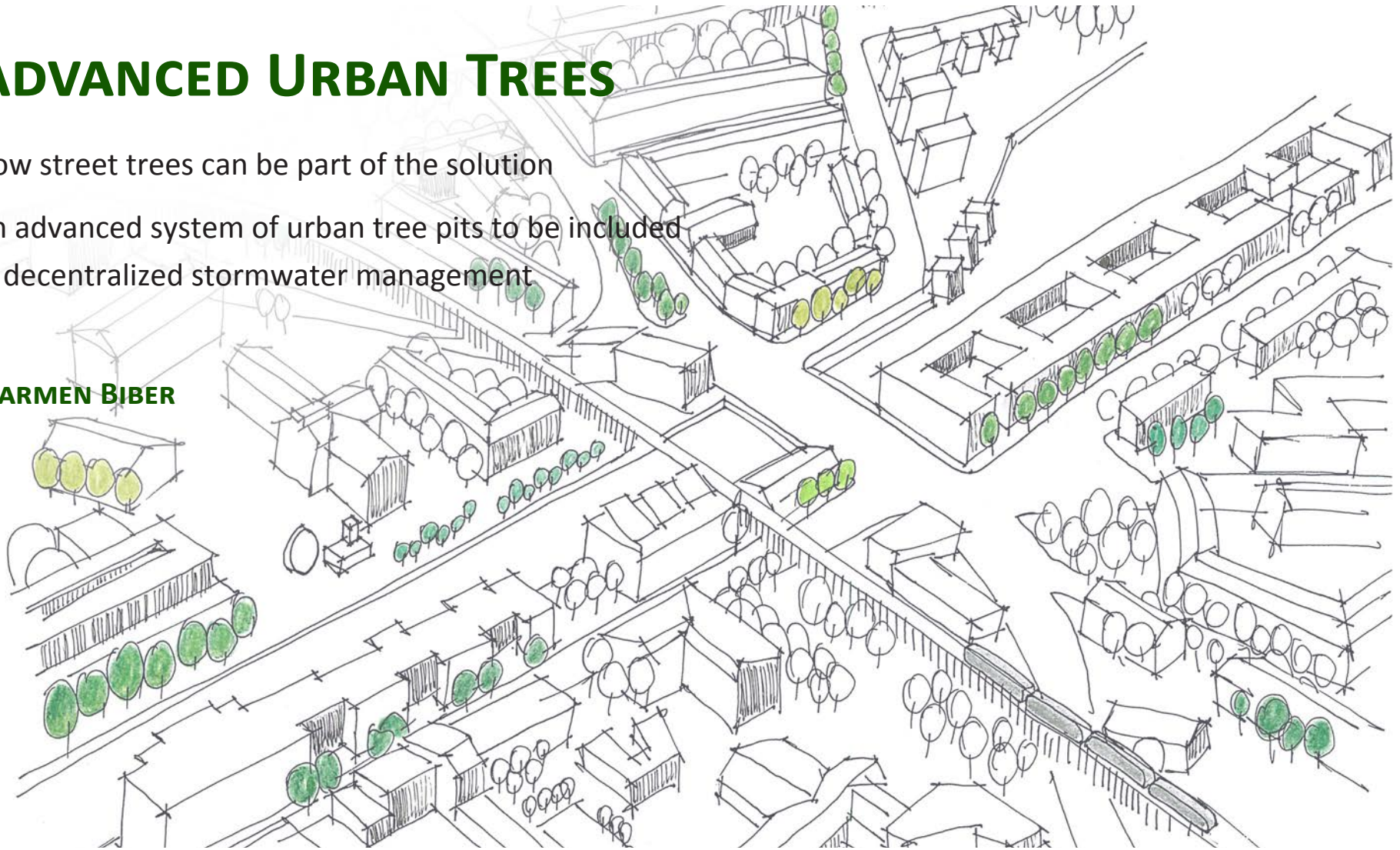


ADVANCED URBAN TREES

How street trees can be part of the solution

An advanced system of urban tree pits to be included in decentralized stormwater management

CARMEN BIBER



MASTERTHESIS

MASTER OF SCIENCE IN RESOURCE EFFICIENCY IN ARCHITECTURE AND PLANNING (REAP)

SUPERVISORS: PROF. DR.-ING. WOLFGANG DICKHAUT AND DR.-ING. ELKE KRUSE

ABSTRACT

Urban trees are growing within extreme conditions. They are influenced by different factors which minimize their natural growth and development. The space above the surface through the intensive use of public open space, traffic space and buildings, limits the development of stem and crown development. In addition, the space underground inhibits root growth through underground services, dense soil conditions with a lack of water and nutrients.

A good foundation provides a building the needed basis to serve people for different needs during decades. In nature and especially in the urban environment the tree pit is the foundation for trees. Urban trees can provide various benefits to the urban environment such as its shadow for people and buildings, living space for animals, natural air conditioning through transpiration and the reconnection to the nature of cities.

The vitality and the intensity of the benefits of urban trees depend mainly on the quality and the size of the tree pit. Especially within the climate change the growing conditions for urban tree become more extreme due to rising heat, surface sealing and pests.

The purpose of this Master's thesis is to determine adequate growing conditions for urban trees. This can be achieved successfully by the technical design of the tree pit and the interception of stormwater.

The inclusion of the three topics, trees, stormwater management and urban environment define the crucial demands which can be met in an advanced system of tree pits.

The techniques of applied practice are included in the development of the advanced system based on the empirical research through case studies. German legal documents and technical requirements finally form the advanced system of tree pits.

The advanced system provides suitable growing conditions for urban trees, however, the entire analysis clarifies that there is no general system for all locations but the tree pit has to be adapted to the specific condition of each location. Climate impact, adjacent buildings and vegetation, existing soil composition and underground facilities should be considered when planning new tree plantings in an urban environment.

The topic of urban trees is a broad international research field regarding planting and preparation techniques, materials and climate adapted tree species. Urban trees are becoming more and more politically appreciated with an increasing financial investment.

Urban trees can be part of the solution in terms of urban development and stormwater management within climate change: increasing the biodiversity of urban nature and reconnect citizens to nature, protecting the urban surfaces against heat and using stormwater in the natural water cycle. Cities will benefit economically, ecologically, socially and visually from vital urban trees.

The sustainable system of Advanced Urban Trees serves as a first basis to rethink the technique for tree pits and shall be adjusted by professional and interdisciplinary work.

