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DOI
10.1016/j.scitotenv.2016.02.097

Publication date
2016

Document Version
Accepted author manuscript

Published in
Science of the Total Environment

Integration of the subsurface and the surface sectors for a more holistic approach for sustainable redevelopment of urban brownfields

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Abstract

This paper presents a holistic approach to sustainable urban brownfield redevelopment where specific focus is put on the integration of a multitude of subsurface qualities in the early phases of the urban redevelopment process, i.e. in the initiative and plan phases. Achieving sustainability in brownfield redevelopment projects may be constrained by a failure of engagement between two key expert constituencies: urban planners/designers and subsurface engineers, leading to missed opportunities and unintended outcomes in the plan realisation phase. A more integrated approach delivers greater benefits. Three case studies in the Netherlands, Belgium and Sweden were used to test different sustainability assessment instruments in terms of the possibility for knowledge exchange between the subsurface and the surface sectors and in terms of cooperative learning among experts and stakeholders. Based on the lessons learned from the case studies, a generic decision process framework is suggested that supports holistic decision making. The suggested framework focuses on stakeholder involvement, communication, knowledge exchange and learning and provides an inventory of instruments that can support these processes.

Keywords: brownfield redevelopment, sustainability assessment, subsurface qualities, spatial planning, remediation

1. Introduction

1.1 Background

Land take as a result of urbanization is one of the major soil threats in Europe and the reason why European policy aims for a net zero land take by the year 2050[1]. This global trend of urbanization increases the importance of careful spatial planning in cities (OECD & CDRF, 2010) and one of the key measures to prevent further urban sprawl and additional land take, is redevelopment of urban brownfields (Pediaditi et al., 2010; Chakrapani and Hernandez, 2012; Bartke and Schwarze, 2015). Brownfields are underused areas with, in many cases, real or perceived, soil and groundwater pollution. Brownfield pollution is a barrier to redevelopment in terms of investment risks, ownership constraints, risk of future liability claims and public stigma (Bartke and Schwarze, 2009; Schädler et al., 2011; Davison and Legacy, 2014).

An additional difficulty for urban brownfield redevelopment is that urban planning/design and subsurface engineering, are carried out in isolation from one another, although the practical site restoration outcome depends heavily on both (Hooimeijer and Maring, 2013; Lackin et al., 2014; Maring et al., 2015). The urban planner/designer usually deals with opportunities for socio-economic benefits while the subsurface engineer deals with the technical challenges of e.g. remediating the site. Urban planning/design decisions are made prior to subsurface engineering decisions, which are usually not considered until implementation of the plan. Consequently, opportunities for more sustainable technical solutions in the realisation phase of the redevelopment process tend to be limited by already approved urban plans and designs.

In the remediation sector, which is one of many subsurface considerations, there is broad on-going work to develop guidelines and instruments that support sustainable remediation (e.g. SuRF UK, 2010; ISO, 2015; Bartke and Schwarze, 2015). In accordance with Bardos et al. (2011), there are several attempts to incorporate sustainability thinking in early phases of projects, because the largest gains can be achieved early on in projects decision processes where there is still room for flexibility. Examples of such attempts are e.g. reviewed in Beames et al. (2014), who list generic sustainability appraisal decision support systems (DSSs) both for technology appraisal as well as for site redevelopment appraisal, with the latter gaining increasing interest in recent years. Sustainability assessment in site redevelopment has been operationalised through approaches that bridge the gap between the generic indicator systems and the diverse range of context specific community considerations (Hartmuth et al., 2008; Bleicher & Gross, 2010). Achieving sustainable development in the process of both site remediation and redevelopment is now widely regarded as a key measure of success (Edwards et al., 2005; Ferber et al., 2006; Schädler et al., 2011; Van Gaans and Ellen, 2014).

Anthropogenic activities in the subsurface include: abstraction of groundwater for multiple purposes, exploitation of raw materials, storage of e.g. heat, cold, radioactive waste and CO_2, underground constructions such as tunnels and garages, foundation of buildings, and remediation of contaminated soil and groundwater (Griffioen et al., 2014). A range of subsurface qualities are described in

[1] EC, 2011. Roadmap to a Resource Efficient Europe. COM (2011) 571 Final. European Commission, Brussels. http://ec.europa.eu/transparency/regdoc/rep/1/2011/EN/1-2011-571-EN-F1-1.Pdf. Accessed February 2016.

Ruimtexmilieu[2] and categorized into four different groups: carrying quality (e.g. basis for building activities, subsurface activities incl. road and rail infrastructure, aquifer thermal energy storage), *information quality* (e.g. cultural historical value, ecological diversity), *regulating quality* (e.g. clean and healthy soil, water filtering soil, water storing soil), and *production quality* (crop production capacity, drinking water, minerals, fossil and geothermal energy). Hooimeijer and Maring (2013) grouped the same qualities differently in order to relate better to the urban planning process, namely as *civil constructions*, *energy*, *water* and *soil*. The latter grouping is used in the System Exploration Environment and Subsurface (SEES) method developed by the same authors (Hooimeijer and Maring, 2012). Involving subsurface engineers in the early planning process in order to give advice on opportunities for sustainable redevelopment of urban brownfields by accounting for the existing subsurface qualities at a site and using those as part of the urban planning and design processes, is believed to improve the possibilities for identifying sustainable brownfield redevelopment strategies. For example, smarter locations of buildings and public spaces can create more cost-effective solutions with regard to remediation, foundations, cables and pipes, water management and energy solutions. Urban plans and designs that systematically consider the subsurface qualities may potentially be smarter as they can lead to increased climate security, to energy-saving, to higher degrees of sustainability and to more sound economic developments. Several projects have contributed to developing holistic approaches to brownfield redevelopment accounting for sustainability aspects, soil and groundwater quality and planning aspects (RESCUE, 2005; CABERNET, 2006; REVIT, 2007; HOMBRE, 2013), but, to the best of our knowledge, there is no published academic paper handling these key issues. The developed holistic approaches suggest considering subsurface and remediation issues earlier in the initiative and plan phases, but do not provide any guidance on the process of knowledge exchange between the surface and the subsurface sectors.

Subsurface qualities that sometimes compete or potentially exist in synergy, are complex. This paper is a first attempt to initiate a discussion in the academic community about integrating the subsurface qualities in the early planning phases of the brownfield redevelopment process. Although the majority of available information sources covering the topic and collated in this paper can be categorized as 'grey literature', these sources nevertheless provide valuable insights. The grey literature sources are thus used in this study alongside scarce and relevant peer-reviewed publications. We consequently use the term redevelopment in this paper as opposed to regeneration as we primary have a site perspective. Nevertheless, for redevelopment to be sustainable, it also needs to be related to the local and regional perspective, i.e. the political and societal visions and ambitions.

1.2 Aim and scope

The aim of this study has been to explore the possibilities of integrating subsurface considerations in the early planning phases and to develop a generic framework for supporting the decision process of sustainable redevelopment of urban brownfields. The suggested framework is developed based on

[2] Handreiking Plannen met de Ondergrond, (2007), available at http://ruimtexmilieu.nl/. This website was developed under the auspices of the Dutch ministry of housing, spatial planning and the environment. Specific link to the subsurface qualities: http://ruimtexmilieu.nl/wiki/ondergrondlaag/ondergrondkwaliteiten-2 (In Dutch, accessed August 2015).

the experiences of three case studies in the Netherlands, Belgium and Sweden, and builds upon the conceptualisation of a holistic approach to sustainable brownfield redevelopment. The outline of the paper is as follows. First, the urban redevelopment process is described in Section 2. Section 3 summarises opportunities identified for enhancing the subsurface in current planning systems, describes the concept of sustainability, and outlines what we envision as a holistic approach to sustainable brownfield redevelopment that includes integrating the subsurface qualities in the early planning phases of the redevelopment process. In Section 4, the various methods applied in the study are presented. The work on case studies and the main lessons learned are presented in Section 5. Section 6 provides a short discussion of the case study results. Section 7 describes a suggested generic framework based on the conceptualisation and the findings in the case studies, and summarises some concluding remarks.

2. The urban redevelopment process

Brownfield redevelopment planning is an elusive field and difficult to grasp because it changes all the time (Nadin and Stead, 2008). The planning conditions for the urban redevelopment process is the result of laws, regulations, policies, and institutions (Figure 1) that influence each other and work together at different scales (local, regional, and national) (Nilsson and Rydén, 2012). The planning systems differ between countries due to culture, but in general there are different scales ranging from municipality level, to regional level and to national level. Furthermore, in the recent decades, for example, the evolution processes in Dutch and Swedish institutions have impacted the planning and building practices in the respective countries (for details see Norrman et al., 2015a).

