

## Intelligent SUBsurface Quality

### Intelligent use of subsurface infrastructure for surface quality

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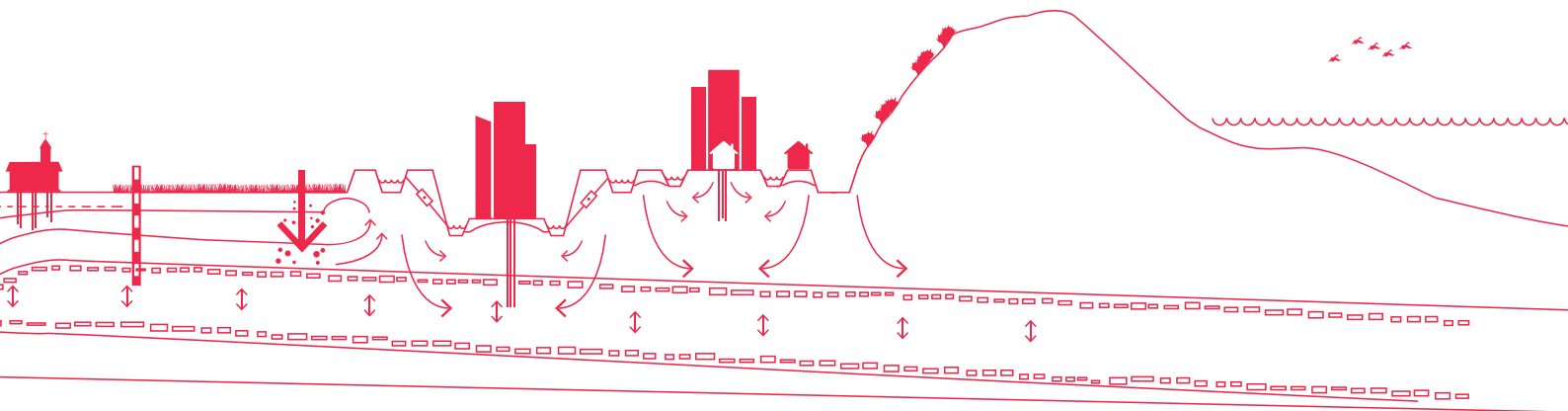
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# Intelligent SubSurface Quality 001

*Intelligent use of subsurface infrastructure for surface quality*



## Colophon

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This project is situated in the DIMI theme safe, sustainable deltas and metropolises with the connecting theme of resilient, durable infrastructure. It focuses on the urban renewal of (delta) metropolises and concentrates on the question how to design resilient, durable (subsurface) infrastructure in urban renewal projects using parameters of the natural system – linking in an efficient way (a) water cycle, (b) soil and subsurface conditions, (c) soil improvement technology, and (d) opportunities in urban renewal (e.g. urban growth or shrinkage). The subsurface is the technical space, the engine room of a city, housing the vital functions of water, electricity, sewers and drainage, but also housing the natural system that is crucial for a stable, green, healthy and livable city. Especially the effects of climate change, the boosts for an energy transition and the fact that there are less financial mean makes the intelligent use of the subsurface more important.

At this point there is no spatial planning of the subsurface, moreover in the trend of designing green/blue infrastructures the benefits of building with nature on the surface level are claimed over

the costly replacement or renewal of subsurface networks. By understanding and re-designing the engine room we aim for a more efficient overall system (starting from the subsurface and reflecting on the surface level). Moreover, the subsurface is a crowded place and without planning it there is no room to make use of novel solutions that the subsurface can offer cities for managing water, heat and renewable energy or underground space more efficiently.

In addition to this, underground infrastructure is very inflexible and can be viewed as a corset to urban form. Here the development of new and more flexible (decentralized) technical systems are interesting, especially when they are connected to solutions for the larger scale of utilities.

Besides the lack of planning in the subsurface and the global trends described above, this project answers to a demographic trend where urbanization is projected as being more dense in urban centers (growth) and less dense in the countryside villages (shrinkage). This is true especially for the Netherlands, however, global trends show that there will be more urbanization but that densities are decreasing due to more

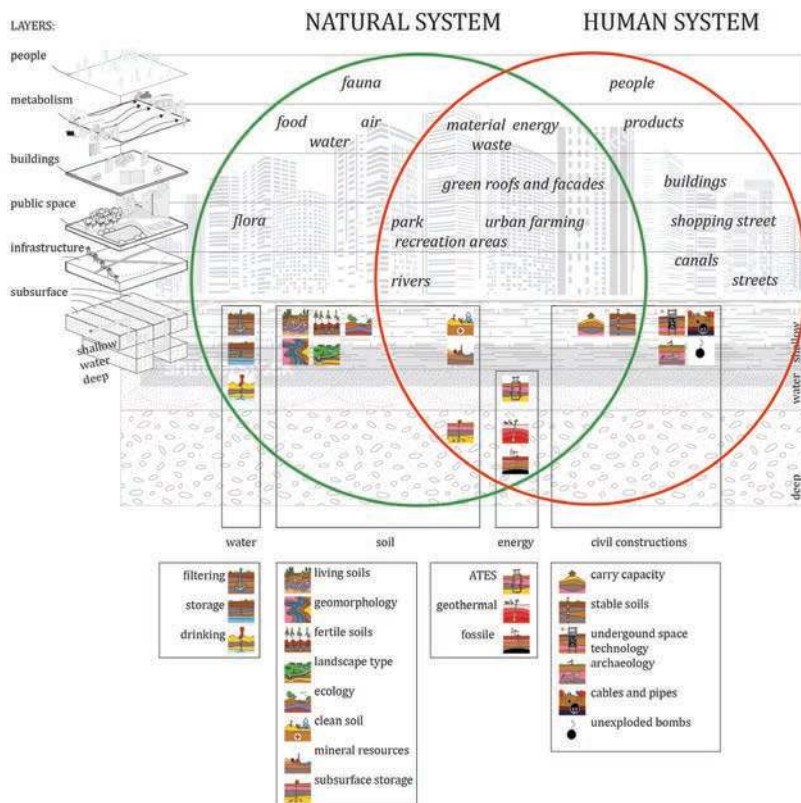


Figure 0.1 Overview of how the natural and human systems are intertwined and how this is also making the surface and subsurface one united space. Source: Hooimeijer & Van Campenhout

space demanded as a result of socio-economic capital accumulation. In both situations, this trend has great influence on design and organization of the technical space, especially in Delta areas where managing soil and water layers is crucial to establish basic physical conditions for urbanization. The densifying urban areas put pressure on vital utilities to service more people, more pressure on space and especially subsurface space where these utilities are housed. As an impact of urbanization, the urban fabric suffers more from severe rainstorms because of soil sealing. At the same time, heat island effect is determined by the availability of open soil, in which blue and green play a crucial role.

In shrinking villages the issues are quite different - vital utilities serve less people which requires existing systems/technologies in place to be adapted. Furthermore, when dealing with higher stormwater quantities, triggered by climate change and urbanization, these areas often become part of water management strategies at larger scales. Therefore, shrinkage has a large impact on the organization of urban development for the maintenance of amenities and public facilities.

### **Research approach**

Considering the issues mentioned, the first step of the project aims at relating technologies developed by disciplines dealing with subsurface to urban design and planning. In particular the focus will be on their potential future synergies and their contribution to urban quality. The main question that drives the research is: How can the different technological artefacts in the subsurface be synchronized offering more space and adding to a better urban quality?

The first part of the research has a broader inquisitive character and was set up according to

the method of Van den Dobbelsteen et al. 2006, which explains the relation between the principles of forecasting, backtracking and backcasting - shown in Figure 0.2. In short they can be defined as (Van den Dobbelsteen et al. 2006):

- Forecasting means 'to estimate the consequences of current developments and our own interventions on long-term effects'.
- Backtracking means to base solutions 'on historical circumstances at the time when there still was a sustainable equilibrium.'
- Backcasting means 'to describe a desired future state at a certain point in time and to translate this state into strategies and measures that we need to develop now.'

The results of this inventory are presented in a first multidisciplinary workshop where possible synergies and reciprocities between the technologies and the relation to (future) urban quality are identified. These ideas and research questions are then evaluated in relation to future scenarios (climate change and urbanization) by urban planners and designers. In a second workshop, these scenarios are then discussed within the multidisciplinary group of experts of the subsurface and urban development aiming at the establishment of a common research agenda. To create a synergistic approach in which a hybrid thinking add solutions beyond the multidisciplinary input, a different type of teamwork is required. The interdisciplinary aims at creating synergies between aspects of theory, method, and process leading to an integrated approach across the different fields. This objective can be facilitated by describing the roles and the working methods of the different experts in a particular context. The DIMI context is the ideal ground for experimental tryout and evaluation of team development in an interdisciplinary context composed by different engineering profiles.

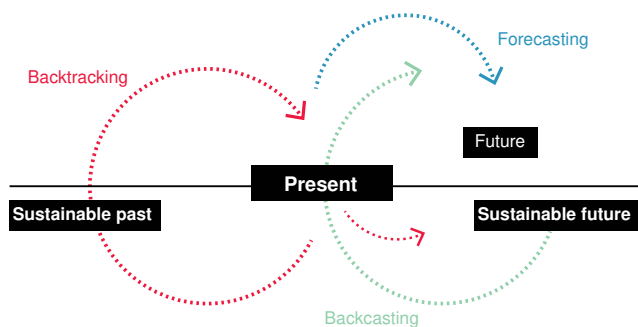


Figure 0.2  
A graphic representation to clarify the principles of forecasting, backtracking and backcasting. (Adapted from: Van den Dobbelsteen et al., 2006, p.3, drawn by F. Lafleur)

## Engineers of the future

Department:

Technology:

Expert:

A "Free Spirits" Think Tank has been set up as a joint initiative of the Dutch 3TU.Centre for Engineering Education and TU Delft's Directors of Education. Its aim is to look ahead to the year 2030 and reevaluate what students' capacities should be, without losing their current core strengths. In five dedicated workshops with 12 senior academic staff, members of the valorisation centre and student bodies, the Think Tank challenged the following key questions:

- What type of students does TU Delft want to educate?
- What are the major changes our students will face in 2030?
- What is the added value TU Delft can deliver in terms of educational content?
- Which learning processes help to sustain preparation of the future engineer?

The Think Tank explored various answers via the method of Design Thinking, known for its effective creation of out-of-the-box solutions for new ways of working. They also set up different pilot projects to explore and discuss the key questions. This special project is one of these pilots because of its interdisciplinary nature in topic and constellation of people in the DIMI project. In line with the project the method of forecasting, backtracking and backcasting is used to get a grip on the future perspectives for engineering curricula and team development in engineering.

Work within this project includes the exploration of working in these profiles, providing more depth to the profiles, validating their relevance for engineering education and engineering interdisciplinary research. The hypothesis is that the integration of different disciplines and the efficiency in team approaches will increase. The ultimate goal is that participants will be able to implement different profiles in their own context to the benefit of the sub-surface engineering for urban space.

### Past

In the past engineers were people who devised

3TU Centre For Engineering Education - TUD

Designing Education for Engineering curricula, team development in Engineering

Dr. Renate Klaassen

skillful and practical inventions. The word engineering is derived from the Latin word ingenium, which means innate quality of mental power. The first engineers in the 13th century were in the army developing military machines and bridges important for military maneuvers. In the middle of the 19th century the civil engineering academy started and here typical engineering topics were mechanics, chemical and hydraulic engineering. At the beginning of the 20th this expanded with electrical, aerospace, mining etc. and in the recent past many sub-disciplines have emerged such as computer, molecular, nanotechnology, mechatronics engineering etc. Each type of "New" Engineers emerged after yet another technological revolution, pre-scientific revolution buildings in the renaissance and an

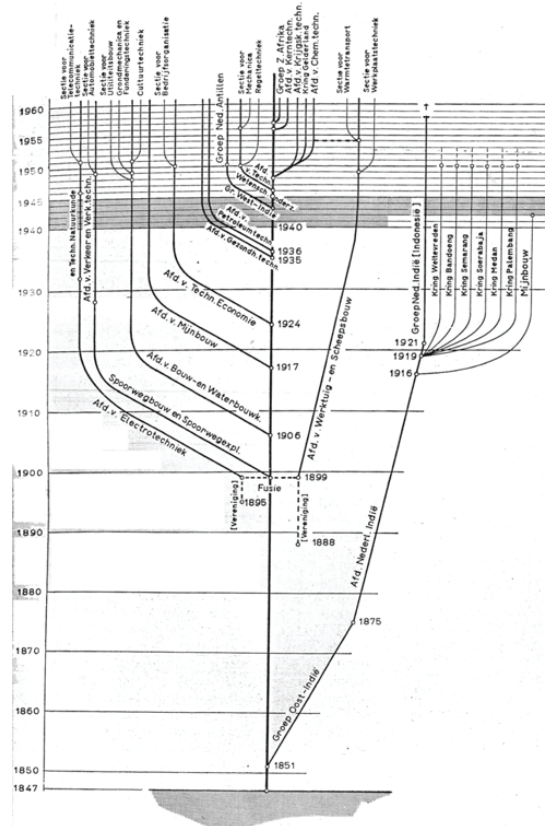


Figure 0.3 The Royal Society of Engineers and development of specialists groups within it. Source: De Ingenieur

WORLD ECONOMIC FORUM  
CONSTITUTION FOR THE FUTURE

### Navigating the next industrial revolution





Revolution	Year	Information
	1 1784	Steam, water, mechanical production equipment
	2 1870	Division of labour, electricity, mass production
	3 1969	Electronics, IT, automated production
	4 ?	Cyber-physical systems

Figure 0.4  
 Overview of engineering impact on society.  
 Source: WorldEconomicForum

engineer like Leonardo Da Vinci. The industrial revolution (18th-19th century) triggered the mechanical engineering to be developed, based on water and steam power. The second industrial revolution before WW II, was the playground for chemical, electrical engineering, mass production transportation based on electrical power. The information revolution gave us microelectronics to automate production (Lintsen, 1985).

#### Present

Today the 4th revolution has arrived with a fusion of technology blurring lines between physical, digital and biological spheres. The velocity, scope and systems impact is larger than any prior revolution. Artificial Intelligence with self-driving cars, drones or virtual assistants are not exceptional anymore. Digital fabrication technologies are interacting with the biological world. Engineers are combining computational design, additive manufacturing and e.g. synthetic biology to create symbioses between body environment and product.

*“Today an engineer is described as someone who has acquired and is applying their scientific and technical knowledge to designing, analyzing and building useful, helpful and functional works. This would involve structures, machines and apparatus, manufacturing processes as well as forecasting their behavior in particular environmental conditions. This is all accomplished with functionality, operational economics and safety to life and property forefront in mind”* (Terrazas). If at one hand industry shows exponential growth in all areas of digitization, on the other our education systems is yeat rather slow in updating its

programs to a newly emerging world.

#### Future

In the future the economy will be driven by customer expectations. Product development will be refined with digital capabilities included in their design. People will work together to mine the vast amount of big data as innovation and disruption continue in a dazzling speed. Big data will be equally used as control mechanism by government and other institutions. It is supposed to avoid harmful warfare via new biological, technological and cyber weapons. The participatory society, in which people have decentralised power, will create mazes in the enforced policy rules and regulations. Research reports issued by governmental legislators or policy makers will be less relevant due to the speed of developments. Climate change and security issues as shown in this report will challenge researchers, regulators, civil participants and business partners to jointly and continuously reinvent the rules.

Only 30% is likely to be prepared to an increased demand in digital technology. This will put pressure on jobs and society, resulting in low skilled/low pay jobs and highly skilled/high pay jobs and robots taking over part of the labor. Furthermore, places suffereing from climate change impacts and socio-economic/ spatial inequality and displacement will demand major changes in the urban areas (Brynjolfsson, 2016). These are only a few of the 4th revolutions trends framed at the world economic forum in 2016 Davos. The expectation is that different type of engineers are needed who while reshaping human life through technological development



are bound to address moral and ethical dilemmas. The engineer faces different sets of problems. The high environmental change disruption requires different needs and requires rapidly changing sets of skills, task and jobs. Jobs are being fragmented and combined in different and new ways, due to work that can be done any place, time and anywhere. Addressing the fourth revolution requires engineers that can work from different profiles (according to the Free Spirits Think Tank) in vastly different contexts, in collaboration with different specialists to create the best solutions for new world scenarios. It is presumed that global digital identities will contribute to solutions being devised at the place where the best talent at that moment is available.

The specialist provides input for the systems

The idea is that when we are aware of our roles we can offer multiple perspectives on the questions that can be addressed while framing a problem starting from each role. One is better able to enact ones role and contribute to the team's final goals. The assumption is that in particular context we choose for our strength. Additionally we expect that these roles are contextually determined by each new setting. So in one setting we might play the role of systems integrator, however, in another we may focus more on the specialist role.

Testing the profiles has four purposes:

- Making a start with the validation of the questionnaire that is developed to define the balance of the profile of people;
- Researching the added value of these roles

Profile	Issues	Example
<b>Front End Innovator</b>	Industry/House hold/personal needs of people living in urban area and finding immediate technological solutions.	Health/Sanitation/Shelter from rain/radiation etc. Technology needed to address these issues
<b>Systems Integrator</b>	Urban planning of (sub)- surface linked to needs, taking calculated risk/providing risk prevention systems, bringing specialists together	
<b>Specialist</b>	Water management transport/systems/ground/soil /buildings- specialist to develop technological solutions/advise SI and FI and CE	
<b>Contextual Engineer</b>	Legislation, ethics and politics for arguing the sustainable solutions that have been jointly developed to solve the complex problems faced in the DIMI project	

Table 1:  
To support the design of future education of engineers four profiles are developed: Front end innovator, Systems integrator, Specialist and Contextual engineer:.

integrator from a technological perspective. The Front End Innovator provides information to the systems integrator on the emerging human needs and translates these for the specialist into workable research questions. And finally, this person arranges together with the Front End engineer the regulations needed to execute the plan. This is necessarily an iterative process. The roles can either shift in emphasis through time or different people focus on different roles in a parallel time and work together interdisciplinary to get a grip onto the societal problem to be solved. Key questions to the team are:

- Does one come up with a different questions and solutions when incorporating these profiles.
- How can we embed this to the advantage of the groups' results.

when working in multidisciplinary teams (when each team member chooses a role);

- Discovery whether all these roles should be addressed during the engineering education studies and what it really consists of;
- Describe how the roles are shaped by previous experiences in learning/working in engineering contexts.

These questions have been made an integral part of the project an interwoven in the activities in the workshops.

## 2/ Introducing the technological domains

The aim of this chapter is to introduce the technological domains that have an important role in the process of urban development. The idea starts from the need to construct a common language between specific technical fields and to research the past, present and future technologies in order to have a systemic perspective over their deployment.

Moreover in order to understand the position of technologies in the subsurface, a 'subsurface' matrix was developed to help visualize the different depth and the potential conflict between them. The matrix will serve as a descriptive table in which present and future technologies are projected with the aim to find synergies and reciprocities within the space of the subsurface.

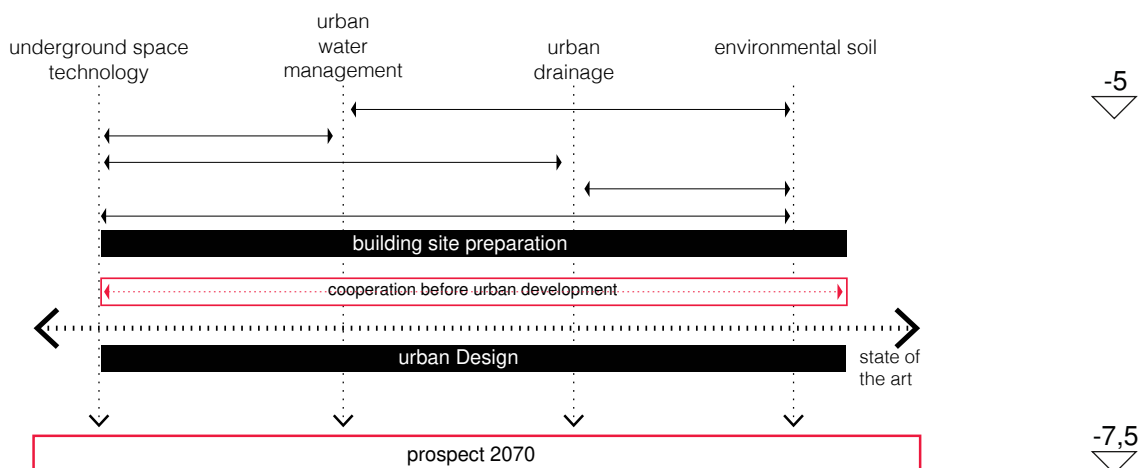


Figure 1.0 showing the state of the art and the possible development of a cooperative model for Urban development and the stakeholders involved, drawn by F. Lafleur

Department:	CiTG/ Geo-Environmental Engineering
Technology:	Biogeocivil subsurface engineering for soil improvement
Expert:	dr. Susanne Laumann

## **Introduction**

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The utilization of natural processes for engineering purposes has been widely discussed in recent years since it might enable the development of cost-effective, robust and environmentally compatible engineering technologies. Within the field of biogeocivil subsurface engineering we aim to use naturally occurring processes to improve soil properties such as the permeability and the strength. Although several civil engineering techniques are available for this kind of purpose, their application gets increasingly complicated with increasing operational scale, for example, in long stretches of canals and dikes or in cities. The STW funded project SoSEAL (SOil Sealing by Enhanced Aluminum and dissolved organic matter Leaching, SoSEAL project proposal, 2013) uses natural processes to reduce the permeability of soils in situ and thus to control the infiltration or seepage of water in subsurface systems. Subsurface permeability can be reduced by precipitation of metal-organic matter (OM) complexes, which is commonly known from podzolization (see figure 1.5). This is a soil formation process, where the mobilization and subsequent leaching of metals, mainly aluminium and iron, and OM in the topsoil followed by their illuviation/ precipitation at greater depth. The accumulation of Al/Fe-OM precipitates results in the formation of an almost impermeable soil layer

(Lundström et al., 2000).

Two other techniques which aim at using calcite precipitation to improve soil properties are BioGrout and EcoGrout. Both techniques are based on Microbial-Induced-Carbonate-Precipitation (MICP) and can reduce soil permeability and increase its strength. BioGrout uses the hydrolysis of urea to precipitate inorganic carbonate minerals (De Jong et al, 2006, van Paassen, 2009). Commercial application is however limited due to the cost of bacteria cultivation and ammonium removal, which is produced as byproduct during the reaction. MICP by denitrification (also called EcoGrout) has therefore received increasing attention as a beneficial soil improvement technique within the last years (van Paassen et al., 2010).

In order to utilize these different natural processes it is necessary to understand which physico-chemical factors are decisive for inducing precipitation of Al-OM complexes and calcite and to what extent the precipitates affect the permeability and in case of calcite also the strength. Work within the projects therefore includes research on the biogeochemical factors controlling precipitation, the development of comprehensive numerical models incorporating all relevant processes as well as upscaling experiments from the lab to the field scale.

## **Past**

In the past, land use and urbanization was restricted to locations where the soil type met the required properties, for example, fertility and stability. Increasing research within the field of soil mechanics revealed that there are numerous soil characteristics like load-bearing capacity, compressibility and permeability that need to be considered before building or landscape construction (Hooimeijer, 2015). The field of soil improvement developed from this knowledge and the wish to alter these soil properties has triggered innovation in order to improve soils performance. One of the oldest and simplest

methods for soil improvement is the removal and replacement of soil (see figure 1.1). This basic idea is followed by other methods such as preloading and drainage that actually use the existing soil and change its properties according to the particular use of the ground (Nicholson, 2015).



**Figure 1.1,**  
showing Soil Improvement by filling of land.  
Source: De Ingenieur

## **Present**

Increasing urbanization lead to the development of numerous soil improvement techniques such as surface compaction, precompression, consolidation as well as drainage and vibration methods that are applied on a regular basis. The choice for the most suitable technique is nowadays made not only based on the physical characteristics of the soil but also based on social, political and economic factors (Nicholson, 2015). Each of the techniques has its own advantages and disadvantages in relation to time, cost and performance. The installation of sheet piles for example can result in the settlement of the adjacent buildings due to vibrations. Grouting fluids that are injected into the subsurface contain hazardous and toxic ingredients that can affect people, livestock and groundwater supply. Therefore, more and more attention has been placed in recent years on methods that assure less environmental impact and are accepted by the local residents (STW 'perspectief' program BioGeoCivil; Jonkers and Van Loosdrecht, 2010). This greatly changes the way that construction projects are undertaken and also effects the

methods, equipment and materials used for soil improvement. New techniques such as the design with geosynthetics or the use of natural processes (biogeocivil engineering, Jonkers and van Loosdrecht, 2010) are emerging with new ideas and application fields every year. BioGrout, for example, has been shown to be able to strenghten granular soil not only on a laboratory but also on a field scale (De Jong et. al. 2013). EcoGrout and SoSEAL are following.

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**Figure 1.2:**  
Sheet piles to secure the dike along the river Mulde, Germany.  
Source: <http://www.constructalia.com>



**Figure 1.3:**  
Jet grouting to surround a radioactive waste landfill  
Source: <http://www.haywardbaker.com>

## ***Future***

With increasing environmental awareness a shift occurred towards sustainable engineering technologies that apply the principle of 'Building with Nature'. This principle integrates infrastructure, nature and society in new or alternative forms of engineering that meet the global need for intelligent and sustainable solutions. One example for a successful project applying this principle is the Marker Wadden project where a number of nature islands in the Markermeer were build using the sediments that have accumulated in the lake in recent decades (Natuurmonumenten, 2015).

This paradigm shift also results in the reduced application of traditional engineering techniques for soil improvement. This is not only related to the costs of these measures but especially to their impact on the surrounding environment and their sustainability. Biogeocivil subsurface engineering is one field within the new generation of soil improvement techniques that allow for predictable, reproducible and sustainable improvement of soils. Based on the increasing knowledge within the field, various soil improvement measures

using different natural processes are designed and applied in the field. These measures can be chosen based on site specific needs and can therefore be applied within various fields starting from water safety and water management to construction and urban development.



