The significance of the subsurface in urban renewal

Hooimeijer, Fransje L.; Maring, Linda

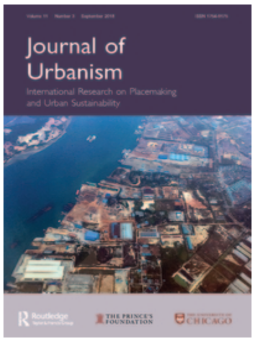
DOI
10.1080/17549175.2017.1422532

Publication date
2018

Document Version
Final published version

Published in
Journal of Urbanism

Citation (APA)
Hooimeijer, F. L., & Maring, L. (2018). The significance of the subsurface in urban renewal. *Journal of Urbanism*, *11*(3), 303-328. https://doi.org/10.1080/17549175.2017.1422532



Routledge
Taylor & Francis Group

Journal of Urbanism: International Research on Placemaking and Urban Sustainability

ISSN: 1754-9175 (Print) 1754-9183 (Online) Journal homepage: https://www.tandfonline.com/loi/rjou20

The significance of the subsurface in urban renewal

Fransje L. Hooimeijer & Linda Maring

To cite this article: Fransje L. Hooimeijer & Linda Maring (2018) The significance of the subsurface in urban renewal, Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 11:3, 303-328, DOI: 10.1080/17549175.2017.1422532

To link to this article: https://doi.org/10.1080/17549175.2017.1422532

Published online: 16 Jan 2018.

JOURNAL OF URBANISM, 2018
VOL. 11, NO. 3, 303–328
https://doi.org/10.1080/17549175.2017.1422532

Routledge
Taylor & Francis Group

OPEN ACCESS Check for updates

The significance of the subsurface in urban renewal

Fransje L. Hooimeijer[a] and Linda Maring[b]

[a]Faculty of Architecture & Built Environment, Department of Urbanism, TU Delft, Delft, The Netherlands; [b]Urban Soil and Water Management Department, Deltares, Utrecht, The Netherlands

ABSTRACT

The subsurface is a technical space, the "engine room of the city," that incorporates the vital functions of water and energy supply, communication systems, sewers and drainage. Natural systems too – crucial for stable, dry, cool and nature inclusive cities – are also largely dependent on the quality of the subsoil. The subsurface is critical in an era of climate and demographic changes, the energy transition and economic uncertainty and constraints. However, due to the domain's current segregation and a weak urban design and planning connection, crucial design potential, benefits and innovations, remain unexploited. This paper first introduces an innovative systems approach, the System Exploration Environment and Subsurface (SEES), to recognise the subsurface as an "under-arching" domain for urban planning and design. The physical impact of the subsurface on the surface quality is described for the categories: civil constructions, water, energy and soil/ecology. After setting understanding of the surface and subsurface as one united space, the paper will go into using the SEES as knowledge brokerage tool, integrating the subsurface artefacts into the design process and how the concept of Reversed Engineering with Nature is useful to uncover synergies between subsurface technologies, new urban maintenance regimes and scripts for design.

KEYWORDS

Urban regeneration; knowledge management; environments; subsurface; design

1. Introduction

Europe is one of the most urbanised continents in the world, in which the Netherlands has the second highest population density after Malta (UN 2014; see: www.ec.europa.eu/eurostat). Land take as a result of urbanisation is seen as one of the major threats to soil in Europe (EC 2012) but this might be curtailed by the re-use of urban brownfield land, better use of urban infrastructure, discouraging greenfield development and the remediation of urban sprawl (EC 2001). The ambition to sustainably urbanise deltas is challenged in the techno-sphere by more complex subsurface conditions and exacerbated by the growing densification that accompanies the popular "compact city" concept (Nilsson et al. 2014).

CONTACT Fransje L. Hooimeijer f.l.hooimeijer@tudelft.nl

The techno-sphere refers to the part of the environment accommodating a wide variety of technological artefacts. This existing construction becomes especially of interest now cities in the Netherlands such as Amsterdam and Rotterdam, have adopted policies to maintain development within existing urban borders and to focus on densification through urban renewal and brownfield development (Municipality Amsterdam 2011; Municipality Rotterdam 2007). Urban renewal is in accord with the concept of Zero-Land-Take (Decoville and Schneider 2016) where it is confined to existing urban areas or brownfields. The latter are defined as:

> sites that have been affected by the former uses of the site and surrounding land; are derelict and underused; may have real or perceived contamination problems; are mainly in developed urban areas; and require intervention to bring them back to beneficial use. (Ferber et al. 2006)

Dealing with already developed sites requires better cooperation between urban developers and subsurface specialists in the early project stages to identify more sustainable redevelopment strategies (Hooimeijer and Maring 2013; Mielby et al. 2016). This is to ensure that the right data is integrated in the new development and that the range of new technological options and urban systems designed to make cities more climate-adaptive are considered.

In urban concepts, the subsurface is usually not identified or included as a technical space, the "engine room of the city" (Hooimeijer and Maring 2015) though it incorporates the vital urban infrastructure of water and energy supply, electricity and communication systems, sewers and drainage. In addition, it houses the natural system – crucial for stable, dry, cool and nature inclusive cities – which is largely dependent on the quality of the subsoil. This role of the subsurface as "engine room" to our urban areas is also critical in an era of climate and demographic changes, the energy transition and economic uncertainty and constraints. By better understanding and re-thinking of this hybrid place, as depicted in Figure 1, and re-designing the "engine room" from the integrated perspective of planning, design and engineering, the objective is to reach an efficient overall urban system that directly supports improvements in the general quality of cities (Hooimeijer and Tummers 2017).

One of the main issues is that urban designers are not used to considering the subsurface in their urban development work, the paradigm that everything is technically possible still sees a separation of urban planning or design disciplines from the engineering phases of urban development (Hooimeijer 2014). The other main issue is that the subsurface is a broad field made up of many different specialists, separated by professional language or outlook, who do not always cooperate. Urban renewal projects need to acknowledge the subsurface's heavy use and that any intentions to restore natural functions might require a completely different approach. The main question addressed by this paper is therefore: how can the subsurface be better integrated into urban development?

To gain a better understanding of the relation between surface and subsurface, the System Exploration Environment and Subsurface (SEES) is used as a theoretical framework. This framework for a knowledge map and systems overview encourages the view that both the surface and subsurface belong to a single space (Hooimeijer and Maring 2013) (Figure 2 and Table 1). This integrated perspective recognises the interdependence of the techno-sphere and the bio-sphere – the constructed and natural systems – within the subsurface and sorts issues into four categories: civil constructions, water, energy and soil. This paper begins by introducing the theoretical background of the SEES approach and then describes the four subsurface categories and their spatial implications. The importance of knowledge

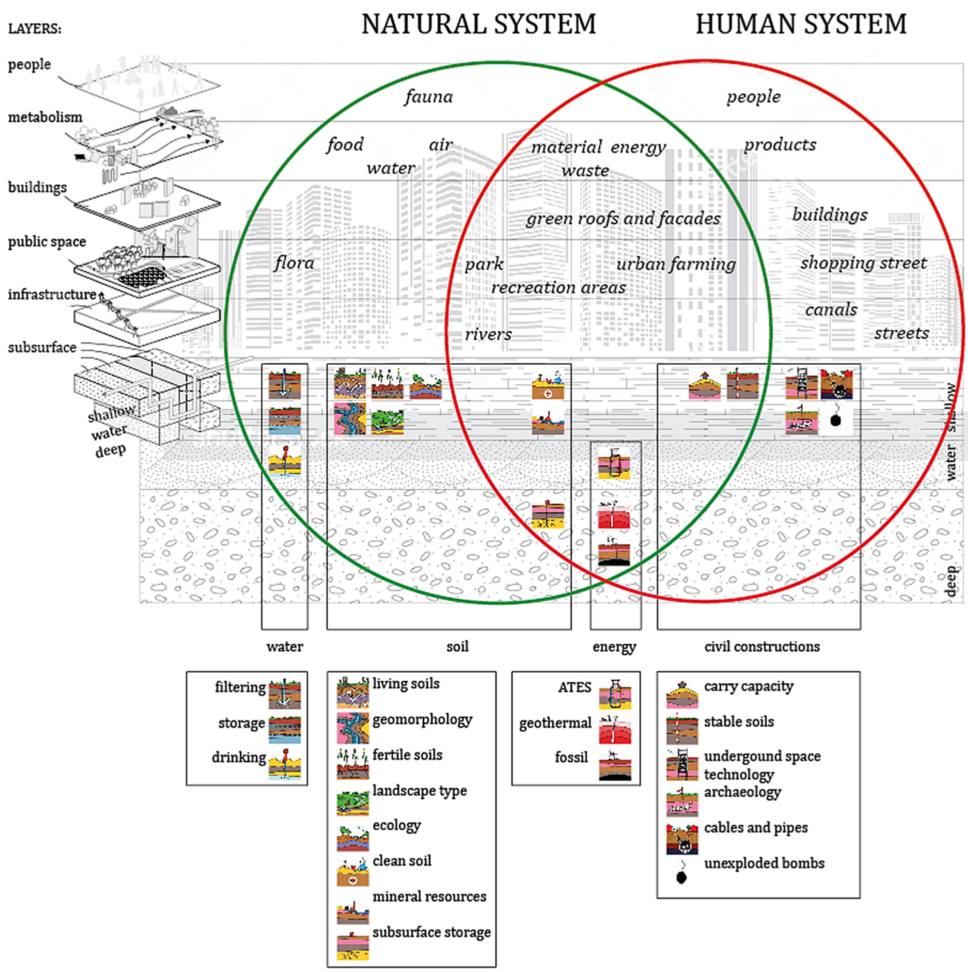


Figure 1. Technical drawing of the surface and subsurface as a single space (Hooimeijer, Maring and Van Campenhout 2016).

management and the role of design within this integrated approach is explained first and then outline some SEES results that offer insights into working with complex systems.

