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Surfacing the urban underground: Knowledge production, modes of envisioning, and politics of visibility

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ABSTRACT

The subsurface is increasingly considered the final frontier of urban development, with marked potential to improve urban spatial problems, resilience and sustainability. At the same time, the literature recognises Urban Underground Space (UUS) as a finite and multi-functional resource that requires holistic and strategic management. However, knowledge of the invisible urban subsurface is obscured by secrecy, fragmented across disciplines, and built on extractive knowledge practices. A lack of long-term planning of UUS perpetuates a first-come-first-served development approach that risks jeopardising future infrastructures and urban sustainability. To address this, there is an effort to gather ever more subsurface data, rendering the invisible visible to urban decision-makers. We analyse and reflect on the limits of current underground planning knowledge, responding to the socio-political gap in UUS literature. We focus on the ontological challenges facing sustainable planning of UUS and present the need to critique how practices of power and politics in UUS knowledge production envision subsurface futures. We present four *modes of envisioning* the urban subsurface, which negotiate its characteristics of invisibility and complexity to shape volumetric potential and possibility. We argue that governance of this invisible urban frontier requires deeper reflection on how the subsurface is rendered visible and in anticipation of which futures. We suggest that a more nuanced lens is required to account for the interplay between power, depth, and volume through the intersections of plural urban subsurface imaginaries.

1. Introduction

The enhanced and systematic utilisation of Urban Underground Space (UUS) is increasingly viewed as a vital strategy for improving the sustainability and resilience of cities around the world whilst also responding to rising urbanisation (Admiraal and Cornaro, 2018; Bartel and Janssen, 2016; Bobylev, 2016). Benefits of this approach include optimising public transit systems and supporting compact-city design (Besner, 2017); mitigating the surface impact on historical or natural environments (Cui et al., 2021); harnessing geothermal energy or storing energy (Admiraal and Cornaro, 2016b); or providing disaster-resistant infrastructure (Bobylev et al., 2012). When the underground is effectively coordinated with surface-level urban development, harmonious three-dimensional spaces can effectively address challenges associated with urban renewal while also accommodating pressures concerned with growing urban populations (Cui et al., 2021). However, such comprehensive urban planning requires deeper integration with surface strategies to enhance efficiency and optimise the functionality of the underground. This necessitates a sophisticated understanding, management and prioritisation of the use of a 'complex multi-functional resource, which comprises both man-made and natural assets and in this way creates actual or potential values to humans' (Volchko et al., 2020, 15). Nevertheless, the intrinsic invisibility of the subsurface poses a significant physical barrier that impedes both the understanding and future exploitation of its potential (Frisk et al., 2022). Given that UUS is a finite, non-renewable resource[1] whose excavation cannot be

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[1] UUS is sometimes referred to as non-renewable, although this quality of the subsurface depends on which aspect of the resource we are concerned with (Bobylev, 2009). To clarify this we refer to Parriaux et al's four resource categories (2004): spatially and volumetrically, it cannot be restored once excavated. Ground water is renewable but extraction or interruption can have lasting effects (Bobylev, 2009); geomaterial extracted for construction is often reused elsewhere throughout building processes (Parriaux et al. 2004). Geoenergy encompasses (renewable) geothermal sources and the potential to store heat seasonally (Parriaux et al. 2004). Our primary purpose in labelling the subsurface as non-renewable is to highlight that, in contrast to development the surface, we cannot spatially perform a 'reset' to the original state once a volumetric incursion or material extraction is made.

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reinstated, critical questions arise regarding prioritisation and long-term planning to ensure the subsurface contributes to resilient urban futures without increasing vulnerability (Bobylev, 2016). Therefore, it is increasingly recognised that societies must substantially reassess the future utilisation of the urban subsurface, aiming to enhance its visibility and dissolve its opacity to urban planners and decision-makers (Broere, 2016).

Expanding on these insights, we identify a significant strand of UUS literature that delves into the potential opportunities, challenges, and pathways to effective holistic planning of UUS and urban infrastructures (e.g., Admiraal and Cornaro, 2016b; Bobylev, 2016; Hunt et al., 2016; Dick et al., 2017; Cui et al., 2021). We identify that this body of work addresses two key challenges. First, the successful integration of the subsurface into policy and governance is hampered by its invisibility to planners and decision-makers, continuing a business-as-usual approach that neglects its potential contribution to sustainable cities (Hunt et al., 2016). Second, the complex dynamics of the subsurface remain inadequately understood, requiring more detailed information and sustainable approaches for managing its interactions and interrelations with the surface (von der Tann et al., 2020). To overcome these challenges, we observe that there is a concerted effort across subsurface experts to know more about the subsurface and to share this knowledge better amongst planners, specialists, and decision-makers at the surface. We refer to this collective initiative as the *visibility project*, as the term highlights the interdisciplinary nature of the effort, which – albeit not uniform – seeks to render the subsurface more visible and, in doing so, to reveal its future potential contributions to the built environment. However, the accumulation of increasingly detailed scientific knowledge concerning the urban subsurface's functions currently overlooks its interaction with social and political spheres, such as the framing of subsurface development in political debates and planning processes (Admiraal and Cornaro, 2020; Doyle et al., 2016), and the negotiation of its benefits and impacts (Graham, 2016). By referring to a burgeoning body of social science literature emphasising the lack of insights into questions of power influencing UUS development, we find support for critically reflecting on the technical focus of the *visibility project*. This nascent attention to socio-political dynamics highlights crucial blind spots to understanding governance issues, such as the valuation of UUS benefits and trade-offs (Hunt et al., 2016; Makana et al., 2016), conceptual interpretations of the subsurface (Hine and Mayes, 2022; Harris, 2014), and visions of its future role in urban development (Hunt et al., 2011; Harle, 2015). Moreover, the scholarly insights into the socio-political dimensions of UUS development suggest that, despite often narrow ontological conceptions of the subsurface in urban and engineering fields, the volumetric visions entangled in underground urbanisation actually stem from 'a myriad of …conceptual wellsprings' offering a rich field for analysis of multi-faceted imaginaries and practices of vertical urban life (Harris, 2014, 602). These multiple and sometimes competing vantages on the urban subsurface invite us to more closely examine the project of rendering the subsurface visible, challenging the premise that simply seeing the urban subsurface will enable holistic and sustainable planning.