**Figure 1.4:**  
Marker Wadden project, building with sediment  
Source: <https://www.natuurmonumenten.nl/marker-wadden/>



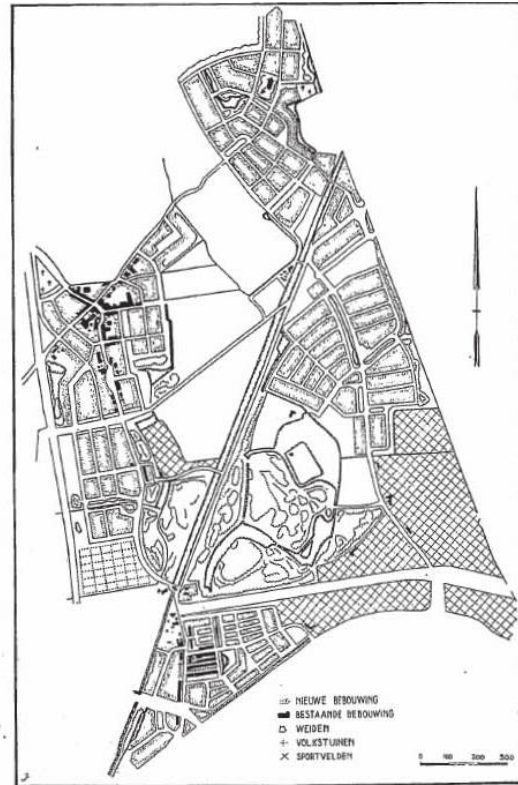
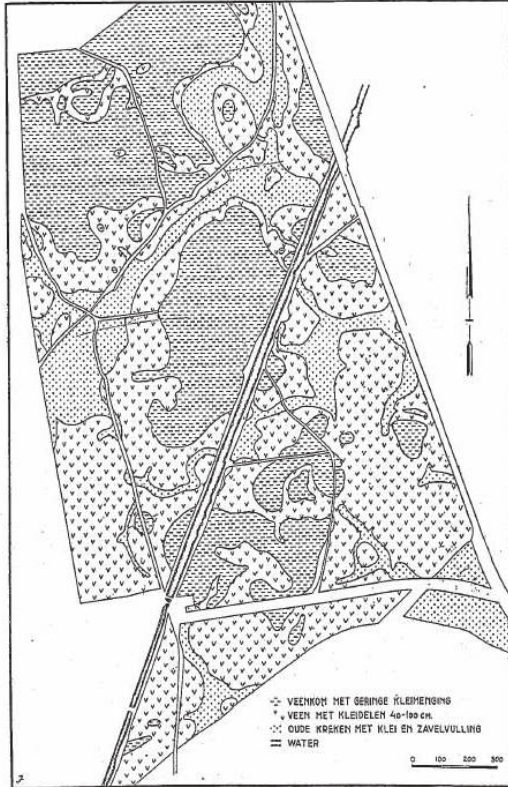


Figure 1.5:  
 Design for Kethel (north of Schiedam).  
 Left: the soilmap of the village Kethel.  
 Legend:  
 1. Peat.  
 2. Peat with clay.  
 3. Clay and sandy clay (old creeks).  
 4. Water.  
 Right: the townplanning map of the village Kethel.  
 Legend:  
 1. New planned houses,  
 2. Existing buildings,  
 3. Pasture land,  
 4. Allotment gardens,  
 5. Playgrounds.  
 Source: Bijhouwer 1947

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Figure 1.6:  
 Podzol  
 Source: <http://www.isric.org/about-soils/world-soil-distribution/podzols>

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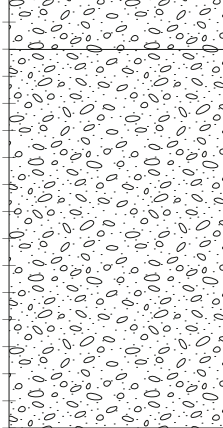
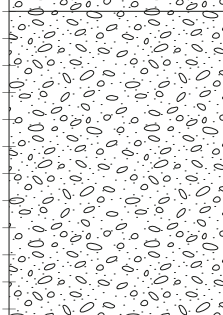
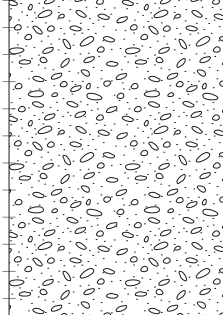
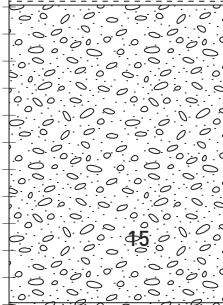
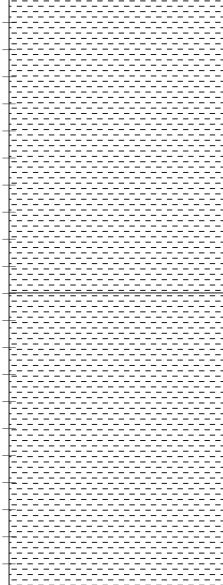
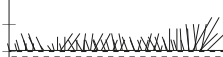
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Department:

CiTG/ Sanitary Engineering

Technology:

Drainage systems

Expert:

prof. dr. ir. Francois Clemens

## **Introduction**

16

Urban drainage systems are essential elements of the interaction between natural water cycle and human activity in the urban setting. Their scope is to manage the rainwater received on the urban surface, groundwater level and the wastewater produced by human activities. These types of water are characterized by highly variable flows in terms of water quantity, quality and solids content. This is why drainage systems in use today are diverse, differing in the fundamental drainage concept, system layout and mode of transport. The major objectives of urban drainage are public hygiene, flood protection and pollution control (Unesco-IHE, 2013). Traditionally, underground combined systems that collect both stormwater and wastewater have been used to protect urban environments from harmful effects, but in the last century they resulted to be not adequate and too rigid to face the climatic and demographic challenges. More and more intense stormwater overloads the sewer system increasing the risk of flooding and thus pollution. At the same time, urbanization leads to larger and denser urban areas, stressing the performance of drainage systems and posing new environmental and social requirements. Specifically, new innovative solutions have to be found to solve spatial issues in the subsurface. Drainage systems have to handle more water, but their flexibility is limited

and space for bigger infrastructure is scarce. The development of new sustainable urban drainage solutions is proposed and includes decentralized wastewater collection and source-separated collection systems, as well as green and blue infrastructures (e.g. green roofs and infiltration systems) that encourage the use of more natural drainage arrangements wherever possible. An optimal compromise between flexibility, robustness, costs and social acceptance have to be found to have an adequate integration on the existing context of the large urban areas and face the current and future challenges. Crossing of networks and infrastructures should be avoided for safety and maintenance issues. In addition, developing and improving research and monitoring of urban drainage processes is needed to conceive better ways to manage short-term quantity and quality variations and long-term problems as network's ageing, thus to create higher efficiency and performance.

## Past

Main condition for the location of settlements in the Netherlands has been the availability of drinking water and food. These conditions were met in locations where smaller rivers flow into larger rivers, here like Rotterdam and Amsterdam have flourished. People drank the water from the canals and rivers, but also used these as sewer. Growing population compromised this way of using natural waters and for drinking water supply people started to use wells to pump up the clean ground water. In the nineteenth century the situation worsened and cities suffered from cholera epidemics. Led by the newly erected health committees the discussion about personal and urban hygiene was high on the political agenda and projects were started to clean the urban waters. Of course the only way to clean the city was to stop throwing waste. In De Ingenieur there are a lot of articles that propose different ways to deal with urban waste like the Liernur system, where waste is collected in bins, or pressure systems that worked with steam. At the end of the 19th century also the discussion to make a separate sewer for rainwater can be found in De Ingenieur. All these ideas are coming back in trying to change the current system: the combined sewer that is flushed with water thus also bringing the infrastructure of clean water into the urban system. These were installed at the end of the 19th century in Dutch cities and have extensively being used during

the last century, especially from the 1970s, for the collection of black and grey water inside buildings and the collection of domestic waste water and stormwater runoff outside buildings. To transport the two types of water, the main sewer is designed with a large capacity and the common mode of transport is by gravity. During dry weather conditions all flows are directed to the wastewater treatment facility; in times of heavy rainfall, the sewer system capacity frequently results not adequate and sewer overflow events occur when such capacity is exceeded. Relief structures called combined sewer overflows (CSOs) were created to divert the exceeding combined stormwater and sewage to an adjacent water body. Such structures avoid overflow in the streets that can cause health problems and environmental damages: the wastewater brought on the streets impoverishes the water quality since it is loaded with harmful pollutants, while flooding can damage infrastructures.

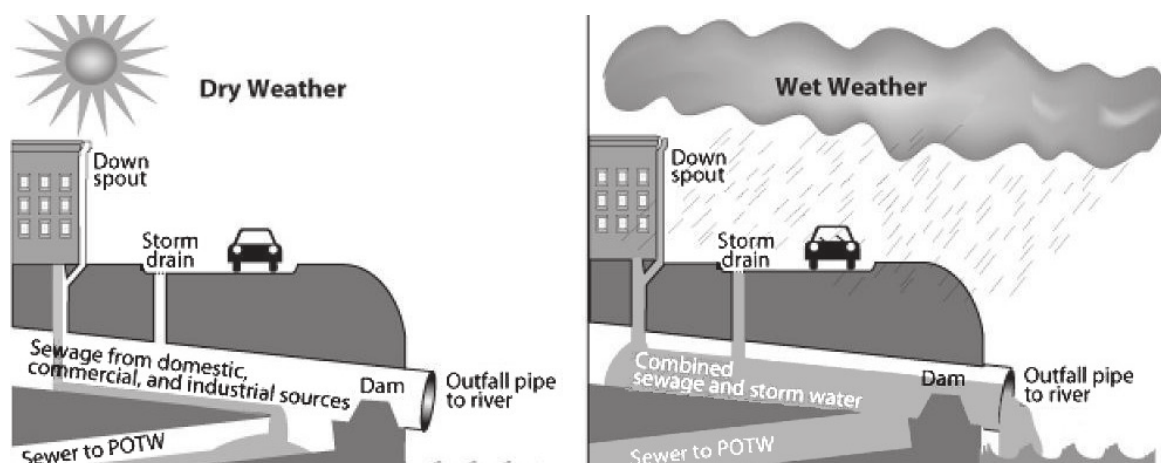


Figure 2.1, Operation of a combined sewer system during dry and wet weather conditions. POTW stands for Publicly Owned Treatment Works; the dam represents the CSO structure. Source: [https://upload.wikimedia.org/wikipedia/commons/0/0b/CSO\\_diagram\\_US\\_EPA.jpg](https://upload.wikimedia.org/wikipedia/commons/0/0b/CSO_diagram_US_EPA.jpg)

## Present

Although some separated systems have been implemented in the Netherlands to separate domestic wastewater from rainwater, the majority of the installations stay as combined systems. Problems of combined systems are the limited network capacity and the mixing of relative clean rainwater with pollutants-loaded wastewater, which represents a risk when overflows occur and impoverishes the efficiency of the wastewater treatments. Separated systems can overcome these problems, but replacement and/or addition of sewerage pipes poses greater difficulties, given the high costs and limited subsurface space. Some innovative and sustainable measures have already been applied to cope with heavy rainfall, to preserve the quality and quantity of water, and to contribute to a new space organization in the surface and subsurface. These are gathered under the name of 'sustainable urban drainage systems' (SUDS) and include different techniques as green roofs, source-separated systems, permeable surface, infiltration trenches, filter drains and filter strips, swales, detention basins, ponds and wetland (NetRegs). These strategies aim to prevent water pollution, to slow down surface water runoff increasing alternative storage, to reduce the flooding risk, to recharge groundwater thus helping drought prevention, to create green spaces enjoyable by the inhabitants of the urban area. The adoption of a storage-oriented (natural system) approach is effective to unload the sewer system

in case of heavy rainfall (Unesco-IHE, 2013): in contrast with the conventional conveyance-oriented approach, which provides for the collection of stormwater followed by its immediate conveyance in the sewer system, the storage-oriented approach provides for temporary storage of stormwater at or near the point of origin, with subsequent slow release to downstream storm sewer or channels. The main strength of such approach is that it deals with the causes rather than the consequences. Sewer networks run under houses and along streets, together with other numerous infrastructures, as subsurface drainage installations to control groundwater level. Hence, the need to organize them in such way to prevent a negative reciprocal influence.

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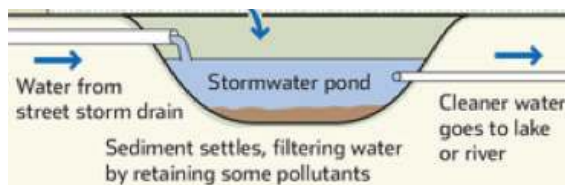


Figure 2.2:  
Stormwater pond configuration: water is conveyed into a pond filled with sediments, before being discharged to a surface water body or to the sewer system. Sediments work as a cleaning filter by retaining pollutants.  
Source: [http://extras.mnginteractive.com/live/media/site569/2008/0910/20080910\\_061148\\_Stormwater\\_295.gif](http://extras.mnginteractive.com/live/media/site569/2008/0910/20080910_061148_Stormwater_295.gif)

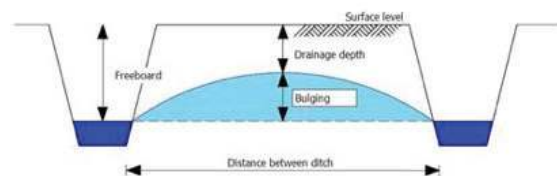
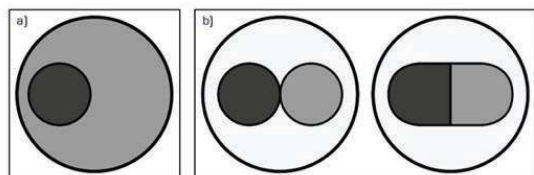


Figure 2.3:  
Subsurface drainage system layout; important variables include drainage depth, discharge level, depth of the drain pipe, drainage system, layout/location of the drain, pipe type and covering, network design.  
Source: Van de Ven, 2015

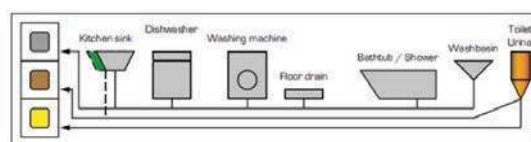
## Future

Besides climate change, of which processes and effects are quite well known (more intense precipitations, but also droughts and heat stress), also demographic growth will entail a change in the available water quality and quantity and a denser accumulation of networks and services, especially underground. The greatest problem resides in the velocity of the changes development, which calls for flexibility of subsurface networks to fit the different possible scenarios, but also robustness to ensure the duration of the installations. Costs considerations have to be carefully carried out to find good compromises in terms of investment, level of service and social and technical acceptability. To come up with the best strategies, therefore, an accurate analysis of the underlying key drivers of the changes expected to affect urban drainage systems is needed (Arnbjerg-Nielsen, 2011). This can be done through monitoring of water quality and quantity in collection systems, as well as the networks itself. In addition, the management of risks and uncertainties in sewer measurements is a key issue for design and analysis of urban structures. Alternatives that can be considered in the future to improve the sanitation system and decentralize services include source-separation in the existing urban water infrastructure (STOWA, 2012). Source-separation is a flexible system that can guarantee a rapid adaptation to changing

requirements and constrains in the urban water infrastructure. Alternative sanitation systems give potential contribution to energy savings, recovery of nutrients and removal of micro-pollutants. Important driving forces for the implementation of alternative systems are: legislative and societal requirements formulated towards wastewater management, and the need for renovation and rehabilitation of existing urban areas and the water infrastructure on short term. Maintenance plays a crucial role: underground structures are difficult to maintain or repair, since they require digging of significant areas of streets. Solutions implemented in the surface or conceived in a more flexible way are needed to allow an easier and periodical maintenance.



**Figure 2.4:**  
Example of source-separation: Pipe within pipe concept consists on the introduction of a small-diameter flexible pipe into the existing drainage network to completely separate black and grey water already at the level of every single sanitary appliance.  
Source: STOWA Report 2012-W14



**Figure 2.5:**  
Comprehensive source-separation concept: black water is fully separated from all remaining domestic wastewater streams and further separated into the yellow and the brown fraction.  
Source: STOWA Report 2012-W14

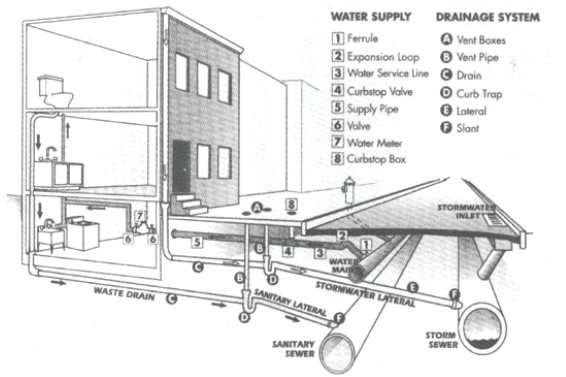


Figure 2.6:  
Separated Sewer System inside and outside building.  
Source: Van de Ven 2015

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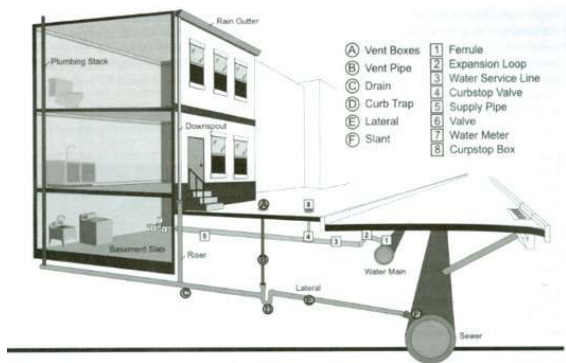


Figure 2.7:  
Combined Sewer System inside and outside building.  
Source: Van de Ven 2015



**Present**

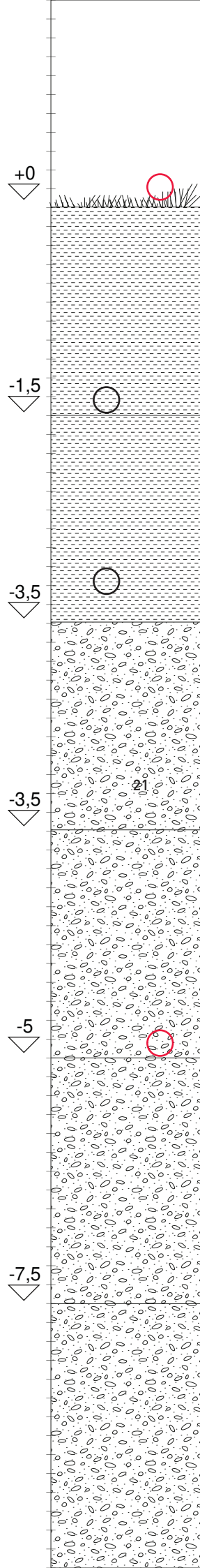


**Future**

PRESENT:

Sewer systems: 1.5 - 3 m below surface

FUTURE: Alternative solutions: on the surface (e.g. retention ponds or infiltration trenches); or inside the current installation (e.g. pipe within pipe), hence same depth; or below old installations (5m)



**Department:**

CiTG/ Water Resources

**Technology:**

Watermanagement and building site preparation

**Expert:**

dr. ir. Frans van de Ven

## **Introduction**

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Water systems and soil conditions influence urban planning as determining factors to create a healthy environment and opportunities. By their manipulation in urban areas it is possible to reduce the cities' vulnerability. The latter is a consequence of the great and fast changes in weather and demographic trends during the last century. New urban areas have to be created while the existing ones have to be reorganized in the near future, since they are getting outdated and not adequate anymore to the new social and environmental requirements. Centralization of services in urban areas makes the underground space limited, crowded with infrastructures as sewers, drains, cables and mains, drinking water pipes, gas pipes, heating systems, foundations and other networks. Water, soil and subsurface flows have to be carefully managed through the development of new solutions to fulfil their space requirements. Safety from coastal, fluvial, pluvial and groundwater flooding has to be ensured, as well as water quality and quantity. Building site preparation plays a fundamental role, since a stable soil and subsurface are the enabling conditions to guarantee safety and stability of structures. Deltas' areas are characterized by soft and unstable soil, prone to subside when loaded or drained. Therefore, an accurate control of soil, surface water and groundwater is needed to

create stable conditions. The ambitions to take in mind while preparing the urban site concern economic and social development, to improve the livability of the area by making it more sustainable, climate-resilient, adaptable, healthy, attractive and pleasant. Resilience and adaptability are key concepts to achieve a sustainable city. Opportunities for the future reside in limiting the throughput of water, energy, nutrients and building materials by using the resources in multifunctional ways, to better manage the space and give the systems more flexibility. Climate resilient cities means that new or renewed urban areas have to adapt to scenarios of higher sea level, more extreme rainfall, droughts and heat stress, in addition to technological and demographic development: the past techniques of draining and supplying the city with water have to be updated and innovated to fulfill the required adaptation in both the surface and subsurface.



## Past

“God created the world, but the Dutch created Holland”. The Dutch have a rich and internationally renowned ‘fine tradition’ when it comes to the intense relationship between urban development and civil engineering. Their expertise and knowledge of hydrological laws and ingenious technology have helped them successfully to make land out of water through the ingenious technology of polders. The dynamics of the regional water system, which include groundwater and rainwater in combination with surface water in a lowland delta facing the North Sea, is crucial for the process of development and urbanisation of the Dutch polders. The Dutch cities are hydrological constructions, with a spatial layout that is strongly connected to the division of land and water through building site preparation. Building site preparation has been done by raising the land level to deal with high water levels, and from the 17th century also by lowering the water level by windmills.

In the second half of the nineteenth century, steam dredges were implemented to the development of building-site preparation. The ‘Integral filling with sand method’ was used and entailed more than 70 cm of sand brought on a surface. This created a tabula rasa area, with homogeneous conditions, where to start the constructive activity. Subsequently, steam-driven pumping stations with centrifugal pumps started to spread in the whole Dutch territory (Hooimeijer, 2011). At this time, water management practices already included control of rivers, drain lakes, reclaim lands and dig canals. Different machines were used to dig ditches and move soil. At the

end of the nineteenth century, with the invention of the sand pump, the hydraulic filling method is improved to both remove soil to deepen canals and rivers, and to fill in areas to prepare sites for building. Sand pumps were then replaced by diesel engines and newer technologies. At the beginning of the twentieth century, important calculation of the rainwater runoff through the city are developed, especially about delay and losses, contributing to a more accurate subsurface drainage planning. Drainage of groundwater for building-site preparation and to prevent flooding on street is made with the use of pumping wells. During the middle of last century, vertical drainage system with sand piles has been introduced to speed up the consolidation process. However, groundwater level was mainly controlled by surface water systems until the 1970s. Only at a later stage, drain systems were used to keep the groundwater level low, especially during building-site preparation, placed up to 3 meters below surface. Plastic (PVC) drains were then applied in substitution to tile drains (Hooimeijer, 2011). From the 1970 other techniques have been developed to prepare sites for building. Partial filling leaves original soil conditions open for urban green structures and is only applying sand under streets and houses. The platform methods does not add a new layer of sand at all but all constructions (roads and houses) are supported by bearing piles. And also other more lightweight materials have been used, like polystyrene, to heighten areas above the groundwater level and stabilize the building site.

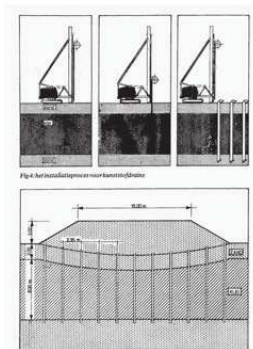


Figure 3.1  
Installation of plastic drains.  
Source: De Ingenieur, 1979.

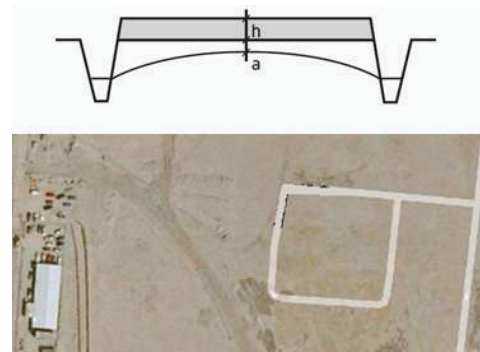


Figure 3.2.  
Integral filling method of building-site preparation  
( $h$  = level of raising;  $a$  = level of groundwater table) and aerial view  
Source: Segeren and Hengeveld, 1984.



## Present

Main recent achievements in water management concern the knowledge about groundwater flows. Groundwater research is important for the draining of polders, seepage, preparing building sites in relation to water nuisance, subsidence and drought. The today's focus in urban planning is a reconnection with landscape, ecology and a better organization of the subsurface space. In building-site preparation, the 'partial filling (excavation) method' does not integrally substitute the existing soil with sand, but leaves room to nature and water in urban landscape: sand is used to fill the excavation under roads and houses only, while garden sites stay of clay and peat. Water and energy networks are placed below the street and the preserved living environment creates more space to new adaptable solutions. With the arise of problems concerning flood risk, blue-green infrastructures have been implemented for the control of groundwater levels and stormwater, as the creation of buffer lakes that can both mitigate the problem of seepage around filled areas and store surplus of rainwater. In addition to groundwater and stormwater runoff control, also surface water, drinking water and wastewater are organized to provide their service with no conflicts, in order to develop their numerous amenities and opportunities. For instance, surface water offers

a storage to rainwater: more canal surface, or an extra area along the canal, can be created to increase the storage capacity in case of heavy rainfall and unload the subsurface stormwater sewers. Sustainable urban drainage solutions also include green roofs, water square or storage on streets. Such solutions, located in the surface, allow to maintain more room in the subsurface for other networks and infrastructures.

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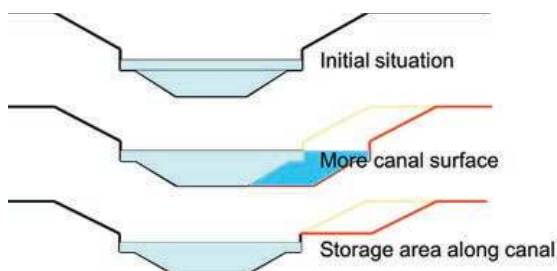


Figure 3.3:  
Solutions to increase storage in the canal: extension of canal surface or creation of a storage area along the canal. –  
Source: Van de Ven, 2015

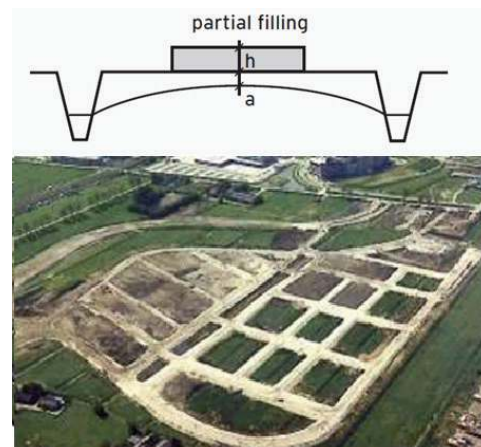
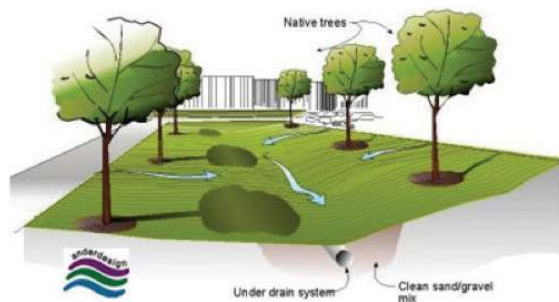


Figure 3.4:  
Partial filling method of building-site preparation ( $h$  = level of raising;  $a$  = level of groundwater table) -  
Source: Segeren and Hengeveld, 1984

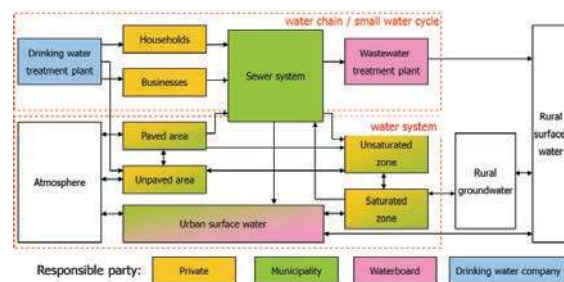
## Future

Integration of water for pleasant purposes and for energy collection has already reached a good level in the Netherlands; however, more adaptability and flexibility of water systems is required, given future scenarios of climate change and demographic growth. Water systems compete with other networks and infrastructures for space requirement, but they also offer multiple amenities. Water holds opportunities for recreation, biodiversity, food production, urban function (e.g. firefighting, heat stress alleviation, energy collector and supplier, etc.), livable and functional space (e.g. floating buildings). An integration between components of the urban water system and respective stakeholders is needed to develop all these possible amenities, as well as cooperation between designers of technology and designers/integrators of space. The social agenda for the design of urban infrastructures and landscape shall include an equity principle able to guide people to a correct sharing of resources. The equity concept has to lead the different owners in the management and organization of urban water systems and their multiple functions. Social responsibilities at both collective and individual level have to be redefined, in light of a system flexibility. Flexibility is not only a physical property of a

given technology, but it also interests the way people approach the systems. Solutions on site and decentralization of services, entrusted to individual management, holds opportunities for resources reuse and to unload the main and rigid networks (e.g. rainwater harvesting tanks). Building-site preparation scientifically depends on seven fields of knowledge, namely general water management, science of soil mechanics, soil improvement, geohydrology, pile foundations and drainage systems. The importance of cooperation among those disciplines is thus straightforward. Building-site preparation has to enhance the relation between making use of soil conditions, space, water systems, and designing quality of living space. Design criteria, incorrect data and confusion about responsibilities (Biron, 2004), worsen the quality of such practice, which mainly relies on knowledge by experience. Technical research and supportive tools of solutions' integration and cooperation represent smart ways of improvement. Particularly, special attention has to be put in the subsurface planning of networks' integration.