2. Unifying the surface and subsurface: a systems approach

Comprehensive strategies for sustainable urban development and their practical application in the contemporary climate still represent a major challenge. It might take a significant cultural shift to adopt sustainable approaches, particularly in the dynamic and complex context of today's cities. The Landscape Urbanism movement in the US (Bélanger 2012; Reed and Lister 2014; Waldheim 2006) does take the biosphere of the subsurface into account but their concepts of "constructed ground" (Pollak 2006), "mat urbanism" (Allen 2002), "dross-cape" (Berger 2007) or "thick infrastructure"[1] prioritise a landscape architectural perspective of the subterranean realm and how it might be approached. There is a need for approaches beyond Landscape Urbanism that can unite our understanding of the surface and subsurface

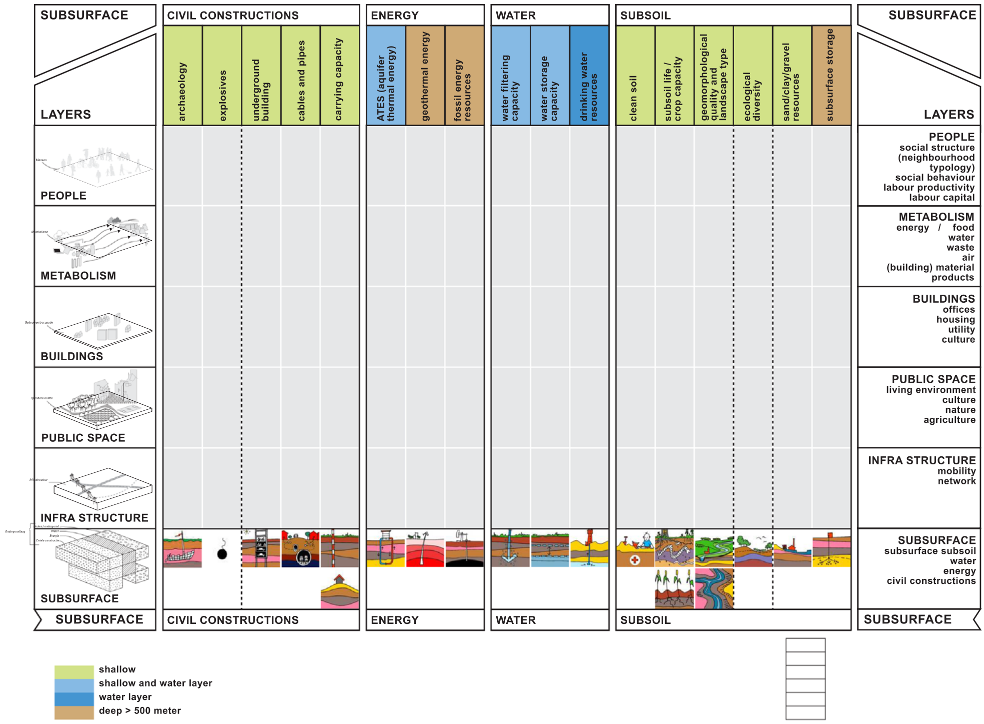


Figure 2. System Exploration Environment and Subsurface (SEES), with the surface on the Y-axis and the subsurface on the X-axis, used for integrating subsurface conditions in urban development (Hooimeijer and Maring 2013).

techno-sphere and biosphere as a single system. The System Exploration Environment and Subsurface (SEES) (Figure 2) has been developed from a theoretical background of systems approaches and complexity theory to do just this. A systems approach is a way of "studying phenomena as emergent properties in an interrelated whole that are mutually consistent and that interact with the surroundings" (Heylighen 2000). This simplifies the subject of study whilst allowing for a meaningful understanding of how diverse elements might relate to each other as well as the varying types of relationships. The SEES basis in complexity theory is important to highlight the non-linearity of decision-making given the inherent unexpected behaviour of agents in urban development and the unforeseen consequences of their interactions (Koppenjan and Klijn 2011). Rhodes (2008) refers to this as the "performance landscape," a systemic model on which agents can rely to avoid being overwhelmed by continuous systems change and the external influence of changes to related systems.

The SEES follows on from the Layers Approach (de Hoog, Sijmons, and Verschuren 1998), a systematic approach to spatial planning widely used in current Dutch planning and design. The method builds on Ian McHarg's (McHarg 1967) Ecological Inventory Approach that his students called "the layer cake" (Whiston Spirn 2000). This was brought to the Netherlands by Meto Vroom, a professor of landscape architecture in Wageningen (the Netherlands), and developed as a strategic planning concept in the 1990s (de Hoog, Sijmons, and Verschuren 1998). The original approach distinguished between three types of connected strata: the occupation, network and substratum layers. These layers represent a spatial system that

Table 1. Per subsurface category, the qualities and their data are discussed using the SEES.

Subsurface category	Subsurface quality	Maps
Civil construction	A cultural historical importance and archaeology	an archaeology and cultural historical maps
	B unexploded ordnance (UXO)	B UXO map
	C underground structures/foundations (see E)	C (see E)
	D cables and pipes	D cables and pipes: sewerage, electricity, cable television, city heating, gas, telephone, drinking water
	E basis for building activities/stable ground	C & E available geotechnical information, cables and pipes, expected settings cables and pipes, expected settings, dry building excavation depth foundations, risks wooden foundations, subsurface objects, height ground level, actual height and difference between actual height and distribution level
Water	Water filtering soil	Average hydraulic head
	Water storing soil	Seepage and infiltration
	Resource drinking water	Hydraulic conductivity
		Soil structure/aquifers
Energy	Aquifer Thermal Energy Storage (ATES)	ATES potential map
	Geothermal energy	Geothermal potential map
	Resource fossil energy	Potential map recoverable fossil energy
Soil	Healthy and clean soil	Soil quality map
	Resource minerals	Extractable minerals
	Crop capacity	Crop capacity map
	Living soil	
	Geomorphology/diversity landscape	Geological values
		Historical information
	Ecological diversity	Ecological map
	Storage of materials	Potential subsurface storage map

incorporates different rates and types, of potential and actual, spatial development and change (Figure 3). The authors intended that the model function as a quick and simple strategic planning tool but not be used to describe or explain the environment and its uses. As such, the Layers Approach could be seen as a performance landscape and while its use is currently all-embracing, this method has also generated criticism (van Schaick and Klaasen 2007, 2011; Sijmons 2002; Tilman 2001). The two significant issues with the use of the Layers Approach are a lack of attention paid to the relationships between the strata and the failure of the layers to represent the complex nature of functions and use. The dynamics of the layers are also not as simple as this approach might suggest with a study by Sijmons (2002), describing these problems and suggesting that clear guidelines are needed for the development of a new model for the district scale:

- The Layers Approach is being used as a descriptive and analytic model of the layered reality. Confusion arises because the original Layers Approach was meant only as a planning instrument and not as a layered reality. For example, in real time, the subsurface does not fit in the first layer.
- The original model is only smart when the hierarchy of the layers is used; it would seem to be necessary to study relations, not hierarchy, when using it as a descriptive or analytic model.
- The biosphere or ecology should be given a basic role in any new model.
- The concept should establish links between inspiring ideas and hard financial conditions (Sijmons 2002).

		Object	Planning Horizon	Role of Nature
	Layer 1	Hydraulics Sea-level rise Groundwater Subsidence	T=50-500	Nature as a means
	Layer 2	Networks Nodes	T=30-100	Nature as a Goal EHS
	Layer 3	Occupation Living Working Recreation	T=10-30	Nature as a Side-effect

Figure 3. The layers approach (de Hoog, Sijmons, and Verschuren 1998).

Van Schaick and Klaasen (2007) also proposes four areas where improvements could be made, including via the use of potential individual activity patterns functional spatial networks that represent flows of people, goods and information, viewing space as a structure containing related spatial elements and physical networks as made up of physical nodes and connections. The success of the Layers Approach suggests it might be a good starting point for a new method to support a cultural shift towards more sustainable use of the subsurface in urban development.[2]

The original approach acted as a stepping-stone for the SEES method, designed as it was from experience with, and criticism of, this Layers Approach whose original application was expanded by including the fundamentals of urban design as well as the introduction of public space and occupation (building) layers (Heeling, Meyer, and Westrik 2002). The subsurface layers have also been more extensively described using findings from the *Manual Planning with the Subsurface* project[3] and the result of all this is the SEES method. This method is comprised of six functional layers and varying dynamics, professionals and fields of knowledge including people, metabolism, occupation, public space, infrastructure and the subsurface (Hooimeijer and Maring 2013).

The *Manual Planning with the Subsurface* project defined the qualities of the subsurface that support the surface. These qualities were classified, in line with many ecosystem services studies, as having production, regulation, carrying and information qualities (Figure 4). This ecosystem-related view is not in line with a traditional spatial planning and design perspective as the categories of production, regulation, carrying and information are not within an urban

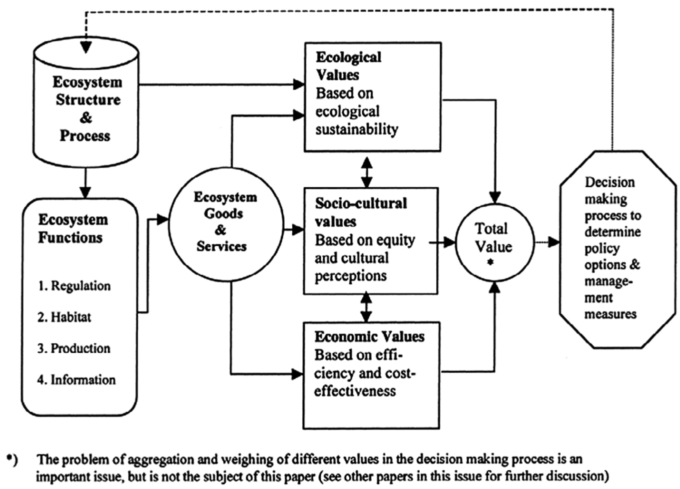


Figure 4. Framework for the integrated assessment and valuation of ecosystem functions, goods and services (de Groot, Wilson, and Boumans 2002).

developer's vocabulary (Hooimeijer and Tummers 2017). For this reason, the SEES method has adopted the more familiar categories of civil constructions, energy, water and soil.