Keywords

Urban trees; decentralized stormwater management; advanced tree pit; Stockholm Solution; structural soil; urban nature

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LIST OF ABBREVIATION

DIN: Deutsche Industrienorm (German Industry Norm)

DWA: Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (The German Association for Water, Wastewater and Waste)

FHH: Freie und Hansestadt Hamburg (The Free and Hanseatic City of Hamburg)

FLL: Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (Landscape Research, Development and Construction Society)

GALK: Gartenamtsleiterkonferenz (Municipal Gardens and Parks Heads Conference)

Units:

m: meter/s

cm: centimeter/s

mm: millimeter/s

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1 INTRODUCTION

Trees are connected with the history of mankind and can therefore be found in the development of cities (Konijnendijk et al. 2005 p.23ff). Until today, trees have been used for different reasons. Within former times, timber was used as reliable building material and firewood.

Hence, it can be declared as a relevant economical resource. Trees have also been serving as a cultural, social and traditional symbol for many countries in the world (e.g. Christmas tree, Maypole or Trees for Topping Out) (Vieth 1995 p.14). Trees have been cultivated in orchards and farmed in relation to the daily fruit supply (Balling 2005). As a design element trees, were and are still are used in the broad application of the architecture of the urban and rural environment. Besides that, trees also comply with high ecological requirements (BMUB 2015a p.23).

The fact that most of us have been climbing trees in our childhood also show their cultural and social significance. Humans are connected with trees. Mankind encounters trees in our daily surrounding here and hereby not only in the rural side

but also in the urban environment such as in dense cities.

With the industrialization in the 18th century in Germany, large land reclamation was carried out by drainage of fields and the artificial water table drawdown. In the 19th century with the development of motorized vehicles, surfaces have been sealed for better traffic efficiency. With urban development in the 20th century more and more surfaces have been sealed, especially with the reconstruction of cities after the Second World War (Holzapfel 2012 p.7).

In correlation with urban development, the organization of water management was initiated. Due to hygienic problems and diseases (e.g. plague and cholera pandemic), the negative image of the city and especially the economic factor of the harbor were increasing (Wilderotter and Dorrman 1995 S.237).

Wastewater was transported out of the city and disposed in nearby rivers. The city of Hamburg, Germany was one of the pioneers in Europe with the innova-

tive construction of drinking water and sewage systems in 1850, designed by the English engineer William Lindley. By sealing natural areas, rainwater was also discharged into the sewage system (HW 2016c).

Due to increasing mobility and transportation, especially in the second half of the 20th century, streets and roads were developed and expanded in order to cope with the traffic load within and outside of cities. For safe driving, the fast discharge of surface water had been perfectly engineered. Throughout history, green areas have been removed for the construction of surface and underground infrastructure (BMUB 2015a p.9). In addition to streets, routes for pedestrians and cyclists have been built and open surfaces have been sealed continuously (Holzapfel 2012 S.82ff).

The pressure through the impact of human development increases and the urban greenery is significantly limited from above and below (EUC 2016). Street trees in particular are exposed on a bigger scale. There are several factors that affect

the tree and inhibit its natural growth: the high load of vehicles on the roots, the consequential compaction of soil, and the lack of water by the discharge of storm-water into the sewer (FLL 2015 p.16).

These factors disturb the natural process of growing and living of street trees. Old trees, which developed their roots before the intense urban expansion, are more or less stable with these circumstances but are becoming weaker (Rol-off 2013 p.30). New tree plantings have little chance to survive in this restricted environment. They are inhospitably sandwiched in a narrow strip between streets and sidewalk.

If street trees start to disappear, the urban greenery will decrease in diversity and lose the connected network throughout the urban landscape. The current situation is in need of change, but which elements and factors need to be changed and how can we proceed?



Fig. 1.01 Trees in a natural environment



Fig. 1.02 Trees in an urban environment

1.1 A fundamental rethink and political inclusion of urban trees

A change is already in progress. Climate change has been one of the initiator for rethinking. By detecting the impact and especially the recognition of climate change, many institutions deal with the causes, effects and consequences. The weather is already changing and cannot be stopped anymore, but the progression and the impacts can be slowed down (Schrader 2016).

Urban environments, especially dense cities are extremely affected by the impacts of climate change. An overall concept for dealing with the impacts must be developed and adapted for the various requirements of different locations. Based on scientific work, climate change has become a wide debate in policy (EUA 2016).

Among many solutions, numerous publications from different institutions refer to the importance of a green infrastructure network in cities. These networks can provide “vegetation, natural habitats and soils which manage water effectively and create healthier urban environment” (US EPA 2014).

Within the state of Germany, the Federal Ministry for the Environment is currently working on a paper called the *Green City*. For the first time, a clear statement by the Federal Ministry will be given to promote the development of urban green infrastructure. This paper underlines the value of urban green infrastructure with a profound effect on planning and financing (BMUB 2016).

Besides having important values to people (e.g. in terms of local recreation), urban green infrastructure is playing a significant role in relation to climate change. Green infrastructure is primarily a producer of clean air by oxygen release, binding of fine particles and carbon dioxide sequestration and storage in vegetative material (BMUB 2015a p.17; p.54 ff). In addition to this, green areas offer unsealed (natural) surfaces for sustainable stormwater treatment. Stormwater can be retained and infiltrated in a sustainable manner without large far-reaching structural changes in urban space (BMUB 2015a p.31).

Based on these considerable reasons, urban infrastructure is promoted and supported politically and financially. Besides parks, cemeteries and playgrounds, street greenery and street trees are also part of green infrastructure (BMUB 2015a p.7). Trees in parks or along streets are especially one of the most productive plants in terms of oxygen production and improvement of air quality. A progressive development should mainly consider to increase the number of new tree plantings (BBSR 2015; BMUB 2016).

Conclusion

To sum up, trees should not only be included as theoretical planning tools of urban strategies for climate change in these reports, but they must become a realistic part of actual projects.

1.2 Assumption and research questions

To make trees part of these projects and to meet the expectations, especially for street trees, their provided growing and living conditions in urban areas must be changed and must be improved.

Hypothesis

The system currently implemented for tree pits does not provide the best foundation for tree growth. To achieve better water availability, decentralized stormwater management can be part of the solution. To meet the demands of decentralized stormwater management, an advanced system for urban tree pits is required.

Prediction

By extensive technical adaptations of tree pits and structural changes, street trees can be offered an improvement of growing condition. By extension of non-compacted soil volume, healthy trees will shape the urban landscape over decades and improve the ecological value of the city.

With the application of proper materials, trees can become part of the solution of

stormwater management by intercepting stormwater in the tree pit with numerous positive side-effects: cleaning of stormwater in a (natural) way, natural irrigation, stormwater retention and delayed discharge.

Research questions

This Master's thesis is structured based on five research questions and intended to show the extent to which the presumption can be supported by facts.

1. How can street trees be offered species-specific growth conditions in highly dense urban space?

2. What technical requirements must be met in order to intercept stormwater in the street tree pit?

3. Which components of international implemented systems of tree pits can meet the demands of street trees, the decentralized stormwater management and the urban conditions in Hamburg?

4. What German legal framework and guidelines must be applied to an advanced system of tree pits for street trees?

5. Who is involved and which responsibility do these actors assume in the planning and implementation process of advanced tree pits?