The different steps in redevelopment projects can be described in various ways (Maring et al., 2013). Here, a typical urban redevelopment process is described as consisting of four phases (Figure 1): (i) Initiative, (ii) Plan, (iii) Realisation, and (iv) Maintenance (VROM, 2011; Verburg and Dams, 2004). The Initiative and Plan phases are part of the Planning process, whereas the Realisation and Maintenance phases are part of the Implementation process (Figure 1). These phases are integrated or separated to varying degrees, but this division serves to symbolise the planning on the one hand and the actual implementation of the plan on the other hand. Christensen (2014) uses a similar division to describe the urban development process from a value change perspective: concept development, the planning process and permits, the preparation of land, the construction of buildings and the sale, rent or use of the area as different events over time.

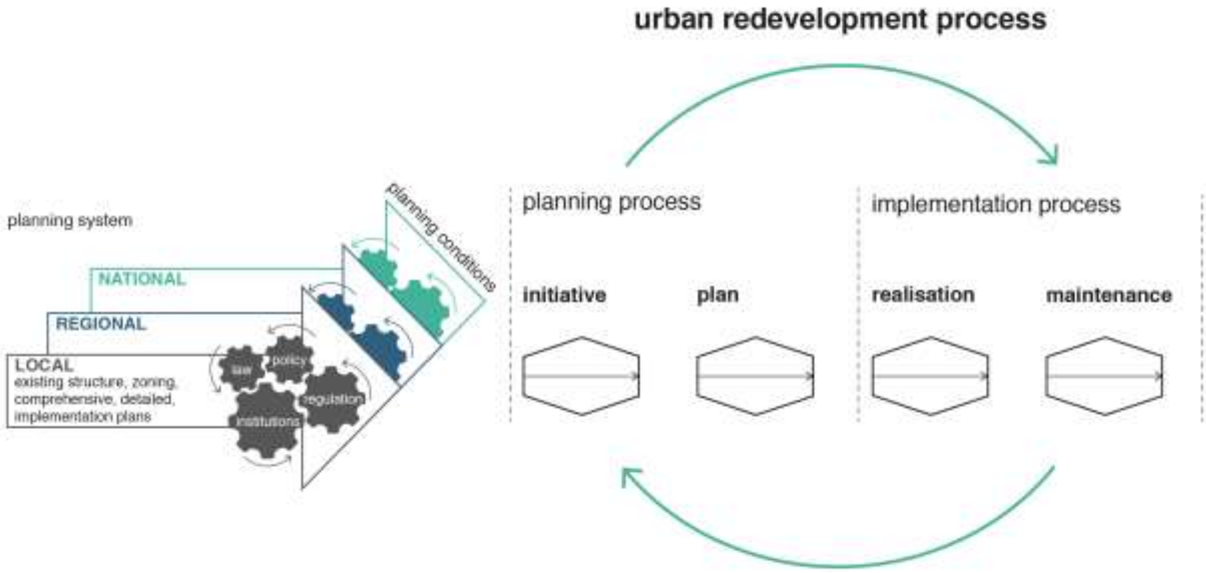

Figure 1. The urban redevelopment process operates within the planning conditions that are the result of all levels in the planning system (local, regional, national) and their respective laws and regulations, policy and institutions. The urban redevelopment process includes the regulatory context as a background to the planning and implementation processes, each with different phases. Illustration by F. L. Hooimeijer, drawn by Janneke van der Leer, ©Chalmers University 2015, reproduced by permission.

Although most articulated in the plan phase, each of the four phases in Figure 1 can generally be described as having two modes: opening up the field of choice to secure as many relevant options as possible (diverging and exploratory) and narrowing down this field of choice through various types of decisions (converging and reducing complexity) (Friend and Hickling, 2005). The plan phase consists of four steps of decision-making (Table 1): shaping, designing, comparing and choosing (Friend and Hickling, 2005) where the former two of these steps open up the planning process and the latter two narrows it down. The further the work is taken in each phase, the more focused the process gets as a result of choices and assessments made along the way (Friend and Hickling, 2005). At the end of each phase, decisions are made which allow launching the process into the following phase. Usually, this is not a linear process since iterations between the phases are likely, especially in existing urban areas, where maintenance of real estate is not the end but the starting point in the redevelopment process (Figure 1).

Table 1. Types of decision relevant in different phases of the redevelopment process (based on VROM, 2011; REVIT, 2007; Friend and Hickling, 2005; RESCUE, 2005; Verburg and Dam, 2004).

Redevelopment phase	Decision on
Initiative	Redevelopment vision
Plan	
Shaping/defining	System boundaries and program of demands
Designing	Urban design options
Comparing	Selection criteria and ranking of alternatives
Choosing	Redevelopment plan
Realisation	Remediation strategy Contractors and suppliers Quality assurance and certification
Maintenance	Monitoring Service-providers

The formal decision-making procedure is dictated by the regulatory setting and the institutional organization within which the decision is to be taken. Regulations and actors often differ between the planning process and the implementation process and the decision processes in the remediation sector are different compared to the urban planning sector. In urban planning, the focus is more on mediating between different interests to reach an optimal solution (Friend and Hickling, 2005), whereas in e.g. soil contamination issues, there are often strict guideline values to comply with (e.g. NV, 2009).

3. Towards a holistic approach

3.1 Chances for enhancing subsurface in current planning systems

The focus in this study is to explore the possibilities of bringing subsurface engineering elements, especially those related to soil and groundwater contamination, which are normally not considered fully until the implementation process, earlier into the planning process. The first step is to look into the current planning systems and to explore the chances for enhancing subsurface consideration within those. The analysis is based on a comparison between planning systems in the Netherlands, Belgium, and Sweden with the framework developed by the BSR Interreg IIIB project COMMIN (Nilsson and Rydén, 2012) [3], as reported in Tummers et al. (2014) and Norrman et al. (2015a).

The comparison resulted in four spatial planning subjects that have a clear relation to the subsurface, and which are similar across the three studied planning systems (The Netherlands, Belgium and Sweden): Heritage (Malta Convention[4]), Environment (Environmental Assessment Procedures[5]), Nature (Natura 2000[6]) and Water (Water Framework Directive[7]). These are well established planning instruments that have the potential to enhance the integration of above- and underground aspects in different parts of the planning systems and building practice: i) in law and regulation, ii) in policy and vision, iii) by structured knowledge exchange, and iv) in the planning, design and construction processes (Figure 2). Here the four categories of subsoil qualities referred to in the Introduction (Hooimeijer and Maring, 2012), are used to give an indication of the possibilities:

1. Civil constructions (archaeology, underground building, cables and pipes, foundations);
2. Water (storage and filtering capacity, drinking water);
3. Energy (Aquifer Thermal Energy Storage (ATES), geothermal and fossil energy); and
4. Soil ecology (clean soil, morphology, ecology, landscape diversity, minerals).

[3] http://www.irs-net.de/forschung/forschungsabteilung-1/commin/, accessed February 9th 2016.
[4] Malta Convention, 1992: http://conventions.coe.int/Treaty/EN/Treaties/Html/143.htm, accessed September 2015.
[5] Environmental Impact Assessment (EIA) Procedures: http://ec.europa.eu/environment/eia/home.htm, accessed September 2015.
[6] Natura 2000: http://ec.europa.eu/environment/nature/natura2000/index_en.htm, accessed September, 2015.
[7] Water Framework Directive: http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm, accessed September 2015.

TOPICS IN SURFACE PLANNING →		Heritage / Environment / Nature / Water
CHANCES FOR ENHANCING THE SUBSURFACE BY	Law and regulation	*Chances for:* - Including the subsurface in planning regulations about heritage, environment, nature and water - Including the subsurface in Environmental Impact Assessment and Water Assessment Test - Subsurface in zoning plans through paragraphs about heritage, environment, nature and water
	Policy and vision	*Chances for:* - Visions on the subsurface in local and regional plans, local policies, as well as in individual projects
	Knowledge exchange	*Chances for:* - Interdisciplinary cooperation - Developing new knowledge by cooperative learning
	Design / construct	*Subsurface in plan and design process needs:* - Better frame of reference - Better instruments (subsurface potential map) - Cultural change from how it is done now
CATEGORIES OF SUBSURFACE QUALITIES →		Civil constructions, Soil / Civil constructions, Soil, Water, Energy / Water, Soil, Energy / Water, Soil, Energy

Figure 2. Identified chances for enhancing subsurface considerations in the current planning systems with regard to four spatial planning subjects: Heritage, Environment, Nature and Water, relating to four subsoil qualities: Civil constructions, Water, Energy, and Soil. Chances are related to i) law and regulation, ii) policy and vision, iii) knowledge exchange, and iv) design/construct.

Ensuring the inclusion of subsurface considerations in the planning process can be achieved by the enforcement of regulations, but it can also be demanded of those in charge of the planning process. If supported by regulatory, legal and policy frameworks and more conscious knowledge exchange, subsurface has a better chance of becoming a self-evident aspect of the planning practice. The identified chances to enhance subsurface in the planning process may also be associated with risks, e.g. increased effort and complexity in the planning process may lead to slower and more costly processes, which should be investigated carefully.