The current design of SEES is the result of the research projects "Design with the subsurface"[4] and "Balance4P,"[5] that included workshops with municipal urban development project teams. The aim was to investigate how knowledge exchange with respect to subsurface data and information could be improved. In addition to the identification of the four new categories, these projects and workshops helped to develop more logically order, and in some cases combine, subsurface qualities.

The SEES has developed into a method that supports and registers knowledge exchange between experts of different fields. It can be used in "Charrettes" where in successive rounds the sectoral data is discussed and step by step brought into information that can be used for planning and design (Lennertz, Lutzenhiser, and Duany 2014). The SEES method provides an overview of the urban system and by relating the "surface" layers to "subsurface qualities," it enables a LEAN[6] thinking work method that avoids mistakes and focuses on quality via direct communications, the setting and maintenance of appointments and by not concentrating on impossibilities. A better end result is likely if SEES is applied at an early stage in the development process but it can also be used in later development phases.

The four categories previously mentioned, their subsurface qualities and links to urban planning and design are described in the following section as well as analysis based on literature reviews and results from the two research projects "Design with Subsurface" and "Balance4P" (Hooimeijer and Maring 2013, 2015; Hooimeijer and Tummers 2017; Norrman et al. 2015).

2.1. Civil constructions

The first category, civil constructions, refers to the techno-sphere – as all artificial and human interventions within the subsurface – and includes the subsurface qualities: archaeology, unexploded ordnance, underground constructions, cables and pipes as well as the carrying capacity and stability of soil (probability of earthquakes or subsidence). As they are linked to human activity, these elements are an integral part of the city structure and therefore closely linked to spatial quality. Whereas surface development is controlled by a highly sophisticated planning system, the subsurface amounts to, quite literally, a hidden sphere in which planning is sketchy at best (Hooimeijer and Tummers 2017). This suggests that were we to better organise and tailor civil constructions to surface development earlier in the planning process, it should be possible to make major improvements in systems efficiency such as more effective links between green spaces, water, microclimate and clean soils.

The clearest example of how this techno-sphere binds the surface and subsurface together can be found within the realms of underground constructions and the cables and pipes. Underground constructions as a function are always part of either a building or, in the case of an underground parking garage or tunnel, the infrastructure system. These constructions in general negatively affect the interactions between groundwater and soil conditions; where disturbed groundwater flows and inadequate carrying capacity can result in structural damage. In the Netherlands, one out of seven and a half houses have wooden bearing piles that will rot if the groundwater table drops too low (Klaassen 2012). Underground constructions can, however, be combined with the excavation of contaminated soil or the reuse of old foundations or quays to create a win-win situation. In Amsterdam's Borneo Sporenburg, the poor quality quay was stabilised by a new foundation shared with the private housing that was then built on top (Figure 5). These shared foundations were paid for by the sale of self-build housing and was not only an excellent technical solution but the placement of smaller houses along the quay also improved the spatial character of the broader site.[7]

The most impressive example of this spatial connection between subsurface infrastructure and the design of urban structures and public space is the "Haussmannisation" of Paris in 1857. Haussmann's boulevards, as one of the largest urban renewal operations in the history of Paris, created a surface infrastructure with a distinct air of grandeur. The main motivation for these boulevards was however the housing of the sewers, that were designed by engineer M. Belgrand (du Camp 1993). Today, both surface and subsurface infrastructure still exists though the original farms that collected the waste for re-use in agriculture have been replaced with sewage treatment plants.

Figure 5. Borneo Sporenburg Amsterdam, along the water the houses built on the old quay.
Source: West 8.

The interplay between soil stability, carrying capacity and building-site preparation is illustrated within the *Grachtengordel*, Amsterdam's Ring of Canals. Here, the balance between water and soil is changed using the excavated soil coming from the construction of the canals to raise the level of the built area (Segeren and Hengeveld 1984). It is this integrated street plan and water system design that demonstrates the relationship between land restructuring, surveying and water management that is the basis of traditional urban development in the Netherlands (Hooimeijer 2014). Jakarta (Indonesia), as an expanding city built on swampy ground, with large water extractions and without adequate water management measures, is an example of a lack of balance in this respect as the city faces subsidence and immense problems with future flooding (Tarrant 2014).

It is clear then, that natural systems should be considered during the planning of human interventions and that interfering in these systems can produce reactions that affect both natural and urban functions, above and below the ground, and on varying temporal and spatial scales. This requires a culture shift and an alternative approach that can align the interests of economic development with care for the environment. The Reverse Engineering with Nature might provide a new engineering approach to sustainable solutions that can be implemented through urban design.[8]

2.2. Energy

In general, energy generation, transmission and storage needs are closely connected to spatial development (MacKay 2008; Sijmons et al. 2014) and with regard to the subsurface involves the subsurface qualities: Underground or Aquifer Thermal Energy Storage (UTES, ATES), geothermal energy and oil, gas or shale gas fossil energy. U/ATES stores heat and cold in the subsoil or groundwater to depths of 300 metres in open or closed systems.

This realm operates on all scales (including that of an individual building, district, regional and national scales) and Sijmons et al. (2014) demonstrated the influence of various energy generation technologies on spatial development. In practical terms, linking open Aquifer Thermal Energy Storage (ATES) systems with urban development becomes spatial in the sense that the hot and cold groundwater wells need to be coordinated to prevent interference between individual systems that inhibit system performance (Bakr, van Oostrom, and Sommer 2013; Moinier 2013). Surface demand for the energy generated in the subsurface, is required in order to prevent losses during energy transport and the heavy-truck access required for system maintenance will also affect public space design. In addition, the impact of ATES on soil carrying capacity is also important with regard to building foundations but this field is still being researched (Bouazza et al. 2011). There have been examples of soils freezing as a result of the re-infiltration of excessively cold groundwater (Bonte et al. 2011) and ATES can also be combined with groundwater remediation (Sommer et al. 2013).[9]

More practical examples for the use of geothermal energy to fulfil spatial objectives can be found in countries such as Iceland and Japan. Iceland in particular, uses this resource to perform many urban functions such as keeping streets snow-free, the supply of energy and for recreation in spa resorts for example. Geothermal energy employs the earth's natural heat but the first attempts to apply this form of heating in an urban setting in the Netherlands (The Hague) failed because part of the 3000 homes required were not build do to the financial crash in 2008.[10] The use of this technology is hampered by its dependence on demand, by its high costs, uncertainties around the life-span of wells and the fact that geothermal energy does not provide cooling (particularly required in office buildings).

Using groundwater as a source of energy might also interfere with other uses such as drinking or industrial water provision. The Heineken brewery in Den Bosch investigated the potential for geothermal energy before another party would to protect their groundwater which is the most important component in the production of their beer. The company is also interested in reducing CO_2 emissions per bottle produced as well as improvements in other sustainability indicators. Their business case included a study to transport residual production heat to homes within a nearby housing association but unfortunately, the potential of the geothermal source was not substantial enough to warrant implementation. Heineken did, however, continue to cooperate with the housing association with the aim of establishing a more sustainable area development in exchange of energy (Heineken 2010).

Developments in the field of energy supply include the emergence of smart grids that will better coordinate supply and demand needs but this requires a well-developed subsurface network of cables and pipes. In conclusion, the relationship between energy and urban development is defined by location (proximity and connection to the source) and quantity (the scale of supply and demand), and this topic should play an important role in the planning of cities.

2.3. Water

The hydrological cycle is an enormous system that integrates the subsurface and surface in effect a river is "groundwater you can see." Water and soil are integrally connected and both play a crucial role in landscape morphology and typology. They are the carriers of the conditions and processes required for the planning and design of natural, agricultural and urban landscapes (van Dorp et al. 1999).

The subsurface qualities in this category are: water filtering and storage, resource for drinking, industrial processes, green-space and agricultural irrigation. These qualities might interact with the subsurface at shallow depths (in the case of phreatic groundwater) or extend to deep groundwater aquifers.

It is no surprise that the Netherlands, known for its water management, is also developing a plan to manage groundwater reserves. A national strategy for the subsurface – "STRONG" – will allocate and organise groundwater resources on a larger scale. An example of urban development allowed in an area set aside for water extraction is Lanxmeer (Culemborg, the Netherlands) where strict measures for the spatial layout and public space design, together with regulations governing water use and discharge are intended to safeguard water quality (Figure 6). Permaculture concepts underlie Lanxmeer's design for adopting natural processes as a core strategic element within the planning process (van Timmeren, Sidler, and Kaptein 2007).

Large-scale extraction of groundwater also impacts the water system as demonstrated in Delft (the Netherlands) with the DSM factory's use of groundwater in their production processes. When the factory closed and extraction stopped, the area suffered problems with water levels and potential subsidence to such extend that the extraction continues today and is pumped to sea. This emphasises how water systems in cities can no longer be seen simply as natural systems and how subsidence issues, together with pluvial floods and water shortages, require a new systems based approach in which open water, open soil, green

Figure 6. The main structure of Lanxmeer is also shaped by the public space, which is car-free green space. Source: Lodewijk van Deysselhof.

roofs, grey-water systems and mechanisms to reduce drinking water consumption are included in district scale solutions.

Taking these subsurface characteristics, including the groundwater system, into account at the early development stages can attract significant benefits. In the Netherlands, there are already several examples that illustrate the concept of "Delta Urbanism" (Meyer, Bobbink, and Nijhuis 2010) wherein the water system is considered a qualitative condition to steer urban design. The city of Rotterdam is well aware that climate change adaptations are necessary to ensure its future viability and to manage the increase in water coming from above, from the river and from the sea. Two underground water reservoirs have been built in the Museum Park (10,000 m^3) and under Kruisplein (2700 m^3) to temporarily store rain-water. These are part of an overall water management strategy in which the natural water system is enhanced via several water squares, green roofs, the enlargement of pumping capacities, a separated sewer system and discharges to open water (Gemeente Rotterdam et al. 2007). The city is implementing measures to increase the amount of exposed soil so as to improve water infiltration rates and enhance its overall green structure. Citizens are also encouraged to include water responsive measures in their gardens and homes so that the overall water system is enhanced and becomes more complex. These measures ensure that the relationships between surface and subsurface are exploited and, while trade-offs are required, water storage and discharge are better integrated. Further, in a system that was previously predominantly public, the role of private stakeholders has been increased. In general, the inclusion of the subsurface offers green and ecologically balanced technical solutions that enhance the overall urban quality.