The overall aim of this paper is to scrutinise the attempts of the predominantly technical *visibility project* to overcome the inherent invisibility and elucidate the complexity of urban underground space in an effort to render this final urban frontier knowable and manageable. We argue that this initial step towards comprehensive planning, *seeing* the subsurface, already embodies particular framing and ambitions for its future use as a volume of social and material potentiality. Furthermore, the UUS field's historical neglect of this social sphere and lack of reflections on the underlying rationalities of subsurface knowledge production place the ambition of holistic and sustainable management of the urban subsurface at risk. The paper is founded on a strategic review of literature from which we develop a proposal for a critical way to understand the imaginative specificities of the knowledge production supporting urban subsurface development.

We make our argument in three steps. First, in Section 2, we address the *visibility project* – the desire for a continuous expansion and refinement of knowledge about UUS through enhancing collaborations among experts across various fields, promoting advanced modelling techniques, and facilitating the dissemination of standardised, accessible data. In Section 3, we address the specific challenges of urban underground planning, highlighting how material complexity, along with social, cultural, and political factors, shapes the production of knowledge informing decision-making. We do so by drawing upon critical urban planning and geography scholars challenging the traditional apolitical views of the subsurface and emphasising its integration with surface spaces and power dynamics. We further build on the 'volumetric turn', which calls for a critical analysis of subsurface knowledge production, questioning its socio-political implications and intended applications. In Section 4, by drawing particularly upon resource geography but also critical urban planning scholarship, we scrutinise how geo-imaginaries – the social practices and technologies that construct subsurface potential – are enacted by the *visibility project* through its epistemic acts and practices of rendering the subsurface visible. After this analysis, we shift our attention to the imaginaries of the urban subsurface identified in the literature. We present four *modes of envisioning* through which the underground's characteristics of invisibility and complexity are negotiated to shape its volumetric potential in distinct but overlapping ways. These modes and the critique of the *visibility project* offer a tentative agenda for urgent research into the socio-political dynamics of the rapidly developing urban subsurface. We conclude our paper with a final discussion in Section 5.

2. The visibility project and its challenges

The UUS literature is primarily concerned with addressing a double-edged *knowledge challenge* in urban underground planning: one arising from the inherent opacity and hence invisibility of the subsurface (Bobylev, 2009; Bartel and Janssen, 2016; Cui and Lin, 2016) and the other from the complexity of geological systems (Hunt et al., 2011) combined with the task of integrating subsurface elements with urban infrastructure on the ground (von der Tann et al., 2020). To tackle this dual challenge, UUS scholars propose several approaches, primarily focused on collaboration, data collection, and data distribution, aiming to enhance urban subsurface knowledge in order to overcome its invisibility and reveal its complex functions and potential. We refer to this uncoordinated but broadly aligned scholarly effort as the *visibility project*.

Whilst issues of transparency in understanding development practices, processes, and material qualities are clearly not limited to the subsurface (e.g. supply chain and corporate governance transparency or tracing contaminants in an ecosystem), it is the juxtaposition of the subsurface against our comprehension of the spatiality of the city above the surface that is unique, e.g., 'open vs solid' (Labbé, 2016). The initiative of increased visibility promises that by seeing the 'Under-land' (Labbé, 2016, 154) and helping decision-makers to fully comprehend the urban volume, holistic UUS planning can be enabled, and cities may better respond to the challenges of resilience and sustainability (Admiraal and Cornaro, 2020; von der Tann et al., 2020). The obscurity of what lies beneath the ground poses one of the most substantial obstacles to comprehensive urban planning (Admiraal and Cornaro, 2016a; Frisk et al., 2022). It affects the awareness and understanding of a diverse array of stakeholders engaged with the subsurface, as well as those who, though not currently involved in planning, are influenced by its development. However, the picture of the city below is incomplete, with data quality and availability often poor, especially in the earlier planning stages of projects (Hunt et al., 2016). Incomplete archival information and difficulties mapping dense urban environments also contribute to uncertain underground assessments (de Mulder et al., 2012). Additionally, effective information sharing is hindered by a lack of centralised, accessible data and organisational fragmentation,

creating an information gap between urban planners and subsurface specialists (Hooimeijer and Tummers, 2017; Darroch et al., 2018; Dick et al., 2017). Consequently, the urban subsurface remains a 'largely hidden realm' (de Mulder et al., 2012) that is 'out of sight, out of mind' for urban practitioners who often do not sufficiently comprehend the full potential of the subsurface for urban goals in their praxis (Van der Meulen, 2016, i).

