared which highlighted 'the potential of that little-used resource' (United Nations, 1985). The

Table 2.3: Classification of Underground Space Use

Classification by	Categories	Specification	References
Function of developments*	Infrastructure	Underground traffic facilities and underground utility tunnels	Bobylev (2009) Kim and Heo (2017) Nishi et al. (1990) Zhang et al. (2011)
	Buildings and structures	Entertainment/cultural facilities, retail, religious centres, office space, production and processing facilities, etc.	
	Storage	Goods, oil, gas, chemicals, waste, energy, ground water	
	Other uses	Disaster prevention, burial, other space	
Function	Source of natural resources		De Mulder et al. (2012)
	Storage of materials (solid, liquid, gas)		
	Space for public and commercial use		
	Space for infrastructure		
	Medium for construction foundation		
	Component in life support systems		
	Archive of historical and geological heritage		
Function	Storage	Natural gas/oil storage; storage of H2, compressed air	Bartel and Janssen (2016a)
	Deposition	Carbon capture and storage; underground waste disposal including storage of radioactive waste, brine injection	
	Productive activities	Mining; use of geothermal energy; storage of heating and cooling energy; utilisation of springs and groundwater	
	Underground structures	Tunnels, technical structures; underground pumped hydro-electric power plants	
Human activities	Groundwater development and management	Groundwater withdrawal for different uses; drainage of excess shallow groundwater; managed aquifer recharge	an der Gun et al. (2016)
	Mining	Extraction of minerals, coal, lignite, building materials, etc.	
	Geo-energy development	Oil and gas development; high-enthalpy geothermal energy development; low-enthalpy geothermal development	
	Disposal and storage of hazardous waste	Waste disposal by deep well injection; carbon capture and sequestration; subsurface storage of radioactive waste; nuclear weapons testing and nuclear power accidents	
	Injection and recovery	Solution mining; injecting residual geothermal fluids; temporary heat storage; storage of hydrocarbons and fluids associated with oil and natural gas production; hydraulic fracturing or 'fracking'	
	Construction in the underground space	Pipelines, sewerage systems and cables; tunnels and underground railways; underground car parks and other underground constructions	
Resource	Groundwater	Drinking or industrial purposes	Introduced by Parriaux et al. (2007), referred to by e.g., Doyle (2016), Li et al. (2013a)
	Space	Place for building and infrastructure construction	
	Geothermal energy	Shallow and deep geothermal energy	
	Geomaterials	Mainly issued from underground excavations	
Categories captured in spatial planning systems	Civil Constructions	Archaeology, explosives, buildings, cables and pipes, carrying capacity	Hooimeijer and Maring (2018)
	Water	Infiltration, storage, drinking water	
	Energy	Aquifer and underground thermal energy, geothermal and fossil energy	
	Soil	Clean soil, soil life and ecology, crop capacity, diversity and geomorphology, mineral resources and underground storage	
Ecosystem service	Provisioning services	Fuel, fibres, food	Millennium Ecosystem Assessment (2005), platform services for soil added by Rawlins et al. (2015)
	Supporting services	Nutrient cycling, soil formation	
	Regulating services	Water purification, flood mitigation	
	Cultural services	Aesthetic, spiritual and recreational functions	
	Platform services	Bearing capacity, electrical earthing potential	
*The categories by function of developments vary between the different authors. Listed categories are examples.			

report was taken note of by the committee, but no further action followed. In particular, two papers by Parriaux et al. (2007) and Bobylev (2009) established the association of urban underground space with different resources: space and materials as non-renewable resources, and water and geothermal energy as renewable resources.

The term resource is intrinsically linked with the notion of exploitation or use by humans, as well as with the discipline of economics and management. In system terms, a resource is a 'stock' that feeds into the system and can be limited (non-renewable), or have the option of being replenished (renewable) (Meadows and Wright, 2009). Analysing the subsurface as a resource acknowledges what the subsurface adds to bigger systems like the city, and illuminates aspects of environmental capacities and their limitations.

Again, a similar conversation exists with regard to the surface. Here, the connection is such that land use planning is the means to control land use change and, therewith, the degradation of the land resource. A particular property of land – and equally of subsurface volume – distinguishing it from other resources is that it stays in place or 'has location'. This implies the involvement and interest of people connected with that location in decisions about land use change (Li, 2014). In addition, that which is called land resource – the available area as such – is here seen as distinct to the resources that the land provides or can provide.

The categorisation of subsurface uses as ecosystem services is less established, with a range of classifications existing for ecosystems themselves. The fifth category of platform services proposed for soil by Rawlins (2015) appears not to have received attention in the ecosystem service literature thus far. Hooimejier and Maring (2018) reject the notion of ecosystem services as not being practical for urban design and planning, which then raises the question of how these two classifications can be purposefully connected; however, Maring and Blauw (2018) refer back to ecosystems as a reference point for potential valuation methods. Referring to management approaches more generally, Maring and Blauw (2018) propose describing the subsurface, the embedded structures and the ecosystem services it provides as assets (see Section 2.3.3.2). This terminology has also been used by Li et al. (2013a) in the context of creating an inventory of the four underground resources described above, as well as by Clarke et al. (2017), who develop a decision support system focussed on under-road utilities.

Coherent with the generation of potential or suitability maps (Section 2.3.3.5) as well as the valuation scheme developed by Coogan (1979), some authors distinguish between the classification of a potential of a given volume or geological formation and the suitability of its use for a specific purpose. For example, Rönka et al. (1998) describe the classification of rock masses under Helsinki in terms of their general feasibility for construction on the one hand, and their suitability for the actual use, integrating accessibility and restrictive factors like the protection of groundwater levels on the other hand. In addition to the classification of subsurface functions as ecosystem services, Price et al. (2016) propose a second classification of the given space or volume, namely, as describing the suitability of the volume in question for a planned use. The potential techniques for evaluating suitability for different functions, however, are not further discussed in their paper. To evaluate the suitability for exploiting the different resources, Doyle (2016) adds and maps out categories of surface-related data, such as accessibility or existing groundwater protection zones (see also Section 2.3.3.5). As such, understanding the basic categorisation of subsurface use or functions as summarised in Table 2.3 is only the first step, and an integration of the terminology will be necessary not only for these basic functions but also for related parameters.

2.4.4. Summary

This section summarised the range of subsurface space and use classifications mentioned in the literature. Overall, it becomes apparent that all of the classification systems reviewed aim to describe the current or potential use or utilisation of the subsurface for human needs, or relate to the administration and management of spatial volumes to accommodate these needs and prevent use conflicts. In particular, when referring to terms like *resources* or *services*, the subsurface and its utilisation is described as input into a bigger system – the city or society as a whole, but also bearing a human-centred utilitarian aspect. The section shows that despite classification being proposed in several papers, there appears to be no discourse about the question of which of these classifications and umbrella terms are the most feasible, the rationale they entail, or their meaning in the context of public policy and the integrated planning approach they promote. Zhang et al. (2017) make an initial effort to encourage such a discourse by discussing classification options and clearly stating the purpose of their suggestion as a classification system that allows registration in a 3D cadastre and definition of property rights. A similarly clear statement of purpose can be assigned to feasibility or suitability studies (see Section 2.3.3.5), as assessing the feasibility or suitability of a volume for a specific use could be seen as a purpose in itself, but is omitted in most of the remaining literature.

2.5. Discussion and problematisation: spatial planning, resource management and systems thinking

The latter two sections have reviewed approaches for holistic subsurface management and underlying categories. Within these, two sets of terminology relating to particular conceptual framings are jointly used. On one hand, authors claim the subsurface should be looked at with regard to the benefits it can provide for humans, which can be mapped and extracted – the *resources* or *services*. On the other hand, it is claimed that the subsurface should be integrated into *spatial planning*, or that the realm of spatial planning should be extended to include the subsurface. This link is not unexpected; in his seminal paper 'The Tragedy of the Commons', Garrett Hardin described the problem of the overgrazing of land if access is not managed (Hardin, 1968) – a problem that can be associated with the planning or regulation of land use and, therewith, space. The scarcity of land in the urban realm, thus, often provides grounds for the claim that underground space needs more consideration (Kim and Heo, 2017; Tkachenko et al., 2015) or, looking at it the other way around, that above as well as below ground uses should be included in land use considerations (Duhamel, 2009).

The process of spatial planning has been institutionalised through a system of 'ruled relationships, roles, and functions' (Pasqui, 1998, as quoted by Sartorio, 2005, p. 26), which has been established in a local context to balance public interests, private property rights, and public participation (McAuslan, 1980). Spatial planning is embedded in local institutions and policies, as well as in values and culture, which makes it an inherently political and location-specific discipline. In addition to addressing local political and public demands, city planners are challenged to respond to increasing economic competition (Newman and Thornley, 1996).

By contrast, the management of natural resources has been mostly discussed from an economic perspective. Activities around geological and biological resources form the subject of natural resource management and economics, which is part of the wider discipline of environmental economics (Sterner, 2003). The Oxford Dictionary defines natural resources as 'materials or substances occurring in nature which can be exploited for economic gain' (Lexico, n.d.). Extending the focus from economic gain to a more general understanding of value, Bridge (2009) calls resources cultural categories 'into which societies place those components of the non-human world that are considered to be useful or valuable in some way' (p.1219). Whether subsurface space can be, or should be, looked at as a resource through this lens has not been explored in depth.

Similar to surface land, subsurface space combines the properties of renewable and non-renewable resources. On one hand, the availability of land for human use or exploitation is comparatively fixed (Hart et al., 2013) whereas, on the other hand, biophysical processes and anthropogenic systems and economies continuously alter the actual use of particular land parcels or areas (Johnson, 2017). Li (2014) points out that compared to geological and biological resources, land (i) cannot be moved and (ii) the use of land in many cases depends on exclusion. With this in mind, the question arises as to whether the space and the resources or services it embeds are primarily considered to be a means of generating economic value or income, or assets that have to be protected (Primmer and Furman, 2012, referring to Hukkinen, 1998). The concept of 'services' here broadens the perspective from the concept of particular resources to the management of 'ecosystems' – systems formed through interactions of living organisms with elements of their non-living environment (Scarlett and Boyd, 2015).

The link between spatial or land use planning and natural resource management is such that, for its part, land use is considered to be the root cause of environmental degradation (Jones et al., 2013), while land use planning is seen as a government means to control land use and, thereby, facilitate natural resource management (Mitchell et al., 2004) and resolve potential disputes about land uses (Cullingworth et al., 2014). Human wellbeing depends on the provision of essential services like food or water (Crossman et al., 2013) and human land use, especially urbanisation, influences the capacity of the world's ecosystem to provide these services (Verburg et al., 2013). Cities consume more resources than are locally available, and thus rely on resources being supplied from outside the city itself (Bai, 2007). In other words, the provision of ecosystem services in cities is decoupled from the place where they are used – food production, water and waste management are located mostly outside of the cities (Gómez-Baggethun and Barton, 2013). The environmental impact of cities is spread across a much larger area than that of the city alone (Agudelo-Vera et al., 2011), and the scale of impact of human actions can be much larger than anticipated when decisions about land use are taken (Crossman et al., 2013). Hence, the necessity of coordinating spatial requirements with the management of available and accessible resources or ecosystem services lies at the core of today's urban and land use planning.

The integration of urban planning and resource management is also described as necessary for sustainable development (Agudelo-Vera et al., 2011), and it has been claimed that a systems approach is required to achieve this (Perdicoulis, 2010). While cities have been described as *ecosystems, social systems,* and *management problems*, it has been claimed that the fragmentation of urban planning into multiple tasks and institutions persists (Orr, 2014), and that in conventional practice the temporal and spatial scope of analyses is still very narrow (Moffatt and Kohler, 2008). Thus, in order to implement a systems approach to urban planning it is essential to recognize different worldviews (Perdicoulis, 2010) and the fact that the city cannot be seen as a static entity but has to be conceptualised as constantly changing (Ross et al., 2008). It is this change that should be navigated through a shift of focus from outcome to purpose, a claim made as early as 1973 by Rittel and Webber (Rittel and Webber, 1973).

Integrating urban planning and resource or environmental management, as well as the application of systems thinking, seems to provide a basis for a better understanding of the nature of underground space and its role in the urban system; however, despite a range of approaches that have recently evolved (see Section 2.3.3), a deeper discussion of the underlying theories and comparison with related fields is lacking. Nevertheless, references to the subsurface as a resource or ecosystem service appears to be gaining acceptance amongst scholars. This notion is intrinsically linked with systems thinking (von der Tann et al., 2016). However, the resource economics literature has not been referred to in the reviewed literature, and the applicability of the relevant economic concepts – such as those relating to resource supply and scarcity, or the influences of developing an exhaustible resource stock on renewable resource flows and availability – has not been tested; likewise, methodologies used in natural resource management have not been applied.

In this context, it has to be questioned whether a chosen categorisation of the space leads to the reinforcement of a present sectoral analysis, where each category responds to a separate set of regulations and policies. In a conversation between the current author and an expert in the field, the latter once said he would approve of the four resources framework suggested by Parriaux (2007) (Section 2.3.3.2) because each of the resources would represent a different profession. This statement underpins the argument that the tendency and temptation to drop back into disciplinary niches has not been overcome, but also raises the question of whether there should be an extra level of regulation or a separate plan for the subsurface, or if increased awareness of the subsurface as a whole in related topics such as groundwater or minerals, or in disciplines like urban planning, would be sufficient. This question is not new: even when the topic was raised in the Committee on Natural Resources of the UN, 'one representative suggested that, in future, the use of subsurface space should be dealt with as an integrated part of other major topics (for example, water, minerals), rather than as a separate agenda item' (United Nations, 1985). However, it has not been explicitly discussed under which circumstances one or the other might be more applicable.

The subsurface is not the only space where the necessity of managing several resources or ecosystem services was not traditionally covered by planning regulation or dealt with under the framework of spatial planning. Until recently, marine activities were only regulated by sector and specific applications for offshore structures (Laffoley et al., 2004). Since the beginning of this century, strategies for Marine Spatial Planning (MSP) were developed to counteract the degradation of the marine environment due to human activities and provide long-term, cross-sectoral approaches to marine management (Jay, 2012). Over the last few decades, MSP has developed from being an idea to being implemented in international policies. Bartel and Jansen (2016b) mention similarities between the two subject areas, in particular the three-dimensional nature and layers of use and the non-uniform data base. The need for a cross-sectoral approach (Drankier, 2012), the valuing of ecosystem services (Barbier, 2012), and the extension from two dimensional to three-dimensional planning (Douvere, 2008) are just a few of the similarities between MSP and underground space planning that could be discussed in more detail. A comprehensive review and comparison of these two fields has not yet been undertaken.

Similar to the context of MSP, better collaboration and coordination between stakeholders and disciplines dealing with subsurface related topics is necessary (e.g., Maring and Blauw, 2018), and it stands out that no research has been carried out that captures the positions of practitioners in the different disciplines. The assumption that a cross-sectoral approach to subsurface interventions would alleviate the everyday work of practitioners has not been challenged, and the question of what such an approach would need to entail in order to do so has not been posed to experts in the different fields. Stakeholder analysis, which has been increasingly used in various disciplines (Reed et al., 2009) and become a common method in participatory natural resource management (Prell et al., 2009), has not been conducted. In the realm of the subsurface, stakeholder voices have, for example, been reported with regard to street works (Hussain et al., 2016) or water (Lienert et al., 2013), but not relating to the subsurface as an integrated entity.

Admiraal and Cornaro (2016) point out that use of the subsurface can contribute to achieving the sustainable development goals set by the United Nations (United Nations, n.d.), in particular through specific interventions like freeing surface land or providing space for flood retention. As such, the integration of urban planning and resource management, as described by Agudelo-Vera et al. (2011), requires an acknowledgement of the subsurface and its role in the planning and analysis of cities, in one form or another. Currently, the multitude of classification systems (Section 2.4) give the impression that there is still a long way to go until the integration of the subsurface into urban strategies can be sought. Of the reviewed frameworks, only Maring and Blauw (2018) explicitly aim towards incorporating systems thinking, in particular understanding the different stakeholder perspectives and the integration of change. However, they describe this shift to a systems approach as challenging. The fact that local initiatives and tailored solutions, like in Helsinki, can be very successful (see Section 2.3.3.1) gives rise to a debate about whether an overarching theory on underground space management would be feasible, and if the corresponding methodologies would be transferable.

2.6. Summary: gaps in the literature and the need for a systems approach

The previous sections introduced the principles of systems thinking (Section 2.2), and reviewed approaches to enable the integration of the subsurface in surface planning or management, as reflected and proposed in the academic literature (Section 2.3). A summary of the classification systems applied to subsurface use (Section 2.4) shows that there is no agreement yet within the field with regard to what determines the unit of analysis when discussing subsurface use or potentials.

The key gaps identified from the literature review are:

a. Despite the multitude of uses and potentials for use of the subsurface being listed, a comprehensive review of the interdependencies between different subsurface uses – spatially-physically, regarding their operation, as well as regarding the relevant legislation – is missing and will depend on the selected classification system.
b. There is, arguably, a missing discourse about the theoretical foundation for urban subsurface management, including the terminology used.
c. Comparisons with other fields of policy and management, in particular urban planning and resource management, to which a lot of the literature refers, as well as Marine Spatial Planning, have not yet been made. The appropriateness of allocating the task of subsurface management to the urban planning discipline has not been questioned.
d. Comprehensive case studies that analyse the current governance setup of specific cities are scarce.
e. Despite a multitude of approaches, practitioners' voices have not been captured and their perception has not been analysed. As such, the awareness of different worldviews appears to be limited to the description of the need for better

coordination, but does not manifest in attempts to elicit and describe these worldviews in order to enable this.

The current review has made a start to contributing to a theoretical foundation for urban underground planning and management by placing the strategies and tools suggested in the literature into the theoretical context of systems thinking. To capture the complexity of the subject area and develop meaningful approaches, more case studies including the elicitation of specific worldviews or mental models are particularly needed, alongside the development of a joint terminology. The following chapter will set out how the current thesis aims to contribute to filling these gaps, in particular providing a comprehensive case study through analysis of the governance setup around London's underground, understanding specific practitioners' perceptions of that same space and expanding these findings to a broader group of practitioners as well as to overarching theoretical and strategic suggestions.

3. Research design and methodology

The obvious, I discovered, is not what needs no proof, but what people do not want to prove.

Russel Ackoff, A lifetime of systems thinking

3.1. Introduction

The previous chapter showed that, to date, no comprehensive theoretical foundation for urban subsurface management has been established. The chapter also pointed out that, in the literature, the need for holistic approaches has been expressed repeatedly, with the most frequently mentioned position being that the subsurface should be integrated into the realm of urban planning. However, there are different ideas about what that means or how that could happen. So far, academic efforts towards integrated urban subsurface management or planning have been focused on descriptive evaluations and the evolving tools and propositions, rather than on developing an overarching (theoretical) framework for analysing and understanding current policy situations. Thus, at the beginning of this thesis stood the question of how to research and analyse the role of the urban subsurface in urban life with all of its functionality, and integrate considerations about the subsurface into project and planning decisions in a holistic way. This chapter will present the methodology employed to engage with this question, including a discussion of the emerging theoretical considerations and the mixed methods research design.

The current research and its methodology was guided by the principles of systems thinking as introduced in the previous chapter. However, even if the development of theories is inherent in the tracing and elicitation of causal mechanisms and thus forms an important part of systems thinking (Mingers, 2015), theory or framework development, as such, is not usually the explicit aim of systems research. Rather, systems thinking is drawn upon to develop theoretical considerations and frameworks applied to a range of problems, and, thus, form a part of the developed frameworks. As such, the scope of systems thinking is seen mainly as a theoretical basis on which to reflect and build on. However, as the philosophical paradigms underlying systems approaches are manifold, speaking about systems thinking without making reference to a specific research paradigm was here not deemed sufficient to comprise the methodological framework on its own. Navigating a middle ground between the main positions in research philosophy, and similar to systems thinking in terms of fostering plurality in methods and worldviews, the paradigm of critical realism was viewed as apt for the current research as it can provide 'a meta-framework for understanding the world as complex and systemic' (Gerrits and Verweij, 2013, p. 168) and, thus, arguably provides a suitable philosophical position for systems thinkers (Mingers, 2015).

This chapter starts by providing a description of the critical realist position adopted in the current thesis (Section 3.2). This description, in combination with the concept of systems thinking, provides the basis for the research design (Section 3.3), as well as the specific methods applied (Section 3.4); namely document review, in-depth interviews and a questionnaire. The following sections provide reflections about research validity (Section 3.5) and researcher positionality (Section 3.6). The chapter is concluded with an overview over the methodology applied (Section 3.7).

3.2. Research paradigm: critical realism

Knowingly or not, each research project or endeavour sits in a philosophical paradigm. This philosophical position or paradigm of a study or thesis reflects a researcher's beliefs and assumptions about what is real (ontology), and how knowledge about this reality can be acquired (epistemology). Traditionally, research (and probably practise) in natural science and engineering was, and often still is, based on a positivist worldview which accepts that a reality exists independently of human perception, and seeks to understand that reality in a deterministic way through observations and measurements (Petersen and Gencel, 2013). This position is, arguably, so ingrained in the engineering discipline that the description of the driving research philosophy and researcher positionality is usually omitted in engineering research. However, the recognition and integration of different worldviews is key in the context of systems thinking and, in the research setting, should include a reflection on the worldview and positionality of the researcher. In light of this assumption, the current section will now describe the research paradigm employed to frame this thesis and provide a grounding for systems thinking.

Even though systems thinking is sometimes called a research philosophy in itself, it is now mainly associated with the development of methodologies for taking action in specific management contexts (Pollack, 2013), with the underlying ontological and epistemological position of systems thinking rarely having been discussed in more recent literature. The reason for this might be that the position on which systems approaches are based developed over time alongside the development of new research paradigms (Mingers, 2015), and thus cannot be discussed in a unified manner. Whilst some systems approaches, such as systems engineering, are associated with a positivist worldview, which accepts the existence of a reality independent of human knowledge or human perception (Nicholls, 2009), others, such as the soft systems methodology that will be described further on (see Section 3.3.1), have traditionally been placed within a constructivist or interpretivist paradigm. In the latter, any truth sits within a specific frame of reference, whereby particular knowledge can only be relative to that subjective frame, and universal knowledge does not exist. Consequently, no real causal explanation or prediction is possible.

Sitting in between the pure positivist/empiricist and the pure constructivist/interpretivist position, critical realism , as introduced by Roy Bhaskar in his book, *A realist's theory of science*, originally published in 1975 (Bhaskar, 2008) shifts the focus of enquiry from empirically observable events to underlying causal mechanisms (Danermark et al., 2012). This, itself, resembles the shift from looking at the world through linear projections of specific events, to observing dynamic feedback loops through systems thinking. Whilst embracing a constructivist epistemology, stating that no knowledge is absolute, Bhaskar accepted a realist ontology. As argument against the constructivist position he presented that if reality was always constructed from a specific viewpoint, knowledge could not be fallible ('epistemic fallacy'), on the grounds that any statement could be claimed to represent an individual reality. Consequently, Bhaskar (2008) argued, in order for research to be meaningful, a reality must exist independently of it being observed or not.

In light of these assumptions, critical realism is here understood to be a position that can guide and enrich the development and application of systems approaches. Critical realism allows to accept a material reality, such as the subsurface, as existent and connect it with an understanding of the human experience as one of the layers of knowledge about that reality. The existence of a material reality itself is essential for professions of the built environment, such as the engineers and urban planners who participated in the current research. At the same time, this paradigm can arguably help the researcher to navigate between physical subject matters that constitute a main area of focus in particular of engineers, concerning ' things to be done and the way of doing them' (Dewey, 1929, p. 68) on one hand, and the need for cross-disciplinary integration in the often qualitative assessments of alternative solutions within the remit of urban planning (Næss, 2015), on the other hand.

Further to this understanding, in critical realism reality is described as layered, according to the degree to which knowledge about this reality is empirically accessible (Næss, 2015). That which is *empirical* comprises the objects and structures that have been experienced or observed. That which is *actual* entails situations and events that can or could be observed, which are generated by objects, events, underlying powers or mechanisms in the *real*. This layering is illustrated in Figure 3.1 using the example of geological exploration. Whilst a borehole record itself is *empirical*, the geology between the boreholes constitutes part of the *actual* – it could, theoretically, be empirically accessed, but has not yet been. The modelling of geology depends on explanations of that which is empirically observed, and will change if another explanation is applied.

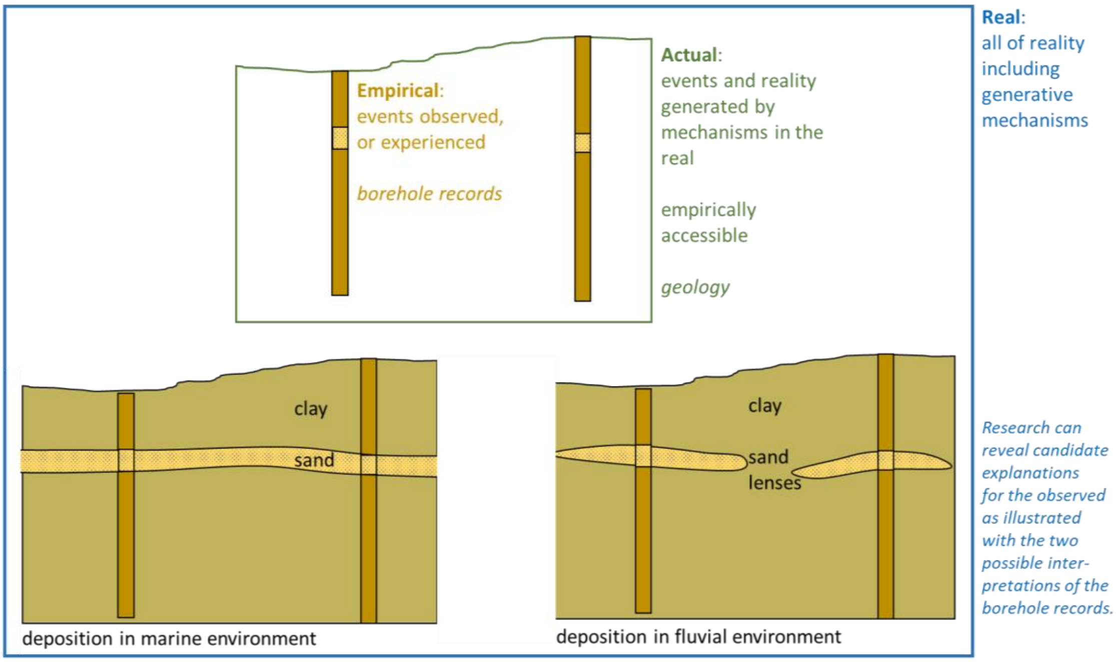

Figure 3.1: Illustration of the nested domains of the critical realist ontology - the 'real', the 'actual' and the 'empirical' – using the example of geological exploration

Note: Aspects of geological exploration and interpretation based on Mingers (2015). Aspects of geoscientific interpretation based on De Mulder et al. (2012)

The epistemological position of critical realism holds that the domain of the *real* can never be captured as a whole (Fletcher, 2017). Consequently, the objective of research within the critical realism paradigm is not, indeed, to capture an absolute truth, but to uncover causal mechanisms that allow for the explanation of observable events or phenomena (Mingers, 2015). It is accepted that these assessments are, in turn, constructed from the unique position of each researcher that influences their possibilities and reasons (Trochim and Donnelly, 2006), and that, therefore, 'research is never value-free but always committed to a particular purpose or interest' (Mingers, 2015, p. 189). However, even though research perceived in this way cannot provide an absolute truth, an explanation of past or current situations can lead to the ability to better assess future events and the effects that different interventions might have (Danermark et al., 2012). With this in mind, it should be recognized that, in contrast to purely positivist empirical research, which claims to be able to find universally valid explanations, the conceptual frameworks grounded in critical realist research are understood to be context-dependent (Bergene, 2007). For the current thesis, embracing a critical realist position thus meant that rather than seeking ultimate facts, critical scrutiny was sought through mobilising different kinds of data and shedding light on alternative interpretations of the processes at play.

Bearing the key assumptions of critical realism in mind, the focus of critical realist research is, firstly, to determine tendencies or 'demi-regularities' observed in empirical data (Fletcher, 2017), and, secondly, to relate these tendencies to generalised theories or frameworks for the purposes of explanation. For the generation of knowledge, two modes of inference are typically referred to across the paradigms: deduction and induction. In deductive analysis, data are generated and specific conclusions deduced based on previously existing frameworks (Patton, 2002), whereas in inductive analysis, the data are analysed to infer general laws, patterns, themes or theories based on specific observations (Danermark et al., 2012). However, in order to develop theories about causal mechanisms following the critical realist position, modes of inference are needed that are less linear in nature. Critical realists refer to *abduction* and *retroduction* for that purpose. Abduction aims at finding the best explanation for an observed phenomenon in the empirical domain through the proposition of hypothetical causal mechanisms in the real domain. Then, through retroduction, frameworks or theories can be proposed that outline the conditions necessary for the causal mechanisms to take effect (Fletcher, 2017). Different to deduction and induction, theory-making through abduction and retroduction are cyclical, iterative processes (Blaikie, 2007) that comprise recontextualisation by looking at a specific field of enquiry through a different or new theoretical lens, and cannot be validated through logical argumentation (Danermark et al., 2012). By applying retroduction and abduction, a researcher moves in a 'spiral' between the literature and empirical observation, which guide him/her towards the elicitation of regularities and their causes, and in that way to 'ground' the theory in empirical observation and literature (Belfrage and Hauf, 2017). These iterative processes can also be identified in the principles of soft systems methodology that were used as a point of departure to guide the current researcher's inquiry. The next section describes this approach.

3.3. Research design

3.3.1. A systems-based approach

The current research project adopted a strategy inspired by the cycle of inquiry laid out in Soft Systems Methodology (SSM), as shown in Figure 3.2. The four key 'activities' carried out – (a) understanding a situation, (b) formulating models of that situation, (c) comparing the models with the perceived real situation to identify action potentials, and, finally, (d) implementing an activity or action – resemble the cyclical patterns of action research (Rose, 1997). However, while research conducted using SSM can lead to an intervention, it does not necessarily have to do so (Checkland, 2000); the overall process can also be used as a sense-making approach for complex situations, in which the fourth step becomes optional. This thesis harnessed SSM to the latter end; that is, to understand the complexity of the urban subsurface planning landscape through (a) providing a rich description of the current situation in London through an analysis of planning policies and identification of stakeholders; (b) conducting an in-depth analysis of the perception of the problem space by key professionals; and (c) broadening the discussing of the elicited understanding though engaging a larger group of professionals. This process represents the process of abductive reasoning set out in critical realism as: (a) the discovery of structures and mechanisms, (b) the construction of models of causality, as the causes are not observable, and (c) the understanding that if a model represents the structure and mechanism of the observed, the explanation is accepted as valid (Blaikie, 2007).

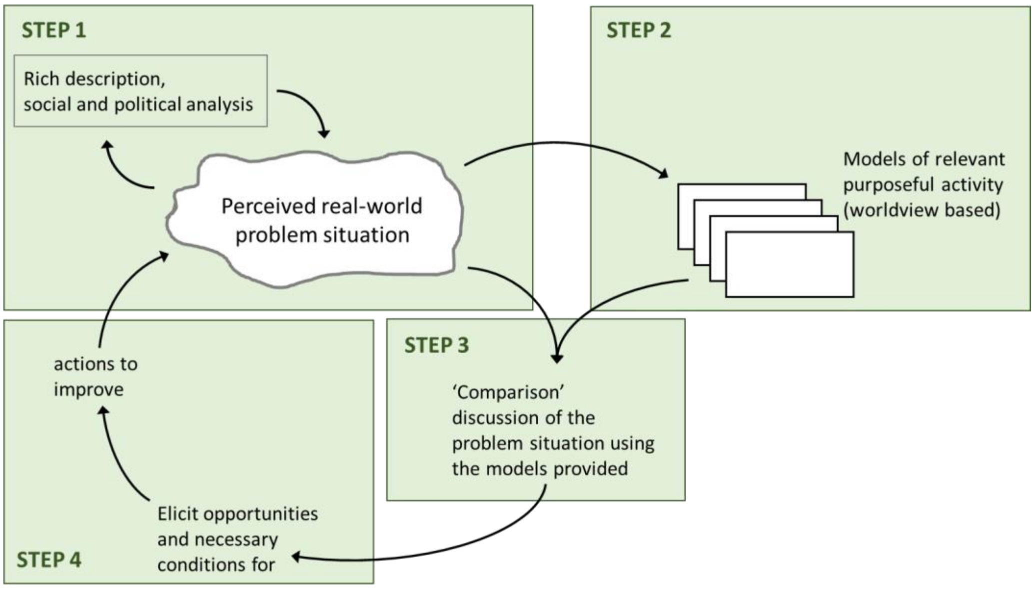

Figure 3.2: The inquiry cycle of SSM (based on Checkland, 2000)

3.3.2. Exploratory mixed methods

Typically, research methods are divided into quantitative and qualitative. Positivist research is associated with the former, that is, with analysing numerical data, which is perceived to be objective, in order to examine the relationships between different variables. For its part, interpretivist research tends to be associated with qualitative methods, which focus on in-depth descriptions and the exploration of individuals' subjective experiences (Clark and

Ivankova, 2016). In the context of critical realism, Danermark et al. (2012) criticise the distinction between quantitative and qualitative methods as restrictive for critical realist research, suggesting the use of the terms *intensive* and *extensive* research methods instead, where extensive data captures widespread trends and explores a topic through a broad assessment, and intensive data delves deep into a topic through in-depth analysis of a case or event (Fletcher, 2017). As such, Danermark et al. (2012) frame the difference between the two sets of methodologies in terms of what questions they are supposed to answer rather than in the use of mathematical or non-mathematical tools. For the critical realist, both kinds of methods can be useful for the identification of demi-regularities and, consequently, for analysis on the path to theory development (Fletcher, 2017). In the context of the current thesis, systems thinking was employed to develop theoretical considerations about urban subsurface planning in general, as well as how these relate to specific local contexts. As such, the research attributes necessity and benefit to both, aiming to gain an in-depth understanding of the situation in a specific location – using London as a case study – including its governance setup as well as the relevant professionals' perceptions of the field. The latter involved conducting a broad investigation into their attitudes, potential discrepancies between desired outcomes and perceptions of true feasibility, and the frequency of importance assigned to certain uses in the subsurface, as well as the potential benefits of, and barriers to, a designated underground planning strategy. It can be argued that in engaging with the given research agenda, a thesis that solely employed one or the other – quantitative or qualitative, or, indeed, intensive or extensive, methods – would be lacking a key constitutive element of understanding that could inform such a strategy and its direction.

Resembling the above, methodological 'pluralism' – that is, drawing upon multiple methods and, indeed, methodologies to build a coherent whole – has also been encouraged in the context of systems thinking (see Richardson and Midgley, 2007). Specifically with regard to the principles of a soft systems methodology, and in combination with the given research objective to better understand the applicability of systems thinking in the context of London in particular and urban subsurface governance in general, both extensive and intensive – or quantitative and qualitative – methods are arguably needed to operationalise the four SSM activities. That is, qualitative methods are needed to develop a rich description of the problem situation and an understanding of key professionals' worldviews, while quantitative methods are required to examine the applicability of the findings from the qualitative exploration in the broader 'problem space'.

In addition, as stated at the start of this research, in the field of subsurface planning theoretical explorations are scarce and, furthermore, a detailed understanding of stakeholder perceptions is lacking. Therefore, to respond to these gaps, both qualitative and quantitative data were mobilised for the purposes of the current thesis. Following an analysis of policy documents to map out the current subsurface governance setup in London, firstly, *intensive* (or qualitative) data were collected through semi-structured, face to face interviews with professional groups most relevant in the field, to explore these stakeholders' perceptions of the 'problem space' in depth. Secondly, *extensive* (or quantitative) data were sought through a quantitative, largely closed-question survey in order to explore how the topic is perceived by a bigger and more diverse group of individuals, and also to triangulate the findings from the intensive analysis with more objective data, in the sense of mitigating the researcher bias that may be more present when conducting face-to-face, in-depth interviews (Clark and Ivankova, 2016), as explained below. Furthermore, this triangulation was also applied in order to tease out areas of potential contradiction as points of enquiry for the theoretical considerations. The following section describes the specific methods in more depth.

3.4. Methods for data collection and analysis

3.4.1. Describing the problem situation through document review and observation

The first step of any research arguably requires a rich description of the problem situation. In the current context, this entailed first understanding the research field in general, as undertaken through the literature review presented in Chapter 2, and, second, engaging with a specific case study area in which to study the problem outlined in order to be able to respond to the research agenda in a concrete, empirical manner.

The important aspects of understanding the specific problem situation, in particular within the remit of SSM, are gaining an understanding of the perceptions and positions of the key stakeholders in relation to the problem situation ('analysis one'), as well as the wider social ('analysis two') and political systems in which the problem situation is embedded ('analysis three') (Checkland, 2000). Role analysis, or analysis one, specifically aims to identify possible *problem owners* – that is, the stakeholders who are not only affected, but who would also have the power to change the given situation. This identification of problem owners is seen as particularly relevant in SSM because the problem itself has to be defined in the language of these groups, as they are the ones who will need to provide knowledge and resources to initiate change (Checkland and Scholes, 1999).

In this thesis, three different kinds of data were considered for the identification and categorisation of stakeholders (Table 3.1) in order to gain an overall picture of the landscape of actors and to specify those most affected by underground planning decisions – and, as such, by a potential designated strategy – as well as those who would themselves influence such strategy (Grimble and Wellard, 1997).

Table 3.1: Data collection for stakeholder identification

Method	List of Documents
Document studies	The Town and Country Planning Regulations 2012 Planning Act 2008 The Infrastructure Planning Regulations 2009 Responses to Draft New Local Plan London Borough of Merton (Oct 2018 – Jan 2019) City Plan 2036 Consultation Responses (Nov 2018 – Feb 2019) London Plan consultation answers (Dec 2017 – March 2018)

Method	Description [including no. of participants]	Date
Observations/ note-taking	Think Deep UK meetings [multiple] and workshops [3]	Feb 2016 – June 2019
	COST sub-urban meetings and conference [3]	Sep 2015 – March 2017
	ITACUS workshop at World Tunnelling Congress [1]	May 2019
	ASK workshop [1]	Jan 2017
	Future Cities Catapult workshop, 'Hidden Depth' [1]	Sep 2015
Interviews	Planners [3]	Jan 2017
	Tunnelling Engineers [5]	Jan 2017

Firstly, document studies of relevant regulations, as well as consultation documents for the London Plan and Local Plans on the one hand and a major tunnelling project in London on the other, provided an insight into who is considered – or who considers themselves – to have a stake. Secondly, and building on this listing of important stakeholders for planning and underground projects, as identified through the relevant legislation, a more comprehensive list of stakeholders specific to London's underground was compiled, informed by document studies, observation notes taken at various meetings of Think Deep UK[1] (TDUK), and discussions with members of TDUK and other experts about who would need to get involved in the process of establishing a subsurface planning strategy for London. Observation notes were also taken at relevant meetings with other groups, namely ITACUS[2] and COST sub-urban[3], during which the question of who should be involved in an underground planning process was either mentioned or implicit in discussions independent of a specific city. These groups consisted of national and international experts in the field,

[1] Think Deep UK is an interdisciplinary group concerned with the role of the subsurface in UK cities. For more information, go to: www.tduk.org.

[2] The International Tunnelling and Underground Space Association Committee on Underground Space (ITACUS) works together with the International Tunnelling and Underground Space Association (ITA) towards the better integration of underground space in cities.

[3] COST sub-urban was a European research project running from April 2013 to April 2017, aiming 'to improve understanding and use of the ground beneath our cities.'

covering a wide range of disciplinary backgrounds. The involvement of the researcher with these groups, in combination with the understanding of key stakeholders derived from the literature review, was deemed to be sufficiently comprehensive with regard to stakeholder identification for the purpose of this thesis. The observation notes taken at the meetings and workshops listed also fed into the discussion of the in-depth interviews and subsequent questionnaire, as shortly described.

Regarding the final list of stakeholders specifically in relation to London, in addition to the literature and observations, the opinion of an expert in the field was sought and taken into account. The final list combines those stakeholders previously listed with professional institutions, as well as with specific interest groups.

Thirdly, to gain an idea of the relative position of these stakeholders, stakeholders were listed and their influence on, and degree of being affected by, a potential subsurface strategy were assessed in eight interviews with tunnelling engineers and urban planners (see Section 3.4.2 for further details). As currently no such strategy exists for London, this can only represent a hypothetical account. For urban contexts in which the development of a subsurface strategy is actually considered, as well as for major infrastructure projects that are being developed, methodologies to map stakeholders (see for example Bryson, 2004) as well as general systems mapping approaches (see for example Sedlacko et al., 2014) of the location specific urban system – including the underground – can provide meaningful tools that should be considered.

To capture the essence of analyses two and three as described in the context of SSM, the policy arrangement approach (PAA) developed by Arts et al. (2000) was identified as a suitable framework (see Chapter 4, Section 4.2). In this framework, a policy arrangement is analysed along four dimensions: actors, rules, resources and discourses. It thus combines analyses two and three in a single framework which, for the purposes of the current research, was extended with a description of the material context to reflect the specific aspects of the research problem at play. That is, the physical space that the subsurface constitutes comes with its own natural constraints, which inevitably impact the social and political context described through the PAA. The analysis of the policy arrangement itself (presented in Chapter 4, Section 4.6) is based on a review of planning legislation on the national and local level, as well as case laws and documentation for subsurface infrastructure projects that provided the up-to-date information sought for this research, and enabled the development of a broad understanding of the way in which the subsurface is currently governed.

3.4.2. Semi-structured interviews

The review of policies and their connection to the subsurface, as well as the analysis of the current governance of London's subsurface, brought to light the central position of planning authorities on one hand, and consulting engineers and technical knowledge on the other hand, the latter being aligned with the aforementioned observation that the main body of literature stems from the engineering discipline (see Chapter 2, Section 2.1). As such, it felt apposite that these professionals needed to be better understood and their position contrasted with that of other professions. Consequently, the decision was made to conduct a set of semi-structured interviews in order to gain an in-depth understanding of engineers' perceptions of London's subsurface and contrast this with the view of urban planners. A semi-structured approach was deemed appropriate as it allows exploring participants' perceptions rather than pre-empting what the problem may be whilst defining basic lines of inquiry (Patton, 2002). Reflecting on the critical realist position adopted in the current thesis, the data collected through the interviews conducted here aids to understand the human experience of the current situation and arrangements around London's subsurface and evaluate its meaning, but cannot for themselves provide conclusive explanations (Smith and Elger, 2012). To provide a comprehensive picture, the interview analysis and discussion are embedded within the findings about the current governance arrangement of London's subsurface from secondary data, as well as the literature.

3.4.2.1. Respondent sampling and access

The semi-structured interviews were sought with planners and engineers who had first-hand experience of planning, constructing or taking decisions about underground projects in London, and who could thus reflect on the problems encountered, and on the need for more structured approaches for the planning and construction of underground structures.

Potential interviewees were purposively targeted (Patton, 2002). They were contacted via email through contacts made by the researcher at topic-related events and through referrals made by those individuals. This kind of sampling, referred to as 'snowball sampling', and engaging individuals who are deemed 'fit for purpose' (May, 2011, p. 100), was chosen because an enumeration of the target population was not possible (Babbie et al., 2015), and because the group of interest in the topic of enquiry were well defined (Gillham, 2008). In addition, potential respondents were recruited through an open email to local planning authorities, as well as engineering consultancies active in the tunnelling sector, given that the tunnelling sector is specifically associated with the planning and construction of interventions in the underground. Necessarily, purposive samples cannot claim representativeness and thus can only be used for exploratory purposes (Babbie et al., 2015). Aligned with the purpose of the current project, Gilham (2008) links these kinds of samples to studies where theoretical rather than empirical generalisation is sought, as in the case of the present study.

An unforeseen dynamic occurred during this recruitment process, which had a bearing on the focus of the interviews. Whilst engineers, in particular tunnelling engineers and engineers working at Transport for London (TfL), reacted positively to the interview request, the planning authorities, even when they were very supportive in their responses, continuously referred the researcher back to tunnelling engineers and TfL and did not engage with follow-up requests. Two interpretations for this are possible: (i) the term 'underground' was used in the request, which might have led to a direct association with the 'London Underground', i.e., the tube, rather than the subsurface as a broader concept; (ii) council officers do not see this field of strategic planning as part of their responsibility.

Consequently, the decision was made to change the focus to depicting the situation primarily from the perspective of tunnelling engineers rather than examining the perception of planning professionals to the same degree. The former group can be considered a small, homogeneous sample, and beneficial to the purpose of exploratory research presented here, as such a sample facilitates the description and understanding of a particular subgroup and their attitudes in depth (Patton, 2002). The limited number of interviews with representatives of planning disciplines was then used to elicit any points in which there may exist differences in perceptions between the two disciplines.

A total of 15 interviews were conducted, with a total of 16 participants as two of the participants were interviewed together. All of the participants had been involved deeply with at least one specific aspect of underground planning throughout their careers. Of the 16 interviewees (Table 3.2), 13 were civil engineers, architects or urban planners by background who had worked in various roles for a client, developer or contractor on at least one of the major tunnelling infrastructure projects that have been realised in London over the last decade, or are currently being undertaken. In addition, many of the participants had been involved with obtaining planning consent, acted as the respondent for interested parties for obtaining planning permissions, or helped in delivering a final construction design. The remaining three participants worked for the GLA and a local council, respectively. The interviews lasted between 45 minutes and 1.5 hours. All interviews were undertaken either at University College London (UCL) or in the participants' offices.

Table 3.2: Interview participants

Profession	Employment remit		
	Consultancy/ Design	**Contractor**	**Public Administration**
Civil Engineer	10	1	
Architect	1		
Urban Planner	1		3

As all participants were assured anonymity, a list of the participants and the full transcriptions of the interviews cannot be provided in this thesis, given that all interviewees referred explicitly to projects they had worked on and to their individual role when working on these projects. Consequently, any larger excerpt of the interviews would have allowed for their identification by other professionals working in the field, and could thus have broken with the ethics standard of confidentiality.

3.4.2.2. Interview topics

Table 3.3 shows the semi-structured interview guide with the main questions that were asked. This topic guide reflects the broad lines of consideration that were identified in the literature and through conversation with/observation of expert groups as previously described. Following the principles of a semi-structured interview, in order to understand if there exists any misalignment between the major issues perceived by practitioners in the London setting and the areas of key focus in the general (not location-specific) literature (see Chapter 2), a way of interviewing was sought that allowed the interview questions to be deliberately open (Creswell, 2014). For example, with the aim of exploring participants' perceptions rather than pre-empting what the problem may be, interviewees were asked where they saw problems and potentials for improvement.

In addition to these semi-structured questions, the aspect of listing and discussing stakeholders was intentionally developed over the course of the interviews. The initial aim was only to identify and categorise stakeholders (Reed et al., 2009). However, over the course of the first set of seven interviews, it became apparent that it was not sufficient simply to ask the participants to identify the main stakeholder groups, but that the question of who were the relevant stakeholders and stakeholder groups had to be captured in a more structured manner. Given the large amount of stakeholders that had been identified through the document review (see, for example, Appendix IX for a list of statutory consultees for Local Plans and specific projects as specified in the Town and Country Planning Act 2012 and the

Planning Act 2008), it was thought that a deeper conversation about stakeholders and their different positions would elicit additional themes more effectively than a simple listing of who the stakeholders were. Consequently, for the remaining interviews a more structured part was introduced.

Table 3.3: Semi-structured interview questions

Introduction

1. Tell me a bit about your professional background and the types of projects you work on.
2. If I say, 'urban subsurface', can you give me five terms that come immediately to mind?

Semi-structured part I – requirements and barriers for better planning for the subsurface

3. From your point of view and drawing on your experience, what are the greatest problems you have encountered with planning/permitting underground assets and/or developments?
4. What would be required to improve today's planning processes? What resources would be necessary?
5. What do you see as the main barriers to overcome? Who could/would need to contribute to overcoming them, and how?
6. From your perspective, what are the main differences between surface and subsurface constructions and developments?

Semi-structured part II – future thinking

7. In your opinion, what are the biggest uncertainties in terms of the future use of subsurface space (in London)?
8. Given these uncertainties, how is or can 'long-term thinking' be considered integrated in your field?

Summing up – necessity

9. What are the main reasons for building in London's subsurface today?
10. Are these reasons justified? What problems do you see?
11. Can you name an example where you think a subsurface development that was realised was not necessary? Please explain your reasons.
12. If the London subsurface was empty, what, in your opinion, should go in there? What should the main purpose/driver of building in the subsurface be?

For this part, the interviewees were asked to discuss and fill in Table 3.4, in which stakeholders were listed and categorised. First, six interest-categories were given based on what had emerged from literature and the previous interviews: 'economic', 'technical', 'environmental', 'societal', 'infrastructure service and management', and 'planning and regulation'. This was done to attune the participants with thinking about the stakeholders in a broader way and to test, whether this kind of categorisation proves meaningful. In an analysis of water infrastructure planning in Switzerland, Lienert et al. (2013) showed through a similar analysis that short-term interests preclude long-term planning, and a similar bias was hypothesised here. Interviewees were given the opportunity to point out additional categories of interests if they felt an aspect was not sufficiently covered. These data are not reported in the main chapters of the thesis as the number of data points was not sufficient to draw a firm conclusion. However, participants did find thinking about how to categorise stakeholders regarding their interest engaging and, thus, the method as such merits further development, in particular if a bigger group of people could be reached.

Following this categorisation, interviewees were asked to rank, on a scale, how strongly they thought the listed stakeholder group would be influenced by a subsurface management regime, and how strong their effect on such a regime would be. As has been stated previously, measuring whether stakeholders have influence on one hand, and whether they are affected by decisions in the field being investigated on the other is common in stakeholder analysis (Grimble and Wellard, 1997), and was seen as valuable here for the purpose of better understanding the stakeholders' position in the overall governance arrangement. Following the recommendation by Cummins and Gullone (2000) of choosing a rating scale which lies within the respondents' common experience, 0-10 was used as a continuous scale as this is commonly used in engineering practice. These data were incorporated into the wider study, influencing the understanding of the current governance setup and specific stakeholder roles sought (see Section 3.4.1).