Based on the findings of the research, the approach of the *advanced system for urban tree pits* is discussed and developed further to achieve more sustainable locations for street trees.

1.3 Structure and method of research

This Master's thesis is part of the research project *Urban tree within Climate change: Monitoring of Climate Impacts and adaptation*. The project develops strategies for adapting urban trees to the effects of climate change in Hamburg. In cooperation with the *Ministry of Environment and Energy of the City of Hamburg, the University of Hamburg, the HafenCity University of Hamburg and Institute of Soil Science at the University of Hamburg*, an overall concept on how to deal with the tree stock and new plantings in the future in the City of Hamburg is to be approached.

This Master's thesis is about street trees, which are trees along traffic areas in different street hierarchies or in sealed surfaces such as open spaces and plazas. It focuses on the planting of new trees and the preparation of the tree pit, including the materials, the construction process and the maintenance, including monitoring and evaluation.

Structure

After an historical overview, the impact of urban development is displayed briefly.

Within the first two parts of the work, the two main topics (trees and stormwater management) will be described in detail. The demands and influences of the urban environment are identified for both topics including the planning framework and its key actors.

The empirical part of the report is presented in Chapter 4. Here, four different internationally implemented systems are illustrated and compared in detail. These systems have been studied and evaluated by specific criteria. The results are summarized as implementation criteria, which are suitable as a basis for the development of an advanced system.

To apply this system in Hamburg, the existing conditions in the city have been analyzed and will be explained in Chapter 5. In addition, the system of tree pits, which is currently used as a standard in Germany, is included in the process and is also displayed.

The overall findings are summarized in Chapter 6. The approach shows how the evaluated implementation criteria can

form the advanced system. The technical design of Engineered Street Tree pits is described in detail on the basis of the legal framework and the involved key actors.

In the last chapter, the benefits of advanced system is presented in detail. It serves as a basis for further adjustments and aims to trigger an interdisciplinary discussion.

Method of research

For the development of an *advanced system for urban trees*, the qualitative method was chosen. On the basis of case study (empirical) research, the influence of applied practices are included. The overall findings, relayed through practical experience, literature research and expert interviews, this Master's thesis reflects a professional analysis and delivers solutions and answers to the research questions.

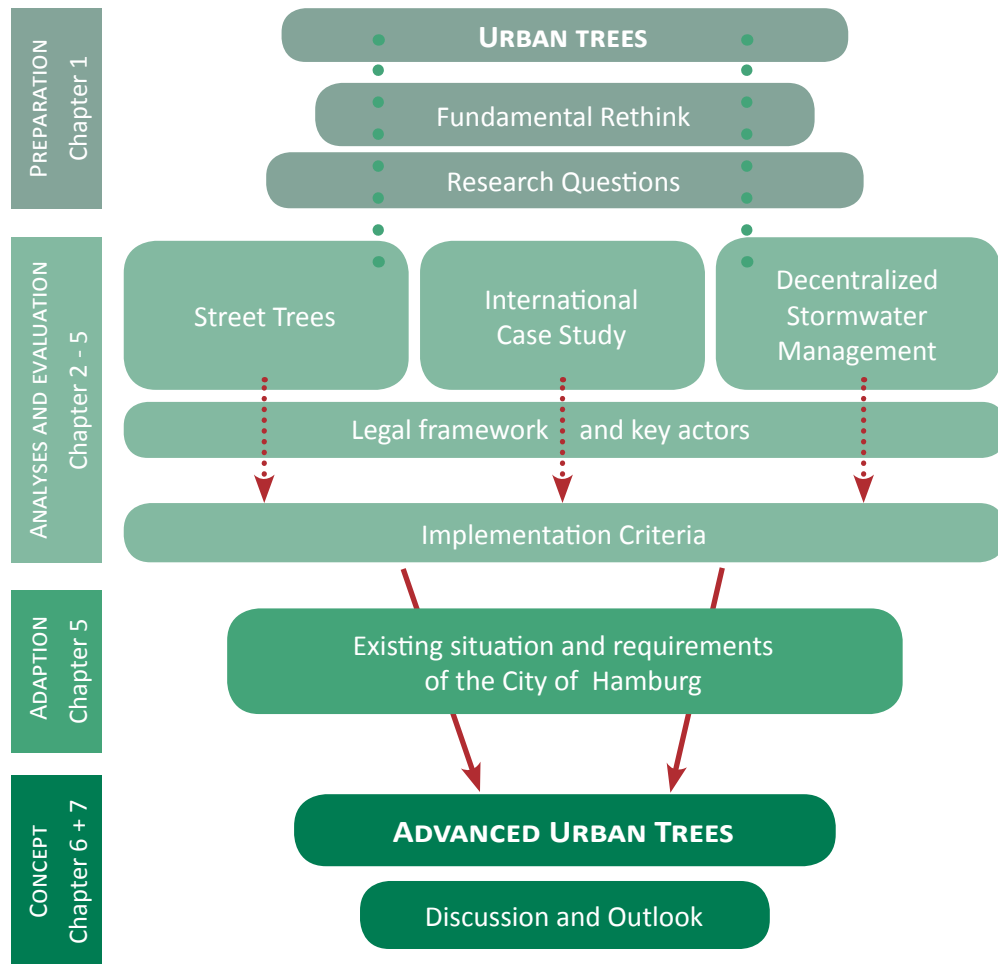


Fig. 1.03 Structure of Master's thesis

2 THE TREE: ITS FUNCTION, DEMANDS AND INFLUENCES WITHIN THE URBAN ENVIRONMENT

In forests, trees are not only standing side-by-side, but influence each other through the soil. By soil organisms, especially by the exchange of soil fungi such as mycorrhiza (increase root function), trees support each other's nutrient uptake through roots. Furthermore, the soil fungi benefit from the products trees produces in the crown and are transported into the soil (LWG 2004). The soil conditions are optimal; a natural entry of organic material through leaves and animals regulates the nutrient content and the pH value (Bartsch and Röhrig 2016 p.275f). An ideal air balance can be adjusted naturally without compaction by heavy weight loading. The water capacity is controlled by a natural water entry through infiltrated stormwater, while groundwater is available enabling a sufficient water supply through the roots (Bartsch and Röhrig 2016 p.244ff).

In cities, nature is still present, but usually it is not grown nature but an established, man-made nature. Most of the park areas and street greenery in cities cannot be classified as a natural environment. However, it can display naturalistic condi-

tions. Besides green spaces, urban trees are part of the green infrastructure in cities which has a balancing function for the urban climate, and therefore an impact on climate change. This is only possible if the greenery and urban trees are offered adequate growing and living conditions (BMUB 2015a p.55).