3.2 Sustainability

To explore the role of the subsurface in realising sustainable redevelopment of brownfields there is a need for insight into what sustainability means and what it implies for urban redevelopment. The generally accepted Brundtland definition, “to meet the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987) needs a more precise formulation. Sustainability in this study is approached as a “strategy for action” (Hooimeijer, 2011): a conscious act of finding a balance between socio-economic needs and the conditions of the natural system represented in the ‘triple bottom line’ of the three P's (People, Planet, Profit/Prosperity) from UN (2002)[8]. In order to design and execute an urban development plan that incorporates and integrates the three P's, one has to weigh the aspects, fully exploit the synergies between them and assess their contribution to the overall plan. This complex process requires innovative and strategic

[8] Another wording for the sustainability domains of society, environment (or ecology), and economy.

action, with in-depth knowledge of aspects and new conceptual ideas on their integration in a given situation. This crucial strategic activity, which we consider to be the basis of sustainability, is captured by adding the fourth P of 'Project' and 'Process' to the 'triple bottom line' (Van Dorst and Duijvestein, 2004). The P of Project represents spatial qualities that are the result of the skills of integrating sustainability aspects into a balanced project-specific design, whereas 'Process' refers to the interaction between stakeholders and their institutional context to realize this design (Van Dorst and Duijvestein, 2004).

We adopt this view with a special focus on the integration between the surface and the subsurface sectors. The P of Project represents qualities that are added by integrating subsurface engineering knowledge into the plan phase of the redevelopment process. The P of Process also represents the interaction and knowledge exchange between the actors in the surface and the subsurface sectors. By this, we also mean that it is the process that is in focus, and not the specific instruments to support the process since their applicability and suitability are expected to differ from case to case (see also Bartke and Schwarze, 2015).

3.3 A holistic approach

Several attempts have been made to develop a holistic approach to brownfield redevelopment accounting for sustainability aspects and planning issues (RESCUE, 2005; CABERNET, 2006; REVIT, 2007; HOMBRE, 2013; UFZ, 2013). The CABERNET (Concerted Action on Brownfield and Economic Regeneration Network) network and the HOMBRE (Holistic Management of Brownfield Regeneration) project advocate a holistic approach that links physical interventions with people-focused interventions from sustainability perspective by involving stakeholders and ensuring knowledge exchange between well-established disciplines in the urban development practice (CABERNET, 2006; HOMBRE, 2013). A holistic approach in this study is conceptualised as integrating multiple subsurface and surface aspects in day-to-day planning and urban development practices, and as supporting a process that seeks to balance the three P's.

A fully holistic approach to brownfield redevelopment requires new legislation and national policies that enable the explicit inclusion of subsurface aspects in the planning process. For example, the Dutch Environmental and Planning Act (will be empowered in 2018) will impose a demand on planners to ensure sustainable use of the multiple subsurface functions in the development process (Lamé and Maring, 2014). However, local policy, project-specific vision-building and voluntary protocols, can also support a holistic approach to brownfield redevelopment. To move forward without demanding change of law and regulation, this study has focused on exploring the possibilities for knowledge exchange by interdisciplinary cooperation and cooperative learning.

To achieve effective inclusion of the subsurface qualities through knowledge exchange into the urban redevelopment process, there is a need to ensure a communication platform for knowledge transfer and exchange within each phase and between the phases. The knowledge exchange process assumes both horizontal (between engineers with different subsurface or surface competences, and over time) and vertical (between subsurface engineers and aboveground planners) flow of information (Figure 3). The knowledge exchange is in focus with regard to the process, but for sustainable solutions the triple bottom line perspective must also be included. In other words, there is a need to ensure that social, environmental and economic effects are considered and evaluated in the process.

The holistic approach is conceptualised in Figure 3 in the context of any one of the phases of the urban redevelopment process as outlined in Section 2, summarised as Balance 4P.

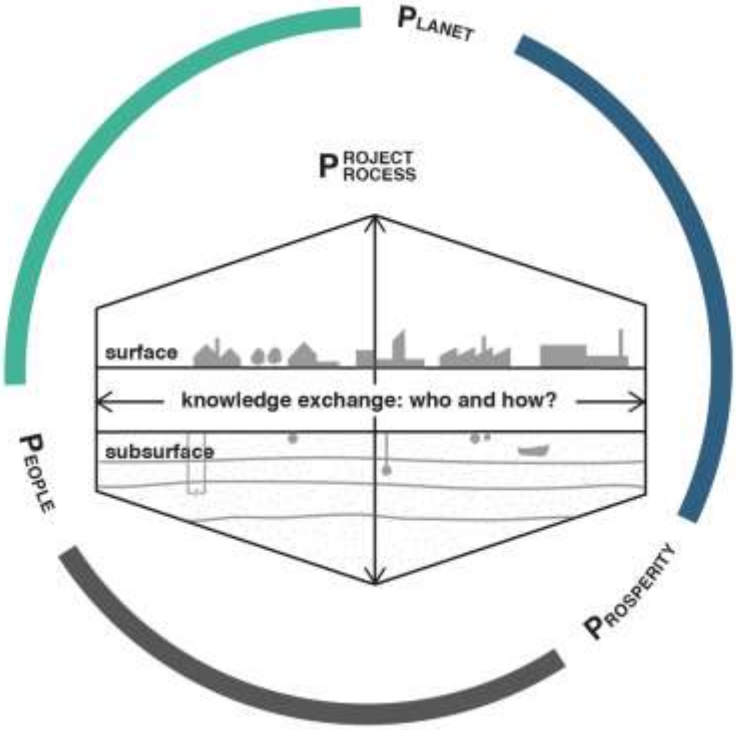

Figure 3. Balance 4P: conceptualisation of a holistic approach to urban brownfield redevelopment. Knowledge exchange between the surface and the subsurface sectors, across disciplines within each sector, and over time about the subsurface qualities of the specific project. Identifying who should be involved in the knowledge exchange process and how can it be mediated adds a P of Process. The three P's of the triple bottom line must be considered and evaluated in each urban redevelopment phase in order to reach a balanced project design. Illustration drawn by Janneke van der Leer, ©Chalmers University 2015, reproduced by permission.

4. Methods

4.1 Case studies and student involvement

The main method in this study has been to use case studies as a means of applying and testing the outcomes of different activities and instruments applied to support the process of knowledge exchange between the surface and the subsurface sectors. Case studies are powerful in that they provide real cases with the inherent complexity that exists and opportunities for learning, but may be limited in terms of being able to generalise results from the cases. Nevertheless, in relation to social sciences, Flyvbjerg (2006) argues against common misunderstandings about case-study research and that it in fact is necessary to produce exemplars. Case studies have been realised using desk studies, individual consultations with stakeholders and workshop settings. Three types of workshops have been carried out: (i) for knowledge exchange between subsurface and surface sectors; (ii) for integration of the sustainability assessment results, and getting feedback on the case study results as well as the elaborated work flow; and (iii) involving students from urban design and subsurface engineering. The stakeholders contributed in the cases with their experiences and knowledge of the real world complexity, as well as their feedback to the analyses made in the cases. The students helped the project team researchers and case holders to "think out of the box", to offer room to practice certain workshop measures and to give more content-rich discussions with the case holders. More information about the student involvement can be found in Norrman et al. (2015b).

4.2 Stakeholder analysis

Stakeholder analysis has been used in all case studies to identify who to involve in different activities. A stakeholder is a person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity (ISO, 2009). It is important to define why a stakeholder analysis is performed, to ensure that the result provides relevant information for the specific task. Stakeholder analyses were carried out in the case studies using the Crosby method (Crosby, 1991; Hermans, 2005)[9]. The stakeholder analysis methodology applied included a quick scan of important stakeholders divided into four groups: (i) knowledge, (ii) regulators, (iii) business, and (iv) society. Further, each identified stakeholder was analysed with regard to: (a) interest in Issue, (b) resources (the resources that can be used in the decision making, e.g. knowledge, information, leverage, money), (c) resource mobilization capacity, and (d) position on issue.

4.3 Inventory of instruments

A multitude of instruments[10] exist that can act as communication platforms and guide sustainable development both in urban planning and remediation projects (Brinkhoff, 2011; Beames et al., 2014; Kok, 2014). The instruments have been developed in different regulatory contexts, with different concepts/ideas of sustainability, to focus on one or multiple aspects of sustainability, and for different tasks in the redevelopment process. In the three case studies, several different instruments were used. The reasons why different instruments were used in the cases are: a) the cases were in different phases of the redevelopment process and had different amount of information available, b) the legislation in the three countries differ, and c) the researchers involved in the three cases had varying knowledge, experience and interest in different instruments. The main focus of the study was to investigate if integrating knowledge about the subsurface in the land use planning process was possible and if it could provide better and more sustainable solutions, thus not focusing on a specific instrument. It is out of the scope of this paper to describe all tools and methods in detail; an overview of the instruments used in the cases with references is given in Table 2 and short descriptions of the applied instruments and those included in the instrument inventory are presented in the Supplementary material (Table S1 and S2).