Table 3.4: Stakeholder identification, categorisation and rating

	Main Interests X: Primary interest(s) (X): Secondary interest(s)							How **influential** is the stakeholder on subsurface planning decisions? 0: no influence 10: very strong influence	How **affected** is the stakeholder by subsurface planning decisions? 0: not affected 10: strongly affected	Please **comment** if your scoring is based on project delivery/ strategic planning only/ if you would like to distinguish between local and general effects, or similar.
Stakeholder	Economic	Technical	Environmental	Societal	Infrastructure service and management	Planning and regulation	None of the above	1 - 10	1 - 10	

3.4.2.3. Data analysis

The interviews were recorded, transcribed, coded using the software NVivo, and analysed following the principles of a thematic analysis as a flexible method to organise and describe the data and search for patterns across the data set. This approach is considered particularly apt for researching topic-areas where participants' views are not known (Braun and Clarke, 2006) as was the case for the current project. Accordingly, the interviews were coded looking for themes and patterns in the data without a predefined framework. The transcription process enabled the marking of relevant comments and modes of expression, as well as a familiarisation with the data. Data coding and a preliminary analysis were done in parallel with interviewing more participants to monitor the development of themes and saturation was considered to be reached when a new interview did not imply additional themes (Fusch and Ness, 2015).

The coding went through several iterations. In a first iteration, the data were coded according to the questions asked, e.g. problems of underground planning. This first coding represented more a structuring of the data than an interpretation. A second iteration reflected on the framework presented in literature (see Chapter 2) to look at the subsurface as a resource. In this iteration, the dimensions of time, space, and value – at this point understood as a purely monetary measure (see Chapter 1, Section 1.2.1) – that are captured in the discussion to the final analysis, emerged (see also poster Appendix V). However, in reflection about these two iterations, it appeared that the actual meaning of the data had not yet been sufficiently captured, in the sense that it represents a perception through a particular professional lens, a layer of knowledge, rather than a truism. The depth of immersion with the data and the familiarity with the data gained by the researcher enabled a third iteration of coding, looking for themes and patterns in the data without a predefined framework, leading to the final analysis of the data.

To add to the reliability of the analysis, at this point the thematic coding was checked by two independent researchers who were sent an uncoded extract from the data and reported back the relevant themes they observed. These were compared with the themes defined by the researcher who presented her main line of thoughts that was approved by both researchers. One of these researchers also reviewed the final analysis confirming that the data was sufficiently captured. As a reflection, it should be mentioned that seeking of support by independent researchers earlier might have enabled a more efficient research process and allowed extending the review process beyond the overarching themes to the individual codes. In lieu thereof, additional validity was sought through presenting as much empirical data as possible and backing up any analytical claims arising from the interviews with empirical quotes (Chapters 4 and 5). This is in addition to the fact that, rather than looking for prevalence across the entire data set, what was sought were meaningful themes relating to the research question (Braun and Clarke, 2006); that is, here, in relation to the participants' perceptions of London's subsurface and its governance. For this data analysis, prevalence was not considered to be crucial but, rather, a rich thematic description of data was sought in order to provide insight into these perceptions and to inform the online questionnaire that constituted the next stage of data collection, as will be described in the following section.

3.4.3. Online questionnaire

Based on the outcomes of the exploratory interviews, as well as the observation notes and the existing literature, a questionnaire was developed for the current study. This served the objective of gaining an understanding of whether the views discussed in the research up to this point could be applied to a broader group of professionals, both in London and across the UK. Indeed, one of the main reasons for using a questionnaire was to reach as many people as possible in a practical manner to engage with the key themes that had been recognised in the interviews and the previous analysis of the situation in London. The questionnaire was also applied to test if specific statements were controversial or widely accepted, thus further exploring the topics that were raised in the interviews. These topics were traced as potential areas of key concern for tunnelling engineers, and, arguably, merited additional exploration with a wider group of professionals in the urban planning discipline and other subsurface related professions.

The questionnaire (see Appendix XII) was produced as a closed-question survey using SurveyMonkey's online survey tool. It began with background questions aiming to uncover the respondent's connection to the subsurface and their involvement with different underground structures in their work, as well as the organisation they worked for. These questions were also meant to 'attune' the respondent with the topic area, as it was expected that some respondents would not be familiar with this.

To measure the degree of respondents' agreement with the statements developed, these background questions were followed by rating-scale questions that applied a 4-point Likert scale. This scale was applied to the questions in line with Czaja and Blair's (2005) recommendation to keep the number of categories small and prevent satisficing – the effect of respondents settling for what they perceive to be a satisfactory answer rather than attempting to answer a question as accurately as possible – which tends to be less frequent when shorter scales are used with even numbers of options that do not provide a middle or neutral point (Krosnick and Presser, 2010). Neutral answers in the middle of a scale might also tempt participants to not state or even think about their opinion if they did not feel strongly about an issue. As such, for respondents who were actually neutral about a topic, a no answer (N/A) field was provided (Nadler et al., 2015; Gillham, 2008). Only one question, assessing the feasibility of certain interventions, was treated differently. Unlike the desirability of interventions, the assessment of feasibility was considered to be a matter of expertise and, instead of an N/A option, an answer labelled "not my area of expertise" was included. This allowed respondents who did not consider themselves knowledgeable enough not to answer the question. To allow respondents to elaborate on certain views and gain the fullest picture possible arising from this mode of data collection, all rating scale questions allowed for comments.

3.4.3.1. Question development

Following the proposition that had arisen from the interview analysis to prioritise subsurface functions according to their importance to the city on the one hand, and their being located in the underground on the other hand, the questionnaire explored respondents' views of the priorities for various underground functions in their respective city of operation. It then investigated the extent of respondents' agreement with specific statements relating to prioritisation, valuation, stakeholders and allocation of planning tasks as had been found relevant from the previous analyses of the governance arrangement around London's subsurface, in-depth interviews, and observations at topic related events. The questionnaire subsequently tested if respondents generally considered a subsurface strategy to be a necessary component, how they would rate the desirability and feasibility of specific potential actions, and which themes should primarily be addressed, as well as their perception of the benefits of, and barriers to, the establishment of such strategies. A matrix mapping out the questions asked against the findings from the analysis of the overall governance arrangement in London (Chapter 4) and in-depth interviews (Chapter 5) can be found in Appendix XIII.

As previously mentioned, a distinction was made between desirability and feasibility for specific actions, as desirability was considered to be possible to answer without expert knowledge, whereas a judgement of feasibility requires this. In addition, this distinction was made in light of the argument that decisions regarding distant future activities can be expressed in terms of desirability, whereas decisions about the near future are often based on the assessment of feasibility (Liberman and Trope, 1998). In addition to the rating-scale questions, one ranking question was included in the questionnaire, asking respondents to rank the importance of addressing different themes with regard to what should be involved in a subsurface strategy. These kinds of questions can help to elicit preferences or priorities in a subtle manner (Gillham, 2008).

3.4.3.2. Questionnaire testing

The questionnaire was tested by expert review. Ornstein (2014) states that in order to obtain an indication of reviewers' consistency, there should be at least three reviewers who provide independent assessments. To ensure an equal representation of the most relevant professions, this number was extended to four, with two experts each representing the main professions that had been targeted in the semi-structured interviews – tunnelling engineers and urban planners working in city authorities. To ensure consistency within each profession, a third representative of each group could have been approached in case of inconsistent feedback. The feedback received concerned the use of specific terminology, which was consequently changed. In addition, it was pointed out that not all respondents may be able to evaluate 'feasibility', leading to the integration of the answer 'not my area of expertise' in the respective questions. London-specific statements were dropped to ensure accessibility to a broader group of respondents. As the feedback was consistent, additional review by tunnelling and planning professionals was not deemed necessary. However, to ensure the accessibility of the language used, the questionnaire was also piloted with one geologist as well as two people who were not part of the targeted group in order to clear any jargon from the questions (Gillham, 2008).

3.4.3.3. Questionnaire sampling and distribution

After testing, the questionnaire was purposively distributed, with the request to the potential respondents to send it on in the hope that it would 'snowball' and reach a large group of 'subsurface professionals'.

The questionnaire was sent to the following email lists and people:

a. UK Collaboratorium for Research on Infrastructure & Cities UKCRIC[4] mailing list
b. TDUK mailing List
c. Institution of Civil Engineers (ICE) Municipal Expert Panel
d. Individuals encountered at conferences and topic related events.

In total, the link to the questionnaire was sent to 312 email addresses. Tunnelling engineers and urban planners were targeted as the groups with primary interests in the subsurface

[4] www.ukcric.com. From this mailing list, members were chosen whose affiliated organisation has a connection to the subsurface in that it either owns, manages or regulates assets in the subsurface.

space, as elicited in the analysis of governance arrangements. In addition, infrastructure owners and operators were also particularly targeted as their assets were found to be central in the interview discussions around space allocation. In addition to the listed groups, two professional bodies, the British Archaeological Association (BAA) and Royal Town Planning Institute (RTPI), were approached in order to counteract an anticipated bias in the question responses towards the tunnelling and engineering professions. Despite a positive response from the BAA, only one archaeologist answered the questionnaire and no response was received from the RTPI.

The number of responses to the questionnaire varied for individual questions between 44 and 60 answers, with an additional 12 responses being rejected due to incompleteness. Participants' affiliations and professional backgrounds are illustrated in Figure 3.3. Here, only groups including more than one respondent are listed, with the remainder grouped under 'others'. With regard to affiliations, these included publishing, education, professional membership bodies, and construction related industries. Concerning their professional backgrounds, law, history, environmental engineering and mechanical engineering, resource and waste management, and archaeology were stated by single individuals. In addition, 10 respondents grouped under the category 'several' in Figure 3.3 stated more than one field as their area of expertise, as follows: Municipal Engineering and Urban Design (2), Geology and Municipal Engineering or Tunnelling (3), Architecture and Design, Tunnelling, Municipal Engineering and Planning (1), Municipal Engineering, Planning and Geology (1), Architecture and Design, Planning and Economics (2), Planning, Architecture and Urban Design (1), Energy and Economics (1). The fact that more than half of the respondents stated engineering or engineering and another discipline as their background (n=32), together with the high percentage of respondents engaged in the field of underground planning, reflects a skewing of the sample towards engineering practices and towards a group that was well-informed about the topic.

While the questionnaire was targeted at participants with a London work focus, it was sent out without this restriction in order to be able to gauge if the answers given applied specifically to London or were transferable to any city. More than two thirds of the respondents (43) stated London, or London and other places, to be their place of work. Of the remaining respondents, the majority worked mainly in the UK (12), and only a few stated their work focus to be international (5). Consequently, the questionnaire answers were assessed in a twofold manner: for the entire group (n=60), as well as for the participants who stated London, or London and other places, to be their place of work (n=43).

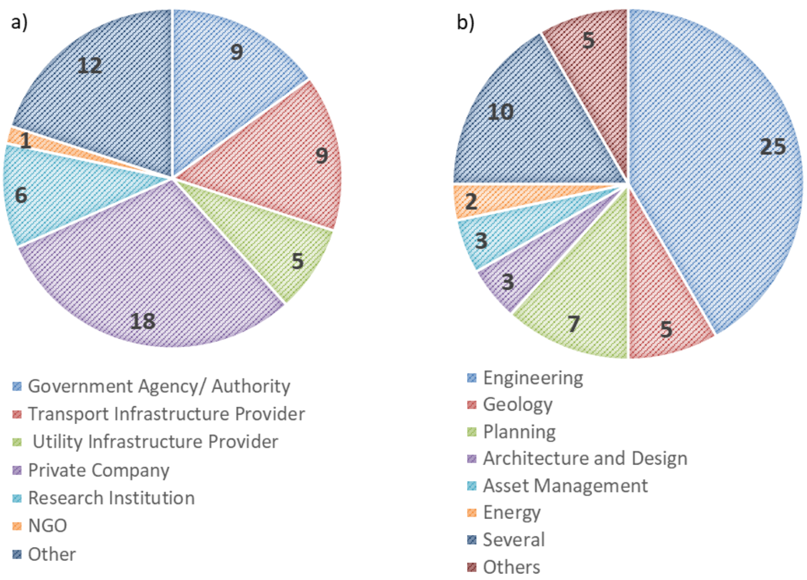

Figure 3.3: Background of questionnaire respondents; a: affiliation, b: professional background

Note: 'Engineering' includes civil engineers (15), tunnelling engineers (8), and municipal engineers (2)

3.5. Validity and research quality

In quantitative research, a project is considered to be valid if the findings are (i) appropriate, meaning that they can be and are derived through the described research process, and (ii) generalisable. In addition, repeatability makes project findings reliable (Creswell, 2014). Consequently, to gain validity and reliability, positivist researchers create and analyse closed systems where specific variables can be isolated and thus interpreted, and experiments can be repeated. However, a similar process is not possible when complex, open and adaptive systems are studied (Winter, 2000). These kinds of systems are constantly changing and, whilst specific research processes might be repeatable in theory, any particular study can only reflect a moment in time of these systems, compromising real repeatability. Particularly relevant for qualitative research is the understanding that each researcher has his/her unique perception and interpretation of the world, and comes to the given research project with his/her capacity for interpretation, theory building and inference. Thus, the concepts of validity and reliability as defined above are not directly transferable to qualitative research.

In the current thesis, whilst the number of questionnaire respondents did not warrant a statistical analysis, the results allowed for an observation of diversity in opinion – one of the recurring themes the current researcher was concerned with – and helped the researcher to further develop her analysis of the research topic. In critical realist research such data, providing indications to the commonality of certain events among a specialist group (Danermark et al., 2012) rather than the statistical significance of the data points (Smith and

Elger, 2012), is accepted as valid. The quantitative data was also mobilised to triangulate the data from the qualitative exploration, increasing overall credibility of the project (Greenhalgh and Taylor, 1997).

For projects with non-representative, purposive samples (Gillham, 2008, see also Section 3.3.4), the point of data 'saturation' is sought as another measure of validity of the qualitative research. Saturation is considered to be reached when additional data points do not yield further improvement of the theory or explanation (Schatz, 2003) and, as previously explained, the current researcher undertook the textual data analysis until this point was reached. Specifically, theoretical considerations and contingent suggestions for urban underground management were developed, capturing the empirical data gathered. Saturation was considered to be reached when it was no longer probable that additional data would lead to significant changes in the developed suggestions.

Finally, in the context of critical realist research, immersion in the domain is considered to be a valuable means of enhancing internal validity (Danermark et al., 2012). Throughout the study period of the current research, the author was actively involved in current discourse relating to the subsurface at a range of topic-related events, presentations and meetings. In addition, as an active member of TDUK, a think tank promoting awareness of the urban underground, she was constantly able to informally test her thoughts with members of the built environment community who consider better integration of the subsurface into urban planning to be important. Combined with ongoing field notes and reflection on the data gathering process, as well as the data gathered as the process unfolded, this introduced a strong degree of reflexivity into the research. Further increasing the overall trustworthiness of the current thesis, the following section will add to this self-critical account of the research process (Nowell et al., 2017).

As responses to the questionnaire mainly came from insiders in the field, rather than pointing towards a generalisable understanding across disciplines that are active in the subsurface, specific points of agreement or potential contradictions could be pointed out. The findings and observations led to theoretical considerations and strategic suggestions, and set out an agenda for further research; these aspects are elaborated on in the following three chapters.

3.6. Researcher positionality

The current study began with the current researcher's observation that her profession, geotechnical engineering, is not commonly recognised in society. This may be because the structures designed and implemented by geotechnical engineers are mostly embedded in the subsurface and are rarely seen; in addition, people often do not know what geotechnical engineers do. As such, the desire arose to make the profession more visible, on the one hand, and to understand its role in broader processes on the other hand. Exposing herself to the literature about the urban subsurface or urban underground planning soon led to the observation of this body of literature mainly stemming from an engineering perspective, where no reflection about theoretical grounding seemed to take place. Instead, it appeared that the various authors approached the 'problem' of underground planning in an engineering way – that is, by proposing a solution that is 'engineered', with spatial optimisation, technological solutions and management approaches being central to this approach. Engaging with different bodies of literature over the course of the research, in particular urban geology, it became clear that the approach taken by geologists is different, as geologists do not need a problem for which to seek a solution. Rather, geologists start from what is already there in the ground and then try to understand how this was influenced, or is influenced, by what is going on in the city above. This observation gave yet more importance to gaining a better understanding of which parameters are based in the engineering worldview, which had been an intuitive motivation at the start of the research, and which lack of understanding was then also found to be a concrete gap in the literature.

Systems thinking requires opening up the discussion of people's perceptions and time-dependent behaviours. However, it also requires a demarcation of boundaries – this applies to engineering as well as research projects, and it is down to the researcher to decide which elements are really relevant in the context of their inquiry. This process was probably the most challenging for the current researcher. A former practising engineer, it is likely that she, in particular at the beginning of the research, omitted certain approaches or ideas in favour of her own worldview. For example, the in-depth interview questions in the interviews, as well as the suggested functions at the outset of the questionnaire, might have pointed too strongly towards projects and engineering interventions, rather than providing a holistic view. The focus on the engineering worldview is thus reflected in the research process itself, through which the position of the researcher changed from a full-fledged engineer towards developing a sensitivity for different worldviews and realising the position of her own assumptions in the engineering discipline.

As such, an iterative research approach that oscillated between detail and strategy, and between individuals and organisations appeared to be the most fruitful way of engaging with the research agenda – circular processes rather than linear ones, as aligned with the idea of systems thinking. This approach and, in particular, the mixed methods used, ultimately supported the evaluation of the subsurface as a multi-functional space that requires integration across sectors and more awareness in the spatial domain.

Ultimately, the inferred findings of any research project, in particular the theoretical considerations made, are necessarily influenced by the researcher's experiences, knowledge, and view of the world. Efforts were made to reduce this bias through detailed reporting of the research process, mobilising multiple methods, continuous sampling to reach the point of data saturation, and the inclusion of empirical data in the research analysis. In addition, it is acknowledged that the observations and suggestions made can only offer candidate descriptions and open up avenues for further investigation, as described at the end of the thesis.

The research position adopted here thus placed the researcher in a continuous conversation and position of reflection about different worldviews – including her own. As practitioners in the field have to provide solutions to 'problems' presented to them by clients, they are often restricted in their opportunity to reflect. The current researcher had the space and, arguably, the responsibility to take on this reflective position.

3.7. Summary of the adopted methodology

This chapter introduces the research philosophy and methodology applied in the current thesis. The research is grounded in a critical realist worldview that is compatible with the principles of systems thinking that has been deemed applicable to the research problem at hand. Specifically, the critical realist paradigm can be seen to be suitable for exploratory research that, like the present study, rather than being directed at a particular problem aims to reveal the relevant underlying mechanisms or under-evaluated questions. Framed by this paradigm and systems thinking, the research design is guided by the concept of circles of inquiry, as introduced by soft systems methodology, with numerous sources of data being explored. Academic literature and policy documents were examined to describe and analyse the general problem area, as well as the specific setting of the subsurface in London. In-depth, semi-structured expert interviews and a questionnaire were then conducted to deepen the understanding of the situation in London and, consequently, link the findings back to the evolving theoretical considerations and contingent suggestions.

The overall research process is illustrated in Figure 3.4. The literature review presented in Chapter 2 explored the general problem space by reviewing current research and evolving approaches, and placing them in the context of systems thinking as a framework for holistic governance and theoretical elaboration. As a more specific problem space, the next chapter,

Chapter 4, presents an analysis of how the subsurface in London is currently governed. Then, Chapter 5 elicits the specific perception of that same space through the eyes of key professionals. Finally, in Chapter 6, the findings from the previous analyses are mobilised to feed into the results of the subsequent questionnaire that engaged a larger group of professionals, leading to a set of overarching theoretical considerations that conclude the thesis.

The next chapter continues the exploration of urban subsurface planning that was started in Chapter 2 by analysing the governance setup in London, mapping out the current planning legislation and stakeholders, and exploring how these interact with the material reality that constitutes the subsurface.

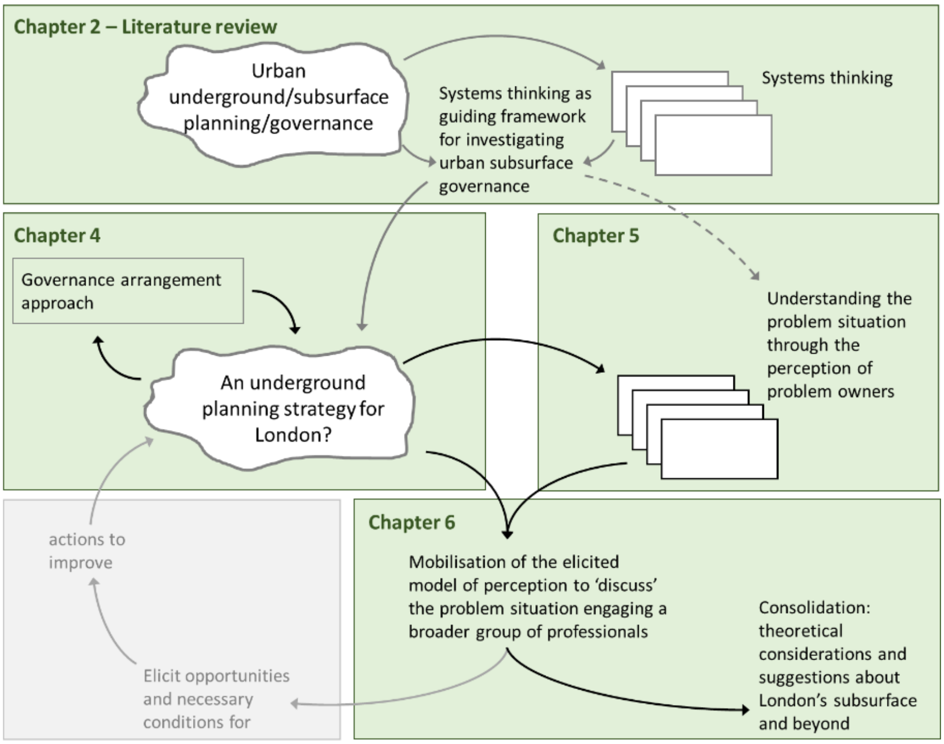

Figure 3.4: Application/interpretation of SSM for the current thesis

4. The governance arrangement of London's subsurface

Section 4.4 builds on a previously published paper (von der Tann et al.*, 2018a), and a limited number of paragraphs in this section as well as one paragraph in Section 4.6.3 are directly drawn from that publication. These paragraphs have been slightly adapted and edited to suit the purposes of the current thesis. For the purposes of readability, they are not highlighted. All parts reproduced here are the author's original work. The complete paper can be found in Appendix II.*

A city like Rome has inevitably evolved around certain definite forces of nature, such as waterways and cliffs. It is possible to transform these topographical influences with the help of diggers and dynamite. Sometimes this kind of modification of the natural world is necessary for the residents, with road tunnels hacked through mountains and sewerage pipes buried underground, but in most respects, humanity concedes to the landscape.

Lizzie O'Shea, Future Histories

4.1. Introduction

The above quote is the beginning of a description of Sigmund Freud's analogy between the city of Rome and the human mind. It goes on to describe how history, the unconscious 'landscape' of our mind, as well as the social context determine who we are and how all these elements need to be analysed in parallel in order to fully understand human consciousness. These three elements are strikingly similar to what appears to be relevant in an urban context, in particular when thinking about the urban subsurface. First and foremost, there is a city's geographical, and therewith also geological, location - its underground, which, due to its invisibility often appears to be 'out of sight, out of mind' (van der Meulen et al., 2016). Secondly, there is the aspect of a city's history that is often connected to its location, as many cities evolved around either accessibility with regard to trading routes or the availability of resources (von der Tann et al., 2018a). Thirdly, and sometimes as invisible as the subsurface itself, the social context of a city also needs to be considered, that manifests in the rules and regulations society has set and accepts around a specific theme, as well as in the different actors and the discourses between them that might constitute change and influence decisions around a topic at hand.

The previous chapter introduced the research strategy of the current thesis, which began with a review of the theoretical framework of systems thinking and the corresponding approaches in Chapter 2. To provide a basis for locating the concepts around, and approaches towards, governing the urban subsurface within the systems framework, as well as to guide the collection of primary empirical data in the following chapters, the current chapter presents a rich description of the present-day situation and governance of the subsurface in the case of London.

It is the above three elements – history, landscape and social context – that shall be looked at in this chapter in order to provide a basis for the analysis of London's subsurface and the question of whether the latter needs more, or more specific, regulation as a whole. These elements also resemble what has been described in Chapter 2 (Section 2.3) as the baseline or starting point that – in a systems-based language – any intervention would have to be based upon (Chapter 2, Section 2.3) (von der Tann et al., 2020). The level of detail of the description and understanding of this baseline would also need to be aligned with the endeavour or project at hand. The aim of the following overview is to gain a general understanding of the developments, policies, people and organisations that have shaped and are shaping the current governance of underground space in London, rather than looking in detail at the development or implementation of a specific project.

As a framework for analysis of the social context, the following section introduces the policy arrangement approach (PAA), as presented by Arts et al. (2000) that will here be employed to provide a different viewpoint and a theoretical perspective on urban subsurface governance, and as a tool that helps to describe and understand individual areas of policy, as well as to gain insights into discursive shifts and institutional contexts (Wiering and Arts, 2006). This approach is extended to include the description of the local geology and human legacy, so as to provide a coherent framing for the analysis of urban subsurface governance. The following three sections (4.3 to 4.5) present fundamental data and information on:

a. the geology and built legacy of the underground (Section 4.3)
b. planning regulations in the UK and London and how the subsurface fits in (Section 4.4)
c. relevant stakeholders in the field (Section 4.5),

that provide the key context for the subsequent analysis and discussion based on the extended policy arrangement approach (Section 4.6).

4.2. An approach to subsurface governance arrangements

In light of the aforementioned considerations, thinking about the urban subsurface prompts a deeper engagement with a city's location as well as the policy arrangement surrounding it. Arts et al. (2000) define a policy arrangement as 'temporary stabilisation of the content and organisation and substance of a policy domain' (p. 54), with the latter domain comprising four analytical dimensions, the first three of which refer to organisational aspects and the fourth to the substance of policy making (Liefferink, 2006):

a. actors and coalitions
b. rules, including policies and formal procedures
c. resources these actors and coalitions can mobilise
d. discourses about the policy domain.

All four dimensions are interdependent and a change in any dimension can trigger a change in the overall arrangement. Arts et al. (2000) illustrate these interdependencies by depicting the arrangement between the four dimensions as a tetrahedron (Figure 4.1). For example, a changing discourse can lead to the engagement of different actors, the allocation of resources and, ultimately, a change in policy.

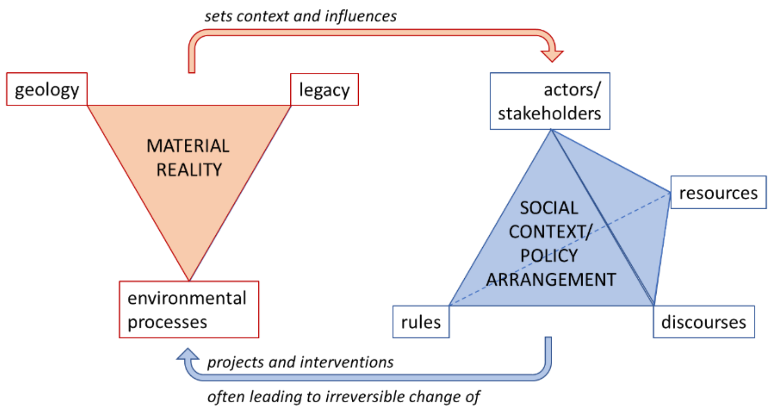

Figure 4.1: Policy arrangement tetrahedron according to Arts et al. (2000) and its connection to the material reality of the subsurface

In the context of the subsurface, in Chapter 2, the existence of a dominating narrative of underground space as being distributed or used on a 'first come, first served' basis (Section 2.1) was noted, with the terminology used to describe the subsurface mainly based on the human uses of the same (Section 2.4). Accepting the presumption that a potential change of this conjuncture would need to originate from the spatial planning domain means that a subsurface planning strategy could be triggered through a change of the discourse, institutions, policies, or resource availability in that domain. However, whilst the PAA provides a basis for the analysis of the societal context, in terms of spatial planning and, in particular, considering the underground, any effort of governance has to be firmly based in and react to the material reality – the geology and human legacy, as well as the physical and environmental processes these are exposed to. As such, the PAA is here extended to include a description of this material reality.

Figure 4.1 illustrates this connection between the social context and the material reality as a feedback loop that can also be found in the circular processes reviewed in Chapter 2 (Section 2.3.3.2). It is acknowledged that the PAA, as laid out by Arts et al. (2000), explicitly aims to analyse a specific moment in time, and thus feedback loops are not touched upon in their elaborations. However, the material aspects form a determining part of the governance arrangement for the subsurface, and the integration of those aspects in the description of a 'temporary stabilisation' as well as, consequently, in their temporal dependencies, appears essential for a holistic approach.

The following sections present aspects of London's geology and built underground legacy that have mutually influenced each other (MOLA, n.d.) (Section 4.3), and two of the organisational dimensions described in the PAA, namely, rules (Section 4.4) and stakeholders (Section 4.5). As will be shown, currently the discourse about urban subsurface management sits within general interest groups, with no resources having been triggered in the relevant institutions. As such, the two remaining dimensions of discourses and resources are not described separately here, but will be discussed in Section 4.6.

4.3. Material aspects: geology and legacy

The geological layers most relevant for engineering purposes and urban functions are the ones relatively close to the surface that can be accessed through digging or drilling. Subsurface levels of up to 100 to 250m are described as 'shallow' and relevant for urban planning (De Mulder et al., 2012), even if the exploitation of resources, such as drilling for deep geothermal energy or groundwater wells, can reach into deeper levels. For London, these shallow layers comprise the formations within the so called 'London Basin', formed around 14 to 24 million years ago (Paul, 2016). Table 4.1 lists the main formations, of which the chalk constitutes the major aquifer of strategic importance. Groundwater can also be found in the Bracklesham and Lambeth Group formations that constitute minor aquifers of local importance and variable lithology (British Geological Survey, n.d.-a).

An extensive description of formations and their engineering properties would go beyond the purpose of this chapter. For a more detailed description of the geology of London, see Sumbler (1996), Royse et al. (2012) and Davis (2016), as well as the website of the British

Geological Survey(BGS). Here, a few examples shall be presented where the geology and hydrogeology have significantly influenced, or were themselves influenced by, the development of London's subsurface use: the accumulation of underground tunnels North of the river Thames, the management of the Chalk aquifer, and the volume of ground that could be described as artificial or man-made. These examples shall provide an idea of the depth of connection between the geology present, the structure of underground uses and the city as a whole.

Table 4.1: Main geological formations in London according to Royse et al. (2012), made ground thickness according to Paul (2016), and values in brackets according to Mathers et al. (2014)

Period and Group	Formations	Thickness [m]	Short description
-	Made ground	0-15	Man-made ground
Paleogene: Bracklesham Group	Bagshot Windlesham Camberley Sand	locally up to 70m	Sand formations of different lithologies, some of which constitute near-surface aquifers
Paleogene: Thames Group	London Clay	90-130 (150)	Grey to blue-grey, bioturbated, silty clay, with a sand-clay sequence serving as an aquitard between the Chalk aquifer and the near surface aquifers
	Harwich	0-10 (12)	Sand and pebble beds
Paleogene: Lambeth Group	Reading Woolwich Upnor	10-20 (30)	Sands, silts, clays and gravels, lithologically variable
	Thanet Sand	0-30 (40)	Coarsening upwards sequence of fine-grained sands and silts, with a basal bed of flint cobbles and nodular flints
Cretaceous	Chalk – various formations	Combined up to 200m	Principal aquifer of the region, artesian aquifer, porous limestone susceptible to collapse due to dissolution

4.3.1. Accumulation of the Underground North of the river Thames

Most of the London Underground is located North rather than South of the river Thames (Figure 4.2), the reason for which has been assigned primarily to the clay geology that is nearer to the ground surface in the North of the river than in the South. Clay is easier to tunnel than the other geological layers and is largely impermeable, so that no groundwater penetrates into the tunnels (Sumbler, 1996). Borehole data by the BGS and information about station depth and location of the London underground confirm that tube lines, indeed, predominantly run in London Clay and only scratch other geological layers where the clay layer is thin (as shown by Paul (2016) for three tube lines). The geology, however, is not the only reason for the concentration of tunnels North of the river: the density of the built city in the North also rendered above ground solutions impossible (Wolmar, 2004). Thus, the development of the underground railway and its distribution in London was shaped by a combination of geological properties, available technology, and the dynamics of urban development at the surface.

Figure 4.2: London Underground map in geographically correct locations
Source: Wikimedia Commons, 2016.

4.3.2. Management of the chalk aquifer

Another interdependency between history and subsurface management can be seen in the change and management of groundwater levels in the London basin. As in many other cities around the world, groundwater levels in London were strongly affected by over-exploitation for industrial purposes, which led to a drawdown of about 65m by the mid-1960s (Jones, n.d.) (see Figure 4.3.) Today, post-industrial relocation and the reduction of industrial activity has led to the contrary problem of rising groundwater tables that could affect the existing tunnels, basements, and foundations. Concerns about a loss of bearing capacity (Wilkinson, 1985) led, for example, to a redesign of the foundations for the new British Library to cope with a potential reduction in effective stress (Price and Reed, 1989). The chemical composition of the rising water facilitates the corrosion of reinforcement, and thus potentially constitutes a threat for the longevity of buried structures (Lerner and Barrett, 1996). In addition, flooding of subsurface infrastructure or basements, shrink-swell movements, uplift pressures under foundations and floor slabs, increased loads on retaining walls, and increased drainage requirements for excavations were listed by Simpson (1989) as potential effects of the rising groundwater table on engineering structures.

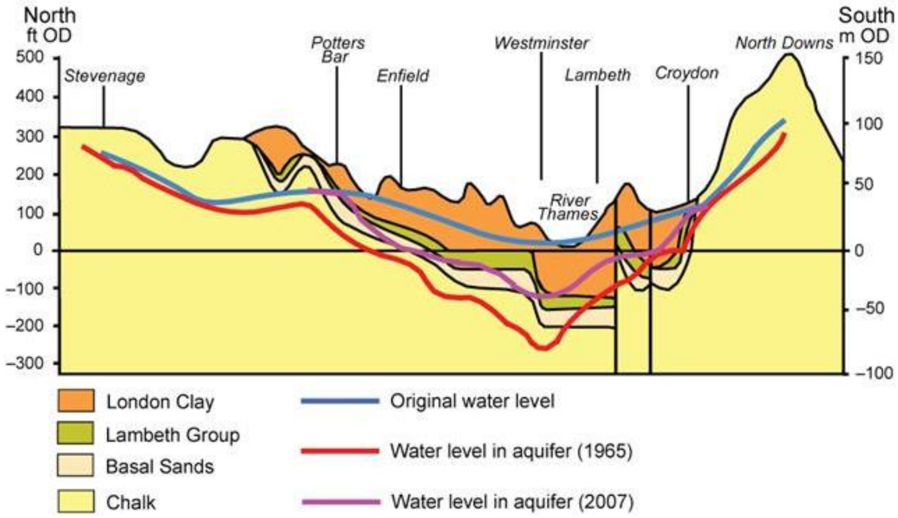

Figure 4.3: Schematic representation of the London Basin and Chalk aquifer groundwater levels Note: reproduced with permission of Thames Water, © 2007; Source: Jones (n.d.)

As a response to these concerns, abstraction rates were increased and are now managed through licencing by the Environment Agency. Approximately 80% of the abstraction is licenced to water companies (Environment Agency, 2018a). Through monitoring and management of the abstraction and recharge schemes, the aquifer is now maintained between an upper and a lower limit, providing an example of how human interventions can lead to lasting changes of an underground system and to circumstances that have to be managed in the long-term.

4.3.3. Artificial ground or anthropogenic layers

'Man-made' or 'artificial' grounds constitute another feature where human interventions in the subsurface manifest for a long period of time: The consideration of these types of grounds or anthropogenic deposits has gained importance in cities, and it has been claimed that a systematic assessment of artificial ground is required to 'inform the planning process and provide the basis for engineering solutions' (Rosenbaum et al., 2003, p. 399). Types of artificial ground have been categorised by the BGS, as illustrated in Figure 4.4. In London, due to the reclamation of land and river bank reinforcement, artificial ground predominately occurs along the river embankment (Mathers et al., 2014). Paul (2016) depicts artificial ground based on the evaluation of inner city boreholes with a thickness of 0-15m (see Table 4.1).

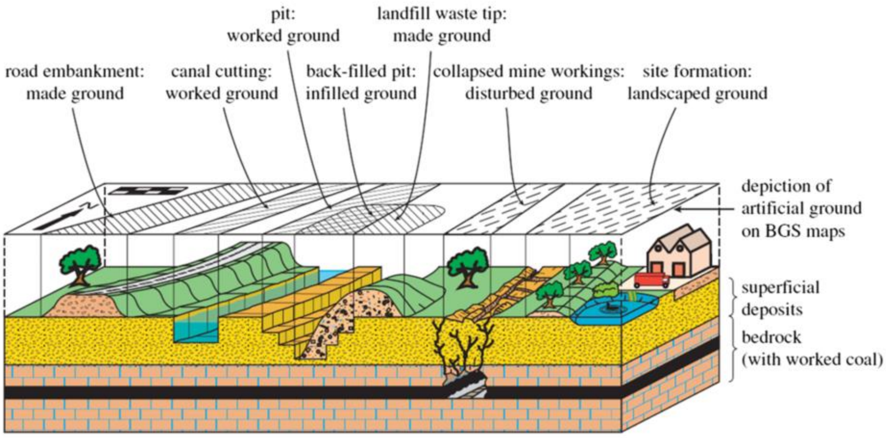

Figure 4.4: Main types of artificial ground as defined by the BGS.

Note: reproduced with the permission of the British Geological Survey, BGS © UKRI – Source: Ford et al. (2010)

However, the categorisation by the BGS might not be conclusive with regard to human impacts on the shallow subsurface. It does not comprise contamination through chemical and biological processes from industrial activities (Price et al., 2011), and Edgeworth (2014) raises the concern that assessments following the BGS' categorisation might be limited to deposits associated with ground modifications, given that the beginning of the industrial period and older anthropogenic layers of archaeological relevance might be missed out in this categorisation. Data about Archaeological Priority Areas, as published by Historic England, show that between 14% and 72% of the ground area of London Councils is considered an area of archaeological interest (see Appendix VII). Thus, that same area is covered by or contains volumes in the ground that have been modified by humans.

The extent of the impact by humans on temporary urban geology as captured in the above data also indicates the relevance of human actions to the future. Edgeworth (2014) suggests the term 'archaeosphere' for the layer of deposits formed or changed by human agency. In this view, the deposits are still in formation and the built environment currently in use has to be seen as part of the future 'archaeosphere' that 'can only be fully understood by reference to human intentions and actions as well as more natural processes' (p. 105). This description is not specific to underground structures, as what currently forms the archaeological layers was previously a part of the built environment above ground. However, the description emphasises that every intervention in the built environment is based on a human objective. The objectives that shape the built environment that is currently in formation and, thus, the archaeosphere of the future, are captured in plans and developments and are scrutinised through the planning system, which will be outlined in the following section.

4.4. Organisational aspects: the underground in urban planning legislation

The previous section provided an insight into particular aspects of the geology and built legacy in London's subsurface. On the project level these aspects coincide with the 'factual core' that is necessarily discussed in desk studies for geotechnical projects, as specified in the British Standard 'Code of practice for site investigations' (British Standard Institution, 2015), reinforcing the understanding of these aspects as baseline: site geology, site history, and site details. Such standards and codes of practice link the empirical description of the underground and the assets within it with a set of rules and regulations that determine how these spaces and elements, as well as the corresponding processes, are currently governed. This section will present an overview of urban planning legislation in the UK, and more specifically in London, as the specific policy area to which management and governance of the urban subsurface are usually assigned (see Chapter 2, Section 2.3.3).

4.4.1. The urban planning system in Britain and London – an overview

The planning system in Britain differs considerably to that in other European countries. Comprehensive planning legislation in the UK, as established with the Town and Country Planning Act in 1947, is embedded within the tradition of the English common law on the one hand, and in the duality of central government and local authority on the other (Newman and Thornley, 1996). The land use planning system 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 (Smith et al. 2016). In London, whilst the 32 boroughs and the City of London constitute the main planning authorities, the Greater London Authority (GLA) was established in 2000 as an intermediate administrative level.

Figure 4.5 provides a current overview of the relevant planning documents in the London boroughs. This summary is based on the National Planning Policy Framework (NPPF) which, together with the National Planning Practice Guidance (NPPG), in 2012/2014 replaced a whole set of planning as well as mining policies:

a) The NPPF and NPPG set out the major guidelines for local authorities to prepare their local planning policies. The core element of the NPPF is the *presumption of sustainable development*, which defines economic, social and environmental sustainability as an aim of overriding importance for the preparation of new planning policies (Department for Communities and Local Government, 2012).

b) The *London Plan* is the main planning document prepared by the GLA. It sets out general strategies for the city, including major development areas and infrastructure projects. The Local Plans developed by the 32 boroughs and the City of London have to comply with the *London Plan* and follow its principal objectives.

c) A *Local Plan* has to be developed by each of the borough's councils. Prior to the implementation of the NPPF, the local planning policies were summarised in the *Local Development Framework*. The planning policies have not yet been adjusted in all boroughs, and the Local Development Framework is still valid.

d) The local councils also prepare *Supplementary Planning Documents* (SPDs) that cover specific topics such as sustainable transport or affordable housing. They can also be area based and provide guidance on a specific area in the borough.

e) Supporting topic-based information, *evidence*, is prepared or commissioned by the councils.

f) In addition, parish and town councils as well as neighbourhood forums can prepare *Neighbourhood Plans*. These, once approved, form part of the development plan of the local authority and are not illustrated in Figure 4.5.

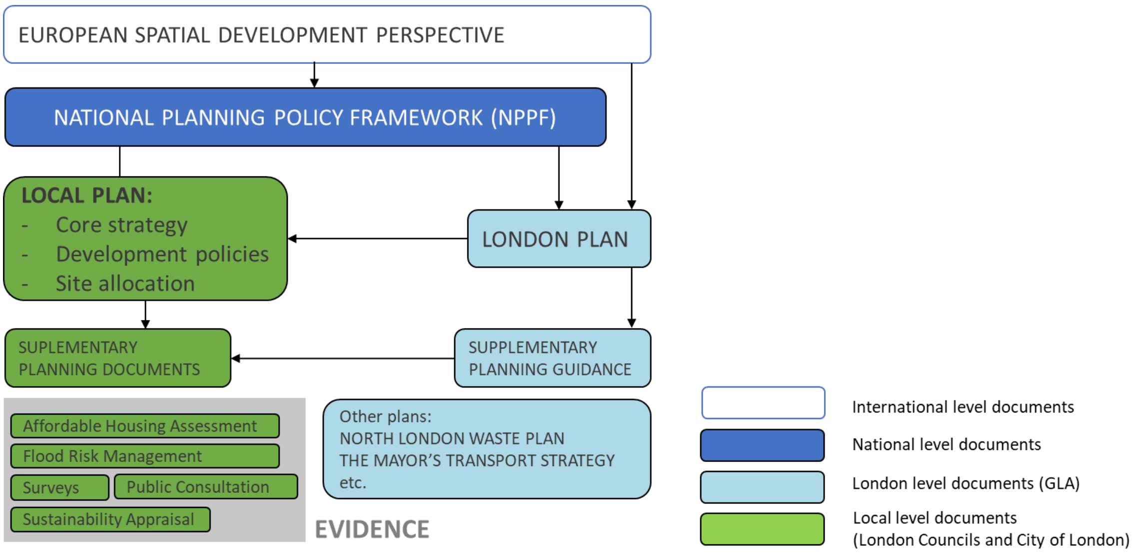

Figure 4.5: Schematic of London Boroughs Local Plan Documents

Uniquely in the United Kingdom, decisions are taken in the format of a discretionary judgement by councillors in local authorities, rather than through following bureaucratic rules (Vigar et al., 2000). The NPPF and NPPG, alongside regulation stemming from European directives, serve as 'material considerations' when decisions about planning applications are taken (Planning Aid, n.d.). The great variety of topic based SPDs and evidence documents prepared or commissioned by the different boroughs (see Figure 4.5) shows that the planning policies are still very varied, and that decisions about planning applications have to take a large variety of aspects into account.

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. In addition, specific underground developments, in particular for utility infrastructure, are permitted without making a planning application (Table 4.2).

Table 4.2: Permitted developments in the underground according to the Town and Country Planning (General Permitted Development) (England) Order 2015 (as amended)

Part	Permitted development
Part 10	Street works
Part 13	Water and hydraulic power supply 'not above ground level'
Part 14	Installation or alteration of ground source heat pumps on domestic premises
Part 15	Development of underground gas mains and pipes as well as electricity lines including the construction of shafts and tunnels
Part 16	Installation, alteration or replacement of electronic communications apparatus

4.4.2. The subsurface in the current planning regime

Of the services and functions currently occupying subsurface space in the UK, many are covered in national environmental and planning policy and legislation. However, the detail to which they are considered and the level at which they are regulated differ widely. For example, whilst much of the environmental regulation about topics such as water or air quality stems from EU directives (von der Tann et al., 2018a), policies around basement development, if any, only exist at local level, mainly in the form of SPDs.

Other topics covered in the Local Plans might imply the intensified use of underground space without stating it explicitly; the promotion of high-rise buildings, for example, often entails deep foundations, and the protection of open space or efforts to recover open space might incentivise the construction of underground developments. In addition, 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. Table 4.3 lists policies in the New London Plan (Mayor of London, 2019) that have or could have an effect on subsurface governance, alongside related policies in the new Local Plans for the London Borough of Merton (Merton Council, 2018) and the City of London ('City Plan 2036', City of London, 2018). Here, what stands out is that apparently not all topic areas are relevant for all boroughs in terms of the development of their Local Plans and, thus, there is a local and topical variance in policies that guide planning decisions.

The discretionary nature of the planning system means that whilst the subsurface in the UK is owned by the surface land owner (cone shaped until the centre of the earth), including all mineral resources – except for oil, gas, coal, gold and silver, which are owned by the Crown (Minerals UK, n.d.) – there exists no legal right for the owner to develop their land, which would include the subsurface; 'however, there is a policy presumption in favour of granting planning permission, unless there are strong public interest reasons against this.' (Vigar et al., 2000, p. 12). Ownership of land – or, here, an underground volume – thus does not necessarily coincide with control over its use (De Mulder et al., 2012). For instance, as has been described with regard to the groundwater under London, the exploitation or extraction of resources is managed by the Environment Agency through permit or licencing regimes.

Table 4.3: London Plan Policies relevant for the urban subsurface (author's own selection)

London Plan Policy[1]	Relevance for the urban subsurface and description of London Plan Policies	Related Merton Local Plan Policy[2]	Related City Plan 2036 Policy[3]
GG2 Making the best use of land	Promotes the development of brownfield land. Remediation of contaminated sites is encouraged.	No specific policy	No specific policy
D8 Tall Buildings	States visual, functional, and environmental impacts of tall buildings. Impact on the underground is not mentioned.	D5.1 Placemaking and Design	S12 Tall Buildings and Protected Views
D9 Basement development	Suggests the development of basement policies for boroughs where this is identified as a local issue.	D5.10 Basements and Subterranean Developments	No specific policy
S5 Sports and recreation facilities	Establishes general support for proposals for sport and recreational facilities.*	O8.5 Leisure, Sport and Recreation	No specific policy
S7 Burial space	Protects burial spaces and promotes re-use or new provision.	No specific policy	No specific policy
HC1 Heritage conservation and growth	States that boroughs should improve access to, and interpretation of, archaeology within their area.	D5.5 Managing heritage assets	HE1 Managing Change to Heritage Assets
G1 Green Infrastructure	Promotes the protection and enhancement of green infrastructure.**	O8.1 Open Space, Green Infrastructure and Nature Conservation O8.2 Open Space and Green Infrastructure	S14 Open Spaces and Green Infrastructure
G4 Open Space			
G7 Trees and Woodlands	Protects trees and promotes an increase in tree coverage.***	O8.4 Protection of Trees	OS2 City Greening
G9 Geodiversity	Protects geodiversity and important geological sites.	No specific policy	No specific policy
SI10 Aggregates	Safeguards sites for aggregate extraction from development to protect access to resources.	No specific policy	No specific policy

Table 4.3 (continued)

London Plan Policy	Relevance for the urban subsurface and description of London Plan Policies	Related Merton Local Plan Policy	Related City Plan 2036 Policy
SI3 Energy infrastructure	Promotes use of decentralised energy systems and renewable energy, including geothermal. S7 City of London promotes pipe subways.	CC8.11 Reducing Energy Use and Carbon Emissions CC8.13 Maximising Local Energy Generation	S7 Smart Infrastructure and Utilities SI1 Infrastructure provision and Connection
SI5 Water infrastructure	Focuses on reduction of water main leakage, supports the Thames Tideway Tunnel.	No specific policy	
S17 Reducing waste and supporting the circular economy	Promotes reduction and recycling of waste, including construction and excavation waste. Includes under-ground construction.	W.6.3 Waste Management CC8.15 Circular Economic Principles	S16 Circular Economy and Waste
SI11 Hydraulic fracturing (fracking)	The Mayor of London does not support fracking.	No specific policy	No specific policy
SI12 Flood risk management	Includes ground water flooding.	F8.6 Managing Flood Risk From all Sources of Flooding F8.7 How to Manage Flood Risk	S15 Climate Resilience and Flood Risk
SI13 Sustainable Drainage	Stipulates a drainage hierarchy with a preference for green features, rainwater use and rainwater infiltration.****	F8.8 Sustainable Drainage Systems (SuDS)	SI1 Infrastructure Provision and Connection
T1 Strategic approach to transport	Promotes public transport and integration of land use and transport. The London Underground is a major part of public transport infrastructure in London.	T6.4 Supporting an Inclusive and Better Connected Transport Network	No specific policy
T3 Transport capacity, connectivity and safeguarding	Specifies that Development Plans should safeguard land used for public transport including new alignments, and also covering sustainable drainage and trees	T6.8 Transport Infrastructure	S9 Vehicular Transport and Servicing

* These are often imagined as being placed underground.
** Underground developments are sometimes mentioned as opportunities to provide open space above ground. This can lead to proposals to excavate below parks or create parks over existing structures (see, for example, the gravel mine, Rectory Farm (Rectory Farm, 2020)
*** Tree roots occupy underground space and can affect underground infrastructure as well as the structural integrity of adjoining buildings.
**** Infiltration techniques influence local ground conditions.