Trees can be very resistant and have the ability to adapt to different conditions. Nevertheless, the whole of the urban and climate-related changes put a very high strain upon trees. The greenery is weakened in its health and vitality and is therefore more vulnerable to disease and minimized stability (Bartsch and Röhrig 2016 p. 34 ff). However, cities must guarantee traffic safety and prevent trees to become a danger to citizens (FLL 2010 p.13).

Section 2.1 explains how trees function in general and what parameters such as soil properties are important with regards to street trees. In Section 2.2 it describes the benefits and the influences on urban trees, as well as the use of climate-adapted trees. In Section 2.3, the key actors responsible for tree planting in cities are

shown including their responsibilities and their interconnections. The legal framework and other guidelines for tree planting and maintenance in cities are clarified in Section 2.3. The implementation criteria influencing an advanced system of urban tree pits are summarized in Section 2.4.

2.1 Tree anatomy and soil properties

A tree is a living organism which has certain requirements in order to grow. The original location of a tree is nature, where it can find sufficient amount of resources such as rooting space, nutrients, light and gases for growth and development within a closed ecosystem. In order to present the basic functions and the processes of a tree it is divided into two parts: the *visible* part above the surface and the *invisible* below the surface (Bartsch and Röhrig 2016 p.12 ff).

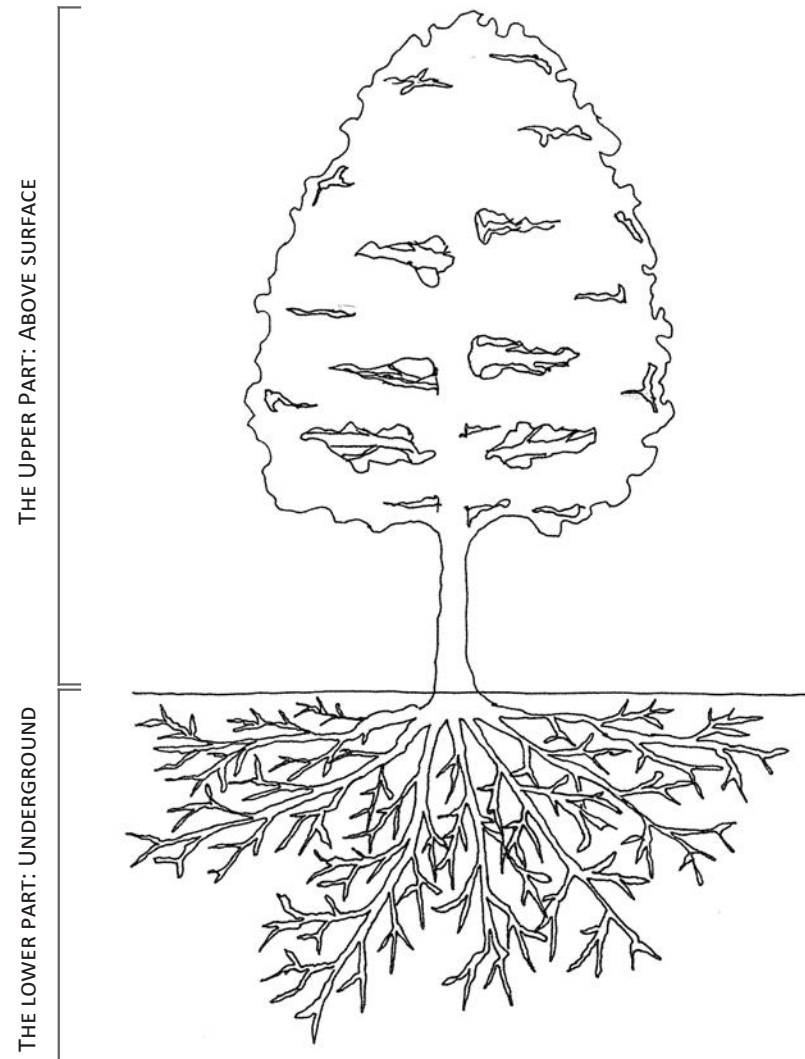


Fig. 2.01 The upper and lower part of a tree

The upper part of a tree

The trunk and the crown, with its branches, twigs and the foliage with leaves, are in the upper part of the tree.

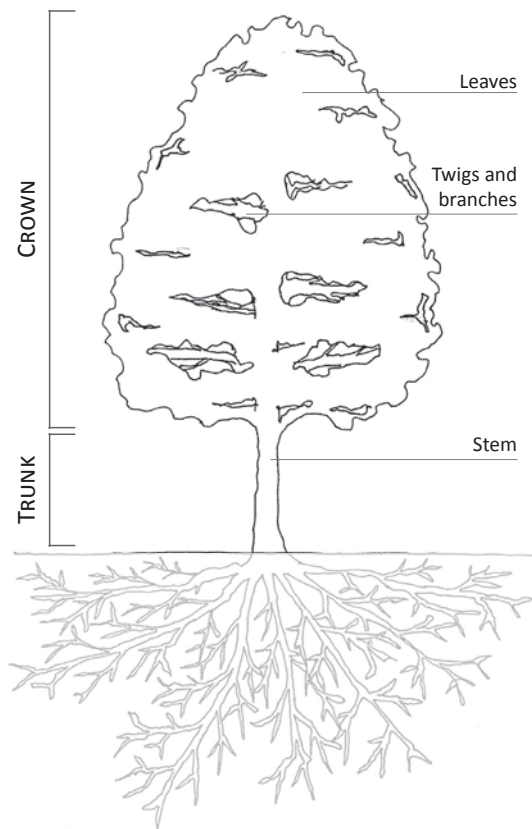


Fig. 2.02 The upper part of a tree

Through the trunk, water is transported from the soil by the roots towards the leaves in the crown to distribute nutrients to the required locations. The leaves capture carbon dioxide from the atmosphere and by the process of photosynthesis, produce chemical energy through the use of solar light energy. The recuperated energy is distributed within the tree and oxygen (and also carbon dioxide) is released into the atmosphere (Schopfer and Brennicke 2010 p. 255ff).

Through the stomata, situated on the underside of leaves, a process of transpiration takes place. This drives the water transport of the tree (Bartsch and Röhrig 2016 p.231). The amount of water released varies with the different species of trees (Mayr 2011). The light intensity, ambient temperature and wind speed influence the processes which takes place in the upper part of the tree. Furthermore, leaves also take up and bind gaseous contaminants such as carbon dioxide and other harmful gases. The amount depends on the size and the age of the tree. They can also bind dust and other fine particulate matter on their leaf sur-

faces. To guarantee ideal operating processes, trees need sufficient space above the surface for the healthy development of the crown and the trunk (Roloff 2013 p.15).

Tree species differentiate in size and in mature crown spread. In literature and in (German) tree nurseries, they are divided into three categories which also determine the necessary above ground space requirements of trees (FLL 2015 p.19).