[9] For details on the result of the stakeholder analyses in the cases, the reader is referred to Norrman et al. (2015b).

[10] The term instruments is here used as a collective term for both methods and tools.

Table 2. Overview of the instruments used in the three case studies. Short descriptions of the instruments are given in the Supplementary material, Table S1 and S2.

Case	Tested instruments	Reference
Merwevier-haven (NL)	System Exploration Environment & Subsurface (SEES) in workshop setting	*Hooimeijer and Maring, 2012*
	Brownfield remit/response tool (BR2)[a)]	*Ashmore et al., 2014*
	Brownfield Opportunity Matrix (BOM)[a)]	*Beumer et al., 2014*
Alvat (BE)	SEES (individual stakeholder consultation)	*Hooimeijer and Maring, 2012*
	OVAM Multi-Criteria Analysis (MCA) incl. CO_2 calculator	*OVAM, 2013*
	Cost-Benefit Analysis	*Dugernier et al., 2014*
	Nature Value Explorer (NVE) – ecosystem service valuation	*Broekx et al., 2013*
	Biodiversity check	*Brabers, 2014*
Fixfabriken (SE)	SEES (workshop setting)	*Hooimeijer and Maring, 2012*
	Social Impact Analysis (SIA)	*Göteborgs Stad, 2015*
	SCORE (Sustainable Choice of REmediation), incl. Cost-Benefit Analysis (CBA)	*Rosén et al., 2015; Söderqvist et al., 2015*
	ESS mapping (Ecosystem Services' mapping)	*Ivarsson, 2015*

[a)] Results not presented in this paper.

5. Case studies – exploring possibilities for knowledge exchange

Three cases of brownfield redevelopment projects were used for exploring possibilities for different activities and instruments to support knowledge exchange between the surface and the subsurface sector. The work in the case studies is summarised here with a focus on the lessons learned from the cases, and is fully presented in Norrman et al. (2015b).

5.1 Merwevierhaven, NL

The Merwevierhavens (M4H) in the Netherlands, is the east part of the old City Harbour in Rotterdam and a former industrial area which is going to be transformed into an area with mixed uses, including residential housing. The site is in the initiative phase of the redevelopment process, and is representative for 'organic development' wherein the light industry will remain and more urban functions will be added to the area. The focus in the M4Hs case was on vision building for the site and generation of possible redevelopment alternatives integrating subsurface aspects: a quantitative sustainability assessment was omitted in the study and instead the SEES-tool was used both for identifying relevant subsurface qualities and their relation to surface layers, identifying redevelopment visions and for exploring these alternative visions. The activities carried out within the M4H case is presented in Norrman et al. (2015b) and the final advice to the municipality is summarised in Hooimeijer and Maring (2014), including the collected idea book for M4H.

The main lessons learned from the M4H case are described in the following. Knowledge exchange in SEES workshops with different experts was a fruitful exercise. With the information a narrower collaboration between the urban planners and engineers was developed. It was also effective to carry out two SEES workshops with stakeholders. The first workshop was carried out for the whole area inviting a broad range of stakeholders, whereas the second one was more directed towards specific parts of the area and specific subsurface aspects of interest which were identified in the first workshop. The planners broadened their vision towards subsurface during the first workshop, and started to ask specific questions in the second workshop on the consequences and costs of subsurface aspects for different redevelopment alternatives. It was also clear from the SEES workshops that the information about the subsurface should be prepared beforehand and delivered in an approachable form for all stakeholders at the workshop in order to make it useful and that preparation of information on subsurface before the workshop can be a very effort- and time-consuming task. For the M4H case, a gap was identified in subsurface data transferring (mainly cables and pipes) when land ownership rights pass from municipalities to private landowners and vice versa.

5.2 Alvat, BE

The Alvat case study site in the Buggenhout municipality in Belgium, is also a former industrial area but here, public interventions are needed for remediation of the heavily contaminated soil and the site redevelopment. It is today an abandoned and underused site situated along the River Scheldt - a so called "black field". The Alvat site is in the plan phase, however no clear vision on future land use has yet been developed, because of the presence of the serious soil contamination and an uncertainty about ownership and responsibilities (the site owner has gone bankrupt). Extensive investigations and partial remediation of the contaminated soil have been carried out by OVAM[11] . The activities carried out within the Alvat case is presented in Norrman et al. (2015b). The focus of the analysis was to work with both the subsurface qualities as well as other urban design aspects to develop alternative designs for the site. The designs were turned into land use maps for four scenarios and evaluated with a number of sustainability assessment instruments (see Table 3).

Some lessons learned from the Alvat case were that most parties involved in the case (municipality, waterway administration, and redeveloper) had limited interests in sustainability assessment tools that support decision making on redevelopment scenarios. Instead, the focus was mainly on legal frameworks and existing procedures (zoning plans, environmental impact assessments, location nature protected areas, maps on water sensitive areas, etc.) that according to the stakeholders already capture a lot of the sustainability aspects. Feedback was also given that the message needs to be sufficiently simple to have impact. A lesson learned and a challenge is to gain an understanding on how different types of sustainability assessments can (i) fit into the entire planning process and (ii) be better integrated in rules and regulation. Although there has been a clear interest from OVAM, practitioners from the municipality were more hesitant about this, but in making the bridge between spatial planning and soil management, the brownfield covenant was considered to be an important policy instrument, as well as the role of individuals.

5.3 Fixfabriken, SE

The Fixfabriken area in Gothenburg, Sweden, is a former industrial area which is going to be transformed into an area with mixed use including housing, offices and light industry. The area is very attractive for developers because of its location in the city and the good connections to transport networks, which significantly influence property values and thus allow for a market-based redevelopment. The Urban Planning Department had, in collaboration with private developers,

[11] OVAM - Openbare Vlaamse Afvalstoffenmaatschappij. The Public Waste Agency of Flanders is a regional authority responsible for sustainable management of waste and materials and prevention of soil pollution and carrying out of soil remediation. http://www.ovam.be/

started developing a program for the area when the case study begun. The activities carried out within the Fixfabriken case is presented in Norrman et al. (2015b). Focus of the work was to use the information from the SEES analysis and consultation with the municipality to generate different redevelopment strategies that considered the identified subsurface qualities as well as land use and remediation options (Garção, 2015). The alternatives did not consider the detailed urban design. Instead, the main interest was to explore the relation between different types of land-use, combined with different remediation options, and the subsequent sustainability assessments (see Table 3).

There was a number of lessons learned jointly by the research team and the practitioners at the municipality from the Urban Planning Department and Real Estate Department[12] from the case study work, listed below.

- Direct communication is more efficient than documents, but expert knowledge still needs to be delivered in formats that are approachable for all involved stakeholders. The SEES workshop was found to provide new information to stakeholders and to be working as a platform for knowledge exchange.
- A structured approach for generating and assessing alternatives can strengthen the work by urban planners by clarifying what the different considerations are and by better motivating the choices that are made along the way.
- Sustainable brownfield redevelopment with the integration of subsurface and surface issues make up a complex decision process. It was clear that all surface and subsurface aspects for the three P's (People, Planet, Profit/Prosperity) could not be covered in one type of analysis.
- A longer time-horizon for planning would make it possible to have another working approach with regard to subsurface qualities, allowing for other redevelopment options than the typical quick and extensive remediation solutions.
- There is a challenge linked to bringing detailed sustainability assessments into early phases of redevelopment planning with regard to communication and use of the results of such analyses, as well as poor data availability. Qualitative and semi-quantitative methods were found to be more relevant to support the planning process.
- Another reflection from the Fixfabriken case was that it is a challenge to transfer developed knowledge from the plan phase to the realisation phase, since both the regulatory systems and the set of involved stakeholders change. An example of this is the fact that the remediation method cannot be regulated in a detailed plan. However, by taking subsurface qualities into consideration in the plan phase, it is possible to make decisions that do not prohibit sustainable solutions in later phases.

6. Discussion

This section discusses the practical outcome and the lessons learned from the case studies, and which aspects of the lessons learned we want to lift forward for supporting sustainable brownfield redevelopment.

[12] H. Kaplan. Personal communication, December 2014, C. Carlsson. Personal communication, June 2015.

A difference in the Alvat case study compared with M4H and Fixfabriken was the roles of the municipalities. For the two latter cases, the case studies were chosen based on an interest to explore the possibilities of the work within the research project at these specific sites. In the Alvat case, the driving force behind choosing the site was OVAM (also one of the funding organisations of the research project), who had an interest in the cleaning up and redevelopment of the site, and not the municipality in Buggenhout. It is possible that the involvement and the feedback from the municipality could have been different if they were the driving force, and if the site was not a "black field" in rural setting with a very high uncertainty regarding the future of the site.