2.4. Soil

The importance of soils is already evident in the above sections and includes the subsurface qualities: healthy and clean soil, living soil, crop capacity, geomorphology, landscape diversity, ecological diversity, source of minerals, storage of materials and CO_2 storage capacity.

Conceptual approaches such as Landscape Urbanism (Waldheim 2006), the resilient city (de Bruijn 2004; Holling 1973; Wardekker et al. 2010), healthy city (Beumer, Bardos, and Menger 2014; de Leeuw et al. 2014; Wuana and Okieimen 2011) and happy city (Montgomery 2013) all stress the importance of soils and these approaches all incorporate the notions of healthy and clean soil, living soil, crop capacity and ecological diversity.

Since the financial crisis of 2008, urban development practice has changed drastically and urban renewal is preferred to Zero-Land-Take. As these projects require much more time to develop, intermediate uses are often employed (Heurkens, de Hoog, and Daamen 2014). This change in the dynamics in urban development suggests that there are opportunities for the intermediate use of polluted areas whilst using Gentle Remediation Options (Cundy et al. 2016). This can be seen in *Le parc du Chemin-de-l'Ile* (Nanterre, France) where remediation is combined with the area's park function.[11]

Crop capacity is also crucial to the emerging trend of urban agriculture as a way of more sustainably designing public spaces to enhance social interaction and shorten the distance between food production and consumers. Urban agriculture also plays a role in the education of children in the cycles of life as well as improving their diet (Duchemin, Wegmuller, and Legault 2008). In many urban areas, however, food production takes place in closed systems (containers) due to suspicions of soil quality (pollution).

On the larger (perhaps even regional scale), soils influence geomorphology and landscape diversity, and therefore, influence urban design. Guatemala City is an example of extreme morphological and landscape conditions where inaccessible space is found in the valleys rather than on the higher ridges that the city occupies.[12] Historically, areas with poor soil conditions house poorer communities while the rich live in areas with more favourable soil conditions. This is not only the case in the Netherlands, where The Hague's poor traditionally lived on peat areas while the rich lived on sand, but also in New Orleans where lower-lying former marshlands now house the urban poor.[13]

Urban ecological diversity is also possible only when there is a conscious effort to work with the abiotic and biotic systems (Tjallingii 1995). One of the subsurface-related interventions where there is a particular opportunity to adopt a different approach is in the preparation of construction sites. Instead of a technical approach – such as adding sand to city streets to counteract subsidence – a Reverse Engineering with Nature mind-set could provide a more tailored approach in which low-lying areas could be retained as green areas such as parks.

Requirements in the Netherlands for "mineral sources" not only influences the architecture but also has a spatial impact at the larger scale of the district as the sands used in construction site preparation is usually extracted locally. This has resulted in numerous "sand-winning" pits and lakes with most city expansions in Utrecht and Den Bosch (the Netherlands), including a lake where sand was mined that now provides local recreation amenity. The most spectacular link between mining and urban development can be found in Kiruna (Norway), where the iron ore mines have left the ground unstable and will force the city to relocate. Since all of the town's residents are also employed at the mine, social acceptance and willingness to bear the financial costs of this move are high. Here, the entire design process and preparation of a future vision for the new town is founded on intensive knowledge exchange and integration of the technical and natural conditions to ensure a sustainable future.

3. Knowledge exchange, the design process and dealing with complex systems

In the previous section, the "performance landscape" of the surface and subsurface was sketched as one united space. It shows how interference in the subsurface system can affect the design process at different times, spatial scales and even in different locations. In addition, the techno-sphere and biosphere with the urban system are now so closely interwoven that the complexity has become difficult to understand, manage or alter when attempting to establish a better and more sustainable urban development. Technical explanations of subsurface qualities and examples of their relation to urban design are present but very sectoral. Proper integration not only links surface and subsurface but also considers the interaction between the subsurface qualities. This is a complex system, with many challenges, that cannot be met with a single solution. In this section, the application of SEES to the design process is described to show how SEES can support knowledge and brokerage when working with the complex system of a performance landscape.

3.1. Knowledge exchange

Knowledge exchange is crucial to the improved integration of the subsurface in surface urban development, and it has the potential to generate new knowledge since it supports and enhances interdisciplinary cooperation (Norrman et al. 2015). Furthermore, with knowledge management, it is possible to handle uncertainties in a qualitative manner. There is a need for deliberate knowledge management, brokerage and mediation, which translates data into information that can be used in spatial development.

In the "Design with the Subsurface"[14] and "Balance4P"[15] projects, workshops with municipal project teams from Rotterdam (the Netherlands) and Göteborg (Sweden) were central to the investigation of integrating surface and subsurface in urban planning and design. These projects defined the barriers, and opportunities for knowledge exchange between engineers, from the subsurface system, and urban planning and design professionals. SEES can be used, as it was in these two projects, to structure knowledge exchange workshops in two ways. Firstly, it works as an expertise map where each expert can indicate their field. As a result, the role and knowledge of the participants becomes clear and when the discussion is about their topic, the participant is properly acknowledged. Secondly, SEES is used to structure the discussion. The topics of the subsurface are discussed following the order of the table (from left to right or the other way around) and linked systematically to the surface layers: infrastructure, public space, buildings, urban metabolism and people. In the workshops in Rotterdam and Göteborg, specialists explained the data for each topic to the urban designers, landscape architects, architects, developers and/or housing corporation representatives. The natural and technical conditions of the site were then explored in dialogue and annotated on a large print of SEES (see Figure 7).

The stakeholder's conclusions or experiences regarding the use of the SEES method was:

- Going through the subsurface topics at an early stage of the project creates opportunities to consider the qualities of the subsurface and results in smarter solutions.
- Going through technical issues together resulted in an open and shared attitude towards the aspired goals of the project. Technical issues did not become insurmountable problems that lead to experts becoming the ambassadors of their own expertise and halting the project. Instead, everybody is a partner and works collaboratively on solutions for the shared goals of the project.
- Looking at the possibilities afforded by all spatial conditions (water, energy, civil constructions and soil), is easier with "live" dialogue between specialists, as information of different kinds is brought together. More crossovers occur as problems are tackled using solutions from another domain.
- A session of this kind is an effective and efficient approach: in just one afternoon, all the important information is identified, and choices can be made about how to proceed and how to investigate further.

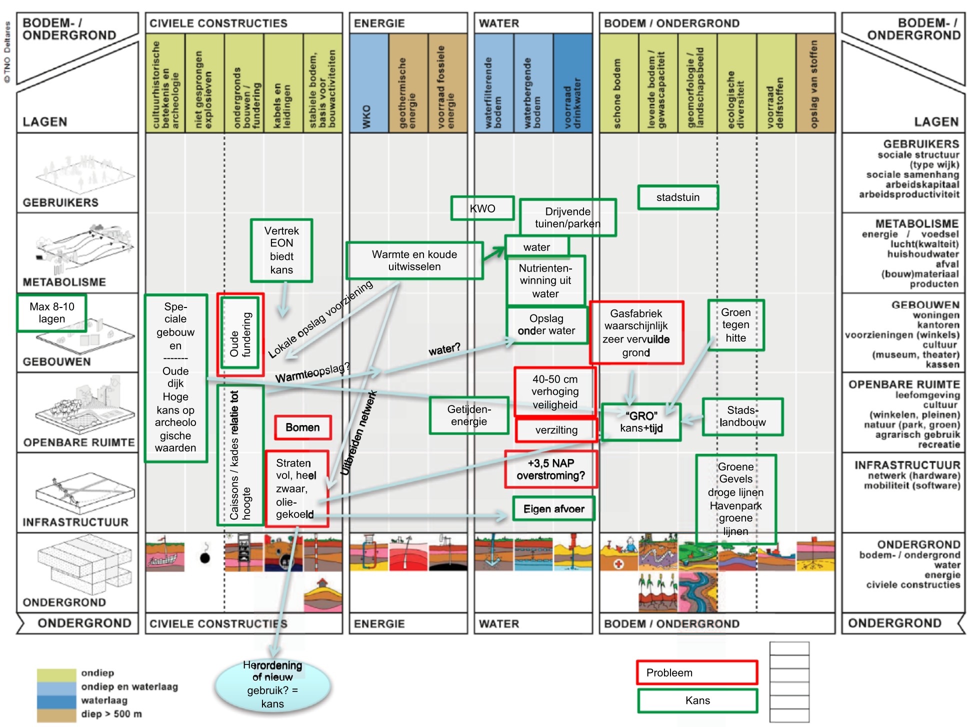


Figure 7. The SEES filled in after used in a workshop, with issues and topic linkages.