The data refers to a natural development of the tree. In cities however, this space is usually not available, particularly in streets where space is restricted by adjacent buildings and other obstacles above and below ground space. Trees cannot attain full development of its final natural size under these hindering urban conditions (Reichwein 2009; FLL 2015 p.16).

	1. Class	2. Class	3. Class
Height (in meter)	20-40	15-20	7-15
Width (in meter) (crown diameter)	15-20	10-15	5-10
Space demand (in cubic meter)	4.000	1.500	1.000

Fig. 2.03 Space demand according to tree size

The lower part of a tree

The invisible part of the tree is underground: the roots. Through the network of roots the tree is anchored to the ground (Kück and Wolff 2014 p.117). Depending on the type and tree species, roots grow to different depths and widths. The different root types are heart root (lime tree, hornbeam, maple), tap root (oak, elm) and flat root (ash, alder). The structure of root systems are basically the same for all species. The more branched the roots are, the better a tree can anchor in the soil and the higher the supply of nutrients. Different sizes of roots form the root system, ranging from under 1 mm to 50mm or bigger. From the main roots, the

fine roots grow. The most active roots of the tree are the hair roots, which are the finest roots of the system. Through the hair roots, trees absorb nutrients and water and are crucial for tree's growth and health (Bartsch and Röhrig 2016 S.19ff).

In nature, the root volume complies with the volume of the tree crown. That means that the tree also needs enough space beneath the ground. There has been intensive researches on roots, their growth behavior and volume in natural and urban areas in the last decades.

According to the German guideline FLL, it is assumed that trees have an average root volume of a minimum 300 m³ (FLL 2015 p.19). However, it is stated in the standard DIN 18920 that "in undisturbed locations roots are even growing out far above the canopy drip. For the protection of vegetation another 3.00 m in addition to the diameter of the crown must be calculated to guarantee that the roots are not damaged" (DIN 18920, p.3).

If the volume of the root system is equal to the volume of the crown, the space

needed underground can be deduced by the given information in the figure 2.03 and 2.05. The figure displays the natural root volume which trees need for a stable and healthy growth.

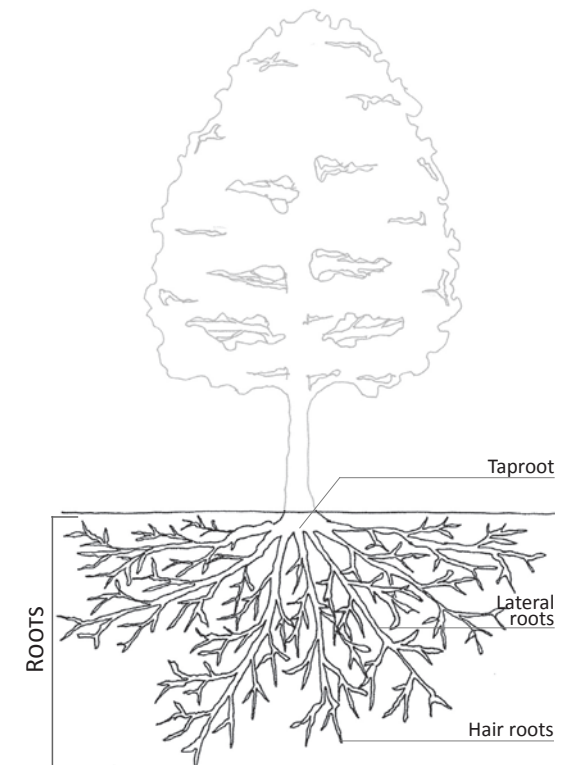


Fig. 2.04 The lower part of a tree

Root growth is dependent on the quality of the soil (FLL 2010 p.17). The soil is a complex system which is influenced by many factors and where a numerous processes run. For simplicity, only the

main factors are explained which can be influenced by the result of this report. The three principal factors are: *the mineral and organic composition of the different types of soil, the pH and the water*

and gas availability of the soil. The better the quality of the soil, the better the root growth and thus the stability of trees and absorption of nutrients. In natural soil, all factors are dependent on each other.

Soil types

The mineral content of the soil can be divided into different classes depending on the grain size distribution and the pore size. The main components of soil are fines (clay), silt, sand and gravel. In addition there are organic components (dead plant and animal material). The composition and the mixing ratio of a type of soil can be determined by a sieve analysis according to the sizes of the materials (Blume et al. 2010 p.173ff).

Depending on the composition of the soil, it can have different properties such as root penetration, water and gas holding capacity, and nutrient content (Figure 02.07). The basic minerals that serve as nutrients (phosphorus, iron, calcium or nitrate (nitrogen) are released by the decomposition of organic substances by microorganisms (Bartsch and Röhrig 2016 p. 177ff; p.251).