Accordingly, rendering the urban underground visible and knowable relies on the ever-increasing collection and continuous interpretation of quantifiable data from scattered observation points to form assessments and visualisations of its likely composition, structural performance, and constrained geophysical force (de Mulder et al., 2012). This endeavour employs diverse techniques, including on-site drilling, remote sensing by satellite and laboratory testing of samples (de Mulder et al., 2012). By 'opening up' the subsurface (Mielby et al., 2017), as enabled by such data collection, it is hoped to provide decision-makers with the necessary knowledge to address complex planning issues of prioritisation and efficient utilisation of this finite resource (Li et al., 2013). Crucially, such planning is anticipatory in character, seeking to overcome potential clashes, accommodate future demand, and manage prioritisation and risk (Bartel and Janssen, 2016; Canto-Perello et al., 2016; Norrman et al., 2016).

The urban underground is transformed into an intricate 'final urban frontier' (Admiraal and Cornaro, 2018, 1) not only due to its invisibility but also because of its significant multifunctional potential (Li et al., 2016; Norrman et al., 2016). In this perspective, integrating the subsurface into urban management and planning strategies is increasingly seen as an urgent necessity (Volchko et al., 2020; von der Tann et al., 2020). Aiming to comprehend this complexity, the *visibility project* necessitates improving the collection and integration of data from a broader range of expert sources, such as geology, hydrology, existing and planned infrastructures, and property demarcation (Besner, 2016; Darroch et al., 2018; Bobylev, 2016). The initiative seeks to overcome traditional sectoral separation through collaboration and interdisciplinarity (e.g., Hooimeijer and Tummers, 2017; Norrman et al., 2016; Dick et al., 2017; Volchko et al., 2020). To progress from merely addressing spatial aspects of physical planning to incorporating more diverse types of information into decision-making processes (e.g., Peng et al., 2023; Volchko et al., 2020), the involvement of a broader range of stakeholders is essential. The UUS literature underscores that subsurface planning requires extensive collaboration among various actors, emphasising the 'vertical' sharing of specialist subsurface information with planners and policymakers (e.g., Dick et al., 2017; Maring and Blauw, 2018).

Moreover, the complexity of integrating the subsurface into urban planning, with its interrelations of uses and potential, requires new management approaches, such as an increasing focus on the theorisation through and application of systems-thinking perspectives (von der Tann et al., 2020). This approach can aid in the sustainable management of the subsurface by revealing complex interactions across different parts of the system and subsystems (von der Tann et al., 2020). The shift to a systems-thinking perspective to understand the complex interactions and interdependencies of subsurface systems vis-à-vis the surface is also perceived as a way to enable effective management of the underground (Bobylev et al., 2022; von der Tann et al., 2020). Although this theoretical application is still a nascent field within the also limited subsurface planning, it is viewed as a promising approach for managing these complexities (von der Tann et al., 2020). For example, it can map risks and help identify the potential for UUS to contribute to the UN Sustainable Development Goals (von der Tann et al., 2021). The geosystem services framework has also been proposed to address the lack of attention to the subsurface in ecosystem services perspectives, which is used more widely in the management of landscapes (Van Ree and van Beukering, 2016). This approach focuses on enhancing knowledge not only of biological and technological aspects but also of the *geo*system, which includes 'geological sequences, structures, landscapes and the rocks, minerals and fossils that are present' (Van Ree and van Beukering, 2016, 30). However, differences in terminology for the subsurface, as well as categorisations and boundaries of systems components, remain a challenge for application (Volchko et al., 2020; von der Tann et al., 2020).

Today, regardless of which framework is used, remedies to address this complexity and multi-dimensionality often manifest in the digital realm. Peng et al. (2023) illustrate that much of UUS planning research is focused on how it can be empowered by multiple sources of data, including urban morphology, spatial statistics, machine learning, complex decision theory and data-driven decision support – much of it is founded on 3D geospatial databases (Peng et al., 2023). A trend can be observed towards more visual and interactive digital models to share knowledge across disciplines, founded on technologies such as GIS (Geographic Information Systems) and BIM (Building Information Models) (e.g., Parriaux et al., 2004; Makana et al., 2016; Price et al., 2018; Zhang et al., 2021; Qiao et al., 2022b). With such models, the ambition is to build readily understandable 3D visualisations (Schokker et al., 2017) through which the user can move at the surface. This tendency reflects a pursuit of increasingly accurate mapping of UUS, such as the creation of urban digital twins (Dick et al., 2017), to guide spatial and urban performance and sustainability (Peng et al., 2023; Zhang et al., 2021). To visually represent the subsurface in relation to urban spatial morphology and enable its integration of subsurface with aboveground planning and design (Hooimeijer et al., 2017), holistic and comprehensive planning collaborations are thus considered necessary. These approaches manage the 'invisible' aspects of the urban realm by using visualisation and computer modelling to understand and communicate the interaction between different systems and components, such as interdependence with geology and existing structures and utilities (Admiraal and Cornaro, 2016a).