1 Mayor of London (2019)

2 Merton Council (2018)

3 City of London (2018)

Separate from the main planning strategies, the London Plan and Local Plans, a range of strategies and plans exist in different underground related sectors that are currently coordinated by mutual consultation between the leading institutions on draft versions, if not at an earlier stage of development. A few examples (without being comprehensive) are given in Table 4.4. The list shows that while joining forces across councils proves necessary for specific topics like waste or flood management, at the same time specific strategies are considered to be required, possibly because the corresponding issues are seen as too complex to integrate into an overarching plan, or more detailed plans are considered necessary to capturing local specifics. Table 4.4 also points towards the fact that whilst planning authorities play an important role in subsurface governance, there are many other relevant institutions and actors in the field. To obtain a clearer picture of those, the following section presents different approaches to the listing and categorisation of stakeholders.

Table 4.4: Plans affecting London's subsurface (author's own selection)

Issue	Plans	Primary responsible bodies in England/London
Flooding	Flood Risk Management Plans	Environment Agency
	London Sustainable Drainage Action Plan	GLA [Thames Water, TfL, London Boroughs for specific actions]
	Local Flood Risk Management Strategies	Lead local flood authorities (in London: Councils)
Renewable Energy/ Energy Supply	The National Renewable Energy Action Plan The Carbon Plan	UK Committee on Climate Change Defra
Groundwater	Thames River Basin Management Plan	Environment Agency
Water supply	Water Resources Management Plans Asset Management Plans	Water companies
Infrastructure	London Infrastructure Plan London Transport Strategy	GLA TfL
Waste	North London Waste Plan South London Waste Plan Joint Waste Development Plan West London Waste Plan	Waste Authorities

4.5. Organisational aspects: who has a stake?

The multitude of topics connected to the subsurface and covered in the planning guidance is necessarily reflected in the amount of institutions, organisations and individuals who are, in one way or another, involved with the subsurface. In this context, stakeholder analysis provides a tool for recognising multiple perspectives rather than creating a platform for negotiation. Who is assigned as having a 'stake' in a particular project or question is determined by the question at hand and, in turn, determines who will be involved in or able to influence decisions (Reed et al., 2009). As no subsurface specific planning strategy or regulation exists for London, and the discourse, as will be discussed, is so far limited to specific interest groups, the current thesis does not deal with an actual resource management issue or conflict in which different interest groups have claimed a position. Instead, it presents a hypothetical account of developing an underground planning strategy and, as such, a complete stakeholder analysis would not have been expedient. Consequently, in the following paragraphs, rather than presenting a conclusive analysis of stakeholders, different perspectives on the listing and categorisation of stakeholders are elicited in an analytical manner to create a rich picture of who has a stake in London's subsurface, and to discuss different starting points for a potential plan-making procedure. The different kinds of data collected for this analysis are presented in Chapter 3 (Section 3.4.1) and will not be repeated here.

4.5.1. Empirical findings

The Town and Country Planning (Local Planning) (England) Regulations 2012 require a local planning authority to invite and take into account representations by residents as well as specific and general consultation bodies, the former comprising governmental agencies and authorities in addition to statutory undertakers, and the latter representing voluntary bodies whose activities benefit the local authority's area, interests of minorities or disabled people, and business interests. Similarly, for specific projects the Planning Act 2008 requires 'applicants to consult affected local communities, local authorities, the Marine Management Organisation (where applicable), people with an interest in the land or who may be significantly affected by the proposal, and bodies prescribed in secondary legislation' (Department for Communities and Local Government, 2012).

There is a limited number of consultees who are prescribed in both sets of regulations and, as such, for plan making, as well as for project approvals, namely: local government, infrastructure providers and government agencies. These are listed in Table 4.5. Even if, ultimately, many more consultees will overlap between consultations for Local Plans and those for major infrastructure projects, owing to their prescription in both sets of regulation, those listed in Table 4.5 thus appear to have a more overarching role that operates on various scales, whereas all other consultees need to be identified in a manner that is specific to the authority or project location. Here, what stands out is that all but Highways England have a direct connection to one or more of the subsurface issues listed in Section 4.4.2., and one of them, the Coal Authority, was established exclusively to manage the legacy of an underground activity. This fact indicates that (a) subsurface topics are assigned relevance, and (b) they constitute overarching multi-scale topics.

As a second step of stakeholder categorisation, following the categorisation applied by the Environment Agency in their River Basin Management Plan (Environment Agency, 2015), the listed stakeholders were evaluated with regard to their role as either regulators of underground activities, operators undertaking those activities, influencers educating or advising on those activities or topic areas relating to the subsurface, or undertakers of underground projects. An additional category of 'base data provision' was created to help understand who is, or would need to be, involved in the establishment and operation of unified data bases about the geology, underground assets and land ownership. It is important to emphasise that Table 4.6 refers to London only, and that the category 'base data provision' was only assigned to those stakeholders currently producing and providing data, not to those who might hold data but do not currently provide it to other parties. As such, the list provides a snapshot in time, and alterations with regard to who provides data and thus who contributes to an evidence base for a potential subsurface strategy, are expected.

Table 4.5: Prescribed consultees for Local Plans as well as infrastructure projects

Consultee	Description
Affected planning authorities (GLA and Local Authorities)	Responsible for developing and enacting local strategies. Local Authorities are Unitary Authorities with responsibility for all areas of local government. They act as Lead Local Flood Authorities, responsible for managing flood risk from surface water and groundwater. Responsible for local planning decisions.
Statutory undertakers	Utility companies (mostly regional) and nationalised companies such as Network Rail that provide infrastructure services. Regulated by Ofwat (water and sewerage), Ofgem (gas and electricity) and Ofcom (communication technology). Water companies are Flood Risk Management Authorities managing risk from water and sewers.
Environment Agency	Non-departmental public body responsible for: - Regulating waste - Treatment of contaminated land - Water quality and resources - Strategic overview of flood risk management (all kinds of flooding) - Managing flood risk from rivers, reservoirs, estuaries and the sea.
Historic England	Non-departmental public body acting as statutory adviser to the UK government on all aspects of the historic environment, including archaeology.
Natural England	Non-departmental public body, responsible for protection and improvement of the natural environment, including its land, freshwater, and geology and soils.
Highways England	Government-owned company responsible for operating, maintaining and improving the strategic road network. Monitored by the Office of Rail and Road (ORR).
The Coal Authority	Non-departmental public body managing the mining legacy, including subsidence damage claims and mine water pollution.

Note: A more comprehensive list of consultees, as listed in the Planning Act 2008, and an example of consultee categories set out for a Local Plan and a specific project can be found in Appendix IX.

Table 4.6: Stakeholders of subsurface planning in London (author's own grouping)

Sector/Stakeholder	Role in managing subsurface activities				
	Regulator	Operator	Influencer	Undertaker of projects	Base data provision
Authorities					
Greater London Authority	X		X		
Local Authorities	X		X		
Regulators					
Ofwat/Ofgem/Ofcom/Office for Rail and Road	X		X		
Government and Agencies National/ England					
Environment Agency	X	X	X	X	
Historic England	X		X		
Highways England		X		X	
Ordnance Survey			X		X
National Infrastructure Commission			X		
Geospatial Commission			X		X
Natural England	X		X		
British Geological Survey			X		X
HM Land Registry					X
Government and Agencies London					
Port of London Authority	X	X	X	X	
London Waste Authorities and Waste Planning Forum		X	X	X	
Infrastructure Providers and Utilities					
SGN/National Grid/Thames Water/UK Power Networks/BT Open Reach/Virgin		X	X	X	
Transport for London		X	X	X	
Network Rail		X	X	X	
Professional Bodies (examples)					
AGS			X		X
BTS/ICE/RIBA/RTPI/RICS/BAA			X		
Centre for Digital Built Britain			X		
Interest and campaign groups (examples)					
Think Deep UK			X		
Urban Design Group			X		
National Infrastructure Planning Association			X		
National Joint Utilities Group			X		
Energy Networks Association			X		

Note: Research institutions, individuals, and individual companies are not shown.

In order to elicit independent views as to whom, of the stakeholders listed, is considered to be the most important when it comes to underground planning decisions, the interviewed tunnelling and planning experts were asked to list who, from their perspective, has a stake, and to rate how influential and how affected the latter would be by an underground planning strategy or planning decisions concerning the underground (see also Chapter 3, Section 3.4.2). The resulting data are illustrated in Figure 4.6. For the sake of readability, only those stakeholders or stakeholder groups are included that were mentioned by at least three participants. In addition, participants assigned similar ratings to all utility companies. Thus, these companies are consolidated as one group. The complete data can be found in Appendix XI.

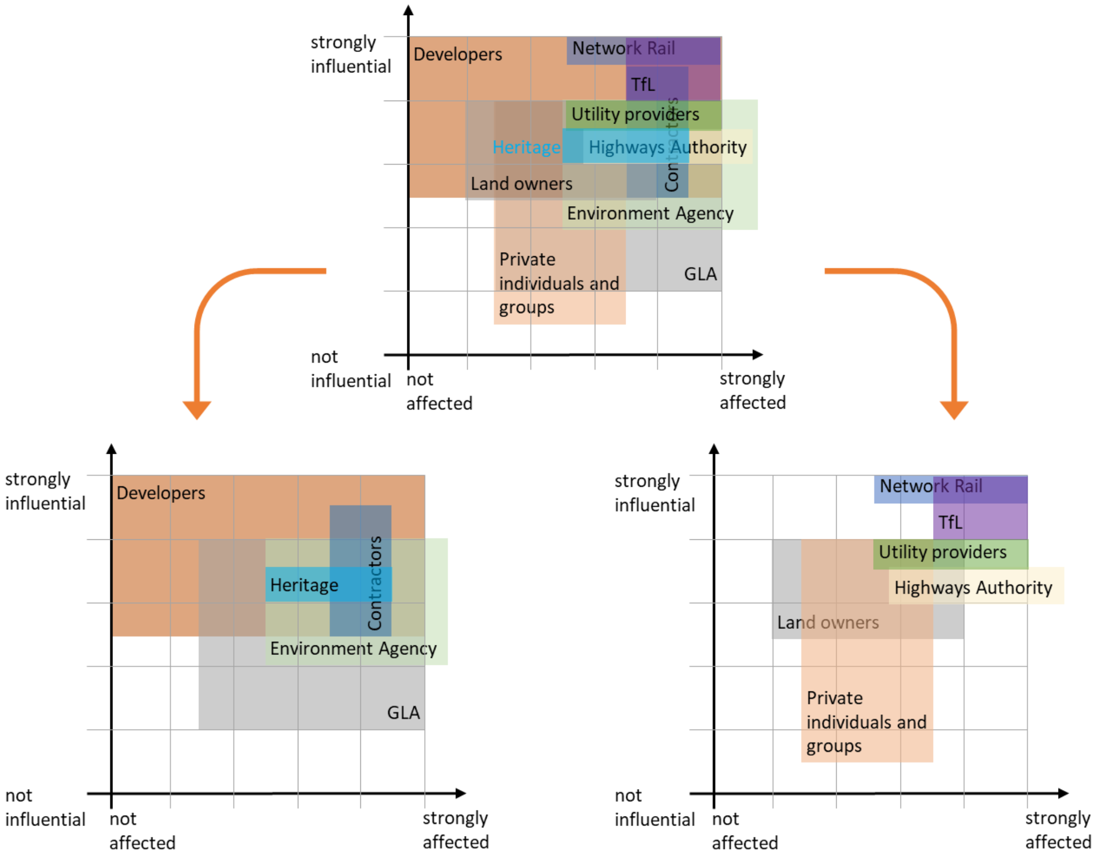

Figure 4.6: **Stakeholder groups and their level of influence on and interest in underground planning, as identified and rated by interview participants**

Note: To aid legibility, the map of responses (top) has been separated in two (below).

Figure 4.6 shows that there appears to be an agreement that infrastructure providers are highly influential to, and strongly affected by, underground planning decisions. Interviewees' ratings of the influence of and impact on private individuals, land owners and developers, as well as institutions like the GLA or the Environment Agency, showed a larger range. Participants commented that their rating of specific stakeholders would depend on the specific project or intervention planned. For example, one participant discussed how land owners and residents are only interested in strategic planning if their own piece of land is affected:

> You know, people don't look at what the Local Plan says until their next-door neighbour says: 'I would like to build six stories on my house and it says in the Local Plan "yes you can". (P09)

Another participant described how:

> Just one person objecting to a scheme could have a big impact on that scheme. The costs or the approach that is taken, or the programme for delivery is changed immensely through perhaps one group or one person saying they don't like this idea. […] And I've seen that happen. (E08)

These quotes show that the level of influence depends on the level of interest that certain stakeholders might have in a project and, in turn, how strongly affected they would be; thus, the two axes in Figure 4.6 are not completely independent at project level. The former quotes also emphasise that individuals might see themselves as mostly affected by specific projects rather than strategic planning decisions or, vice versa, only individuals directly affected by specific projects are considered to have a stake. Only one participant named the public as a stakeholder, referring however specifically to passengers (see Appendix XI). In this context it should be noted that given the participants' expertise, this illustration represents mainly their views on the stakeholders of underground projects, rather than on who should have a stake in a potential plan making process (see also Chapter 5).

The groups in Figure 4.6 overlap largely with those who are assigned multiple roles in Table 4.6, ultimately designating three groups as key stakeholders for the development and establishment of a potential underground planning strategy in London:

a. Infrastructure and utility providers
b. Authorities and government departments
c. Local and national government agencies.

One additional point needs to be made: in addition to these specific stakeholder listings in the London setting, general discussions were held and observation notes taken in groups consisting of stakeholders engaged in the area of subsurface planning, in particular TDUK, ITACUS and COST-suburban. In these groups, discussions about who needs to be involved in the process towards integrated underground/ subsurface management focus more on the necessary expertise than on the specific institutions or organisations. In particular, the following professions were repeatedly listed:

a. Engineers (Tunnelling, Geotechnical)
b. Geologists

c. Urban planners
d. Architects
e. Legal experts
f. Archaeologists
g. Economists
h. Data Scientists.

This kind of categorisation may be considered meaningful as these interest groups seek a general examination of the role of the subsurface in cities and the development of transferrable principles. It also shows that in order to realise a meaningful process of working towards a new policy or strategy, expertise from various disciplines is required in addition to the representation of relevant institutions and organisations. For a specific local solution to be found, it has to be understood how this expertise is embedded in the local institutions and organisations involved in planning that were previously listed. These interactions will be discussed in the next section, subsequent to a brief consideration of feedback loops between the material reality and the social context described. Both provide the basis for a discussion of the current discourse – or lack of discourse – around subsurface planning in London.

4.6. Analysis and discussion: the governance arrangement of London's subsurface

The insights into London's subsurface presented in the previous sections illustrate that the subsurface, the materials within it, and the functions it serves – including the provision and filtering of groundwater, space for underground tunnels and archaeological heritage – have had a profound effect on how London developed, and vice versa. The described material reality (the geology and human legacy present in a location as well as environmental processes), together with the social context provide the baseline for the development of a potential new policy and the discussion of whether such a policy is needed, what its specific purpose would be, and – if such a need is established – if it should be integrated into existing plans or constitute an independent area of planning and governance.

Following a closer consideration of feedback loops between the material reality and the social context, as illustrated in Figure 4.1, this section will first examine the organisational aspects, the connections between policies and actors as described in Sections 4.4 and 4.5, and the particular position of engineers. Following this, the section will focus on the dimensions of discourse, or substantive aspects[5], reflecting on the rationale and purpose for a potential underground planning strategy, and the discourses present.

4.6.1. Feedback loops between material reality and social context

The examples given in Section 4.3 illustrate the deep entanglement between the built environment in London and the geology present. Based on the social context, humans plan structural interventions, such as the London Underground, that, once completed, become part of the material reality and, as such, constitute boundaries for any future intervention. 'The result of human action gets internalised in the system and acted upon' (von der Tann et al., 2016, p. 361).

The continuous management of the Chalk aquifer is an example of how human interventions led to lasting changes in an underground system and to circumstances that have to be managed over the long-term. The resulting expenses have been termed 'eternal cost' in the context of resource exploitation. For example, as a consequence of coal mining in the Rhein-Ruhr area in Germany, the land in the area has settled up to 25m (Ringelsiep, 2014). The reestablishment of the natural water regime would flood large areas of land, and rain water penetrating into the old mines could cause the contamination of groundwater. The costs of managing the water system in this area are estimated at 300 million Euros per annum for the first few years (RAG Stiftung, 2019).

The London example differs in that the extracted groundwater is being utilised and, as such, is currently fed back into the urban water cycle (Bricker et al., 2017). However, in both cases the original intervention was focused on the short-term benefits and the consequences for eternity were not foreseen. The irreversible change of material reality led to the formation of a new policy arrangement. The continuous management of the water regimes became necessary because the built environment in the respective areas was developed on the basis of the water regime at the time of development. It is these kinds of 'eternal cost' that an underground planning strategy would seek to pre-empt – either though preventing the intervention in the first place or by incorporating the effects of discontinuation into the design of the structures that might be affected.

Open loop ground source heating and cooling schemes provide an illustrative case. In these schemes, heat is abstracted from groundwater that is later re-injected back into the aquifer

[5] Liefferink et al. (2006) refer to the dimension of discourses as 'substantial' (Liefferink et al., 2006, p. 47). However, as this dimension entails the narratives, different viewpoints and discussions held, 'substantive' appeared more apt and is thus used in the current Chapter.

(Horobin, n.d.). For the heat pumps to work efficiently, they rely on a specific temperature difference between the water and the surface air. In London, the Environment Agency has reported an increase in water temperature, leading to some schemes becoming less efficient or inoperable (Management of the London Basin Chalk Aquifer, 2018). Whilst not yet generating ongoing expenses, investment into these schemes might not have been profitable as the rise in temperature was not foreseen and, consequently, not accounted for in the original design and calculations of profitability.

These feedback loops between the material reality and human activity confirm that the use of the underground is 'very much situational' (Suri and Admiraal, 2015, p. 5), but also demonstrate that the picture of a 'chaotic' space is somewhat misleading. Rather, some specific elements – in this case, the groundwater table – are highly managed in order to avoid effects on the built and social environment. The notion of 'incidental interventions' (Admiraal and Cornaro, 2016, p. 215) is also deceptive, considering the amount of functions, institutions, people and regulations that govern the space. However, the examples discussed here illustrate that the spatial dependency of different functions, planning guidelines and decisions are not sufficiently understood or integrated. The interaction between spatial planning and flood risk, for example, is still mainly treated as one-directional in that the water system is managed according to approved land uses, rather than land uses responding to changes in the water system (Tempels, 2016). A similar observation can be made for most of the categorisation systems presented in Chapter 2 (Section 2.4) – all but the categorisation by Hooimeijer and Maring (2018) that implicitly includes a duty of care for 'soil' – as they are one-directional in presenting the possible utilisations of the ground by humans and do not mention the influence that humans exert on the ground.

This observation contradicts the data about areas of archaeological interest, as well as the more general description of anthropogenic layers and man-made ground presented in Section 4.3. Whereas the latter are direct descriptions of human alterations of the geology, the former is an example of where a function that was up until recently fulfilled by the geological subsurface, namely, the provision of space, has now been transferred to volumes and materials that are man-made. A similar observation can be made for the provision of construction materials. Whilst London is currently largely dependent of imports to cover the need for construction aggregates, the GLA estimates that 15%-43% of aggregates could have been covered by the re-use of construction, demolition and excavation waste in the years 2008-2017 (GLA, 2018). In this way, such construction waste takes the space of another function usually assigned to the subsurface: the provision of materials. The recognition of this replacement of subsurface functions by man-made materials not only strengthens the proposition to define the current geological time period as 'Anthropocene' – that is, as human-influenced, as first declared by Crutzen and Stoermer (2000) – but also reinforces the notion that the concept of the Anthropocene is fundamentally linked to the underground (Melo Zurita et al., 2018).

4.6.2. Organisational aspects

The concept of underground governance is commonly placed in the urban planning domain, which is understood as the development and implementation of strategies and plans to regulate and balance the various potentials and current uses of land (see Chapter 2, Section 2.4). When urban planning is referred to in the context of the urban subsurface, it is often imagined as a detailed land-use plan setting out fixed locations for specific types of developments or infrastructures. However, the concept of masterplans setting out fixed allocations of space has been challenged in recent years (see Chapter 2, Section 2.3.3.1) and, as has been described in Section 4.4, whilst this kind of *binding* planning policy is prevalent in most of the European countries, planning in the UK is *discretionary*, meaning that the plan is a document that provides general guidance, but any project or development decision is 'subject to administrative and political discretion,' (Albrechts, 2004, p. 744) resulting in a 'notable absence of certainty' (Albrechts, 2004, p. 744). In this context, planning is supposed to guide developments to be in accordance with the various policies – for example, to make sure that developments in areas with a high risk of flooding take appropriate measures. As such, any concept for an underground plan or strategy would, arguably, have to help the integration of these policies, be based on the local context, and be integrated in the landscape of plans, strategies and regulations already present.

Figure 4.7 illustrates how the stakeholders and policy documents listed in Sections 4.4 and 4.5 are connected, using the examples of flood risk and waste management (for flood risk see Alexander et al., 2016). Local planning authorities (LPAs) have a dual role in that they prepare and adopt the Local Plan (in accordance with the NFFP and the London Plan) and, at the same time, are responsible for evaluating planning applications. In doing so, they are required to ensure that an application is in accordance with the plans and policies set out. Equally, the key stakeholders identified in Section 4.5 and responsible for the subsurface related plans and strategies set out in Table 4.4 are often involved in plan-making, but also act as consultees for specific planning applications. However, it is the responsibility of the local planning authorities (LPAs) to consult the relevant stakeholders with regard to a planning application (see Table 4.5); Figure 4.7 shows the central position of the LPA as a linkage point between strategic planning and project decisions.

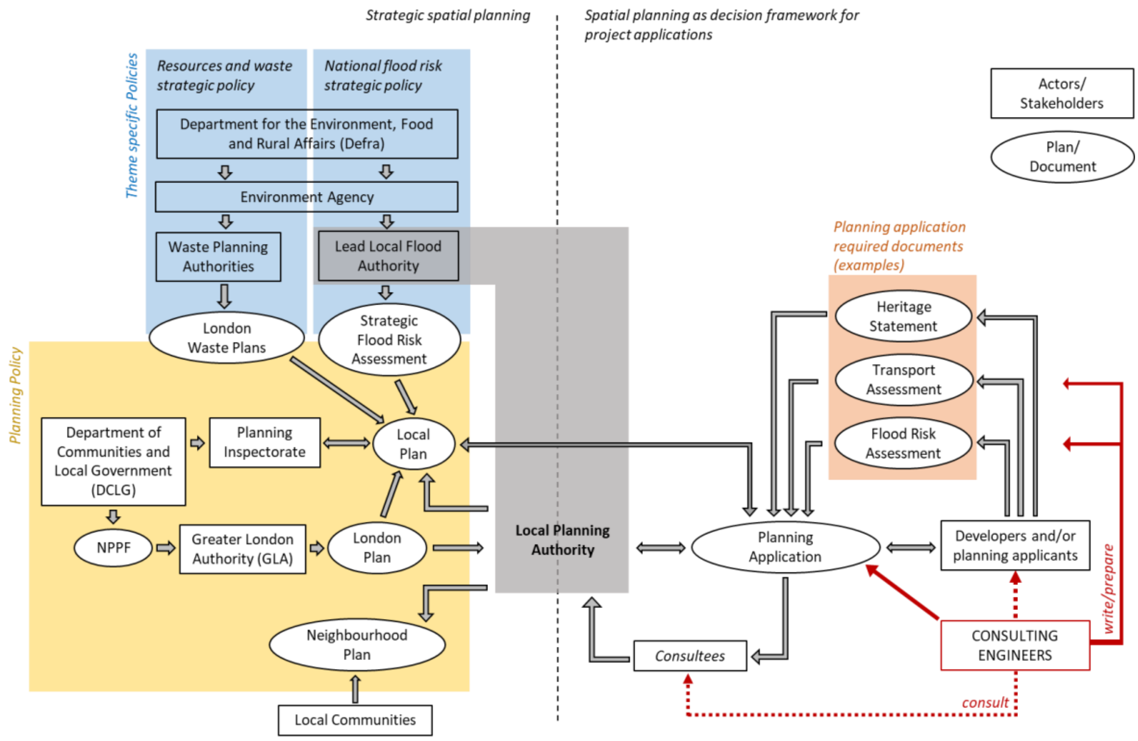

Figure 4.7: **Connections between actors, policies and instruments involved in spatial planning and two examples of underground-specific topics (amended from Alexander et al., 2016)**

A second aspect illustrated in Figure 4.7 is how the strong feedback loops and pathway dependencies between the material reality and the social context described in Section 4.6.1 put those groups who have the resources to change the material reality in a central position. Developers of buildings and infrastructure who have or are able to raise the required financial resources play an essential role. However, to be able to capture the described feedback loops and establish a bidirectional – or even multidirectional – understanding of the interaction between spatial planning and subsurface functions, a comprehensive understanding of the material substance and processes taking place is required, placing technical and engineering knowledge in a key position for mediating this space. Engineers not only design the temporary support and final structures, but also compile supporting documents, such as transport assessments, and serve as consultants to consultees. This is particularly prevalent in the context of the underground, where even small projects require an intervention in a material present. As all stakeholders require technical explanations to be able to form an informed opinion on suggested plans or projects, the role of engineers is to learn from existing projects, capture the newly produced knowledge when new projects are implemented, and develop and convey an understanding of the complexity of the urban subsurface as well as the embedded infrastructure systems (Nelson, 2016). Engineers thus serve as intermediaries between specific projects and the various stakeholders, and occupy a position of high responsibility and power.

The list of plans affecting London's subsurface, collated in Section 4.4.2 (Table 4.4) and reflected in Figure 4.7, illustrates how complex governance issues currently continue to be managed by being divided into tasks perceived as manageable. However, when everything is physically located in the same space and thus spatially interdependent, a different approach may need to be considered. The question of how a change in governance could come about, and whether the current discourses might lead to such a change, will be discussed in the following section.

4.6.3. Substantive aspects

The identification of knowledge as a powerful resource for interventions into the subsurface offers an explanation for the observation that a lot of the literature about underground planning stems from the engineering discipline (see Chapter 2). It appears to be consequential that for engineers, who plan and implement spatial interventions, the main rationale of a strategy, as stated in the literature, can be summarised as the improved spatial coordination of subsurface functions and the efficient use of space. The rationale or approach towards an underground planning strategy can, however, differ when people are writing from different disciplinary perspectives – even if there is no explicit discourse, experts approach the topic from a different standpoint. For instance, geologists might frame their objective for a new approach as an optimisation of the interaction between humans and geoservices, with a focus on the processes that explain how certain formations came into existence, allowing the geologist a meaningful interpretation of point data and model building. Lawyers writing about the field might focus on the allocation of ownership and refer to rights as well as the prioritisation of conflicting uses. Ultimately, planners might ask how subsurface conditions, its uses or potentials can influence strategic themes and objectives.

Clearly, these topics overlap, and an integration of various areas of expertise is required in order to provide a strategy going forward. In light of the previously described structures, it becomes apparent that whilst the planning system sets out a framework to balance different interests and topics, particular aspects are addressed separately and only come together regarding specific planning applications or projects. However, whilst internationally the discourse – and, consequently, allocated resources – around the role of the subsurface in urban planning is starting to gain momentum, in the UK this has, to date, been limited to specific interest groups such as TDUK, and to a few cities, in particular Glasgow. Thus, for London, targeted resources – here referring to the assets that actors can mobilise, including funding, knowledge or technology (Wiering and Arts, 2006) – are mobilised only in these specific contexts, and no resources are allocated directly to the topic itself. Consequently, even the starting point for a subsurface planning strategy remains vague.

4.6.3.1. Purpose of an underground strategy

The latter observations signal that the starting point, or main purpose, of establishing an underground strategy may already be controversial. The purpose of a system defines its boundaries and determines how the system will be analysed, or what it will be measured against. As such, understanding and agreement about the purpose of a specific intervention as well as the establishment of a new policy, strategy, or framework, is crucial for their respective acceptance and evaluability, as well as for definition of the necessary next steps. The strategies presented in Chapter 2 (Sections 2.3.3.1 to 2.3.3.3) all focus on the spatial allocation of different functions, either through the establishment of a masterplan, or through the efficient weighing of different potential functions for the same volume. In practice, underground masterplans remain few, and other ways of integrating knowledge about the subsurface and related opportunities into urban planning are gaining importance.

The City of Glasgow, for instance, took part in an European research project that aimed to provide better subsurface information to support decision makers (COST sub-urban). This engagement has led to the integration of the subsurface into Glasgow's new City Development Plan. The plan, adopted on 29th March 2017, explicitly makes reference to the subsurface in that it includes geodiversity in its policy on the natural environment, and committed Glasgow City Council (GCC) to addressing subsurface infrastructure as well as ground source heat in a supplementary guidance document on resource management (GCC, 2017a, 2017b). In line with the overarching project, the intention for the integration of the subsurface into urban planning here was to provide a better understanding of the subsurface in order to aid decision makers in the realm of urban planning, rather than to establish an independent strategy. GCC focusses its efforts on building knowledge about the subsurface in the local authority, and at the same time building an understanding of which data about the subsurface could be useful for planning considerations.

Following these observations, it appears that rather than an independent strategy, the common denominator between the different disciplines, and thus the purpose of the overarching discourse, might be to seek a better explanation of the (three-dimensional) spatial and material dimensions of various policies and strategies on all levels in such a way that the long-term impact on the subsurface, and the functions that it embraces, come to be recognised.

4.6.3.2. Urgency

Considering the origins of planning more broadly, the reason for establishing an urban planning regime in the first place can usually be traced back to the industrialisation and issues of public health and housing – urgent problems that affected individuals at all levels of society, as well as the society as a whole, and ultimately led the government to take action. A similar urgency is described for the recently established area of Marine Spatial Planning (MSP), into which the traditional realm of spatial planning has been extended (see Chapter 2, Section 2.6) owing to increasing concerns about the conditions of marine ecosystems (Jay et al., 2012).

Appendix XVI presents a juxtaposition of the conceptual and practical elements of MSP with the elements of urban planning, and the particular elements of what a strategy for urban subsurface planning could look like. In the context of the current argument, it is noteworthy that the urgency of introducing a specific planning strategy for underground space is much less extensively articulated than that for urban planning or MSP. The purposes previously mentioned for the establishment of an underground planning strategy usually concern the economic development of a region (see, for example, McNeill, 2019), and even if a shift towards economic drivers has also been observed for urban planning strategies in general, the question can be raised whether the establishment of an underground planning strategy in London shares the same urgency.

Following these remarks, and independently of the form that an underground strategy could take, the establishment of a planning strategy for the underground or the integration of the underground into urban planning does not appear to constitute an area of urgent action where the problem is already at hand but, rather, could provide an opportunity to pre-empt specific problems that are predicted to occur. For instance, in the City of Glasgow it was found that the poorer part of the population was exposed to pollution originating in brownfield sites, leading to a lower life-expectancy in these specific areas (Dick, 2017). These kinds of examples indicate that whilst specific problems like urban sanitation systems or general concepts, such as those relating to MSP, allow for the development of transferrable technological solutions and the definition of drivers, the urgency of establishing a planning strategy for the subsurface can only arise and be answered locally. Local drivers include land scarcity above ground, prospects of intensified use, congestion in the subsurface, or, more recently, responses to climate change.

4.6.3.3. Enabling mechanisms

Despite the lack of discourse about the integration of the subsurface into planning in London, related discourses have gained awareness and mobilised significant resources. These can serve as enabling or 'bridging mechanisms' (Alexander et al., 2016) that facilitate the cooperation between stakeholders or related policy arrangements, and thus help to overcome the described sectoral fragmentation. For example, the increase in the number of basement developments triggered a public discourse in the media, mainly with negative connotation assigned to these developments, reflected in terms such as 'millionaire basements' (BBC One, 2015). Baldwin et al. (2018) mapped residential basement developments across seven London boroughs between 2008 and 2017 and discussed how these are emblematic of the 'profound plutocraticisation' (p. 17) of London, extending the notion of control by the super-rich into the subsurface. This discourse has led to increased awareness of the topic and the development of specific policies in a growing number of London Boroughs, as well as an acknowledgement of the issue in the London Plan (see Table 4.3). The example shows that the public can claim agency on subsurface related topics when it is made aware of and feels affected by projects and will thus demand adjustments of policies by their local planning authorities. As expressed by one of the interviewed participants (see Section 4.5.1), this kind of response usually only gets triggered if there is a direct effect of a particular scheme on specific people or groups. This bears the question of what is required to activate public response and involvement if the impact of measures taken is less direct than for specific projects or regarding more overarching planning efforts.

In addition, in London and the UK, the discourse around data management and sharing, in particular of utility data, is gaining momentum (see von der Tann et al., 2018a). The efforts currently undertaken aim to improve the situation by providing spatially referenced data. In particular, at shallow levels of the subsurface, insufficient spatial coordination appears to persist (see, for example, Likhari et al., 2017), and efforts such as the one by the Geospatial Commission who, in April 2019, announced the ambition to create an Underground Asset Register (GOV.UK, 2019), can serve as bridging mechanisms that not only facilitate better coordination between stakeholders, but also initiate spatial integration between the different subsurface topics that are aligned with the overarching purpose of a strategy, as previously outlined. Through the process of data integration, several of the stakeholders listed in Table 4.6 as undertakers of projects as well as asset owners will become data providers. This change in role towards managing the subsurface might trigger a change in discourse and mobilise additional resources.

In addition to specific topics, overarching themes, such as urban resilience or responses to climate change, can constitute a discourse that bridges different disciplines and may thus enable integration processes. The example of Glasgow shows how discourses about energy provision (Glasgow is looking into extracting heat from waters in abandoned mine workings, see British Geological Survey (n.d.-b)), or inequality can lead to a recognition of the subsurface and integration of the respective considerations into planning.

Furthermore, institutional or organisational stakeholders bridge different categories of subsurface usage and would thus have an opportunity to foster improved coordination within their particular organisation. The central position of the LPAs in the current arrangement, and the powerful position of technical knowledge highlighted in Section 4.6.2, beg the question of how the necessary knowledge is provided to or within the authorities. The fact that planning permission needs to be granted and requires judgement means that well informed, independent 'judges' are needed.

4.7. Summary

This chapter has illustrated the context and governance of London's subsurface. The underground location of tube lines, the management of the deep aquifer, the provision of mineral resources and the prevalence of artificially modified ground or areas of archaeological interest were presented as examples of the co-evolution between the development of London as a city and the use or formation of its subsurface. Following an introduction into the urban planning regime in London and an evaluation of the most relevant stakeholders, the current governance arrangement around London's subsurface was analysed and discussed, employing a modified version of the policy arrangement approach developed by Arts et al. (2000). For a specific moment in time, the original approach distinguishes between the organisational aspects (actors, rules, and resources) and substantive aspects (discourses) of a policy arrangement. In the current chapter, material aspects were added, as these are understood as an essential basis for the study of subsurface governance.

This chapter also highlighted that feedback loops between the material reality and the societal context, or, more specifically, human influences on the material reality, are not sufficiently recognised, with a demonstration of how the discretionary nature of the UK planning system puts LPAs, on the one hand, and engineers and technical knowledge on the other hand, in powerful positions to mediate strategic plans and influence specific project applications and decisions. By way of comparison, the introduction of Marine Spatial Planning in recent years presents a case to which a strong sense of urgency – and, thus, a well-defined purpose for establishing a new plan or strategy in the spatial planning domain – can be ascribed. Despite the fact that, following the data presented here, no sense of urgency could be assigned to the concept of underground space planning in London at this moment in time, there appears to be a need for recognition and better understanding of the spatial and material effects of specific interventions, as well as of the policies and strategies. Current discourses around data management or energy provision could facilitate the process towards a spatial integration of the various strategies that are in place.

Following this analysis of mainly secondary data, the next chapter will consider in greater detail how London's subsurface and the potential for a planning strategy are perceived by engineers and planners – those professions here determined as most central or powerful in the current policy and governance arrangement.

5. An underground strategy for London: insider perspectives

Tunnelling Engineer: 'The ground conditions, the geology, a lot of it is still unknown. I mean we know what the stratigraphy is in London, but there is quite a lot of detail within that stratigraphy that we don't understand properly yet and we don't know about.' (E06)

Urban Planner: 'Archaeology is a big issue [in Inner London]. There are layers and layers of archaeology. Anywhere that hasn't already had a building, basement or subsurface structure built, there would be archaeological studies needed to look at what's down there.' (P09)

Tunnelling Engineer: 'The piecemeal development of the underground assets and the piecemeal development of the standards, for example fire ventilation etc. mean that every scheme has had its own rules.' (E08)

5.1. Introduction

The above quotes show that the three topics presented in the previous chapter – geology, history and society – are not only present in the discussion about urban underground management, but also unresolved. The quotes signal that: the geology in London is too complex to be understood to the degree necessary for projects to cover all uncertainties; historical layers remain unknown and will only be excavated once a construction project is underway; and the planning frameworks within which big infrastructure projects are taking place are continuously evolving leading to a different set of rules for every project.

As presented in Chapter 2, research that reports stakeholders' voices on the urban subsurface, and analyses of these voices that go beyond a purely empirical understanding of the field are scarce. The current chapter begins to fill this gap by presenting a thematic analysis of interviews that were conducted between November 2016 and March 2017 with tunnelling and planning professionals in London. 11 of the 16 individuals interviewed were tunnelling or geotechnical engineers with extensive experience working on projects in London's subsurface. As such, the analysis represents the specific views of engineers working in the field and reflecting on the particular situation in London. Additional interviews with an architect and four planning professionals, who engaged with the topic of subsurface management on a more general level, but who have also worked in the London context, provide a point for reflection and contrast, and help to bring the engineers' views into clearer relief. It is here also recognised that there is not a singular engineering perspective; it might differ between interviewees. To enable the reader to distinguish between interviewees, in the following sections the participants who are engineers will be labelled with the letter E, whilst participants who are planning professionals, including the one architect interviewed, are labelled with a P. Regarding the use of pronouns, even though four of the interviewees were women, the male pronoun will be used throughout so as to not reveal the identity of the participants. For a more extensive description of the methodology, see Chapter 3, Section 3.4.2.

The analysis of these different actors' perception of the subsurface builds on the understanding that the statements made by participants reflect a broader meaning informed by the socio-cultural context of each participant that can be elicited in such an analysis (Braun and Clarke, 2006). The analysis of what participants perceive to be the reasons for building in the subsurface and what the subsurface represents in further context of these developments, provides the context for asking if there is a strategic need for improvement. The approach followed here is inductive, that is, the themes and meanings presented emerge from the data rather than representing an organisation of the data according to a predefined framework. The analysis is complemented by literature references to explain the context.

5.2. Perceptions of the underground and strategic need for improvement

Approaching the idea of how the subsurface is governed from a systems perspective, having an awareness of, and reflecting on which elements of a problem description reflect a specific worldview is crucial (see Chapter 2, Section 2.4, Pericoulis, 2010). Any intervention or strategy builds on an understanding of what is there at a given moment and where change is needed. The former can, at least partly, be described in an empirical way, as presented in Chapter 4. The need for change, however, will always reflect the specific worldview of the decision maker or person discussing it (Blockley and Godfrey 2017). As such, in the analysis that follows participants' general perceptions of the subsurface are elicited, and a deeper level of meaning is then assigned to the reasons for building in the underground before inferring and discussing areas of strategic need.

Chapter 2.4 reviewed how subsurface uses are categorised, showing that major differences exist even in basic terminology describing what is listed as a use or function in the first place. In all of the categorisation systems proposed, however, one or more of the use categories describe 'space' or built developments. Perceptions of the subsurface and the need for a strategy are here explored primarily with regard to those developments. While the interview guide (see Chapter 3, Section 3.4.2) was designed to give participants the space to speak about other topics, such as underground resources or water, the bulk of the interviews was conducted with tunnelling engineers whose professional role is directly connected to creating underground structures and – contingent to their profession – engineers spoke primarily about built space. Thus, the following analysis focuses on these developments. The thematic map shown in Figure 5.1 provides an overview over the findings and the key areas of focus of this section, as follows.

It became apparent that two rationales were reflected in the reasons for building in the subsurface, as stated in the interviews: going underground as opportunity and going underground as imperative (Section 5.2.1). The general discussion about the urban underground in London indicated two different, overarching perceptions. On the one hand, the subsurface and spaces created within it were seen as assets, in that they embody value. On the other hand, these assets in the subsurface, including the geology, were seen to represent a constraint to the development of future assets and thus to the future development of the city (Section 5.2.2). The analysis of expressed needs for strategic change and the barriers to those directly followed from both – the reasons for developing such spaces within the subsurface and the perception of the subsurface in general (Section 5.2.3). Ultimately, a juxtaposition between the interviews held with planning professionals and those with engineers enabled the analysis to elicit where the described perception might be specific to the engineering profession (Section 5.2.4).

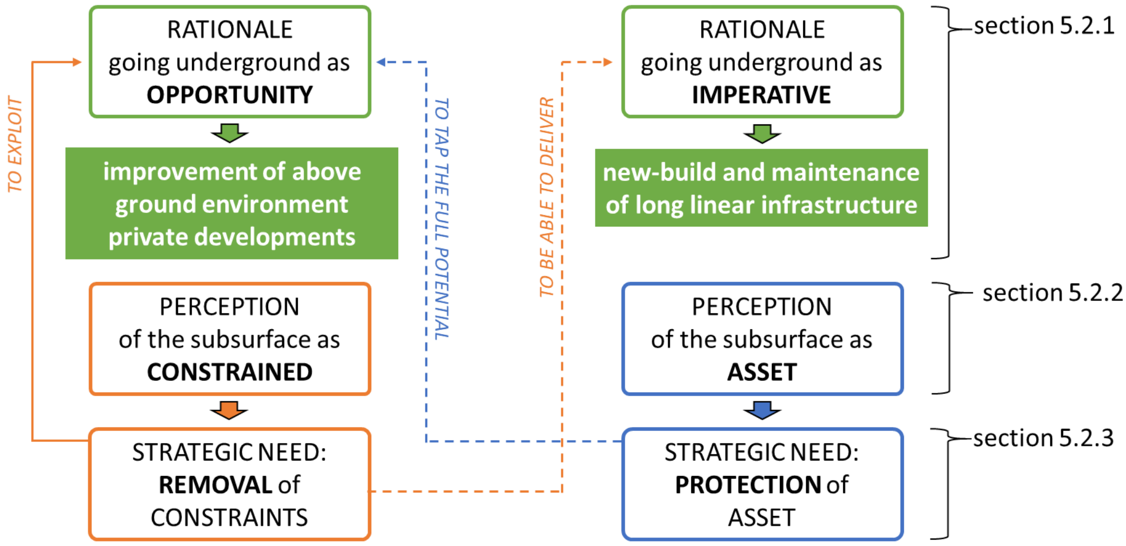

Figure 5.1: Perception of the underground – thematic map

5.2.1. Rationale for subsurface development: opportunity versus imperative

The ways in which the reasons for building in the subsurface, or the drivers for subsurface development, are specified is interrelated with the categorisation of subsurface functions, as discussed in Chapter 2 (Section 2.4). Still, whilst the compatibility of different functions might be listed in some publications (see, for example, Le Guenan and Gravaus, 2016), no hierarchy is established between the drivers or use categories. From the interviews conducted here, it emerged that whilst there are some general enablers of, or constraints to, underground development, there is a distinction to be made with regard to the perceived necessity for specific structures to be placed underground. While this necessity is implicit in the lists of drivers for underground development, it is also important to make it explicit for the following analysis. As previously mentioned, the focus here is on the development of space, i.e., engineered structures. The main themes that emerged are discussed in the following paragraphs.

5.2.1.1. Going underground as opportunity

Improving the conditions on the surface and economic gain were the two main topics under which the participants described building in the underground to be an opportunity. Specifically, protecting people from the above-ground – natural – climate, lack of space above ground and improving the amenities of the above ground city or landscape were mentioned. E13 raised the critique that this opportunity is often missed:

> Look […] at the M25 for example. And imagine how beautiful the landscape around London was before the M25 got built. […] How many tunnels are on the M25? Just leave that one with you. A27 around Brighton. Can you look at Brighton being nestled in the South Downs surrounded by beautiful hills? How many tunnels are there around Brighton? One. How many should there have been? Probably three or four. […] And that's gone, that landscape is gone. Partly because they value agricultural landscape in agricultural terms and not in landscape terms and there is no way in these government regulations of valuing the landscape.

This participant describes how placing infrastructure below ground can protect landscapes that would be significantly affected by above ground roads or rail tracks. The decision for building transport infrastructure above ground is assigned to a fallacious assessment of the value of the affected landscape. E13 further explained that in urban spaces, building these infrastructures below ground provides an opportunity for improving or protecting the above ground landscape or urban space, and is also connected to an opportunity for the economic development of that space:

> I learned that sort of thing in Italy, where the city of Turin […] realised [that] the surface railways were a blight on the economic and social development of the city. […] You know, roads we can cross. Railways, some of these are major barriers to social and economic development. So, they've gone back and

> undergrounded […] all the infrastructure. […]. And actually, it brought a huge benefit to the city.

Whilst this interviewee criticises the decisions for allocating space to specific infrastructure schemes, either between an above-ground and a below-ground solution, or between different potential routes, the need for the infrastructure itself was not questioned by any of the interviewees. In other words, none of the participants stated doubts or raised a question about the necessity or justification for these schemes. This differs to the participants' descriptions of vertical developments, especially basements, where they could see the opportunity for the land owner, but questioned their necessity and thus their justification; for example:

> You can't get around the speed on the surface that you can in a tunnel underground. So, I think from a transport network perspective, I think it's justified [to construct them underground] and I think underground railways are a very good solution to a lot of the problems that we have. From the perspective of rich property owners that live maybe in western parts of central London and want big massive basements to increase the value of their houses and put garages and cinemas and swimming pools in, I think that's probably less justified. (E06)

This quote expresses an essential difference between horizontal infrastructure, associated with public needs, and vertical developments that are associated with private opportunities. Whereas for the latter the decision for approval is directly tied to the location and the evaluation of 'need' correlates with the planning assessment, for the former, the need arises as response to urban development, and the evaluation of and decision for possible locations follows. If the need is established upfront, going underground can become an imperative.

5.2.1.2. Going underground as imperative

The perception that for specific structures, in particular long linear infrastructures, building underground is an imperative, i.e. there is no other option, came up repeatedly throughout the interviews. The perception of this imperative was linked to the evolution and density of the city above ground, such as in the following quote: 'cities get to a certain point where they have to go underground. Because there are too many conflicts of physical movement at surface level.' (P04)

Similar to when building in the subsurface is perceived as an opportunity, as discussed in Section 5.2.1.1, here the necessity for building below ground emerges from a reaction to what lies at surface level. The imperative to go underground arises from the existing density of construction and movements above ground, which in itself develops and grows over time until an intervention above ground is perceived as impossible. At the same time, participants described density as requisite for underground metro systems in that a certain density is necessary in order to make the provision of metro access feasible: 'you can't put a metro in an urban sprawl. It doesn't work very well. You need a greater density [of] population.' (E07). As such, in particular for newly accessed areas, the form of public transport provided and the density of urban areas was seen to co-evolve, rather than one preceding the other. This aspect is also captured in the following quote:

> Even though you're building a, you know, 20 story building above ground, the foundations then go 40m below. That creates a below ground of an island. […] Those [developments] are linked to transport nodes. […] [Developers] are dependent on them and they work with them, but they affect them. (P01)

In addition to the connection between the provision of transport and dense developments, this quote emphasises that any above ground development has an underground element. While the shape and depth of this element depends on the structure as well as the geology present, any building above ground requires a foundation. Hence, whilst the imperative to occupy underground space might comprise mainly long, linear infrastructure, the realisation of vertical developments also depends on the provision of bearing capacity and the necessary space for the required foundation. However, the options for space allocation underground were described as less flexible for infrastructure than for vertical developments:

> Transport is a different issue in a way to development of office buildings for example. […] With the underground, if it's a transport network you're connecting A and B. […] I think perhaps it's just long, linear projects like that, and they have a particular social need as opposed to office buildings, where if you've got a constraint, say you can't build over five stories there, someone would say, well we'll go over there and build it there instead. You can't really do that with a transport scheme, because the whole objective is to connect certain areas. (E06)

The interviewee here expresses how the necessity for placing infrastructure underground is directly linked to its specific route or destinations. Again, this refers to a point in time when the need to supply a specific area with infrastructure has already been accepted. Changing the route would fail to meet the original objectives or purpose for building the infrastructure. Imposing constraints on the development of these schemes, similar to sightlines above ground, would thus create a constraint on formulating new ambitions for the development of urban infrastructure.

The imperative for major infrastructure schemes to be placed underground, as stated in the interviews, did not only include transport schemes. Sewers have been placed underground for centuries: the first underground sewers were built in Roman times, and, at least since the installation of the system designed by Joseph Bazalgette in the middle of the 19th century, all sewerage in London has been underground (Burian et al., 2000). One participant referred to the London Power Tunnels:

> You can't put the cables below the footpath. Because that would mean digging up 32km of roads across London. […] You can't go and dig up Oxford Street because it's a very busy place. [...] You can't dig up the roads and you can't put overhead lines across central London. So, you have no choice but to put it in a tunnel. (E02)

The London Power Tunnels will replace existing electricity lines that are currently placed in the roads with 32.5 km of tunnels (National Grid, 2020). As such, the imperative here does not arise from a lack of space on the surface or at the current position for the structure itself but from the disruption that the construction would cause in its current position in the road network. The London Power Tunnels thus will replace existing structures because maintenance of the existing structures is not perceived as feasible. However, the maintenance of tunnelled underground structures was described as desirable, in particular as the space for new structures might become scarce not only under the roads, but also at deeper layers.