In case of Rotterdam Merwevierhavens, the method was taken further by producing a Subsurface Potential Map that could be included in the vision document and play a role in the development of specific blocks in the area (see Figure 8). The Subsurface Potential Map transforms the data into visual information about the subsurface that the urban designer can then use as a design guideline. It is selective, showing what artefacts in the subsurface have a direct impact on surface developments and the spatial interaction between the different subsurface qualities. Crucial to the Subsurface Potential Map are the corresponding sections that demonstrate the graphic interface between the surface and subsurface (Bélanger 2012). Together they work as a script on which the programming and the designing of a project can be done, as well as provide freedom and inspiration for concrete options

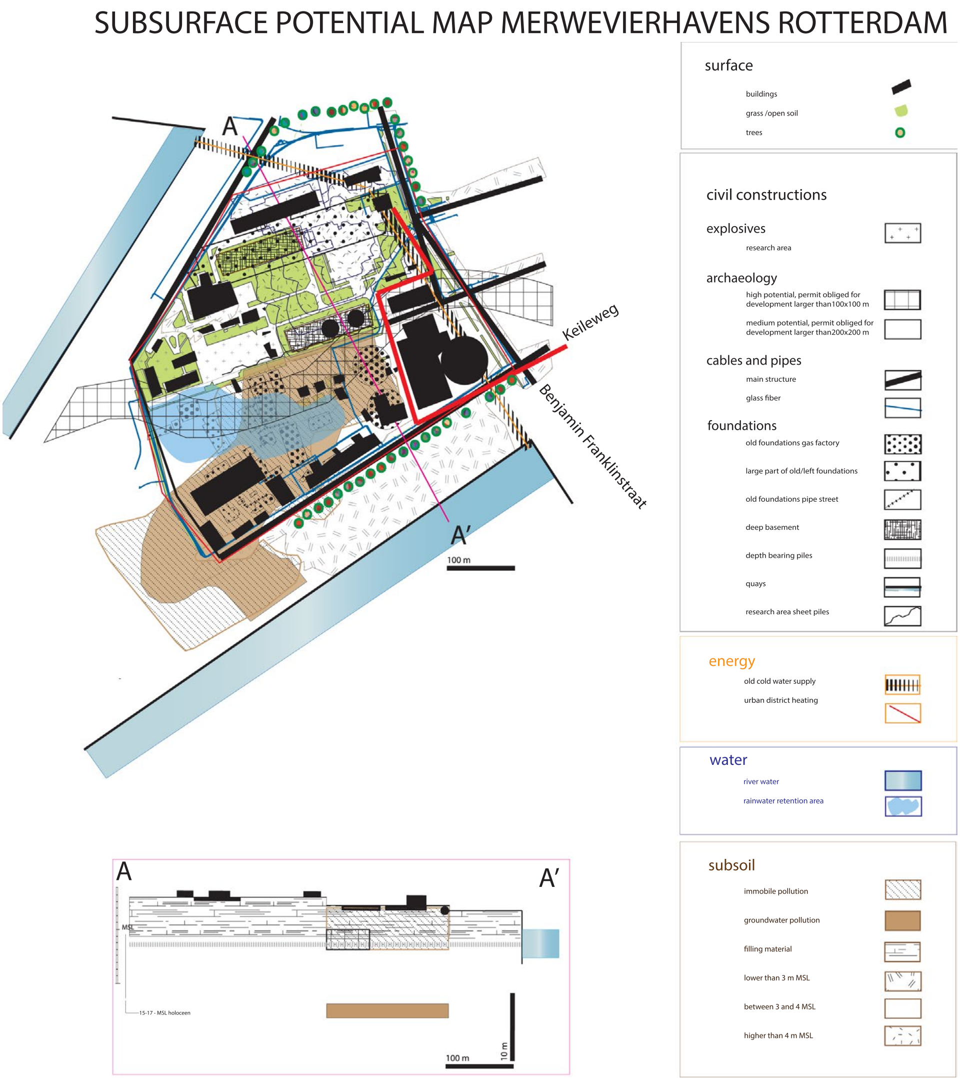


Figure 8. The Subsurface Potential Map transforms the data into information about the subsurface that the urban designer can use as a design guideline (Hooimeijer).

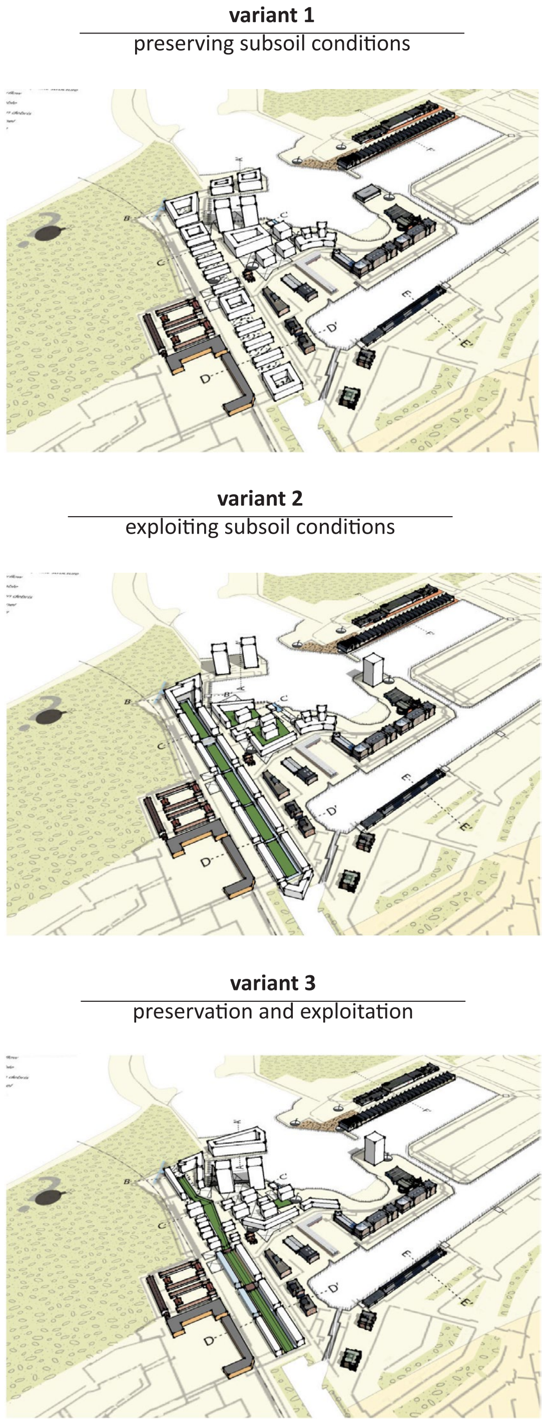


Figure 9. The Subsurface Map is used to make different design principles (van der Graaf 2014).

and solutions. Another important aspect of the Subsurface Potential Map is that it is an interactive PDF in which layers can be turned on and off. This is very helpful to selectively display information in order to make specific interactions clear or zoom in on situations. Figure 9 shows a design exercise by van der Graaf (2014) who used the Subsurface Potential Map to draw different design options, from different starting points within the existing spatial qualities and technical constraints.

Other work that supports the importance of visibility and presence between the subsurface and surface is the work by landscape architect Seth Denizen who made the "Urban Soil Taxonomy: The Eighth Approximation." Denizen's work identifies the characteristics of the urban subsurface and visualises them with inspiring graphics (Figure 10).[16] These first steps from a designer can only become more common practice when the integration of the subsurface in spatial design becomes easier through more conscious knowledge exchange.

Further research is being conducted into the architectural representation of the subsurface in planning documents, focusing in particular on the design of legends (Hooimeijer, Kuchincow Bacchin, and Lafleur 2016). The COST SUB URBAN Action[17] network has its focus on realising this in the 17 European countries that are participating, in which the Netherlands is the frontrunner in implementing the subsurface into visions (Lamé and Maring 2014) and Finland currently preparing a Subsurface Master Plan for Helsinki (Figure 11) (Ikävalko, Satola, and Hoivanen 2016). This Subsurface Master Plan manages the necessary knowledge to give purpose to the subsurface qualities in urban redevelopment; however, the subsurface should be considered earlier in the development process, rather than during the design phase.

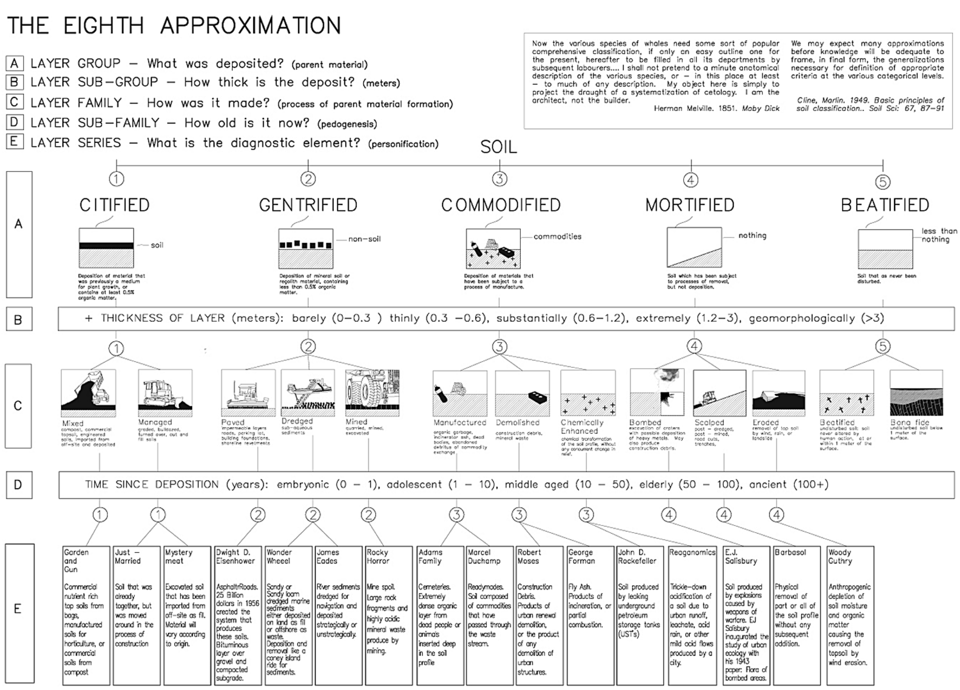


Figure 10. Landscape architect Seth Denizen made the "Urban Soil Taxonomy: The Eighth Approximation" which identifies the characteristics of the urban subsurface.

Figure 11. Subsurface Master Plan Helsinki.
Notes: Greyish colours: current underground facilities and tunnels, bluish colours: planned future underground tunnels and facilities, brown: bedrock resources near the surface suitable for the underground construction, white triangles: access tunnels to underground spaces (Ikävalko, Satola, and Hoivanen 2016).

3.2. The design process

Urbanism is about integrating social, cultural, economic and political perspectives with the natural and man-made conditions of an urban landscape in order to shape and plan for more sustainable development. Urbanism is, in essence, transdisciplinary because an urbanist works to integrate the goals of stakeholders of all disciplines in an urban plan and design. The act of integration and design requires systemic knowledge on a wide range of subjects (shown in Figure 12). According to Thompson and Tuden (1964) design is the method to find the right measures for a project, in particular when both problems and agreements are unknown (see Table 2). The success of this exploration depends on understanding the capacities and constraints of each separate field during the design process. The design process is done by a sequence of visualisations, or the so-called "design thinking process." Because of the value they bring, visual representation and visualisation tools are also called "the mother of all design tools" because they are used in every stage of a design thinking process (Liedtka and Ogilvie 2011).