**Figure 3.5:** Blue-green solutions are preferred over grey structures for their flexibility, adaptation and for the added value they give to daily life. In the picture a swale is shown: an artificial low section meant to manage water runoff, increasing infiltration and filtering pollutant. Source: <http://www.sudswales.com/wp-content/uploads/2011/06/swales-diagram.jpg>



**Figure 3.6:** Total urban water system: water cycle components are gathered in two main groups: small water cycle and total urban water system. For each component, the respective responsible parties are shown by different colors - Source: Van de Ven, 2015



- Present
- Future
- X Drains
- Y Trenches
- Z Cables

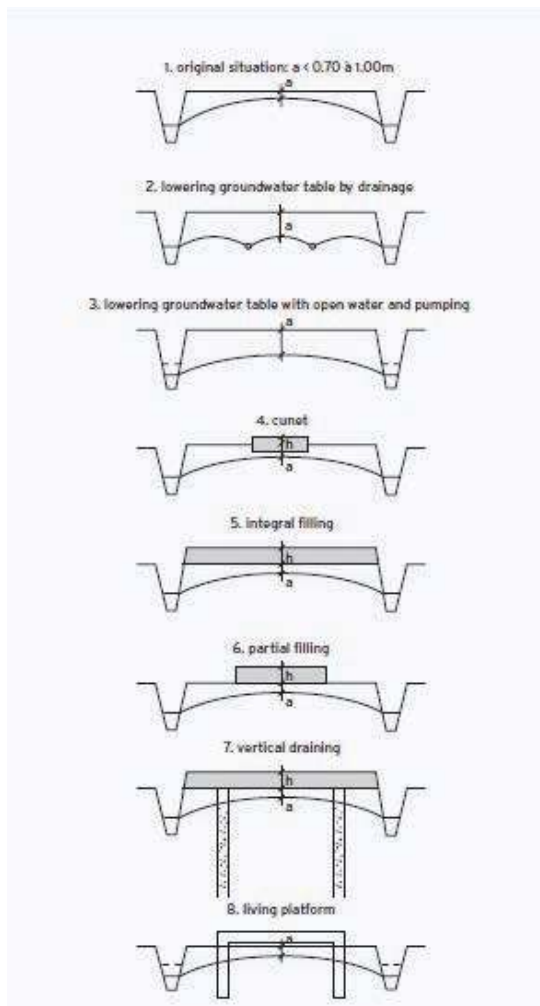
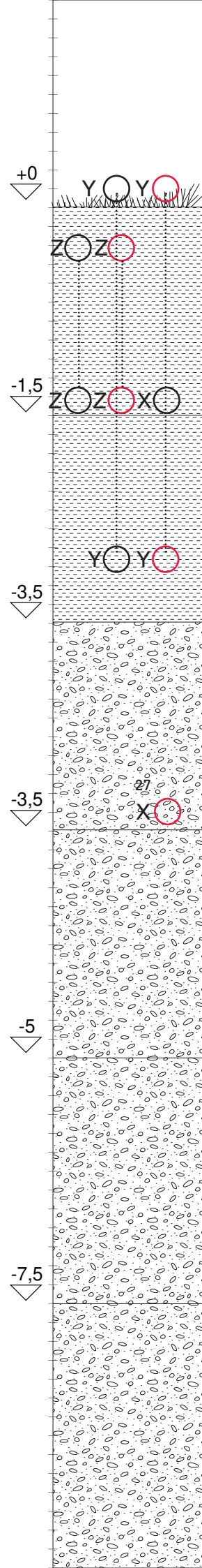


Figure 3.9:

- I. CUNET: sand in road strips transported by truck;
- II. CUNET: sand in road strips transported by rail with vertical drainage;
- III. Integral: hydraulic filling (layer of sand without vertical drainage);
- IV. Integral: hydraulic filling with vertical drainage;
- V. Integral: filling with sand transported by truck and with vertical drainage;
- VI. Integral: filling with sand transported by truck and then covered by a layer of sand by hydraulic filling and with vertical drainage.
- VII. CUNET: polystyrene and other light materials in road strips;
- VIII. Partial: living platform method where buildings, roads, sewer and cables are built on bearing piles;
- IX. Partial: lowering of the groundwater level in combination with the partial method II.

Source: Van de Ven, 2015



Department:

Technology:

Expert:

CiTG/Geo Engineering

Underground space technology

Dr. ir. Wout Broere

## Introduction

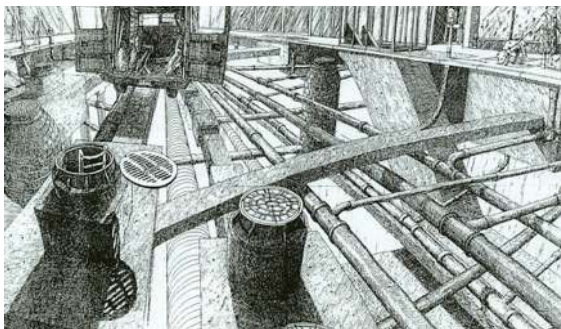
The world-wide trend of increased urbanization creates problems for expanding and newly-developing cities alike. Population increase leads to an increased demand for reliable infrastructure, nowadays combined with a need for increased energy efficiency and a higher environmental awareness of the public. The use of underground space can help cities meet these increased demands while remaining compact, or find the space needed to include new functions in an existing city landscape (Broere, 2015). In many cases, underground solutions to urban problems are only considered if all other (above ground) options have been exhausted. When underground solutions are considered and evaluated from the planning or initial project stages onwards, more optimal solutions will become possible. Expanding cities will need to meet the increased demands for infrastructure. Without efficient transport infrastructure, cities will sprawl away from the urban core, which strains the environment by creating more traffic congestion and travel time, loss of valuable farm land, and inequitable allocation of resources (Thewes et al., 2012). In developed countries the urban expansion is less rapid, but the demographics of the population will change, with an increasingly large group over 60, and a decrease of populations outside the major cities. These population changes bring about new demands on the functions a city must provide and on the layout of the city, and call for continuous improvement in sustainable and resource efficient urban development (Li et al. 2013).

Probably the most recognized need for keeping cities compact and efficient is the need to introduce mass transit systems. Travel times and energy use can be reduced by using separated rail systems, and further surface area savings are attained when moving to underground mass transit systems. Similarly, surface space is saved and the quality of the urban environment is improved if car related infrastructure, such as roads and car parks, are moved subsurface. Use of the underground is not limited to large scale infrastructure projects. The increasing amount of different utilities that is placed in the shallow subsurface strains the available space in the utility layer. Especially the addition of separated sewage systems for household waste water streams and storm water and of distributed heat-and-cold (ATES) storage systems or shallow geothermal systems requires a large underground footprint if all placed directly in the ground. If not properly regulated and zoned, the increasing number of utilities creates underground space shortages in the shallow subsurface utility layer, and often causes increased surface disruptions given the increased number of parties that needs to inspect, repair or replace their underground utilities. Underground zoning and combined placement of utilities in utility tunnels will alleviate the strain on underground space (Hunt et al., 2014).

## **Past**

With the expansion of cities in the nineteenth and twentieth century, construction of infrastructure starts above ground. Underground construction is considered only if surface solutions are exhausted, and as the resulting projects are mostly complex and costly, the result is that underground construction is perceived as an expensive solution. Moreover, construction of underground facilities is mostly done in open construction pits, leading to severe surface disruptions.

Urban utilities are partly placed below ground in the utility layer, but their number is limited and maintenance is not often needed. There are no perceived space constraints and there is hardly any need for repairs or replacements of these new systems. The impact of urban quality is minimal and most utilities are protected from the elements. Direct placement in the soil is seen as cheap and effective.



**Figure 4.1,**  
Limited number of utilities and underground facilities leaves space for future development.  
Source: D. Macaulay, 1985



## Present

Relocation of transport infrastructure to the sub-surface frees up urban space and improves the quality of the urban landscape. Construction techniques have improved and made constructions with a low impact on surface life, such as tunnel boring, possible. Underground car parks and metro systems are common solutions. Underground extensions to (public) buildings are considered if surface options are limited. Use of underground is decided on a first come-first serve basis.

Underground zoning is not common, different constructions are often not linked together, and no integral framework balancing the various needs at city level is used.

The number of different utilities has increased. Apart from water, gas, electricity and (single) sewage systems, new service providers have placed their utilities in the utility layer. Telecom, data and cable-TV, district heating, geothermal and heat-cold exchange systems all require space. Surface disruptions due to maintenance become more common and at key locations underground space constraints emerge.

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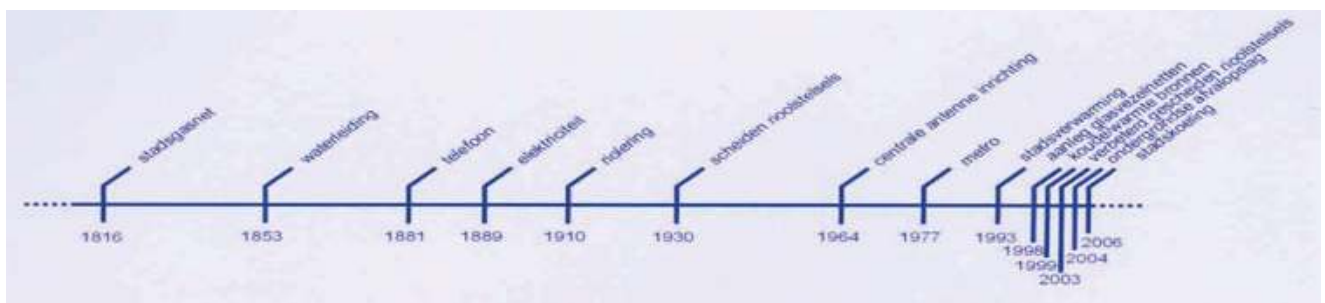
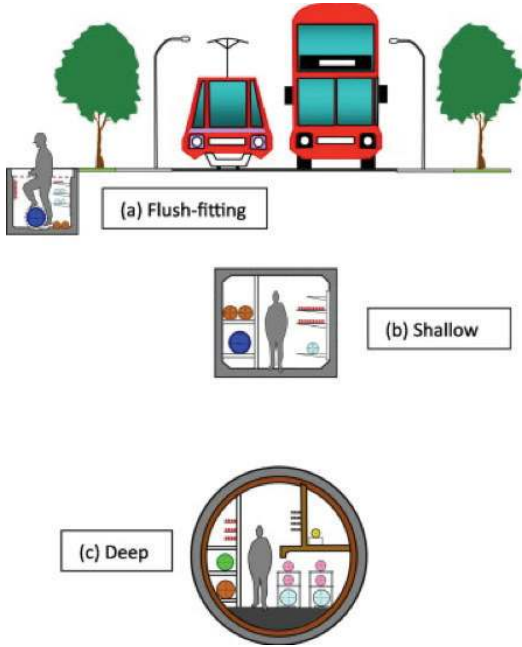


Figure 4.2:  
Increasing number of functions placed in the utility layer leads to underground space constraints.  
Source: Bosch et al., 2013

***Future***

The need to include underground space in urban development should be recognized in early project stages. Integrated planning of surface and subsurface urban development, combined with underground zoning and an integrated framework balancing the various needs (space, resources, water, heat and energy, bio-zone) of the city is needed. Different underground facilities can be interlinked creating additional value.

Additional utility systems will be introduced, including separated waste-water systems and district-wide energy storage grids. To reduce the required underground space, and reduce surface disruptions due to maintenance, utilities can be placed in multi-utility tunnels. A transition from existing placement in the soil to the MUT is needed, both from a construction as an economical viewpoint.



**Figure 4.3:** Placement of utilities in multi-utility tunnels alleviates space constraints and eases access for maintenance.  
 Source: Rogers et. Al, 2012



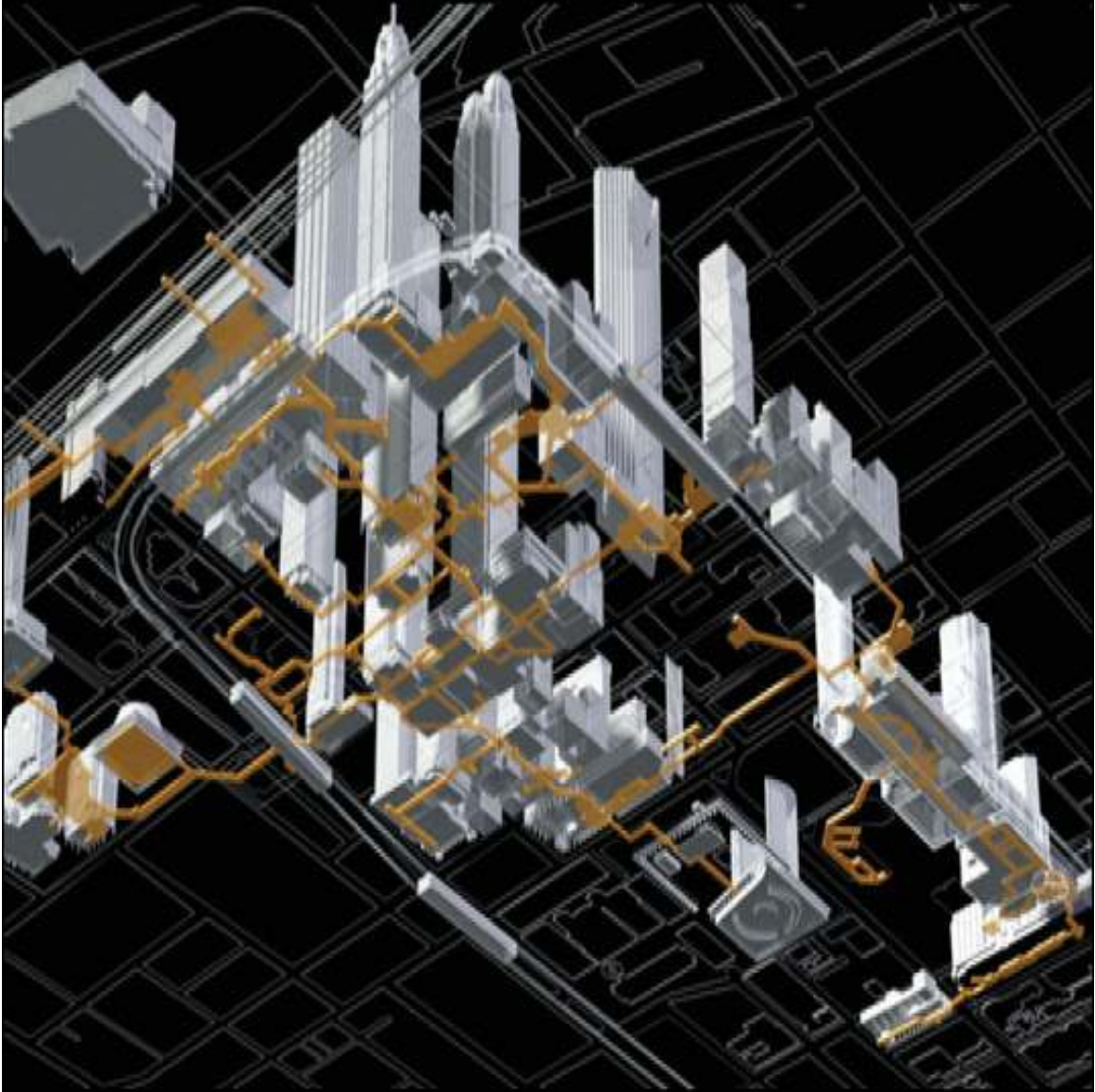


Figure 4.4:  
(Future) Integration and connection of underground facilities creates additional value for the system,  
Source: Belanger, 2008

- Present
- Future
- X Utilities
- Y Underground infrastructure

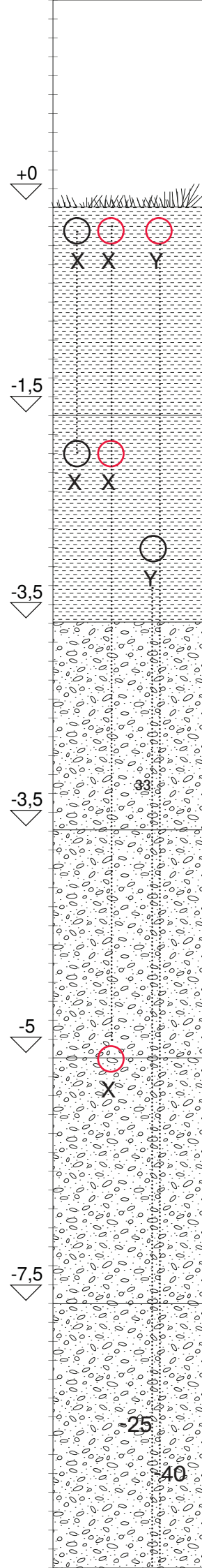
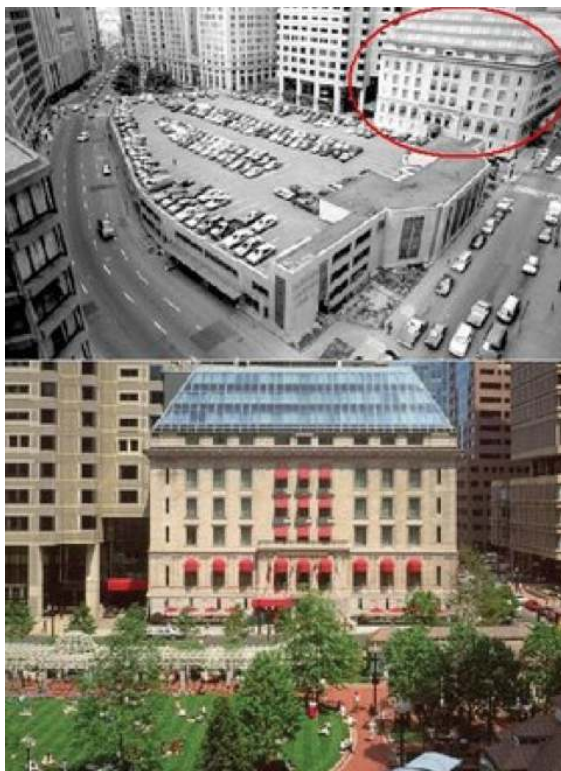


Figure 4.5:  
 Shift of surface infrastructure to the underground improves urban quality. First come-first serve mentality leads to future development constraints.  
 Source: Thewes et. al., 2012

## Subsurface Matrix

**Present**



**Future**



Technologies:

Utilities



Underground infrastructure



Drains



Trenches



Cables

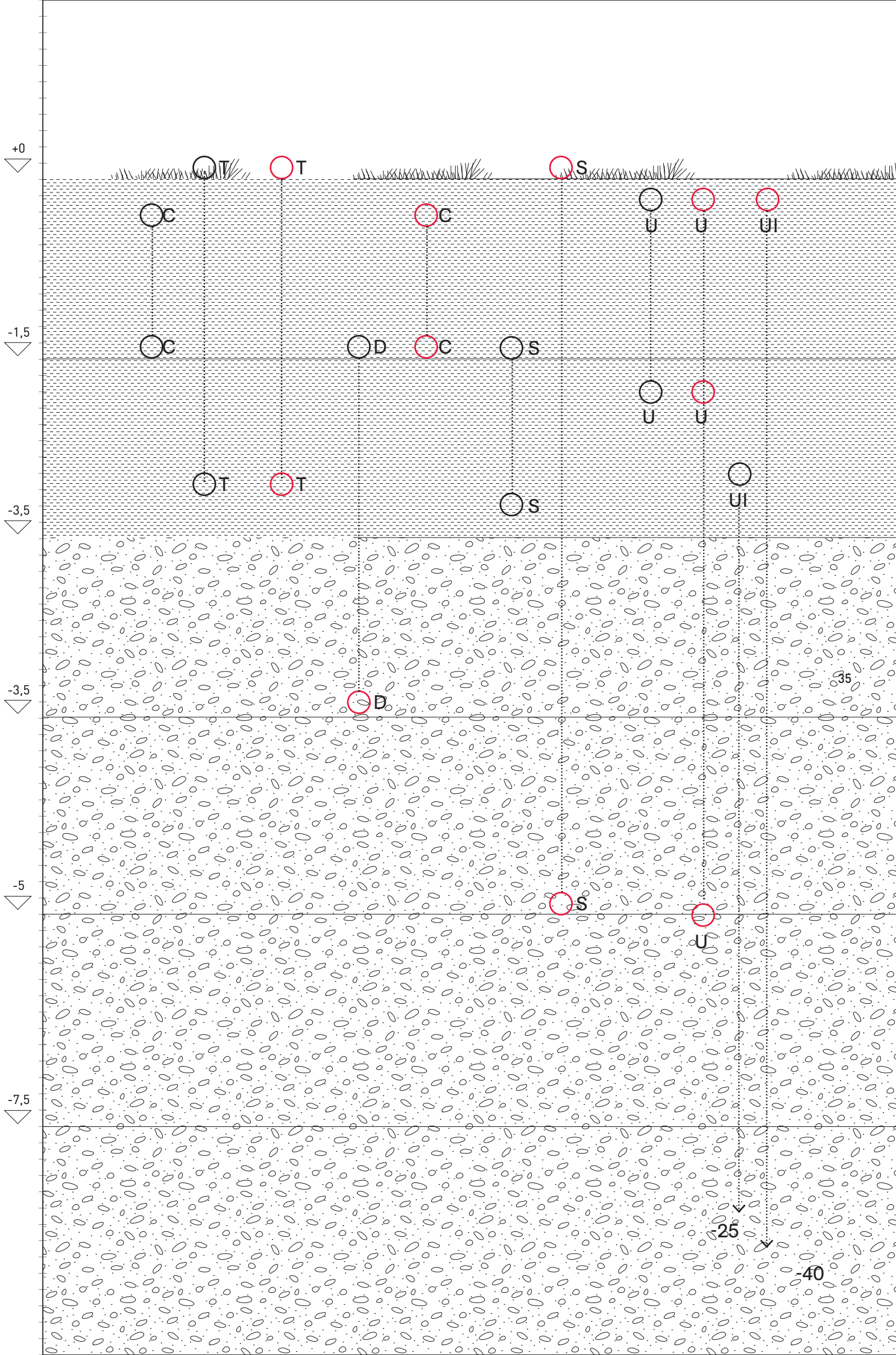


Sewer systems:



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The subsurface matrix was created in order to position the technologies in the subsurface and to understand potential present and future conflicts over their spatial deployment.



To reach a truly interdisciplinary approach there is a need for a 'common language' and understanding of each other's disciplinary concepts. To support this the four technical domains are translated into the urban language and visualized in their spatial context. The drawings are done on three scales: the city, the neighbourhood and the household in which their implications in subsurface-surface as one united space are highlighted.