In summary, tunnelling solutions were perceived by interviewees' as an imperative or a necessity if an above-ground or trenched solution appeared to be unfeasible owing to high land values or the disruption that it would cause. For vertical developments, whilst an evaluation of the interaction of the structure with the soil was highlighted as necessary and as potentially involving the implementation of structural foundation elements such as piles, the development of open spaces below ground was perceived as opportune, but not compelling.

5.2.2. Conceptualisation of the subsurface: asset versus constrained space

Both the rationale to go underground because there is an opportunity or because it is an imperative are directly connected to perceiving the subsurface as an asset or as valuable – the perception of going underground as beneficial pervaded most of the interview extracts presented in the previous section. At the same time, research participants described the underground space and construction within it as highly constrained and complex.

5.2.2.1. The subsurface as asset

According to the ISO Standard for asset management, ISO 55000 (British Standards Institution, 2014) an asset is an 'item, thing or entity that has potential or actual value to an individual or organisation.' (p.2) As such, the notion of something being an asset is directly linked to assigning a value to it. The ISO describes 'value' as context dependent and 'tangible or intangible, financial or non-financial' (British Standards Institution, 2014, p.3, see also Section 1.2.1). To this effect, engineer participants assigned value to the subsurface in various ways: The general benefits of putting infrastructure underground rather than above ground, including the value of the landscape or urban space that could be protected, were already mentioned in the previous section. Also, the imperative to put infrastructure underground, as described in Section 5.2.1.2, was linked to the value of the land above ground. The way in which this also postulates the assignment of value to the subsurface was expressed by E07:

> I think especially in cities like London now, the subsurface is becoming so valuable in a sense because the surface assets are so valuable. Because let's take Crossrail. I mean if you could have built Crossrail through the middle of London by knocking a few buildings down you would probably have done that. But the surface assets – highways, buildings, parks – are so valuable, you have to put it underground. But that in itself makes the subsurface hugely valuable. Because it suddenly has got this immense value in terms of you can't use the surface, therefore you've got to use the subsurface. Therefore, you should protect corridors in the subsurface.

The participant here explains that the increasing financial value of land and assets built on that land directly imply a value increase of subsurface space below these assets, primarily if a new structure or urban function is to be implemented for which there is no space on the surface. There is a strategic need formulated here to protect corridors in the subsurface for future infrastructure which will further be discussed in Section 5.2.3. However, it should be emphasised that the value assigned to the subsurface is connected to its ability to provide space for a strategic need of the city, and is thus directly linked to processes above the surface. The underground is seen as a strategic asset in cities 'like London' that are densely built-up and with high-value surface land – in particular for urban functions in cases where there is no alternative space to put them.

The provision of infrastructure above or below ground was also compared with examples of where surface space is freed from a function – the presence of which on the surface is perceived as unfavourable for the city – by putting it underground. By expressing that above ground infrastructure can constitute spatial barriers that are difficult to cross, the participant describing his experience in Turin (see Section 5.2.1.1) noted that the benefits – and thus value – of putting infrastructure underground extend beyond the financial value of the physical infrastructure itself. Further to the extract quoted in Section 5.2.1.1, E13 lamented 'a lack of awareness of the benefits of underground space', and claimed that 'it's perceptions of benefits that need to be challenged.'. However, a solution for how this could be done was not offered in the interviews. Rather, E13 pointed out additional challenges, namely, that 'people need to understand that at the time when projects are created and sparks initiated in terms of what could be done,' and that the current ability to plan ahead and measure the socio-economic benefits of infrastructure over their lifetime is limited:

> Crossrail has been designed for 2040 or something like that, which is perceivable, it's in our life-time. But actually, if you're measuring the benefit in 2040, what's the benefit in 2100 for example? […] The benefit is much greater and should be seen in a much bigger context.

Both of these points articulate the concern that owing to the current lack of foresight in planning and a misperception of underground space – not only by the public, but also by planning professionals – opportunities might get lost. It was acknowledged by some interviewees, that value materialises over time, rather than directly in the moment of intervention, and that an opportunity is connected to a specific point in time. The investment in this moment in time, however, must be presented as economically reasonable for the investors. This was perceived by participants as a hinderance due to another misperception about the value of underground space: the cost of underground construction. Referring to the Infrastructure Cost Review (HM Treasury, 2010), E10 commented:

> What do tunnels really cost? […] It was, everybody was brainwashed into thinking that tunnelling was very expensive. […] [The Infrastructure Cost Review] showed very clearly that tunnels get cheaper the bigger and longer they are. Definitive proof. […] But it's completely ignored by the planning authorities. […] Tunnelling in this country is perceived to be extremely expensive. It's not. Tunnelling in this country is perceived to be extremely risky. It's not.

The value of underground spaces is thus, in the view of the quoted interviewees, misconceived on both sides of the cost-benefit equation. Up to this point, even if not explicitly stated, this referred to underground space that has not yet been occupied. However, the value of existing structures was also mentioned, again mostly in the context of infrastructure and the benefits that such infrastructure, in particular transport schemes, can bring to a city in terms of unlocking the value of surface land.

The allocation and value of space was not only discussed with reference to the above-below dichotomy, but was also seen to be dependent on the depth of the infrastructure in question. Referring to the Victoria Station upgrade, one participant described the following:

> What we did at Victoria was great. I mean we jet grouted the terrace gravels to allow us to build tunnels linking the new north ticket hall to the existing south ticket hall at shallow level. And people liked to say, "well, why would you spend so much money?" Because we probably spent as much on ground treatment as we did on tunnelling. The reason is because by putting the tunnels on shallow level, we gained nine minutes passenger journey saving time per passenger. For half the passengers. That's 14 million passengers per year – nine minutes. That has a huge value. I think it's something like 5 pounds an hour. So, if you multiply that, that pays the jet grouting within a matter of few years. Whereas if you go deep you don't get those passenger journey savings. So, it's all about passenger journey time savings. Because all these congestion relief schemes are all about how much time can you save for the passenger, how easy can you make the journey through. And you drop all the tunnels way below everything else, that's not easy for the passenger. Easy to tunnel, easy to build, but not good for the passengers. (E07)

Whilst depth might be important for transport infrastructure, as described, this factor might be less vital for other functions. However, the latter quote expresses that the value of the space differs depending on its location, the purpose it is used for, and what the provision of the same function in an alternative space or ground layer would look like.

Participants discussed how the perceived cost of underground construction makes it difficult to perceive the value of the resulting projects and thus also affects seeing the underground as a strategic asset. The understanding of this asset in terms of value capture was predominantly discussed in terms of its interdependency with land values.

The increase of land values in London was described indirectly to be influencing the use and value of the underground by:

a. unlocking the potential to build underground through making the development of large basements viable, in particular in Inner London boroughs, leading to the use of more underground space for private functions;
b. making surface land unfeasible for linear infrastructures and thus 'pushing' them underground;
c. influencing opportunities for specific underground projects given that, with rising land values, the necessary land purchase to access deeper soil levels gets too expensive to justify.

The reverse effect, that is, the effect that the condition and use of the underground in a specific location can have on the surface land value was also mentioned, in that:

d. shallow underground constructions already present can make the development of the land above difficult, and thus have a negative effect on the land value;
e. the provision of infrastructure unlocks surface value. This referred to transport schemes that generally increase the surface value, as well as the utility infrastructure that is necessary for any development.

In addition to the connection between subsurface use and developments with the surface land value, questions were also raised about a potential difference in value of subsurface volumes depending on their depth, accessibility, the function to be provided by occupying the space, and the ability to capture long-term value in the business model of an infrastructure project.

Regarding the notion of value as described by the interviewees, this was discussed mainly in terms of financial value, and was restricted to developed spaces. Whilst other topics or underground functions to which value could be assigned, such as heritage protection (see also Bricker et al., 2019), were touched upon in the interviews, only the protection of above-ground landscapes was explicitly connected with a sense of appreciation or value. Other points such as archaeology were mentioned as a constraint to underground development. For example, P11 commented that:

> Crossrail 1 for example, they discovered that old burial site, when they were digging that and then obviously there is all the historic-archaeological [excavation] that kicked in and delayed the project for a period of time at that location. […] There would have been a contingency in there. But it's just an

> added cost to society, isn't it? Because we don't have an adequate understanding of what [is there].

This quote clearly suggests that the participant, in this case an urban planner, conceptualised the archaeological find as a barrier that added cost to the project, rather than interpreting the presence of an archaeological site in the subsurface as a value for the city in itself. The participant here associates these costs to a lack of knowledge about the subsurface. His statement is indicative of a perception of the underground that is opposite to an asset-based one: the subsurface as a constrained space.

5.2.2.2. The subsurface as constrained space

As described above with regard to archaeological finds, and concurrent with the description of the subsurface through a perspective of value and value capture, a more problem-focussed perception of the subsurface was articulated throughout the interviews: that of the subsurface being described as complex and constrained. This notion referred first and foremost to the perceived congestion of the space with a range of structures that leave little space for further developments, but was then reinforced by three general requirements that respondents indicated would make underground construction feasible and viable: technical feasibility, financial viability, and acceptability. Limitations of the data available about these structures as well as the geology present, and the complexity arising from fragmentation in governance, were described as constituting constraints to further development of the city and the efficient use of space.

Congestion

When speaking specifically about London, the 'congestion' of the subsurface space with physical assets leading to limited possibilities to increase infrastructure capacity, and the potential to run out of space, were at the centre of interviewees' concerns. As described in Chapter 4, the subsurface in London has been used extensively and the use of underground space has been growing over the last 150 years:

> Over the centuries, […] we have seen the progression from a time when people would put buildings on timber piles, […] through then developing the early metros and the early sewer systems in London in Victorian times. And more modern approaches have been to, well, expand the metro exponentially very quickly and the same with the water supply, sewer network, the power supply network, the utilities. In parallel with that, developers have put up buildings that are taller and bigger, and they go underground with basements for space saving,

> such as putting plants and carparks underground. As the buildings got taller, the foundations and piles needed for those got deeper. So, over the decades the underground space has become very crowded. One of the biggest problems as a tunnel engineer is finding a way through that, or under it, or around it, when you're planning a new piece of underground infrastructure. (E08)

Similar to this quote, mentions of congestion in other interviews coincided with descriptions of successive development of the spatial uses of the subsurface and its consequence of now needing to 'thread the needle' through a multitude of structures when a route for new infrastructure is sought. The distinction between horizontal infrastructures and vertical developments, discussed in Section 5.2.1, was here reiterated. The way the situation is described is such that what is there, and how it has grown over time, sets the premise or boundaries for what can be planned now and how it is planned. As E05 expressed:

> Is there space for everything? It is quite congested, isn't it? If you look at a plan or a 3D model, of Kings Cross station for example, you wonder if there is any ground left to support the buildings on the surface and so on, don't you?

This quote indicates that structures in the underground not only occupy the space or volume of the structure itself, but also alter the conditions of the surrounding soil, such as the bearing capacity needed to support the above-ground structures. Another similar consideration would be drainage capacity. This was not directly mentioned in the interviews, but is described in, for example, Fausey (2005). Sometimes, these alterations are targeted, such as the increase of soil strength through grouting that was described for the Victoria station upgrade in Section 5.2.1. However, any of these alterations of the subsurface are irreversible (von der Tann et al., 2016). Thus, the appropriateness of any structure underground can only be questioned and decided about before it is built, and the decision cannot be revised. This gives an indication as to what the notion of a prevalent 'first come - first served' approach to space allocation in the subsurface (see Chapter 2, Section 2.1) refers to: what is there first cannot be demolished and replaced, but will stay and constrain whatever comes next forever. Querying the common description of this aspect as problematic, E13 stated:

> There is a first come first served [attitude]. But if you've got the idea and the knowledge and the money and the financial backing, and you can get through the planning regime, then why shouldn't you get there first?

The latter quote highlights three aspects as necessary, but also sufficient, conditions for underground developments to be planned and implemented: technical feasibility that is established through knowledge, financial viability comprising the availability of funds and profitability of the investment, and acceptability manifested as approval through the planning regime. Each of these were further described as complex to prove or assess, as will now be expanded upon.

Technical feasibility

Feasibility refers to the capacity of something to be done or carried out (Merriam-Webster, 2019). To assess whether or not a project is feasible thus entails understanding what is possible. Feasibility studies of construction projects also include establishing whether a project is viable, as well as considerations about planning permission and other statutory approvals (Designing Buildings Ltd., 2019). Whilst it is acknowledged that these are interrelated, viability and acceptability are here discussed separately, with a focus on technical feasibility. This comprises the available technologies as well as the engineering expertise to provide optimal solutions within a specific geological setting and built environment.

The underground projects referred to here are being developed for specific urban environments and geological locations. Technologies that respond to the specific geological features are an essential part of successful project delivery. However, developments will be constrained by limited knowledge about the structural elements of buildings, as well as by the position and condition of shallow utilities, as described by E07 with regard to building foundations:

> What you realise is that it is very difficult to know, even in this age of technology, when in theory you should be able to find out what the foundation of a building is. There should always be those records. They are just not there. […] It is so difficult to find records of existing buildings. It is also very difficult to know whether a structure has deep foundations. (E07)

One of the planning professionals further described how this lack of data leads to project designs that are based on a large number of assumptions:

> It's just based on a visual assessment of the buildings that are there. It's sort of a guess as to roughly what the foundation size and depth might be. And then you thread your way through a number of guessed points. (P01)

According to this quote, project planners rely on scarce information and historical knowledge such as the year of construction of a building to deduce an assumption about the probable type of foundation. If mistaken, this can lead to significant additional, or unnecessary investments. Echoing this, another interviewee (E03) described a project where major measures had been undertaken to stabilise a building next to an excavation that was believed to have a slab foundation. During construction it was revealed that the building was actually founded on piles making the planning and some of the construction effort redundant.

Similar difficulties were expressed with regard to the quality and accessibility of records for horizontal infrastructure, including tunnels and shallow utilities where, in addition to the low accuracy of data and tedious processes required to access them, the secrecy around these data was commented on, in particular referring to potential terrorist threats if the location of all assets were to become known. At the same time, the geology under London was described as too complex to be entirely predictable, as stated in the quote at the beginning of this chapter. As such, expertise is needed to interpret the available data, evaluate the risk, and design a feasible solution for a problem or project idea at hand. This was touched upon by participant E13, who expressed the notion that insufficient expertise can lead to deficient assessments, which can, in turn, lead to misinformed project decisions. E13 described one specific situation where, in his opinion, the solution provided by the engineers was not optimised, unnecessarily increasing the cost of the project:

> The scheme was completely on a fundamentally wrong basis. […] It's very easy then to force the cost up […] Fairly easy for people to lose schemes because they are conceived to be the wrong cost, the wrong benefit.

E13 further commented that while for many of the current projects in the subsurface more optimized solutions could be found, insufficient expertise hinders optimisation and can even lead to projects being rejected. As such, engineers facilitate not only project delivery, but also play an essential role in mediating project decisions, thus making engineering expertise a vital component in infrastructure planning. In this context, concerns were expressed about the impartiality of expertise available to decision makers in London, in that the same companies who provide advice will consequently compete for design contracts and thus have an interest in the projects going forward.

Participants described how the availability of suitable technologies is entangled with the development of projects. On one hand, technologies were mentioned that were developed specifically to solve a particular problem. On the other hand, one participant gave an example of the first underground railways being built using cut and cover, because the tunnelling technology was not advanced enough to construct them at a deeper level. Both examples show how knowledge and technologies co-evolved with the problems encountered. 'It's almost, a need comes first' (E14), before engineers are incentivised to develop a project or a technology.

Financial viability

The perception of project cost and the interrelation between land value and underground developments have been discussed previously (see Section 5.2.2). The mention of viability here shows that the two perceptions of the subsurface as an asset and constrained space are not contrary but overlapping. The constraints described constitute barriers to the perception of the space as an asset or to harnessing its value. It should be reiterated that both the value of subsurface developments, in particular infrastructure, as well as construction costs were described as misperceived (i.e. interviewees claimed that underground development might be viable when perceived not to be because the value assessment of underground solutions in comparison to above ground solutions does not take the right parameters into account and costs are overestimated). As has been mentioned in Section 5.2.2.1, rising land values were noted as enabling underground developments in two ways. Firstly, for long linear infrastructures, land value can be an enabler for placing them underground because the value of the existing buildings that might have to be altered or demolished would not warrant an above ground solution. Secondly and conversely, for investors, increasing land values make the development of underground spaces more viable as building underground can release additional commercial gain.

In addition to the assessment of the costs and benefits of a project, participants made a point about the availability of funds. Here, apart from specific funding models for big infrastructure projects, another difference between singular developments and infrastructure was pointed out; namely, that for the regulated infrastructure industries the available money is linked to funding cycles in which the asset owners have to allocate their budget to maintain the functionality of their network. As will be discussed in Section 5.3.1, these fairly short time cycles may affect the capacity for long-term assessments and thus inhibit a better spatial coordination of interventions.

Acceptability

The planning regime enables – or indeed inhibits – underground developments, in the same way to above-ground developments as any development needs to be approved by local authorities before it can be built. Whereas for vertical developments planning permission needs to be obtained from the local council, long linear infrastructures cross a range of constituencies, and there exist different routes to obtaining planning consent (see Section 4.4). Several of these were alluded to by the interviewees, always in connection with discussing the duration of the consent process, the question of power distribution, and the management of involved or affected stakeholders, or the interdependence between these.

E08, for example, assigned the reason for the lengthy process to the number of stakeholders affected:

> Getting permission to construct new underground works takes a long time. Because you have to go systematically along this route, this alignment. Because all the examples I'm thinking of tend to be linear tunnels or linear things. Anyway, you go systematically along the alignment, assessing what the impact would be on all the stakeholders that are there. From those that are on the periphery where we don't expect there to be any noticeable impact actually, to sometimes where there would be significant impact. Right up to the point where in some situations we need to buy or purchase a building – someone's asset, so that we, the tunnel engineer or the new asset can be constructed. (E08)

It is here emphasised that for linear subsurface assets, the number of stakeholders who have to be informed and consulted is much larger than for projects at surface level or with only a localised extension into the subsurface. With regard to planning applications, the impacts described are evaluated in the Environmental Impact Assessment (EIA). As E14 pointed out:

> It's not so much the scheme itself or the design of the scheme. It's about the impacts that the construction of that scheme and the operation of that scheme will have on stakeholders. So, the Environmental Impact Assessment, the Environmental Statement is probably THE key document […] 'Cause that's where the project sets out the effect the scheme will have on the public and other stakeholders.

The Environmental Impact Assessment (EIA) has to be submitted as part of the planning applications for specific projects and is sometimes part of the feasibility study (Designing Buildings Ltd., 2019). The EIA requires developers to describe the effects of a proposed development on (a) population and human health; (b) biodiversity; (c) land, soil, water and climate; (d) material assets, cultural heritage and the landscape and (e) the interaction between those factors (The Town and Country Planning (Environmental Impact Assessment) Regulations 2017). It is notable that the latter participant described the environment on which the impact is assessed in terms of the stakeholders involved or affected, rather than the built and ecological environment itself, as might be assumed. This framing implies that any part of the environment will only be taken into account if it is represented by human advocates.

That the EIA is submitted with the planning application or even undertaken as part of a feasibility study means that the effects on the environment will have to be sufficiently understood at that point in time. To achieve that level of understanding, the design of the project has to be well advanced:

> As part of the Environmental Impact Assessment, you have to say what the effects of tunnelling will be on the build environment, and in particular heritage sites. […] You have to say which listed buildings will be affected, how much they will be affected, what kind of damage they will have and what you will do about it. So that requires quite a mature level of design in order to determine precisely what those impacts will be. […] Which can constrain you a little bit when you then come to do the detailed design work later on. Because you can't do something that's significantly gonna change what you said would be the impact. (E06)

This requirement for robust designs early on and a resulting reduction of flexibility later on in the project delivery stage was remarked upon by several participants. Stakeholder management as such is directly associated with the consenting regime and approval times. The participants described stakeholder management as crucial to a project's success not only for general project acceptance but also because objections by stakeholders could considerably delay projects. In turn, it was described how these processes allow stakeholders to have a significant impact on project decisions:

> So, it's understanding the environment we live in in the UK, about the fact that everybody has the ability to have their say. Following through the process. But it means that you end up with a lot of potential impact of what would definitely be the cheapest method. But it's understanding that this is the society we want to live in. (E14)

In this quote, it is acknowledged that the complexity of project planning and delivery that arises from the obligation to inform and consult affected parties, as well as the associated time required for the approval processes, are political choices which are influenced by and – vice versa – influence society. These processes and choices will evolve with time, implying a different set of rules for every scheme being built, as expressed in the quote by E08 at the beginning of this chapter referring to the small frequency of major long infrastructure projects in London, again placing these projects in relation to smaller projects and above ground (vertical) developments. E10 described how these evolutions can interact with project planning and delivery when the approval processes are protracted:

> It takes so long for these projects to get from an identification of the need through all of the processes to getting it built. It takes so long that two things happen: the ground rules change. The need moves somewhere else, simply because this thing hasn't been built. So, people do other things. That's one thing. Number two, the technology changes. Suddenly there are better ways of doing this. Cheaper ways, more efficient ways. So that means "oh, we could do this, we could do that." So, what you get is effectively a mission creep. The scheme gets more complicated or it tries to get bigger. And the third thing is costs escalate. Technology tends to hold that back. But the tunnelling costs aren't the only costs. And the main cost in London, that's being a problem, is property cost. And third-party liability cost. (E10)

The participant here expressed how the three enablers or conditions for underground projects – technical feasibility, financial viability and acceptability – are interconnected and how human behaviour adds to the equation: The evolution of the socio-technological environment suggests that a proposal that was suitable at a specific moment of time may no longer be suitable at a later point. 'People do other things' refers to people adapting to the built and social environment, in this case to an environment without the new infrastructure being built. Interests and resources are shifted to other projects. Once again, the cost of land is mentioned as a deciding factor for tunnelling projects.

The acceptability of underground developments is bound by the specific location, including the underlying geology, the built environment and society – including its multitude of actors, rules and discourses – as well as the specific moment in time. The evaluation of technical feasibility was described as constrained by the available data about the geology and structures present as well as by engineering expertise, financial viability, the availability of funds, and the prevailing perceptions of the cost and value of underground constructions. All of these factors contribute to a general sense of complexity that needs to be captured in project proposals and planning applications and provokes the question as to what strategic steps could be introduced to reduce this complexity and make optimal use of the asset that the underground, in view of the participants, constitutes.

The previous sections have alluded to several points from which a necessity for improvement can be derived. In particular, respondents mentioned the need for a change in the perception of value, as well as for new concepts of prediction and foresight to enable comprehensive and long-term evaluations of project proposals, in addition to the need to safeguard infrastructure routes and construct strategies to improve data availability about utilities.

Whereas value capture and improved predictability appeared as nondescript concepts or visions, prospects for safeguarding routes and data access and management were discussed in more detail. Each of these represent a more general strategic need that directly echoes one of the two perceptions of the subsurface that have been described, namely the subsurface as an asset on the one hand and the subsurface as constrained space on the other hand, and is connected to the presented rationales for building underground: better data would mean removing some of the described constraints (Section 5.2.2.2), and the safeguarding of routes would mean protecting the asset (Section 5.2.2.1) that has sometimes been called a 'non-renewable resource' (see Chapter 2) for future strategic needs. These strategic needs will be elaborated on in the next section.

5.2.3. Strategic need: protection for the future and removal of barriers to development

Following the insights provided in the previous sections into how the subsurface is conceptualised by engineers in general, this section explores the consequent strategic needs for management or governance in greater depth. Specifically, this section presents how the mentioned concerns relating to safeguarding connect the question about the availability of space with considerations about foresight, and how improvements in data availability would dismantle present barriers to individual subsurface developments.

5.2.3.1. Protection of the underground asset for the future

As previously indicated (Section 5.2.2.1) the perception was evident of a need to protect additional corridors London's subsurface because the surface land value is too high for infrastructure to be built there. Yet, the topic was discussed ambiguously throughout the interviews. Whilst the strategic need for some kind of future proofing was generally acknowledged by the interviewees, the actual feasibility was often questioned. E07 gave an example where, in his opinion, the opportunity for safeguarding has been missed. Referring to access points rather than the route itself, he described how the need for an extension of the Bakerloo line to Lewisham had been projected for a long time, but the rapid development of the area would now make it difficult to find suitable sites for the stations. With regard to the underground corridors, E07 questioned the practicability of actually protecting them over a longer period of time:

> On Crossrail, even with the safeguarding in place, it was very difficult to protect that corridor. It relied on local authorities picking up planning applications and recognizing that they would potentially have an impact on Crossrail.

The participant here touched upon the question of who, if safeguarding were to be in place, would be responsible for monitoring the corridor and what knowledge might be required for the relevant authorities to do so. He continued to describe how, when Crossrail was actually being taken forward, buildings along the route had been built where piles did interfere with the route. 'We'd have to change things because the piles were in'. As such, despite safeguarding in place, the 'first come, first served' situation could not be overcome. In addition, E06 described how, for the purpose of safeguarding tunnel corridors, given that they have an effect on many people, a high certainty is required that the scheme will actually be built in the specified location:

> I noticed, just during the development of Crossrail, where we've had a number of routes safeguarded because [it was not] quite decided which one is best. The outcry from blight, so people who say they're restricted from developing those areas because of the possibility that Crossrail might come later on – that's been significant and we've had a lot of pushback from people. […] So, the development blight issue could be quite significant if you're planning strategically for the future. I mean you could be saying you can't build anything with deep foundations across this part of London and then in reality never construct anything there. (E06)

The participant went on to explain that the requirement for certainty contradicts the need to remain fairly 'vague' in order to 'allow for a number of eventualities' when the ability to predict future needs is limited. In addition, the ability for authorities to hold on to valuable land for potential future transport routes was questioned as councils or governments face the same uncertainty as developers (E13). It was, moreover, asserted that the planning certainty for different schemes is often not high enough to coordinate the safeguarding of several routes that interfere with each other:

> It's very hard. What actually happens is, I'm working on Crossrail 2 and I'm trying to get a new metro across the Thames and then I'll go to the Thames Tideway team and say: 'how far did you get with your design?' And they'll say: 'well, not very far, we've got an idea that we want it here'. And I say: 'well is that fixed, should I reserve it? […]' and they go: 'well, we don't know yet, because the government hasn't promised that they'll pay for it anyway. We have no funding.' And then you're left having to just take a pragmatic approach. You understand that there is potentially gonna be another project there and you want to keep away from it and then you end up making an agreement saying 'well,

> let's pretend you are gonna build your tunnel and let's say it's at that level, and we'll design ours to miss it, but if anything changes we have to agree to coordinate again and make adjustments as necessary.' That's just what happens all around London for all the jobs. (E08)

This quote raises the point that a strategy involving the safeguarding of routes, in particular if the required certainty shall be reached, would mean a significant amount of funding. It also alludes to the current way in which these situations are handled: spatial conflicts are resolved and agreements on mutual responsibilities between different projects or clients are found in expert conversations between engineers.

Overall, whilst safeguarding was expressed as desirable in order to retain the potential for future infrastructure routes in the subsurface, and not safeguarding routes once the need for a specific scheme was projected was criticised, participants expressed doubts about the practicability of safeguarding more routes in Inner London. Insufficient certainty about future infrastructure needs, insufficient knowledge in authorities, and the amount of funding needed to produce designs to the detail required were the main points of concern. In addition, there appeared to be an acceptance of the system as it is and whilst some past decisions were criticised and the concern expressed about running out of space (see Section 5.2.2.2) no sense of urgency for change emerged.

5.2.3.2. Removal of constraints for developments

In contrast to the concept of safeguarding, participants did not question the need for improvement regarding removal or, at least, the facilitation of processes around the described constraints, in particular the management and governance of diverse subsurface data and collaboration between asset owners. The need for these data 'to be able to plan our developments in a strategic way' (E12) was emphasised alongside the problems caused by the lack of reliable data. One effect of a lack of collaboration was expressed by E02:

> (A) lack of collaboration represents a delay of design information. So, there is a cost to that, it is a delay of the programme. If people are not coming together, if the different disciplines are not coming together, then the risks will not be fully captured during design. Which has an impact during construction that the design stage is passing risks, health and safety risks on to those who are on the construction site. (E02)

The participant described how information that is not communicated can cause delays and influences the capacity to identify and relay risks. The unknowns that unnecessarily remain in the project constitute a risk that needs to be managed throughout the project stages and will ultimately affect the quality, programme, and cost. One currently much discussed process responding to such risk is building information modelling (BIM). BIM entails the creation and management of digital representations of built assets that enable capturing design information and constrains. The functionality of BIM has been extended from capturing primarily physical characteristics through computer aided design (CAD) data (level 1) to integrate environmental data (level 2) as well as functional characteristics, such as the construction programme, cost, or facilities management (level 3) (BIM Wiki, 2019). In the context of the current thesis, there might be a – to the knowledge of the author not yet explored – potential to mobilise BIM tools also for the capturing of the governance regimes that are operating at the time of design and construction of subsurface projects. Information about the relevant standards, contracts, laws and regulations that influence and sometimes determine project development could allow scrutiny beyond the assessment of physical characteristics and design collaboration when former projects drawn upon to inform future plans and aspirations.

Apart from collaboration in the project design, E14 remarked that the knowledge transfer between the contractors and managers of different project stages could also be improved with regard to the management of affected stakeholders. In addition, the potential for better communication and integration of data and processes was raised in relation to adjacent councils that are affected by the same project in collaboration with designers and contractors: '[we could] get together and do it collectively, rather Hammersmith and Fulham are sitting there, another Council there doing the same stuff, you know, reinventing the wheel.' (E03)

Overall, a sense of incomprehensibility was expressed about the fact that information is not shared and asset data are not currently available, as reflected in the quotes in Section 5.2.2.2 with regard to knowledge about building foundations. E12 asserted that it would be possible to capture all aspects of data sensitivity and security in an appropriate data management system. He attributed a mental barrier to the anticipated amount of work necessary to provide the data in a unified format, and commented that data owners would only undertake this work if it were to be made mandatory through a high-level decision: 'If we need such information, it needs to trickle down from the government into the local councils and to the infrastructure owners – then they would make it happen'. (E12)

The latter participant further referred to the implementation of a standard format for geological data established by the Association of Geotechnical & Geoenvironmental Specialists (AGS) (AGS et al., 2015), where a similar process was successfully facilitated and emphasised that a central authority would need to take responsibility for the process (see von der Tann et al., 2018a). However, E15 described how in a previous attempt by the Greater London Authority (GLA) to establish an asset register, the procedures for onward data security were insufficient, and that currently the data owners and data users do not trust each other. The participant clearly stated that the sharing of information cannot be one-sided, but needs to rely on mutual openness.

This section has shown that, whilst both the safeguarding of infrastructure routes in the subsurface and minimising constraints to subsurface developments by improving the information about what is currently there and through collaboration between stakeholders were seen as potentially beneficial, the actual process of the former was described as challenging and its practicality questioned.

Thus far, this chapter has presented the perception of the subsurface based on the interviews conducted with engineers who have extensive experience working on underground projects in London. The next section points out the themes that the planning professionals added to the discussion and reflects on whether the perceptions discussed in the previous sections are exclusive to the engineering profession.

5.2.4. Worldviews: planning and engineering

As mentioned in the introduction to Section 5.2, the participant engineers largely limited their discussion to the built developments in the subsurface. Planning professionals, on the other hand, raised a broader range of topics. Referring to the topics that appear in the local plan of one of the London Councils, P09 listed the following as relevant planning topics connected to the subsurface:

a. flooding
b. archaeology
c. utility infrastructure
d. transport infrastructure
e. contaminated land
f. excavation waste
g. impact of climate change on buildings, in particular rainfall patterns and soil shrinkage.

Note that what is listed here are all aspects of the physical environment. Ultimately the meaning of all of these for planning is determined by the effects they have on local communities or people. The fact that this was not mentioned by participants here means that either the main purpose of planning, that is serving the citizens of the local authority and city, is not in the focus of the participants' attention, or so self-evident that it does not appear necessary for them to mention.

As has been argued, the impact of a project on the listed considerations – apart from point d that describes the infrastructure itself – is evaluated over the course of planning applications. Once planning consent is given, many project parameters appear immutable to engineers and thus become constraints for the engineering project. Speaking particularly about the definition of the 'site', here meaning the surface extension of projects, an architect commented:

> It's an artificial constraint that is given to the project. It's a so-called boundary or requirement of the project but it's not true, it's not a true one. […] The real constraints, you have things like water tables, you have got the existing stations that are there, you have got the actual tunnelling sequence of ground conditions. […] You have access points where you can get in and out. […] You have to be quite careful about what you call a constraint or not. Because sometimes they are just something that has a consequence but then you can build anything – you can do anything, it all comes [down] to cost and the programme issue and risk.

Though this statement does not contradict the views previously relayed, it does emphasise that, in the view of the participant, the parameters summarised under 'feasibility' and 'viability' in Section 5.2.2.2 are actually constraints whereas 'acceptability' is a matter of choice. This suggests that whilst engineers can perceive planning regulation as constraining, planning professionals perceive those elements as constraints that sit in the realm of engineering expertise and might be seen as 'manageable' by engineers. As E13 stated: 'there is no need to be worried about ground movement. It's not an issue. The bigger issue is developing underground space. Ground movement can be managed.'

The project focus of engineers might also explain why safeguarding and data management were the two areas of conceivable improvement. One of the planners, by contrast, commented that when an attempt is made to safeguard an infrastructure alignment, this is 'the only time the underground is dealt with in a spatial and strategic planning context' (P04), and no wider effects of underground developments are assessed. He further stated:

> I worry that there are things that may be there that haven't gone through a rigorous assessment of: Are they needed? Are they desirable? I mean I don't think it's up for me to say that someone does or doesn't need a basement in their house.

The participant here compares the situation to the above-ground where, in his opinion, the assessment is more rigorous. This quote calls for a rigorous assessment of 'need' but does not specify how 'need' is defined. In this context, P01 questioned if using underground space to increase the value of above ground property is justified in the case of developments that might restrict future possibilities:

> For very high commercial gains like the super basements type of things that have been built […] I would worry that those are affecting the future proofing of certain things. And that could be very dangerous and detrimental, and it's not controlled. (P01)

Putting this statement in context with the rationales to build in the underground, as expressed by engineers, the latter participant further expresses that the exploitation of the underground potentials or opportunities might become a threat for those structures for which there is no other possible location, and that this is where planning expertise and strategies could help.

Beyond what was discussed in Section 5.2.3, only one specific suggestion for subsurface governance was touched upon: the definition of functional layers in the underground, similar to categorisation by depth or the example of Rotterdam presented in Chapter 2 (Section 2.4). One of the engineers interviewed, however, rejected this concept as utopian:

> There is probably a utopia where you could say, well the rule is there shall be no basements deeper than six meters, two levels or something. And everything below that, the next five meters below that shall all be for sewer tunnels and utility tunnels. And then the next ten meters below that shall always be for transportation schemes. So that's quite a utopian [view]. On a practical level, sewers need to flow downhill naturally. So, you're always gonna have at one end of a sewer scheme like tideway, it's right near the surface, at the other end it's sixty meters deep. (E08)

This description stands independent of the local geology, or existing assets, conveying that the needs and purpose of a project will determine the form of the subsurface structure. This is relevant because it shows how wider scale planning and engineering expertise that set out requirements for specific projects are interdependent and how both are needed to deliver functioning solutions.

Planner participants expressed that the evidence currently in place is insufficient to make a case for establishing an overarching subsurface policy. They described how in the case of deep basement developments, regarding which several London councils have established policies in recent years, evidence for regulating policies could only be collected once a certain number of structures had been extended into the ground, whereby the restriction of these developments was mainly motivated by citizen complaints: 'on the local level, it tends to be reactive. It tends to be*:* our residents don't like all these basement developments, we need to do something about it' (P09). This statement describes public discourse amongst citizens as a main leverage point for change. However, it presents the role of planning officials in the current setup as reacting to citizen demands, rather than as co-producing – and facilitating the process of co-production of – projects and planning policies together with the citizens affected and interested.

Participants further suggested that a strategic subsurface policy would have to be established in the London Plan rather than in local plans, reinforcing the described need for better data management and coordination between neighbouring authorities:

> If you had a London wide approach, then it just would be more coordinated and probably more coherent. And hopefully with appropriate mapping and information that's more comprehensive and not just a jigsaw puzzle with each authority sort of putting their own little piece in and hoping that it all joins up. (P09)

Planning professionals also confirmed the need for better data management and that a central authority would need to take charge of such a project, including consultants and construction companies as data providers:

> Data is important. […] All these different players, engineering firms [list of engineering companies], all these different companies do work for developers and infrastructure providers and so on, and make their own [map of assets]. But then they retain ownership of that data and it's not shared with other people, so then other people have to come and do the same work again to get that. And I would like to see improved governance in order to force people, OK, if you're mapping underground assets in this location you have to submit your data to a central authority […]. And we can take that information and progressively develop a picture of what is underground. (P11)

Overall, both professional groups stressed the dependence of their work – the development of underground spaces and, respectively, the development of planning policies – on perceived need and available funding. Indeed, the question of need emerged in both groups, directly in the form of the assessment of societal need in statements by planning professionals, and indirectly in the emergent distinction between opportunity and imperative rationales for underground developments or infrastructure by engineers. The ability to predict – or its limitation – was mentioned by planning professionals with regard to formulating policies and by engineers with regard to infrastructure needs; there appeared to be a general acceptance of the consequential reactive nature of the space and its governance. Participants agreed that data management and collaboration between different sectors, as well as neighbouring councils, is an area in need of strategic improvement. The question of who could coordinate such collaboration remains.

5.3. Discussion: critical dimensions of underground governance

From the analysis in this chapter, there seems to be a lack of integration and consequently a need for careful consideration of the interrelations between:

a. short-term considerations and spatial arrangements necessary for particular projects and the idea or scope for long-term strategic spatial planning
b. the above ground and the below ground space, and
c. different prospects or purposes of using the subsurface as reflected by different actor groups.

These three points reflect three core dimensions along which the urban subsurface space needs to be governed, which permeate the themes identified in Section 5.2: a temporal dimension, a spatial dimension and a sectoral dimension. Regarding the latter, 'sectors' are here not only understood as infrastructural sectors but rather as clearly distinguishable groups of actors that share a common role or set of regulations that govern them. These three dimensions have been described in the urban planning realm as fragmented and adverse to the logic of systems thinking (von der Tann et al., 2016, referring to Orr, 2014, and Moffatt and Kohler, 2008). An equivalent distinction has been made for the governance of infrastructure by Wegrich and Hammerschmid (2017) who connect all of these dimensions to the creation of value or the availability of financial resources for specific projects. For the underground, the appreciation of the irreversibility of interventions and the pursuant pathway dependency, as well as the complex interrelationship between land value and project viability, add extra complexities. Focussing on the urban underground, the following sections examine each of the three dimensions in turn.

5.3.1. The temporal dimension

It has been said about infrastructure that fragmentation arises across time as new demands are made and predictability is limited (Wegrich et al., 2017). In the underground, given that interventions, once implemented, cannot be corrected and pathway dependencies are strong, each construction project manifests in the occupation of space, posing constraints to subsequent projects in the spatial dimension (see Chapter 4, Section 4.6.1).

The irreversible nature of human interventions in this space coincides with a limited ability to foresee what will be needed. As has been discussed in Section 5.2.2.2, there is an acknowledgement that rules and regulations constantly evolve alongside people's needs and opinions, and that thus there are moments in which certain investments and projects are feasible and others when they are not. Acceptability and viability are assessed in a specific moment in time and the duration of the approval processes alone can imply a shift in perception between the moment an application is submitted and when it is granted.

The arising need to balance the provision of short-term certainty and the retention of longer-term flexibility was described by the interview participants on a strategic as well as a project level. This challenge of satisfying the short-term interests of financial stakeholders and at the same time obtaining the maximum possible value for society in the long-term has been described as the paradox of governance in post-modern times by Moffatt (2014), who postulates a 'lack of time sense' in post-modernism that 'seems to undermine any conscious consideration of and discussion on the future' (p. 209). This author further describes how, whilst society increasingly understands the longer-term impacts of decisions and supports concepts like sustainability and resilience that embrace longer-term thinking, the actual time horizons of decision taking are reduced to those of the private sector (Figure 5.2) and characterised by discontinuity.

The paradox shown in Figure 5.2 illustrates the parallel trends of acceptance of ecological and systems perspectives on the one hand and ongoing fragmentation of the planning-, decision- and implementation processes on the other hand (Moffatt, 2014). Similarly, Rogers (2018) writes about the different time horizons referred to in environmental science compared to current infrastructure timings, and describes how different long-term scenarios for population distribution have 'profound implications for how civil engineers should design local and national infrastructure systems' (Rogers, 2018, p. 3). He emphasises that understanding of history of each specific city is crucial to facilitating longer term predictions and argues for the use of extreme far-future scenarios to test the usefulness of interventions. However, what can be tackled through engineered interventions in the present still accounts for how far (or, rather, how near) into the future the project can be imagined as well as the acceptability of these imagined futures by the public and different sector groups. Methods facilitating foresight such as scenario planning might be able to further this imagination but, arguably, should include the wider society to do so.

Image redacted due to copyright.

See Moffat (2014), Figure 5.

Figure 5.2: Paradox of governance in post-modern times based on Moffatt (2014), redrawn by author.

In ecological systems, each object or organism works within a specific temporal scale and it is the multitude of scales within the overall system that provides the grounds for resilience (Moffatt, 2014). The integration or at least acceptance of different time scales is thus crucial for the establishment of a resilient city that can respond to human need and that sits within a human value system. With regard to underground infrastructure, the current London Infrastructure Plan, for example, was released in 2015 (Mayor of London, 2015) and identifies and prioritises infrastructure for London up to 2050, establishing a time horizon of 35 years. Yet, the built interventions planned here will remain and influence the city over a much longer time period. At the same time, the investment in infrastructure is mostly managed in shorter, 5-year cycles (such as the control periods for Network Rail, see National Audit Office, 2015).

In this dynamic, different professions work at different temporal scales (Figure 5.3). Whilst the role of engineers is to build infrastructure that will still be present in the long-term, planners work with long-term projections to define actions in the present without necessarily considering the specific spatial constraints that will be the focus of engineers. As such, and as indicated in Figure 5.3, an iterative process of understanding the impacts of interventions in the long-term, integrating those involved in planning considerations and (re-)defining engineering interventions is necessary showing a need for closer collaboration between the two professions. The processes for receiving planning consent should mediate between different scales; however, as described by research participants, the multitude of permits and the spatial and sectoral fragmentation along an infrastructure route lead to a high amount of dependencies between the variety of time periods necessary for receiving those permits and executing the defined work. Thus, the described iterative coordination between planners and engineers is necessary to long-term considerations as well as to the implementation of specific projects.

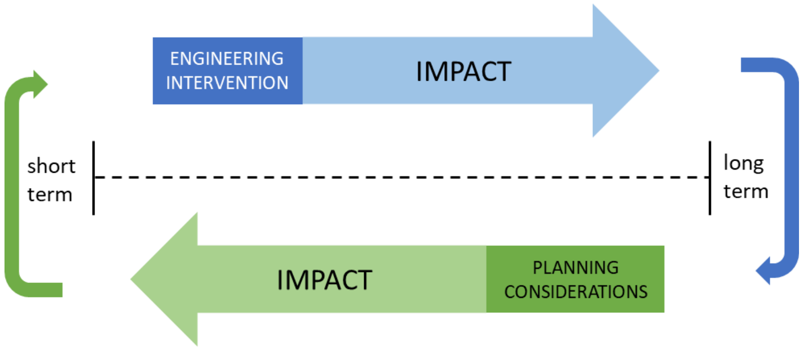

Figure 5.3: Temporal work scales and directionality of impact by engineers and planners.

5.3.2. The spatial dimension

The analysis of the perception of underground space, as well as that of the reasons and strategic needs, clearly showed that the underground is always perceived and described in relation or comparison to the above-ground. As such, the integration between the two and the understanding of how they interrelate is crucial for underground governance. Descriptions of the urban underground in literature tend to focus on the underground in a way suggesting that this interrelation might be forgotten. Differences in perception and governance between above ground and below ground that have been identified in this research are summarised in Table 5.1.

In Table 5.1, an emphasis is placed on underground infrastructure as presented through the perspective of engineers. The listed aspects show the increase in complexity and the reduction in certainty for linear, horizontal projects compared to point interventions that are primarily vertical. Furthermore, the mutual dependence of underground and above-ground structures is such that existing and new-built developments require the maintenance and extension of underground infrastructure services whilst, in turn, any underground structure requires access points from the surface to the depth of the structure itself in order to be useable. If these connection points are neglected – for example, geothermal capacity is often discussed without explicitly thematising the need for spatial elements to access it – any attempt for governance of the subsurface as a continuous asset will be expendable.

In addition to the vertical integration, the horizontal extension of the different functions is also relevant. Some functions only extend to the space directly below. Other functions extend much further as they may, for example, impact an aquifer that does not respond to regional or council boundaries. Linear infrastructure has clear connection points extending from where a service function is produced to where it is needed (Table 5.2). The presented imperative for linear infrastructure to go underground is connected to its ability to cross boundaries that would not be possible at the surface level.

Table 5.1: Aspects of above ground – below ground integration

Aspect	Above Ground	Below Ground
Knowledge base	'Everything is known'	Many unknowns
Form of linear infrastructure	Roads – between buildings	Multi-layered linear infrastructure
Design dimensions	2D planning (maps) + building heights regulations	3D thinking required
Directionality (conflict)	Primarily vertical structures	Primarily horizontal structures (infrastructure)
Ownership	Public – private distinction clear	Public – private distinction not always clear
Interdependence	Developments depend on below-ground infrastructure Development details depend on local geology (bearing capacity, groundwater)	Infrastructure serves above ground developments Dependent on above ground space for access
Technical solutions	Optimised	Often not optimised, overdesigned
Financial value	Land value as established measure	Value of underground volume not established
Stakeholders for specific projects	Few (manageable)	Few for local developments Many for linear structures (challenge to manage)

Table 5.2 shows that similar to the temporal dimension, the spatial dimension ranges across different scales from specific projects to geographically defined entities like aquifers. As has been argued, the pathway dependency here is the spatial manifestation of decisions and projects, meaning that the temporal and spatial dimensions are intrinsically linked. While decisions that enable underground interventions reflect specific moments in time, the interventions themselves cross multiple sites, spaces, and geologies. They remain in place or impact the subsurface for a long period of time and this impact can be traced, as previously illustrated for the London aquifer in Chapter 4. It is interesting to note that for water flows, the interaction between the surface and subsurface has also been modelled (British Geological Survey, n.d.-c), and scholars have noted that cross-scale interactions need to be understood for urban flood management (see Zevenbergen et al., 2008). As such, it appears that the integration across temporal and spatial scales is more advanced for water management than for other subsurface related topics and, therefore, that flood and water

management might constitute a useful area of practice to refer to as an example of these integration processes.

Table 5.2: Aspects of horizontal integration

Aspect	Description	Consequence
Load bearing	Load spreads beyond the boundary of the asset	Load bearing needs to be guaranteed when building in the vicinity
Groundwater flow	Groundwater flows	Flows have to be guaranteed
Infrastructure	Crosses council boundaries	Needs coordination with all crossing councils to be built

Regarding the integration and management of spatial data, the geological data provide a reference for initiating data sharing about underground assets. However, while there appears to be a general acceptance of the incompleteness, fragmentation and coarseness of geological datasets, for asset data, there appears to be less understanding and acceptance of the fact that 'information [is] not being given or not being given correctly' (E05). This hints towards a difference in perception of the two data sets, as asset data is data about man-made structures and should, therefore be made known. Geological data are perceived to be less 'risky' than asset data, potentially because geology is not human-made; the volume is owned, but what is in there can be inferred from models. Geology is thus (maybe) not perceived as an asset in the same way as man-made structures are. As the value of geological volume only materialises though exploitation of the geology or space, any calculation will necessarily remain vague until a function is allocated to a specific volume. The ability to actually exploit it will depend on spatial access, as well as on protecting and maintaining the exploitable functions of the ground.

5.3.3. The sectoral dimension

This dimension comprises the private and public sectors with their various areas of expertise including their specific sets of rules, code of practices, legislation, regulations, and worldview (even if the latter is not homogeneous). These sectors can be seen as communities of practice responding to their own codes of conduct and norms and furthering knowledge within the community (Wenger, 2011). To understand their actions, it is important to understand the set of norms that they respond to and function under, and how they perceive their role within the specific context in which they work. The engineering and planning professionals interviewed represent just two of a range of groups active in, or affected by, the development of underground space or other subsurface functions. For the subsurface to be governed as one entity, a new community of practice would be needed that overlaps with traditional sector domains.

The expressed lack of, and need for, collaboration between different institutions, asset holders and project partners suggests a high degree of fragmentation across sectors, whereby each community perceives the other sectors and their actions or expertise as a boundary to their own tasks rather than as an incentive for collaboration. This problem has been thematised with regard to the planning system in the UK by Vigar et al. (2000):

> The system has been pulled away from a role in strategic territorial integration. It has become a 'sectoralised' regulatory system, co-existing and sometimes coming into conflict with other regulatory systems, most notably that concerned with environmental quality led in the UK by the Environment Agency. (p.10)

Vigar et al. (2000) also express that the planning systems and other regulatory systems, in particular environmental regulation, are not always aligned, showing that the sectoral fragmentation encompasses both the actors and the regulatory regimes surrounding these actors. Integrating the subsurface into the current planning regime, as is sometimes suggested, thus involves the risk of extending this fragmentation into the subsurface rather than achieving the expressed goal of integration.

A way of initiating the overcoming of sectoral fragmentation in the subsurface could be the establishment of a joint classification of subsurface uses and entities. The review of categorisations of the subsurface presented in Chapter 4 (Section 2.4) shows that no unified terminology has yet been established. The different considerations mentioned by planners and engineers strengthens the argument that without a consistency of conceptual frameworks that are represented in these classifications, the fragmentation of worldviews that sit within specific sectors or communities of practice will persist. As a starting point, von der Tann et al. (2018b) suggest to distinguish categories of subsurface content and subsurface use similar to the distinction between land-cover and land-use for surface land.