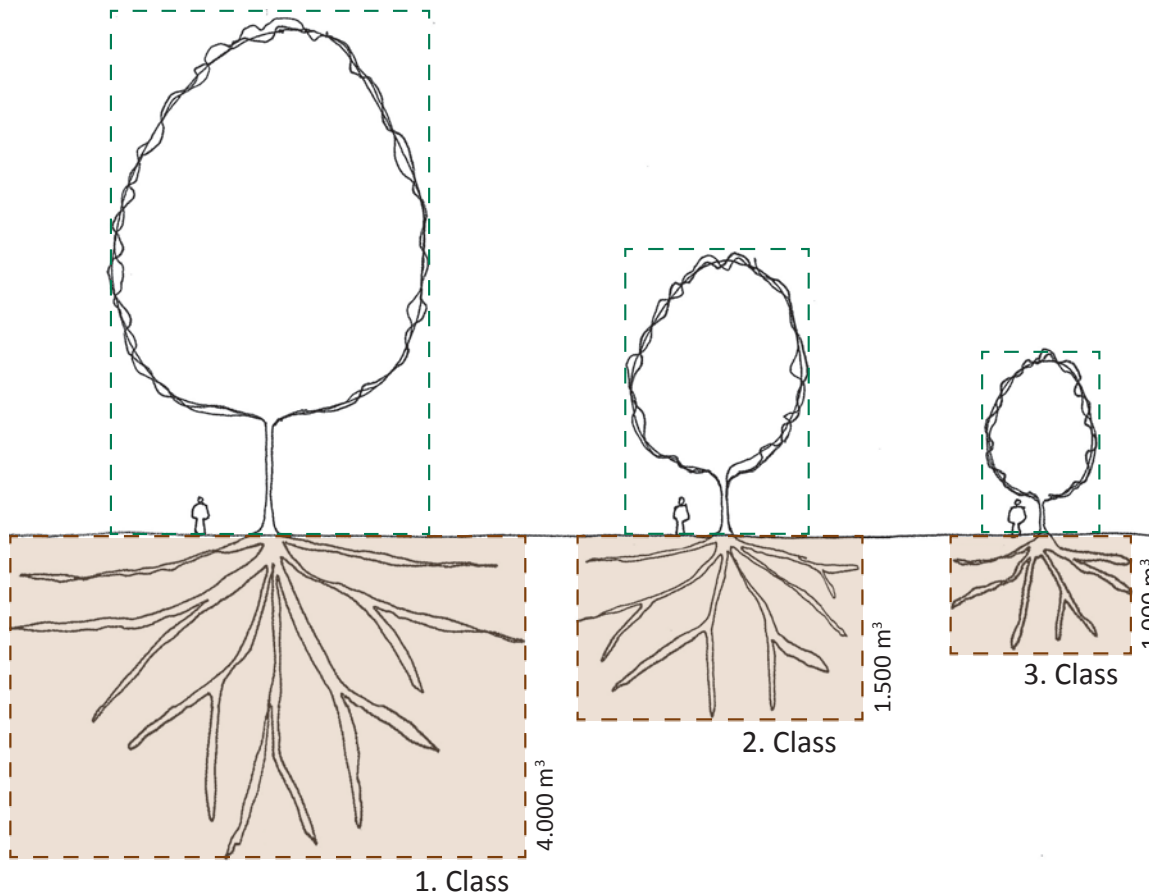


Fig. 2.05 Different tree sizes and their above and underground space (according to a natural development)

Pollutants (oil, etc.) may limit the decomposition and the processes and thus the availability of nutrients (Blume et al. 2010 p.33ff).

pH- value

The quality of these processes, release and transport work, effect nutrient availability and are dependent on the pH of the soil. At a pH level that is too high or

low, this availability is no longer guaranteed. A lack of nutrients restricts root growth and overall the vitality of trees. The main nutrients are best available for trees within the neutral to slightly acidic range (Figure 02.07). Furthermore, it also depends on the tree species and their related ideal pH. A large number of trees require a slightly acidic to slightly alkaline soil (LWG 2014b).

The pH-value depends on the chemical constitution of the soil, which is specified by the concentration of hydrogen ions (H_3O). The higher the concentration, the more acid the soil is. These hydrogen ions are created in different ways; for example, by the biological respiration activity (decomposition of organic substance by microbes and roots respiration), washed out mineral content of the soil (e.g. granite) or fertilizers (nitrogen and sulfur) (Bartsch and Röhrig 2016 p.227).

Soil type	Fine soil			Coarse soil	
	Clay	Silt	Sand	Gravel (round/angular)	Boulder (round/angular)
Size in mm	< 0,002	0,063 - 0,002	2- 0,063	63-2	> 63
Air content	0-15 %		30-40%		40-60%
Pore voids	poor/low				
Air feed-through					
Water flow					
Root growth					
H ₂ O holding capacity	high				
Plant available H ₂ O					
Nutrient content					

Fig. 2.06 Different soil types and their properties

Adding different natural (e.g. humus) or chemical products (e.g. fertilizers) to the soil, can influence the pH. By using natural material, the reaction takes longer but also serves as a long-term constant pH. On the other hand, chemicals can have a fast influence but with a short-term effect (Zeitz 2003). For example, adding chalk can achieve a pH of 6-8 depending to the existing soil conditions (DWA-138 2005 p. 17).

The productivity of soil microbes also depends on the temperature, moisture and oxygen content of the soil (Zeitz 2003).

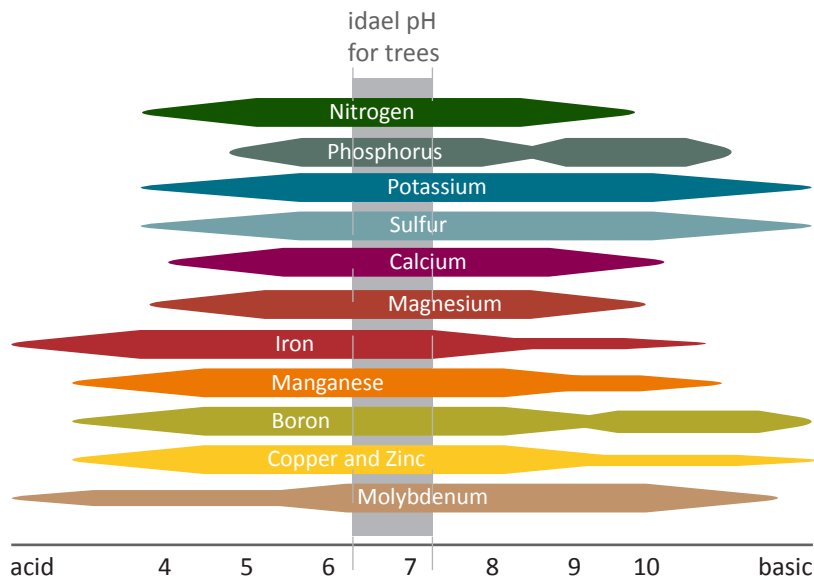


Fig. 2.07 Availability of nutrients within the different pH

Gas and water content

The gas, and especially oxygen, content is important for the respiration of the roots that ensures proper root functions and the microorganisms needed oxygen for the decomposition process. The soil should not be saturated with carbon dioxide (CO_2) and nitrogen (N), which is produced by the respiration of the roots and the microorganisms. The gas exchange

with the atmosphere is essential. This exchange is regulated by the air voids in the soil. Only loose soil contains air pores. In a compacted soil without air voids no biological and chemical processes can take place (Schopfer and Brennicke 2010 p. 125; p.206; p. 250).

Water takes up and transports nutrients. The presence and amount of water in the

soil depends on whether it has rained or whether plants have been irrigated and water can infiltrate or through water tables in the soil. However, not all water in the soil is available for trees. The water that is available for plants is held in the pores between the soil particles, the so-called Capillary Water. The other type of water available for plants is the gravitational water, which is held by the tension of soil particles (see Figure 2.08) (Blume et al. 2010 p.181).

The quantity of water which is actually available for the plants depends on the soil composition and texture. Different types of soil can hold and bind different amounts of water. The denser the soil, such as in types of clay, the more water it can hold. The higher the quantity of large pores present, the less water can be bonded (Blume et al. 2010 p.182).