Though the outcomes of the scientific project had no significant impact on the decision making process of the Alvat site, outcomes of the stakeholder analysis and the different assessment tools confirmed the need for intervention by OVAM. The potential revenues from the redevelopment both as housing area and industrial area were largely insufficient to cover the costs for remediation. After the partial remediation performed by OVAM, this financial gap was smaller but still existing which is still a barrier to attracting private investors. Remaining legal uncertainties on the potential redevelopment scenario (housing or industrial areas or mixed land use) are an even more important barrier for private investments.

The case study where the municipality was most eagerly involved in exploring new instruments and working approaches, and ultimately to use the result, was in the M4H case, were also the municipality itself funded parts of the work, thus investing both money and time. They have engaged in exploring the possibilities for knowledge exchange between sectors because especially the engineering department already has this on their agenda for a long time and are trying to have the urban development department include the subsurface in the vision-building for redeveloping the harbour area. This is already a long and slow process but a culture change is developing. The work in the M4H case provided insight into problems with regard to subsurface data transfer and possibilities to include subsurface aspects into tender documents.

For Fixfabriken, the proposed plan[13] by the Urban Planning Department in April 2015 can be considered to be in accordance with one of the least preferred alternatives in the assessment carried out within the research project. Reasons for this divergence in results are primarily because of the politically highly prioritised objective to, as fast as possible, deliver more housing in Gothenburg. In real life, this objective overruled the other objectives which were considered in the assessments in the research project. Moreover, the research project had an explorative intention and the assessments did, therefore, not consider some of the boundary conditions of the real case, e.g. the fact that the private developers would not be willing to invest money in remediating a site if the revenues by being able to sell housing in a later stage were uncertain or delayed, especially since the revenue level had already been informally guaranteed by the municipality. However, the knowledge gained from the workshops and the students' work was still used by the municipality and incorporated in the in-depth description[14] of the basis for the detailed plan proposal submitted for

[13] http://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Majorna%20-%20Program%20f%C3%B6r%20Fixfabrikomr%C3%A5det-Program%20-%20samr%C3%A5d-Program/$File/Program.pdf?OpenElement (Access date 2015-06-30) *In Swedish*

[14] http://www5.goteborg.se/prod/fastighetskontoret/etjanst/planobygg.nsf/vyFiler/Majorna%20-%20Program%20f%C3%B6r%20Fixfabrikomr%C3%A5det-Program%20-%20samr%C3%A5d-

public considerations during the period April to August 2015. It cannot be stated that the work in the research project was effective in supporting the decisions taken by the municipality, but it did, however, provide insights of a more qualitative character for the individual officials involved in developing the plan proposal.

The main focus of the work in the case studies has been on the inclusion of subsurface and sustainability aspects in the initiative and plan phases to derive the associated benefits in the realisation and maintenance phases. It is evident from the case studies that there is a large amount of available information about the subsurface, but this information is not systematically used in the planning process today. An illustrative example is the statement: "Aha, I thought it was better to involve the geotechnical engineer once the design was ready" (trans.) when discovering that the geotechnical engineer could actually contribute a lot concerning the site based on his knowledge, experience, and existing material. Such a statement symbolises that subsurface engineering knowledge is not always fully appreciated. It exists, but to be fully considered it needs to be placed in context and to be made part of the planning process. Improved coordination, cooperation and knowledge exchange between the surface and subsurface sectors within and between redevelopment phases is a precondition for an effective decision process in brownfield redevelopment. However, as the format of such knowledge exchange is typically not regulated, there is a need for an appointed person (by the organization or by own interest, with mandate to ensure cooperation between the sectors and orchestrate knowledge exchange, i.e. there must be someone consciously including this activity within the decision process.

It is also clear from the three case studies that the soil contamination issue had different importance at the different sites. In an urban setting, where land values normally are high, the soil contamination issue becomes one of many pieces in the jigsaw puzzle of urban planning. In a setting where value is harder to generate through redevelopment, soil contamination can be a stagnating factor, and public intervention is needed to start redevelopment. From an urban planning perspective, remediation is just one subsurface aspect which needs to be considered along with others, and along with other considerations not connected to the subsurface at all. Typically, the focus in the planning process is on the end-result (the plan) and not on the pathway leading there. From a remediation perspective, sustainability is not only associated with remediation technology but also with the foreseen land-use (remediation targets) and the time frame available for remediation. Smarter planning considering remediation aspects in early phases is believed to lead to more sustainable redevelopment (SuRF-UK, 2010). However, smarter planning in early phases should also include broader subsurface aspects than just soil contamination. Archaeology, energy, civil constructions, geotechnical issues and groundwater are also important to consider in early phases of planning to reach sustainable redevelopments (Hooimeijer and Maring, 2012).

The System Exploration Environment and Subsurface (SEES) method proved to be an effective communication platform for stakeholders when applied in a workshop setting, allowing for knowledge exchange and assisting in highlighting obstacles and chances for subsurface inclusion in the planning process. However, the choice of instruments is not only phase-specific but also case-

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specific. This does not only apply to the level of data availability, but also relates to communication of the results of the analyses – as reflected upon both in the Alvat case and the Fixfabriken case. In early phases, where planners normally operate, qualitative results, or semi-quantitative results may be easier to communicate than fully quantitative (although uncertain) results. Reasons for this may be the potentially large uncertainties but also its relation to other types of input in the decision process, which may be of more qualitative nature. Consciously including subsurface aspects in the generation of redevelopment alternatives is crucial. If carried out properly, the chosen sustainability assessment instruments may or may not be those that explicitly account for subsurface aspects. In the latter case, subsurface aspects are then considered indirectly by exploring the generated alternatives. As Bartke and Schwarze (2015) state, there is no perfect tool, there is always a trade-off between what is scientifically most correct and what is applicable. Based on the findings in our cases, we would argue that a tool that can support the process of communication and knowledge exchange efficiently is good enough if there, at the same time, is a conscious process of ensuring that all relevant aspects are considered, and if not covered by one tool, that additional analyses are carried out.

In the field of decision analysis, the generation of alternatives is an activity as important as their assessment (Keeney, 1982). Also in planning and design practice, the focus, in general, is on identifying alternatives as a result of mediating between different interests (Friend and Hickling, 2005). The idea to find a solution that fulfils a set of objectives to the greatest extent possible while at the same time not excessively violating interests of different groups is in line with decision analysis. Decision analysis, however, implies an explicit accounting for and documentation of the advantages and disadvantages of a set of alternatives that form the basis for the final decision. But similar to a mediating planning and/or design process, decision analysis can also be used as a way of refining options. The experience from the Fixfabriken case study was that the planning process can be strengthened by adopting a decision analysis perspective, generating clear options and then analyse those from different perspectives.

7. Conclusion: A generic framework to support knowledge exchange in the decision process

The preconditions and the applied instruments in the three cases differ widely, as well as the national procedures. Nevertheless, it was possible to learn across the three cases and the following section concludes the paper by suggesting a generic framework (Figure 4) aimed to guide project teams willing to engage in enhancing the subsurface into the planning process within existing legislation by knowledge exchange and thus to work towards a more holistic approach. To reach sustainable redevelopment strategies, not only the triple bottom line of the three P's (People, Planet, Profit/Prosperity) should be in focus, but also the context and uniqueness of each redevelopment project (the project-specific conditions) as well as the decision process itself (who and how), i.e. the fourth P.