5.3.4. Value and need as fragmenting and integrating concepts

Integration along all three, the temporal, the spatial and the sectoral dimensions, has to do with value capture and realisation. Persistent trends of financialisation lead to fragmentation in time and space and a lack of collaboration between sectors inhibits the establishment of overarching value assessments. It is here not proposed that value be treated as an independent dimension as, in itself, it is multidimensional and cannot – as has been shown – be reduced solely to the financial question. In particular, the values attached to cultural or personal experiences are always constructed in an individual setting. The financial value that is assigned to land both above and below ground depends on parameters like its current or potential function, special properties and access. They should also include parameters like the connection to the land and the meaning that is assigned to its current quality by the people affected by potential change. Value assessments have to integrate the above and below ground, and take their interdependencies into account.

The financial value of land, and the development of land value in London over the last few centuries, are a much-discussed issue in the academic literature (see, for example, McAllister, Shepherd, and Wyatt, 2018). As presented in the current analysis (Section 5.2.2), the availability and condition of underground space as well as the infrastructures placed in the subsurface influence the land value and, in turn, land value influences the feasibility of underground structures. Frameworks for subterranean land rights and valuation, such as the one being developed for Singapore (Ng and Choy, 2018) support the concept of unlocking financial land value through underground construction and thus establish an important role for engineers in extracting this value (McNeill, 2019).

Given that value is reflected in individual perspectives, the sectoral fragmentation also implies a fragmentation in understanding value, which needs to be overcome in order for effective collaboration to take place. In other words, silo thinking results in silo valuations of the subsurface. This is problematic because it affects the ability to integrate different time scales, benefits and purposes into the evaluation of the development and implementation of subsurface interventions. Suggestions as to how to overcome this divide include assessments of social value (Bricker et al., 2019), or refer to the assessment of ecosystem services (Maring and Blauw, 2018) (see Chapter 2, Section 2.3.3.2). Ecological or ecosystem values of the underground have also been discussed by Bobylev (2018) and are inherently acknowledged in the Environmental Impact Assessment (EIA). Qiao et al. (2019) propose a method for the monetary valuation of urban underground space, calculating the 'replacement costs' for services provided by underground space developments. However, all of these propositions are targeted at the assessment of the impact and benefits of specific interventions, and depend on a categorisation of uses or services, potentially with a distinction between the value of the subsurface space or function itself (direct use value) and the value created through preventing something else (indirect use value).

As has been discussed repeatedly, a unified classification has not been established and would thus stand at the beginning of any effort to assess the value of the subsurface. Value goes beyond monetary valuation, and other forms and meanings of value should be assessed.

Some of these were not explicitly mentioned as valuable in the interviews. For example, historical and heritage values were touched upon by planners, but described as constraints by engineers, reinforcing the necessity of evaluating different perspectives on what is valuable.

Value could also be tied to a more integrated perception of time, assessing continuity rather than use value in a specific moment. As Moffatt (2014) states, 'from an ecological perspective, the value or integrity of the 'system' can be defined by its ability to provide continuously the services upon which humans or other species depend' (p.209). This change of perspective would facilitate a better integration between long-term impacts and short-term commitments (Section 5.3.1).

In this context, it is relevant to question how the 'need' for an intervention is established. The 'need' for infrastructure is, for example, often tied to development opportunities. From the empirical data gathered, there emerged two aspects related to need. On one hand, there arises the question, if a function or development is desirable, is it needed by society? On the other hand, there is the question of whether it needs to be constructed in or occupy a specific location. The imperative described in Section 5.2.1.2 arises from a combination of the two – a function is perceived as needed and can only be established in a specific location if it fulfils that need. As such, assigning priority to those functions appears justified and the question remains as to how these can be identified. Figure 5.4 illustrates a prioritisation matrix, similar to a risk matrix that is commonly used in asset management to prioritise maintenance projects, which could provide a tool with which to discuss the urgency and spatial dependency of underground assets.

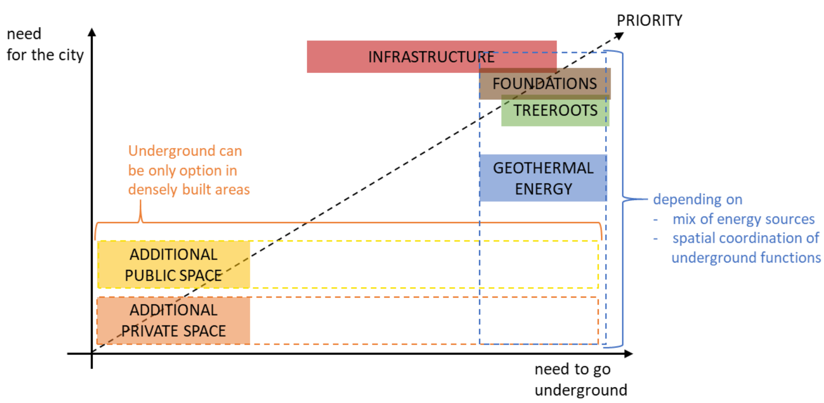

Figure 5.4: Sketch of a prioritisation matrix for underground space functions

In Figure 5.4, in addition to the main functions mentioned in the interviews, geothermal energy and tree roots are shown to illustrate how the need for certain functions will vary depending on priorities set by the city or specific professional viewpoints. In times of climate change and population growth, a discussion needs to be held about which functions might be essential and urgently implemented, rather than about what opportunities may emerge. Instead of predicting demand, perhaps a more appropriate assessment would be one forecasting which infrastructures, that today might be perceived as a 'nice to have', might become indispensable and perceived as imperative in a changing climate. It is also necessary to foresee or capture citizens' perceptual shifts, in that once a potential is realised and normalised it might be perceived as a need. This rationale is reflected in the following quote about Toronto, where the cold climate is a determining factor for people to spend time indoors and the reduction of exposure to weather conditions was expressed as a *need* rather than *potential*: 'in Toronto, there is the whole underground network because it's just too cold to go outside' (E14).

This shift also implies an increasing separation from the 'outside', perceived as nature, and points to the necessity of examining whether this is a generalised desire or intention. Infrastructures in cities work as mediators between nature and humans in that they replace the natural flows (Beck, 2016). The introduction of sewerage systems has been described as 'cleaning' the cities, but it also removed the nutrients. With the growth of cities, resources have been increasingly extracted outside the city's boundaries and transported in, whilst waste is removed from the city and treated or landfilled outside. The separation between what is wanted in the human environment and what is undesirable is mediated by infrastructural developments. This is highly relevant to undergrounds, where the unwanted products of our human life are constantly stored, located, transported or injected. Climate considerations will have to reflect our historical tendencies to use the underground for these purposes.

This leads to a question about what and for whom the urban underground should be used. Infrastructure projects are often seen to be a public good. However, better definitions of public benefit are required as currently the value generated by major infrastructure schemes – in monetary terms – often manifests in increasing land values around the infrastructure and is, therefore, primarily captured by private land owners (Dark Matter, 2019). Here, the issue raised about engineering expertise is crucial. If engineers have the role of evaluating different options and unlocking additional value for society by building underground spaces, it is important to ask in which institutions – e.g. local authorities or government agencies – engineering expertise might be required (see Chapter 4), and how the outsourcing of such expertise might affect the information available and, ultimately, the decisions that are taken.

Capturing the urgency of interventions, as represented in the distinction between an imperative and an opportunity in the engineers' perceptions of the subsurface, could improve the evaluation of different scenarios and also provide a meaningful point of comparison of different worldviews. The distinction between opportunity and imperative for occupying underground space could help to assess priorities for future developments. If the imperative only exists for infrastructure, as suggested in the interviews, this means that, ultimately, infrastructure plans would be needed. With the establishment of the National Infrastructure Commission in 2015, the UK government has taken steps to prioritise this area of activity. However, whether the spatial perspective is sufficiently present in the evaluations has to be questioned. Moffatt and Kohler (2008) observed that when considering the methods with which to calculate resource flows, '*the spatial perspective is mostly absent*' (p.266). Likewise, a concern was expressed in the current interviews that the decisions about new infrastructure schemes did not take the availability of underground space into account. Thus, a need is indicated for a spatial evaluation of current infrastructure plans and projections, one that would also involve an assessment of urgency for different interventions.

It is interesting to note in this context, that with regard to specific project decisions, the prioritisation of functions already exists. For example, the Environment Agency distinguishes between projects according to their significance, allowing for nationally or regionally significant infrastructure schemes where the protection of groundwater, as usually required, is not possible if the EA gets fully involved in the development of the scheme and mitigation efforts (Environment Agency, 2018b).

Finally, it has to be noted that in this discussion of value as well as in the interventions proposed by research participants, whilst it was suggested that plans, projects, reporting or governance could be changed, the overall conceptualisation of the underground as an asset or utilitarian space was not questioned. Beyond this study, it should be asked if other ways of perceiving the subsurface and interacting with the underground exist as well as, if it is utilised, whose interests this utilisation ultimately serves. Ultimately, the purpose of the built environment and with it the purpose of the associated professions is to serve society. In Chapter 4 (Section 4.6.2), it was shown that engineers and planners are central to the current governance arrangement of London's subsurface. As such, one could argue, they have a particular responsibility for keeping this purpose in mind. Technocratic settings with a focus on 'making things work' or busy work schedules can, at times, get in the way of such reflective position that also requires communication of professional knowledge to a wide range of people (see reflection in Chapter 3, Section 3.6). In light of this consideration, the suggested reframing of the purpose of an underground strategy – or at least that of initiating a process towards such strategy – as gaining a better understanding of spatial and material aspects of subsurface related policies (Chapter 4, Section 4.3.6.1) can only be seen as a starting point. For a strategy to be meaningful, the impact of these policies on the affected communities has to be evaluated. A better understanding of the underground and the interdependencies with the above ground as well as subsurface into such evaluation could, in addition to the spatial and material aspects, foster learning about social inclusions and exclusions that underground interventions might create and consequently change the result of such evaluations.

5.4. Summary

This chapter presents a thematic analysis of the interviews with tunnelling and planning professionals in London. The analysis demonstrates the underground to be conceptualised as an asset while, at the same time, spatial, temporal and planning considerations make it a very constrained space. With regard to structures being placed into the ground, a distinction was made between understanding underground space as an opportunity to extract value and seeing an imperative to place certain functions perceived as necessary for the city to function – especially infrastructure – into this space. Suggestions for strategic interventions directly referred to this perception, in that the safeguarding of routes would protect corridors for these necessary interventions and an asset register would remove some of the described constraints. A better understanding of underground experts' perceptions would help with initial efforts to overcome the persistent fragmentation in the field that was found to be present in all three – the spatial, temporal and sectoral – dimensions. Integrating the evaluation of the need for, or the urgency of, interventions into the assessment of value appears to be a necessary step towards more integrated approaches to urban underground space allocation.

Following the detailed look at engineering and planning professionals' perception of London's subsurface in the current chapter, the next chapter will present and analyse data collected in an online questionnaire in which the present findings were tested and expanded with a wider group of respondents. The second part of Chapter 6 will then reflect on the combined findings and their implications in light of the conceptual framework of systems thinking presented in Chapter 2.

6. Systems thinking as a facilitator of integrated urban underground governance

Subterranean surroundings, whether real or imaginary, furnish a model of artificial environment from which nature has been effectively banished. Human beings who live underground must use mechanical devices to provide the necessities of life: food, light, even air. […] The underworld setting therefore takes to an extreme the displacement of the natural environment by a technological one.

Rosalind Williams, Notes on the Underground

6.1. Introduction

The previous Chapter presented in-depth interviews with tunnelling engineers and planning professionals, against the background that these two disciplines occupy central positions in the current governance of London's underground space, as illustrated in Chapter 4. The importance of technology – and, therewith, technical knowledge – in the realm of underground space is emphasised by what Rosalind Williams posits in the above quote: that a major difference between the above-ground and the underground lies in the fact that people spending time in underground places need to accept that, there, they rely on other human beings, as all life supporting functions are provided through technology (Williams, 2008). As such, it appears logical that the expression of the need for change towards more active management and planning of the subsurface – as expressed by engineers in light of its non-efficient use, leading to congestion and loss of potentials, including loss of access to new spaces (see Chapter 5) – also originates primarily from the engineering discipline (see Chapter 2).

The current chapter complements the findings from the previous chapters with a discussion of the empirical results of a questionnaire pertaining to a subsurface strategy (Section 6.2), which was conducted with the aim of reaching a bigger group of participants and more diverse professionals. Specifically, this part of the study engages with questions that had arisen throughout the preceding research process, such as whether an underground planning strategy is needed for London, the purpose it could have, and which specific actions it might entail. Based on these empirical data and in consolidation with the findings from previous chapters, Section 6.3 connects back to the theoretical framework of systems thinking set out in Chapter 2. The ensuing critical discussion expands on the current understandings of the subsurface, considering the tensions and the need to compromise between integration and segmentation, between harnessing opportunity and protecting the 'pristine', and between positive and negative feedback loops.

6.2. Empirical study

Building on the findings from Chapters 4 and 5, and as detailed in the methodology presented in Chapter 3 (Section 3.4.3), a questionnaire was conducted with the main aim of exploring the actual potential for a designated planning strategy for the subsurface, and what this strategy could entail. *Planning strategy* is here understood – and was defined for respondents – as a participatory process applied to analyse and allocate the environmental capacities of the ground, as well as the current and future human utilisations of, and interventions in, the subsurface in an urban area. Consequently, what such a strategy might entail included questions about who should participate in the process, which functions would need to be allocated in the space available, and how the allocation process could be conducted. The resulting data, including respondents' comments on specific questions where provided, will be discussed in the following sections.

6.2.1. General need for a subsurface strategy

As detailed in Chapter 3, the link to the questionnaire was sent to potential respondents via email. Of the respondents who responded to a majority of the questions (n=60), only 18% (11) had never heard about the concept of underground planning/planning for the urban subsurface. Of the 82% (49) who had come across the concept before, more than a third (19) were either part of an initiative around urban subsurface planning (15), or part of the development of a comprehensive urban planning strategy in their city (4). It should be borne in mind that the previous engagement of a majority of respondents in the field of subsurface planning will have influenced the responses here presented.

Building on indicative responses in the in-depth interviews, questionnaire respondents were asked if they considered a designated planning strategy for the subsurface to be something that is needed. As can be seen from the breakdown of their responses in Figure 6.1, the vast majority asserted that there was, indeed, a general need for such strategy. Only one respondent aligned themselves in opposition to such a strategy, while a handful expressed indifference.

Of the respondents who did not choose one of the proposed answers (marked 'Others' in Figure 6.1), six made statements in favour of a planning strategy, commenting that 'totally needed' was too strong a statement, or clarifying that this should not be independent of the above ground strategy – which, in their opinion, is also lacking. One of these respondents also commented that the necessity for a subsurface planning strategy would depend on the particular city, and that in certain cities strategies are already in place. Of the remaining two respondents in this category, one suggested a sectoral approach of 'one aspect at the time', without specifying the sectors, whereas the other stated that progress in the area would not currently be possible owing to too many unknowns. It can be argued that both of these specific statements strengthen the proposition presented in Chapter 4; namely, that a process towards an overarching planning strategy – which most participants expressed as being strongly in favour of – could be facilitated through integrated data management, or, vice versa, that better integration of the data could serve as an enabling mechanism to trigger exchange and collaboration between asset owners. Data integration, and the process towards such an integration, entails a specific aspect that could be targeted independently, as claimed by the first respondent, and would begin to fill the knowledge gap alluded to by the second respondent. Consequent to this observation, and in accordance with the findings from Chapter 4, the following two sections present first the rationale, specific actions, potentials and barriers for an overarching planning strategy (Section 6.2.2) and then, separately, similar considerations for improved data management (Section 6.2.3). The percentages reported in the text are relative to who answered, excluding N/A answers.

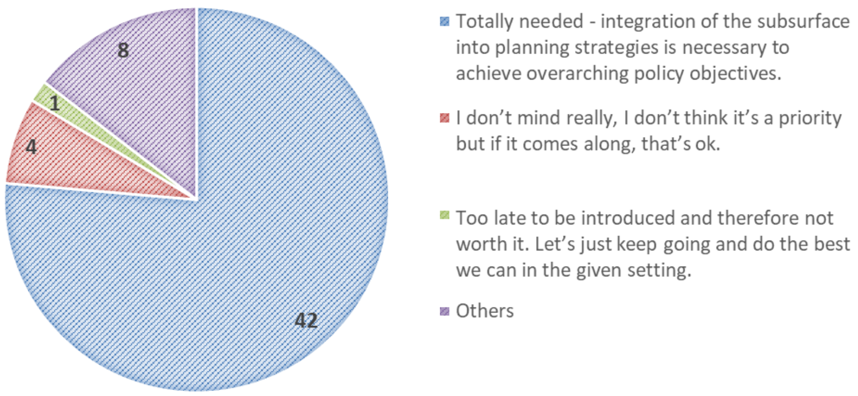

Figure 6.1: Respondents' assessment of the need for a subsurface planning strategy (n=55)

6.2.2. Respondents' views of a subsurface planning strategy

Respondents' general attitude in favour of taking action towards an integration of the subsurface into the realm of urban planning (Figure 6.1) was further reflected in their rating of the desirability of specific actions that could be taken towards a planning strategy (Figure 6.2). As can be seen from this evidence, all of the proposed actions were predominantly rated as either strongly desirable or desirable, with the highest approval rates assigned to the integration of the subsurface into Local Plans and the safeguarding of transport routes, both of which more than 95% of respondents adjudged to be desirable or strongly desirable. It is noteworthy that respondents also largely agreed that all of the suggested actions would be feasible, with the feasibility rating here revealing if the respondents think that a specific measure is actually achievable rather than 'wishful thinking'. Regarding solely the safeguarding of functions for as yet unforeseen uses, and the streamlining of consenting regimes, more than 20% of respondents were of the opinion that those actions were not, or probably not, feasible. The high approval rate of supplementary planning guidance for the subsurface reflects the fact that this is the way in which the integration of specific topics into urban planning is currently being handled in the UK (see Chapter 4); moreover, the fact that respondents provided no further comments to this section of the questionnaire suggests that such integration via the current system was generally accepted as a way forward.

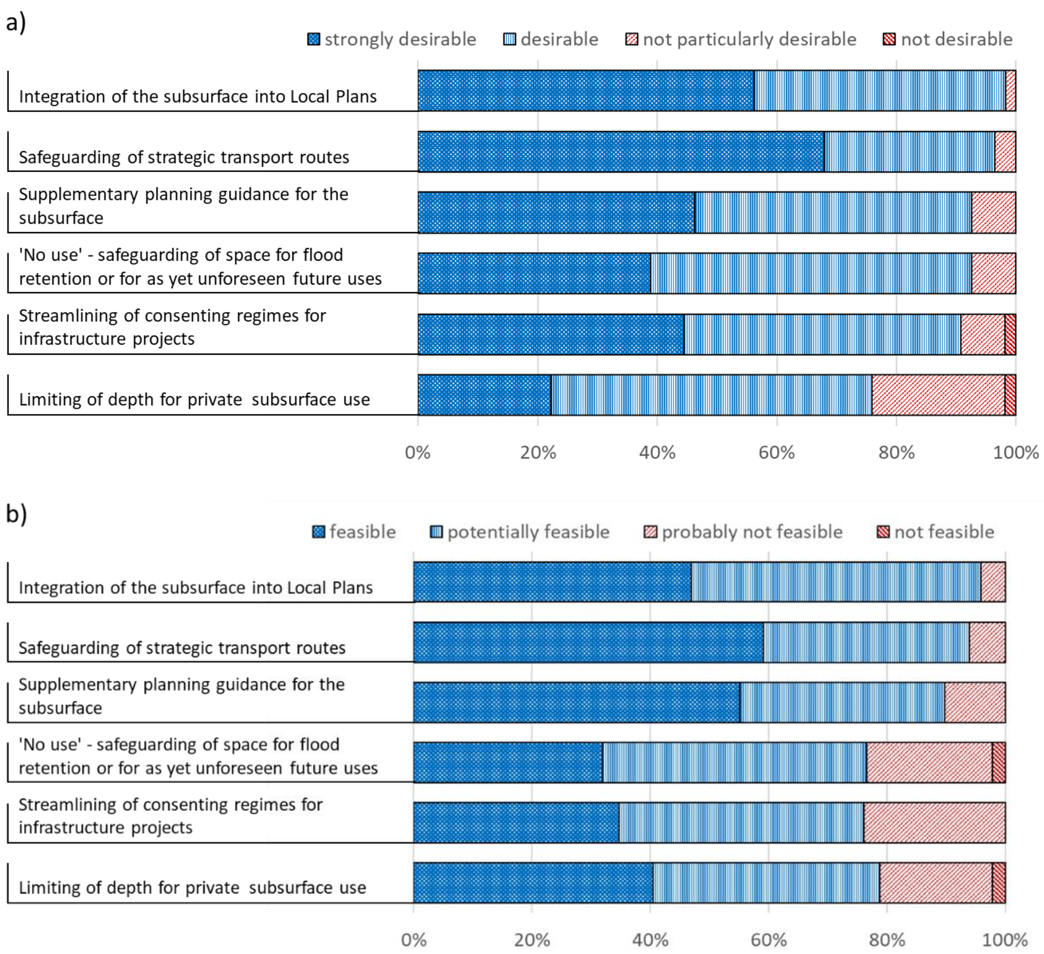

Figure 6.2: Respondents' view on the a) desirability (n=53-57, excluding N/A answers) and b) feasibility (n=46-49, excluding N/A answers) of specific actions to be considered within an underground planning strategy

As shown in Figure 6.2, also more than 75% of respondents considered a limitation of depth for private developments as desirable and feasible. Such limitation is one way in which the allocation of rights to occupy space is dealt with in other countries, and the high approval rate here suggests that these respondents were familiar with this approach. For example, in 2000 Japan introduced the Act on Special Measures concerning Public Use of Deep Underground, which restricts private developments to 40m depth, with an allowance for deep foundations to reach up to 10m into the bearing stratum (Kishii, 2016). This approach corresponds to the observation that respondents, when considering the general rationale for an underground planning strategy, largely agreed or strongly agreed that the attribution of ownership in the subsurface is often unclear (Figure 6.3). However, even if the suggestion to limit the permissable depth for private use might provide a clearer delineation of use rights, access to the deeper levels will have to cross shallow levels, and the time needed to reach deeper levels for those functions where humans access the space might constitute a concern.

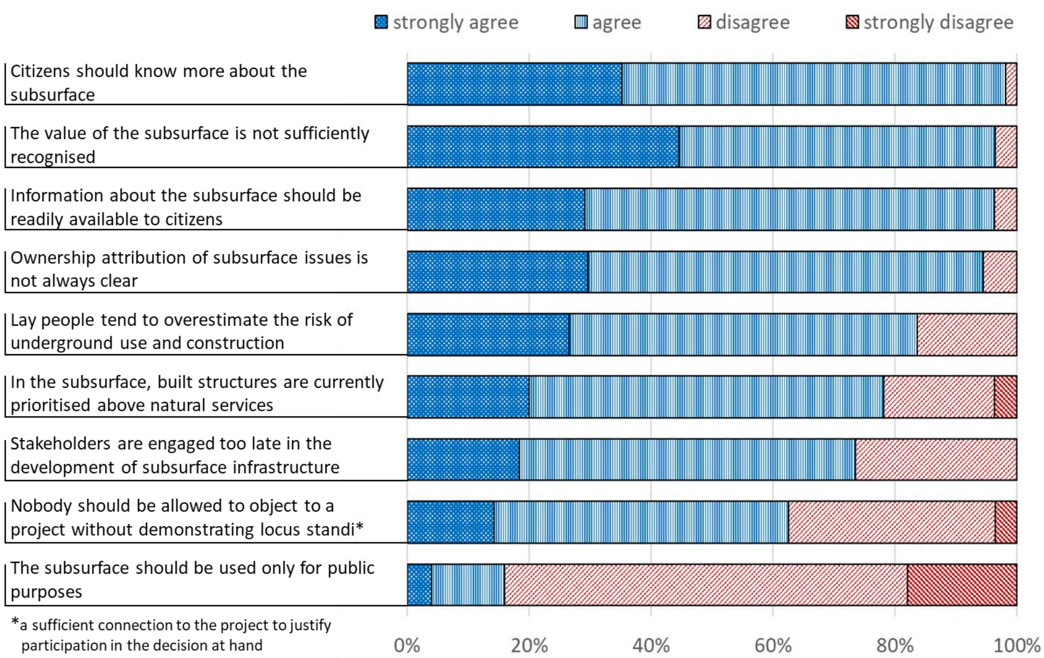

Figure 6.3: Respondents' views of general rationale for an underground planning strategy (n=50-56, excluding N/A answers)

The consideration of property alone when looking at a specific volume is, arguably, too narrow to capture the spatial complexity of interactions between the built and natural environment. Darroch et al. (2018) provide a more comprehensive framework through which they propose analysing underground metro infrastructure in terms of its presence (what already exists and what is required), property (who owns it, rights and responsibilities), and protection (how the metro's ongoing presence is ensured). This framework shows that property rights and ownership of the space, as such, are only a fraction of the legal and interstakeholder considerations that constantly surround underground structures. In particular, the question of protection remains challenging as, firstly, only known assets can be protected through the design of new developments; and secondly, as has been alluded to in Chapter 5, the protection of space for future assets has proven to be difficult. In addition, even if a specific volume in the subsurface itself is kept untouched, construction in adjacent volumes can influence the conditions for construction in that space. The – financial – value assigned to subsurface space will, arguably, depend on its accessibility and, thus, the costs associated with developing the space.

Further engaging with the aforementioned rationale for an underground planning strategy, the large majority of respondents (96%) expressed that the value of the subsurface is not sufficiently recognised (Figure 6.3). The meaning of 'value' was not further specified in the question, but the high approval rate confirms the findings from Chapter 5, where it was discussed how the conceptualisation of 'value' needs to extend beyond its monetary definition and – as this conceptualisation sits within the individuals' understanding – an integration of different stakeholders' views is necessary to do so. As such, the fact that the value definition needs to be expanded is here reflected in the strong agreement amongst respondents (98%) that citizens should know more about the subsurface (Figure 6.3), and that that information should be readily available (96%). This is, on the one hand, again linked to the need to capture different opinions in order to reach an integrated definition of value, and, on the other hand, to the notion that lay people overestimate the risk of subsurface interventions (84%), as borne out in the current data (Figure 6.3). Both of these aspects open up a question about the accessibility of data and information, not only for experts within the built environment, but also for stakeholders beyond the expert groups involved with subsurface construction or assets, including the general public.

The better accessibility of data and information stemming from that data would arguably also facilitate a different approach to stakeholder involvement and consultation in specific projects. From the interview data, an inherent conflict had emerged between wanting to involve and inform citizens on the one hand, and efficient management of the construction site on the other, as the disruption to citizens is ultimately minimised when the construction time is also minimised. At the same time, the involvement of citizens' could actually trigger delays, in turn increasing disruption for others. In this context, respondents largely agreed that stakeholders are engaged too late in the process of infrastructure development (74%, Figure 6.3). In addition, 93% of respondents expressed that community feedback is necessary at the level of plan making (Figure 6.4), as earlier consultation might help to mitigate these effects, and, at the same time, declared themselves to be in favour of a restriction of the rights to object to specific projects, with 63% agreeing or strongly agreeing with the suggestion that such an objection should be limited to those who could demonstrate a sufficient connection to the specific project in order to justify their participation in the decision at hand ('locus standi').

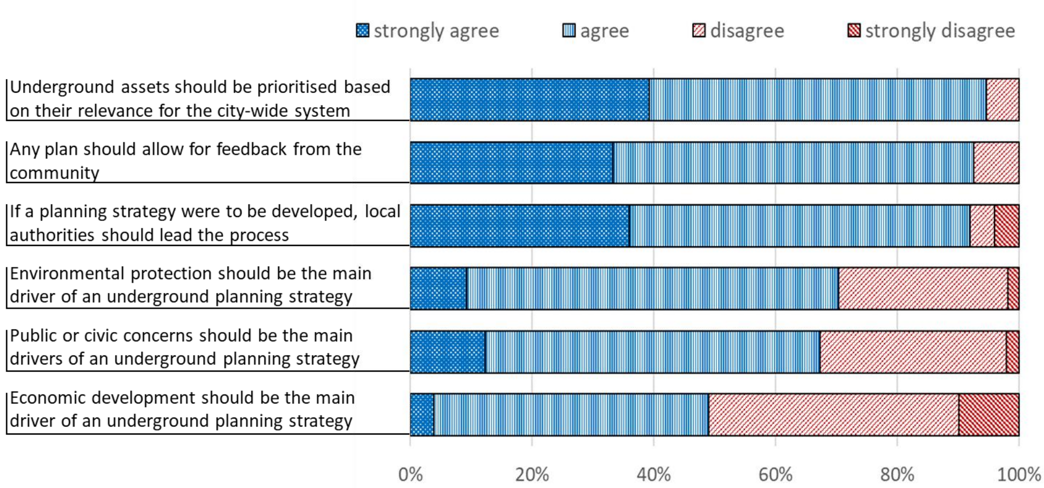

Figure 6.4: Respondents' views on directional statements for an underground planning strategy (n=49-56, excluding N/A answers)

The implication of this finding, in combination with the observation made in Chapter 4 (Section 4.5) that land owners and residents are usually only interested in strategic planning if their own piece of land is affected (see also Appendix X), is that, potentially, citizens' involvement should happen at this higher level, and not only during project implementation stage; a question thus has to be asked about how this could be facilitated. Better communication with, and the early involvement of, citizens in the development of high-level plans might alleviate citizens' needs to comment on specific project proposals that sit within these plans, ultimately enabling efficient decision making when it comes to project implementation.

With regard to current governance of the subsurface, 80% of respondents indicated their belief that the built environment is currently prioritised compared to environmental functions (Figure 6.3). However, the evidence also shows a gentle hint towards a potential change in priorities – or a change that should happen in the respondents' opinion: of the three pillars of sustainability posited to respondents as potential drivers for the development of a strategy (economic, social, and environmental), the highest level of agreement was reached around environmental protection, with 70% of respondents agreeing or strongly agreeing that this aspect should constitute the main driver. Regarding economic development as the key driver of the same, a similar number of respondents agreed (49%) and disagreed (51%) with the statement, suggesting that the understanding of the role of finances and the underlying economic models might provide a point for discussion that needs to be clarified and agreed on, again coming back to the question of value, how it is defined and unlocked (see Chapter 5, Section 5.3.4). In this context, the controversial nature of the questionnaire respondents' answers about economic development as driver for an underground strategy also suggest that when agreeing to the statement that the value of the subsurface is not sufficiently recognised (Figure 6.3), respondents did not necessarily refer to financial value or financial value only, and, again, that a broader value definition might be necessary to capture the role of the subsurface for the city.

Regarding allocation of the planning task, a great percentage of respondents (92%, Figure 6.4) felt that a strategy would have to be led by the local authorities, recognising the centrality of the position of those authorities, as shown in Chapter 4. This statement also implies that this may be seen as an urban rather than a regional or national task. With regard to the development of a strategy, the prioritisation of functions according to their relevance for the city-wide system was seen as necessary by 95% of participants (Figure 6.5.). In terms of these actual functions, respondents rated underground infrastructures as most essential (Figure 6.5), namely, sewage tunnels and underground rail and stations, thus supporting the focus on infrastructure that was elicited and discussed in Chapter 5. In addition, drainage capacity, groundwater provision and bearing capacity were also seen as significant, with more than half of the participants rating them as essential.

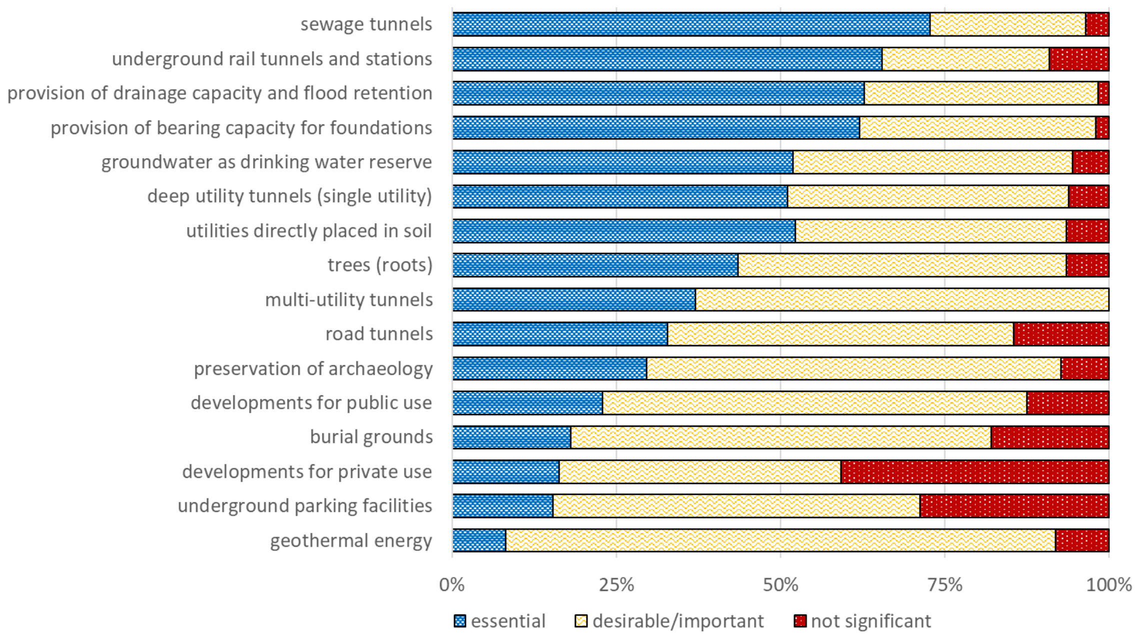

Figure 6.5: Respondents' perception of significance of different uses for the city (n=52-59)

It is interesting to note here that geothermal energy was not thought to be essential by a majority of participants. This signifies that what is already there and currently in use might be perceived as more essential than those functions that are anticipated, but have not yet been established, as well as those that are not constantly in use, such as archaeological remains. This perception might well shift over the following years given the increasing pressure to counteract climate change.

The lower rating of the significance of private developments for the city in general in Figure 6.5, as well as the substantial agreement to prioritise functions according to their role for the city-wide system (Figure 6.4) are somewhat at odds with the low rate of agreement with the statement that the subsurface should be used for public purposes only (Figure 6.3). This discrepancy may suggest that whilst public functions are seen as more relevant for the city, the restriction of private developments was not a key concern among respondents.

In the comments provided to the question illustrated in Figure 6.5, that is, how important they considered the listed subsurface uses to be for the development of their city and the wellbeing of its population, waste collection and water recycling were mentioned as additional functions that could be potentially relevant. One respondent stated that any function that does not need to be at surface level should be placed underground, while another mentioned with regard to bearing capacity that development plans would have to be known about in advance in order for the developments not to become blocked by underground structures. These statements underpin the necessary integration between the above and the below ground, as elicited through the in-depth interviews and discussed in Chapter 5, as these are currently often described as two distinct realms of space and governance (see Chapter 5, Section 5.3.2, Table 5.1). However, stating that anything not needed on the surface could be placed underground also entails a risk of maintaining the status quo that is shaping and managing the subsurface as a reaction to surface needs, rather than as an integrated entity.

Two further comments on the same question referred to the fact that needs with regard to subsurface space might be changing. One respondent commented that multi-utility tunnels could provide space for future utilities not yet invented. Another respondent anticipated the importance of underground parking was anticipated to diminish with the move away from vehicular traffic and associated parking. These comments open up a question about the adaptability of underground structures, on one hand, and the longevity of these structures on the other, as discussed later in this chapter.

In general, underground structures have a high degree of permanence: once a structure in the underground is built, it is difficult to change its form or size. As such, opportunities for structural adaptation can only be integrated insofar as future uses are anticipated when a structure is planned. However, it shall be mentioned here that underground space might not be as static as commonly thought – by removing soil and filling or piling it somewhere else, humans constantly create new ground (see Chapter 4, Section 4.3). In addition, the claimed pertinence might not be unique to underground structures. As Næss (2015) writes, 'the street network in inner parts of many cities is still characterized by the street pattern established several hundred years ago' (p. 1236). As such, the described pertinence of underground structures might be attributed to their function as infrastructure rather than their location in the subsurface. This, in turn, strengthens the inherent link between the urban subsurface and infrastructure as presented in Chapter 5.

Overall, the main benefits of a potential underground strategy were seen as lying in reaching high-level objectives (Figure 6.6), namely, counteracting congestion in the subsurface, contributing to overarching policy aims and discovering of untapped opportunities, rather than achieving specific aims like safeguarding routes or simplifying consent procedures, which were chosen less often. It is here worth noting, however, that the latter two aspects were chosen more often by engineering professionals. This suggests that the need for safeguarding infrastructure routes as drawn out from the in-depth interviews with engineering professionals (see Chapter 5, Section 5.2.3.1), may, indeed, sit within engineers' perception of the space, and be less of a concern to professionals in other disciplines.

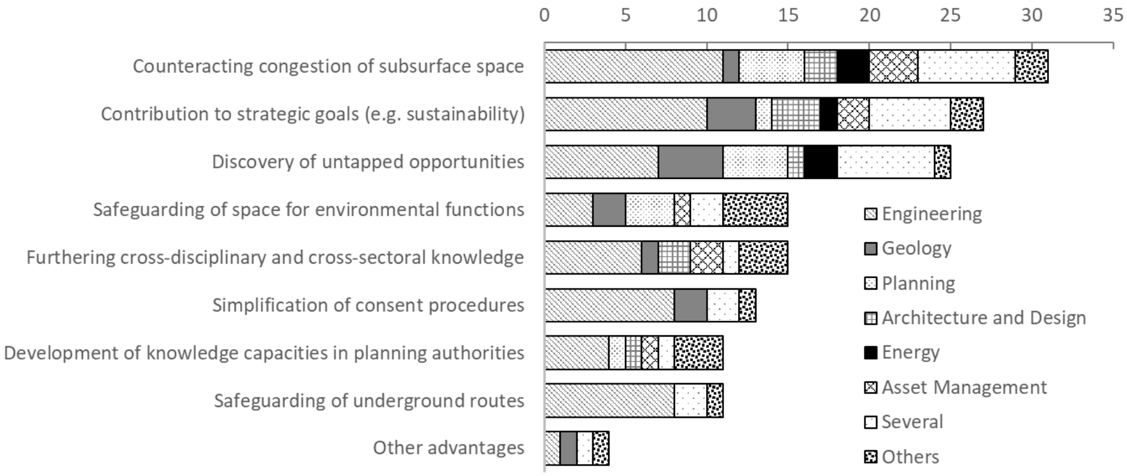

Figure 6.6: Main potential benefits of an underground planning strategy

Note: 'several' combines respondents who stated more than one area of expertise and 'others' those who specified a different area of expertise, including, law, history, or archaeology (see Chapter 3, Section 3.4.3, n=55, up to three answers possible)

A similar picture evolves from respondents' ranking of the themes to be addressed in a strategy (Figure 6.7): contribution to overarching policy objectives, data availability, congestion of subsurface space, streamlining of legal procedures, valuation and project finance, and environmental protection were all rated high by a large number of participants. The average ranking of the highest rated, 'overarching policy objectives', is 3.8, while the one for the lowest rated, 'technical challenges', is 5.6, showing a fairly narrow range. Next to 'technical challenges' also 'stakeholder management' was rarely rated as 1st or 2nd priority (average rating 5.5), demonstrating that respondents assign a low priority to these topics in the process towards an underground planning strategy. However, all of the themes were ranked high by some participants and low by others, showing that generally all of these topics need to be addressed when considering a planning strategy. One respondent who did not rank the items commented that the issues were too overlapping and that assigning a lower priority to some could be detrimental to the whole process.

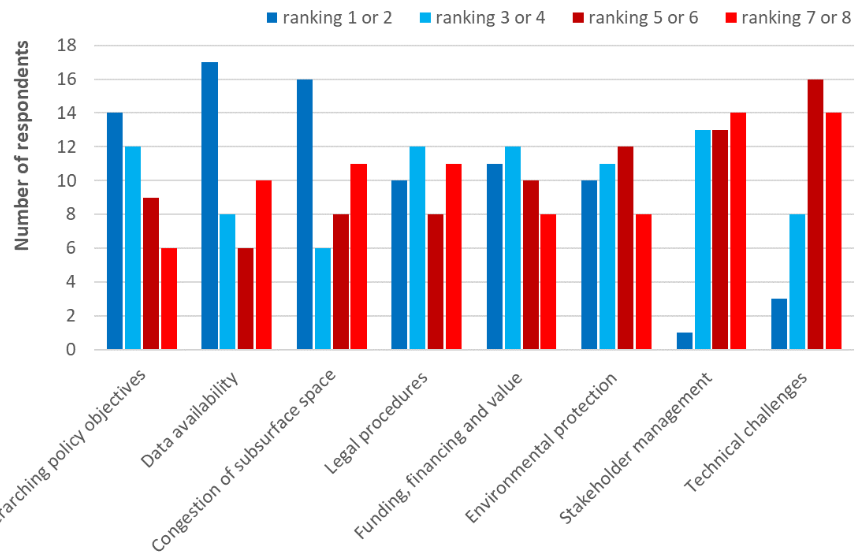

Figure 6.7: Ranking of specific themes to be addressed in a subsurface planning strategy (n=41)

Overall, the ranking of themes by the respondents shows that all the listed themes have to be acknowledged and, arguably, integration across all topic areas is needed. As such, establishing an actual priority of the listed items, which would mean some of the items being construed as of lesser importance, does not seem expedient. However, there may be scope to address and discuss specific, highly ranked, items upfront. In particular, the high rankings of 'overarching policy objectives' and 'data availability' (average ranking 4.0) strengthen the proposition that emerged from the analysis in Chapter 4; namely, that overarching policy aims and data could provide starting points and constitute mechanisms that facilitate a subsequent integration process. Other items are, arguably, just as important, but could be treated at this point in time as boundary conditions for the strategy development process and be integrated at a later stage. As such, the implication of these findings, taken together, is that an independent or preceding strategy towards better data management and sharing appears apposite.

This implication was also reinforced through the comments that accompanied the question of which factors were perceived as the main barriers towards the construction of a subsurface planning strategy (Figure 6.8). Here, data appeared again as a major concern, with one respondent commenting that comprehensive knowledge of assets already present in the subsurface would be required which, in turn, would make significant capital expenditure and centralisation of information necessary, while another respondent stated that any potential model might be unreliable as high security data might not be included. As shown in Figure 6.8, many respondents (n=20 of 55) were of the opinion that increased bureaucracy constitutes one of the main barriers for establishing an underground strategy; however, the fact that conflicts with existing plans and regulations were rated as a non-significant barrier suggests that they also believed that coordination within the planning regime would be possible if the need would arise. The potential that a new strategy might be inflexible and/or conflict with existing plans and regulations, did not appear to be a major concern for respondents reinforcing the observation made earlier that the integration of the subsurface into the Local Plan and the development of specific supplementary planning guidance were perceived as both desirable and feasible (Figure 6.2).

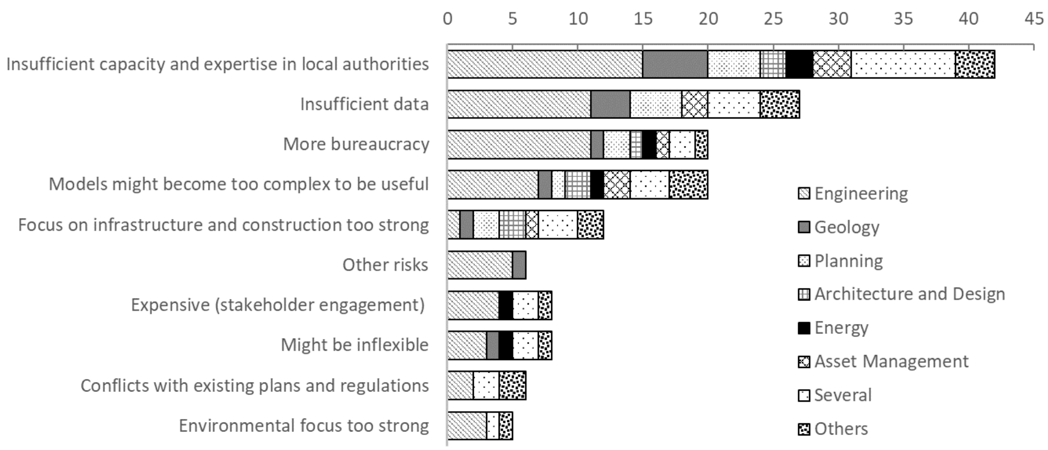

Figure 6.8: Main risk of/barriers to establishing an underground planning strategy (n=55, up to three answers possible)

As stated previously (Figure 6.4), in respondents' opinion, local authorities would need to lead the process towards an underground planning strategy. This corresponds to three quarters of respondents naming 'insufficient capacity and expertise in local planning authorities' as the most significant barrier to establishing such a strategy (n=42 of 55, Figure 6.8). It should be noted that this response is not dominated by a specific profession and thus appears to be a cross-discipline concern. It reinforces the findings from Chapter 4 that technical knowledge would occupy a central position if integration across sectors operating in the underground were to be sought. It also demonstrates that capacity building and education might be major tasks on the way towards this integration. However, looking back at the benefits of having an underground planning strategy (Figure 6.6), few respondents answered that capacity building in planning authorities would constitute a main benefit, suggesting that capacity building is seen as a necessity rather than an opportunity.

6.2.3. Respondents' views of a specific data strategy

The existence and availability of geological, geotechnical and geochemical data is characterised by a multitude of owners and data formats (Schokker et al., 2016). As discussed in Chapter 5 insufficient data about subsurface assets was described as a hindrance by tunnelling engineers, with decentralised data management seen as leading to extensive duplication of work (see Chapter 5, Sections 5.2.2.2 and 5.2.3.2). This shortcoming has been recognised in the industry and, throughout the course of this research, a lot of efforts to improve the management of subsurface asset data have been undertaken – not only in the UK, but also worldwide. Recent and current efforts to improve the management of subsurface asset data in the UK are summarised in von der Tann et al. (2018, Appendix II) and mentioned in Chapter 4. Current initiatives and research focus mainly on two areas of action: 1) establishing a unified data format, and 2) establishing a central repository. The analysis of the current data, as will now be reported, overlaps with the findings of these efforts.

In general, questionnaire respondents agreed or strongly agreed with the statement that data, as well as the overall understanding of the subsurface system, are currently insufficient (87% and 93%, respectively), that this insufficiency makes it difficult to quantify project risks (98%), and that a better data base would reduce overall project costs by facilitating better designs (98%) (Figure 6.9). Only the approval of the statement that the lack of data would lead to the unnecessary involvement of stakeholders was slightly weaker, but generally still high (82%). This is in accordance with the data presented in the previous section where it was discussed that respondents perceived the earlier and better information of citizens to be desirable (see Figure 6.4).

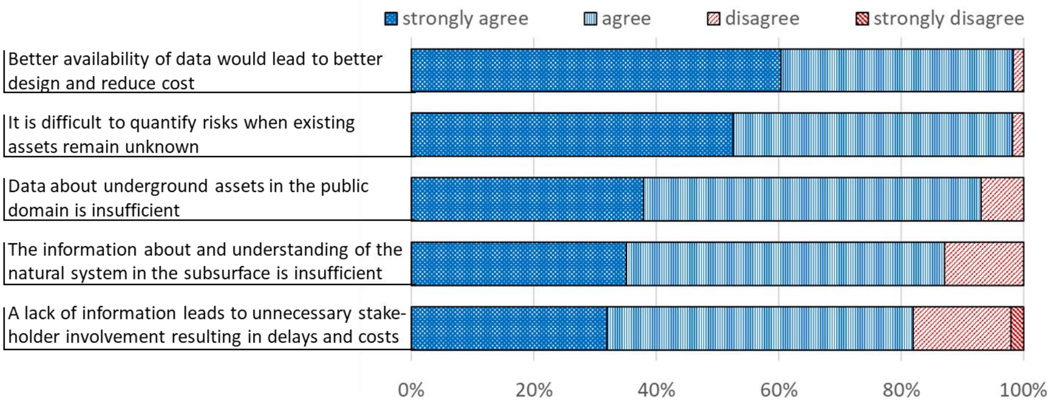

Figure 6.9: Respondents' views on general rationale for an underground data strategy (n=50-58)

As for the planning strategy, all of the specific actions proposed here were generally considered by respondents to be desirable as well as feasible. In particular, nearly 60% of participants rated the creation of an asset registry as highly desirable (Figure 6.10a) and 100% thought it would be feasible or potentially feasible (Figure 6.10b). The creation of an integrated 3D model of all underground assets, as well as the integration of this model with a model of the built environment above ground, were equally seen as desirable and also workable. Only the feasibility of integrating environmental processes into potential models, as well as the mapping and safeguarding of as yet unused space were judged with slightly less confidence, with more than 20% of respondents stating that those actions would not, or probably not, be feasible.

Following the spatial visualization of the subsurface, facilitating efficient change monitoring and data accessibility were stated as the main benefits that a data strategy could deliver (Figure 6.11). However, in the space for comments adjoining this question, one respondent expressed the concern that not all data might be included due to security concerns which could, in turn, render the models unreliable. Other comments included further benefits of an integrated data strategy, namely, that it could help to avoid the duplication of work, that an otherwise 'disparate' community could be brought together, and that the forward planning of infrastructure works in an integrated way could be facilitated. These comments reinforce the points made earlier in this chapter as well as in Chapter 4 (Section 4.6.3.3) regarding a data strategy as a mechanism to facilitate stakeholder cooperation, as well as an enabler towards a comprehensive strategy.

It remains to be noted that the remainder of the suggested benefits, namely, the establishment of standards for data collection and records, understanding of data gaps, the possibility of overlaying different kinds of information and enabling research, were chosen by a significantly smaller number of participants. These standards already exist in some areas, such as the – now widely accepted – data format for geotechnical data (AGS format, see

Bland et al., 2014), or the code of practice for collection, recording and sharing of location information data of buried assets (PAS 256) that has been launched in April 2017 (see also von der Tann et al., 2018a, Appendix II). This suggests that these items might be seen as a condition of achieving the benefits expressed, rather than as ultimate benefits in themselves.