This water permeability is defined by the k_f -value (DWA-138 2005 p.15). Sand keeps little water and has high water permeability. In contrast, silt and clay hold a lot of water and make it available to plants. The higher the silt and clay content, the more

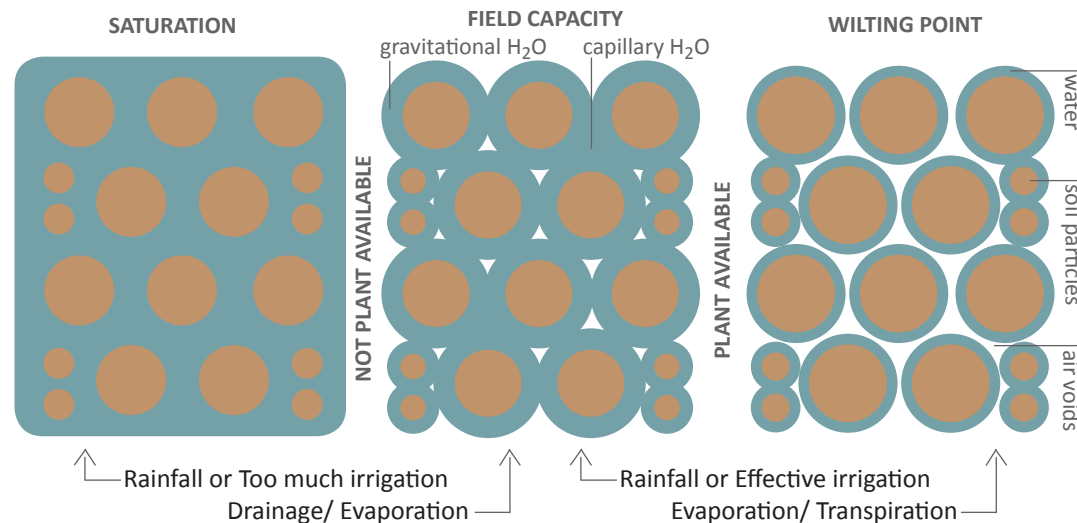


Fig. 2.08 Plant-available water in the soil

water can be kept but on the other hand a too high clay content can cause water-logged soil. However, with too much water (meaning too much moisture), roots can start to rot. In contrast, without enough water they can dry out and die. In addition, if implemented in an urban environment the soil must also meet the demands of load bearing capacity. The

soil composition must be balanced out on the different materials with its properties to achieve an optimum of water and gas supply in the soil (FLL 2010 p.39).

To conclude, the function of a tree must be seen as an entire system. The processes taking place in the ground form the basis for the development of the tree. If

a tree has the best possible conditions in the *upper visible part*, without the *lower part* having the same conditions, a species-appropriate development of the tree cannot be guaranteed. A tree can cope with damage to the crown or the trunk when it has a good foundation that provides sufficient nutrients, air and water.

In particular, this shows that the soil is the most important component of a tree's health and growth. An optimal location provides optimal growth conditions. In nature, these soil structures have grown over the centuries and fit in the circulation of an ecosystem with sufficient resources. The location of the city is created artificially and offers poor conditions. Therefore, it is essential to prepare the tree pit with proper materials so that a more natural development can be achieved.

Only under these conditions can trees be strengthened in an urban environment and be resilient against fluctuations in nutrient and water supply and disease.

2.2 Trees in cities: benefits of trees and the influences by urban environment on street trees

2.2.1 Benefits of Urban Trees

A tree with good vitality has many advantages to the city. They characterize the city not only in the aesthetic appeal as landscape elements, which contribute to the cultural and social identification with seasonal interest and welfare impact of citizens, but also have particular economic and ecological benefits for a city (FLL 2015 p.14f).

After storms and accidents, trees are mentioned in the news with negative headlines. If a tree causes any kind of damage, it is published that it was the tree's fault by growing inappropriately or that it has an aggressive root growth. However, falling trees or branches, and superficial roots causing tripping are often an effect of poor vitality due to limited space, and declining health (WDR 2016; WZ 2015; B. B. C. News 2016; Channel New Asia 2016).

Beside such negative views of urban trees, there are many positive effects highlighted in various political, scientific, or public reports and journals.

Many benefits of trees are not visible or are perceived only indirectly. As a result, sometimes trees are not valued with appreciation and esteem, compared to their benefits. But they contribute significantly to the urban ecosystem.

One effect, which can be recognized broadly, is its shadow which provides higher amenity in parks, open spaces and along streets during warm and hot periods. Sealed surfaces or building facades, which are normally heated up by the sun and radiate heat back into the environment, are protected by the shadow provided by the crown of the tree. The direct sunlight is reduced and, in return, reduces the urban heat island effect (BMUB 2015a p.88).

The larger the tree crown, the more shade a tree can provide. The exact interception of solar radiation and also precipitation interception can be measured by the leaf area index (LAI). It depends on the summarized size of the leaf surface in context of the covered surface (Bartsch and Röhrig 2016 p. 139).

The crown also acts as natural air conditioning with an effect on the microclimate: Through transpiration of leaves, the water that evaporates cools the environment (BMUB 2015a p.55). The actual transpiration activity varies between different species. Trees directly improve the air quality by taking up and binding harmful gases as well as fine particles (see section 2.1). They also provide habitat for a variety of plants and animals and thus contribute significantly to biodiversity in the city (Roloff 2013, p.20).

Urban greenery can contribute to an increase in property values. For example, old solitary trees by its quality and identification feature (TEEB 2016 p.197).

Trees are an investment in the future. They deliver their benefits as a return of the investment of being planted and maintained properly. The main goal of tree planting should always be to achieve a fully and healthy developed tree.