Corner (2006), argues for moving from aesthetic design to operational logic and from aesthetic categories to strategic instrumentality. Corner calls for a focus on the agency of landscape, how it works and what it does, rather than simply on its appearance. In the Landscape Urbanism discourse the natural system is put forth as the leading operational logic and landscape architecture is granted the ability to make urban structures more durable and sustainable (Waldheim 2006). In genuinely integrating the subsurface, meaning including more than the natural system; it pursues a holistic approach and considers a Reversed Engineering with Nature. Transdisciplinary collaboration should have a generalist approach

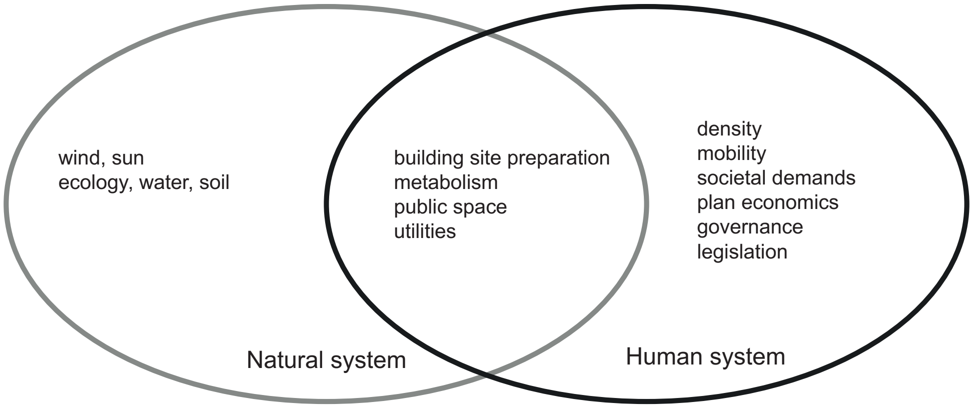


Figure 12. Overview of topics the urban planners and designer synergise in an urban plan.

Table 2. Thompson and Tuden (1964).

	Problems and goals →	
Measures ↓	Familiar and with existing agreement	Unfamiliar and there is no agreement
Known	Optimisation	Negotiation
Unknown	Innovation	Design

and start, through design thinking, to understand the natural system collectively with "spatial technology." Thus, not only prioritising the operational logic of the natural system, but combining this with the agency of the technological urban constructions already in place. Synchronisation of time, space, technology and interests, should lead to a combined language, shared methods, unified concepts and integrated scales that could be visualised, in the SEES or a Subsurface Potential Map.

This interdisciplinary approach can be integrated in the design process even though the latter is ambiguous, personal and somewhat intangible. van Dooren et al. (2013) has shown that integration of other disciplines is essential part of the process of design and that it can be included in a framework. This framework is not a step-by-step guide for a successful design process, but is an overview of five generic elements involved in designing, that make the design process more explicit and structured. The five elements are:

(1) Experimenting: trying out different alternatives, out-of-the-box thinking.
(2) Guiding theme or qualities: taking the programme or another idea as a starting point/concept.
(3) A frame of reference or library: examples of other designs or principles.
(4) Sketching/modelling: representation or visualisation of ideas.
(5) Domains: design is about making space with structures, for functions and within an urban and social, historical and philosophical context.

To exploit the potential of the subsurface van der Graaf (2014) utilised this framework in an effort to understand how the subsurface could be investigated during the experimentation (1) at the beginning of the design process. As a result, the subsurface is not just a guiding theme (2) but an influential element in the qualities of the local conditions. Subsurface aspects are derived from a wide variety of expertise, and it is not the job of the urban designer to investigate them all. By collaborating with different experts, and using deliberate knowledge brokerage instruments, like the SEES, urban designers will now be able to include the technical space of the city in their work. The design process investigates spatial opportunities at the surface level and creates a coherent design that relates to the subsurface characteristics of a site. This requires a sufficient understanding of subsurface conditions and a transformation of the data into the language of sketches and models (4). For example, the Subsurface Potential Map clarifies the main characteristics of the subsurface and the spatial effects at the surface level to enable urban designers to experiment and establish links between different solutions. This strengthens the solutions and contributes to a coherent end result. Urban designers should experiment with the unknown aspects of the subsurface in order to expand their knowledge and experience. Urban designers should become familiar with data modelling, understanding the influence of subsurface factors, and have generic solutions available in a frame of reference (3); only then can the subsurface conditions become a integrated part of the built environment. Subsurface conditions are not an obstruction to the urban design process: when addressed as part of the domains (5), they can enrich the final design and secure sustainable urban development.

3.3. Dealing with complex systems: reversed engineering with nature

The integration of the subsurface in surface spatial developments has a small frame of reference due to its complexity. There is an extremely large, diverse amount of knowledge and experience, laws, regulations that involves many stakeholders (Hooimeijer and Tummers 2017). This is not fully captured by the simplified classification of the techno-sphere and biosphere; many other issues are involved in the urban development process, for example, the relation between public and private, or health and ethical issues. The Industrial Revolution created the dominance of the idea of efficiency through machinery, and today, relates to a large disciplinary gap. This paradigm of efficiency is the foundation of modern professionalism, but is not applicable to problems of open societal systems. The segregation between civil engineering and urbanism started at this juncture. Addressing this segregation, Webber and Rittel (1973) defined engineering tasks as "tame" problems and social tasks as "wicked" problems. Webber and Rittel define the problems that natural scientists deal with as tame ones: the problem is clear and it is easy to quantify when the problem is solved. In contrast, the urban designer deals with open societal systems, the wicked problems, which do not have easily clarified traits. In order to find the balance between the tame and the wicked, the SEES works as the performance landscape (as defined by Rhodes 2008), the elements of the system are modelled and the SEES works as a reference for stakeholders to easily refer to without continuously tracking changes in the whole system. Moreover, the model allows for non-linear ways of working. The SEES closes the disciplinary gap in an instrumental way, by bringing together information from different disciplines new crossovers become possible and can tackle problems using solutions from another domain. But the SEES is not an instrument that solves problems or complexity, instead it is a tool, and it will always be the direct interaction of experts that works best.

Klein Woolthuis et al. (2013) highlights the importance of entrepreneurs in sustainable development in a paper about institutional theory and the role of institutional entrepreneurs, or people who are capable of changing the institutions. There is rarely only one person capable of change in urban development, but instead is subject to "distributed agency," a term introduced by Garud and Karnøe (2003) to explain the product innovation processes. They argue that, in the process of development, different steps require different knowledge and commitments; therefore, it is not a linear process with the same professionals. Klein Woolthuis et al. (2013) use the case of Lanxmeer (the Netherlands) to demonstrate how these principles of institutional entrepreneurship and distributed agency are the foundation of sustainable development. Lanxmeer (Culemburg) is a small scale, self-organised, sustainable housing area that is internationally recognised design that exemplifies social and urban quality interwoven with smart development and nature. Many actors were involved, including producers, users, evaluators and regulators. Subsurface qualities were exploited. The urban design of Lanxmeer is based on the concept of permaculture, this concept is also used to derive the application of the technical systems (van Timmeren, Sidler, and Kaptein 2007). The project is illustrative of the Reversed Engineering with Nature concept; trade-offs and synergies are found between the categories of civil constructions, water, energy and soil and implemented as a continuous system that runs through the surface and subsurface.

Reversed Engineering with Nature is a concept that goes beyond Landscape Urbanism because it does not ignore the techno-sphere but carefully creates balance in an effort to find cooperation with the biosphere. It relates the tame and wicked knowledge fields, actors and looks at the city as a hybrid performance landscape. Thus, not only allowing the operational logic of the natural system to take the lead, but working together with the agency of the technological urban constructions that currently exist. Synchronisation (in time, space, technology and interests) is one of the main goals in this approach.

4. Conclusions

The purpose of this paper is first to give shape to the integration of the surface and the subsurface systems; through enabling the subsurface to influence urban planning and design and tackle current trends such as climate change and energy transition. Emphasis was placed on the importance of knowledge exchange, a cultural shift towards recognising the apparent relationship between the subsurface and surface, and exploiting that relationship in urban design. Deliberate knowledge exchange is a key to the resolution and understanding of complex issues and an essential result of the cultural shift involving changing in practice.

The scientific challenge stated in the introduction was: How can the subsurface be better integrated into urban development? The answer is that the subsurface should be a new field for interdisciplinary research. In urban renewal and the redevelopment of brownfield land, the subsurface and surface, and particularly where the natural and man-made systems connect, should not merely co-exist but work together. Turning to an approach that starts from the merits of natural systems and balance these out with state-of-the-art technology will lead to innovative solutions. This approach of Reversed Engineering with Nature involves an enormous change in attitude, organisation and design in urban projects, and it requires close cooperation between urban designers and engineers.

The SEES facilitates this by providing an overview of the different fields of knowledge that involve the subsurface and displays their connection to surface planning and design. The framework is considered a "performance landscape" that supports three tactical ingredients: the knowledge map, the system overview, and knowledge brokerage between disciplines of different natures. It brings together different agents and enables distributed agencies to adapt to the "wickedness" of urban development. The ultimate aim is to identify opportunities in the synergy of different systems, and use that synergy to add to the general urban quality. During the design process, use of a Subsurface Potential Map can operationalise the subsurface information, making natural conditions a priority and carefully balanced with the technical applications. In this way, the Reversed Engineering with Nature approach is developed further.

However, the SEES and the Subsurface Potential Map alone are not enough to facilitate a Reversed Engineering with Nature approach; precise research into architectural representation is needed to create a sufficient link between subsurface and planning documents, and to uncover synergies between subsurface technologies, new urban maintenance regimes and scripts for design.