Despite these efforts, we find that the visibility project often remains a call for 'cognate interdisciplinarity' (Evans and Marvin, 2006) that rarely seeks synthesis across broader disciplinary domains. Expertise on the underground is confined to a limited group of specialists with extensive knowledge of local conditions, primarily maintained through interpersonal relationships rather than being effectively recorded and shared upwards to planners early in the process (Hooimeijer and Tummers, 2017; Dick et al., 2017). In UUS literature, direct expert experience and case-based learning are dominant, with advanced quantitative planning tools to disseminate this knowledge still lacking (Peng et al., 2023; Zhang et al., 2021; Volchko et al., 2020; de Mulder et al., 2012). Ingold and Simonetti (2018) observe that despite a discursive shift towards greater interdisciplinary collaboration in recent years, significant gaps persist between earth science practitioners and social scientists (Simonetti and Ingold, 2018, 20). Besner's observations (2016) support this, noting that in the realm of the subsurface, it is civil engineers who have become the sole experts, often at the exclusion of urban planners and architects. In this sense, the *visibility project* generates technically focused knowledge (Melo Zurita, 2020) shaped by a specialised epistemic culture. This predominantly technical focus on the subsurface potentially neglects the lessons learned by the urban planning disciplines at the surface. Specifically here, systems-theory is often criticised for its inability to 'tackle untraceable and indeterminate [urban] problems' (von der Tann et al., 2016), such as complex interrelations that resist quantification but also, more pertinently, the interactions with socio-political domains. The absence of input in UUS literature from the social and political realms side-steps these challenging issues (Melo Zurita et al., 2020). Currently, political issues and social benefits related to the subsurface are considered separate 'soft issues' often excluded from quantitative analyses (von der Tann et al., 2020), with 'hard knowledge' provided by expert groups favoured – a feature observed in the built environment more broadly by Petts et al. (2008) in their study of urban interdisciplinarity.

3. Rethinking the urban subsurface: knowledge, power, and the politics of visibility

As a consequence of this technical focus, the urban subsurface is often more widely portrayed as an apolitical, empty space in contrast to the surface (Melo Zurita et al., 2020). Looking at approaches to resource management taken in other realms, such as conservation management, we begin to see the hidden tensions of such conceptualisations. Here, Murray (2007) observes that issues are intentionally 'rendered technical' as apolitical processes whilst, in fact, stimulating certain political responses. There are parallels, too, in the broader de-politicisation and technocratic take-over of urban planning (Schoneboom et al., 2022) and the wider issue of the deliberate severance of politics from development governance to form what Ferguson (1994) calls an anti-politics machine. What exacerbates this technical framing is the subject's optical invisibility – the subsurface's contributions are typically hidden from daily life and local politics in a well-functioning city. As Squire and Dodds (2020) have charted, the subsurface has been long overlooked, and subterranean geopolitics undertheorised. On closer inspection, the techno-scientific image of the urban subsurface begins to show signs of strain. As we will demonstrate in this section, the difficulty in *fully* knowing the urban subsurface lies not exclusively in the dual technical challenges of material opacity and the intricacy of the subsurface but also in social, cultural and political interrelations underpinning its very knowledge production (and in due course planning decision-making). In this section, we demonstrate how seeing the urban subsurface as an overtly political volume consequently requires subjecting the *visibility project* to greater critique as it presents the subsurface as actionable.

To do so, we turn to recent geography and urban studies literature, which begins to show that the urban subsurface is inseparable from the surface, tied into its political negotiations as an ultimately interconnected space (Ruming et al., 2021). Underground and vertical development is intertwined with the political practices and power relations of the city, as for example demonstrated by Ruming et al.'s (2021) analysis of the mapping of subterranean risk in Newcastle, Australia, where the vertical is incorporated into city development and financial assemblages. Such research challenges the apolitical and dominantly technical view of the underground, observing urban underground space as dynamic and power-saturated rather than static and, in an urban ecological vain, as spheres of intense flows and networks (Connor and McNeill, 2022). This scholarly attention to the societal relations with the material subsurface is forming a growing field featuring both volumetric and subterranean turns. The volumetric turn emphasises the significance of vertical dimensions – height and depth – in understanding urban space, challenging the traditionally dominant horizontal focus in urban studies, whereas the subterranean turn illuminates the interplay between power, infrastructure and politics that occurs specifically within the subsurface (Ruming et al., 2021). For example, Graham et al. (2013) explore the politics of infrastructure buried beneath the streets in Mumbai, where the subterranean becomes a site of both neglect and strategic control. Similarly, in his study of Bucharest's metro system, O'Neill (2024) demonstrates how class and capital are spatially inscribed beneath the surface through property speculation and informal economies.

Particularly relevant to the aims of this paper is literature that explores the power relations embedded in the subsurface's knowledge production. In arguing for increased attention to the political in the urban subsurface, we see this not just as an additional dimension of complexity – instead, it demands questioning the production of knowledge itself, asking 'for whom' (Melo Zurita et al., 2020) seeing into the urban depths is benefiting and how. With respect to the *visibility project*, it is important 'to understand how the subterranean anthropocentric is rendered knowable and under what socio-scientific, technological and cultural conditions' (Melo Zurita et al., 2018). For example, Wang (2021) observes how, through geological characterisations and risk assessments of groundwater extraction in Taiwan, 'power is exercised, or distributed, through three dimensions' both via material agency and state institutions over the farming community (Wang, 2021, 219).