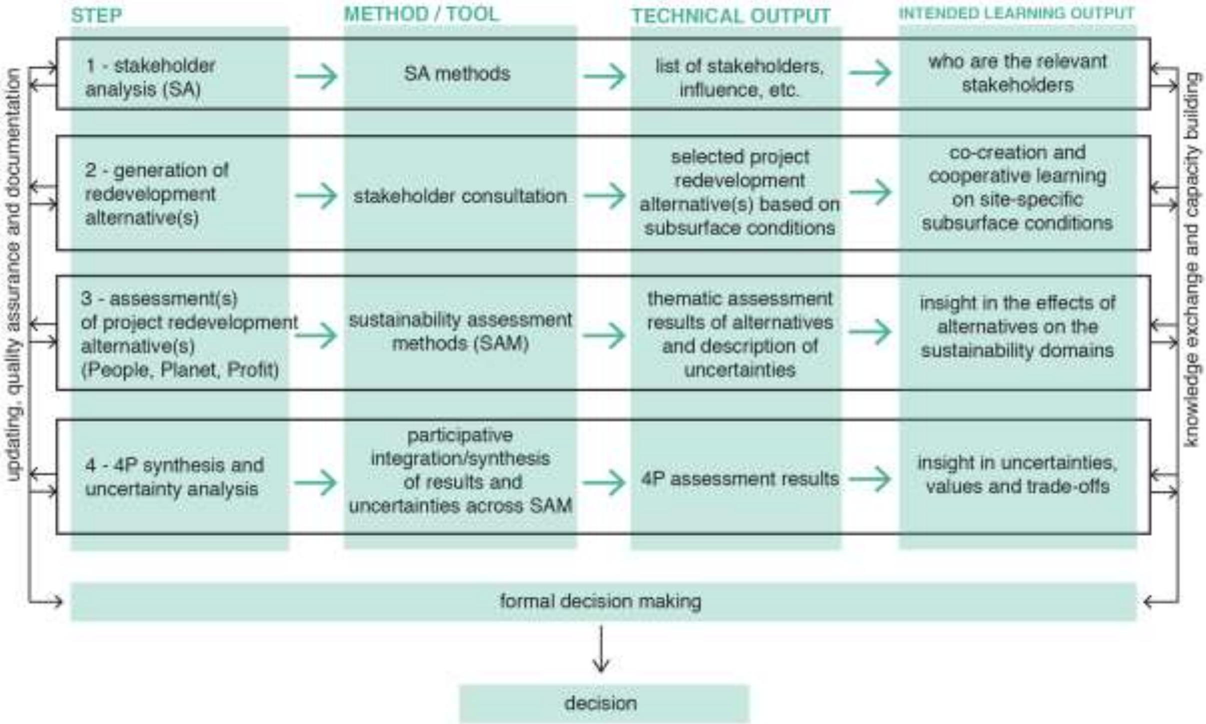

Figure 4. A suggested generic decision process framework to enhance knowledge exchange between surface and the subsurface sectors to support a holistic approach for sustainable brownfield redevelopment. Illustration drawn by Janneke van der Leer, ©Chalmers University 2015, reproduced by permission.

The suggested framework includes four steps: (1) stakeholder analysis, (2) generation of redevelopment alternatives, (3) sustainability assessment of the alternatives, and (4) synthesis of the assessment results, including uncertainty analysis. Each step represents activities that supports knowledge exchange between disciplines and cooperative learning, and inclusion of the three P's in assessing alternative redevelopment scenarios. Each step provides input to the next step but the nature of the work is optimally iterative. Such iteration is important for gradually refining the results, incorporating new information, involving new stakeholders and ensuring the overall responsiveness of the project to changing conditions. It is also important to assure the quality of the results, properly document them and communicate the essence to the stakeholders, project team members and decision-makers in approachable formats. The outlined four steps in the decision process framework are meant to support the formal decision making. It is generic enough to be applicable in each phase of the urban redevelopment process, but suitable instruments may differ between the steps.

7.1 Step 1. Stakeholder analysis

For redevelopment projects, it is crucial for the project team to map the stakeholders that are or should be involved. Focus here has been to involve also subsurface engineers in the planning process, but there are of course other crucial stakeholders since all three P's are to be considered. The stakeholder group, or their interests, might change during the project and the redevelopment phases. Therefore, the stakeholder analysis should be repeated for each phase or when (major) changes occur in e.g. boundary conditions or involved parties. However, different stakeholders are often relevant for different tasks and activities. A specific challenge is how to include absent voices, e.g. of future inhabitants or future generations. To achieve efficient knowledge exchange in communication activities, stakeholders must invest their time and contribute with their experiences and skills, and being willing to learn from others. Studies on stakeholder engagement and information needs in relation to brownfield regeneration can be found in e.g. Cundy et al. (2013) and Rizzo et al. (2015).

7.2 Step 2. Generation of alternatives

Once stakeholders are identified and analysed, consultations should be initiated in order to generate redevelopment alternatives through knowledge exchange between subsurface engineers, planners, designers and other identified stakeholders. This is at the heart of the suggested framework: a deliberate and exploratory process of including subsurface qualities and generating redevelopment alternatives based on that. The methods for stakeholder consultations in the case studies included workshop settings, face-to-face interviews, and individual student projects. Other methods for stakeholder consultations are e.g. web-based seminars, group interviews and questionnaires. However, activities involving stakeholders cannot be effective unless there is a well-structured communication platform for knowledge exchange between involved parties. In the case studies, the SEES methodology was used but not always in a workshop setting. Exchange of knowledge between sectors by interdisciplinary cooperation and collaborative learning is best achieved by physical meetings where all relevant stakeholders are actively involved. For efficient knowledge exchange it is crucial to deliver the right information in the right format, at the right time and at the right place (Busink & Schouten, 2006). The information should be delivered in a format that is understandable to the receiver, i.e. "show the maps but be the legend yourself" (Postma, 2011).

Table S1 (Supplementary material) presents a list of instruments that may specifically support generation of alternatives, including subsurface aspects. Some of these instruments may be used for a (qualitative) sustainability assessment as well, but are lifted forward in Table S1 for their potential to support the process in Step 2.

7.3 Step 3. Assessment of alternatives

Step 3 is aimed at supporting the deliberate consideration of the three P's (People, Planet, Profit/Prosperity) in the Process. The choice of the sustainability assessment tools/methods is highly project- and phase-specific since their appropriateness depends on context, stage of the redevelopment process, available expertise, data availability and national legislation. Different tools/methods can (should!) be combined in order to address all three P's. In the case studies, appropriate methods/tools were selected and used for assessment of the three P's depending on the case-specific conditions.

A summary of some available tools/methods that both handle subsurface aspects and address assessment of three P's the reader is referred to Table S2 in the Supplementary material. It is also possible to use sustainability assessment methods which do not explicitly consider the subsurface if subsurface qualities have been integrated in the generation of alternatives.

7.4 Step 4. Synthesis

Different sustainability assessment instruments may provide contradictory results since they take different aspects into account (e.g. Beames et al., 2014). The assessment results generated by different instruments may thus affect ranking of redevelopment alternatives in different ways, which indeed was the case for the Fixfabriken site. The participatory synthesis of results is, therefore, an important final step of the decision process framework. In the suggested framework, it is proposed to be performed as a qualitative and integrating analysis of the outcomes together with stakeholders. The outcome of such a deliberation is not necessarily integrated into one final figure, but can be used as input for further stakeholder discussions and subsequent decision-making. The objective of applying the assessment instruments is to bring complementary knowledge into the discussion by ensuring that the three pillars of sustainability are taken into account.

7.5 Final remarks

Practical implementation of the decision process framework may be associated with the following obstacles:

- Lack of regulatory and policy support for systematic inclusion of subsurface in the planning process;
- The quality of the information transfer during the redevelopment process when involved actors and applicable regulatory frameworks change over time;
- Limited interest of the stakeholders and planners for subsurface inclusion and sustainability assessments in the initiative and plan phases due to the complexity of urban redevelopment projects; there are typically high degrees of uncertainty and inclusion of subsurface issues add further complexity;
- Constrained planning project budget and unclear distribution of risks and costs between developers and planners with regard to subsurface investigations and solutions: who is willing to pay for early investigations if future revenues are highly uncertain?

The additional chances for enhancing the subsurface as listed in Figure 2 should be investigated further in order to explore the possibilities for a fully holistic approach, i.e. where the inclusion of the subsurface in early phases is supported on several levels. Although there may be obstacles associated with the implementation of the suggested framework and thus achieving the desired knowledge exchange and cooperative learning, the anticipated advantages of working towards a holistic approach to sustainable brownfield redevelopment are (i) redevelopment plans that allow for smart, cost-effective and sustainable solutions in the implementation process by making explicit use of subsurface information and knowledge in the planning process, and (ii) possibilities for more long-term sustainable planning with regard to the subsurface by increased awareness of the subsurface as a resource and the associated risks and possibilities.

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 (dossiernummer 50424). In addition, the Municipality of Rotterdam, Port of Rotterdam, Gebiedsteam M4H, Programmabureau Stadshavens Rotterdam and Gemeentewerken Rotterdam are acknowledged for being willing to invest both money and time into the work with the case study within the research project, and being enthusiastic about it. Hanna Kaplan, Christian Carlsson from City of Gothenburg, and Elisabeth Forsberg representing the private developers HSB and Balder are greatly acknowledged for investing time and efforts in the work with the Fixfabriken case study, and always having a positive attitude and being co-explorer, despite limitations in available time. All students and stakeholders are acknowledged for contributing with time, their skills, experiences and knowledge. Two anonymous reviewers contributed to improving the manuscript and we are forever grateful to Janneke van der Leer for drawing (and redrawing) the illustrations.

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Supplementary material

Tools and methods to support generation of redevelopment alternative(s) and subsurface inclusion

Table S1. Overview of the selected tools/methods to support generation of redevelopment alternatives and subsurface inclusion (based on Kok, 2014).