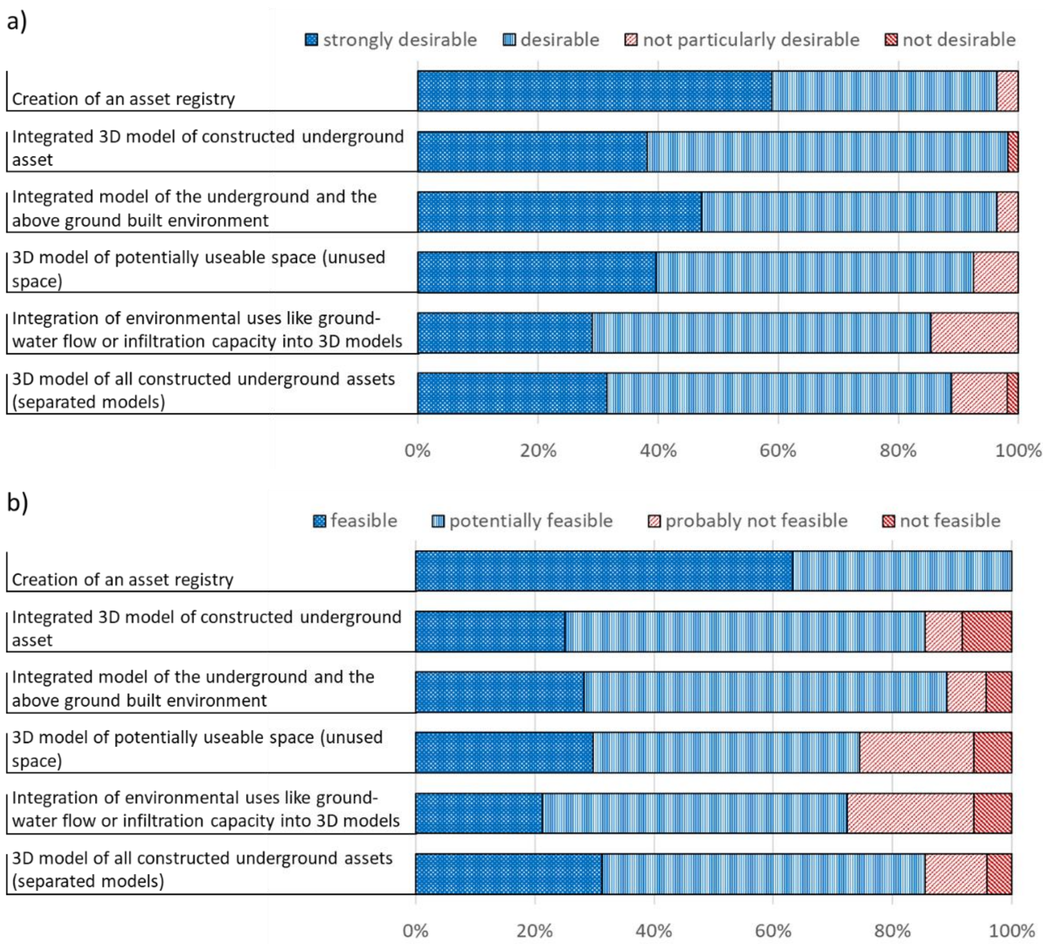

Figure 6.10: Respondents' views of a) desirability (n=53-57, excluding N/A answers) and b) feasibility (n=46-49, excluding answers stating 'not my area of expertise') of specific actions to be considered within an underground data strategy

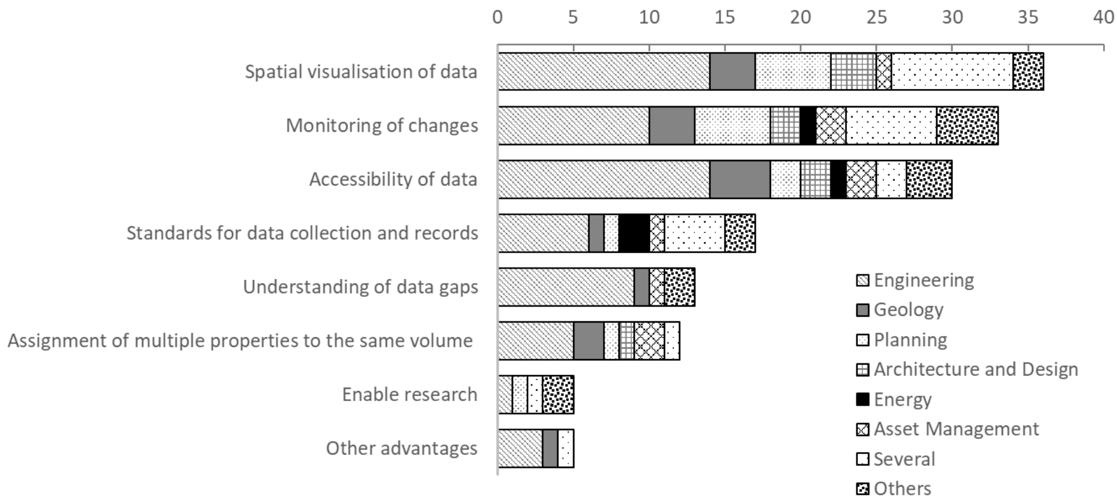

Figure 6.11: Main benefits of a comprehensive data strategy (n=55, up to three answers possible)

6.2.4. Synthesis

The study presented in the previous sections explored the actual potential for a designated planning strategy for the subsurface through a questionnaire that was responded to by a diverse group of professionals, the majority of whom had been involved in the field of subsurface planning beforehand. In addition to desirability and feasibility of specific measures towards a planning strategy, the questionnaire explored topics that had been indicated as relevant in the in-depth interviews through testing the controversiality of specific statements.

In general, the questionnaire confirmed the main findings from Chapters 4 and 5, with respondents' manifesting the broad agreement that a better integration of the subsurface into urban planning is, indeed, needed. Specifically, the analysis of the questionnaire responses reinforced the important role of data integration for this process. Arguably, data not only provides a baseline and starting point, but data management also may serve as an enabling mechanism that can facilitate the establishment of links between different actors as well as potentially allowing earlier and better-informed citizen participation. Overall, the analysis of the questionnaire responses indicates that current efforts towards a data strategy can lead to the establishment of trust between stakeholders and provide the basis for further coordination, as well as for a more comprehensive planning strategy. In particular, informing citizens could facilitate more engagement at the plan making stage, ultimately helping the consultation process move towards project implementation as the overarching objectives could thus be better communicated. As such, one of the implications of these findings is that an involvement of citizens at higher levels of planning should be sought.

The aspect of community involvement, and the importance of understanding communities' needs and perceptions of value also resonates with a finding from the in-depth interview data that was reinforced in the questionnaire: that, in order to capture the meaning of the subsurface for a city – be it in a specific strategy or elsewhere – and, ultimately to be able to formulate a strategy that reacts sensitively to local specifics, a broader definition of value is needed. As has been pointed out in Chapter 5 (Section 5.3.4), this should go beyond a purely financial assessment of the impact and benefits of specific interventions and consider different time scales, past and future.

The next section will return to elements of systems thinking, as laid out in Chapter 2, to conceptually synthesise the findings from Chapters 4 and 5 and the section presented above. In particular, the definition of system purpose, dimensions of integration, and dynamic behaviours are discussed. Thoughts on ownership are also presented as a topic that is connected to the question of value definitions and prioritisation of subsurface functions as arose in the context of interviewees' and questionnaire respondents', but one that has, so far, not been discussed beyond purely legal aspects in academic contexts.

6.3. Consolidation: the underground in the urban system

In Chapter 2, the appropriateness of considering the subsurface as separate from the city it lies beneath was questioned, and the argument made that its analysis as a sub-system of the city may, in fact, be the more appropriate approach. The objectives for the development of the city as a whole are often defined in urban plans or strategies. They are defined by planning professionals, and should reflect the current political situation. For example, sustainability and achieving sustainable cities has been conceptualised as a purpose of planning efforts in the UK planning system, where the 'presumption of sustainable development' is highlighted (see Chapter 4, Section 4.4.1). In this understanding, if the subsurface is thus conceptualised as a sub-system, it needs to be possible to name the function or purpose that it fulfils for the city as a whole.

6.3.1. Purpose: the ground as enabling context

The above considerations emphasise that the subsurface cannot be analysed in isolation, but is directly connected to the definition, locality, and identity of the city are also aligned with those laid out by Maring and Blauw (2018), who propose evaluating the potential contributions of the subsurface 'asset' in light of the overarching objectives of urban planning, such as responding to climate change (see Chapter 2, Section 2.3.3.2). However, these kinds of purpose definitions for the overarching system, the city, may be seen as vague and subject to interpretation when it comes to defining the role of the sub-system – here, the underground – in fulfilling these aims.

To help the conceptualisation of this quandary, it is here proposed that (a) the city as a whole and (b) the ground could be defined as 'context systems'. The term 'context system' stems from Martin (2004), who defines seven systems that encompass a problem situation, and deems the understanding of these systems and their interactions to be necessary for successful systems engineering. The context system, in his definition, is the 'set of facts or circumstances that surround a situation or event' (Martin, 2004, p. 1), and constitutes the system in which the problem is located. Once an engineering intervention ('intervention system') – which, itself is embedded within a 'realisation system' – is implemented ('deployed system'), the context system, in which other, 'collaborating systems' are embedded, will be modified ('modified context system'). As Martin (2004) describes, while these modifications can provide a response to the defined need or problem, they may also cause unintended consequences.

What is relevant here, as shown in Figure 6.12, is that when it comes to interventions in the subsurface, the context of the problem or definition of the given need, and the context for responding to that need, are not aligned. In this picture, the ground itself could be conceptualised as an 'enabling context system', in which several 'embedded systems' are embedded (Figure 6.12). The ground, or geology, enables the construction of developments or infrastructure, the storage of resources and the flow of groundwater. The current system of governance, as mapped out in Chapter 4, focuses on these embedded systems that provide different functions to the city as a whole. Interventions are triggered within any of these systems as responses to a need or 'problem' in the city, called here the 'defining context system'. The aim of urban subsurface planning is to lift the level of governance from the embedded systems to the enabling system, in order to then be able to assess interdependencies and harness synergies between them.

The described misalignment also means that the modification of the context is only anticipated for the city, without due regard for the modification of the 'enabling context' – the ground. Conversely, in the planning of specific projects, the integration of these projects into the urban system is not questioned, as the context under analysis is mostly that which lies in the direct vicinity of the project itself. In other words, the definition of the need for an intervention is largely ignorant of the spatio-material context of the subsurface, whereas a specific project plan might be similarly ignorant of the overarching, city wide system.

This observation also provides a possible explanation for why the changes in context have, so far, not been consistently captured, as manifest in the lack of consistent records of subsurface assets. If the context for an intervention is set with respect to the city as a whole – without the integration of the subsurface setting into this picture – then the changes of context will also be only, or at least primarily, looked at from this perspective. As such, the demand for infrastructure, for example, will be identified by considering demand and supply at the surface, and then necessarily realised – as stated by interview participants (Chapter 5, Section 5.2.1.2) – in the subsurface, rather than by integrating the consequences of such an intervention into the subsurface context.

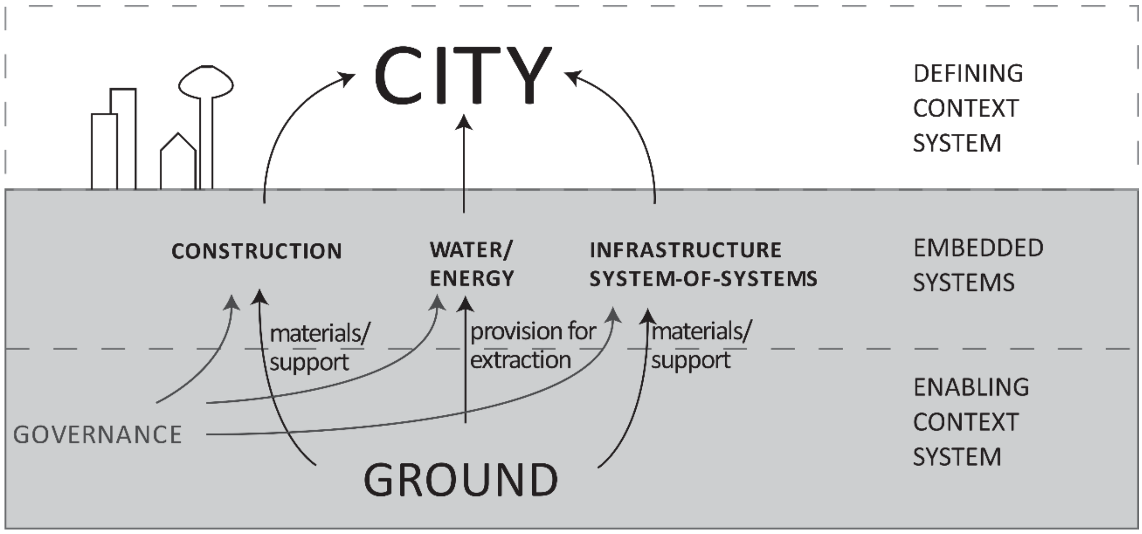

Figure 6.12: The subsurface as a subsystem of the city

6.3.2. Integration: defining a core

A key aspect that is reflected in the documentary research presented in Chapter 4, as well as the questionnaire responses reported in Section 6.2, is that an integration between the context systems for a) planning and b) project implementation could be facilitated through better acknowledgement and integration of the subsurface within urban governance (rather than specifically urban planning) at all scales. At the same time, and as previously expressed, this integration could also be facilitated through a more thorough evaluation and explanation of the short- and long-term spatial effects of subsurface interventions and, therewith, by shifting the focus from 'who' governs to 'what' is being governed (Gormally et al., 2018).

It has been demonstrated that technical knowledge and accessibility of information are key to facilitating this shift. Thus, the conceptualisation of an independent strategy for data, or for integrating data management, evokes a sequence of integration processes, as listed in Table 2.2 (Chapter 2). Data integration can enable sectoral integration which, in turn, facilitates the integration of processes that ultimately lead to spatial as well as conceptual integration (Figure 6.13). However, current efforts in the UK, such as two pilot projects for an underground assets register led by the Geospatial Commission (see GOV.UK, 2019), focus on the location mapping of built assets, particularly utility infrastructure, and a categorisation of subsurface or underground space that could go beyond such description, such as by integrating considerations of ownership (see next section), has not yet been discussed.

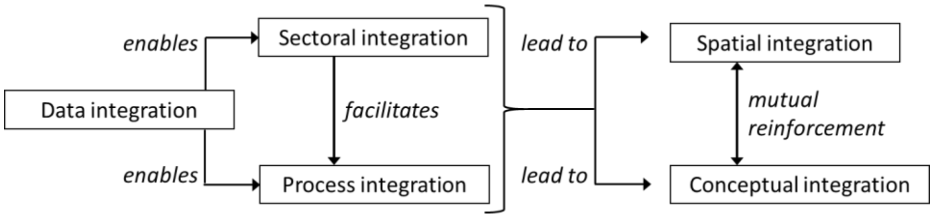

Figure 6.13: Integration process observed/anticipated in working towards an urban underground strategy

In this context, it is important to emphasise that, ultimately, any additional strategy should reduce rather than increase complexity. If changes are not captured, complexity generally increases given that information about built structures will not be available when future interventions are planned. Conversely, if such changes are captured, learning can be facilitated. The example of a data strategy – first entailing the unification of data formats and the establishment of an asset repository – may thus lead to a reduction in complexity by streamlining the data access processes and, subsequently, facilitating a better understanding of the enabling, spatio-material context. On the other hand, whilst the concept of safeguarding, or the fixed allocation of space for specific (future) functions, might be desirable, its enforcement was described as challenging and as potentially creating additional complexity (see Chapter 5, Section 5.2.3.1).

The analysis of the governance arrangement of London's subsurface in Chapter 4 (Section 4.3 to 4.5) illustrated how – as is common in the management of complex systems – the space is currently managed through spatial and sectoral separation into 'manageable' chunks. For an integrated planning strategy to be realised, this segmentation needs to happen in such a way that the interaction between segments is coordinated, knowledge exchange facilitated, and potential synergies noted and exploited. The task of integration, therefore, does not necessarily mean breaking down established sectoral boundaries but, rather: convening collaborations and learning between the plurality of the worldviews and approaches present; facilitating the alignment of the various sectors and topic areas with the overarching policy objectives, as well as across spatial boundaries; and guiding the evolution of the different sectors in a dynamic way. Depicting systems approaches as loops (see Chapter 2, Figure 2.1) may, however, lead to the illusion that all of the sectors involved would embark on the same journey or process. However, given the complexity of the topic area, tailored, specialised reporting and evaluation will remain necessary, and a flower model (depicted in Figure 6.14) might be more appropriate to capturing parallel process cycles without losing track of the necessity of integration between them.

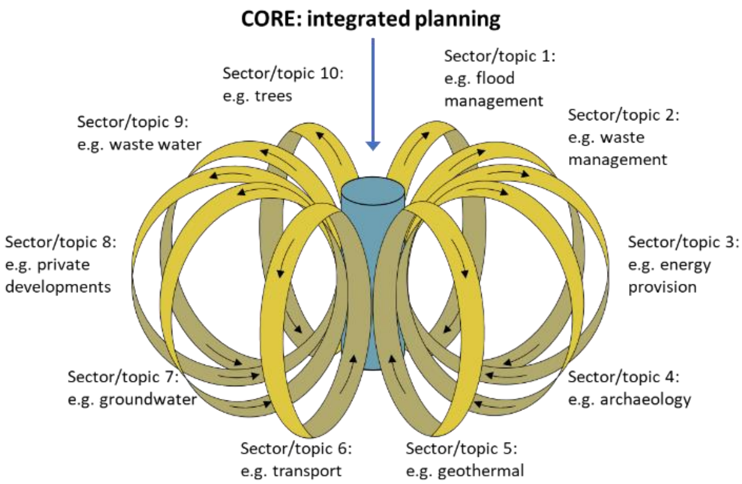

Figure 6.14: Flower model of integrated subsurface governance

Subordinating the purpose of the subsurface and the systems embedded within it to overarching policy objectives at the city level raises the question of prioritisation, particularly if space and resources are scarce. Coming back to the distinction made in Chapter 2 (Section 2.5), different to the discipline of urban planning, where the need for management or regulation ultimately stems from the necessity of tackling a societal problem (see Chapter 1, Section 1.1), with regard to natural resources the need for managing a specific resource – especially in smaller-scale situations – arises from the fact that access to that resource is necessary for basic human existence (Grimble and Wellard, 1997). The notion of 'congestion' (see Chapter 5, Section 5.2.2.2) leads to the conceptualisation of underground space as a limited resource, as suggested by several authors (see Chapter 2, Section 2.4). If such a conceptualisation were to be accepted, the question could legitimately be asked as to which functions allocated in the subsurface are more or less essential to the city and if they need to be allocated in the subsurface (as suggested in Chapter 5, Figure 5.4). Moreover, which of the subsurface functions are actually indispensable, and for whom, could also be questioned. Labelling the subsurface as a whole, and underground space in particular, as a resource, thus calls for a discussion of ownership and access that goes beyond the legal allocation of public or private rights to use the spatial volume, or to exploit the embedded resources or properties such as minerals, water, or geothermal energy. Such a labelling calls for a discussion of the subsurface as a commons.

6.3.3. Ownership and access: the subsurface as a commons

In his seminal article 'The tragedy of the commons', Hardin (1968) described situations in which individuals use a commonly accessible resource in such a way that the net gain for themselves will increase, but the situation for the community or society as a whole will worsen. The mitigation of the resulting risk of resource depletion – the 'tragedy' – has been claimed to necessitate a clear definition of ownership and corresponding governance models (Anderson and Grewell, 1999). Systems thinking is conceptually linked with commons management through Elinor Ostrom's work on governing the commons, for which she was awarded the Nobel Prize in 2009 (Nobel Media AB, 2020). The concept of commons is thus associated with the need to protect the resource from a growing appropriation through individuals, or 'the governance of individual rational action in a context where outcomes are dependent on the actions of all other resource users' (Berge and van Laerhoven, 2011, p. 161). A growing body of literature has examined the commons following Hardin's and Ostrom's work. While a comprehensive review and discussion of this literature would go beyond the purpose of this discussion, a few observations shall be made that appear meaningful in the context of this thesis.

First, there is a distinction to be made between a 'commons' and 'common goods' or 'common pool resources'. A common pool resource has the following characteristics: (a) it is difficult to exclude individuals from its use, and (b) the consumption of the resource reduces the overall resource stock and, thus, its availability (see, for example, De Angelis and Harvie, 2014). While, for the subsurface, the latter is clearly true – as has been repeatedly stated, any use of or intervention in the subsurface changes the conditions over the long term – the former characteristic does not directly apply to the subsurface. Even if the attribution of ownership of the subsurface is often perceived to be unclear (see Section 6.2.2), in the UK it is legally defined by the volume owned by the owner of the surface land, with specific functions being governed through consenting regimes (see Chapter 4). Access to the subsurface for most uses requires permission, financial effort, as well as technical knowledge. As such, the exclusion of individual use occurs in a twofold manner: on one hand, through the consenting regimes and, on the other, through the complexity and cost involved with accessing the space.

Consequently, if related to the categorisation of economic goods, the subsurface as owned by the owner of the surface land above it currently occupies the space of a private good rather than that of a common resource. Transferring the ownership of these volumes from private to public shifts this categorisation to a 'quasi-public good' (see Zhang et al., 2017). As has been stated previously, countries like Japan distinguish between layers of the subsurface that are eligible for public or private use. The questionnaire analysis revealed that respondents were largely in favour of a similar proposition for London or their respective cities, perceiving a benefit in the establishment of a clear, upfront split between the two ownership regimes (see Section 6.2.2). Currently, in London, transfer from the private into the public domain happens on a project-by project basis, as happened for example through the Crossrail Act 2008 that gave the Secretary of State the right to compulsory-purchase land necessary for realisation of the project (Crossrail 1), including, in particular, acquisition of the subsoil more than 9m beneath the subsurface for the main route. These kinds of interventions remove the right of the exclusive access to specific volumes by their individual owners by incorporating these volumes into the public domain. Zhang et al. (2017) suggest sorting the different uses of the subsurface into the categories of public, quasi-public, and private goods; however, the subsurface as a whole continues to escape the conceptualisation as a pure common good and, consequently, as a good or resource prone to the 'tragedy of the commons' as such.

Nevertheless, the subsurface is still subject to the properties associated with such a tragedy. In particular, the terminology of 'congestion', as used by the interviewed engineers in the context of London's underground (see Chapter 5, Section 5.2.2.2) and the counteraction of which has been stated as one of the main motivations for the establishment of a subsurface planning strategy by questionnaire respondents (see Section 6.2.2), is often applied with regard to public goods coming to be used beyond a feasible threshold. As was also described in Section 6.2.2, there is a disparity between respondents endorsing the prioritisation of functions that serve the city as a whole against the small percentage agreeing with reserving underground space exclusively for public functions. This indicates not only that the specific legal situation but also wider concepts of ownership would need to be discussed if any new governance regime for the subsurface were to be sought. The 'commons' provide such a concept.

Today's understanding of 'commons' as 'any natural or manmade resource that is or could be held and used in common' (Berge and van Laerhoven, 2011, p. 161) integrates the presence and properties of the 'resource' itself with the organisational and productive processes surrounding it (Fournier, 2013). It has been said that what makes a resource a 'commons' is the governance arrangement that prevents the 'tragedy' (De Angelis and Harvie, 2014), whereby the process of 'commoning' involves the expansion of the value definition beyond financial value, or the shift 'from extractive models […] to generative value models, practices that enrich the communities, resources etc. to which they are applied' (Bauwens and Niaros, n.d., p. 3). Interpreting the subsurface as a 'commons' would, thus, require an engagement from and with the communities to share the knowledge and care about the subsurface and establish an understanding of how the identification with the land – including the subsurface – is influenced by subsurface interventions. This acknowledgement is also very much aligned with the described need in the current study for a change of understanding in terms of the value of the subsurface, which was highlighted by interview participants and confirmed by questionnaire respondents (see Section 6.2.2, as well as Chapter 5, Section 5.3.4). This, in turn, suggests that the question of whether the subsurface should or could be managed as a commons should be asked independently of its categorisation in terms of economic goods.

Discussing urban commons in the city of Bengaluru, India, Benjamin (2011) writes that 'at the back of our minds, the term "commons" evokes a sense of not just "public" use, but also of a "pristine" character' (online) which has to be preserved. He continues to describe that in the following narrative:

> There lies a notion of 'fixity' around the idea to define such [pristine territory] via fenced off boundaries. With this, there is an underlying desire and anxiety that the city's growth will undermine this ideal. In this form of thinking, the main progressive agenda would be to ensure, via the 'plan' and the 'rule of law', that city management and policy – driven by progressive technical rationales – ensure 'urban commons'. Here lies a conceptual catch. (online)

Following this line of thought, whilst the fixed allocation of underground space through masterplans – as has been done, for example, in Helsinki, is currently being implemented in Singapore, and has been proposed by several authors (see Chapter 2, Section 2.3.3.1) – might allow for the optimisation of the space through the definition of spatial boundaries for specified forms of property, it might also imply the risk of limiting the scope for future adaptation. As such, a fixed allocation of space could actually lead to the 'un-commoning' of the underground, rather than enable the capture of, and dynamic adaptation to, emergent system behaviours.

In the case of London, it appears that even if space was allocated in a piecemeal manner, the way in which the city was historically governed could be considered closer to the concept of 'commoning' than a masterplan fixing the allocation of all available space and thereby, in the terminology of commons governance, 'enclosing' the space. This more dynamic space allocation, reacting to needs when they arose, has led to systems like the London Underground today being assigned a high value, not only financially, but also as a point of identity for the city. The 'first come, first served' approach, criticised as unsustainable in the literature (see Chapter 2), might, indeed, comprise an aspect of flexibility that should not be disregarded. In comparison to the surface, tunnels in the subsurface can be routed to avoid existing structures, and thus react flexibly to newly arising needs. This is not possible in the same way at surface level, in particular when the area is already developed.

As demonstrated in Chapter 5, having this flexibility to connect 'A to B' in the subsurface so as to unlock surface value or to upgrade infrastructure without major disruptions to daily urban life makes underground space highly valuable (see Chapter 5, Section 5.3.4). This observation might also offer an explanation for the description of underground space as 'congested' (see Chapter 5, Section 5.2.2.2) suggesting a 'chaotic', as opposed to an ordered, allocation of space. However, the same observation could also be interpreted as a manifestation of utilising the higher spatial flexibility available, in which case the question remains as to whether this flexible allocation of space reduces opportunities for the future or bears 'eternal costs' (see Chapter 4, Section 4.6.1), and whether the congestion of space referred to by interview participants can be analysed through the theory of economic goods. In order to do so, arguably, the question needs to be asked if the threat of over-congestion of underground space can only be counteracted through enclosure, or if it is possible to design adaptive governance regimes as 'contexts in which improvements, as emergent properties, might be possible' (Ison et al., 1997, p. 261).

Ultimately, an underground governance regime, including the definition of ownership and access/use rights, needs to balance the two overarching objectives set out in Chapter 5; namely, protecting the subsurface from inappropriate use and, at the same time, harnessing opportunities and responding to needs. Arguably, what is perceived to be appropriate will be based on local traditions and value systems, as well as on the material properties of the available space and the available technologies at a certain moment in time. Without an understanding of the spatio-material context in conjunction with the overall regulatory context of a specific city, any approach towards the planning and governance of the subsurface will not be able to capture the complexity of the issue at hand or foresee the associated risks, nor sufficiently capture the value of the subsurface and the functions embedded within it for the city.

6.3.4. Feedback loops and pathway dependency: between agility and stability

In addition to the above considerations about ownership, the management of the commons and, indeed, systems thinking as presented in Chapter 2 (Section 2.2.1), are directly connected to the question of how humans deal with unintended consequences or emergent behaviours, which, in turn, is based in the world-views of the respective society or individual actor. Marshall (2012) states that mental models of a 'progressive vision' 'account systematically for diminishing return (negative-feedback) aspects but not the increasing return (positive-feedback) aspects of dynamic processes' (p. 126), with the 'collaborative' vision of the commons offering an alternative approach. This difference also reflects in the following two opposing ways in which systems can be managed: whereas top-down approaches are geared towards preventing negative feedback loops through integrated assessments and early recognition, bottom-up approaches aim towards the establishment of conditions that enable the identification and harnessing of positive feedback loops, with negative feedback loops being met through adaptation (see von der Tann, 2019, Appendix IV, for an example of top-down versus bottom-up approaches in urban underground planning).

The concept of (positive and negative) feedback loops posited in systems thinking rejects linear projections, whereby systems approaches are usually presented as circular (see Chapter 2, Figure 2.1). However, these circular illustrations can be somewhat misleading as, even if monitoring and re-evaluation is mentioned, they appear to suggests that it is possible to go back to the starting point of the process and the temporal dimension appears somewhat absent. With regard to the subsurface, the feedback loops between the material reality and the social context as described in Chapter 4 (Sections 4.2 and 4.6.1) and specifically with regard to the irreversible changes to the 'context system' that lie within human interventions in the subsurface (see Section 6.3.1), imply a pathway dependency of human actions that, arguably, needs to be addressed if a holistic approach to governance of the subsurface were to be sought. The irreversible nature of interventions in the underground and the longer life time of structures in the subsurface compared to those at surface level (Rogers, 2009, see also Section 6.2.2), means that any intervention changes the baselines for any future intervention in the spatial vicinity. Consequently, a spiral along the time dimension (Figure 6.15) would be a more accurate systems representation of subsurface development as this illustrates that, despite the learning taking place, the starting point or baseline is never the same but, rather, constantly evolving.

The built environment and, with it, the urban subsurface, is constantly evolving along a path of selection and adaptation, and both the material and contextual baseline, as well as specific intervention processes, need to be constantly reassessed. As has been discussed in Section 6.3.2, the availability of data about the subsurface provides a means of supporting this process. This further strengthens the argument that processes that facilitate data exchange not only work towards removing constraints, as emphasised by interview participants (see Chapter 5, Section 5.2.2.2), but also provide a forum that may enable further collaboration and integration (see Chapter 4, Section 4.6.3). However, it is also important to note in this context that learning in the built environment is not necessarily accumulative. As was alluded to in Chapter 2 (Section 2.2.3), the focus of overarching policy objectives, and therewith the 'purpose' of urban planning evolves with history and the reasons for placing specific functions underground emerge from specific historical situations (see Chapter 1, Section 1.1) in addition to, as pointed out in Chapter 5, restrictions above ground.

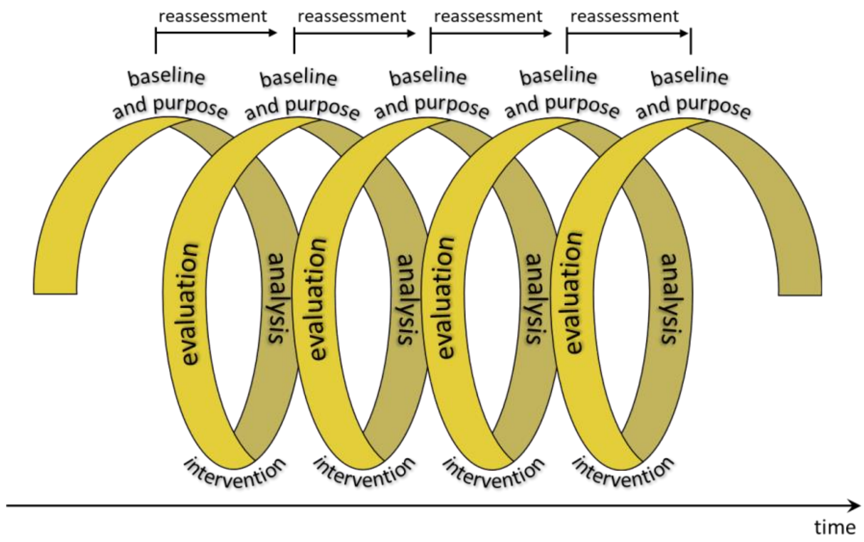

Figure 6.15: Time spiral of system approach for a clearer understanding of system behaviour
Note: For simplicity, the feedback loops within one cycle depicted in Figure 2.1 are not depicted here.

The concept of pathways entails not only evaluating potential futures, but also invites looking back. Pathway dependency is significant when previous choices result in structures that are difficult to change and limit current choices in potentially undesired ways (Liebowitz and Margolis, 1995). With regard to London's subsurface, this is arguably the case for the necessity of managing the groundwater table in the deep aquifer to ensure the structural integrity of tunnels and above ground developments, as described in Chapter 4 (Section 4.3.1). While, in London, pumped water is currently fed into the city's freshwater supply, in other settings similar provisions are of a purely preventative nature and lead to 'eternal costs'. To prevent the latter from arising, pathways need to be assessed in such a way that both foreseeable negative feedback loops can be prevented, and emergent positive feedback loops can be identified and harnessed. These considerations reinforce the previously constructed argument that a balance is required between centralisation and collaboration, as illustrated in the flower model presented in Section 6.3.2 (Figure 6.14).

Notwithstanding the questionnaire respondents' generally positive responses to the notion of a planning strategy that integrates the subsurface (see Section 6.2.1) has to be treated with care, as this approach does not necessarily allow for integration or for challenging the current sectoral division if it is sought through the improved integration of the subsurface within the planning system as it is. Even if the transition from a laissez-faire to a more structured governance of the subsurface is starting to take place in various cities worldwide, in turn fostering cross-sectoral or cross-disciplinary initiatives, it appears that engineers – perhaps owing to the permanence of the structures they build – tend to favour ‘structured’ or ‘predictable’ approaches, such as safeguarding (see Chapter 5, Section 5.2.3.1) or master planning (see Chapter 2, Section 2.3.3.1). These insights lead to two overarching reflections.

Firstly, in order to capture pathway dependencies at different temporal scales and ultimately facilitate holistic approaches towards subsurface governance, it might be beneficial to distinguish between those interventions that create a relatively stable structure in a relatively stable environment, such as tunnels, and those interventions that change or trigger the emergence of natural or social processes, such as the use of groundwater. This distinction would require a definition of stability and a spatio-temporal delineation of the various processes at play. The approaches evolving from this distinction would then need to be able to react to stable parameters with higher degrees of certainty and planning, and to less stable parameters with more flexibility. In this context, it appears coincident, but also coherent, that masterplans for the subsurface have, to date, only been realised in cities with a rock base – a stable geology.

Secondly, engineers’ inclination towards ‘plannable’ pathways is also reflected in the fact that, for the realisation of any project, engineers have to navigate within the existing governance setup; this, in turn, may lead to them holding on to the basics of that setup, even if improvements are discussed. In these mechanisms, silos may be replaced with another type of silo, rather than any real change being initiated. Wiering and Arts (2006) describe this as a change of ‘near core’ discourse elements, ‘without changing the “deep core beliefs” so as to ensure that the “old” organisational structures – organisations, interaction rules, resources – are perceived as being necessary and that they therefore should be maintained’ (Wiering and Arts, 2006, p. 328, referring to Sabatier and Jenkins-Smith, 1993). Resonating with this thought, Hall and Tewdwr-Jones (2011) describe early thinkers in urban planning as ‘very much physical planners’, who ‘saw the problems of society and of the economy in physical terms, with a physical or spatial solution in terms of particular arrangement of bricks and mortar, steel and concrete on the ground’ (Hall and Tewdwr-Jones, 2011, p. 53). Reflecting on this distinction, it appears that engineers who write and speak about the spatial planning of the subsurface, as reflected in the reviewed literature and drawn out from the in-depth interviews in the current study, may be referring to a similar account of planning and what it means. Hence, it might be challenging for engineers to embrace the notion ‘that not all problems are capable of simple solution in these physical terms – or the more disturbing notion that there might be cheaper or better solutions to the problems, of a non-physical character’ (Hall and Tewdwr-Jones 2011, p. 53). Encouraging professionals/those who have a stake in the subsurface not only to take different worldviews into account in their respective fields of practice, but also to reflect on their own perceptions, concepts of systems thinking may help alleviating these effects.

6.4. Summary

This chapter brings together the empirical data from the questionnaire conducted with the data and analysis from previous chapters, as well as the overall conceptual framing of the current thesis. The questionnaire analysis strengthens the findings from the previous chapters, further emphasising the importance of data availability for working towards an integrated governance strategy, as well as the argument for expanding the understanding of the value of the subsurface for cities beyond monetary evaluation.

The chapter explores how integrated governance of the subsurface could be navigated by conceptualising the subsurface as an 'enabling context system' that needs to be better aligned with the 'defining context system' – the city. To coherently capture the ideas of systems thinking that rejects linear projections of the future and fosters multidimensional and multilateral thinking (see Chapter 2), it is here proposed that conceptual models depicting two-dimensional loops do not suffice, and that more-dimensional graphics, such as spirals and flowers (see Figures 6.14 and 6.15), should be consulted. Based on these considerations and challenging common perceptions of the subsurface, it is questioned if concepts of master planning might hinder attempts to manage the subsurface as a commons and reasserts the conceptual and practical challenges that would need to be balanced for a holistic approach towards urban subsurface governance:

a. Cross-sector integration and efficient work in the respective sectors
b. Harnessing opportunities and protection of the underground space for the future
c. Agility and stability as associated with bottom-up and top-down approaches.

Systems thinking can facilitate working towards this balance through its advocacy of embracing multiple perspectives and a plurality of methods (see von der Tann et al., 2016), and through its seeking out and harnessing of emergent behaviours with positive effects whilst preventing those with negative effects. Ultimately, the principles of systems thinking can guide a process towards a holistic assessment of the subsurface value for cities and an integrated approach for governing the urban subsurface that reacts sensitively to local specifics whilst also embracing spatial, sectoral and temporal complexities.

7. Conclusions and further work

7.1. Summary and key conclusions

This thesis investigated how the conceptual framework of systems thinking could contribute to a holistic understanding and practice of urban underground governance. The three aims of this thesis were to: (1) understand the potential utility of systems thinking for the analysis of the urban subsurface through a review of the relevant literature, and to define a coherent research approach towards investigating urban underground governance; (2) provide a rich description of the perception of London's subsurface and the current approach to its governance as a case study, in order to improve the understanding of the current and potential importance for cities to more intentionally govern their subsurface use; and (3) develop theoretical considerations that could be used to make strategic suggestions towards holistic and integrated governance of the urban subsurface in London and beyond. The following sections provide an overview of the main conclusions drawn. As the third objective ties the empirical findings back to the review of systems thinking and literature, the following paragraphs will report on objectives one and three together.

7.1.1. Governance and perception of London's subsurface

The subsurface in London, as in many cities worldwide, has been historically utilised for different purposes. Over the course of the last two centuries, an increasing amount of structures and utilities have been added under the city, whilst the utilisation of underground resources such as groundwater and materials has continued. Despite the importance of these resources and structures for the functioning of cities like London and worldwide, it is only in recent decades that the role and value of the subsurface in the built environment has been recognised by built environment professionals and academics.

The task of more intentionally governing the urban subsurface is usually assigned to the realm of urban planning, whilst a major body of academic literature in the field stems from the engineering discipline. Consequently, the analysis of the current governance arrangement of London's subsurface was based on a review of planning legislation and consultation responses to local plans. It revealed that Local Planning Authorities on the one hand, and the technical knowledge held by engineers on the other, occupy key positions in that arrangement. The analysis also highlighted that the current discourse around an overarching underground strategy for London is still limited to special interest groups. At the same time, the analysis illustrated that related initiatives, such as those working towards the establishment of a repository of underground assets, as currently underway in London and the UK, could play a role that goes beyond their currently defined purpose in enabling a process towards a more integrated planning approach.

The central position of technical knowledge – and, hence, of engineers – in managing London's subsurface was further investigated through in-depth interviews with professionals from the tunnelling and planning sectors. The thematic analysis of these interviews showed that engineers perceive London's subsurface simultaneously as a precious asset that presents an opportunity for extracting value, and as a very constrained space – constrained, that is, mainly by the multiple assets embedded within it and insufficient data about these assets. The interview data also showed that the perception of constraints associated with underground space differed between planning and engineering professionals, and was connected to the field of practice of each respective discipline. It is here also argued that this potential antagonism is amplified by the temporal scales that the two professions work within or towards; that is engineers implementing projects today that will alter the environment in the long-term and planners working with long-term scenarios and projections in order to make decisions about present-day interventions. In light of this, it can be concluded that a closer cooperation between the two professions that embraces iterating between considering specific engineering interventions and long-term urban projections would be beneficial and, indeed, necessary in order to mitigate the effects of the described constraints.

Further to the described study and proposed integration of timescales, the analysis also revealed that the underground is always described in relation or comparison to the above-ground. In particular, the research highlights that engineers described an imperative for long linear infrastructure to be built underground as this, in a built-up area, cannot be accommodated above ground. Based on this reasoning, the engineers involved in this research inferred a strategic need for the safeguarding of infrastructure routes, which, at the same time, they described as being difficult to operationalise in practice. Taken together, the implications of these findings lead, firstly, to the recommendation that the priority of underground uses be assessed through the evaluation of the city's need for them on the one hand, and the necessity of placing them below ground on the other. Secondly, the implications of this work demonstrate that the underground in cities cannot be analysed independently of the city as a whole.

7.1.2. Systems thinking for integrated urban subsurface governance

The analysis of an online questionnaire answered by a range of professionals in the field showed that little controversy or disagreement exists between the experts involved regarding a general need for change towards integrating the subsurface into urban planning considerations. Recognising the need for the integration between sectors, as well as for a consideration of different temporal and spatial scales when developing in the subsurface and planning for the city as a whole, the current research applied the concepts of systems thinking to suggest candidate models to explain the current situation pertaining both to the academic analysis and policy making around the integration of the urban subsurface into urban planning, as well as lines for further thought.

Firstly, taking the observation that the underground can only be analysed in the context of the city as a whole, the current thesis argues that there exists a misalignment between the context in which a problem or need in the given field is defined – the city, i.e. the 'defining context system' – and the context in which this need is responded to – the underground, i.e. the 'enabling context system'. This argument, in turn, leads to the case being made for why the integration of the subsurface – and its spatio-material properties – into the realm of urban planning is essential if a systemic approach is to be sought.

Based on the literature review, theoretical considerations and empirical findings that emerged from this thesis, it is further proposed that understanding integrated planning as a forum where the different sectors come together will facilitate a balance between cross-sector integration and efficient work in the respective sectors. In addition, systems thinking reveals the inadequacy of linear projections into the future that are not able to capture the complexity that human action within the built environment entails. In light of this, and with regard to the subsurface in particular, this thesis also highlights that the feedback loops between the material reality and the social context are currently not sufficiently recognised, leading to the aforementioned lack of data about the location of subsurface assets, and strengthening the argument made about the integration-promoting role of subsurface data provision.

The fact that any intervention in the subsurface changes the original system and, thereby, the baseline for future interventions, leads to the recognition of pathway dependencies. To further the aforementioned integration of the varying timescales that the different professions work within, it is recommended that the respective stability or agility of the structures and materials embedded in the subsurface be assessed, and their governance approaches aligned with this assessment. In this context, the research posits that the fixed allocation of space in the underground might inhibit rather than enable a flexible reaction to newly arising societal demands, and that the drive to fix allocation may, indeed, be based in the engineering discipline rather than on an integrated assessment. The research further suggests that citizens' involvement in the early stages of the planning process of underground uses would be beneficial and could counteract this bias.

This thesis affirms the original concern it began with – that the underground is currently not sufficiently recognised in its own right and in its role for the city as a whole, and that a new definition of its value is needed that embraces different perceptions, captures different timescales, and also reflects on alternatives to the interventions proposed.

7.2. Limitations and areas of further work

The current research provides an insight into the governance setting of London's subsurface by describing its material reality and social context. A comparative analysis with other cities applying the same framework was beyond the scope of the project, but could provide further insights into the applicability of the suggested conceptualisation of the subsurface as 'enabling context system' for the city. In particular, the conceptualisation of the temporally-dependent feedback loops between the material reality and the social context prompts the need for a retrospective, comparative analysis of how the use of the subsurface has developed in different cities. Such an analysis could also engage with the question of at which point in the development of a city the underground became relevant, and which parameters drove and now constitute this relevance.

Shifting the question of system purpose from the specific functions provided by the underground towards a more general understanding of how these functions – and, therewith, the subsurface – contribute to overarching policy objectives, might lead to the determination of mutually exclusive or synergetic spatial effects resulting from different overarching objectives; indeed, an integration of such effects in future methodologies at the city level appears to be expedient. Combined with such future methodologies (see for example Rogers and Hunt, 2019), also the presented considerations relating to the stability and agility of material contexts on the one hand, and approaches to governance on the other, could be further investigated. A better spatial understanding would enable the integration of spatial effects into these methodologies, and thus make them more tangible. In addition, it would be interesting to study the concepts of agile and iterative management concepts in software engineering approaches, and test if they might be transferrable to the context of planning and the built environment.

The presented in-depth interviews focussed on engineering professionals, with fewer interviewees from the planning discipline; moreover, whilst the questionnaire sampling targeted a wider field of professionals, engineers comprised the majority of respondents. This skewing of the sample, and of the perceptions that emerged, arguably reflects a skewing of how subsurface space is currently conceptualised in practice; that is, predominantly through an engineering view. Additional in-depth interviews with professionals of other disciplines, such as geology or archaeology, as well as asset owners, would provide a meaningful addition to the presented dataset.

Given the scope of the current research, the voices of civil society or the general public could not be captured. This was addressed by mobilising some of the questionnaire questions to gain an insight into how citizens' involvement is perceived by practitioners, leading to the suggestion that such involvement should be considered early on in the planning process. Further work is needed to understand the general public's perception of the subsurface in cities and the value they assign to it. Understanding these perceptions of value and developing a framework for valuation that could capture these perceptions would aid to ultimately ensure a fair use of subsurface space and, thus, should be further developed as an objective of urban planning research and practice. The proposed considerations about conceptualising the subsurface as a commons could lead to a more balanced approach towards urban underground governance and merit further investigation.

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Appendices

Appendix I. A copy of von der Tann et al. (2016)

This article can be found following the link below.

https://doi.org/10.1016/j.proeng.2016.11.710

Appendix II. A copy of von der Tann et al. (2018a)

This article is open access and can be found following the link below.

https://doi.org/10.1680/jcien.17.00028

16th World Conference of the Associated Research Centers for the Urban Underground Space (ACUUS 2018)
5-7 November 2018, Hong Kong

HOW TO DISTINGUISH DIFFERENT USES OF THE (URBAN) SUBSURFACE – A MISSING DISCOURSE

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Abstract

How to manage the limited underground space available or accessible in urban and rural areas has been increasingly discussed and investigated in recent years. Proposed frameworks and methods supporting holistic management of the subsurface aim to describe and evaluate current and potential future functions and suggest strategies for the development and implementation of those into relevant plans, policies or projects. Each of these frameworks builds on an underlying classification of underground space use, for example distinguishing categories of resources, services, functions, or layers delineated by depth.
This paper reviews classification systems found in the literature, discusses the meaning and applicability of some of them and points out why classification is important. Rather than presenting a solution, the paper introduces and prompts a discourse on how underground space is classified and how the chosen classification influences academic thinking as well as management strategies and planning policy in the field. It is proposed that classification of underground space could be discussed similar to the classification of surface land distinguishing primarily between content (geology and assets present), and use (what it is used for). To cover a variety of situations and problem statements, multiple classification systems might be needed. A clear statement of purpose and a conscious choice of classification in each case will enable a meaningful discourse, provide a basis for comparative studies and enhance cohesion amongst practitioners.

Keywords: urban underground space, urban subsurface, classification, land-use planning

1. Introduction

The scarcity of subsurface or underground space and subsequently the necessity for strategies for effective and sustainable allocation of the different potential functions of that space have been discussed by a range of authors (e.g. [1], [2], [3]). In the light of global challenges like population growth and climate change, the topic has gained increasing attention in recent years.
Most of the literature about urban underground space or urban subsurface space refers to an up-front classification of that space dividing it into categories of what it can or could be used for. To express the importance and use of the urban subsurface or subsurface in general, authors categorize for example the *resources*, *services* or *use-categories* that the ground and embedded structures can provide. In this context, reasons for choosing a specific set of categories are usually not laid out. However, the chosen terms serve as basis for subsequent analysis of, for example, present use, potentials and conflicts - listed categories and classes can be described, evaluated, or compared. From the perspective of systems thinking, the terminology used defines the distinction between elements of a system as well as their role for the system itself [4] and thus plays an important role for the discussion of any system looked at.
In the context of land-use planning, categorisation of land-use and land-cover is a much-discussed issue. Classification systems have been established in national contexts (for example in the UK see [5]) as well as by international organisations [6]. Bowker and Star [7] discuss the relevance of classification systems for public policy in land-use planning, stating that the categories chosen and classes assigned to an area of land have significant influence on its future economic development. They stress that once a classification system is established, it becomes fairly inflexible - changing the
1. overarching system and specific categories once assigned is difficult.

In general, classification systems are necessary for the creation and usability of datasets and documents like standards and regulations. In the context of mapping and sharing of utility- and other subsurface related data, for example, in a recent report for Future Cities Catapult "ontology/ semantics/ terminology" is highlighted as one of the "general problem spaces" [8]. They point out that a common understanding of terminology is necessary for coordination and data sharing between stakeholders and that mapping and sharing of data is only useful if the meaning of that data and the categories in which the data are captured, are not contested.

Given the relevance of classification for mapping subsurface data as well as in land-use planning, it is remarkable that with regard to organisation and use of the urban subsurface, the issue of categorisation as such and the meaning it has for the subsequent analyses have rarely been touched upon; Identifying the types of underground applications has been mentioned as a challenge for the establishment of an underground masterplan in Singapore [9] and Coogan in 1979 discussed classification and valuation stating that in particular with regard to the different uses of the space no systematic classification exists [10]. In their review of classification of built structures and developments in the urban underground and the registration, Zhang et al. [11] note that even for these structures the existing classification systems are still insufficiently defined. And Hooimejier and Maring explicitly refer to categorization when grouping ecosystem based subsurface qualities into four categories that relate to specific issues in urban planning, but do not discuss the topic in more detail ([12], as referenced in [13]). These publications show that categorisation of underground space use is not straightforward. However, so far, no broad discourse of the topic has taken place.