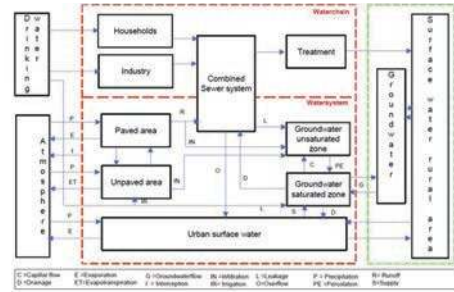
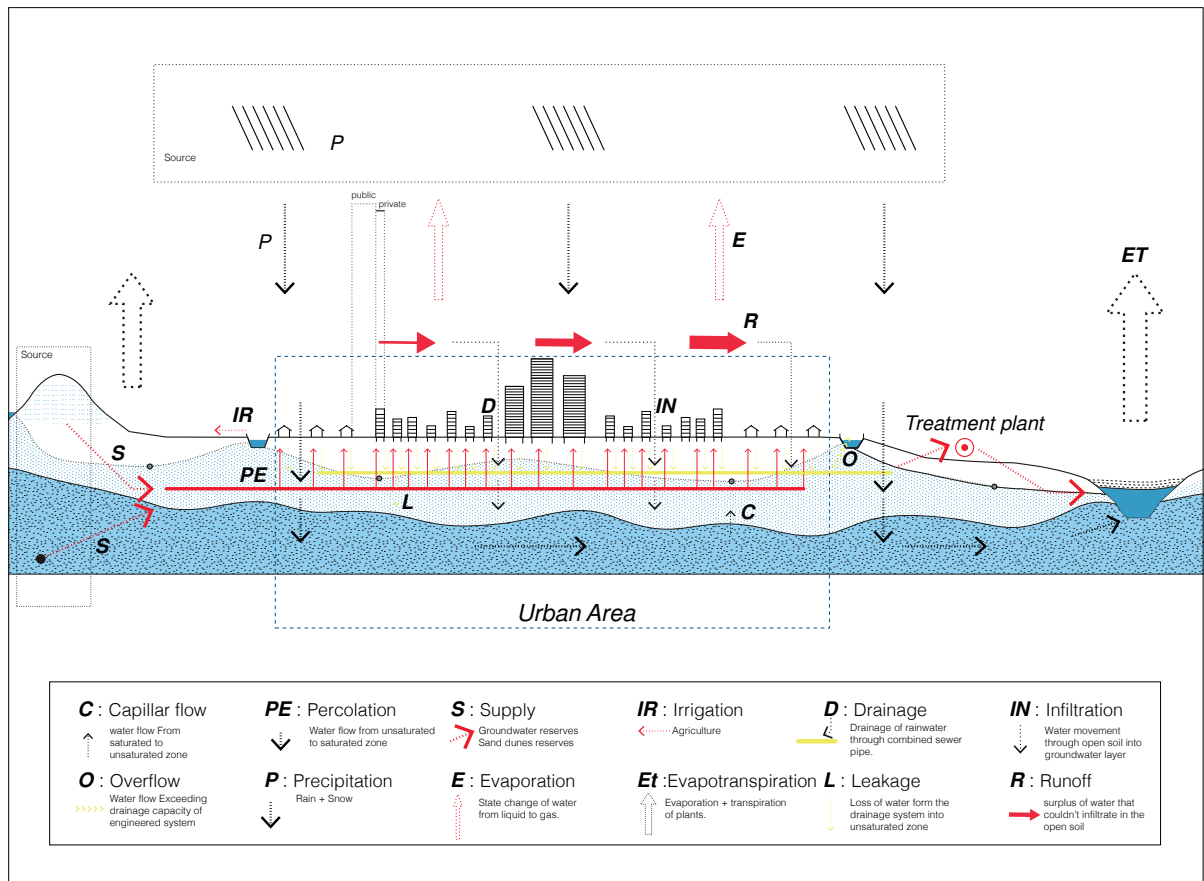


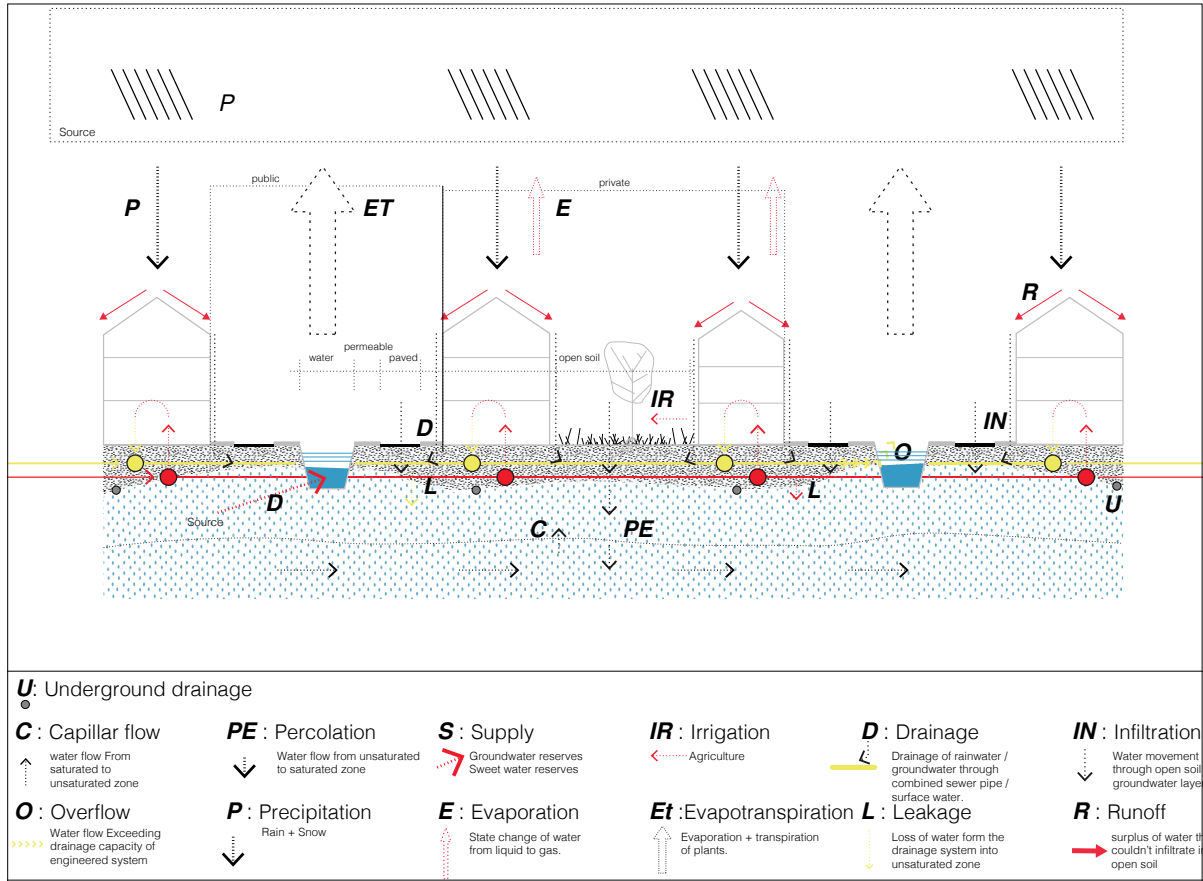
Figure Schematisation of the urban water system with a combined sewer. Source: Van de Ven, 2015

**Watermanagement and drainage systems**

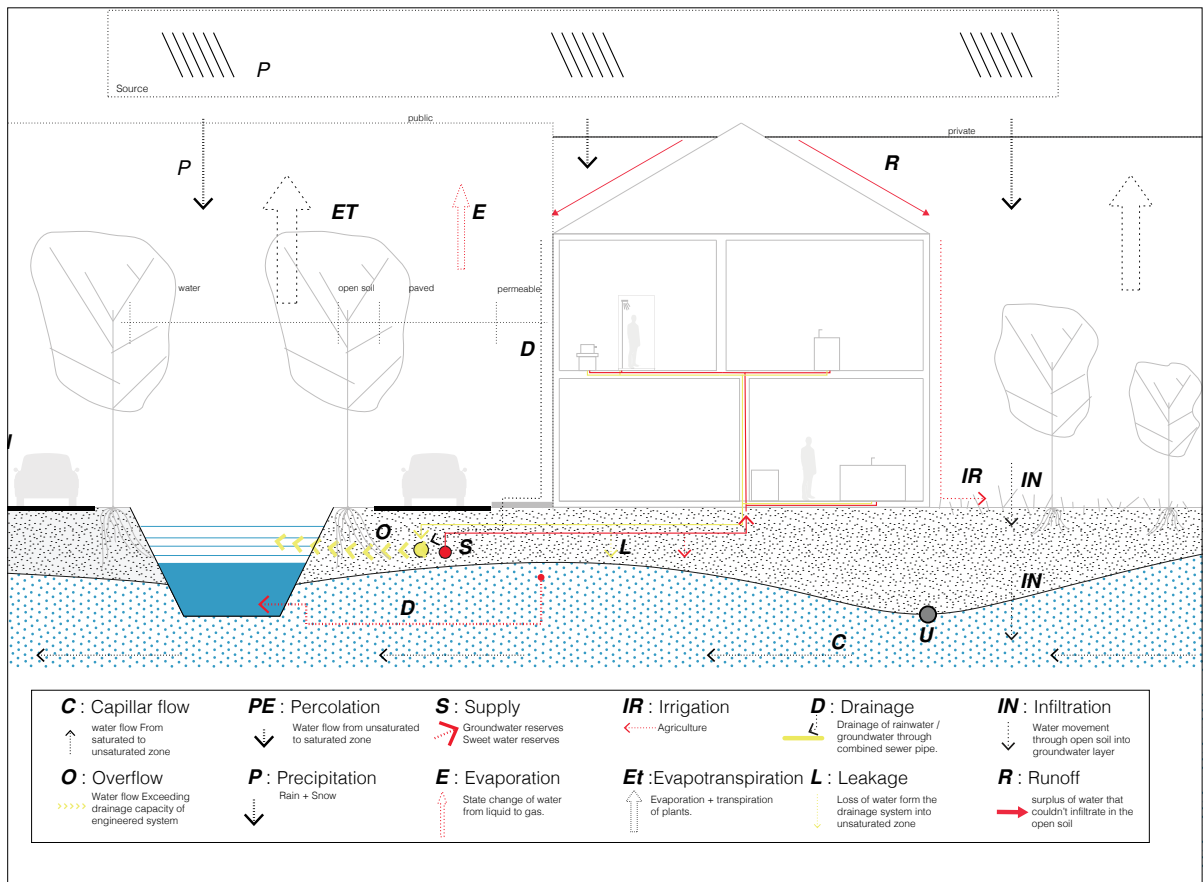
City scale



## Neighbourhood scale



## Household scale

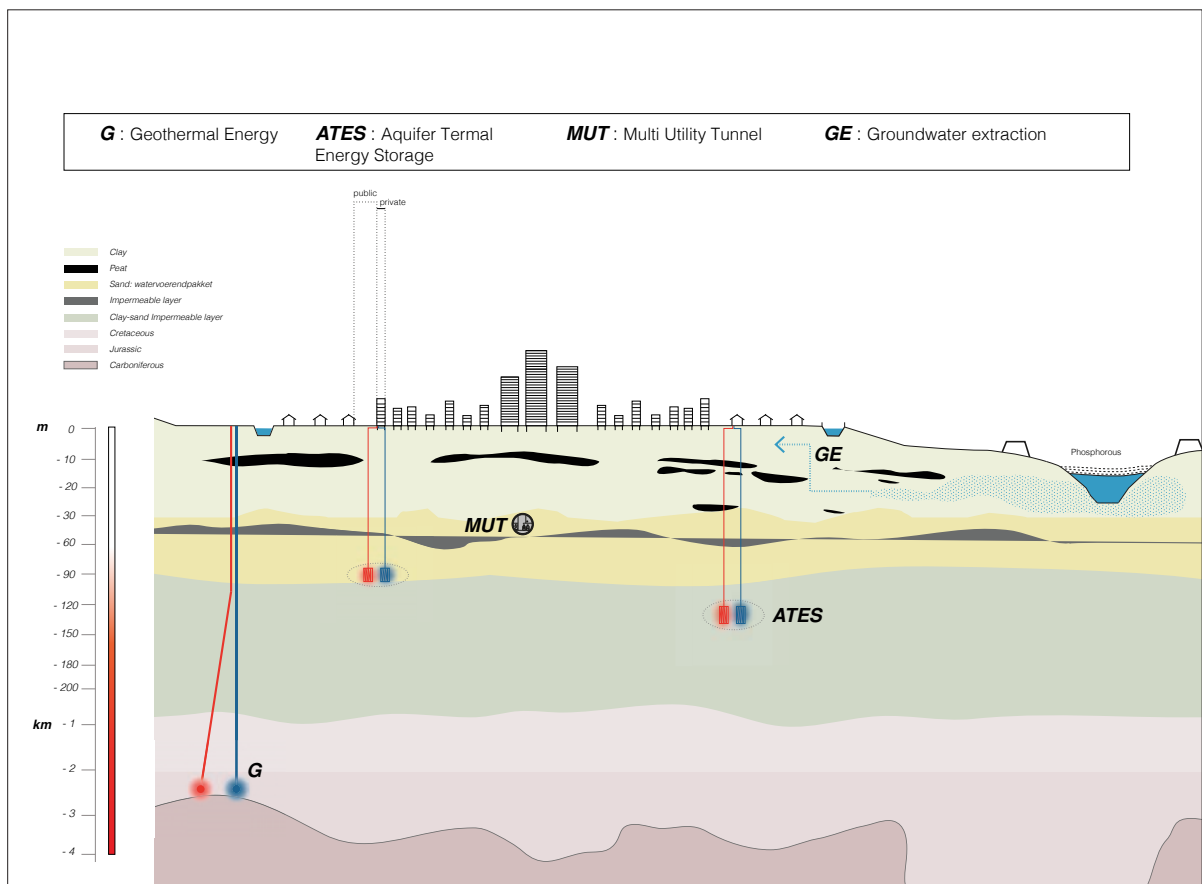




## Underground space technology

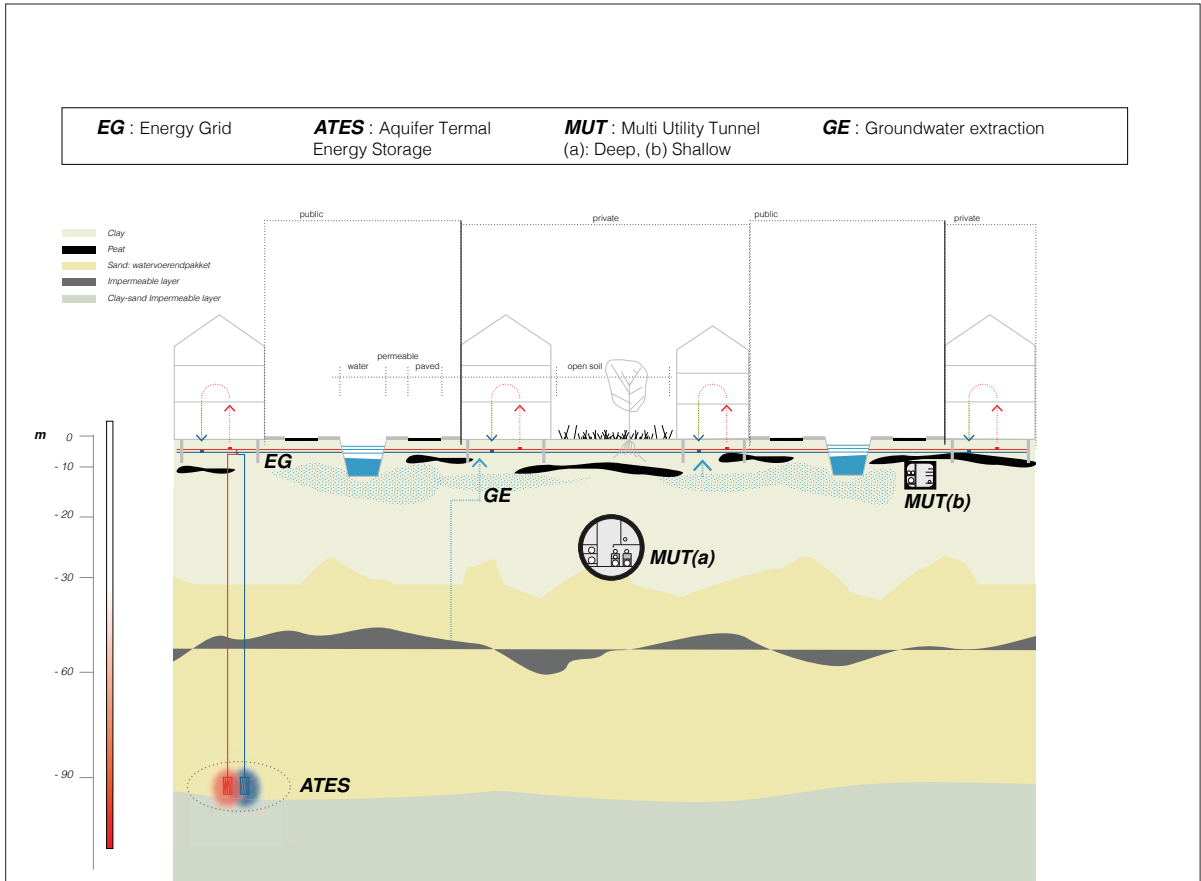
38

City scale

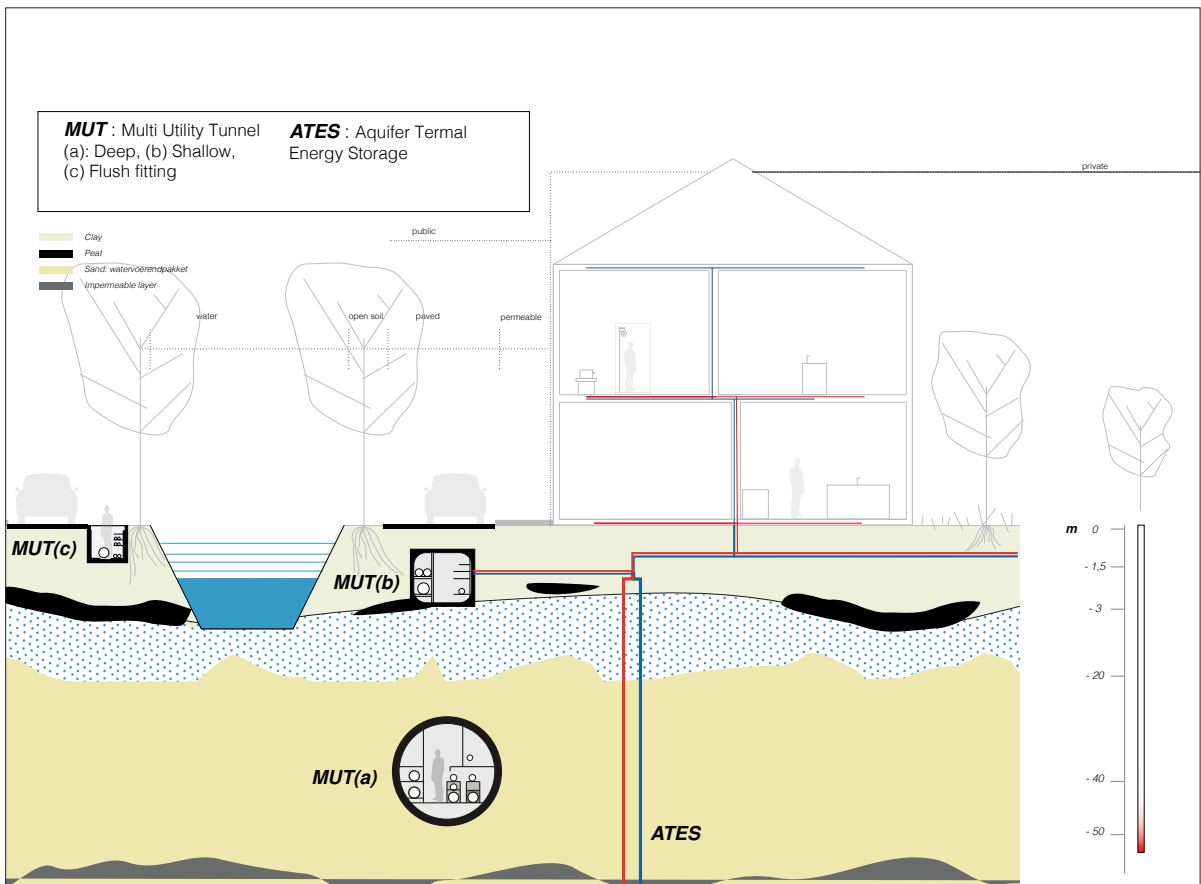




## Neighbourhood scale

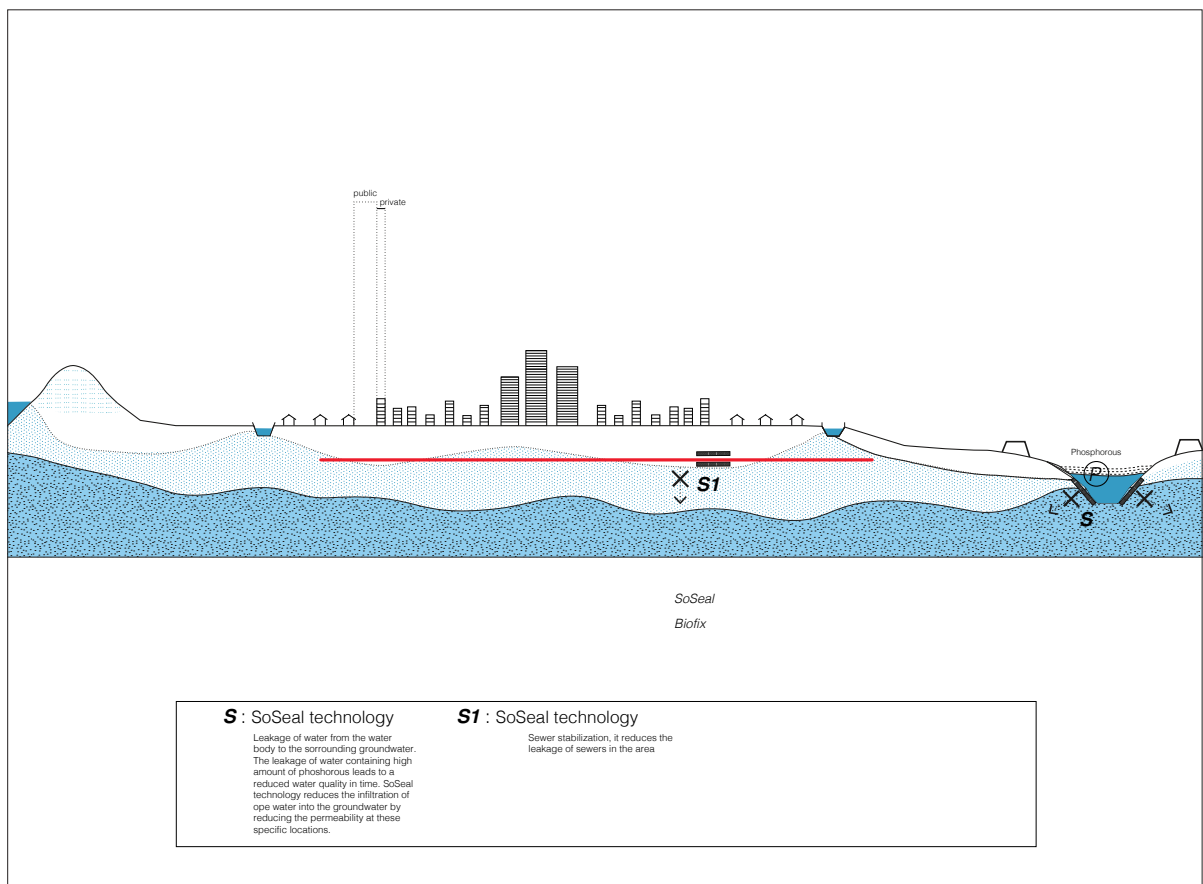


## Household scale

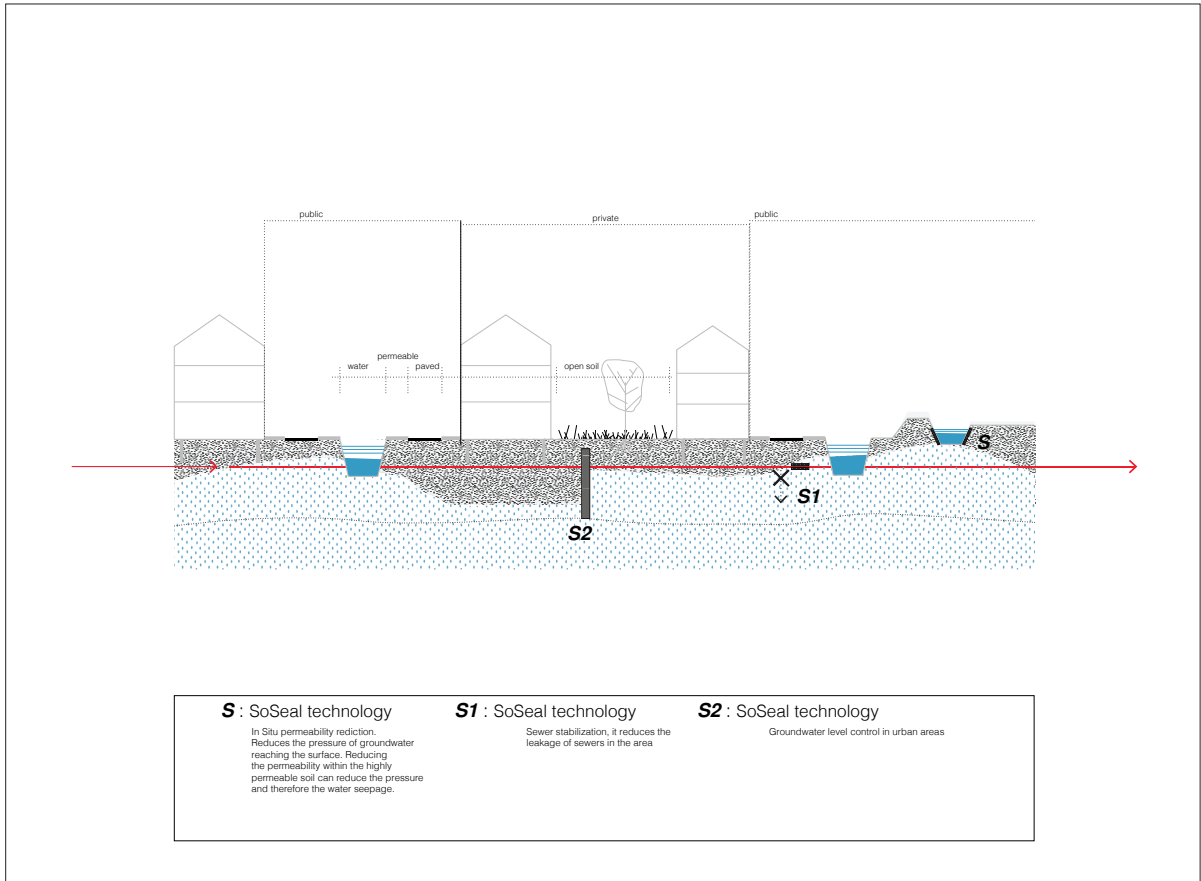


***Biogeocivil subsurface engineering  
for soil improvement***

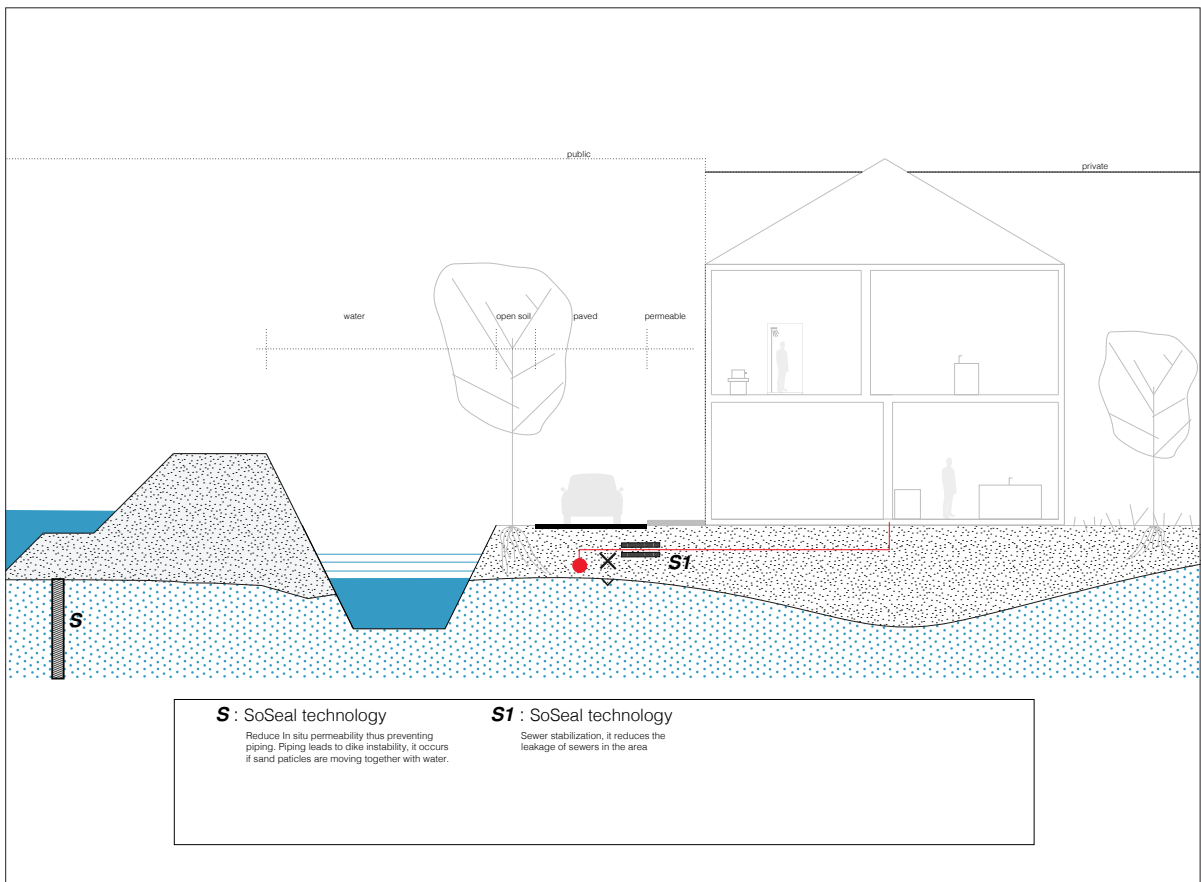
City scale



Neighbourhood scale



Household scale



Subsurface Matrix vs. scenarios

This matrix offers an overview of the applied research methods, the steps and the perspective in the project. It shows how the initial technologies are connected to spatial interventions, if they are interdependent amongst each other, how they offer opportunities and constrains, what is the impact on urban management, and finally their contribution to the three scenarios discussed from page 74.