Notes

1. These concepts are not all described in scientific literature but are part of urban concepts in practice, see for example cdrchouston.org/blog/2012/11/16/thick-infrastructure (checked 4 August 2017).
2. The theoretical description of the SEES largely comes from: Döpp, Hooimeijer, and Maas (2012). The SEES is the result of the subsequent development of the Urban Climate Framework, the six layers, which was developed in cooperation with Sonja Döpp and Nienke Maas (TNO). The subsurface was added in cooperation with Linda Maring (Deltares).
3. *Handreiking plannen met de ondergrond* on www.ruimtexmilieu.nl is a website that was built for the former Dutch Ministry of Transport, Spatial Planning and Environment by H2Ruimte, TNO, Dauvellier Planadvies, MoceaN and Alterra.
4. By TNO, Deltares, SKB, the Ministry of Infrastructure and Environment and the municipality of Rotterdam see: https://publicwiki.deltares.nl/display/SEES/HOME+English.
5. Snowman financed project by TUD, Deltares, Chamlers and VITO see: http://www.chalmers.se/en/projects/Pages/Balance-4P.aspx.
6. LEAN thinking as a term was coined by James P. Womack and Daniel T. Jones to describe a business methodology that aims to create value and eliminate waste. They came up with this term when studying the Toyota Production System.
7. See http://www.west8.nl/projects/urban_design/borneo_sporenburg/.
8. http://www.ecoshape.nl/overview-bwn.html.
9. http://www.arcadis.nl/projects/Sanergy_de_synergie_van_2_werelden_Bodemenergie_en_grondwatersanering.aspx.
10. http://geothermie.nl/geothermie-aardwarmte/projecten/aardwarmte-den-haag.
11. http://www.nanterre.fr/353-parc-du-chemin-de-l-ile.htm checked 24 June 2015.
12. See: http://issuu.com/oficiocolectivo/docs/inverscape_s__barranco_inverted_sep.
13. http://www.compendiumvoordeleefomgeving.nl/dossiers/nl0072-landschapstypen.html?i=12-62.
14. By TNO, Deltares, SKB, the Ministry of Infrastructure and Environment and the municipality of Rotterdam see http://www.skbodem.nl/project/31.
15. http://www.chalmers.se/en/projects/Pages/Balance-4P.aspx.
16. See: https://anthropocenesoil.wordpress.com/2012/03/20/urban-soil-taxonomy-the-eighth-approximation/.
17. This is a subsidy from the European Union supporting networking across Europe around certain topics. See: http://sub-urban.squarespace.com/#about.

Acknowledgements

The SNOWMAN Network and the national funders in this network are acknowledged: SNOWMAN (SN04-01), Formas (Dnr 216-2013-1813), Stichting Kennis Bodem (SKB, D3146), and OVAM. In addition, the Municipality of Rotterdam, Port of Rotterdam, Gebiedsteam M4H, Programmabureau Stadshavens Rotterdam and Gemeentewerken Rotterdam are acknowledged for their willingness to invest both money and time into the work with the case study within the research project, and for their consistent enthusiasm. Hanna Kaplan, Christian Carlsson from City of Gothenburg, and Elisabeth Forsberg for representing the private developers HSB, and Balder, who are greatly acknowledged for investing time and effort in the work of the Fixfabriken case study, and for always having a positive attitude and being co-explorers, despite limitations in available time. Additionally, all students and stakeholders are acknowledged for contributing time, skills, experiences and knowledge, and finally the Editors Team of Urbanism for the English editing.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Fransje L. Hooimeijer is assistant professor in the department of Urbanism at Delft University of Technology. She is specialized in system integration of planning, design, and engineering. Her main research topics are integrating water and the subsurface system into spatial development.

Linda Maring (MSc) is a senior researcher in the Urban Soil and Water Management Department of Research Institute Deltares. She is an expert in the field of subsurface, especially in accommodating the link between the subsurface and spatial planning for governments and in European and national research projects.

References

Allen, S. 2002. "Mat Urbanism: The Thick 2D." *CASE: Le Corbusier's Venice Hospital and the Mat Building Revival*, edited by Hashim Sakris, 118–126. London: Prestel.

Bakr, M., N. van Oostrom, and W. Sommer. 2013. "Efficiency of and Interference Among Multiple Aquifer Thermal Energy Storage Systems; A Dutch Case Study." *Renewable Energy* 60: 53–62. Dec.

Bélanger, P. 2012. *Landscape Infrastructure: Urbanism Beyond Engineering*. Wageningen: WUR.

Berger, A. 2007. *Drosscape: Wasting Land in Urban America*. New Jersey: Princeton Architectural Press.

Beumer, V., P. Bardos, and P. Menger. 2014. *Decision Support System on Soft Reuses*. Technical Report HOMBRE. doi:10.13140/2.1.3175.0722.

Bonte, M., P. J. Stuyfzand, A. Hulsmann, and P. Van Beelen. 2011. "Underground Thermal Energy Storage: Environmental Risks and Policy Developments in the Netherlands and European Union." *Ecology and Society* 16(1): 22. www.ecologyandsociety.org/vol16/iss1/art22/.

Bouazza, A., R. M. Singh, B. Wang, D. Barry-Macaulay, C. Haberfield, C. Chapman, S. Baycan, and Y. Carden. 2011. "Harnessing On Site Renewable Energy Through Pile Foundations." *Australian Geomechanics* 46 (4): 79. Dec.

de Bruijn, K. 2004. "Resilience and Flood Risk Management." *Water Policy* 6: 53–66.

du Camp, M. 1993. *Paris, ses organes, ses fonctions et sa vie jusquén 1870* [Paris, Its Organs, Its Functions and Its Life Untill 1870]. Monaco: Rondeau.

Corner, J. 2006. "Terra Fluxus." In *The Landscape Urbanism Reader*, edited by C. Waldheim, 21–33. New York, NY: Princeton Architectural Press.

Cundy, A. B., R. P. Bardos, M. Puschenreiter, M. Mench, V. Bert, W. Friesl-Hanl, I. Müller, et al. 2016. "Brownfields to Green Fields: Realising Wider Benefits from Practical Contaminant Phytomanagement Strategies." *Journal of Environmental Management*. doi:10.1016/j.jenvman.2016.03.028.

Decoville, A., and M. Schneider. 2016. "Can the 2050 Zero Land Take Objective of the EU Be Reliably Monitored? A Comparative Study." *Journal of Land Use Science* 11 (3): 331–349.
van Dooren, E. J. G. C., M. F. Asselbergs, M. J. van Dorst, E. Boshuizen, and J. van Merrienboer. 2013. "Making Explicit in Design Education: Generic Elements in the Design Process." *International Journal of Technology and Design Education* 2013: 1–19.
Döpp, S., F. L. Hooimeijer, and N. Maas. 2012. "Urban Climate Framework: A Systems Approach Towards Climate Proof Cities." In *COMPACT I: Public Administration in Complexity*, edited by L. Gerrits and P. K. Marks, 244–257. Litchfield Park, AZ: Emergent Publications.
van Dorp, D., K. J. Canters, J. T. R. Kalkhoven, and P. Laan. 1999. *Landschapsecologie: Natuur en landschap in een veranderende samenleving* [Landscape Ecology: Nature and Landscape in a Changing Society]. Amsterdam: Boom Publishers.
Duchemin, E., F. Wegmuller, and A. M. Legault. 2008. "Urban Agriculture: Multi-dimensional Tools for Social Development in Poor Neighbourhoods." *Field Actions Science Reports* [Online], Vol. 1|2008, Online Since 16 January 2009, Connection on 10 October 2012. http://factsreports.revues.org/113.
European Commission (EC). 2012. *Guidelines on Best Practice to Limit, Mitigate or Compensate Soil Sealing*. Commission Staff Working Document, 12.4.2012, SWD (2012) 101. Brussels: EU. http://ec.europa.eu/environment/soil/pdf/soil_sealing_guidelines_en.pdf.
European Commission (EC) Expert group on the urban environment. 2001. *Towards More Sustainable Urban Land Use: Advice to the European Commission for Policy and Action*. Brussels: EU. http://ec.europa.eu/environment/urban/pdf/landuse_wg.pdf.
Ferber, U., D. Grimski, K. Millar, and P. Nathanail. 2006. *Sustainable Brownfield Regeneration: CABERNET*. Network Report. Nottingham: The University of Nottingham.
Garud, R., and P. Karnøe. 2003. "Bricolage Versus Breakthrough: Distributed and Embedded Agency in Technology Entrepreneurship." *Research Policy* 32: 277–300.
Gemeente Rotterdam, Waterschap Hollandsche Delta, Hoogheemraadschap van Schieland en de Krimpenerwaard, Hoogeheemraadschap van Delftland. 2007. *Waterplan 2 [Water Plan 2]*. Rotterdam: Gemeente Rotterdam.
van der Graaf, P. 2014. *Integrating the Subsurface in Urban Design How to Take Subsurface Aspect into Account in the Process of Urban Designing*. Theory paper master thesis University of Technology Delft.
de Groot, R. S., M. A. Wilson, and R. M. J. Boumans. 2002. "A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services." *Ecological Economics* 41 (3): 393–408.
Heeling, J., V. J. Meyer, and J. Westrik. 2002. *De Kern van de Stedebouw in het perspectief van de 21ste eeuw. Dl. 1. Het ontwerp van de stadsplattegrond* [Fundamentals of Urban Design in Perspective of the 21st Century, Design of the Urban Plan]. Amsterdam: SUN.
Heineken. 2010. *Duurzaamheidsverslag* [Sustainability Report]. Den Bosch: Heineken. http://www.heinekennederland.nl/~/media/Websites/Heineken%20Nederland/Afbeeldingen/Content/Duurzaamheid/2010_Duurzaamheidsverslag.ashx.
Heurkens, E., W. de Hoog, and T. Daamen. 2014. *De Kennismotor, Initiatieven tot faciliteren en leren in de Rotterdamse gebiedsontwikkelingspraktijk* [The Knowledge Motor, Initiatives to Facilitate and Learn From Practice of Area Development in Rotterdam]. Delft: TU Delft.
Heylighen, F. 2000. "Foundations and Methodology for an Evolutionary World View: A Review of the Principia Cybernetica Project." *Foundations of Science* 5: 457–490.
Holling, C. 1973. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics* 4: 1–23.
de Hoog, M., D. Sijmons, and S. Verschuren. 1998. "Herontwerp van het Laagland." [Re-design of the Low Lands.] In *Het Metropolitane Debat* [The Metropolitan Debate], edited by J. Blom, 74–87. Bussum: THOTH.
Hooimeijer, F. L. 2014. *The Making of Polder Cities: A Fine Dutch Tradition*. Heijligen: Jap Sam Publishers.
Hooimeijer, F. L., and L. Maring. 2013. "Ontwerpen met de Ondergrond." [Design with the Subsurface.] *Stedebouw & Ruimtelijke Ordening* 6: 52–55.
Hooimeijer, F. L., and L. Maring. 2015. "Machinekamer van de Stad." [Engine Room of the City.] *Land en Water* 11: 16–18.