This paper recollects the rules for a comprehensive classification system, reviews classifications of underground space that have been mentioned in the literature and discusses if following established definitions and strategies in land-use planning could support the development of a suitable classification system for underground space. It is shown that the proposed systems are significantly less detailed compared to established (national) land-use classifications and that a discussion about terminology to enable the knowledge exchange in the field is long overdue.

2. Classification – Background and Principles

Shared terminology is the basis for communication of knowledge and the need to ensure consistency of conceptual frameworks within any discipline or field of knowledge leads to a degree of formalization [14]. In this process, individually held mental concepts get concretized ([14], [15]). Thus, a negotiated classification system will embody the worldview of the people involved in its generation [14] and any classification can only represent a limited reflection of the social or natural world [7]. Consequently, the establishment of a classification system always carries the risk of silencing another point of view [16]. While "classification is human" [7] and a way to facilitate the communication of knowledge between a range of individuals [14], it is important to be aware of this limitation. In addition, classification systems can be difficult to change once established and thus not be suitable for or even constitute a barrier to change [15].

Classification is "a spatial, temporal, or spatio-temporal segmentation of the world." [7] and a classification system consists of categories into which the described world or entities can be divided. These categories, their definition and delineation provide the basis for analyses as well as communication. An ideal classification system has three main properties ([7] and [17]): First, it is complete, meaning no element in the described entity exists that cannot be assigned a category. Second, no overlap between categories exists. Thus, in an ideal system, each element would be only assigned to one category and this assignment would be unambiguous. Last, the ideal system builds on consistent rules and principles for identification and naming of categories as well as ex- or inclusion objects.

Whilst it might not be possible to meet the requirements for an ideal classification system [7] and overcome the limitations described, these points provide a background to discuss classifications proposed in the literature and the ontological and semantical diversity needed for analysis of and management strategies for the urban subsurface.

3. Categories in Land-use Planning

As the need to manage the subsurface more systematically is often discussed as a need to integrate the subsurface into planning efforts ([1], [2], [3]), it seems imperative to look at the way land uses are categorised and how that relates to subsurface uses. In land-use planning, a distinction is being made between *land-cover* and *land-use*, the former describing the material – the observed, biophysical surface – and the latter describing the function - the human use of and impact on that surface [18]. Note that in this categorization existing constructions are understood as land cover, whereas specifications like *residential* define a land-use [19]. Whereas the definition of land-cover is usually restricted to the surface, land-uses can extend above and below the surface if the geographical location is the same. For uses that extend across wider areas below the surface like deep mining, only their impact on the ground level is recorded as land-use ([17], [5]).

There is no singular internationally agreed classification system for land-use [20] but classification techniques, i.e. the classification system itself combined with the technology or method how to survey and map land-use, have attracted a considerable amount of research (see for example review in [21]). Established classification systems like in the UK defined for the National Land Use Database [5], are shaped by their specific purpose and build on underlying value systems [17]. Consequently, multiple systems exist but clear principles are set for naming and identification and elicitation of the purpose or justification of specific classes and categories as well as the scheme in that they are organised appear to be part of the classification process.

4. Subsurface or Underground?

Moving from surface land to the volumes that lie below, it stands out that even the definition of the overriding term is vague. If the term “land” is defined rarely [17], the authors are not aware of a single definition of *subsurface* or related terms in the literature. The two terms *subsurface* and *underground* appear to be used interchangeably. Other terms used less frequently are *subterranean* and *below-ground*. According to Golany and Ojima [22], these two terms are used for the shallow subsurface and they adopt the term *geo-space* for deeper levels, a term that does not appear to have been used more recently. It is important to note that this usage of the synonymic terms potentially delineates divisions between research communities; A comprehensive discussion of this effect goes beyond the objective of this paper, but a brief search in Scopus reveals that of 53 papers found searching for *urban subsurface* and 520 papers found searching for *urban underground* only 4 papers are overlapping. This is relevant in so far as it suggests that which term is used by a specific author might be by chance and important contributions can be missed when the literature is reviewed.

For the purpose of this paper, the *subsurface* or *underground* shall be defined as volume or space that is or was filled with natural material as part of the Earth’s crust or with anthropogenic deposits and thus required or requires extractive and drilling technologies to be accessed by humans. The space can be divided in volumes that have describable physical properties that can subsequently be assigned a function or potential function of usability for human purposes. This description in essence is equivalent to geology and man-made ground consolidated with built structures in the ground and embraces the process of exploitation or gaining access. Structures that are first built and later covered with soil might be a point for discussion as these structures are sometimes mentioned as examples of underground developments.

5. Classification of Subsurface Volumes

Accepting the definition above, it becomes apparent that a similar distinction to the one into land-use and land-cover can be made for the subsurface that is already implicit in the literature but not usually referred to in this way. It is proposed here to speak of *volumes* to take account of the three-dimensionality, and to use the term *subsurface content* as equivalent to *land-cover* and *subsurface-use* as equivalent to *land-use*. This is similar to what Coogan proposed in 1979 when he distinguished between physical aspects (particle dependent space and particle independent space) and artificial space (man-made, transparticulate, need specific) on the one hand, and uses (where subsurface space is useful for humans) of natural and artificial space on the other hand [10]. Other classification systems are reviewed and discussed.

6. Subsurface content

From this viewpoint, *subsurface content* comprises the materiality and properties of the subsurface volume at this moment in time. This is largely equivalent with the geology for which established classification schemes exist. However, whereas in non-urbanized areas the geology and assigned properties constitute the subsurface content, in urban areas, in particular in shallow levels, man-made assets can occupy a major proportion of the volume available.

Similar to land-cover data being described as necessary baseline information for planning and research [23], systemic approaches to subsurface management include availability and accessibility of data about geology and subsurface assets as a baseline for planning. With the proposed terminology, these – and consequently the baseline for planning and management - would be combined in one term. This creates a clear distinction between the current efforts to map and identify subsurface assets as for example in the UK and Singapore [24] and more visionary questions of what the subsurface should be used for.

Whereas the mapping of subsurface assets, in particular of utility infrastructure, poses a range of challenges with regard to location, geological observation and modelling are established procedures and technologies. Questions of data sharing and compatibility are common to both [25]. The process of observation poses a major difference to land-cover, where satellite data can cover whole areas. Observation of the subsurface has a lower resolution; Boreholes are point measurements and require drilling and non-invasive techniques like ground penetrating radar are more systemic but can only provide specific properties of the surveyed ground volume. This restriction implies that whilst the data to observe land-cover can be updated to observe changes, the observation and modelling of the subsurface is based on an accumulation of data over time that allows refinement of models and observation of change is restricted to monitoring points for example of the groundwater level. However, this might only reflect that processes of change in the subsurface are slow compared to the surface. In both fields, the characterization process and quality of the resulting characterization depends on the availability and quality of data as well as available technologies and expertise of the operator and there is a need for integration of different kinds and scales of data [23, 26].

One additional challenge for the definition of subsurface content shall be mentioned: it requires a definition of which level to consider the surface, or under which condition to consider the man-made structures part of the subsurface. Different to what is defined as man-made ground by geological surveys, man-made subsurface could include for example earth-sheltered buildings, that often are only covered with a thin layer of soil. The surface equally gets changed, if large volumes are excavated like for example in quarries. This man-made change of the surface shape and therewith subsurface volume adds an additional layer of complexity and a discussion about which properties a build-up space must have to be considered part of the subsurface volume is required. These could for example include the number of vertical walls in contact with ground, or cost of demolition or structural change compared to surface structures.

3.

7. Subsurface use

Rather than describing physical, theoretically observable properties, equivalent to land-use *subsurface-use* describes the activities or functions for which humans utilize subsurface volumes. Equally to the description of *subsurface-content*, this terminology is not new; Bobylev [2], for example, explicitly refers to users of urban underground space, attributes them to different sectors and provides a list of structures associated with each use. And as mentioned above, Coogan made a similar distinction already in 1969 [10]. However, most papers list fairly broad categories or only give examples of categories rather than claiming to be comprehensive.

Table 1 provides an overview of categories for subsurface space proposed in the literature. Classifications by depth that can be a method to assign different depth to the appropriate level of administration [27] or, respectively, to allocate specific uses to specific depths [11] are not listed.

In the top columns *function* or *activity* is used as overarching terms, which are here accepted as equivalent to *use*. It stands out that a lot of authors apply *use* or *function* to refer to developed space only, meaning man-made structures and converted natural cavities (from here onwards referred to as *underground developments*), and functions that are or could be developed in these structures. The majority of these functions could also be placed on the surface and the according categorization systems are comparable to *use classes* in the UK planning system, in particular if utilities are not included. As listed in Table 1, de Mulder et al. [28] integrate functions of subsurface developments with natural functions or services of the geology like storage and bearing capacity. Bartel and Jansen

Table 1. Classification of Underground Space Use

Classification by	Categories	Specification	References
Function of developments	Infrastructure	Underground traffic facilities and underground utility tunnels	[2], [32], [33], [34]
	Buildings and structures	Entertainment/ cultural facilities, retail, religious centres, office space, production and processing facilities, etc.	
	Storage	goods, oil, gas, chemicals, waste, energy, ground water	
	Other uses	disaster prevention, burial, other space	
Function	Source of natural resources		[28]
	Storage of materials (solid, liquid, gas)		
	Space for public and commercial use		
	Space for infrastructure		
	Medium for foundation for construction		
	Component in life support systems		
	Archive of historical and geological heritage		
Function	Storage	natural gas/oil storage; storage of H2, compressed air	[29]
	Deposition	Carbon Capture and Storage; underground waste disposal including storage of radioactive waste, brine injection	
	Productive activities	mining; use of geothermal energy; storage of heating and cooling energy; utilization of springs and groundwater	
	Underground Structures	tunnels, technical structures; underground pumped hydro-electric power plants	
Human activities	Groundwater development and management	Groundwater withdrawal for different uses; Drainage of excess shallow groundwater; Managed aquifer recharge	[30]
	Mining	Extraction of minerals, coal, lignite, building materials, etc.	
	Geo-energy development	Oil and gas development; High-enthalpy geothermal energy development; Low-enthalpy geothermal development	
	Disposal and storage of hazardous waste	Waste disposal by deep well injection; Carbon capture and sequestration; Subsurface storage of radioactive waste; Nuclear weapons testing and nuclear power accidents	
	Injection and recovery	Solution mining; Injecting residual geothermal fluids; Temporary storage of heat; Storage of hydrocarbons and	

		fluids associated with oil and natural gas production; Hydraulic fracturing or "fracking"	
	Construction into the underground space	Pipelines, sewerage systems and cables; Tunnels and underground railways; Underground car parks and other underground constructions	
Resource	Groundwater	drinking or industrial purposes	introduced by [3], e.g. referred to by [35], [36]
	Space	place for building and infrastructure construction	
	Geothermal Energy	shallow and deep geothermal energy	
	Geomaterials	mainly issued from underground excavations	
Categories captured in spatial planning systems	Civil Constructions	Archaeology, explosives, buildings, cables and pipes, carrying capacity	[37]
	Water	Infiltration, storage, drinking water	
	Energy	Aquifer and underground thermal energy, geothermal and fossil energy	
	Soil	Clean soil, soil life and ecology, crop capacity, diversity and geomorphology, mineral resources and underground storage	
Ecosystem service	Resources or provisioning services	fuel, fibres, food	[38], extended with platform services for soil by [39]
	supporting services	nutrient cycling, soil formation	
	regulating services	water purification, flood mitigation	
	cultural services	aesthetic, spiritual and recreational functions	
	platform services	bearing capacity, electrical earthing potential	
* The categories by function of developments vary between the different authors. Listed categories are an example.			

[29] as well as van der Gun et al. [30] shift the focus entirely to these natural functions. Bartel and Jansen [29] propose a classification that takes the direction and finality of material movement from or into the subsurface into account whereas van der Gun et al. [30] distinguish *extraction* and *use* and focus on interactions of functions with groundwater that in their opinion is particularly vulnerable to pollution and depletion. These examples show that the classification systems in the literature differ considerably with regard to detail and depend on the respective purpose of study. To constitute complete classification systems however, it is necessary to introduce an extra category of *no use*. This can mean temporary preservation for future use or complete exclusion of use [31].

Similar to the interrelations between land-use and land-cover [17], in some cases, subsurface-use can be inferred from subsurface-content and vice versa. Without setting out a comprehensive scheme here, for example, an archaeological site would probably describe both, a content and a use. In other cases, a specific subsurface-use might correspond to different contents. For example, the uses *foundation* or *drinking water extraction* could correspond to the structures themselves but also to the zone of the soil and aquifer influenced by the load or extraction (Figure 1). On the other hand, one content category or volume can correspond to different uses, for example if a volume is influenced by a load but also serves as zone from which geothermal energy is extracted.

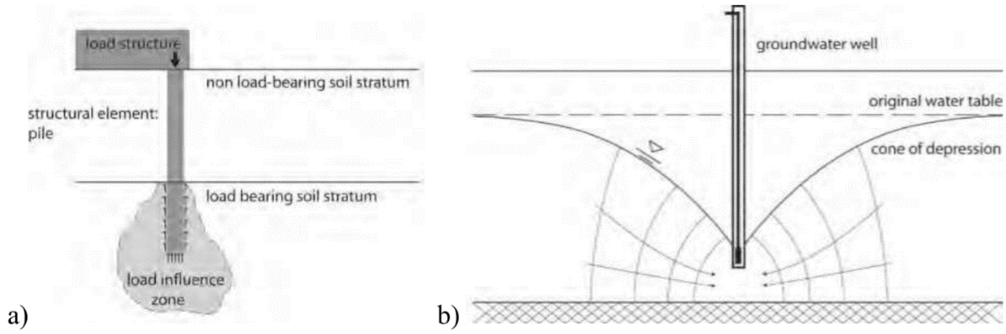

Figure 1. Schematic of possible subsurface-content categories for the use a) foundation and b) drinking water extraction

Figure 1 also illustrates another aspect that should be considered: In general, for every use there are two kinds of structures or zones, the ones where the actual use is located and the one that is needed to access it. Thus, a distinction of these two kinds of structures might be apposite.

The distinction between subsurface-content and -use also potentially allows the establishment of a clear account of change. Uses can change without the content changing or the content can change through the use. Van Os *et al.* [40], for example, illustrates sequences of activities in a salt dome. And the statement that every intervention in the subsurface changes it irreversibly [2] refers to a use changing the content or, in other words, exploiting a part of what some authors refer to as non-renewable resource.

8. Subsurface resources and services

Different to classification by use or function, other classifications listed in Table 1 aiming to cover the whole of the subsurface volume rather than only subsurface developments are referred to *resources* or *services* the subsurface can provide by a range of authors.

The concept of underground space as a resource was brought into awareness by the UN Committee on Natural Resources in 1983. A resolution requested the Secretary to have a look into the issue [41] and the subsequently a progress-report was prepared which highlighted *"the potential of that little-used resource"* [42]. The report was taken note of by the committee but no further action followed. In particular two papers by Parriaux and Bobylev ([2], [3]) established the association of urban underground space with different resources: space and materials as non-renewable resources, and water and geothermal energy as renewable resources.

The term *resource* is intrinsically linked with the notion of exploitation or use by humans as well as with the discipline of economics and management. The oxford dictionary defines natural resources as "Materials or substances occurring in nature which can be exploited for economic gain." [43]. In system terms, a resource is a 'stock' that feeds into the system and can be limited (non-renewable) or have the option to be replenished (resource) [44]. Analysing the subsurface as a resource acknowledges what the subsurface adds to bigger systems like the city and illuminates aspects of environmental capacities and their limitations.

Again, a similar conversation is present for the surface. Here, the connection is such that land-use planning is the means to control land-use change and therewith the degradation of the land resource. A particular property of land – and equally of subsurface volume – distinguishing it from other resources is that it stays in place or "has location". This implies an involvement and interest of people connected with that location in decisions about land-use change [45]. Also, what is called *land resource* – the available area as such - here is distinct to the resources the land provides or can provide.

The categorization of subsurface uses as ecosystem services is less established and for ecosystems themselves a range of classifications exist. The fifth category of platform services as proposed for soil by Rawlins [39] appears to not have received attention in the ecosystem service literature so far.

Hooimejier and Maring [37] reject the notion of ecosystem services as being not practical for urban design and planning which creates a question of how these two classifications can be purposefully connected, however, Maring and Blauw [46] refer back to it as reference for potential valuation methods.

Both these systems sit somewhat in between the suggested classification of subsurface-content and subsurface-use as which category of resources or services would be assigned to a specific volume depends largely on the content, but the exploitation of the resource or service would constitute a use category. In literature, sometimes the term *potential* is used to describe the occurrence of a resource in a particular location and the term *suitability* to describe if exploiting the resource in this location would be feasible in the context of the specific analysis and location [36].

9. Discussion

Scholars and practitioners writing about subsurface-use aim to describe the current or potential use of the subsurface for human needs ultimately to improve the administration and management of subsurface volumes to accommodate these needs and prevent use conflicts now and in the future.

The proposed distinction of content and use establishes a clear and inevitable connection between the geology and the planning discipline by accepting the content as basis for interventions and therewith the planning process. This is different to the current approach in particular in cities where interventions in the subsurface often have to accommodate for example supply of what has been planned on the surface level. Recent efforts, for example in Europe [see 47], aimed at creating a better link between geology and planning and the distinction between content and use could be helpful to establish that link and make the inherent interrelation between the two disciplines more explicit.

With this in mind, it is not proposed to introduce a standardized system of categories for subsurface space, but to encourage a discussion about classification with similar rigour as land-use. Similar to land-use, classification systems will have to be specific to the country and potentially the purpose or task for which they shall be employed. However, once established in a governance framework, for example a masterplan, it will be difficult to change them and there is a risk of establishing new “silos” of expertise. Therefore, and to allow definition of new categories in the future, it is important to a) clearly state the purpose of classification in the first place and b) integrate the discussion about categories of use not only in the process of development of such frameworks but also in the process of revision.

Establishing a classification of uses of the subsurface and understanding the whole of the subsurface as one resource, parallel with discussing the resources and services it can provide, appears purposeful given the call to integrate the subsurface into planning efforts ([1], [2], [3]). The planning discipline is focused on the assessment of need for different land-uses and allocation of these uses to suitable land areas. In the local context, the owners of the land are often the initiators of change and land-use planning involves balancing the interests of a variety of stakeholders [48]. At the same time, it is important to be able to link environmental and also socio-economic features to the land-use types to assess the influence on the resources and services available. The suitability of classification systems to analyse change and resource management at various spatial and temporal levels has to be discussed [49]. Also, the attribution of value to a use category - that might involve exploitation of one or more of the resources or services available - might be more straight-forward than attributing the value to the resource or service without applying it in the context of a use-case.

Classification is relevant and has to enable analysis of synergies and trade-offs amongst the relevant potential benefits or indeed disbenefits of using the subsurface if an effective framework for decision making is sought. A better understanding of the impact of classification systems on these decisions is needed.

10. Conclusions

This paper summarized the range of subsurface space and use classifications mentioned in literature. It showed that despite classifications being proposed in several papers, there appears to be no discourse about the question which of these classifications and umbrella terms are the most feasible, the rational they entail, or their meaning in the context of public policy and the integrated planning approach they promote. Zhang *et al.* [11] make a start to encourage such a discourse for underground constructions by discussing classification options and clearly stating the purpose of their suggestion as a classification system that allows registration in a 3D cadastre and definition of property rights. This paper aimed to prompt a parallel discourse for all utilisations of the subsurface and proposed as a starting point to distinguish between subsurface-content and subsurface-use similar to land-cover and land-use and discuss the subsurface resource as a whole (volume) independent of the specific resources or services it provides. Different classification systems can be required for different purposes making a clear statement of purpose alongside rules for categorisation indispensable. Deliberate choice of classification allows consistent attribution of properties and will facilitate important discussions amongst academics and practitioners for example about valuation of the subsurface and its uses for the urban environment.

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Appendix IV. A copy of von der Tann et al. (2020)

This article is open access and can be found following the link below.

https://doi.org/10.1016/j.undsp.2019.03.003

Appendix V. Poster presented at ASK Workshop

Accessing Subsurface Knowledge (ASK) Workshop, Glasgow, 30.01.2017

Is There Plenty Of Space Underground?

Understanding the Urban Subsurface as a Resource

UNIVERSITY OF BIRMINGHAM

UCL

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AIMS AND OBJECTIVES

This research aims to understand the role of the subsurface for urban sustainability and resilience through the lens of systems thinking and resource management.

The following questions are being explored:

1. Who are the main actors using and planning for the subsurface?
2. What are the main problems when planning subsurface assets as perceived by different actor groups?
3. How can the problems elicited be captured in a resource management framework?

SYSTEMS THINKING

The multitude of subsurface **functions** and **actors** dealing with those functions requires integrated thinking about the effects between the different functions as well as the interaction with the surface to react to and be prepared for the global challenges of **growth** and **climate change**. In addition, human interventions in the urban subsurface **create legacy** (Figure 1). They will lead to permanent change of the geological, hydrological and ecological regimes that consequently will need to be managed.

Systems thinking and the concept of resource management can advance the understanding of **path-dependencies** and resulting externalities regarding utilisation of the urban subsurface.

INTERDEPENDENCIES AND CHALLENGES

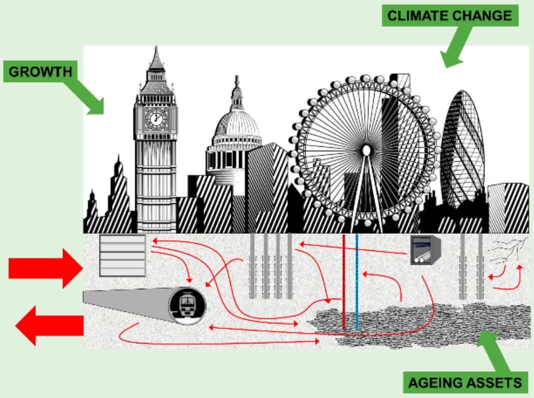

Figure 1: Utilisation of the subsurface – interdependencies, challenges, and flows.

The various functions of the subsurface and subsurface assets are not independent of each other. They not only can block each other competing for space, but also effect each other in many direct and indirect ways.

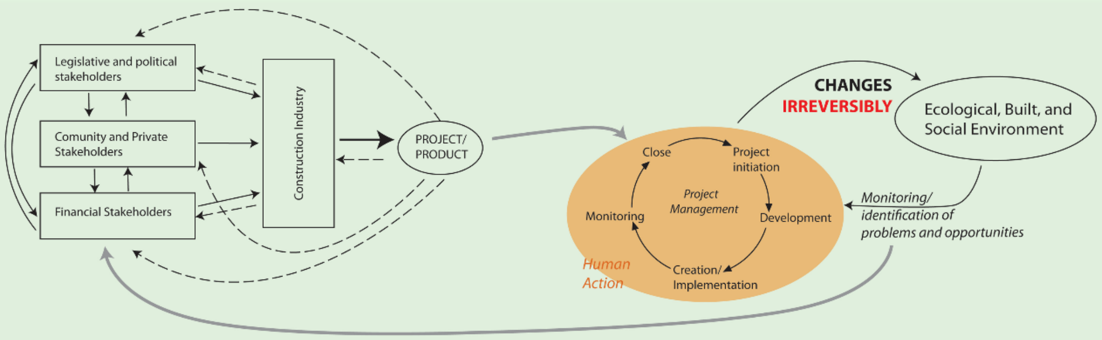

Figure 2: Stakeholder model. The construction industry acts as intermediary between the various stakeholder groups and the project/ actions undertaken. The resulting, partially irreversible, changes in the ecological, built and social environment in turn influence decisions about future action.

RESOURCE MANAGEMENT

The subsurface has been called a resource in various publications. In the context of systems thinking, a resource poses a constraint on the system it serves.

In the context of the urban subsurface, three resources have been identified through interviews, which need to be managed in an integrated manner: VALUE, TIME, and SPACE.

The conceptualization of SPACE, TIME and VALUE is debated preliminarily by looking at issues of resource scarcity, resource allocation, resource regulation (legal) and associated uncertainties (Table 1).

		PROBLEM RELATING TO			
		RESOURCE SCARCITY	RESOURCE ALLOCATION/ FUTURE PROOFING	RESOURCE REGULATION (LEGAL)	ASSOCIATED UNCERTAINTIES/ UNKNOWNS
RELATING TO RESOURCE	COST	Overspending Limited budgets	Value of unlocked/ unlockable space	Compulsory purchase	Technical: ground conditions Quantification of unknowns
	TIME	Efficiency in planning process	Coordination of various projects Longevity of end product	Planning time before consent is granted Standardized time frames for design life	Growth – demand and technology
	SPACE	Site definition Restrictions through legacy Lack of space	Public versus private interest Comparison to above ground Connection to above ground Lack of spatial plan	Compulsory purchase Ownership	Lack of asset data Lack of spatial plan

Table 1: Examples themes mentioned in interviews with tunnelling engineers categorized according to the three resource framework.

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Appendix VI. Poster presented at ISNGI

International Symposium for Next Generation Infrastructure (ISNGI)

London, 11.-13.09.2017

INTERNATIONAL SYMPOSIA FOR NEXT GENERATION INFRASTRUCTURE

UCL

Loretta von der Tann
Christian Bocci
Brian Collins

What goes where?

Rethinking spatial allocation of infrastructure services

INTRODUCTION

The growth of the global population and the urban population in particular is one of the major challenges of our time. Associated with a growing urban population is a need to extend the capacity of the infrastructure services we are accustomed to. At the same time infrastructure needs might arise that we do not know of yet. What infrastructures are perceived as necessary and where they are placed significantly influences urban life.

The discourse about infrastructure is often based in two-dimensional thinking. Three dimensional models are commonly project or discipline specific. Accepting that 'hard' infrastructure will always be needed in cities, and given our streets become more and more congested above ground as do we need to be more creative about which services we really need, where we put them, and how they are governed?

HYPOTHESIS

Better awareness and visualisation of the third and forth dimension of infrastructure on all levels of planning and delivery could lead to significant improvement of the discourse about and ultimately the allocation of infrastructure.

Figure 1: Dronning Eufemias gate, Oslo. The picture integrates the support structure of the road, clearly visualizing the three-dimensionality of infrastructure.

VISUALISATION

Cross-sections are a critical tool for planning infrastructure in particular underground visualizing the geology and physical obstacles along specific alignments (Figure 2). Could their use be extended to grasp the three-dimensionality of cities?

Imagery in which the city is visualized in a three dimensional manner including the subsurface beyond visionary illustrations is rare (Figure 1). Could such imagery support the development of more comprehensive mental models of the urban space?

Digital twins can be used for real time assessment and monitoring of infrastructure. Could they also provide a visual tool?

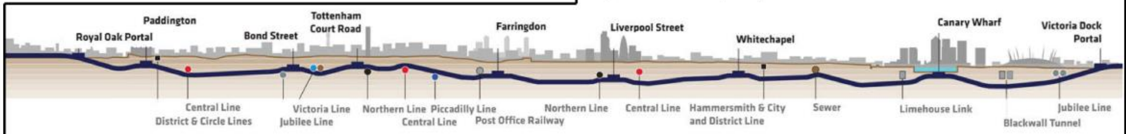

Figure 2: Section showing the alignment of Crossrail and major infrastructure the new tunnels cross.

PATHWAYS

Once set, the main routes of 'hard' infrastructure are rarely changed. Thus, with the construction of hard infrastructure we not only create value for the future but also frequently set the preconditions for further infrastructure and urban development. There seems to be a risk that we are not sufficiently understanding the influence of spatial parameters over time and how the allocation of infrastructure shapes our cities.

Can overhead, visible allocation of infrastructure (Figure 3) change the flexibility of service provision and does it influence the citizen's awareness?

Figure 3: Overhead infrastructure. Permanent electricity cables in Japan (left) and temporary dewatering pipes in Berlin (right).

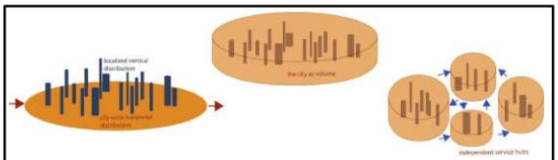

Figure 4: Current and alternative mental representations of infrastructure

MENTAL MODEL

The currently predominant form of visualisation in maps and building sections suggests a mental model of infrastructure services as illustrated in Figure 4.

What would change if the mental model would be that of the city as a volume ore independent volumetric service hubs?

QUESTIONS

Could spatial allocation of infrastructure be treated as a part of infrastructure planning early in the process rather than as a response to a prior determined demand?

What can emergent cities that are in the process of developing their infrastructure systems learn from cities with long established systems regarding infrastructure allocation?

The questions raised on this poster resulted from a series of discussions with representatives of Think Deep UK. It is a proposition rather than presenting research results. We would love to hear your thoughts and inputs: loretta.tann.13@ucl.ac.uk

Figure 1: Statens Vegvesen as reprinted in Erikson, I. et al., 2016. Oslo. TU1206 COST Sub-Urban WG1 Report. Available at www.sub-urban.eu
Figure 2: http://www.crossrail.co.uk/construction/tunnelling/railway-tunnels/
Figure 3 (left): http://www.spoon-tamago.com/2015/06/24/chaotic-photographs-of-electric-cables-suspended-over-japanese-streets/
Figure 3 (right): http://www.morethangreen.es/en/berlins-pink-pipes/

UKCRIC ice Institution of Civil Engineers

Appendix VII. Method for literature selection

The literature selection started with a general search on Google scholars for the terms "subsurface planning" "urban underground" and "underground planning". The relevance of the resulting publications was first assessed by reading the title and first sentences of the abstract as would appear in the search engine. At this point it was decided if a paper would be saved and read further. The software Zotero was used to save, structure and annotate the literature. All of the above terms were maintained as Google Scholar alerts for the duration of the research resulting in approximately 30 publications per week. Additional relevant publications were identified through snowballing, reading though the reference lists of the included papers and applying a similar judgement process to the above.

The final selection for the papers included in Section 2.2 and 2.3 were influenced by the publication process of the paper reproduced in Appendix IV. In the published paper, the first section presents a reflection and review of the development of scholarship about urban underground planning up to approximately the year 2000. This section was mainly written by one of the other authors of the paper, and is not included in Chapter 2 because it was not considered essential in the context of research problematisation for the current thesis. Section 2.3 focusses on the more recent literature and publications before 2000 were only included if they represented an additional argument toward the problematisation sought, that was showing the range of approaches presented in literature and discussing their connection to systems thinking and systems approaches. Additional confidence in comprehensiveness was gained through peer-review by the co-authors as well as two independent reviewers.

Section 2.4 builds on the observation by the researcher, that to write about the subsurface or underground in a structured manner, many of the reviewed papers uncritically present a categorisation of what the subsurface represents at the start of their papers and build their methodology and discussion on that categorisation. As for Sections 2.2 and 2.3, comprehensiveness was sought with regard to the presented approaches. As such, following the first search and structuring, additional publications were only included if they presented a set of categories not previously encountered.

Over the course of the research, the body of literature continued to grow. As both papers included in Chapter 2 were submitted for publication in May 2018, literature after this date is not included.

Appendix VIII. Archaeological Priority Areas

To gain an understanding of the coverage of archaeological finds or the potential for new discoveries in London, areas categorised as Archaeological Priority Areas (APAs) are summarised in Table IX.1 for 12 London boroughs. The Local APAs have not yet been revised in the same form for the remaining boroughs (Historic England, n.d.).

Table VIII.1: Archaeological Priority Areas (APAs) as summarised by the respective councils

Borough	Area [ha]	APAs Tier 1 [ha]	Tier 2 [ha]	Tier 3 [ha]	total [ha]	Percentage of total area [%]
Westminster	2,203	177.35	717.92	405.2	1,300.47	59
Barking and Dagenham	3,780	26.46	841.96	958.43	1,826.85	48
Camden	2,179	57.1	253.68	327.92	638.7	29
Croydon	8,650	205.39	1,296.14	1,672.15	3,173.68	37
Hackney	1,905	18.04	411.11	366.26	795.41	42
Islington	1,486	24.87	183.86	-	208.73	14
Kensington and Chelsea	1,238	27.65	287.43	-	315.08	25
Merton	3,762	48.84	1064.75	316.34	1,429.93	38
Newham	3,857	39.62	902.86	1828.24	2,770.72	72
Redbridge	5,644	143.7	982.46	1283.67	2,409.83	43
Tower Hamlets	2,158	38.32	770.89	658.47	1,467.68	68
Wandsworth	3,522	0.08	971.58	608.25	1,579.91	45

Appendix IX. Consultees according to Town and Country Planning Regulations 2012 and the Planning Act 2008

As a first point of reference, the current study considered statutory consultees for Local Plans according to the Town and Country Planning Regulations 2012, and for infrastructure projects according to the Infrastructure Planning Regulations 2009 that refer to the Planning Act 2008. As examples, the specific list of consultees for the new Local Plan in Wandsworth (Wandsworth Council, 2019) and an underground project currently underway, namely Thames Tideway (Thames Water, 2013), helped to establish the consultees' connection to the London subsurface. Figure X.1 lists the groups and categories set out for the two cases.

Town and Country Planning Regulations 2012

Specific consultation bodies

- The Coal Authority
- The Environment Agency
- Historic England
- Marine Management Organisation
- Natural England
- Network Rail Infrastructure Limited
- The Highways Agency
- Adjoining Local Planning Authorities
- Relevant telecommunications/electricity/gas companies
- Relevant Primary Care Trust
- Relevant sewerage and water companies (here Thames Water)
- The Mayor of London (including TfL)

General consultation bodies
(example categories as listed for Wandsworth council)

- Adjoining boroughs
- Architects, planners and other professionals
- Builders
- Community groups
- Conservation and heritage groups
- Developers
- Employment/business interests
- Environmental groups
- Health organisations
- Housebuilders
- Housing associations
- Police and other emergency services
- River and Riverside interest group (including the Port of London Authority)
- Statutory consultees*
- Transport groups
- Utility companies

*Statutory consultees are those organisations and bodies, defined by statute, which local planning authorities are legally required to consult before reaching a decision on relevant planning and listed building consent applications.

Planning Act 2008

- The relevant Regional Planning Body (here GLA)
- The Health and Safety Executive
- Relevant authorities: Health and Safety, police, regional development
- The Commission for Architecture and the Built Environment
- The Equality and Human Rights Commission
- The Commission for Sustainable Development
- The Homes and Communities Agency(a)
- The Environment Agency
- The Historic Buildings and Monuments Commission for England
- Natural England
- The Joint Nature Conservation Committee
- Relevant statutory undertakers
- The Highways Agency
- The Maritime and Coastguard Agency
- The Marine and Fisheries Agency
- The Civil Aviation Authority
- Integrated Transport Authorities (ITAs) and Passenger Transport Executives (PTEs)
- The relevant Highways Authority
- Transport for London
- The Rail Passengers Council
- The Disabled Persons Transport Advisory Committee
- The Coal Authority
- The Office of Rail Regulation and approved operators(a)
- The Gas and Electricity Markets Authority
- The Water Services Regulation Authority
- The relevant waste regulation authority
- The British Waterways Board
- Trinity House
- The Health Protection Agency
- The relevant local resilience forum
- The Crown Estate Commissioners
- Neighbouring authorities
- Directly affected authorities
- Non-statutory consultees
- Landowners
- Community consultees

Figure IV.1: Statutory consultees for a Local Plan and an Infrastructure Project, according to the relevant legislation

In accordance with the fact that the Infrastructure Planning Regulations 2009 (see above) deal with specific project proposals rather than with strategic plans, the list includes infrastructure regulators and specific commissions as statutory consultees, with a distinction between the cases in which a consultee has to be consulted or a notification is sufficient. Affected statutory undertakers and authorities are likely to be higher in number for long, linear infrastructure projects than for local plans, as the infrastructure might cross the remit of several councils.

Appendix X. Mapping of London stakeholders

In order to gain a better understanding of the connection of different consultees listed in Appendix IX to the different subsurface topics listed in Table 4.3 (Chapter 4), consultation responses to the Draft Plan for the City of London and the London Borough of Merton are mapped out in Figures XI.1 and XI.2. These two examples were chosen because the individual consultation responses were published in the public domain. For other councils, only overview reports were available in the public domain. It should here be noted that the figures can only be indicative, as consultees may not have responded if the topics they considered to be relevant were covered to their satisfaction in the proposed plans.

For the City of London, Natural England stated that it had no comments to make on this consultation. The same applies for Highways England who did, however, state that they examined the Plan as well as the Transport Strategy. As such, this agency is considered to have an interest in transport policies. There is no basement policy in the City of London and no responses to this topic were to be expected. In addition, nobody commented on the provision of energy infrastructure, perhaps because the different infrastructures are bundled in the City Plan Policies. The promotion of pipe subways by the city was supported by individual respondents.

For the London Borough of Merton, a large number of individuals and local community groups responded to the consultation, in sum covering most topics of the proposed plan, often concerning a specific site or location within the council's remit, or a specific topic that lay within their interest. Similarly, developers mainly commented on site allocations and design considerations. However, as might be expected, the responses of the required consultees listed in Chapter 4 (Table 4.6) generally focused on their particular area of responsibility and individuals usually were concerned with one particular aspect only. Neighbouring authorities only commented on transport infrastructure that would cross the council's boundary, implying that more issues are considered transboundary in the historic and densely build environment of Inner London.

Figure XI.1: Mapping of stakeholder responses to Draft Plan for the City of London (City of London, 2018) against subsurface related topics

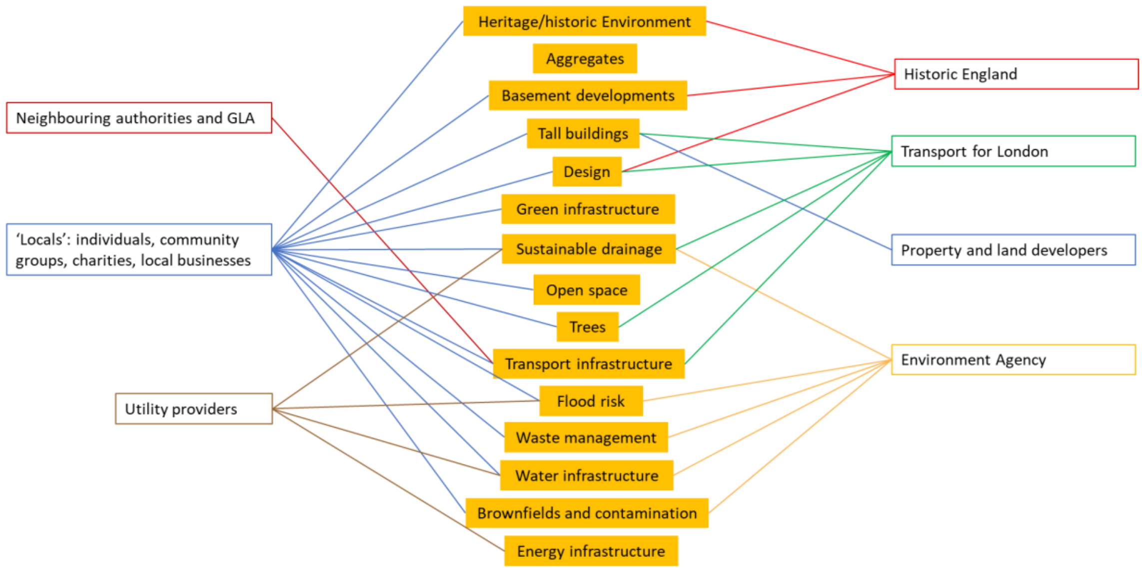

Figure XI.2: Mapping of stakeholder responses to Draft Local Plan for the London Borough of Merton (Merton Council, 2018) against subsurface related topic

Appendix XI. Stakeholder listing and rating

Structured interview part (interviews nr. 8 to 15)

A. In your experience, who is influential to and/or affected by the planning/use of subsurface space?

B. Please categorise the stakeholders in terms of their main field of interest:

- **Economic**
  low costs, be cost-efficient make profit, customer satisfaction, reputation (follow up contracts), compensation for disturbance/land use, maximise land use value
- **Technical**
  'make it work' – high standard technical solution, safety (margins), compliance with technical standards
- **Environmental**
  protection of groundwater, flood protection, soil contamination, ecosystem services, minimise impact of human interventions
- **Social/Civil Society**
  advocate for citizens' interests, social acceptance, participation, information, fulfil expectations, good relationships with local actors, groups, etc.
- **Infrastructure service and management**
  Supply a service, minimise disruptions, hygiene, supply safety, optimisation of infrastructure scheme, security of operations, good project management
- **Planning and regulation of the built environment**
  strategic planning, land use planning, legal compliance, harmonisation of guidelines, implementation of regulations
- **NONE**
  No interest/not affected in terms of the above categories, main driver of becoming involved in planning decisions is to continue business as usual/not to be disrupted in everyday undertakings.

C. On a scale of 0 to 10, please rate the stakeholders in terms of:

a) Their impact on planning decisions relating to subsurface projects
(0: 'stakeholder has no influence', 10: 'stakeholder can take decisions')
b) How strongly they are affected by planning decisions relating to subsurface projects
(0: 'stakeholder is not affected', 10: 'stakeholder is strongly affected')

The data drawn from the structured part of the interviews is presented on the following pages.

Stakeholder	Main Interests X: Primary interest(s) (X): Secondary interest(s)							How influential is the stakeholder on subsurface planning decisions? 0: has no influence 10: has a very strong influence											How affected is the stakeholder by subsurface planning decisions? 0: not affected 10: strongly affected											Comments Please comment if your scoring is based on project delivery/ strategic planning only/if you would like to distinguish between local and general effects or similar.
	Economic	Technical	Environmental	Societal	Infrastructure service and management	Planning and regulation	NONE	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	Colour/interviewee coding: E06 E07 E08 P09 E10 P11 E12
TfL – Metro	X(X) (X)	X X	X(X)	X(X) (X)	XXX XX	XX										X X X	X X	X X			P		L					X	X	AFFECTED AT STRATEGIC LEVEL Depends on scale of project. L: local Rail, Metro, Highways: "anything that involves people" Can be high if adjacent P: project
TfL – Road	X(X)	X (X)	X	X(X)	X XX	X X						X				X X	X	X									X		X	AFFECTED AT STRATEGIC LEVEL Can be high if adjacent
NR-Rail	X(X) (X)	X X	(X)	(X) (X)	XX XX	(X)								X X		X	X	X X			P		L						X	AFFECTED AT STRATEGIC LEVEL Depends on scale of project. L: local Highly affected
Utility Providers, general/statutory authorities	(X)	X(X)	(X) (X)	(X)	X X X	X(X)								X	X	X		X									X X X		X	Regulated monopolies – less economic Additional Interest: Health and Safety Often have significant influence on how underground space is configured and constructed. Their assets may be heavily affected.
NG-Power	X(X)				X	X								X				X			S						L		X	AFFECTED AT STRATEGIC LEVEL +security
TW - water supply	X (X)		X		X X									X				X			S						L		X	AFFECTED AT STRATEGIC LEVEL
TW – waste water	X(X)		X(X)	(X)	X X								X	X										X					X	AFFECTED AT STRATEGIC LEVEL
Developers, land owners, private stakeholders	XXX XX	X(X)		X	(X) X	X (X) X (X)		X			X		X X			X		X							X	X	X		X X	Both (strategic and project level) Planning as a barrier, infrastructure as enabler Highly affected Often have significant influence on how underground space is configured and constructed. Their assets may be heavily affected. May have influence on how the scheme is configured if they are contributing to the development of the underground space.
Private individuals and groups, residents	(X)	X	(X)X	X X	X						I X			L	X		X				X			X			X		X	Affected at project level, temporary I: individual (generally/directly), L: lobby group

Stakeholder	Main Interests X: Primary interest(s) (X): Secondary interest(s) Economic	Technical	Environmental	Societal	Infrastructure service and management	Planning and regulation	NONE	How influential is the stakeholder on subsurface planning decisions? 0: has no influence 10: has a very strong influence 0	1	2	3	4	5	6	7	8	9	10	How affected is the stakeholder by subsurface planning decisions? 0: not affected 10: strongly affected 0	1	2	3	4	5	6	7	8	9	10	Comments Please comment if your scoring is based on project delivery/ strategic planning only/if you would like to distinguish between local and general effects or similar. Colour/interviewee coding: E06 E07 E08 P09 E10 P11 E12
																														Range of effects depending on proximity of stakeholder to new underground development, or the potential use by the stakeholder, or other local effects.
Public – passengers	X		X	X		(X)										X					L									FOR MAJOR PROJECTS
British Gas	(X)				X													X			S						L			S: strategic, L: local
Telecoms, smaller services	X(X)	X			X	X											X	X			S						L		X	Affected at project level, temporary +security
Heritage			X X	X		X								X		X	X		←							X			→	
Historic England				X										X												X				Archaeology is primary interest
Statutory bodies (EA, LPA)			X													X										X				
Environment Agency		X	X XX			X								X	X	X	X	X						X	X	X	X			Potential effect
Environmental lobby			X											X	X						X	X								
GLA	X	(X)	X	XX X	X	XX X						X				X	X	X				X				X	X X			As property owners +security
Neighbouring authorities						X					X													X						
Site owners/land owners and property	X X	X		X	X								X	X		X									X		X X			Often have significant influence on how underground space is configured and constructed. Their assets may be heavily affected. May have influence on how the scheme is configured owing to the impacts.
Land owners - adjacent		X		X							X															X				Low influence unless many adjacent owners object.
Highways Authority	(X)	XX		(X)	XX	(X)									X	X	X	X X			P	←				→ X				highly affected INFLUENCE DEPENDS ON AMOUNT OF INTERFACES, P: Project
Visitors				X				X																X						
Airports	(X) X		(X)	(X)	X			S									X	L										X		S: strategic, L: local area around the airport
Construction contractors	(X) (X)	X X			(X)											X	X X							X			X	X		

Stakeholder	Main Interests X: Primary interest(s) (X): Secondary interest(s) Economic	Technical	Environmental	Societal	Infrastructure service and management	Planning and regulation	NONE	How influential is the stakeholder on subsurface planning decisions? 0: has no influence 10: has a very strong influence 0	1	2	3	4	5	6	7	8	9	10	How affected is the stakeholder by subsurface planning decisions? 0: not affected 10: strongly affected 0	1	2	3	4	5	6	7	8	9	10	Comments Please comment if your scoring is based on project delivery/ strategic planning only/if you would like to distinguish between local and general effects or similar. Colour/interviewee coding: E06 E07 E08 P09 E10 P11 E12
Local authorities	(X) X	(X) (X)	(X) XXX	XX XXX	(X) X X	(X) XXX						X					X X	X X X	L							X	X X	X X	X X X	L: their own decision. As property owners +security Local authorities often have some influence on the decisions during consultation. They can be affected because some underground space developments (e.g. transport) often have a significant effect on their borough.
Security services																		X											X	Add security as extra interest
National Government		(X)	X	X		X												X												
Promoters	x	(x)	(x)	(x)														X											X	Secondary interests mainly to achieve primary interest
Sensitive receptors (theatres, studios, etc.)	X	X			X											X					X							X		Range of effects depending on proximity of stakeholder to new underground development, or the potential use by the stakeholder, or other local effects.
Operator (of the new asset)		X																X											X	
Educational facilities			X	X	X					X				X							X						X			Range of effects depending on proximity of stakeholder to new underground development, or the potential use by the stakeholder, or other local effects.
Government (SoS Transport)/DfT	X					X												X						X						
Design panels		X												X							X									
Mayor's Office	X			X		X										X							X							
Groups/associations			X	X					X							X				X							X			Range of effects depending on proximity of stakeholder to new underground development, or the potential use by the stakeholder, or other local effects
Businesses – commercial (e.g. retail)	X								X							X				X							X			Range of effects depending on proximity of stakeholder to new underground development, or the potential use by the stakeholder, or other local effects
Businesses – non-commercial	X			(X)																										
Transport operators		X			X	X								X										X						
Engineering design consultants	(X)	X			(X)								X											X						

Appendix XII. Questionnaire

Planning for and with the subsurface

Questionnaire

Thank you for taking part in this research and filling in this questionnaire. It should take around 20-25 minutes to complete.

Purpose

The purpose of the questionnaire is to investigate how different groups, e.g. planners, council officials, engineers, geologists or utility providers, understand current needs and potentials with regard to the management of the subsurface in urban areas.

Subsurface refers to all potential functions or utilisations of the ground (here referred to as **assets**), for example groundwater, infrastructure, preservation of archaeology, spatial developments, or geothermal energy. **Shallow, individually buried utilities** are explicitly **excluded**, as the related issues have been recurrently discussed and are covered elsewhere.

A ***planning strategy*** in this questionnaire is understood as a participatory process by which to analyse and allocate the environmental capacities of the ground, as well as the current and future human utilisations of and interventions in the subsurface in an urban area.

Data Processing

By filling in the questionnaire, you agree for the information given to be processed for the purposes of the research study undertaken by Loretta von der Tann (the researcher) on Management of the Urban Subsurface, and to be published in the researcher's PhD thesis, journal papers, as well as potentially wider media.

All information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998. Confidentiality and anonymity will be maintained unless anonymity has been waived in writing.

Thank you for taking part in this research. We appreciate your contribution. Please also share with interested colleagues.

Page 2: Respondent information

1) What field do you work in?

   [governance authority/regulator/transport infrastructure provider/utility infrastructure provider/private consultancy firm/research institution/NGO/other – please specify]

2) What is your background?

   [Geology/Hydrogeology/Planning/Architecture/Environmental Science/Municipal Engineering/ Tunnel Engineering/Law/Archaeology/Economics/Energy/Mining /Urban design/other > please specify]

3) Where in the UK is your work located? Please name the city/area about which you consider yourself the most knowledgeable and answer the questions referring to that city/area. If you work across the UK, please choose one city, or leave blank.

   [Inner London/Greater London/Birmingham/Glasgow/Leeds/Bristol/Liverpool/ Manchester/Sheffield/Edinburgh/other – please specify]

4) Have you previously come across the idea of subsurface planning/planning for the urban subsurface?