The matrix also gives insight into the relevance of the four engineering profiles. It shows that the constraints are particularly relevant for the contextual engineer, while urban management pertains to the systems integrator. The technology, dependency on other technologies, and space applications tend to belong to the realm of the specialist.

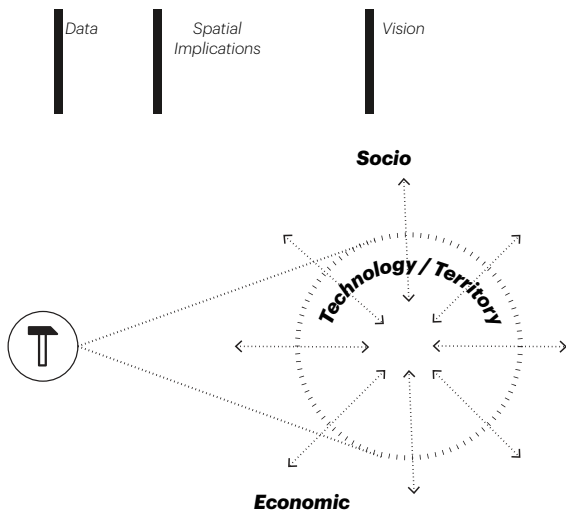


Figure 5.1: The diagram shows, conceptually, the process of the research, starting from technologies, understanding their relation and implications in space, and eventually building a vision in which the deployment of technologies are related to socio-economic dynamics. In this sense the diagram wants to show the rising complexity of the research process as an outcome of this explorative method.

	TECHNOLOGY	DEPENDENCY ON OTHER TECHNOLOGIES	OPPORTUNITIES
<b>Soil improvement</b>	SCC – Soil carrying capacity (BioGroutt)	UST: carrying capacity to support infrastructures	UWM: managing the groundwater table (recharge)  Sewer: flexible pipes
	SP – Soil permeability reduction (SoSEAL)	UWM: groundwater flows  UWM: water quality	
	QS – Quality of soil GRO (field not investigated in the project)		UST: excavation  UWM: water quality
<b>Urban Drainage (Sewer)</b>	- Sink disposal: Organic waste; flexible pipes (more capacity; heat-energy recovery from pipes)	UWM: Separate system + water quality  QS - Quality of soil	UST utilities  UWM: balancing the capacity of the sewer system (unload the network)
	- Source separation: Urine/feces (Yellow/grey/ black water) separation to recover nutrients		SCC
<b>UWM (Urban Water management)</b>	- Smart piping - Infiltration crates - Helophyte filters / Constructed Wet Lands (water quality) - Underground buildings - Nature based solutions	- Quality of soil  Sewer systems  UST: groundwater	UST utilities  Underground buildings can offer storage  Sewer: flexible pipes
<b>Building-site preparation</b>	- Partial-filling technique - Nature based solutions - New architectural typologies		SP
<b>UST (Underground space technology)</b>	Multi Utility tunnel	Soil improvement and UWM: UST deals with soil quality, soil carrying capacity and water flows (groundwater)	Multi-functionality  SCC
<b>Values</b>			

SPACE APPLICATION (RELATION TO SPACE)	URBAN MANAGEMENT	CONSTRAINTS	PP: PUBLIC/ PRIVATE	Steam shrinking	Warm densification	Steam densification
<ul style="list-style-type: none"> <li>- Allows for urban nature (Relief)</li> </ul>	<ul style="list-style-type: none"> <li>- New maintenance plan</li> <li>- No applied sand</li> <li>- Maintenance of dikes</li> <li>- Quality control programming</li> </ul>	<ul style="list-style-type: none"> <li>- Irreversible?</li> <li>- Time</li> <li>- Governance (urban programming)</li> <li>- Legal</li> <li>- Financial</li> </ul>	Improve PP S/XL relation	Smart soils for water units	Smart soils reduce maintenance and includes nature	
<ul style="list-style-type: none"> <li>- Improves functionality (Robustness)</li> </ul>	<ul style="list-style-type: none"> <li>- Maintenance</li> <li>- Connection to pipe system</li> <li>- Trade off water &amp; public space system</li> </ul>	<ul style="list-style-type: none"> <li>- Technology up-tale (social acceptance and adaptation)</li> <li>- People behavior</li> </ul>	Improve PP S/XL relation			
<ul style="list-style-type: none"> <li>- Determines functions</li> <li>- If it is good quality → green spaces (Design with nature)</li> </ul>	<ul style="list-style-type: none"> <li>- Trade off function &amp; excavation management</li> </ul>	<ul style="list-style-type: none"> <li>- Health</li> <li>- Depreciation</li> <li>- Governance (urban programming)</li> <li>- Legal</li> <li>- Financial</li> <li>- Technology up-take (social acceptance and adaptation)</li> <li>- People behavior</li> </ul>	Public			
<ul style="list-style-type: none"> <li>- Quantity of space and material functionality</li> </ul>	<ul style="list-style-type: none"> <li>- Waste/sewer community</li> <li>- Sewer planning</li> <li>- Improve system flexibility and material</li> <li>- More systems lead to more space occupied, thus more maintenance is required</li> <li>- More waste utilities involved</li> <li>- No more sand</li> </ul>	<ul style="list-style-type: none"> <li>- Health</li> <li>- Depreciation</li> <li>- Governance (urban programming)</li> <li>- Legal</li> <li>- Financial</li> <li>- Technology up-take (social acceptance and adaptation)</li> <li>- People behavior</li> </ul>	<ul style="list-style-type: none"> <li>- Relation S/XL connections (small/big scale)</li> </ul>	<ul style="list-style-type: none"> <li>- Sink disposal with flexible pipes</li> <li>- Source separation</li> </ul>		<ul style="list-style-type: none"> <li>- Sink disposal with flexible pipes</li> <li>- Source separation</li> </ul>
<ul style="list-style-type: none"> <li>- Main infrastructure</li> <li>- Design of surface and materials</li> <li>- Use of surface water</li> <li>- Programming (water quantity and quality) + public space</li> </ul>	<ul style="list-style-type: none"> <li>- Water quality (rules)</li> <li>- System of water bodies or flows</li> <li>- Water communities (water boards and polders community)</li> </ul>	<ul style="list-style-type: none"> <li>- Health</li> <li>- Soil sealing</li> <li>- Maintenance</li> <li>- Governance (urban programming)</li> <li>- Legal</li> <li>- Financial</li> <li>- Technology up-tale (social acceptance and adaptation)</li> <li>- People behavior</li> </ul>	<ul style="list-style-type: none"> <li>- Relation S/XL groundwater</li> <li>- Intermediate scale QS</li> </ul>	<ul style="list-style-type: none"> <li>- Nature based solutions</li> <li>- Green roofs</li> <li>- Green roofs facades</li> <li>- Partial filling new foundations</li> </ul>	<ul style="list-style-type: none"> <li>- Green roofs</li> <li>- Infiltration crates</li> <li>- No filling for maintenance, nature based solutions</li> </ul>	<ul style="list-style-type: none"> <li>- Green roofs</li> <li>- Smart piping</li> <li>- Infiltration crates</li> <li>- No filling</li> <li>- New building typology</li> </ul>
<ul style="list-style-type: none"> <li>- Multifunctional land use (public)</li> <li>- Mobility improvement (private)</li> <li>- Maintenance improvement</li> </ul>	<ul style="list-style-type: none"> <li>- Smart pipe management</li> <li>- Street maintenance is about efficiency, flexibility, costs, logistics</li> <li>- Underground space buildings, trade off old/new foundations</li> <li>- Excavate polluted soil</li> </ul>	<ul style="list-style-type: none"> <li>- Risk with excavation</li> <li>- Governance (urban programming)</li> <li>- Legal</li> <li>- Financial</li> <li>- Technology up-tale (social acceptance and adaptation)</li> <li>- People behavior</li> </ul>	<ul style="list-style-type: none"> <li>- Community of owners</li> <li>- Clustering in smart pipes</li> <li>- PP knowledge relation</li> </ul>		<ul style="list-style-type: none"> <li>- Trade off with suburbs that will be decentralized, inner city MUT</li> <li>- Urban district heating</li> </ul>	<ul style="list-style-type: none"> <li>- Underground water storage</li> <li>- MUT (deep)</li> <li>- Urban district heating</li> </ul>
				<ul style="list-style-type: none"> <li>- Affordability</li> <li>- Biodiversity</li> <li>- Flexibility</li> <li>- Livelihood</li> <li>- <b>Appropriateness</b></li> <li>- Efficiency</li> <li>- Collaboration PP</li> <li>- <b>Awareness</b></li> </ul>	<ul style="list-style-type: none"> <li>- Affordability</li> <li>- Biodiversity</li> <li>- Flexibility</li> <li>- Livelihood</li> <li>- <b>Appropriateness</b></li> <li>- Efficiency</li> <li>- <b>Collaboration PP</b></li> <li>- Awareness</li> </ul>	<ul style="list-style-type: none"> <li>- Affordability</li> <li>- Biodiversity</li> <li>- Flexibility</li> <li>- Livelihood</li> <li>- Appropriateness</li> <li>- <b>Efficiency</b></li> <li>- <b>Collaboration PP</b></li> <li>- <b>Awareness</b></li> </ul>

Spatial principles and public space

As a result of the first workshop on reciprocities, the various technological applications were classified.

The aim of this chapter is to show the application and implications (in principle) of such technologies in the public space and urban structure. This is another contribution to the 'common language' and a method to allow us to first approach the spatial deployment of such elements toward the visionary projections which will follow in the next chapter.

The technical innovations are:

*Soil improvement SCC*

- Soil Improvement (BioGrout)
- SoSEAL (bioswale / bioretention cells)

*Urban Drainage (Sewer)*

- Sink disposal - flexible pipes
- Source separation

*UWM (Urban Water management)*

- Smart piping (bioswale, raingarden, bioretention cell)
- Infiltration crates
- Helophyte filters/ Constructed wetland
- Underground buildings

*Building-site preparation*

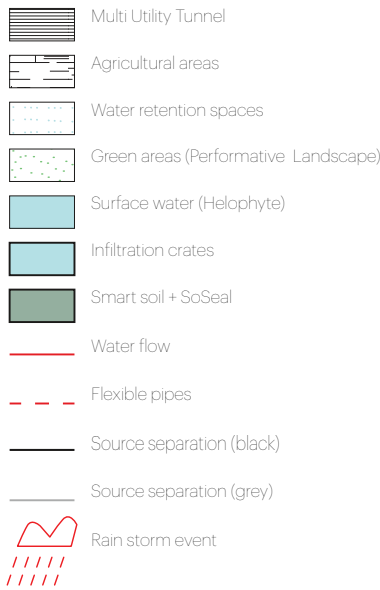
- Partial-Filling method and design with subsidence
- Nature based solutions
- New architectural typologies Urban Drainage (Sewer)

*UST (Underground space technology)*

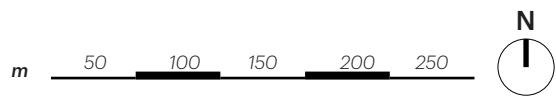
- MUT Multi Utility Tunnel (flush fitting shallow/deep)

For each technology the effect on public space and urban structure is visualized and brought in relation to the densification and shrinkage scenarios. The cases of Rotterdam and Borculo are used to illustrate respectively the densification and shrinkage scenarios.

**Legend Public space**



**Legend Urban Structure**



Densification: Rotterdam



Shrinkage: Borculo





Smart Soil Improvement (BioGrout)

*Technology:*

- Creating a higher carrying capacity.
- More efficient usage of soil on a very local scale.
- Facilitating more possibilities for building with nature on a larger scale given the focus on a smaller scale.
- Reducing maintenance cost on sewers.
- Usable for efficient water management.

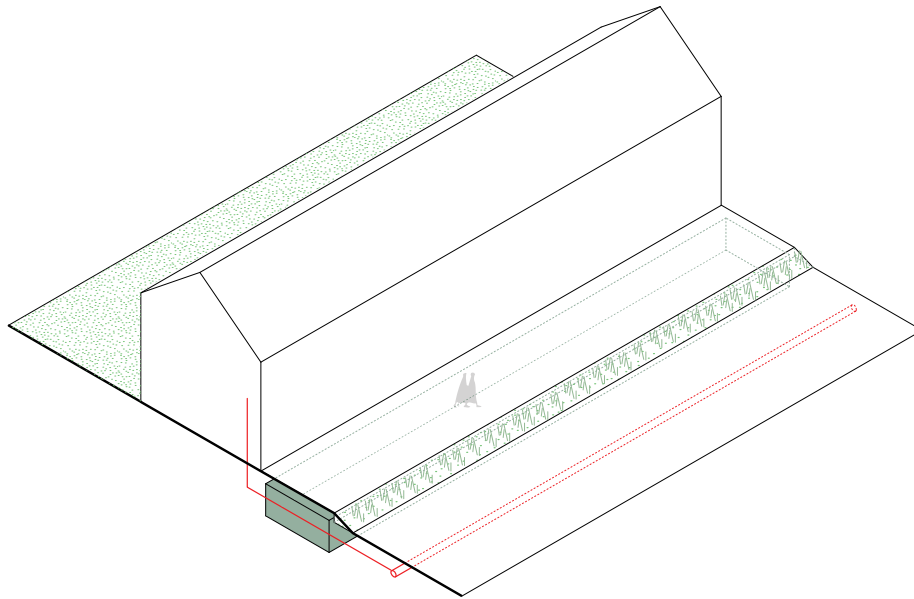
*Technology in relation to urban structures*

- The improvement of soil stability on the smaller scale has effect in the larger urban structures in the sense that new maintenance regimes of streets and sidewalks, aimed at more small located improvement, will bring to the larger scale the opportunity to re-nature.

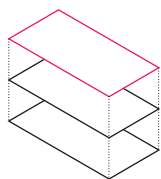
*Technology in relation to (urban) spatial qualities*

- Allows for urban nature – change in relief – in the design of public space by site specific soil stability and scaling down building-site preparation regimes.

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Facts



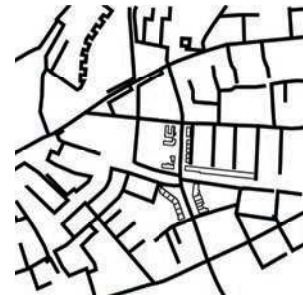
Surface

Subsurface

Public / Private



Densification



Main structure

Shrinkage



-  Re-Nature
-  Soil improvement (BioGrout)

SoSeal (bioswale / bioretention cells)

*Technology:*

- Making soil impermeable.
- Creating water management units on the smaller scale.
- Control on soil and water pollution.

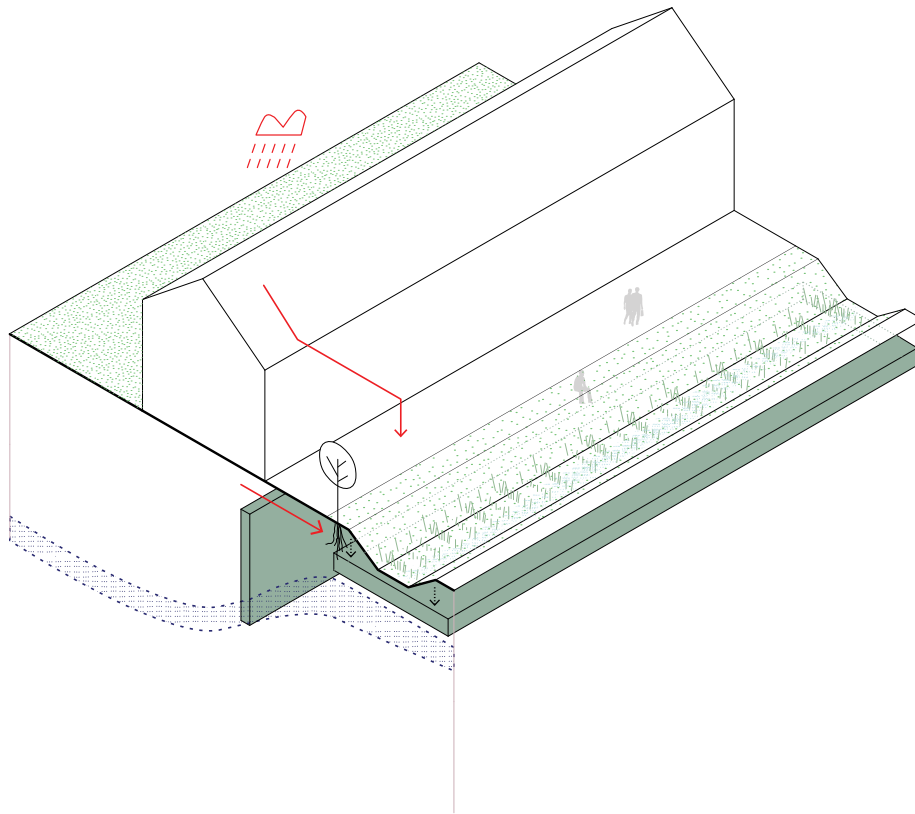
*Technology in relation to urban structures*

- Adaptability of water infrastructures is the key for a more flexible urban setting.

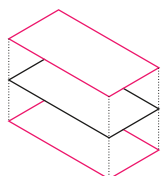
*Technology in relation to (urban) spatial qualities*

- Ability to create open soil with small scale water units and visible water systems bring meaning and improvement to the spatial qualities.
- Steer functionality by pollution control.

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Facts



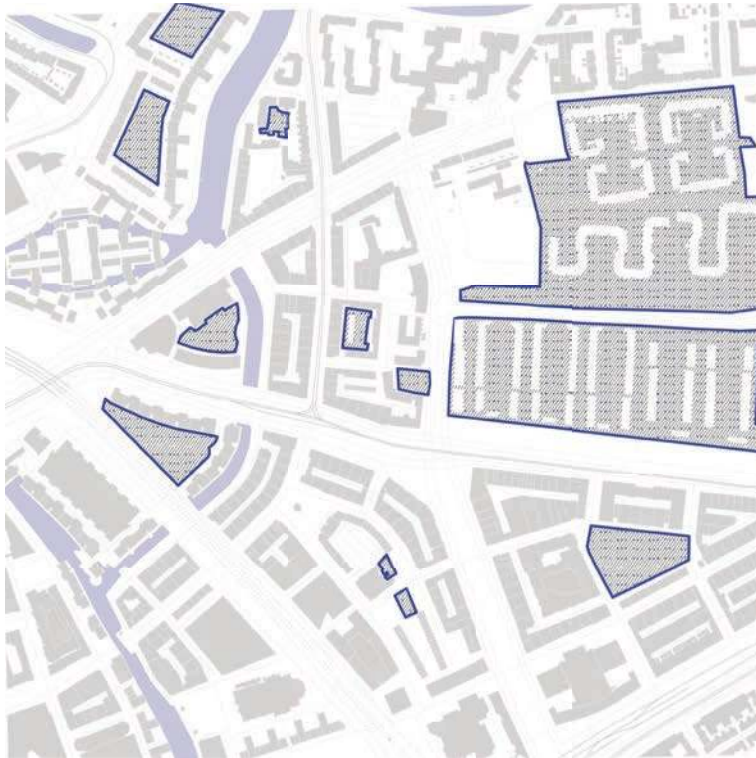
Surface

Subsurface

Public / Private



Densification



Shrinkage



SoSEAL (bioswale/bioretention cells)

Sink disposal - Flexible pipes

*Technology:*

- Organic waste separately distributed with waste water through flexible pipes.
- Opportunity to create local sewage treatment plant, smaller sewage community systems. Towards decentralization.

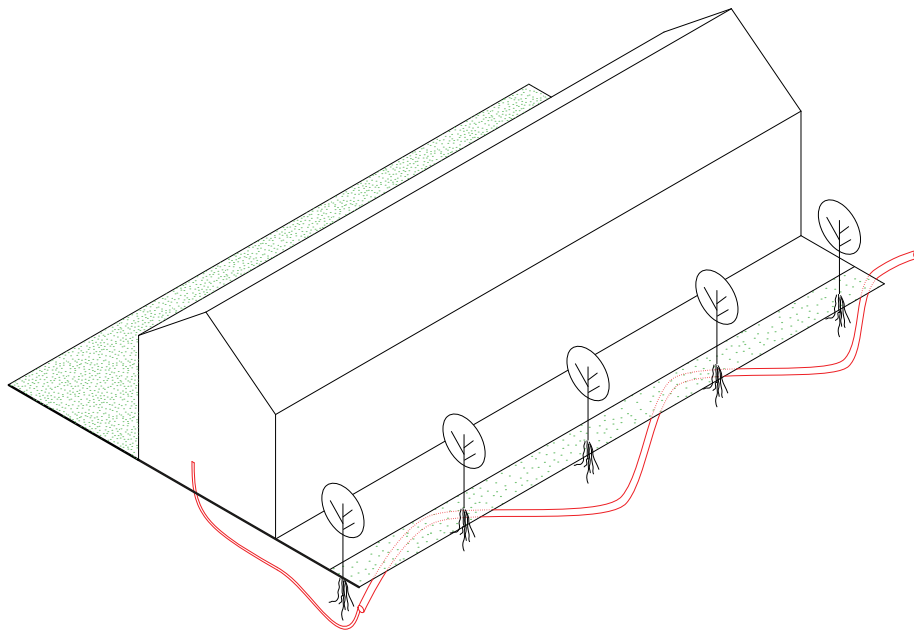
*Technology in relation to urban structures*

- At the larger scale, the introduction of more green space and decentralized waste treatment impacts urban performance and the metabolism of the urban system.

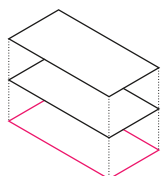
*Technology in relation to (urban) spatial qualities*

- Flexible pipes are confronted in relation to fixed pipes, reducing costs and adding flexibility also in public space design, because they can be moulded more efficiently.
- Creating on site biogas production plant from housing compost that is transported through flexible pipes.

50



Facts



Surface

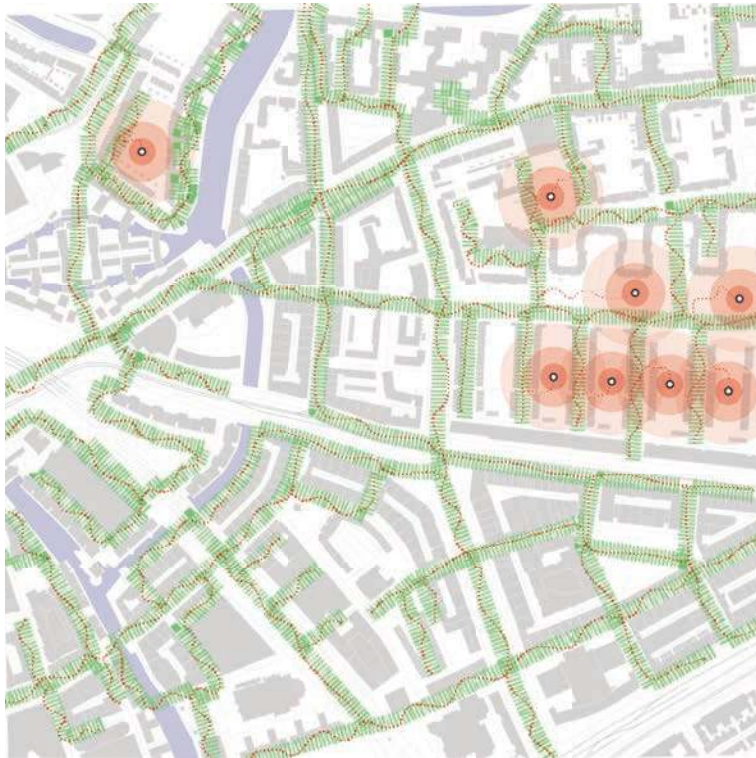
Subsurface

Public / Private

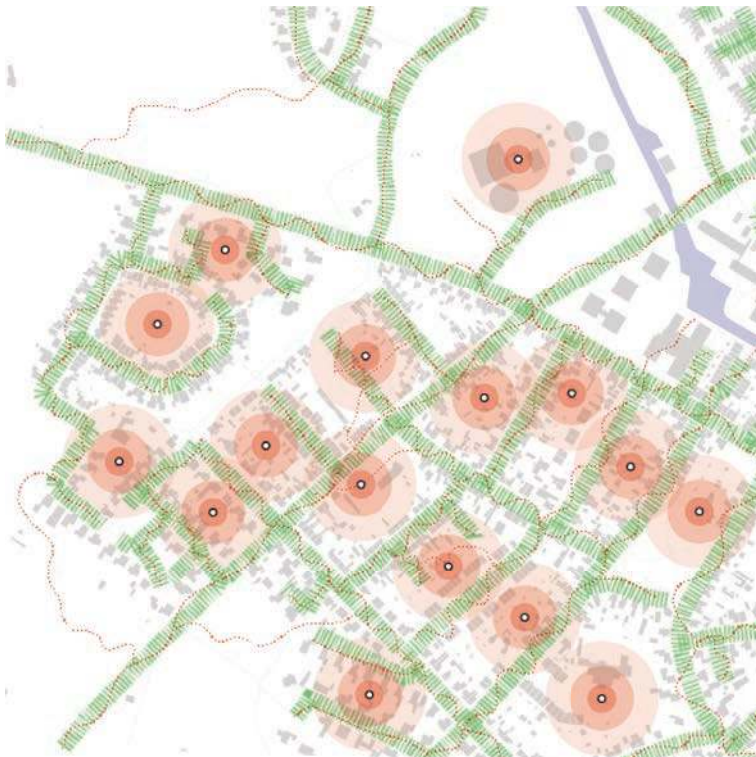




Densification



Shrinkage



-  Sink disposal - flexible pipes
-  Local Treatment plant
-  Re-Nature
-  Sink disposal - flexible pipes

Source Separation

*Technology:*

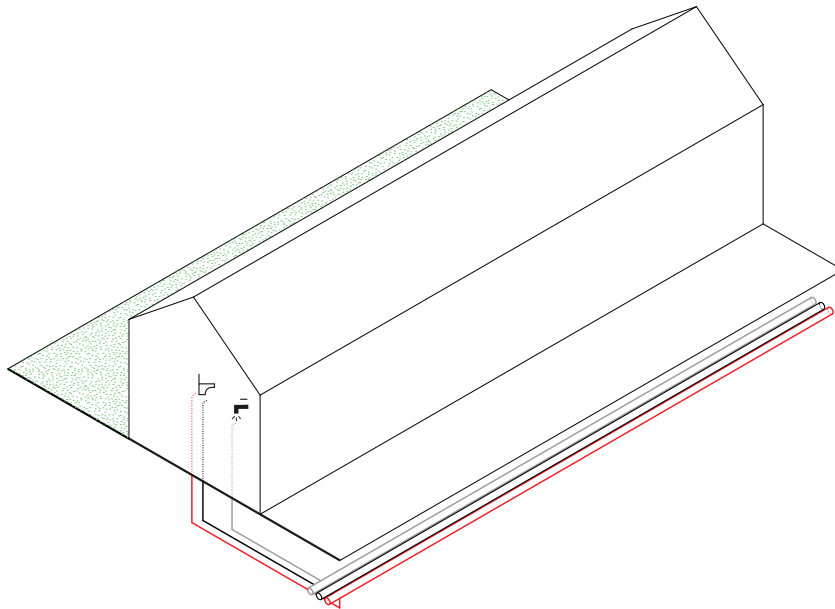
- Introduction of different waste flows.
- Local sewage treatment plant, smaller sewage community systems towards decentralization.
- Recovery of nutrients

*Technology in relation to urban structures*

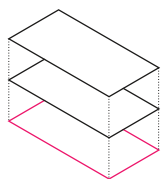
- At the larger scale, the introduction of more green space and decentralized waste treatment impacts urban performance and the metabolism of the urban system.