Adopting perspectives which view the urban underground volume as a geopolitical space (Wang, 2021) can illuminate several concerns around the *visibility project's* pursuit of more subsurface data. The *visibility projects*' rationale for acquiring and disseminating data, improving cross-sector collaboration, and providing a comprehensive perspective to decision makers – a call for 'stronger knowledge' (de M Raposo, 2021) – assumes that the urban subterranean can be effectively managed by a better understanding of the system's complexity and to achieve this by overcoming its invisibility. Yet, the prevailing engineering approaches to infrastructure knowledge focus predominantly on the human modification of the subsurface by application of the physical sciences (Zalasiewicz et al., 2014). Geography and urban studies literature recognises the ways in which the *production of knowledge* for specific *purposes* and within specific epistemic communities creates, lays claim to, and reinforces certain knowledge of the underground. Miller et al. (2008) note, for example, that in the scholarship on social-ecological systems and urban ecology principles, natural science values often predominate as the primary means of understanding system behaviour (Miller et al., 2008). Whether this epistemic dominance is problematic, they argue, depends on the *intention* of the knowledge (Miller et al., 2008, 46). The tendency to render spaces technical thus frames the subject for certain outcomes (Murray, 2007). Ingold and Simonetti (2022) likewise argue for a re-conceptualisation of underground knowledge and materiality not on its *nature* but on its *use* (Ingold and Simonetti, 2022). That is to say, on the anticipatory rationalities of underground knowledge production by the user. In this way, the *visibility project*, as a project of knowledge production, defines a particular intention for the future of the subsurface. As (Marston and Himley, 2021) discuss, underground knowledge is formed by dominant modes of knowing which are interested in resource-making – the *becoming* of the resource. The question we must ask ourselves is whether this is the same mode of knowing that can support sustainable use of the urban subsurface.

Crucially, what this literature highlights is that such knowledge production consequently requires careful scrutiny of exactly which knowledge is given credence over others and which modes of knowing are repressed or overruled in pursuit of certain human uses. For example, Kroepsch and Clifford observe a deliberate deployment of unknowability where inscrutable spaces beneath the surface are deliberately rendered apolitical, forming blind spots in wider debate and enabling a continued extraction of resources (Kroepsch and Clifford, 2022). By now, it should be clear that the ontological priority given to certain objects, materials, and resources within the subsurface's central epistemic cultures shapes the underground's power relations. This Instone (2019) demonstrate in the case of Melbourne's grasslands, where multiple ontological frames are identified, but governance is defined by only one such frame, which lends power to particular modes of existence at the exclusion of others. In such ways, the dominance of specific epistemic cultures is critical to how UUS is known and thus managed and planned. As we discuss in the next section, this has implications for how the *visibility project* bounds the possible urban subsurface futures we can imagine.

4. Shaping subterranean futures: the power of geo-imaginaries

In this section, we shift our attention to the imaginative capacity of urban subsurface knowledge, focusing in particular on the role of maps and mapping tools in rendering the urban underground visible. We firstly review literature that marks such epistemic practices of visualisation as critical sites of power which can cement future visions of the nature and potential of that which cannot be comprehended from above by human sight. Analysis of the anticipatory and imaginative role of such visualising practices enables us to tease out the *political* of

subsurface knowledge – often obscured by comprehending urban subsurface knowledge as a purely technical exercise. After this overview, we present four distinct but overlapping modes of *envisioning* through which the underground's dual characteristics of invisibility and complexity are negotiated and, in so doing, shape its volumetric potential.

As we have discussed, the *visibility project* seeks to make legible the urban subsurface to support its long-term and strategic planning. Pickles (2003), writing on maps in urban planning, notes that the provision of visual data is only one part of the role of planning cartography – planning as an act more openly contains a dualistic role, firstly to 'render the social and built environment in graphical form', and secondly to extend demands and desires into a future, actionable, vision. To render a natural system technical is an attempt to render it improvable, achieved principally by bounding, mapping, and characterising the 'arena of intervention' (Murray, 2007, 126). Particularly for the spatio-temporal, anticipatory problematic of subsurface planning, this process of imagining and negotiating urban futures through scientific practices is foregrounded. This dynamic is well studied in resource geography, political geography, and critical urban literature (see e.g., Kuchler and Bridge, 2023; Fry and Murphy, 2021; Ruming et al., 2021). However, the *urban* subsurface has not been examined through this lens to the same extent. Resource geography scholars refer to the (re)shaping of future subsurface potential through epistemic practices as geo-imaginaries (e.g., Kuchler and Bridge, 2023; Fry and Murphy, 2021). The knowledge produced by the *visibility project* is a political act of envisioning a future potential in the urban subsurface, sustained through technologies of visualisation and intervention. For example, UUS 'does not occur or exist' without human infrastructural intervention (Darroch et al., 2018, 450) – there is nothing there until we draw and build it; UUS has the potential to store excess energy from the increasing use of renewable technologies (Darroch et al., 2018) – recognising volume now that there is use for it; the rising demand for UUS to house 'ultra secure' data centres (Taylor, 2023) – the bedrock's impenetrability as an asset. Such labels of potential combine techno-epistemic practices to bring specific futures to bear.