   [Yes, my city implements a comprehensive planning strategy and I am involved in the process;

   Yes, I am part of an initiative concerning urban subsurface planning or management;

   Yes, I am aware of developments in that area but am not involved;

   No, I have thought about the need for more structured approaches but have never come across an initiative;

   No, I have never thought about it but the concept is instantaneously convincing;

   No, I have never thought or heard about it]

Page 3: Characterisation of interest in the underground and underground assets

5) Categorise the relationship between yourself and your organisation with the various subsurface assets or uses. Please choose all relevant categories.

	I work mainly on/about	In our projects we have to consider	My organisation owns	My organisation manages
Transport tunnels				
Groundwater aquifers				
Groundwater wells				
Geomaterials				
Geothermal energy				
Foundations				
Contaminated soil				
Sewage tunnels				
Utility infrastructure				
Tree roots				
Archaeological sites				
Basements and other underground developments				

6) Categorise **your organisation's activity** with regard to the various subsurface assets or uses. Please choose all relevant categories.

	My organisation is involved in the planning of	My organisation is involved with the delivery of	My organisation is consulted with regard to	My organisation has to give consent for
Transport tunnels				
Groundwater aquifers				
Groundwater wells				
Geomaterials				
Geothermal energy				
Foundations				
Contaminated soil				
Sewage tunnels				
Utility infrastructure				
Tree roots				
Archaeological sites				
Basements and other underground developments				

Page 4: Relevance of underground functions and management issues

7) For the **development of my city and the wellbeing of its population**, I consider the following uses of the subsurface to be:

	Essential	Important	Desirable	Not Significant
Geothermal energy				
Groundwater as drinking water reserve				
Provision of drainage capacity and flood retention				
Underground/metro tunnels and stations				
Road tunnels				
Sewage tunnels				
Deep utility tunnels (single utility)				
Multi-utility or multi-service tunnels				
Utilities directly placed in soil				
Trees (roots)				
Developments for public use (e.g. museum extension)				
Developments for private use (basements)				
Provision of bearing capacity for foundations				
Preservation of archaeology				
Burial grounds				
Underground parking facilities				

8) How strongly do the following uses of underground space **impact on your professional work?**

	Strong impact	Some impact	Little impact	No impact
Geothermal energy				
Groundwater as drinking water reserve				
Provision of drainage capacity and flood retention				
Underground/metro tunnels and stations				
Road tunnels				
Sewage tunnels				
Deep utility tunnels (single utility)				
Multi-utility or multi-service tunnels				
Utilities directly placed in soil				
Trees (roots)				
Developments for public use (e.g. museum extension)				
Developments for private use (basements)				
Provision of bearing capacity for foundations				
Preservation of archaeology				
Burial grounds				
Underground parking facilities				
Soil contamination				

Page 5: Validity of specific statements concerning urban subsurface management

9) How strongly do you agree or disagree with the following **general** statements?

	Strongly agree	Agree	Disagree	Strongly disagree	N/A
a) For an underground planning strategy, the relative importance of the various uses of the subsurface for the city should be evaluated.					
b) Economic development should be the main objective of an underground planning strategy.					
c) Environmental protection should be the main objective of an underground planning strategy.					
d) In the subsurface, uses for the common good should be prioritised.					
e) In the subsurface, built infrastructure and developments are normally prioritised above natural services such as the filtration capacity of groundwater.					
f) If a planning strategy were to be developed, the city authorities (e.g., the GLA in London) would need to initiate and facilitate the process.					
g) The value of the subsurface is not sufficiently recognised.					
h) Underground assets should be categorised and valued according to their relevance for the city-wide system.					

10) How strongly do you agree or disagree with the following statements about **people and stakeholders**?

	Strongly agree	Agree	Disagree	Strongly disagree	N/A
a) Nobody should be allowed to object to a project without demonstrating locus standi (a sufficient connection to the project to justify participation in the decision at hand).					
b) Stakeholders are engaged too late in the development of subsurface infrastructure.					
c) Information about the subsurface should be readily available to citizens.					
d) Citizens should know more about the subsurface.					
e) Any plan should allow for feedback from the communities.					
f) Ownership attribution of subsurface issues is not always clear.					
g) Lay people tend to overestimate the risk of underground construction.					

11) How strongly do you agree or disagree with the following statements regarding **subsurface data and knowledge**?

	Strongly agree	Agree	Disagree	Strongly disagree	N/A
a) Data about underground assets in the public domain is insufficient.					
b) It is difficult to quantify risks when existing assets remain unknown.					
c) Better availability of data would lead to better front-end design and cost reductions.					
d) The information about and understanding of the natural system (e.g. behaviour of water, geotechnical parameters) in the subsurface is insufficient.					
e) A lack of information leads to unnecessary involvement of stakeholders. This results in delays and costs.					

Page 6: Specific themes and actions

12) How would you rank the importance of addressing the following themes if a strategy for managing the subsurface were to be developed? We are aware that these themes are interdependent and cannot always be clearly distinguished. Please rank in priority from 1 to 8.

	Ranking
Data availability e.g. access and availability of information on the location and ownership of existing assets, geological and geotechnical data	
Stakeholder management e.g. involvement of all relevant parties, prevention of delays arising due to objections	
Technical challenges e.g. enlargement of existing tunnels, longevity of materials, tendency to overdesign	
Congestion of subsurface space e.g. strategies to deal with the finite availability of space, prioritisation of specific functions for future uses, longer term planning of schemes	
Legal procedures e.g. consenting regimes, time from project identification to delivery, procurement, ownership of space	
Environmental protection e.g. groundwater protection, protection of archaeology, filtration capacities	
Funding, financing and value e.g. value capture of underground space and assets, long term planning of assets vs. shorter term political cycles	
Overarching policy objectives identification of objectives and their potential effects on subsurface use, e.g. mobility, energy transition, resilience	

13) Is it **desirable** for the following actions and solutions to be considered within a planning strategy?

Action/solution	Strongly agree	Agree	Disagree	Strongly disagree	N/A
a) Creation of an asset registry					
b) 3D model of all constructed underground assets					
c) Integrated 3D model of constructed underground assets integrated with the above-ground built environment					
d) 3D model of potentially useable space (non-used space)					
e) Integration of environmental uses like groundwater flow or infiltration capacity into 3D models					
f) Streamlining of consenting regimes for infrastructure projects					
g) Safeguarding of strategic transport routes					
h) 'No use' – reservation of underground space (volumes) for flood retention (storage of flood water) or not yet foreseeable future uses					
i) Limiting of depth for private subsurface use					
j) Supplementary planning guidance for the subsurface					
k) Integration of the subsurface into Local Plans					

14) Is it **feasible** for the following actions and solutions to be considered within a planning strategy?

Action/solution	Strongly agree	Agree	Disagree	Strongly disagree	Not my area of expertise
a) Creation of an asset registry					
b) 3D model of all constructed underground assets					
c) Integrated 3D model of constructed underground assets integrated with the above-ground built environment					
d) 3D model of potentially useable space (non-used space)					
e) Integration of environmental uses like groundwater flow or infiltration capacity into 3D models					
f) Streamlining of consenting regimes for infrastructure projects					
g) Safeguarding of strategic transport routes					
h) 'No use' – reservation of underground space (volumes) for flood retention (storage of flood water) or not yet foreseeable future uses					
i) Limiting of depth for private subsurface use					
j) Supplementary planning guidance for the subsurface					
k) Integration of the subsurface into Local Plans					

Page 7: Risks and benefits of an underground strategy

15) What do you think could be the **main advantage/s** of a comprehensive underground **DATA** strategy for your city? (up to three answers possible)

- ☐ To be able to monitor changes of underground space use including construction projects as well as environmental data
- ☐ To be able to view the data spatially to understand which functions are located where in the subsurface, and to locate potentially unused volumes
- ☐ To be able to access all data in a straightforward and collated way
- ☐ To have established standards for data collection and records
- ☐ To be able to assign multiple properties to the same volume (for example, groundwater flow and geological properties)
- ☐ To understand where the data gaps are
- ☐ To enable research
- ☐ Others – please specify.

16) What do you think could be the **main advantage/s** of a comprehensive underground **PLANNING** strategy for your city? (up to three answers possible)

- ☐ Stopping the congestion/continuous unplanned congestion of subsurface space
- ☐ Helping to achieve overarching policy objectives like resilience or the energy transition
- ☐ Discovery of untapped opportunities to use the subsurface
- ☐ Simplification of consent across council boundaries
- ☐ Safeguarding of space for traffic routes
- ☐ Safeguarding of environmental functions
- ☐ Development of cross-disciplinary knowledge
- ☐ Development of knowledge capacities in planning authorities
- ☐ Others – please specify.

17) What do you think could be the **main risks/barriers** to a comprehensive underground **PLANNING** strategy for your city? (up to 3 answers possible)

- ☐ Would create more bureaucracy without creating benefits
- ☐ Might be inflexible
- ☐ The available data is insufficient to reliably inform a strategy
- ☐ Focus on the environment could be too strong
- ☐ Focus on infrastructure projects and the construction industry could be too strong
- ☐ Would generate cost for more intensive stakeholder engagement not currently accounted for
- ☐ Could be in conflict with existing plans and regulations
- ☐ Authorities might not have the capacities or expertise to implement a strategy
- ☐ Models might become too complex to be useful
- ☐ Others – please specify

Part 8: Summing up

18) After filling in this questionnaire, in my opinion the idea of engaging in a process to develop a subsurface planning strategy is:
    - □ Unnecessary. Everything works fine as it is and we have more important problems.
    - □ Totally needed – the integration of the subsurface into planning strategies is necessary to achieve overarching policy objectives.
    - □ Too late to be introduced and therefore not worth it. Let's just keep going and do the best we can in the given setting.
    - □ I don't mind really, I don't think it's a priority but if it comes along, that's ok.

19) Anything we missed? Please point out any suggestions/questions/points we might have missed. Comments and additional suggestions are welcome.

    [TEXT BOX]

Thank you page

Would you be happy to be interviewed in a follow-up interview by the researcher? These data will not be connected with your answer.

- □ Name of Organisation:
- □ Responding person:

Appendix XIII. Mapping of questionnaire questions against findings from secondary data and interviews

	Topics covered in Chapters 4 and 5													
Questionnaire topics (not including respondent information)	Material aspects	Organisational aspects	Substantial aspects (discourses)	Specific discourse on data management	Going underground as opportunity	Going underground as imperative	Subsurface as asset	Subsurface as constrained space	Protection of asset	Removal of constraints	Spatial dimension	Temporal dimension	Sectoral dimension	Value and need
Q7: Relevance of underground functions			x		x	x								x
Q8: Impact on professional work								x					x	
Q9: Validity of specific statements														
a – e: prioritisation of functions					x	x	x							x
f: allocation of task		x	x											
g – h: valuation			x				x							x
Q10: People and stakeholders														
a – b: stakeholders		x										x	x	
c – e: public knowledge and participation		x											x	x
f: ownership		x			x									x
g: valuation							x							x
Q11: Subsurface data														
a/d: insufficient data and information				x				x						
b, c and e: value of data/cost of insufficient knowledge				x				x						
Q12: Priorities for action (ranking)			x	x		x					x			x
Q13/14: Specific actions for a planning strategy (desirability/ feasibility)														
a: asset registry	x		x	x						x				
b – e: 3D model	x			x						x				
f: improvement of consenting regimes		x								x		x		
g: safeguarding of routes						x	x		x		x	x		
h: unused							x		x					
i: limiting of depth – layered approach		x	x											
j/k: SPG/ local plan		x									x			
Q15: Benefits of a DATA strategy				x			x		x				x	
Q16: Benefits of a PLANNING strategy			x		x				x					x
Q17: Risks of/barriers to a PLANNING strategy		x	x									x		

Appendix XIV. Questionnaire data for participants working in London

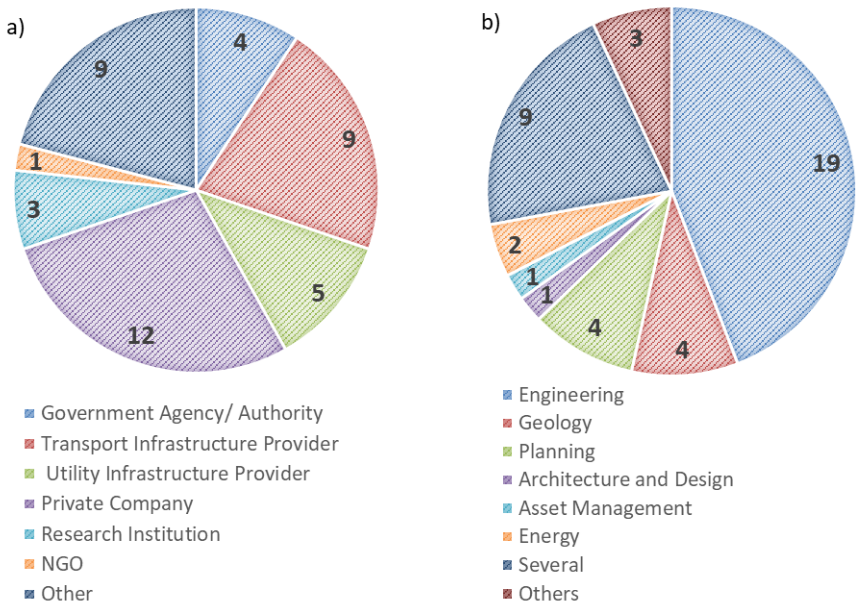

Figure XIII.1: Background of questionnaire respondents; a: affiliation, b: professional background ('Engineering' includes civil engineers (11), tunnelling engineers (6), and municipal engineers (2))

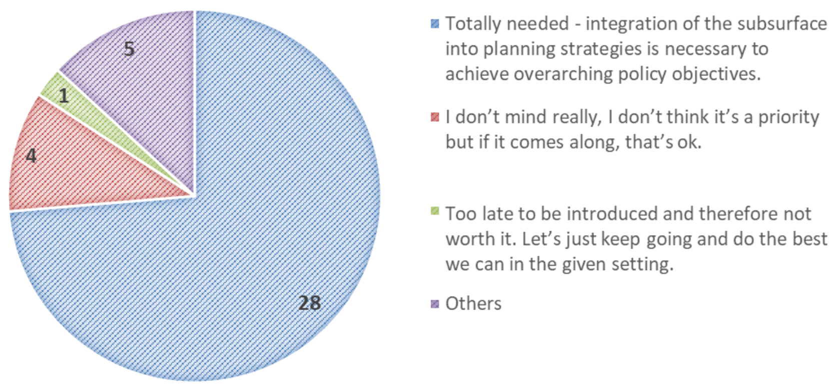

Figure XIII.2: Respondents' assessment of the need for a subsurface planning strategy (n=38)

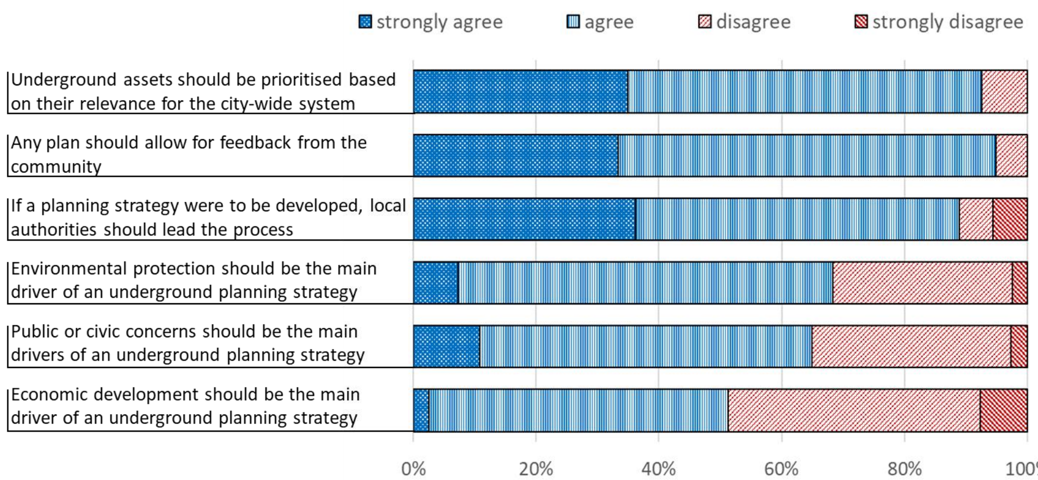

Figure XIII.3: Respondents' views on directional statements for an underground planning strategy (n=38-41, excluding N/A answers)

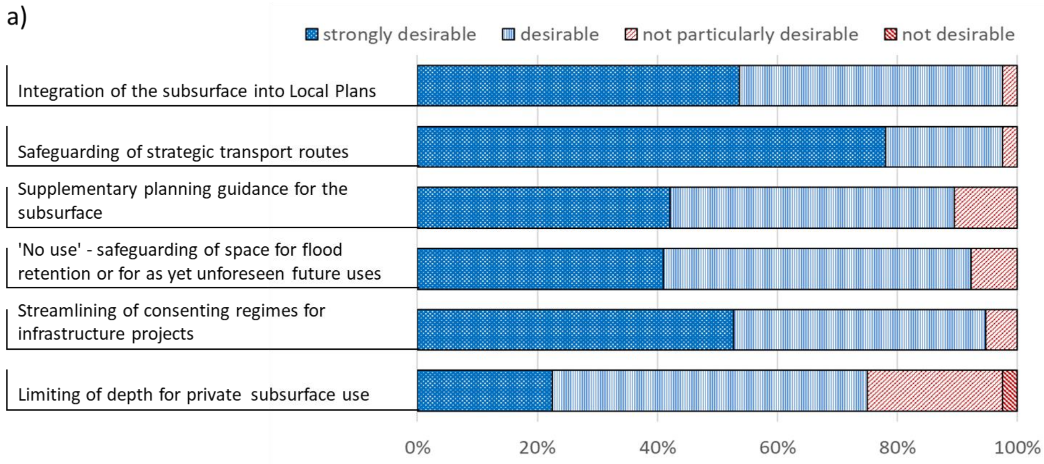

Figure XIII.4: Respondents' view on the a) desirability (n=38-41, without N/A answers) and b) feasibility (n=35-39, without answers stating 'not my expertise') of specific actions to be considered within an underground planning strategy

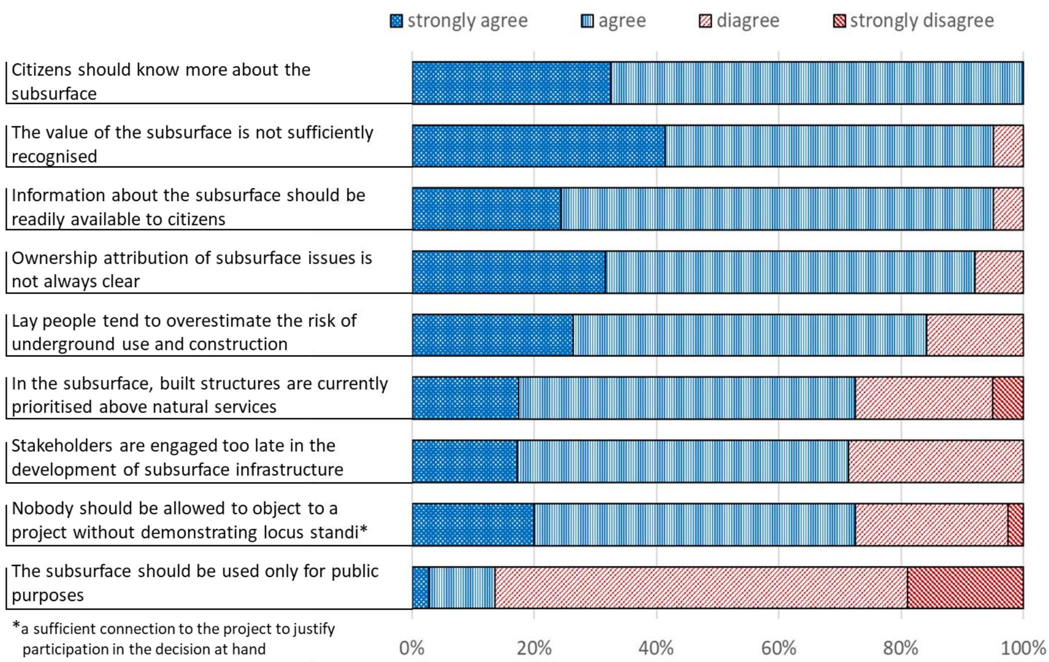

Figure XIII.5: Respondents' views of general rationale for an underground planning strategy (n=39-43, excluding N/A answers)

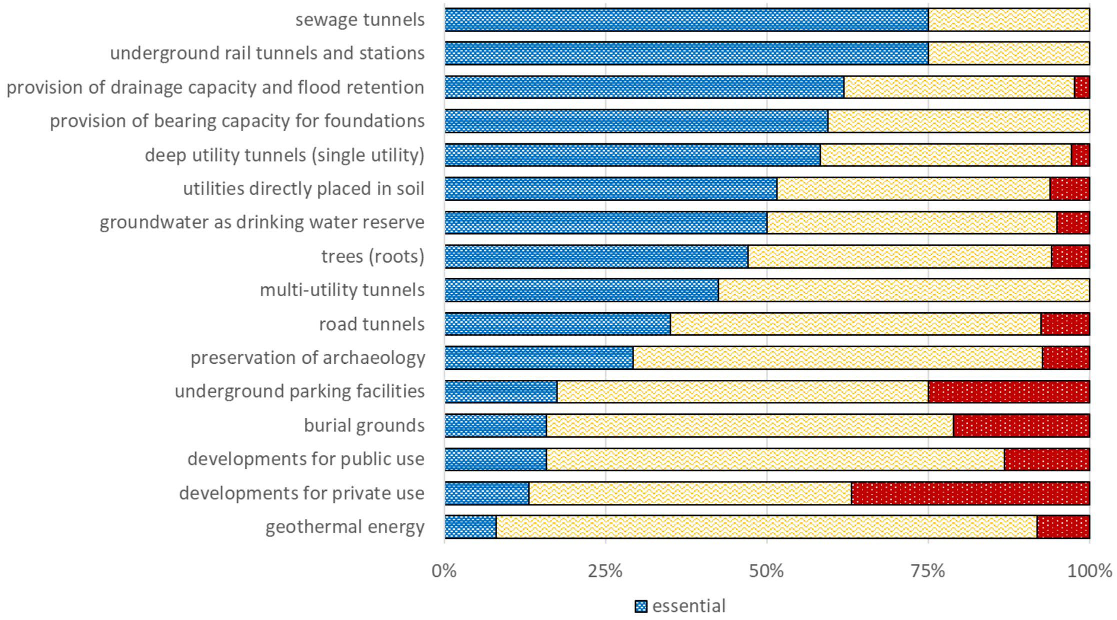

Figure XIII.6: Respondents' perception of significance of different uses for the city (n=38-41)

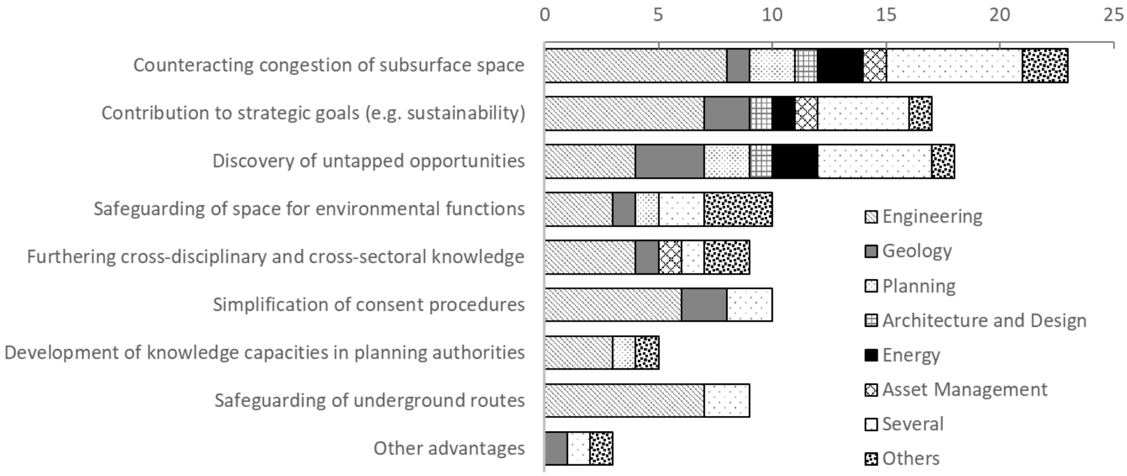

Figure XIII.7: Main potential benefits of an underground planning strategy (n=38, up to three answers possible)

Figure XIII.8: Main risk of/barriers to establishing an underground planning strategy (n=38, up to three answers possible)

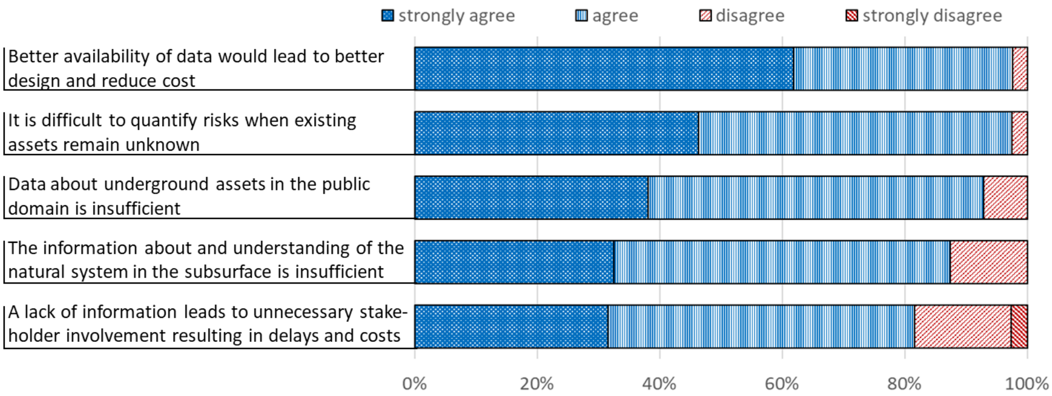

Figure XIII.9: Respondents' views on general rationale for an underground data strategy (n=41-43)

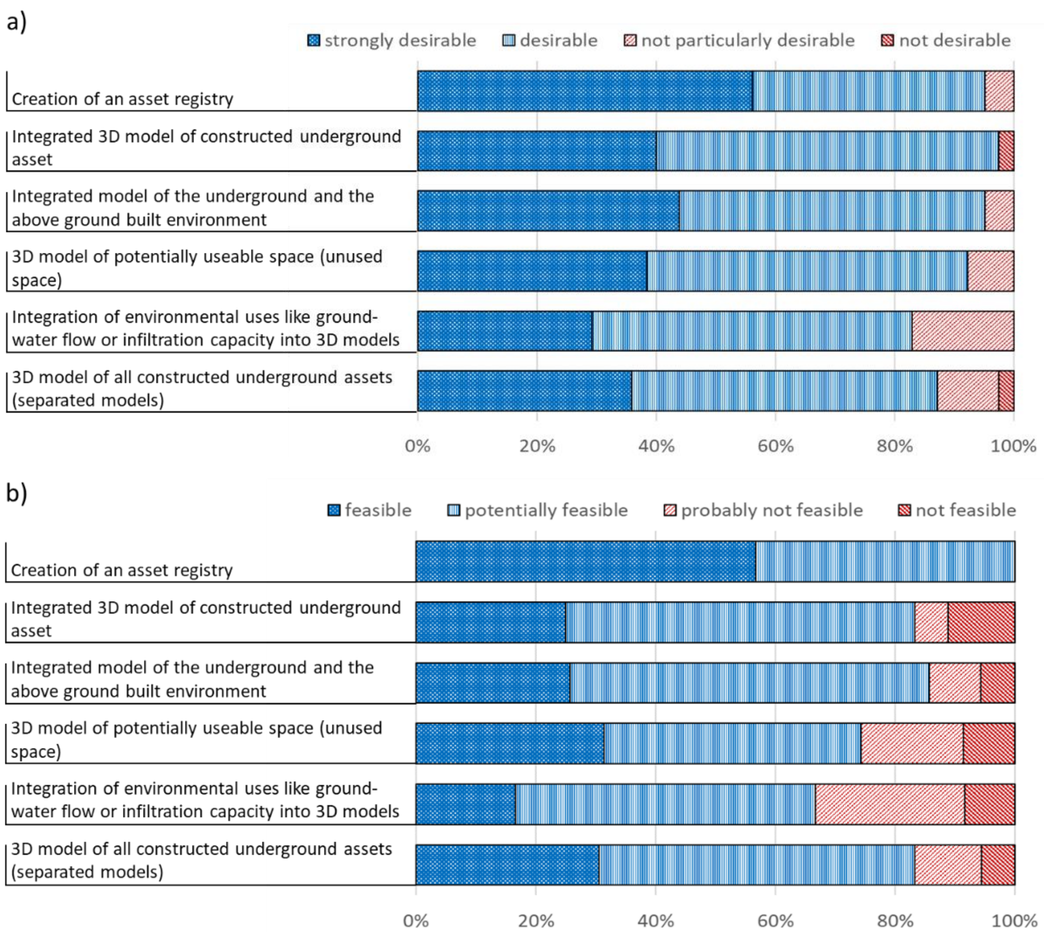

Figure XIII.10: Respondents' views of a) desirability (n=39-41, excluding N/A answers) and b) feasibility (n=35-37, excluding answers stating 'not my area of expertise') of specific actions to be considered within an underground data strategy

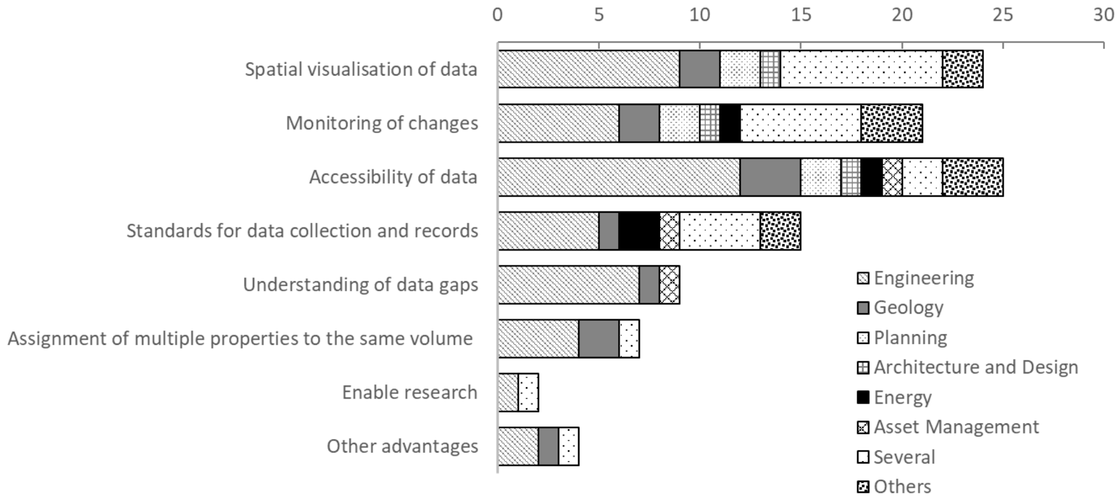

Figure XIII.11: Main benefits of a comprehensive data strategy (n=38, up to three answers possible)

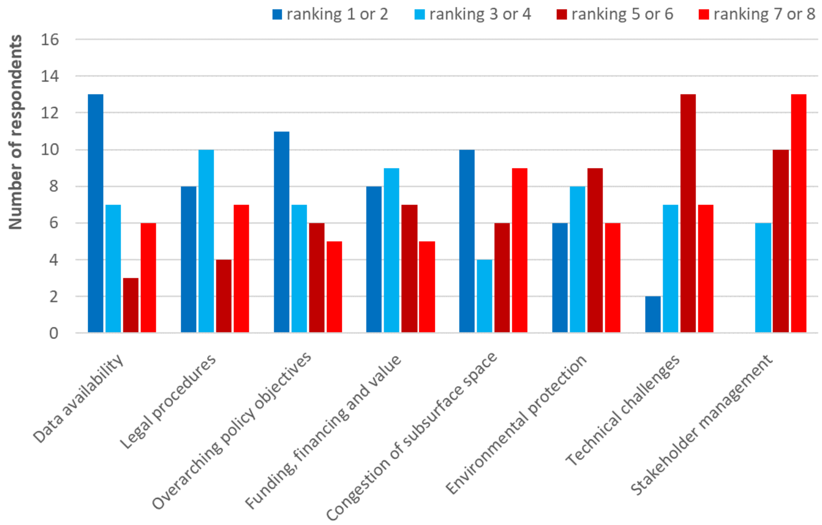

Figure XIII.12: Ranking of specific themes to be addressed in a subsurface planning strategy (n=29)

Appendix XV. Selected process diagrams

Diagrams constituted an important tool of data gathering and analysis throughout this project, 'for reassessing and improving the problem solvers' interpretations of the problem' (Rose, 1997). An emphasis was placed on models and perceived purposes through the lens of specific stakeholder groups or disciplines, and flow-diagrams were developed to discuss the topic from various points of view. Given that these diagrams were used to stimulate thoughts and discussions, they were not constructed to be representative of testable theories (Blaikie, 2009) but, rather, were used for the exploration of linkages. This appendix collates the diagrams and figures that constituted important steps in the process.

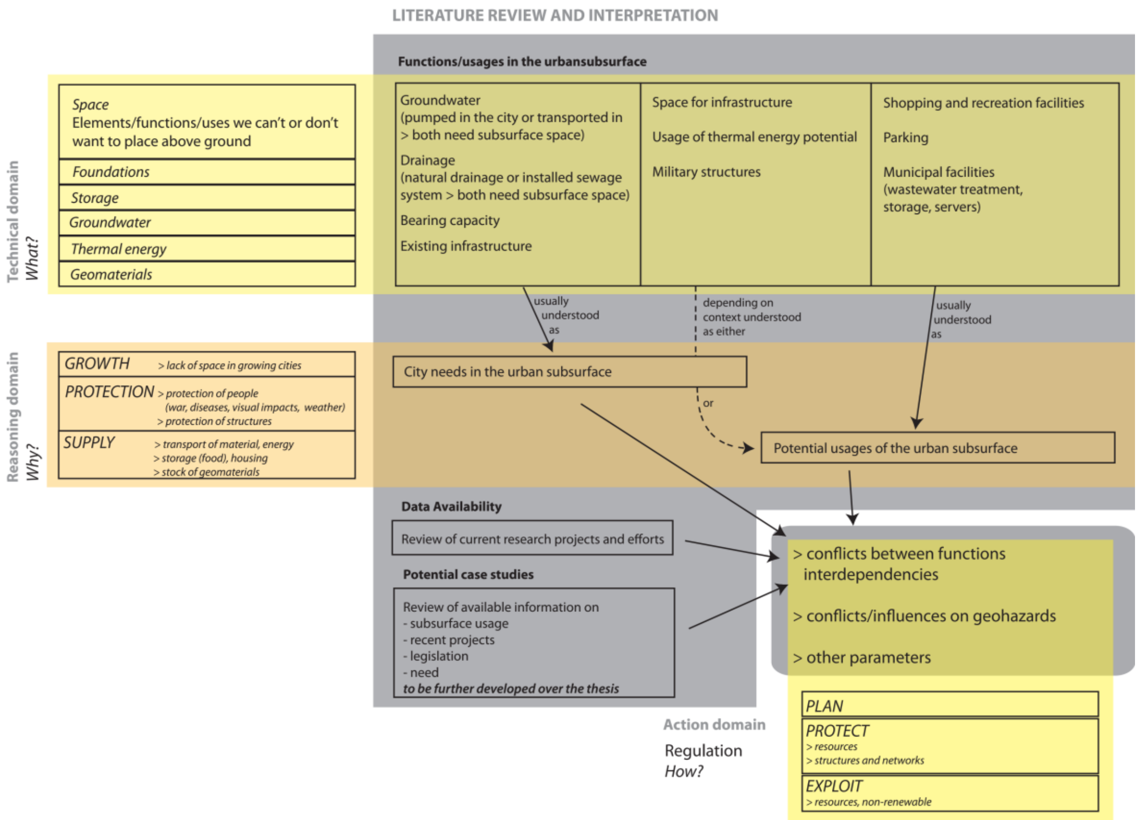

Figure XV.1: Mapping of different categorisation domains for subsurface functions

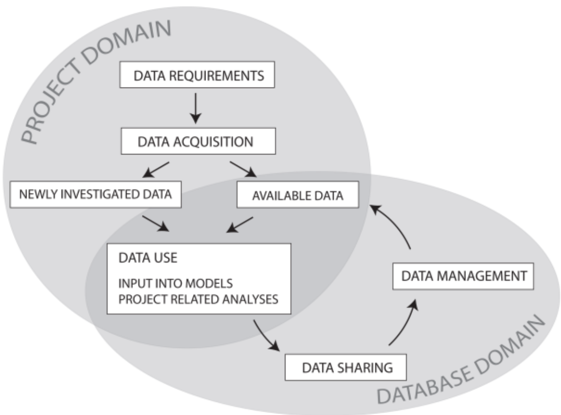

Figure XV.4: Sketch of data relations

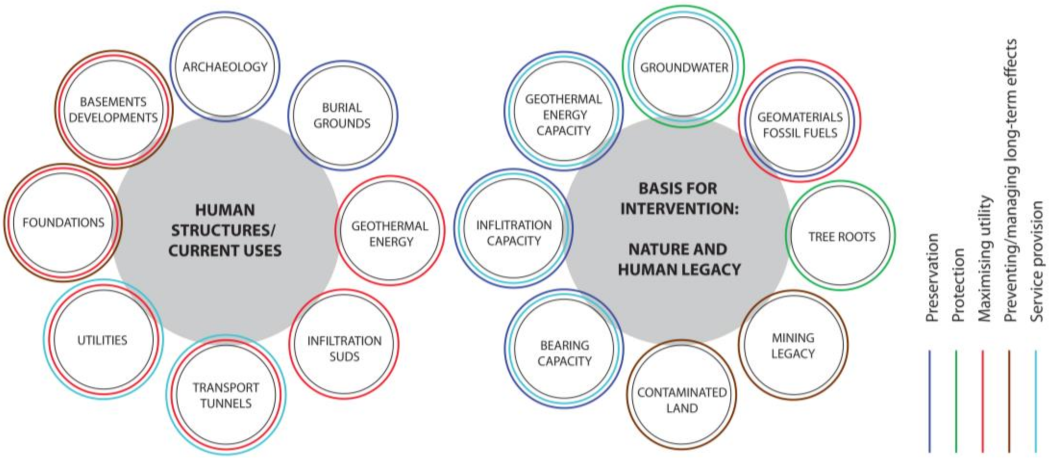

Figure XV.2: Purpose domains of subsurface management

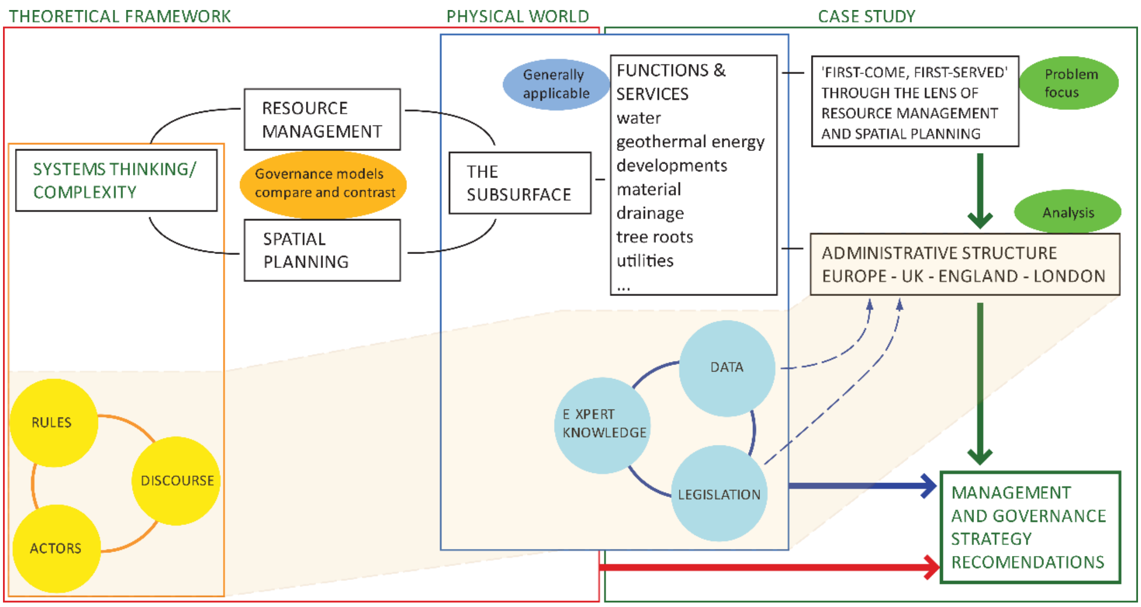

Figure XV.4: Outline of research process, early stage

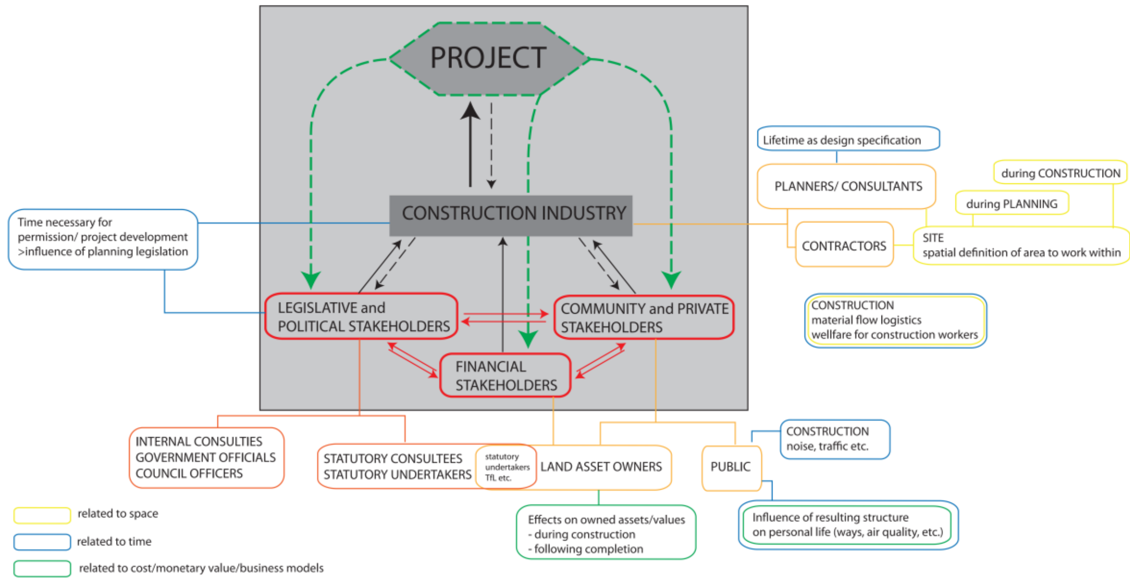

Figure XV.5: Mapping of stakeholders related to spatial, temporal and value dimensions of subsurface governance

Appendix XVI. Urban planning, marine spatial planning and underground planning – a juxtaposition

The call for a more conscious or more holistic management of the subsurface engages two sets of terminology, stemming from urban planning on the one hand, and resource management on the other (see Chapter 2, Section 2.4). As has been described, these two fields of policy and scholarship are not independent: insofar as land can be seen as a limited resource, resource management is an integral part of spatial or territorial planning. However, the purpose and specific objectives of land allocation and spatial regulation can, arguably, be of a political rather than economic nature. This tension, which also manifests in the fact that the same land providing different resources can potentially lead to conflicts and create the need to set priorities, is generally present in urban settings, and would also be expected to arise in a hypothetical underground planning regime. To put the concept of subsurface planning into the context of planning efforts more in general, this appendix draws on another field of enquiry where the traditional realm of spatial planning has been extended to capture a new need for better management and resource protection and allocation: marine spatial planning (MSP), juxtaposing this with urban planning as well as with the evolving concept of underground planning.

The attempt to draw lessons from related policy fields in the same country appears to be unusual in academic literature. Theories pertaining to lesson-drawing (Rose, 1991), institutional transplantation (Mamadouh et al., 2002), and similar studies usually deal with using knowledge and experiences gained in institutional setups and policies in one country to improve or evolve the situation in another country. However, in practice, policy or strategy transfer happen continuously: arguably, people working in institutions and administrations who are responsible for the implementation of different policies will very directly apply their knowledge from one field to another. In the context of London, learning from one major tunnelling and infrastructure project to the next could be analysed as a form of policy transfer, as these projects are implemented under a project-specific law or extensive development consent orders (DCOs) (see Section 4.4). The example of Crossrail shows that this kind of learning is deemed crucial. Crossrail created a legacy framework presenting a range of 'lessons', with the corresponding documents made publicly available (Crossrail, 2017). Different to the concept of lesson drawing as mentioned above, in the example of underground projects, policies and guidelines will change from one project to the next. In the specific example of Crossrail, the initiative for knowledge transfer was taken by the organisation of one specific project to capture lessons learned for projects to come with topics ranging from technology to geology and governance.

Similar to this 'project-to-project' learning, the current Appendix aims to explore valuable insights that can be gained from MSP as a new field of planning that has extended the realm of spatial planning to including a spatial entity which previously had been seen as a source for services, but had not been governed from a spatial point of view. In her comparison of the management of public land and the establishment of marine spatial planning in the US, Gopnik (2015) criticises the fact that the existing juxtapositions of MSP and land use or town planning present thought provoking, 'casual' policy analyses, but do not provide analytical rigour. For the purpose of this thesis, this juxtaposition is considered to be a useful input into the understanding of where the urban subsurface could be placed within existing planning considerations. Table XV.1 summarises the parameters taken from literature about urban planning and marine spatial planning, and contrasts them to what a potential subsurface planning strategy could entail. The juxtaposition of the three illustrates which areas of concern are general to planning and which are specific to the underground.

Table XV.1: Juxtaposition of scope of subsurface planning with urban and marine spatial planning

Parameter	Urban and land use planning	Marine spatial planning (MSP)	Subsurface planning
Overriding concern/ purpose/ drivers	Evolved with history[1]	Wellbeing of ecosystem/marine environment	Subordinated to overarching urban objectives Human wellbeing in the urban environment
Pressures on the space or system	Urban growth Public health Waste	Human activities Deterioration of ecosystems Increasing number of fixed, built structures[2] Climate change effects Natural hazards Shoreline dynamics	Human activities Increasing number of fixed, built structures Climate change effects Natural hazards Population growth
System focus	Infrastructure (health and sanitation, general supply and waste management)	Ecosystem [well defined marine ecosystem]	Linear infrastructure, water (urban) Geosystem (rural) [ill-defined as new concept]
Dimensions of use-coordination	Traditionally 2D (some height restrictions)	3D and layered (for example, boats above fish above cables)	3D and layered

Table XV.1 (continued)

Parameter	Urban and land use planning	Marine spatial planning (MSP)	Subsurface planning
Mapping and data necessities	Detailed physical maps available Mapping of social parameters emerging	Fragmented monitoring, (physical) mapping is limited compared to that of land[3]	Fragmented asset database, partly difficult to access Geological data integrated into BGS database.
Interaction focus	Urban – rural (supply, waste)	Land – sea (coastal ecosystems)	Above ground – below ground (soil)
Nature of human activities	Spatially fixed or mobile	Spatially fixed or mobile, areas sometimes indeterminate (determination undertaken through MSP) Temporal, seasonal variation	Spatially always fixed Temporal variation with regard to water (groundwater, flooding)
Potential for spatial development	Dependent on availability of access routes at surface level	Only partially developable	Dependent on availability of technologies and access routes (spatial): - at surface level - from the surface down
Ownership	Public and private spaces coexist	Generally understood as public[3]	Depends on country UK: volume belongs to surface land owner; however, compulsory purchase rights are often granted for major infrastructure
Spatial fixation of human activities[4]/ pathway dependencies	Generally strong (built environment) Street layout usually fixed, permanence of buildings varies	Activities spatially less fixed than in terrestrial environment, but with stronger temporal variation	Stronger than terrestrial environment/planning, infrastructure is particularly pertinent
Traditional governance[5]	Private initiative/project	Project/activity-specific	Project/activity-specific
Sense of place	Strong	Strong[6]	Weak
Permanence of interventions	Layout high, function (building) low	Varies	High
Tragedy of the commons: free access leading to overuse	Debated as 'urban commons'	Very present, such as in fisheries	Not currently debated (see Chapter 6, Section 6.2.3)

[1] See Vigar et al. (2000) regarding the UK and the origin of town planning; specifically, public health and housing and, later, other concerns including the promotion of good conditions for the general public, and redistribution or growth management to prevent sprawl.

[2] Kidd and Shaw (2014).

[3] Gopnik (2015).

[4] Kidd and Ellis (2012).

[5] Jay (2012).

[6] Shackeroff et al. (2009).

Glossary

Anthropocene	Proposed geological epoch defined through the human impact on the material formation of the Earth's and its atmosphere.
Crossrail (1 and 2)	Crossrail 1 is a 117km new East-West railway crossing London, including 21km of twin tunnels under central London. Crossrail 2 is a proposed North-South railway, including 36km of tunnels under central London.
Desk study	First phase of a site investigation for the development and implementation of new projects.
Feedback loop	Cause-and-effect process. In the current thesis used in particular to describe the spatio-material manifestation of engineering interventions in the subsurface that alter the conditions for future interventions
London Power Tunnels	National Grid project replacing cables beneath the road network in London with deep tunnels. Phase one of the project (LPT1) involved 32km of tunnels, phase 2 (LPT2) that is currently being prepared will involve another 32.5km of tunnels.
Problem situation	Used in soft systems methodology for the situation in which a problem or task is set. To capture the complexity of any such situation, a rich description is necessary.
Undergrounding	Putting structures underground that had been previously above ground.
Thames Tideway	25 km tunnel currently under construction to increase the capacity of London's sewerage system and reduce overflows of sewerage into the river.
Victoria Station Upgrade	Largely finished project to increase the capacity of Victoria station including a new ticket hall and 300m of new connecting tunnels.