Tool/method	Description	Phase [a)]	T/M [b)]	Access	Language
System Exploration Environment & Subsurface (SEES)	The SEES method supports an interactive workshop with experts from surface and subsurface fields, and other stakeholders in order to lift forward obstacles and chances associated with subsurface in the planning process. Subsurface: civil constructions (archaeology, cables and pipes, unexploded ordnance etc.), energy (aquifer thermal energy, geothermal energy, fossil energy resources), water (water filtering and storage capacities, drinking water resource), soil quality, soil ecological diversity, geomorphological quality and landscape type, sand/clay, gravel resources, subsurface storage. The method takes into consideration the 3 P's: People, Planet and Profit/Prosperity (in terms of the mapped opportunities/obstacles). The method was applied in the all three case studies for generation of redevelopment alternatives with focus on subsurface. Link: https://publicwiki.deltares.nl/display/SEES/HOME+English	I, P	M	Free	Dutch English
De Bodem: Een Stevige Basis *'The Soil: a Solid Base'*	A method supports the optimal implementation of the subsurface in spatial planning. Subsurface: groundwater, energy, soil quality and ecology, archaeology, cables and pipes, underground civil constructions. Link: http://www.bodemambities.nl/Voorbeelden/De_bodem_een_stevige_basis	I, P	M	Free	Dutch
Ontwikkelingsmodel Ondergrond *'Development Model Subsurface'*	A guide for organisations that are engaged in spatial development: how to incorporate the subsurface in this process? After a test to see to which degree the subsurface- and planning departments are currently cooperating, the organisation follows steps to improve cooperation. Subsurface: SQA, groundwater, energy, soil ecology, cables and pipes. Link: http://soilpedia.nl/Wikipaginas/Ontwikkelingsmodel-ondergrond.aspx	I, P	M	Free	Dutch
Zeven sleutels voor waardevolle afweging *'Seven keys for a valuable consideration'*	Guidelines for incorporating the subsurface in the spatial planning process. Subsurface: pipes and cables, underground facilities, carrying capacity, archaeology, soil ecology, soil chemical quality, energy, groundwater. Link: http://www.cob.nl/kennisbank/webshop/artikel/zeven-sleutels-voor-een-waardevolle-afweging.html	I	M	Free	Dutch
Brownfield Opportunity Matrix (HOMBRE)	The 'brownfield opportunity matrix' is a means of identifying and discussing soft re-use restoration opportunities. It provides a means of identifying services from the restoration project and the interventions requited to deliver them (Bardos et al. 2016). Subsurface: SQA[c)]. Link: http://bfn.deltares.nl	I, P	T	Free	English

	Bardos, R. P., Jones, s., Stephenson, I., Menger, P., Beumer, V., Neonato, F., Maring, L., Ferber, U. Track, T. and Wendler, K. (2016) Optimising Value from the Soft Re-use of Brownfield Sites. *Submitted to special issue Sustainable Soil & Water in STOTEN.*				
Eco-Dynamisch Ontwerpen *'Eco-Dynamic Design'*	A method helps to clarify the sustainability objectives in infrastructure projects and translate them into a concrete and coherent package of measures that combine the dynamics of the natural system with possibilities in necessary construction works. Subsurface: soil ecology. Link: http://www.deltares.nl/nl/expertise/100847/lijninfrastructuur-en-industrie/2041785	P	M	Free	Dutch
Ondergrond Stratego *'Subsurface Stratego'*	A communication platform for stakeholders aimed at identifying obstacles for (conflicting interests in) underground space use in the planning process. Subsurface: cables and pipes, thermal energy storage, other underground civil constructions. Link: http://www.grontmij.nl/ondergrondstratego	I, P	M	Com-mercial	Dutch
Serious Game Ondergrond *'Serious Game Subsurface'*	A multiplayer computer game that educates the user about the role and importance of the subsurface in spatial planning. The interests of different stakeholders are represented in roles to provide insight into each others' position. Subsurface: archaeology, geology, cables and pipes, soil contamination, groundwater, underground constructions, energy. Link: http://www.bodemtool.nl/?page_id=261	I	T	Com-mercial	Dutch

[a)] The urban planning phase for which the tool/method was developed (the applicability of tools/methods does not necessarily depend on the phase but on the data availability). I: initiative phase. P: plan phase. R: realisation phase. Mn: maintenance phase.

[b)] M: method, T: tool.

[c)] SQA: Soil quality aspects related to contamination.

Tools and methods for sustainability assessment

Table S2. Overview of the selected tools/methods for sustainability assessment (further developed from work by Kok, 2014).

Tool/method	Brief Description	Phase[a)]	M/T[b)]	P1[c)]	P2[d)]	P3[e)]	Access	Language
Category I: Sustainability assessment of remediation alternatives								
Multi-Criteria Analysis (MCA) incl. CO_2 calculator	The method was developed by the Public Waste Agency of Flanders (OVAM) for assessing the sustainability of remediation alternatives. It considers 3 main impact categories (environmental, technical and financial) using both qualitative and quantitative indicators. The environmental aspect is divided into 'local' and 'regional/global' impacts. The CO_2 calculator is used to evaluate one of the 'regional/global environmental impacts', that being the carbon footprint of the different remediation alternatives. The performance of the remediation alternatives are determined by weighting and aggregating the indicator values. The method was used in the Belgian case for sustainability assessment of remediation alternatives in the urban plan/design phase. Link: http://www.ovam.be/batneec-evaluatie-met-co2-calculator	R	M/T	+	+	+	Free	Dutch
SCORE (Sustainable Choice of REmediation), incl. Cost-Benefit Analysis (CBA)	SCORE is an MCDA method which allows for transparent assessment of the sustainability of remediation alternatives at contaminated sites. SCORE evaluates the performance of alternatives relative to a reference alternative in the economic, environmental and social sustainability domains. The economic domain is addressed by means of CBA. Qualitative assessment is performed in the environmental and the social domains using scores. Although the tool was designed for remediation projects and the later development phases, it was used in the Swedish case study for sustainability assessment of redevelopment scenarios in the plan/design phase. Link: http://publications.lib.chalmers.se/records/fulltext/183067/local_183067.pdf	R	M/T	+	+	+	On request	English
DESYRE (DEcision Support sYstem for REhabilitation of contaminated sites)	DESYRE is a GIS-based software composed of six interconnected modules that provide site characterization, socio-economic analysis, risk assessment before and after the technologies selection, technological aspects and alternative remediation scenarios development (Pizzol et al., 2009). The decisional process implements a Multicriteria decision analysis (MCDA) methodology which supports the ranking of rank remediation technologies and the selection of alternative remediation scenarios to be discussed with decision makers and stakeholders. It can support the definition of remediation plans and the design of remediation/regeneration plans. Moreover, it can support the analysis of different land uses on the basis of a socio-economic perspective. Subsurface: SQA[f)], HR[h)]. Pizzol, L., Critto, A., Marcomini, A., 2009. A spatial decision support system for the risk-based management of contaminated sites: the DESYRE DSS. In: Marcomini, A., Suter, G.W., Critto, A. (Eds.), Decision Support Systems for Riskbased Management of Contaminated Sites.	(P), R	T	+	+	+	Free/ On request	English

	Springer, New York. Link: http://www.iemss.org/iemss2002/proceedings/pdf/volume%20tre/287_critto.pdf							
Sustainable Remediation Tool (SRT)	The SRT tool allows for the comparison of the following remediation technologies according to sustainability metrics: excavation, soil vapor extraction and in-situ thermal desorption, in the unsaturated zone; and pump and treat, enhanced bioremediation, in-situ chemical oxidation, permeable reactive barriers and monitored natural attenuation in the saturated zone. The tool combines an environmental footprint assessment and a total cost evaluation. SRT also includes a module for allowing stakeholders to weight the different environmental impacts and total cost. Subsurface: SQA[f)]. Link: http://www.aecom.com/News/Innovation/_projectsList/U.S.+Air+Force+Sustainable+Remediation+Tool	R	T	+	+	+	On request	English
GoldSET	GoldSET is an MCDA-based tool developed for oil and gas, public sector, waste water management, transportation, mining, remediation and construction. Management alternatives are compared using a range of different quantitative and qualitative indicators within four general sustainability domains: environmental, social, economic and technical. Subsurface: SQA[f)]. Link: www.gold-set.com	I, P,	T	+	+	+	Commercial	English
Risk Reduction, Environmental Merit and Costs tool (REC)	The tool is a decision support system based on multi-attribute value theory considering contaminant risk reduction, environmental impacts and costs associated with remediation alternatives. Subsurface: SQA[f)], ER[g)]. Link: http://www.ivm.vu.nl/en/projects/Archive/REC/index.asp	R	T	+	+	+	On request	English Dutch
Symbiosis in Development (SiD)/ Urban renaissance	'Urban Renaissance' is a system for sustainable redevelopment of neighbourhoods, cities and regions, using the Symbiosis in Development (SiD) framework as a basis. The tool uses eight categories: materials, energy, ecosystem, species, health, culture, happiness and economics. Link: http://www.except.nl/en/articles/148-symbiosis-in-development-sid	I, P, R, Mn	M	+	+	+	Commercial	English
Category II: Sustainability assessment of reuse scenarios at brownfields								
Matrix Decision Support Tool (MDST) or SAMLA	The tool provides a basis for discussion and interactivity in the spatial planning process. It includes an assessment of environmental, social and economic aspects to support climate-change adaptation strategies and other municipal management and land-use decisions, such as potential soil remediation strategies (Andersson-Sköld, 2014). Subsurface: SQA[f)]. Andersson-Sköld, Y., Suer, P, Bergman, R., Helgesson, H., 2014. Sustainable decisions on the agenda – a decision support tool and its application on climate-change adaptation, Local Environment, DOI: 10.1080/13549839.2014.922531 Link: http://www.swedgeo.se/upload/publikationer/Varia/pdf/SGI-V612.xls	I, P	T	+	+	+	Free	Swedish