*Technology in relation to (urban) spatial qualities*

- Creating on site nature based sewer treatment.



Facts



Surface

Subsurface

Public / Private

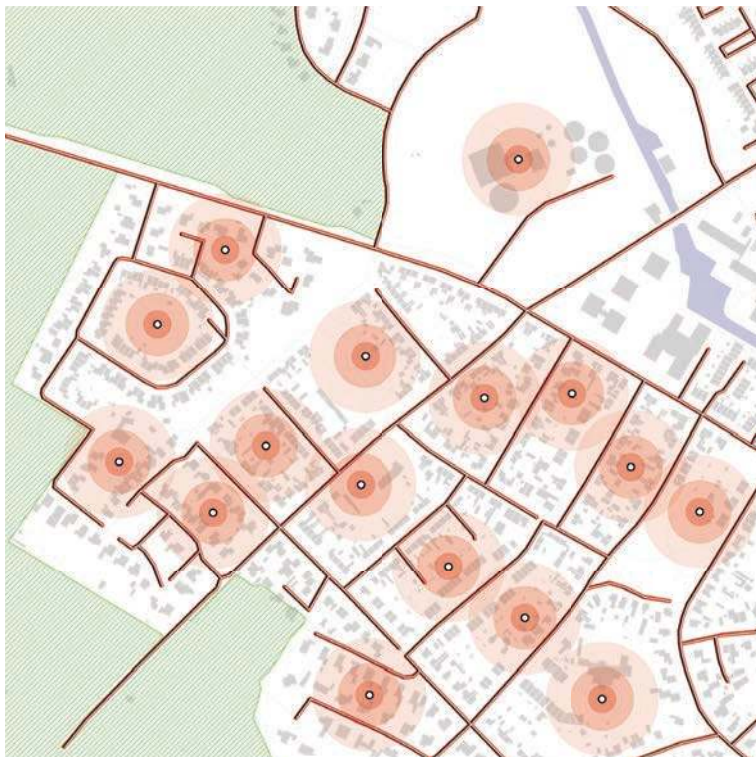




Densification



Shrinkage



- Sewer network (mainline pipes)
- Local Treatment plant
- Source separation

Smart Piping (Bioswale, Raingarden, Bioretention cell)

*Technology:*

- Smart piping in relation to the natural system can make room for a more efficient and flexible system.
- Rainwater harvested can be used for irrigation.

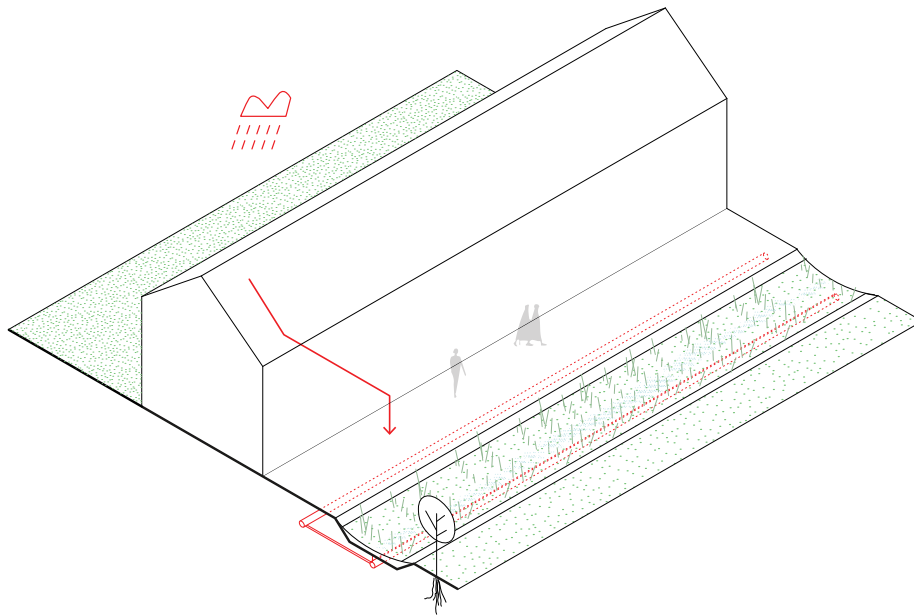
*Technology in relation to (urban) spatial qualities*

- Visible water systems bring meaning and improvement to the spatial qualities.
- Decentralized system of stormwater management, considering that every lot could become a surface detention or infiltration area, potentially enhances urban greenery and decreases landscape fragmentation.

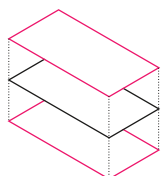
*Technology in relation to urban structures*

- Main infrastructure of green spaces
- Adaptability of stormwater infrastructure is the key for a more flexible urban setting.

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Facts



Surface

Subsurface

Public / Private



Densification



Shrinkage



- Smart piping (Bioswale)
- Smart piping (Bioretention cell)
- Smart piping (Rain Garden)

Infiltration Crates

*Technology:*

- Rainwater harvesting in crates under streets.
- Water can be used for irrigation.

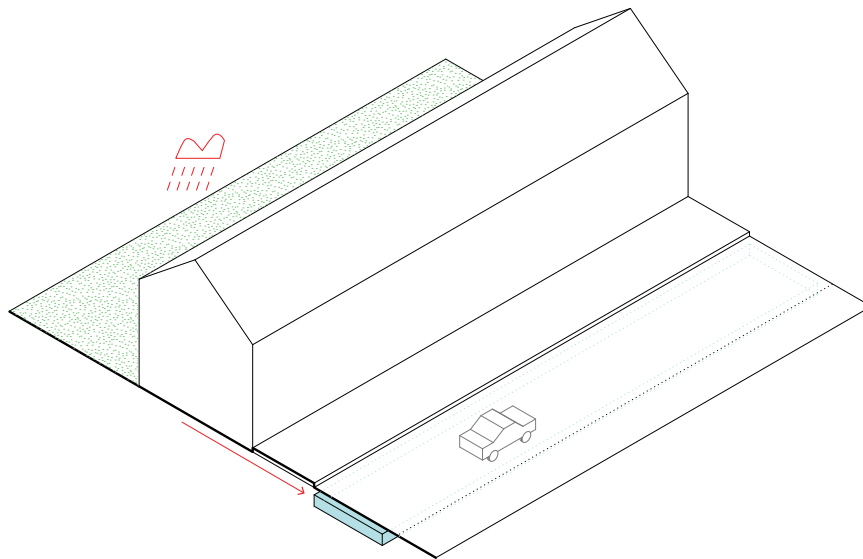
*Technology in relation to urban structures*

- Could be applied to road and rail infrastructures in the city, offering densification possibilities.

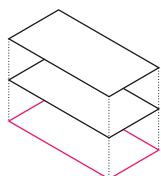
*Technology in relation to (urban) spatial qualities*

- Efficient use of space making design of public space more flexible.

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Facts



Surface

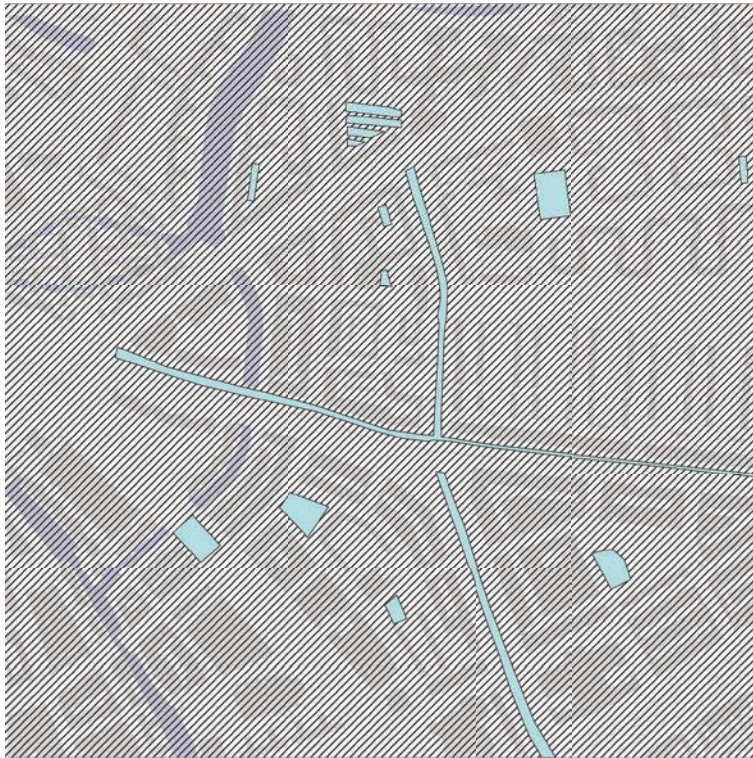
Subsurface

Public / Private





Densification



Shrinkage



Helophyte Filters / Constructed wetland

*Technology:*

- Natural cleaning of water.
- Unload of sewers.
- Functional use of open water.

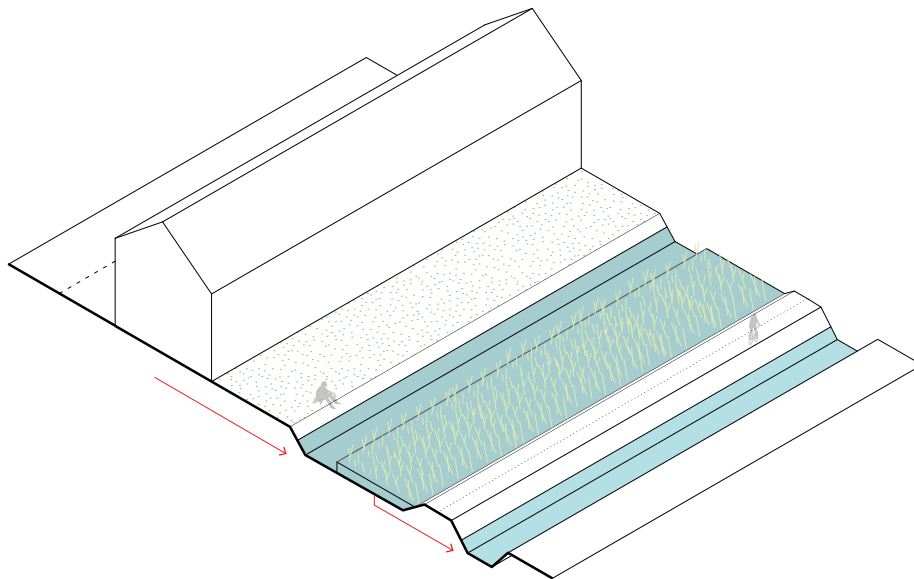
*Technology in relation to (urban) spatial qualities*

- Visible water systems bring meaning to the public realm and improvement of its spatial qualities.
- Re-naturalization of open water systems.
- Implications on urban health (e.g. insects/disease proliferation)

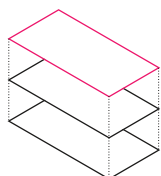
*Technology in relation to urban structures*

- Main infrastructure will become more green and blue.
- Proximity to underground drainage and open water system.
- Adaptability of water infrastructures is the key for a more flexible urban setting.

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Facts



Surface

Subsurface

Public / Private



Densification



Shrinkage





Underground Buildings

*Technology:*

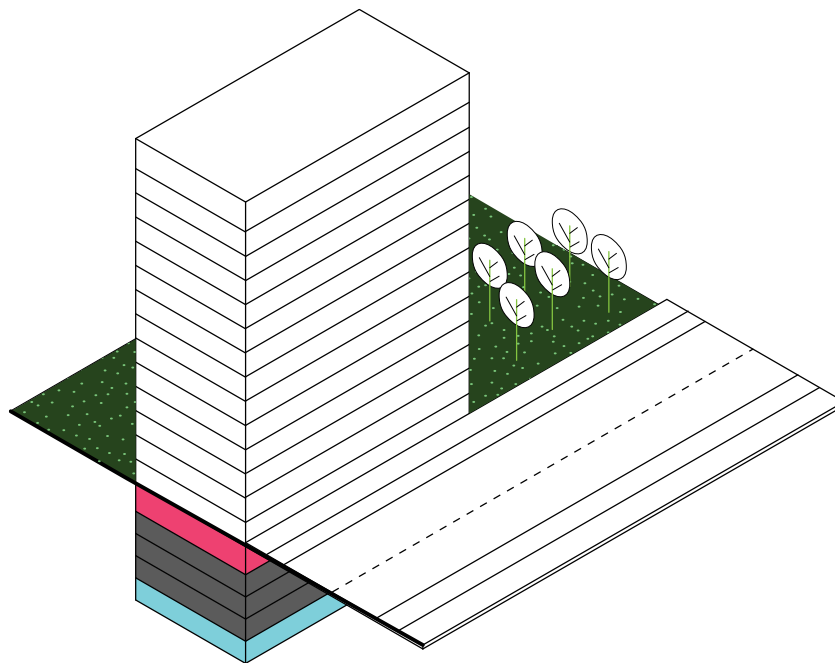
- Building subsurface storage.
- Rainwater harvested can be used for irrigation.

*Technology in relation to (urban) spatial qualities*

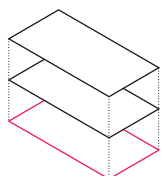
- Efficient use of urban space can improve design of public space.

*Technology in relation urban structures*

- Increase and efficient storage capacity makes water infrastructures more adaptable and create more flexible urban setting (densification).



Facts



Surface

Subsurface



Commercial



Parking

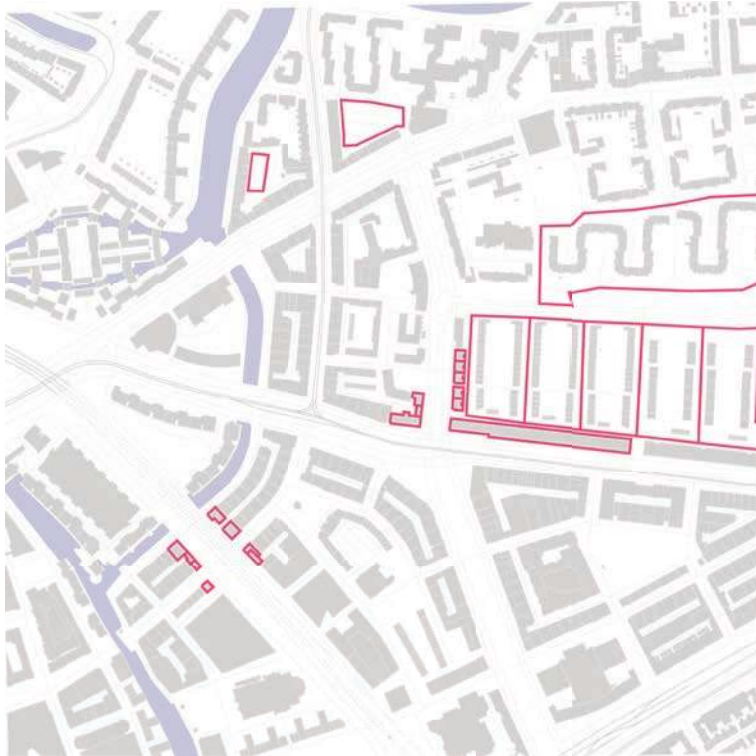


Water Storage

Public / Private



Densification



Shrinkage



Partial Filling method and Design with subsidence

*Technology:*

- Adding stabilizing sand in smaller locations, structures.

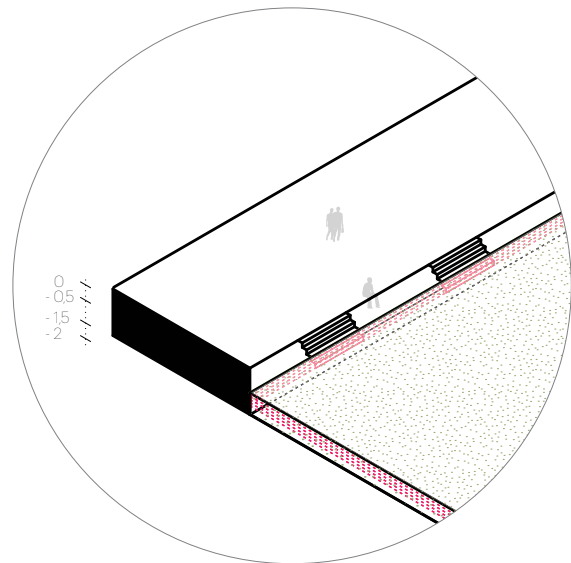
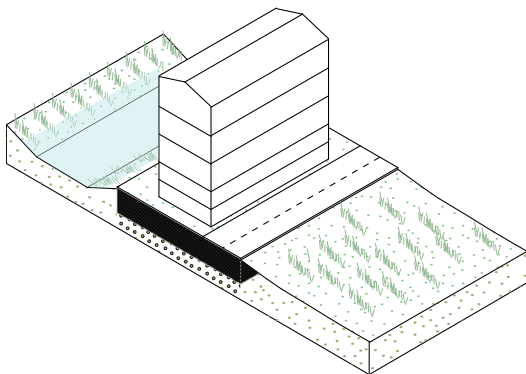
*Technology in relation to (urban) spatial qualities*

- More space for nature based solutions.
- More differentiated design of public space.

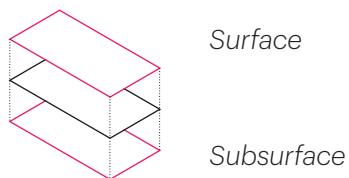
*Technology in relation to urban structures*

- Re-nature on a larger scale.

62



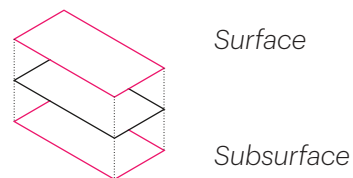
Facts



Public / Private



Facts



Public / Private





Densification



Shrinkage



-  Design with subsidence
-  MUT Multi Utility Tunnel (shallow/deep)

Nature Based Solutions

*Technology:*

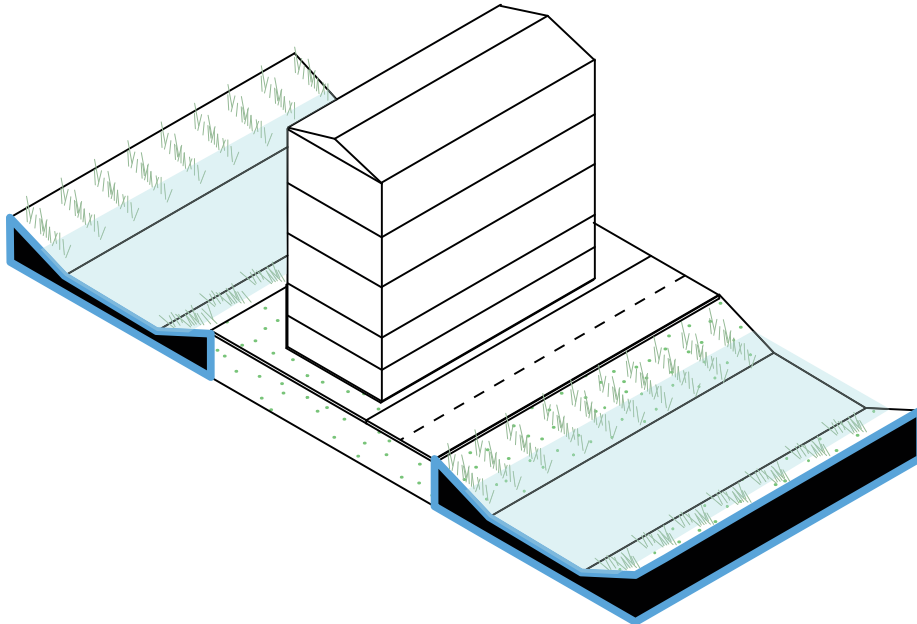
- Various technologies that adapt to and work with ecosystem services.

*Technology in relation to urban structures*

- Re-nature on a larger scale.
- New/ revised urban morphology.

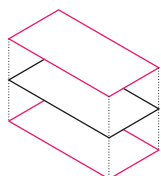
*Technology in relation to (urban) spatial qualities*

- Enforcing ecosystem of green structures of the city, making them more water responsive and enlarging the fertility of the urban soil.
- More differentiated design of public space.



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Facts



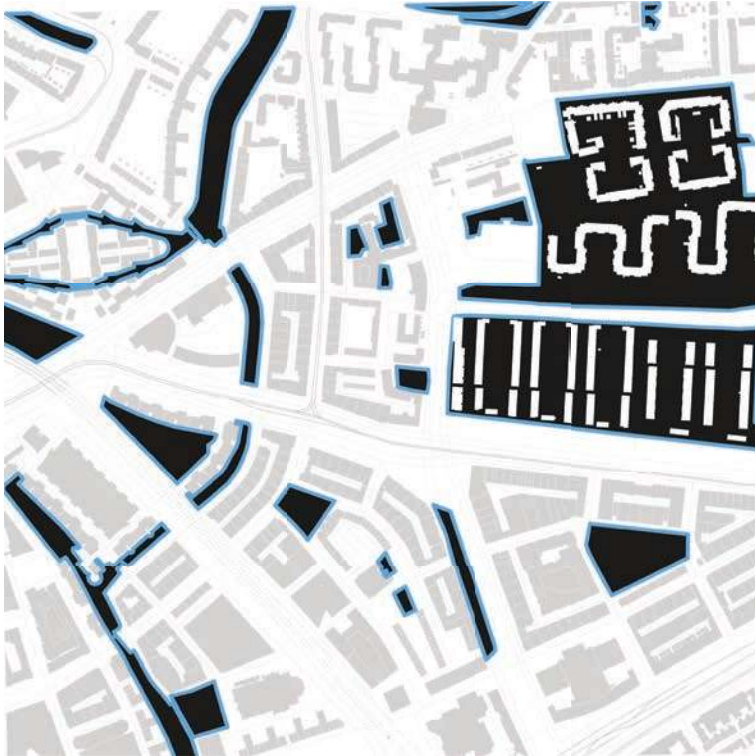
Surface

Subsurface

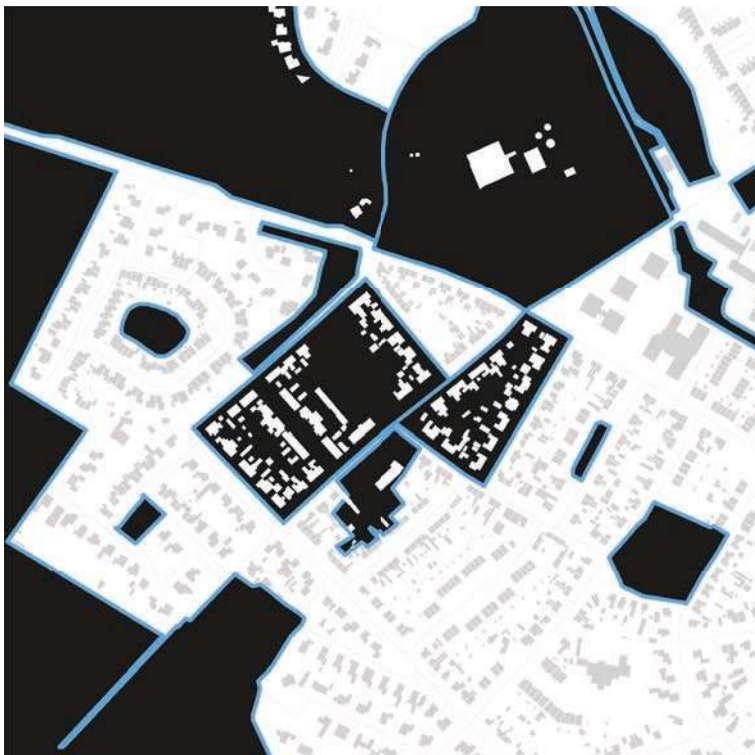
Public / Private



Densification



Shrinkage



Partial-filling method



New Architectural Typologies

*Technology:*

- No building site preparation by adding sand, partial application of Biogrout and new building typologies.

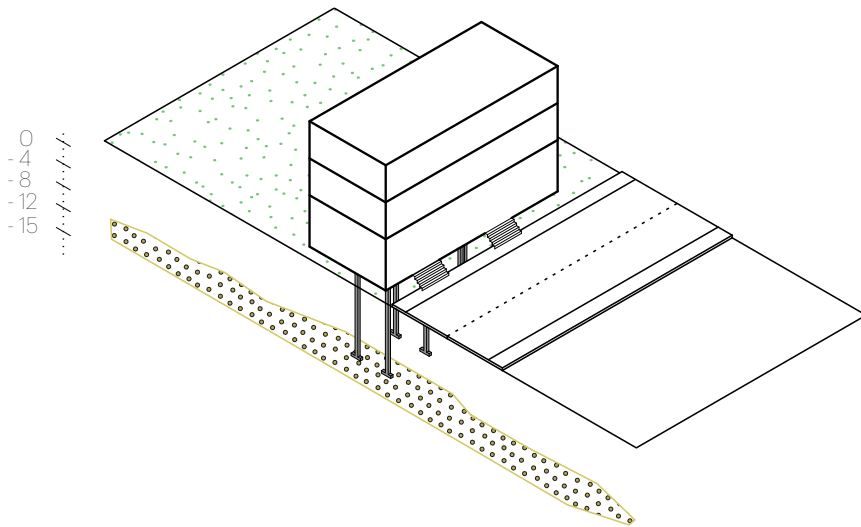
*Technology in relation to urban structures*

- Re-nature on a larger scale.
- New/ revised urban morphology.

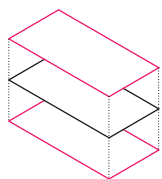
*Technology in relation to (urban) spatial qualities*

- More space for nature based solutions.
- More differentiated design of public space.