These imaginaries work not just in broad, societal anticipatory terms but have particular spatial power implications for the urban realm. Scientific renderings have the ability to create and reproduce 'scientific territorial imaginaries' (Himley, 2021, 4), selectively defining certain aspects over others through a 'simultaneous process of erasure and reimagination' (Bridge, 2001, 2155). In a case demonstrating vertical power dynamics above the surface, Wilmott and Wood (2024) show the role of possessive logics entering through California's planning basemaps. These cartographic tools are ubiquitous, but their generation is often unquestioned – they derive from computer interpretations of satellite images, compressing the vertical dimension, and thus also the marginalised communities who live in the shadow of elevated infrastructures (Wilmott and Wood, 2024). This cartographic erasure invites us to ask for whom the map is and exactly what territory it defines. Going beneath the surface, such territorial logics are typically linked more explicitly to the subterranean materiality. For example, as (Garrett et al., 2020) note, 3D mapping technologies activate previously dormant land resources and open new possibilities for imagining future uses of those spaces. Through the cartographic practices of calculation and visualisation, volume is manipulated in pursuit of subterranean futures – volumetric quantification of a resource is an anticipatory act (e.g., the advancements of geosystem services classifications by Lundin-Frisk et al. 2025). In spite of significant uncertainties in subsurface data, geologic science practices can be understood as techno-political practices that shape vertical territory (Bridge, 2013). By rendering the subsurface visible in a certain way through particular cartographic tools, the *visibility project* thus evokes specific volumetric futures (after Fry and Murphy, 2021). Here examples include the city-state of Singapore, which invokes national territorial expansion in its vertical development (McNeill, 2019) or the promissory real-estate market surrounding London's iceberg houses (Graham, 2016). These attempts to territorialise the subterranean emerge 'through transformative technologies' that 'control, colonise, and populate beyond-the-human worlds previously considered asocial' (Billé, 2020, 2). Whilst mostly still spaces beyond effective political control, for now (Billé, 2020), today's advances in cartographic technologies create new conditions of possibility for volumetric territorialisation (Marston and Himley, 2021). This compels us to recognise the responsibility that comes with visualising the invisible half of the city and projecting future aspirations onto this finite and complex space.

Building on these scholarly insights, we suggest that research on UUS should critically examine the practices of imagining the future, especially whilst the finite and complex subsurface is paradoxically rendered both empty and, simultaneously, as a multi-functional resource of plentiful potential. This involves asking: what visions of the future are driving underground development practices, and what power dynamics are embedded in these imaginaries? The underground is ripe as a 'visionary site for technological futures' (Hawkins, 2020), with a long imaginative history entangled with myths, technology and ideology (Williams, 1990). Attention to power operating through imaginaries of the future subsurface matters because imaginaries – as collectively held, institutionally stabilised, and publicly performed visions of desirable futures (Jasanoff and Simmet, 2021) – have the power to form and maintain urban institutions, policies, and behaviours (Upham et al., 2023). Furthermore, subsurface imaginaries channel power over resources and territory (Kuchler and Bridge, 2018), streaming from its past sediments (Smith and Tidwell, 2016), with significant implications for holistic and sustainable planning. We propose four distinct yet interrelated imaginative modes of combining the traits of invisibility and complexity to interrogate specific visions of the subsurface. These modes are derived from an analysis of illustrative examples taken from literature from both UUS and adjacent fields concerning specifically urban development.

4.1. Nothingness

The first mode of envisioning the subsurface in urban development conceptualises it as empty. This perspective enables large infrastructure projects and facilities to be 'dumped' in the subsurface, thereby freeing valuable surface space. Despite technological advancements that reveal more properties of the subsurface, Melo Zurita et al. (2020) finds a persistent discourse of 'nothingness' permeating dominant techno-scientific decision-making. The scholar argues that this framing renders the subsurface as a *sub terra nullius,* allowing projects to be proposed on what is perceived as an epistemological blank slate (Melo Zurita et al., 2020). Nothingness is a vision long associated with projects of territorial control and often articulated through techno-centric lenses (Bridge, 2001), but its role in the urban subsurface is less recognised. As an example, Melo Zurita et al. (2020) discusses the Brenner Base Tunnel case, where her tunnelling colleagues justify the underground construction of transit tunnels by emphasising the absence of surface-level pre-conditions (e.g., people, cars, and houses) in connecting point A to point B. This mode of thinking, grounded in an ontological dichotomy of the surface, thrives on its invisibility. Similarly, Connor and McNeill (2022) observe that cities are, in fact, fundamentally shaped by their foundational geological layers and histories that remain hidden and thus unknown to most people. Billé (2022) further suggests that this societal conceptualisation of the underground creates geopolitically unconscious spaces that, enabled by new technologies and human–machine assemblages, are ripe for exploitation and colonisation. These spaces exist outside of the traditional scope of analytic focus (Billé, 2022). For this mode to be sustained, the communication of visibility must be controlled by those seeking to leverage its volumetric potential, maintaining a wider social nothingness to avoid contestation. Melo Zurita et al. (2020) calls for this perspective to be challenged by actively recognising 'the social, political and financial effects of this perceived emptiness.'