Megasite Management tool suite (MMT) (TIMBRE)	'MMT' is a software tool for finding the optimal reuse scenario for large contaminated sites based on (remediation) costs, economic feasibility and a sustainability assessment. It involves stakeholders in determining problems and sustainability indicators for the site and it guides the process from the initiative up to the planning phase: the optimal scenario is determined and represented in a map of best practice land-use classes. Subsurface: SQA[f)], HR[h)]. Link: http://www.ufz.de/index.php?en=19610	I, P	T	+	+	+	Free	English German
Site Assessment and Land Re-Use Planning Tool (SAT) (TIMBRE + UFZ)	A web-based decision support tool for defining the optimal land-use scenario for the site based on subsurface remediation costs, the market value of land and assessments of health risks and sustainability. 'Expert' and 'light' versions are available. Subsurface: SQA[f)], HR[h)]. Link: http://www.timbre-project.eu/en/site-assessment-tool.html	I, P	T	+	+	+	Free	English
SMARTe	SMARTe is a decision support system for developing and evaluating future reuse scenarios for potentially contaminated land. SMARTe includes open source tools for stakeholder analysis, assessment of HR and ER, and financial calculation. Subsurface: SQA[f)], ER[g)], HR[h)]. Link: www.smarte.org	I, P	T	+	+	+	Free	English
Brownfield Remit/Response (BR2) tool (HOMBRE)	A systems-based approach, Brownfield REMIT/RESPONSE (BR2), to assess the impact of brownfield redevelopment on the surrounding urban area has been developed. This utilises REMIT/RESPONSE combined with urban theory to develop a dynamic model of the generic impact of brownfield redevelopment that when combined with site-specific information can be used to identify and compare the impact of different redevelopment options.. Subsurface: SQA[f)]. Link: http://www.zerobrownfields.eu/HombreTrainingGallery/HOMBRE_D6.2_final.pdf Accessed August 2015	I, P	T	+	+	+	Free	English
Category III: Sustainability assessment of urban planning scenarios with specified subsurface aspects								
Omgevingswijzer *'Environment Indicator'*	A tool helps to assess the sustainability of projects in a systematic manner. By rating impacts on indicators in the environmental, social and economic domains, a clear overview of project performance is provided to project members in order to facilitate scenario assessment and communication. Subsurface: SQA[f)], energy. Link: https://omgevingswijzer.org/	P	T	+	+	+	Free	Dutch
Ambitieweb '*Ambition web*'	A web-based diagram for defining the level of ambitions for a project using 7 'sustainability' themes, i.e. energy and climate, materials, accessibility, water and soil, nature, living environment, and profit. Used to facilitate workshops with stakeholders. Subsurface: SQA[f)]. Link: http://www.aanpakduurzaamgww.nl/pdf/Het%20Ambitieweb%20%28factsheet%29.pdf	I	T	+	+	+	Free	Dutch
Duurzaamheidsprestatie op Locatie (DPL)	A sustainability assessment tool with multiple applications: assessment of the sustainability of project scenarios; comparison and monitoring of neighbourhoods; setting sustainability	I, P	T	+	+	+	Com merci	Dutch

'Sustainability Achievement on Location'	ambitions for a project and improve communication on integration of the subsurface and natural system in urban planning. Modules include Subsurface, Financial profile, Climate, BiodiverCity, and Business area. Subsurface: geological value, archaeology and cultural history, soil, groundwater, biodiversity, carrying capacity, renewable energy from the ground, water, underground construction, cables and pipes. Link: http://www.ivam.uva.nl/dpl-ondergrond						al	
BodemTool (Soil Tool)	A software tool allowing for 3D visualization of the planning area, including the subsurface. It helps to assess the effects on people, planet, profit, project and public. Subsurface: soil structure, cables and pipes, and underground facilities. Link: http://www.bodemtool.nl/	I, P	T	+	+	+	Com merci al	Dutch
Category IV: Sustainability certification in development projects								
BREEAM and the Code for Sustainable Homes	A method that supports local planning authorities by providing them with a guide on sustainable design and construction, and a scheme for rating and certifying the performance of new homes. Link: http://www.breeam.org/page.jsp?id=268	I, P, R, Mn	M	+	+	+	Com merci al	English
BREAAM-NL Gebiedsontwikkeling *'BREAAM Spatial Development*'	A method that not only consider the sustainability performance of a single building, but of an entire area. Area developments are assessed on six sustainability categories: area management, synergies, resources, land development, welfare/prosperity and area climate. Subsurface: Link: http://www.breeam.nl/gebied/breeam_gebied/	I, P, R, Mn	T	+	+	+	Com merci al	Dutch
Category V: Complementary assessments								
Cost-Benefit Analysis	A method for assessing the economic value of the parcel after remediation and redevelopment. The method was used in the Belgian case study to calculate net income for alternative redevelopment scenarios and alternative configurations of land use (industry, residential low and high density), i.e. the amounts available to cover for expenses and risks for the investor. Link: http://www.ruimtelijkeordening.be/NL/Diensten/Onderzoek/Studies/articleType/ArticleView/articleId/8833/Analyse-van-de-financiele-gevolgen-van-ruimtelijke-beslissingen-kader-en-beschrijving-van-enkele-situaties	R, Mn	M	-	-	+		Dutch
Social Impact Assessment (SIA)	The SIA tool is developed by the City of Gothenburg for planning and design phase of development process. It is a simple matrix, which takes four different social aspects into consideration: Cohesive city, Interactions, Everyday life and Identity. Those aspects are analysed with regard to five different scales: Buildings and places, Neighbourhood, District, and City. The matrix was used in the Swedish case study to investigate the social impacts with regard to alternative redevelopment strategies against the current situation.	P	T	+	-	-	Free	Swedish

	Link: https://goteborg.se/wps/wcm/connect/7a225b9b-821e-435d-80ba-f3fba09fd443/OPA_SKA.pdf?MOD=AJPERES							
Nature Value Explorer (NVE)	The Nature Value Explorer is an online tool, developed for the Flemish government, to explore the impact of ecosystem restoration on human welfare. Different valuation techniques can be applied: (i) qualitative scoring how important a service is in a specific area, (ii) quantitative valuation of the importance of ecosystem services in physical terms (e.g. tons of C sequestration, amount of visits per year), (iii) monetary valuation of the societal value. The tool was used in the Belgian case study to monetize ESS[i]. Link: www.natuurwaardeverkenner.be	P	T	-	+	+	Free	English Dutch
Biodiversity check	The tool is developed by the non-profit organization "Vrienden van Heverleebos and Meerdaalwoud" (VHM) with the purpose to provide insight to project developers and urban planners into the impact of spatial developments on the value of nature and biodiversity of a certain project site. The tool was used in the Belgian case study for qualitative assessment of the effects on ESS[i] associated with redevelopment scenarios. Link: www.biodiversiteitstoets.be	P	T	-	+	-	Free	Dutch
ESS mapping (Ecosystem Services' mapping)	A method for mapping changes in ESS[i] (associated with different redevelopment scenarios) includes three principal steps: (1) identification, (2) quantification, and (3) valuation. The process is guided by a "check list" made up of soil and urban ESS gathered from the literature. The method was used in the Swedish case study for qualitative assessment of the impacts on ESS (i.e. addressing only Planet). Reference: Ivarsson, M. (2015). Mapping of Eco-System Services in the Fixfabriken area. Method development and case study application.	I, P	M	-	+	+	Free	English

[a] The urban planning phase for which the tool/method was developed (the applicability of tools-methods does not necessarily depend on the phase but on the data availability). I: initiative phase. P: plan phase. R: realisation phase. Mn: maintenance phase.

[b] M: method. T: tool

[c] P1: people. [d] P2: planet. [e] P3: profit. . -: no indicators incorporated in instrument. +: indicators incorporated in instrument.

[f] SQA: soil quality aspects related to contamination. [g] ER: ecological risks. [h] HR: human health risks. [i] ESS: ecosystem services.