66



Facts



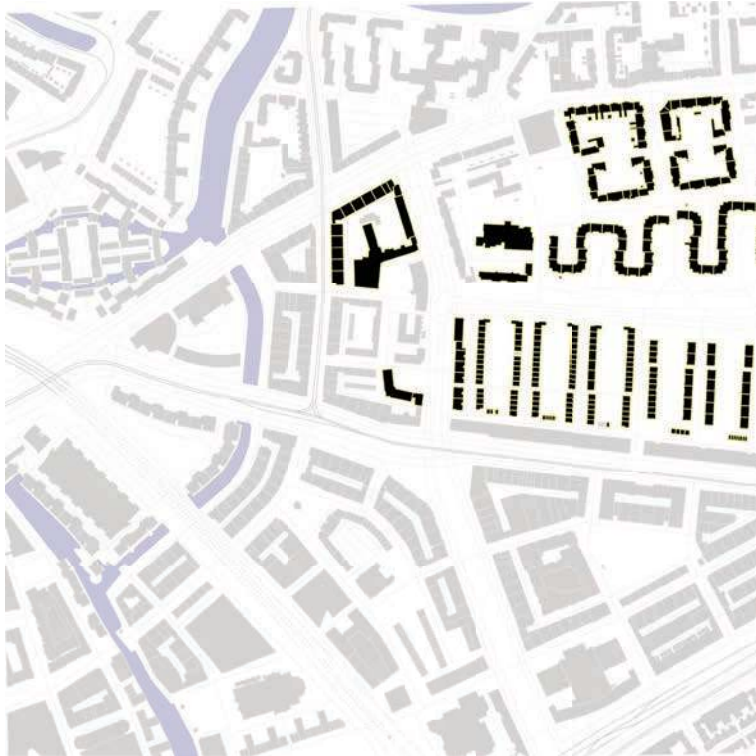
Surface

Subsurface

Public / Private



Densification



Shrinkage



 New architectural typologies

MUT Multi Utility Tunnel: Flush Fitting

*Technology:*

- Organizing underground infrastructure in an efficient way.
- Easier maintenance.
- Easier adding/changing systems.
- More clear governance.

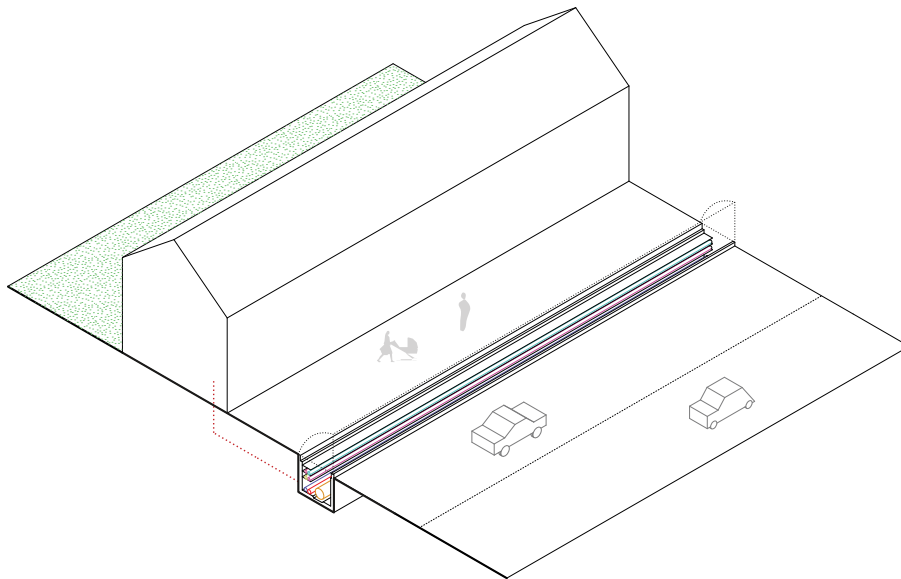
*Technology in relation to urban structures*

- Option to densify but also re-nature on a larger scale.
- Improved urban structure in the future.

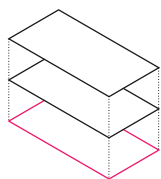
*Technology in relation to (urban) spatial qualities*

- Efficient use of surface space can increase urban quality.
- More room for nature-based solutions.

68



Facts



Surface

Subsurface

Public / Private



Densification



Shrinkage



- Re-Nature
- infiltration crates
- Underground buildings

MUT Multi Utility Tunnel: Shallow / Deep

*Technology:*

- Organizing underground infrastructure in an efficient way.
- Easier maintenance.
- Easier adding/changing systems.
- More clear governance.

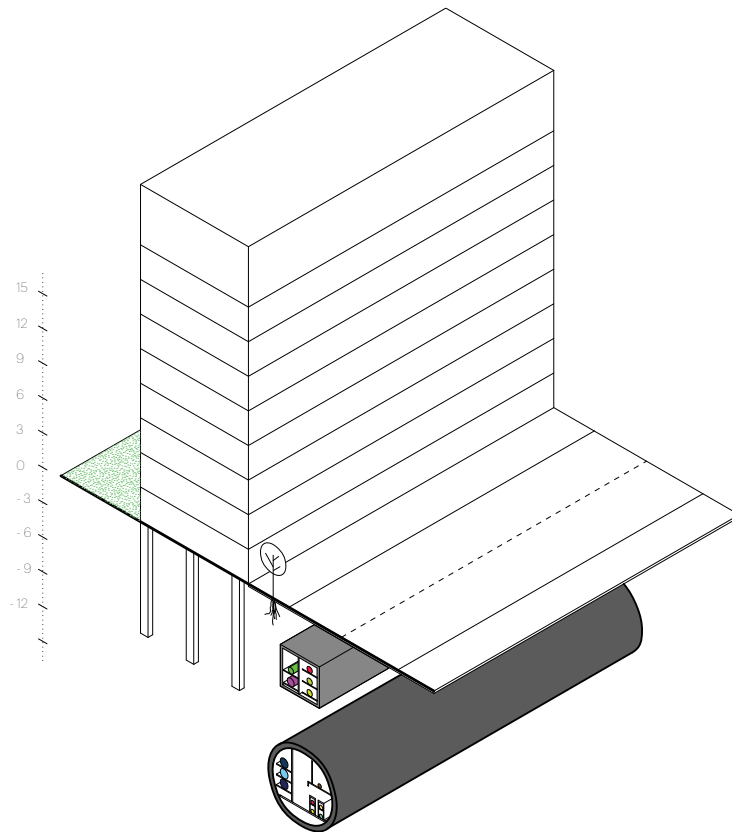
*Technology in relation to urban structures*

- Option to densify but also re-nature on a larger scale.
- Improved urban structure in the future.

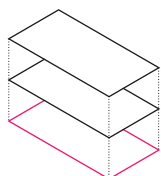
*Technology in relation to (urban) spatial qualities*

- Efficient use of surface space can increase urban quality.
- More room for nature-based solutions.

70



Facts



Surface

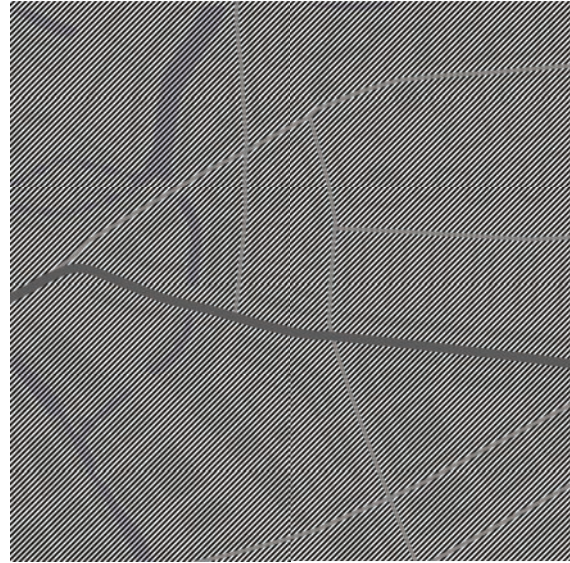
Subsurface

Public / Private





Densification



Shrinkage

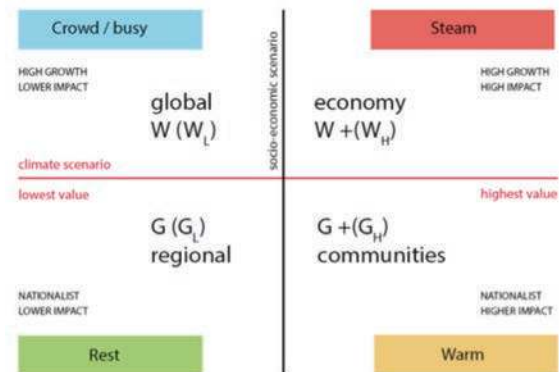


-  Re-Nature
-  infiltration crates
-  MUT Multi Utility Tunnel (flush/fitting)



## Explanation of the warm and rest scenarios

The shrinkage and densification scenarios are placed in relation to two climate and socio-economic development possible future. The work with scenarios offers a possibility to compare future opportunities and challenges in a more defined field.



**Figure 6.1:**

The 4 scenarios undertaken in the research are adapted from LANDS and delta scenarios. Source: JPI Urban Europe Green/Blue Cities, TUDelft 2015.

WARM - NHI  
(Nationalist Higher Impact) – (GH)

- Number of residents constant up to 2050 followed by a drop to 12 million in 2100
- Slight economic growth up to 2050 followed by slight decline
- In due course urbanisation falls dramatically
- Area of land used for agriculture remains relatively constant
- Natural surface area grows slightly
- Increase in winter precipitation from 14% to 28%
- Decrease in summer rainfall from -19% to -38%
- Sea level risen by 85 cm in 2100

This scenario is characterised by a regional or nationally focused perspective, with a high environmental awareness, albeit with a strong nationalist rather than federal EU perspective. The Dutch population will be some 16 million in 2040 but may be less and will exert only minor pressures on the environment as a consequence. GDP around 50% of that in the W scenarios, at only 30% above that of the reference in 2001, hence unemployment will be high and innovation low. There will be reductions in energy use, and freight movements due to reduced consumer demand, although personal travel will increase slightly, although commuting for work will be mainly within local areas. Housing growth will be modest (0.3%), as will urbanisation, which in some instances may be contractions in cities.

The demand for commercial premises will be roughly the same as in 2002, albeit with a different distribution of types of development. Rural development, employment and commercial practices will all fall drastically compared with 2002. There will be a large demand for nature space, up by some 120,000ha, but other land needs for recreation and sports activities will increase by only a small fraction. Water retention area needs will increase only slightly by some 2000ha compared with 2002. By 2085 society will either have attained an equilibrium with the capacity of the planet and the Dutch people, or semi-collapsed due to its' inability to support communities. The greater climate change compared with NLI scenario above, may make the situation even more difficult than for that scenario due to low GDP growth and lack of innovation. The Netherlands may need to be in a federal EU, in which the majority of services, systems and support for citizens is provided collectively. Climate change will not yet be stable, with ongoing changes still happening.

By 2040 temperatures will have risen by about 1°C. In winter rainfall increases by 8%, number of wet days increases by 2%; number of days where rainfall exceeds 10mm increases by 20%. 10-day 10 year return period rainfall increased by 12% in winter. In summer, daily maximum temperatures increased by circa 2°C; mean rainfall reduces by circa 8%; maximum hourly rainfall intensity by up to 14%; numbers of wet days in excess of 20mm, reduces by up to 6%. Solar radiation increased by

up to 5%. Highest precipitation deficit exceeded in ten years increased by 17%. Air pollution increases and the numbers of elderly dying in summer heat and smog increases (number of summer days exceeding 25°C up by 35%), with numbers exceeding those not dying in winter as winter temperatures are elevated (+3.6°C coldest winter day).

By 2085 temperatures will have risen by about 1.5°C. In winter rainfall increases by up to 28%, number of wet days up by 1%, but number of days where rainfall exceeds 10mm increases by 24%. 10-day 10 year return period rainfall increased by 12% in winter. In summer, daily maximum temperatures increased by circa 2°C; mean rainfall is decreased by up to 38%; maximum hourly rainfall intensity increased by up to 19%; numbers of wet days in excess of 20mm, by up to 14%. Solar radiation increased by up to 6%. Highest precipitation deficit exceeded in ten years increased by 17%. Air pollution increases and the numbers of elderly dying in summer heat and smog increases (number of summer days exceeding 25°C up by 50%), with numbers exceeding those not dying in winter as winter temperatures are elevated (+4°C coldest winter day).

#### STEAM - HGHI (High Growth Higher Impact) – (WH)

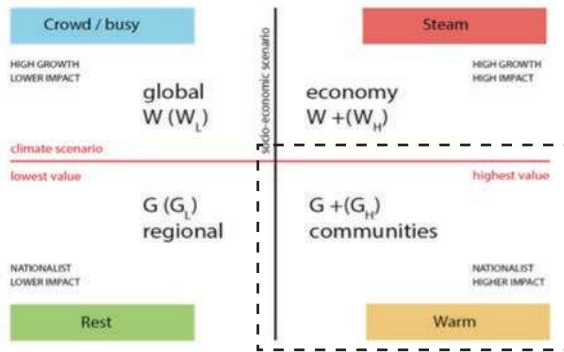
- Number of residents rises to 20 million in 2050 and 24 million in 2100
- Economy continues to grow by over 2% per year
- Continued urbanization
- Area of land used for agriculture reduced up to 2050 followed by increase
- Natural surface greatly reduced after 2050
- Increase in winter precipitation from 14% to 28%
- Decrease in summer rainfall from -19% to -38%
- Sea level risen by 85 cm in 2100

This scenario is characterized by strong internationally based economic vitality with relatively few constraints against e.g. environmental degradation; hence a wide range of innovation emerges. Urbanization continues to grow as does the population and demand for commercial space. European environmental legislation is deliberately overlooked. Increased population – at least 20 million, with more than 10 million households, many with single occupancy (up 1.9% from 2002). There is major disparity in income between the population groups, although employment rates are high, but regionally variable across the country, with fewer in agriculture and

heavier industries, although commercial agriculture e.g. greenhouses increases significantly (+60% from 2002). All forms of transport show increases in use. There is an increased demand for sports and recreational spaces (up by some 20-50,000 ha). The demands for access to nature especially by urbanites increases by more than 100% increasing by some 120,000ha (compared with 2002). There is also a big demand to increase water retention near rivers and urban areas (up by 5000ha). By 2085, the trajectory of economic growth is still being pursued, albeit the effects of environmental ignorance and undervaluing, has become apparent with major impacts on society leading to constraints on the free-for-all of the economic growth pursuit.

By 2040 temperatures will have risen by about 2°C. In winter rainfall increases by up to 17%, number of wet increases by 2.5%, but number of days where rainfall exceeds 10mm increases by 20%. 10-day 10 year return period rainfall increased by 17% in winter. In summer, daily maximum temperatures increased by circa 2.5°C; mean rainfall decreases by up to 13%; maximum hourly rainfall intensity by up to 25%; numbers of wet days in excess of 20mm, unknown but expected to be somewhere between being reduced by 9% or an increase of up to 14%. Solar radiation increased by up to 7%. Highest precipitation deficit exceeded in ten years increased by 25%. Air pollution increases and the numbers of elderly dying in summer heat (number of summer days exceeding 25°C up by 70%) and smog increases, with the numbers exceeding those not dying in winter as winter temperatures are elevated (+5°C coldest winter day).

By 2085 temperatures will have risen by 3.5°C, winter rainfall increases by 30%; number of wet days increase by 3%; days with rainfall in excess of 10mm increases by 60%. 10-day 10 year rainfall increases by 25% in winter. In summer, daily temperature maximum increase by 4°C; mean rainfall decreases by up to 38%; maximum hourly rainfall intensity by up to 45%; numbers of wet days in excess of 20mm, unknown, but could be decreased by 15% or increased by up to 14%. Solar radiation increased by up to 10%. Highest precipitation deficit exceeded in ten years increased by 50%. Air pollution increases and the numbers of elderly dying in summer heat (number of summer days exceeding 25°C up by 130%) and smog increases, with the numbers significantly exceeding those not dying in winter as winter temperatures are elevated (+8°C coldest winter day).



General considerations:

- Limited increase of infrastructures and utilities but, higher demand capacity;
- Low economic development leads to the stagnation of the available budget for investments;
- The impact of climate change gives incentive to adapt with sustainable measures;
- Densification includes more stakeholders to align;
- Policies are not yet aimed at adaptation.

What will be needed to achieve:

- The densification of the urban environment will have to be accommodated.
- The general behaviour and expectation of the population will have to be changed as the pressures of climate change and densification has a big impact on the liveability of the city;
- To support new technology and a more sustainable development we need willingness to adjust people's behaviour.

Underground space technology:

In the long run Multi Utility Tunnel (MUT) will save money on multiple aspects of underground infrastructure and offers opportunities for new subsurface infrastructure, like a heat network. This technology becomes more valuable for densifying areas and makes the underground infrastructure more compact and easily accessible. A reduction of the required subsurface space for cables and pipes allows for a more flexible usage of the now freed underground space.

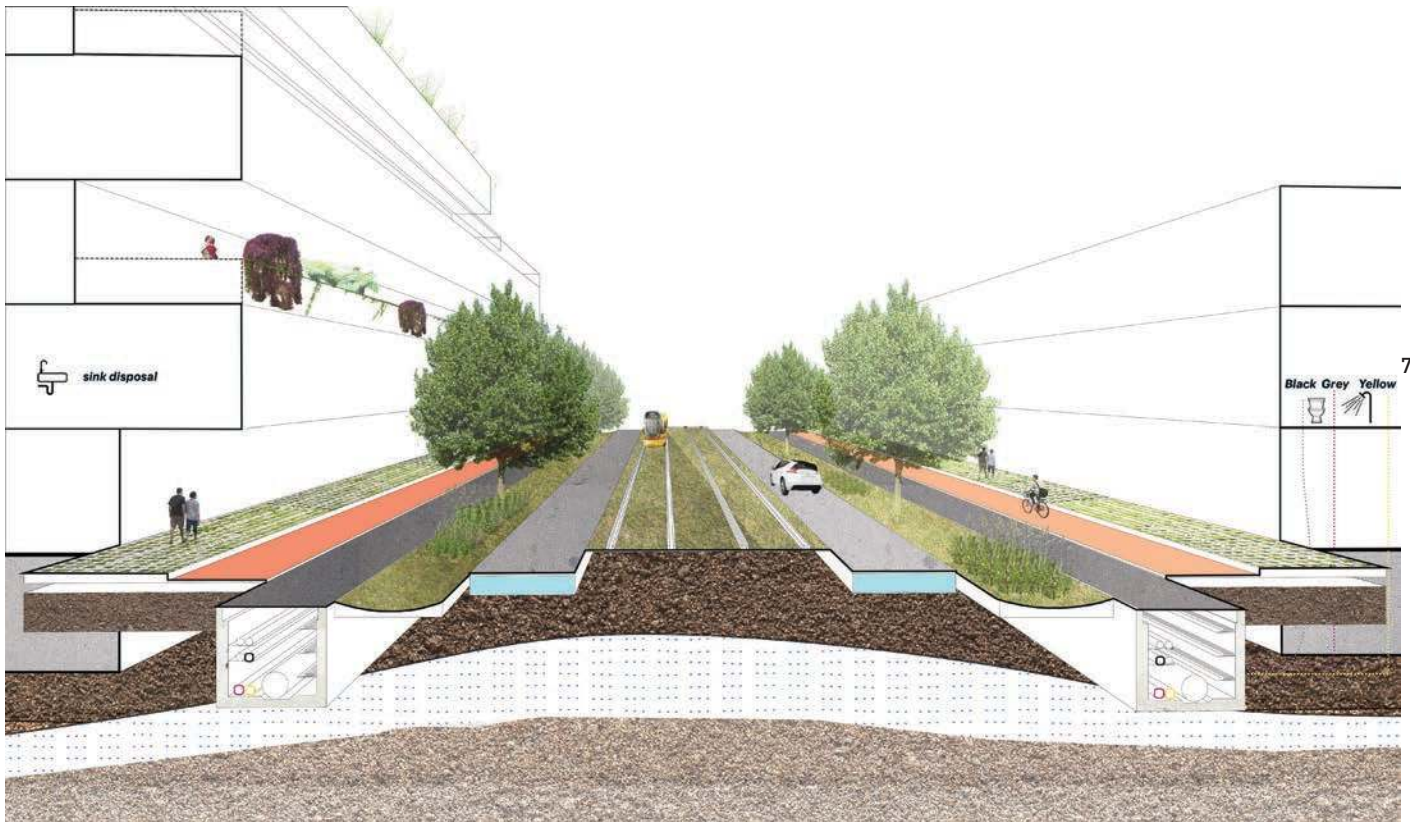
This in turn makes the space above ground more flexible and multifunctional.

Soil:

With the technology of BioGrout & SoSEAL the usage of soil can be expanded, facilitating more possibilities for building with nature, fixate old infrastructure, like a leaking sewer, and increase carrying capacity allowing for cheaper construction of new buildings.

Water management and urban drainage:

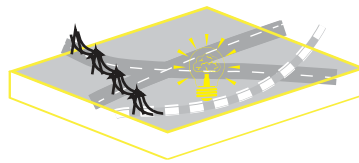
Improved water management systems via surface measures reduces the demand on the sewer to drain the water and can prevent damages as a result from pluvial flooding. A new waste water system that separates faeces from urine creates the possibility for urban harvest of nutrients. The benefits of nature based water management measures have long-term benefits, but their costs might represent a challenge when applying such measures in a comprehensive manner. They do facilitate the multifunctional usage of space providing opportunities for the improvement of spatial quality and therefore the acquisition of multiple benefits that can be monetized, e.g. amenity and health. In this regard, the pressure from climate change creates one of the best opportunities for the improvement of our cities. The more flexibility MUT gives more possibilities for water management construction, operation and maintenance.



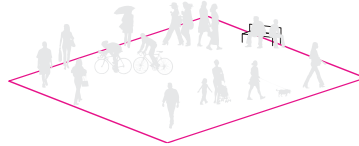
## Adaptation Pathway

This scenario is characterized by densifying cities, high climate change, and limited financial resources. To conceive a better urban setting, the focus is given to three concepts: reuse; decentralization; sharing. Around these three foci, the different pathways define the needed steps to achieve the end goals. All changes are based on a new urban structure design and operation which is supported by cultural change - i.e. community uptake of new measures and behavioural change: since the technology improvement is limited due to less economic resources, more pressure is put on the social component. Via educational programs and raising awareness, changes are expected in people behavior.

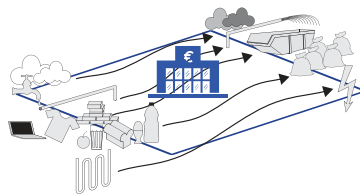
*Space / technology*



*People / society*

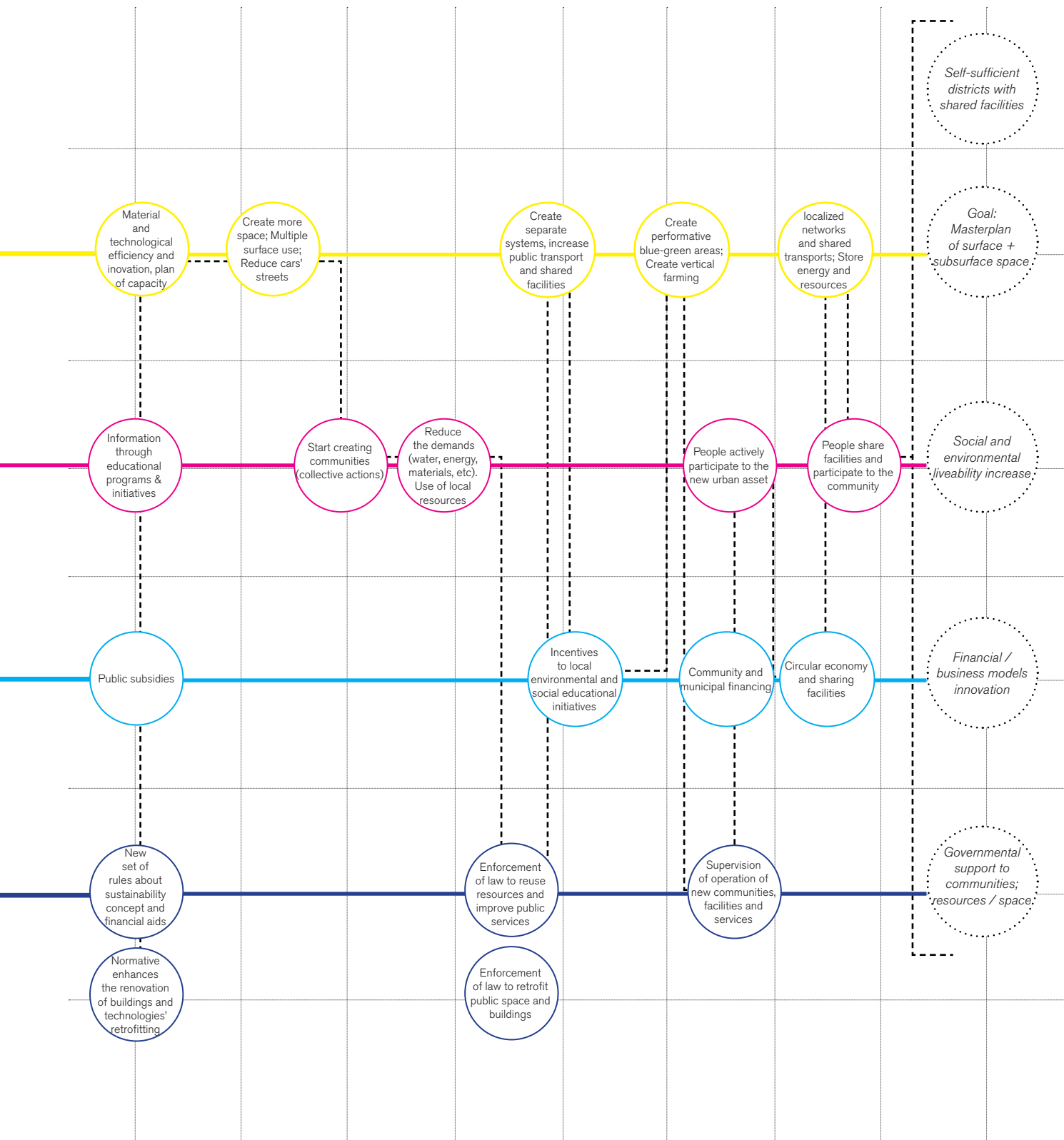


*Institutional*

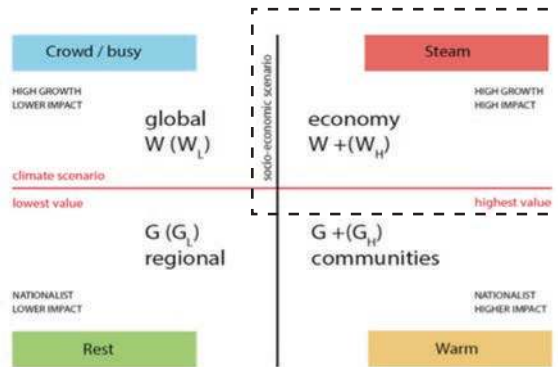


*Financial*









General considerations:

- Increase of infrastructures and utilities;
- Higher demand for quality of life (infrastructures quality);
- More conflicts among stakeholders and in policies;

What will be needed to achieve:

- For both big and small infrastructures: higher auto sufficiency in terms of operation and energy requirements. This could be achieved by decentralization;
- More flexibility in a limited space;
- Pressure in the involved parties towards agreements in light of the urgency of new space and energy requirements.