4.2. Anticipating risk

The second mode takes a very narrow lens on what is made visible, building on the mapping technologies of specific political assemblages and ways of seeing (Marston and Himley, 2021). For example, in Ruming et al.'s (2021) study of the interactions between mining histories and contemporary urban development demands in Newcastle, Australia, anticipatory rationalities emphasise the mapping of existing voids and previous subsurface constructions, framing them as risks (Ruming et al., 2021). In this case, the mapping is primarily concerned with subsidence risk, which could limit surface development potential. As the authors note, this approach contrasts with typical subsurface mapping, which aims to quantify the underground resource (Ruming et al., 2021). In a similar vein, some environmental subsurface frameworks highlight the need to quantify and monitor contaminant legacies (Sahely et al., 2005; Zargarian et al., 2016). Hine and Mayes (2022) demonstrate how the construction of risk around subsurface unknowns – by the extractive industry and government agencies – eliminates potential 'innovative post-mining imaginaries and encourages a public disengagement with place'. In this context, the unknowability of the underground is portrayed as threatening materiality 'to justify the erasure of the surface of coal mine sites from the physical and political imaginary' (Hine and Mayes, 2022, 8). This mode leverages the subsurface's invisibility as a rationale for avoiding deeper engagement with its complexities, particularly in situations where the risks cannot be adequately equated with the potential benefit (thus invoking other modes). In this manner, the calculation of subsurface risk employs complexity as a means to resist alternative imaginaries of future development.

4.3. Anticipating potential

The third mode increasingly recognises the subsurface for its high potential across multiple sectors and dimensions, riding on positive understandings of its complexity. This emphasis on its multi-functional nature sees the subsurface resources as contributing to more resilient cities by mitigating natural or man-made disasters (Bobylev et al., 2012; Admiraal and Cornaro, 2020; Zargarian et al., 2016) or to sustainability by reducing urban energy demand, facilitating urban food growth, or improving the efficiency of public transit (Price et al., 2016; Norrman et al., 2020; Cui and Lin, 2016). Motivated by the uncertain environmental urban futures, this mode places attention on the capacity of the subsurface to enhance urban resilience, framing it as a source of potential solutions (Connor and McNeill 2022). An example is the recent application of geosystem services (GS) in a pilot study area in Gothenburg, Sweden, where subsurface qualities were mapped to identify potential uses in construction, geothermal energy production and stormwater storage (Norrman et al., 2021). Additionally, GS was employed to inventory fossils, archaeological heritage and existing structures to form a balanced assessment. Nevertheless, this mode of anticipating potential presents challenges for sustainable subsurface management. It relies on the epistemic tools of disciplines like geology, which tend to envision the underground as a volumetric 'space of potential [resource] abundance', to overcome the inherent invisibility of the spaces in question, relying on calculation and projections to render them 'real' (Connor and McNeill, 2022). This anticipation of future potential is in potential conflict with the parallel UUS demands of preservation and functional allocation (see e.g., Krzywoszynska, 2020, on soil management).

4.4. Speculating on value

The fourth and final emerging mode centres on speculation over the value of the urban subsurface. There are formal efforts in some countries to integrate the subsurface into surface real estate markets or establish pricing models specifically for the underground (Qiao et al., 2022a). However, this mode is more loose, concerning itself with the legibility of the subsurface as part of a 'calculative, promissory, financialised territory' (Connor and McNeill, 2022). Making the urban subsurface visible in this way occurs regardless of the formalised governance or market objectives and relies on the 'inscrutability' of subterranean knowledge (Kroepsch and Clifford, 2022). In this mode, invisibility and complexity are constantly shifting to maintain an open field of speculative possibility (Kuchler and Bridge, 2023). The careful push and pull of what is known and what is seen gives space to speculative activity. In this way, the subsurface's indeterminate character and deep uncertainty (Harris, 2014) create 'unstable relations between knowledge and matter' (Ballestero, 2019), allowing for competing visions and anticipations of the underground's (fiscal) potential. Importantly, this mode is not about simply volumetric potential but rather the potential for realisation of fiscal gain through control of ownership or management, taking a distinctly territorial turn.

5. Concluding discussion

In this paper, we have characterised the predominant focus in current UUS literature on rendering the invisible urban subsurface visible – with the aim of facilitating holistic and strategic subsurface planning – as the *visibility project*. Moreover, we have highlighted a significant research gap in the predominantly technical UUS literature concerning the socio-political dynamics of urban underground development and planning praxis. By drawing on a broader spectrum of social science scholarship, including resource geography and urban studies, we suggest that this socio-political blind spot undermines the pursuit of comprehensive and strategic subsurface planning, as it neglects the critical role of *power* in seeing UUS. In particular, there is an insufficient reflection on the power dynamics embedded in the predominantly techno-scientific knowledge production of the *visibility project*, which we argue has two far-reaching consequences for the long-term governance of the urban subsurface.

The first concerns the imaginative and anticipatory role of urban subsurface knowledge. As the *visibility project* seeks to collect ever more information to inform subsurface planning (von der Tann et al., 2020), we observe that there has been a notable shift in the conceptual understanding of the urban underground. Once regarded as a void for filling with the surface's unwanted infrastructure and services, it is gradually being re-imagined as a multi-functional resource with significant potential for contributing to sustainable and resilient cities (Norrman et al., 2020). We argue that this ongoing shift marks a critical juncture in resource-making, where greater scholarly attention must be placed on understanding the embedded power dynamics of envisioning the future potential in the *visibility project's* knowledge production. In particular, as the process of envisioning the future of the subsurface travels 'upwards' from subsurface experts to urban planners, the intersection between broader planning objectives and specific urban subsurface insights emerges as a critical area for research that requires further analysis.