Hooimeijer, F. L., and L. Tummers. 2017. “Integrating Subsurface Management into Spatial Planning in the Netherlands, Sweden and Flanders.” *Proceedings of the Institution of Civil Engineers – Urban Design and Planning* 170 (4): 161–172. Aug.

Hooimeijer, F. L., T. Kuchincow Bacchin, and F. Lafleur, eds. 2016. *Intelligent SUBsurface Quality: Intelligent Use of Subsurface Infrastructure for Surface Quality*. Delft: University of Technology. https://pure.tudelft.nl/portal/en/publications/intelligent-subsurface-quality(6eff83a8-d0c6-438e-aa42-0dbd03835ac9).html.

Ikävalko, O., I. Satola, and R. Hoivanen. 2016. *Helsinki TU1206 COST Sub-urban WG1 Report*. Helsinki: Cost Sub-Urban. https://static1.squarespace.com/static/542bc753e4b0a87901dd6258/t/5707847d37013bb703023e29/1460110490550/TU1206-WG1-007+Helsinki+City+Case+Study.pdf.

Klaassen, R. 2012. “Bacterial Decay in Wooden Foundation Piles – Patterns and Causes: A Study of Historical Pile Foundations in the Netherlands.” *International Biodeterioration & Biodegradation* 61 (1): 45–60. Jan. 2008, Elsevier.

Klein Woolthuis, R., F. L. Hooimeijer, B. Bossink, G. Mulder, and J. Brouwer. 2013. “Institutional Entrepreneurship in Sustainable Urban Development: Dutch Successes as Inspiration for Transformation.” *Journal of Cleaner Production* 50: 91–100.

Koppenjan, J., and E. H. Klijn. 2011. “Complexity, Which Complexity? Three Perspectives on Complexity Applied to Decision-making on Revitalizing the Centre of Rotterdam South.” Paper for ASPA (American Society of Public Administration) Conference ‘Challenges of Making Public Administration and Complexity Theory Work’, Erasmus University Department of Public Administration, Rotterdam, June 23–25.

Lamé, F., and L. Maring. 2014. *Into Dutch Soils*. The Hague: Ministry of Infrastructure and the Environment.

de Leeuw E., A. D. Tsouros, M. Dyakova and G. Green 2014. *Healthy Cities. Promoting Health and Equity – Evidence for Local Policy and Practice. Summary Evaluation of Phase V of the WHO European Healthy Cities Network*. Copenhagen: WHO.

Lennertz, W. R., A. Lutzenhiser, and A. Duany. 2014. *The Charrette Handbook: The Essential Guide to Design-based Public Involvement*. Chicago, IL: APA Planner Press.

Liedtka, J., and T. Ogilvie 2011. *Designing for Growth: A Design Thinking Tool Kit for Managers*. New York: Colombia University Press.

MacKay, D. 2008. *Sustainable Energy Without Hot Air*. Cambridge: UIT Cambridge. www.withouthotair.com.

McHarg, I. 1967. “An Ecological Method for Landscape Architecture.” *Landscape Architecture* 57 (2): 105–107.

Meyer, V. J., I. Bobbink, and S. Nijhuis. 2010. *Delta Urbanism the Netherlands*. New York: American Planning Association.

Mielby S., I. Eriksson, S. D. G. Campbell, J. de Beer, Helen Bonsor, C. le Guern, R. van der Krogt, et al. 2016. *Opening Up the Subsurface for the Cities of Tomorrow. Considering Access to Subsurface Knowledge – Evaluation of Practices and Techniques*. COST Action TU1206 SUB-URBAN | WG2 Summary Report. https://static1.squarespace.com/static/542bc753e4b0a87901dd6258/t/58528a3f59cc68429282d7b1/1481804379913/TU1206-WG2.0-001+Opening+up+the+subsurface+for+the+cities+of+tomorrow.pdf.

Moinier, S. 2013. *Constructed Wetlands Redefined as Functional Wetlands*. Report number 1202415-047. Utrecht: Deltares.

Montgomery, C. 2013. *Happy City: Transforming Our Lives Through Urban Design*. New York: Farrar, Straus and Giroux.

Municipality Amsterdam. 2011. *Structuurvisie Amsterdam 2040 Economisch sterk en duurzaam* [Structure Vision Amsterdam 2040 Economical Strength and Sustainability]. Amsterdam: Municipality Amsterdam. www.amsterdam.nl/wonen-leefomgeving/structuurvisie/.

Municipality Rotterdam. 2007. *Stadsvisie Rotterdam Ruimtelijke Ontwikkelings Strategie 2030* [Vision Rotterdam Spatial Development Strategy 20130]. Rotterdam: Rotterdam Counsil. www.rotterdam.nl/DSV/Document/Stadsvisie/STADSVISIEROTTERDAM_2030_dec2007.pdf.

Nilsson, K., T. A. S. Nielsen, C. Aalbers, S. Bell, B. Boitier, J. P. Chery, I. Zasada. 2014. *Strategies for Sustainable Urban Development and Urban-rural Linkages*. Research Briefings, March 2014, European Journal of Spatial Development. http://www.nordregio.se/Global/EJSD/Researchbriefings/article4.pdf.

Norrman, J., Y. Volchko, F. L. Hooimeijer, L. Maring, K. Kain, P. Bardos, S. Broekx, A. Beames, and L. Rosén. 2015. "Towards a Holistic Approach for Sustainable Redevelopment of Urban Brownfields." *Science of the Total Environment* 563–564 (1 Sept. 2016): 879–889.

Pollak, L. 2006. "Constructed Ground: Questions of Scale." In *Landscape Urbanism Reader*, edited by C. Waldheim, 125–139. New York: Princeton Architectural Press.

Reed, C., and N. M. Lister, eds. 2014. *Projective Ecologies*. New York: Actar D.

Rhodes, M. L. 2008. "Complexity and Emergence in Public Management: The Case of Urban Regeneration in Ireland." *Public Management Review* 10 (3): 361–379.

van Schaick, J., and I. T. Klaasen. 2007. "Dynamics of Urban Networks as Basis for the Re-development of Layers Approaches." In *Conference Proceedings International Seminar on Urbanism and Urbanization*. Delft: TU Delft.

van Schaick, J., and I. T. Klaasen. 2011. "The Dutch Layers Approach to Spatial Planning and Design: A Fruitful Planning Tool or a Temporary Phenomenon?" *European Planning Studies* 19 (10): 1775–1796.

Segeren, W. A., and H. Hengeveld. 1984. *Bouwrijp maken van terreinen* [Preparing Sites for Building]. Deventer: Kluwer.

Sijmons, D. 2002. "Met beide benen op de Ondergrond." [With Both Legs on the Subsurface.] In *Landkaartmos*, edited by D. Sijmons, 135–159. Rotterdam: 010 Publishers.

Sijmons D., J. Hugtenburg, A. van Hoorn, and F. Feddes. 2014. *Landscape and Energy Designing Transition*. Rotterdam: nai010 Publishers.

Sommer, W. T., B. Drijver, R. Verburg, H. Slenders, Vries E. de, I. Dinkla, I. Leusbrock, and J. T. C. Grotenhuis 2013. "Combining Shallow Geothermal Energy and Groundwater Remediation." In Proceedings of the European Geothermal Congress 2013, Pisa, Italy, June 3–7.

Tarrant, B. 2014. *Special Report: In Jakarta, That Sinking Feeling is All Too Real*. Reuters. http://www.reuters.com/article/2014/12/22/us-sealevel-subsidence-jakarta-sr-idUSKBN0K016S20141222.

Thompson, J. D., and A. Tuden. 1964. "Strategies, Structures and Processes of Organizational Decision." In *Readings Inmanagerial Psychology*, edited by H. J. Leavitt and R. Pondy, 457–473. Chicago, IL: University of Chicago Press.

Tilman, H. 2001 "Selectieve decentralizatie van de macht." [Selective Decentralization of Power.] *De Architect* March 2001: 46–50.

van Timmeren, A., D. Sidler, and M. Kaptein 2007. "Sustainable Decentralized Energy Generation & Sanitation: Case EVA Lanxmeer, Culemborg, the Netherlands." *Journal of Green Building* Fall 2 (4): 137–150.

Tjallingii, S. P. 1995. *Ecopolis, Strategies for Ecologically Sound Urban Development*. Leiden: Backhuys Publishers.

United Nations (UN) Department of Economic and Social Affairs, Population Division. 2014. *World Urbanization Prospects: The 2014 Revision, Highlights* (ST/ESA/SER.A/352). http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf.

Waldheim, C., ed. 2006. *Landscape Urbanism Reader*. New York: Princeton Architectural Press.

Wardekker, J. A., A. de Jong, J. M. Knoop, and J. P. van der Sluijs. 2010. "Operationalising a Resilience Approach to Adapting an Urban Delta to Uncertain Climate Changes." *Technological Forecasting & Social Change* 77 (6): 987–998.

Webber, M. M., and H. W. J. Rittel. 1973. "Dilemmas in a General Theory of Planning." *Policy Sciences* 4 (2): 155–169.

Whiston Spirn, A. 2000. "Ian McHarg, Landscape Architecture, and Environmentalism: Ideas and Methods in Context." In *Landscape Architecture*, edited by M. Conan, 97–114. Dumbarton Oaks: Trustees for Harvard University.

Wuana, R. A., and F. E. Okieimen. 2011. "Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation." *ISRN Ecology* 2011.