Underground Space Technology:

The Multi Utility Tunnel is an opportunity, especially the deep utility deep tunnel which not only safes space in the underground but especially reduces disturbances at surface level when maintenance is required. The positive features of the MUT are less interference between networks; more flexibility in operation and maintenance; improved mapping of underground networks. Negative features: problems with utilities owners given that different parties are involved. Financial means do not represent a constraint to this

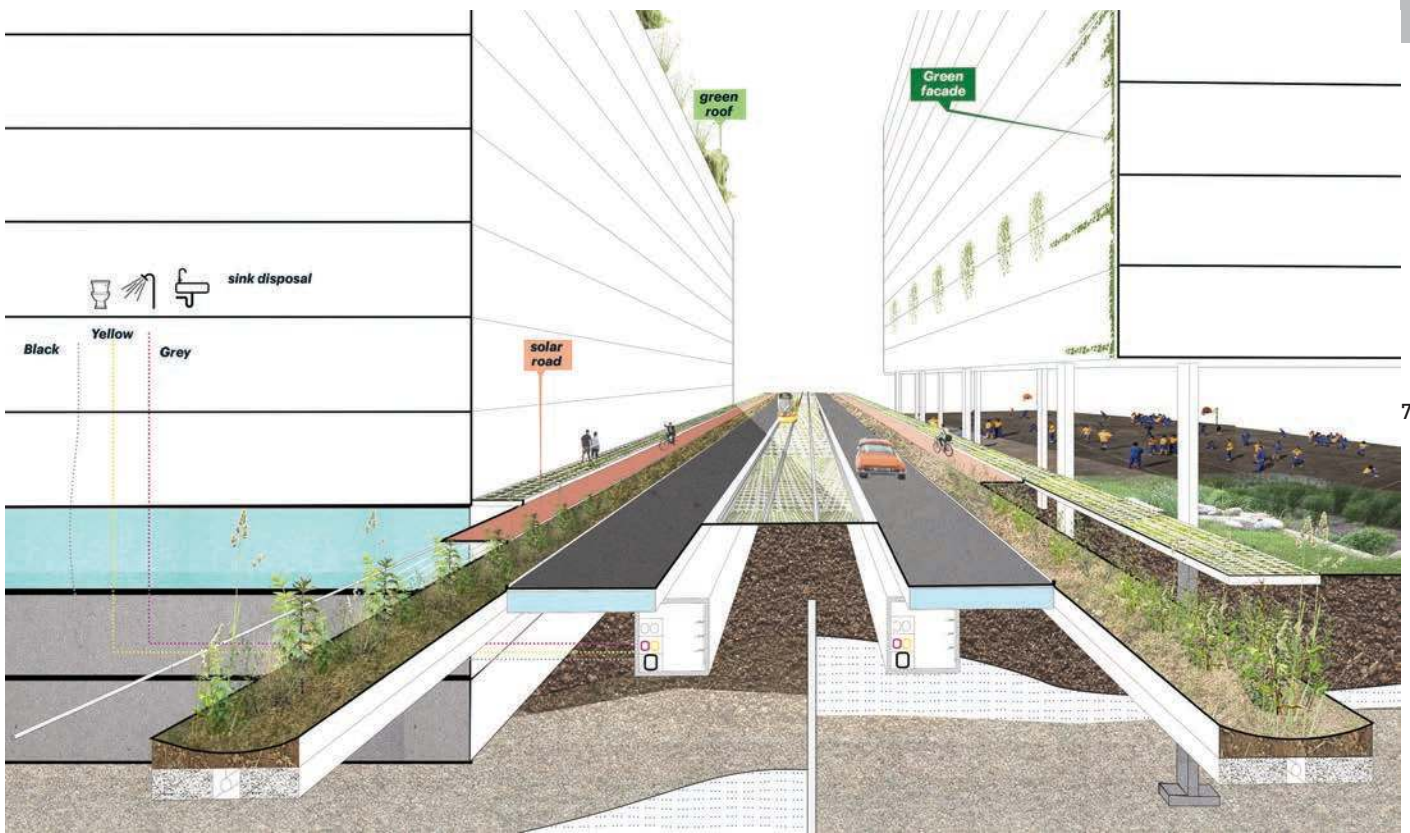
technology in this scenario given the economic growth.

Soil:

With the technology of BioGrout & SoSEAL the usage of soil can be expanded, facilitating more possibilities for building with nature, fixate old infrastructure, like leaking sewers and increase carrying capacity allowing for cheaper construction of new buildings.

Water Management & Urban Drainage:

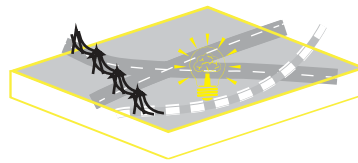
In the steam, high-pressure growth situation, the quality and quantity of water are potentially managed with high-tech nature based solutions. The MUT can store innovative systems of separated water and waste flows. Buildings are harvesting stormwater, using and cleaning water in such a quantity that it has a positive effect on urban water management at the larger scale.



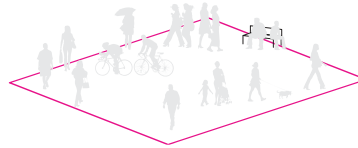
## Adaptation Pathway

This scenario is characterised by densifying cities, progressing climate change, and an increase in financial resources. These conditions have been translated in a spatial vision in order to reconsider new phases of potential infrastructural deployment. It follows two major issues that offer opportunities: 1) the need to conceive “vertical strategies” for the integration, synchronization and co-existence of uses (live, work, leisure, production) and infrastructures (green, blue, grey); 2) the need to redirect financial (research) investments and regulatory mechanisms towards technological, environmental and socio-cultural policies. Since urbanization and better financial means will increasingly rise in this scenario, higher pressures are expected on resources and on the management of flows needed to sustain the city. In addition, interdependencies between the city and its hinterland have to be rethought at a larger scale.

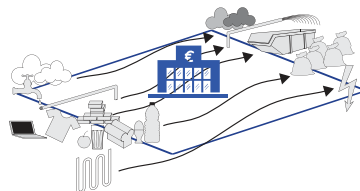
### *Space / technology*



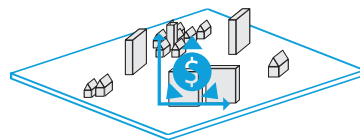
### *People / society*

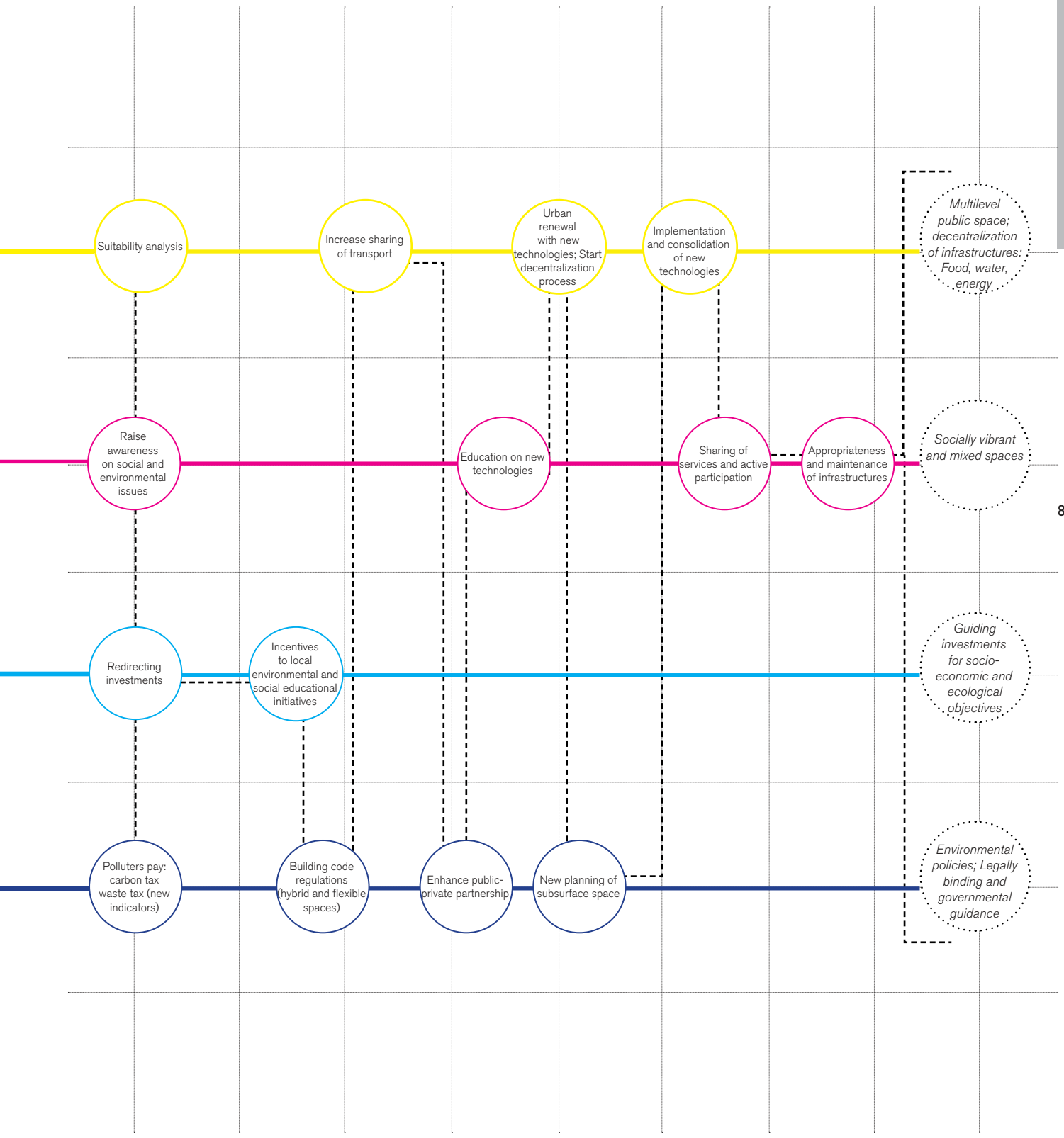


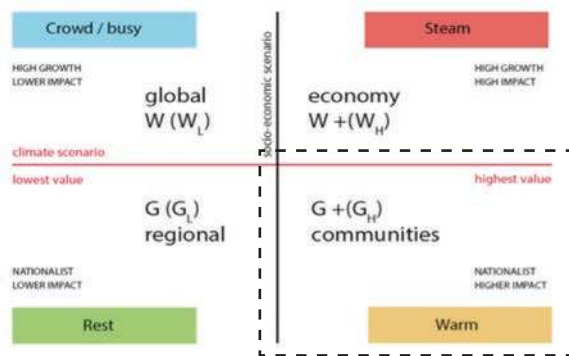
### *Institutional*



### *Financial*







General considerations:

- Increase availability of surface space;
- Increase availability of economic investments;
- Lower attractiveness of small cities, migration to cities in search for job opportunities;

runoff and overflows, filtration of grey water in phytoremediation ponds). Solutions on-site (reuse of water for local purposes) will positively contribute to large-scale issues.

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What will be needed to achieve:

- To mitigate the effect of climate change through flexible surface/subsurface infrastructures;
- Re-thinking urban surface qualities and natural development;
- To rethink the role of shrinking cities within networked city regions with local economies;

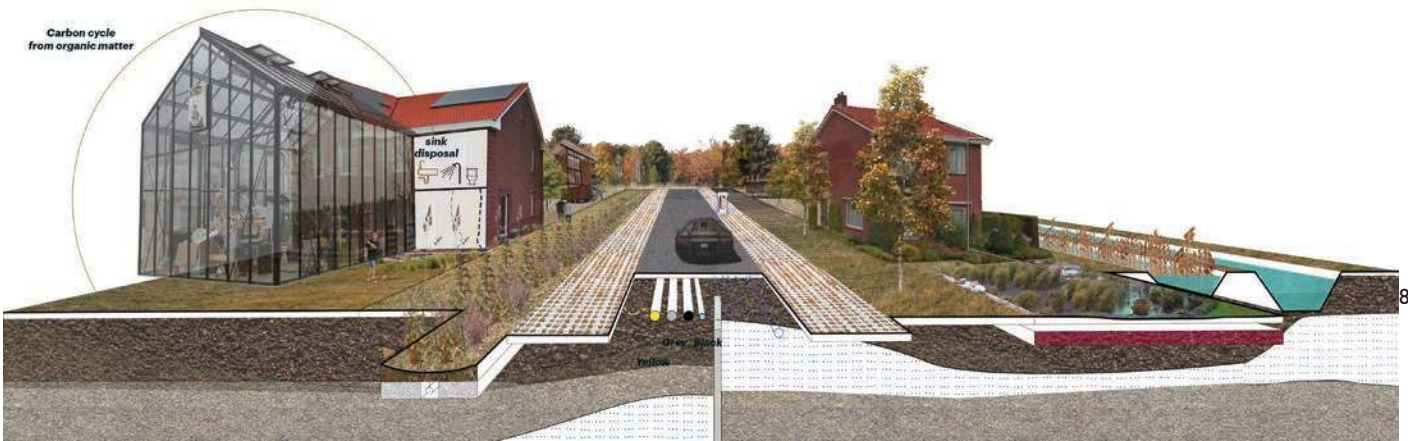
Soil:

Soil improvement techniques are punctual, they are directed to fix a certain problem, and their application have benefits at the larger scale. They can be smartly used to improve conditions for a better use of the shrinking area (supporting sewer, groundwater screens etc).

Water Management & Urban Drainage:

Water holds a plenty of opportunities, it can be used for energy supply, cooling, recreation, irrigation. The combination of its function (multi-functionality) creates a good connection with other infrastructures and services. Adaptability of water infrastructures is the key for a more flexible urban setting given its systemic nature opportunities to incorporate surface and subsurface technologies for water management (management of rainwater

Carbon cycle  
from organic matter

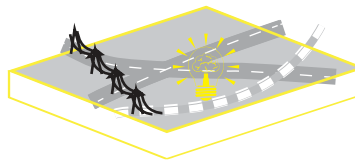




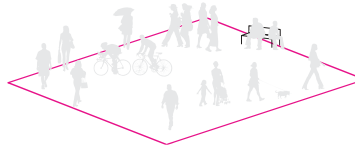
## Adaptation Pathway

This scenario is characterized by shrinking small-medium size villages, high climate change and an increase in financial means. A new urban and landscape development is envisioned and its principles are based on two main opportunities: 1) Re-thinking the role of communities in the co-design, 2) co-implementation and co-maintenance of infrastructures. The extensive financial investments must be redirected toward innovation in the following domains: social (educational, private – collective partnership), ecological (circular economies/bio-based economies) and economical (new business models, specific incentives/ subsidies). All of these have to be steered with specific laws and regulatory mechanisms aimed at boosting such processes.

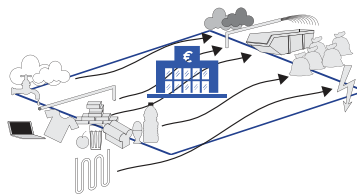
### *Space / technology*



### *People / society*

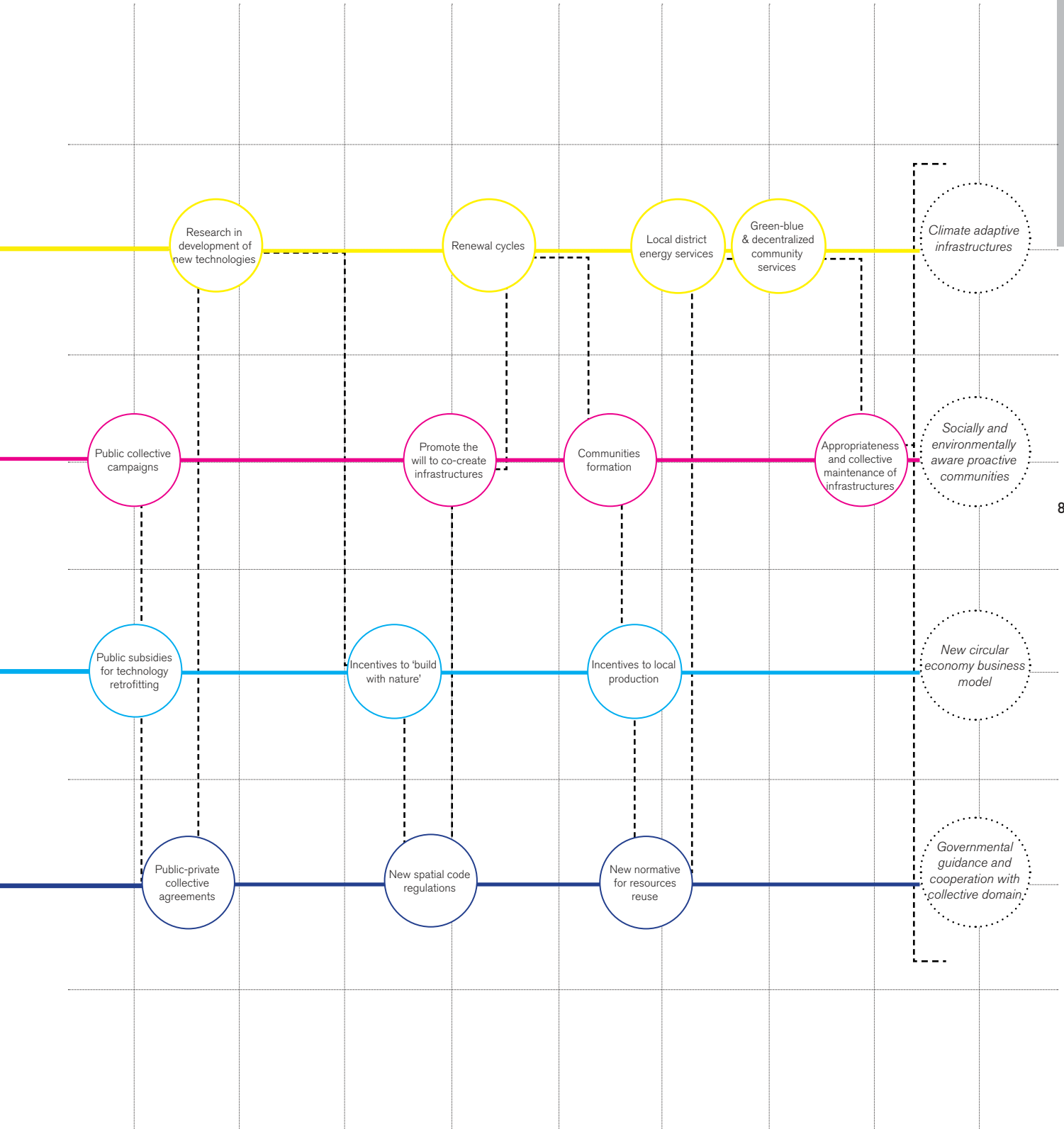


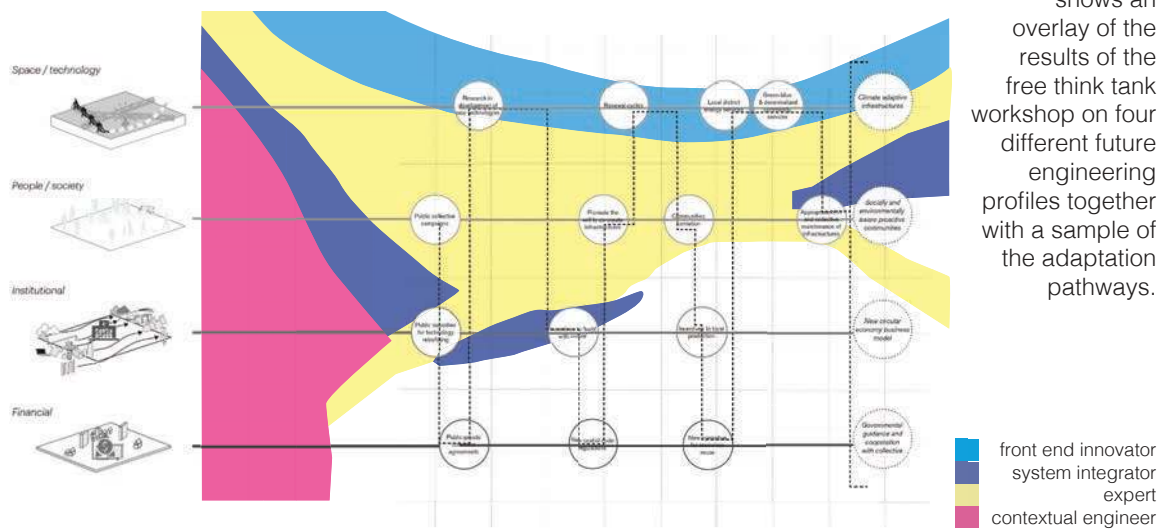
### *Institutional*



### *Financial*







The interdisciplinary group participants in the research have filled in a questionnaire to define the strengths of four roles in their work. The whole group scored highest on the systems integrators role. Yet most of the participants are strong in two to three roles as can be derived from the individual scores. See figure 7.2

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*The key question for this profile is "How can we integrate object oriented parties and systems for a complete solution"?*

The systems integrator has a wide scope of technological fields in complex environments. Within the university the systems integrator works in interdisciplinary teams from different faculties and industrial partners. With its helicopter view he/she can connect the different components to design and operate

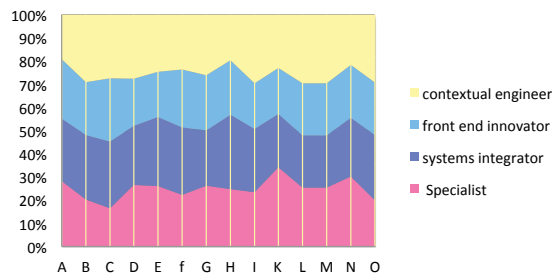
an integrated system. They systems integrator works with complex problems and breaks them down into smaller parts. He/she monitors and facilitates specialists to explore the parts and to develop overlapping solutions to eventually combine them into integrated, interdisciplinary and complete solutions

First and foremost they felt it should not be used as a categorisation tool, but as an explorative indication that helps one prepare for the activities in a working environment. Most of the participants considered that their education and experience in practice had shaped them and allowed them to take on different roles in different contexts.

The conclusion was that if we are talking about education, students should become acquainted with all these roles before they might choose for a particular strength. Moreover, students should over time elaborate on different profiles and acquire strength in at least two of them to reach interdisciplinary working between sectors.

### Results questionnaire about the participants

In the chart a graphical overview of the entire team and their individual bandwidth in which the above argument is nicely supported. It shows a more or less equal distribution across profiles with small emphasis on the favoured profile. Whether this is due to a lack of discrimination of the profiles or whether we should see this as reality is to be discovered in a wider validation of the questionnaire. The participants did, despite small difference recognise themselves in the profile definition.



### Conclusions

The general considerations of using the engineering profiles as a part of this project were:

- The validity of the profile questionnaire,
- The usability of profiles in a multidisciplinary research context,
- The relevance of using profiles in Engineering education.

### Validation

Participants did largely recognize themselves in the profile questionnaire results and felt the profile dominance was based on background, education and experience. Behaviors linked to taking up a particular role is not evident yet. Therefore the profile questionnaire needs to be tested more widely and it should be researched what different types of people would use in terms of knowledge, skills and behavior in particular profiles/roles.

### Added Value

The profiles are either experienced as not very contributive to creating multiple perspectives in team work. They would be limiting freedom and cause students to be pigeonholed. Others tend to see the profiles as relevant learning experience and preparation for real work and a basis for true collaboration. It is emphasized, however, that students should experience all roles and that professional may have to work from a matrix perspectives creating both disciplinary and profile differentiation.

### Exploration for Education

The relevance for education also shows a divide in opinions as shown by the following remarks: "During education your interest changes and you choose what fits best. Being assessed to fit a certain box (or profile) wouldn't help. Maybe I would feel more for defining more competencies that could be useful for an engineer. Give freedom to students what competences they like to develop."

Or as very helpful: "For sure it would have helped (the profiles), now it took me over 20 years to get where I'm now."

It shows there is still a need for establishing in what way the profiles can be embedded to create the best possible group results. And how we can at the same time explore ways to embed profiles in the educational program that do not limit the developmental potential of students.

What will be needed to achieve:

An in-depth description of needed profiles/roles in different pathways/layers

To re-consider when and in what way profiles can be of added value to multi-disciplinary contexts

A guideline on when and how profiles can contribute to improve engineering education.

For a full profile description please view:  
[https://issuu.com/danielleceulemans2/docs/future\\_proof\\_profiles\\_digital](https://issuu.com/danielleceulemans2/docs/future_proof_profiles_digital)

The explorative method of this project brought forward insights and design methods for the urban renewal of (delta) metropolises where resilient, durable (subsurface) infrastructure is carefully balanced out with parameters of the natural system. The question "how can the different technological artefacts in the subsurface be synchronized offering more space and adding to a better urban quality?" is answered by taking procedural steps from the technology (the knowledge of) to the design of public space and urban main structures. In each step the translation from the engineering language to the language of the urban designer (and vice-versa) is done producing an informative and useful overview in how to relate technological artefacts to urban quality.

In order to reach interdisciplinary design, we used explorative research in creating a shared language. Explorative research has been useful because the problem we are tackling is a wicked problem that has not been clearly defined. The exploration was framed by co-creation in workshops and later a more precise elaboration of these results in the working group. The three main methods that build the framework are:

- *Forecasting, backtracking and backcasting* (Van de Dobbelsteen et. al, 2006) enables all participants in a project to really understand the technological artefacts as dynamic features of the city and enable them to include them in creative thinking.

- *Visualization*, enables data from engineers to become information that can be included in the creative process. The visualizations offer the ability for engineers to see their technological artefacts in the complex urban context.

- *Vision making*, ensures that values and maximum benefits are attained to all parties from taking an integral infrastructural approach. As a planning instrument, the construction of a shared vision supports the decision making process, encouraging professionals to take up this approach. At this stage, pathways are developed towards future implementation considering cultural, institutional, financial and spatial/technological dimensions.

As an outcome, by applying this framework, the direct relation between technology in the subsurface and the design of public space and urban main structures in urban development was made clear between the pool of participants in this project. In particular, the focus was placed on potential future synergies between technologies and their contribution to urban quality. This is the start of a working method that could include more technologies and a further elaboration of the visualization of the surface and subsurface as one united space.

This research is the start of further research on the reciprocities and trade-offs between infrastructure design, spatial morphology and liveability and delivered the following research agenda:

Specialist:

- Biogeocivil: What are the effects of BioGrout & SoSEAL over time and can they be reversible?
- Biogeocivil + Urban Drainage: How can we use soil improvement technologies for water decentralization mechanisms and in soil remediation?
- Urban Drainage: How can current sewer systems be adaptive toward shrinking amount of users, where and what is the tipping point?
- Urban water management and urban drainage: What will be the changes in water and waste flows in circular systems and how can these be rearranged?
- Urban water management and urban drainage: What is the role of water flows in a circular urban metabolism?
- Urban Drainage: How can you reuse the organic material in water in synergy with other needs for example, waste organic material as input to local farmers?

Systems Integrator:

- How can we introduce MUT in existing urban conditions where there are no regeneration incentives and diminishing replacement cycles?
- How can BioGrout & SoSEAL help to restore ecological qualities in badly contaminated industrial areas?

Front End Innovator:

- How do you determine the extend the costs of a technology on the short term can be covered by benefits brought by the natural system in the long term?
- How can increase of rain infiltration in the private domain be increases in such a way the costs at the larger scale for discharge can be brought back?
- What is the potential growth of re-nature measures concerning institutional, regulatory, social, economic and technical barriers: how to overcome them?
- Who is going to invest in decentralized technologies for surface qualities in a shrinking village?

Contextual Engineer

- How can urban planning (policy, regulations, laws, institutions) and design (social, financial, technical) be empowered to utilise the subsurface technologies?
- What is the impact on public health when the subsurface is better integrated in urban planning and design?
- How do people change their habits in order to accept a radical change of infrastructure?



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