We have illustrated the power relations within this evolving conceptualisation by identifying four *modes of envisioning* the urban subsurface that underpins the *visibility project*. Importantly, while these modes are distinct, they often overlap and intertwine in complex ways, enabling continued subsurface development in relation to the surface. Consequently, one mode may pave the way for another or serve to exclude certain future possibilities. For example, in their study of a non-renewable aquifer in the Colorado Plateau, Kroepsch and Clifford (2022) illustrate how the underground system is perceived as an 'inscrutable space' (Kroepsch and Clifford, 2022, 172). Its complexity leads to poor understanding, allowing it to remain 'invisible' in development discussions and sustain a 'fiscally-oriented inertia' for operators. The aquifer's delayed response to human impact decouples cause and effect, suppressing Mode 2 and facilitating surface development based on an assumed abundant water supply (Mode 3). Similarly, Ballestero's (2019)

study shows how subsurface modelling and data interpretation are used to estimate potential water extraction (Mode 3) and intertwine with regulatory permits and property development speculation to fuel fiscal growth despite uncertain water supply (Mode 4). In other cases, such speculative activity is less tangible. The challenges of knowing the subsurface often result in gaps in legislation, perpetuating perspectives such as Mode 1. Graham's (2016) study of London's 'iceberg houses' reveals how luxury properties expand downwards into previously unexplored subterranean spaces, exemplifying a new development frontier. Here, actors who can afford the risk (downplaying Mode 2) see volumetric and financial potential (mode 4), contingent on the gaps between demand in the surface property market and surface-oriented planning governance (Mode 1).

We propose that seeing the urban subsurface as a nexus of 'imaginative possibilities' (Woon and Dodds, 2021) can drive important research to reveal cities' challenges and opportunities around holistic and strategic planning as it is made knowable. As demonstrated in this paper's selection of literature, the interface between invisibility and complexity is negotiated through a powerful political project – a project of resource-making – to harness urban subsurface resources or territory. However, as our *modes* illustrate, visions of the future of the urban subsurface are not homogeneous; rather, a 'shifting set of imaginaries intersect' to render the underground knowable (Connor and McNeill, 2022, 3). The careful manipulation of invisibility and complexity occurs as the full potential of urban subsurface resources is only recently being increasingly recognised and mapped (Bobylev, 2016; Doyle et al., 2016; Peng et al., 2023). This dynamic allows various imaginaries to overlap, interact, fragment, and exclude, shaping the political agenda. As Ruming et al. (2021) highlight, urban subsurface knowledge is deeply interconnected with the surface, and opportunities for development, use, and exploitation are intertwined with evolving regulatory regimes and technological advancements (Ruming et al., 2021, 161). We, therefore, argue that urban underground planning must carefully consider the role that visions of subterranean futures play in its governance, particularly if UUS is to contribute holistically and strategically to sustainable and resilient cities.

Secondly, we emphasise the need to critically reflect on the process of rendering the urban subsurface visible, particularly through the *visibility project*'s cartographic practices, such as mapping and volumetric appraisals of underground space. Making the urban underground visible is key to creating and controlling subterranean territory (Connor and McNeill, 2022, 5), a process that requires mapping and planning (Garrett et al., 2020). As Billé (2022) notes, 'it is only by repressing cultural and social entanglements that the political and cartographic legibility can be enacted at the surface' (Billé, 2022, 151). We argue that these mapping tools do more than merely document the subsurface – they actively embed and enable specific visions and assumptions about the future, which then influence how the subsurface is planned, developed, and governed. Marston and Himley (2021) emphasise the critical role of science in this 'volumetric turn', where cartography shapes how the subsurface is understood and controlled (Himley, 2021, 4). At this stage of resource exploration, maps solidify claims to hidden and inaccessible spaces (Murray, 2005). However, in attending to cartography's powers, we must also be wary of the limitations of spatial conceptualisations of territory. As Adey argues, we must begin to understand volume in other ways than simply territory to focus more explicitly on the forces and matter which fill it (Adey, 2013). Wood-Donnelly (2024) clearly demonstrates the limitations of 'spatial power containers' in her work on Arctic governance. She argues that we must focus on the 'dialectical and co-constitutive dynamic' between spatial and ontological understandings of sovereignty as control of 'norms, discourses and exploitation' (Wood-donnelly, 2024, 14).

Moreover, these practices, which not only attempt to visualise the underground but also project future possibilities, often reflect the priorities of dominant epistemic cultures (e.g., engineering as urban statecraft (Björkman and Harris, 2018). Currently, the process of making the urban subsurface visible and communicating its potential is primarily controlled by these dominant knowledge systems, which privilege certain technical and scientific approaches. This restricts broader, more inclusive understandings of the subsurface—e.g., Billé's (2022) transspecies and transscalar notion of subterranean geopolitical unconscious, limiting the diversity of perspectives that could inform more holistic planning and use of underground resources. Indeed, alternative perspectives might begin to understand the urban subsurface as dynamic, vital, and fully entangled with urban politics, seeing importance not just in how we visualise the subsurface but in managing temporally and spatially diffuse interactions in a volume that holds power to give and to take from futures of urban sustainability. Future research and practice on urban subsurface planning should challenge epistemic dominance by incorporating a wider array of perspectives, methodologies, and knowledges.

CRediT authorship contribution statement

Alexander Craig-Thompson: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Magdalena Kuchler:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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