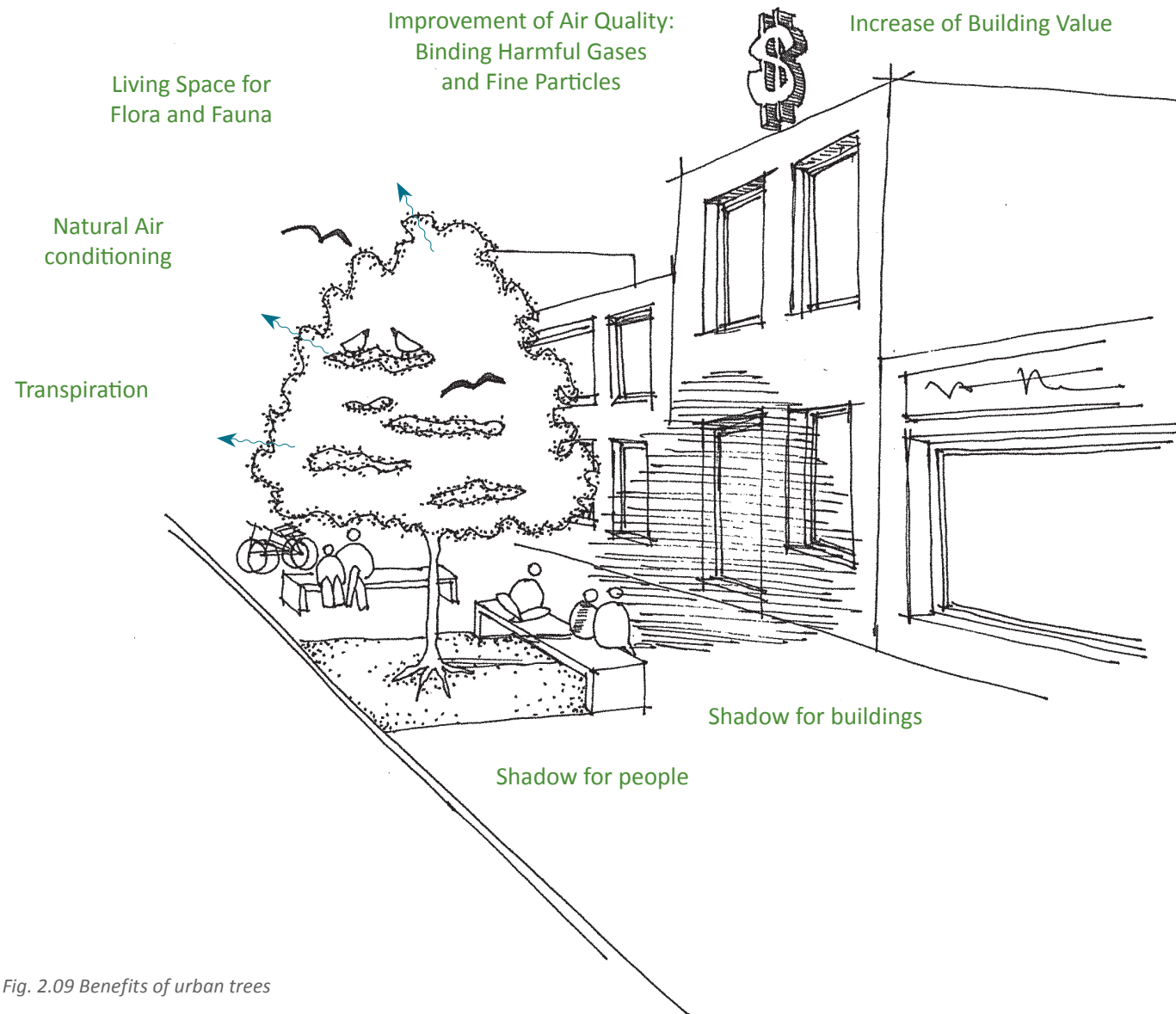


Fig. 2.09 Benefits of urban trees

2.2.2 Influences on street trees by the urban environment

To provide such positive effects trees must have the basic conditions and soil requirements met, as mentioned in Section 2.1. For example, transpiration and energy conversation cannot be achieved during times of water scarcity (BMUB 2015a p.55). As a result of a decreased transpiration, the temperature of the leaf surface itself increases and heat the environment. The microclimate cannot be improved, but rather increases the ambient temperature (Leuzinger, Vogt, and Körner 2009). In the urban environment there are various factors which restrict trees in growing and developing in growth and development.

Intensive Use of Public Open Space in cities

Public space must accommodate several different needs: pedestrian flow, sitting areas, bicycle lanes, streets, parking areas and public transportation. For all of these needs, the surfaces become sealed with different materials such as asphalt, concrete slabs and stones to meet the respective loading bearing capacity (FGSV 2012 p.7).

Street trees especially are extremely exposed to these situations, growing along streets that need to withstand high traffic loads, depending on the street hierarchy. Since the volume of traffic in cities increases (HSH 2015), the mechanical forces on the surfaces rises immensely. Higher forces lead to a stronger compaction of the soil.

As a result of standing on dense soil, tree roots cannot grow into deep soils but only grow superficially where they find space and can reach sufficient oxygen and air for the gas exchange. Sealed surfaces can be deformed by tree roots, becoming dangerous for pedestrians, bikers and vehicles (Reichwein 2009). The other effect of sealed surfaces is that the soil cannot breathe, which means the gas exchange is interrupted. In addition, the stormwater of the surfaces is just discharged into the sewer system and does not reach the soil and infiltrate (BBSR 2015 p.8).

Urban use also causes damage to the upper part of the tree. A free-standing trunk on the one hand can be damaged by strong solar radiation, which results in

broken bark, due to of high temperature differences (Schneidewind 2010). Furthermore, mechanical forces can happen with cars hitting the trunk or bicycles being locked to the trunk. If the bark of a tree is damaged, the softer inner timber is exposed. The tree is highly vulnerable and its vitality starts decreasing (Jeschke 2011).

Soil conditions

As already mentioned, the sealing of the surfaces and thus compacting the soil has far-reaching problems for street trees.

Due to the compacted soil pores are crushed, which normally provide aeration and water holding capacity. As stated in Section 2.1 p.21, deep-growing roots stabilize the tree. With the main roots only in superficial soil layers, the tree cannot stand against forces like storms. As a result, trees can become a danger to people's life.

Available water in the soil is scarce in urban soils. On the one hand, water table drawdown brings water to a depth not

reachable by trees (Lehmann and Stahr 2007 p.250). On the other hand, water cannot infiltrate due to compacted soils and sealed surfaces. There is only a tiny amount of water in the upper centimeters under the pavement, such as concrete slabs. This is another reason why tree roots grow near the surface to reach that small amount of water (Roloff 2010 p.196). During warm periods, these upper layers dry out quickly due to rapid heating of those sealed surfaces. The consequences are that trees are more exposed to drought.

Squeezed between buildings, lanterns and overhead lines of trams, trees cannot establish their crown properly or are pruned immensely. Besides the negative effects for the tree, a small crown has a small habitat for birds and insects, which decreases the biodiversity in the city. The tree has only a slight shadow and cannot contribute as much as usual possible to the reduction of urban heat islands (Roloff 2013, p.22).

Urban soils

In urban environment there are almost no natural soils. Urban soils are mainly composed of different soil types in unilateral and small-scale layers. Building materials such as crushed concrete and other residues can also be found, which can cause excess water. The very low nutrient content in the mixture of soils and materials reflects a disturbed soil property, which is inappropriate for plant growth (Lehmann and Stahr 2007 p.248ff).

In urban environments, the use of de-icing salt is tremendous. Through splash water from streets and stormwater from sidewalks, high amounts of salt are washed into the tree pit. The nutrient uptake is impaired by the high salt content. If no more nutrients are delivered into the cells of the tree, they die slowly. This can be seen at the marginal brown area of leaves, which is an indicator for the so-called *Tree necrosis*. In the soil, microbes and soil fungi are also severely damaged or die due to a high salt content, with the soil activity steadily declining (GALK 2011a).

The pH of urban soils is rather basic. Due to concrete and limestone debris being washed into the soil, the pH level can vary from 7.5 to pH 8.5. A high pH limits the solubility of nutrients (chemical elements) and limits root growth and health (Beede et al. 2005). Substrates for tree planting are often in an alkaline range with pH values between 7.2 and 7.5, sometimes as high as 8. Rarely there are substrates that are below a pH of 7. These results are based on the raw materials for substrates such as sand, gravel, grit and organic part compost, with most of them having a pH above 7 (LWG 2014b).

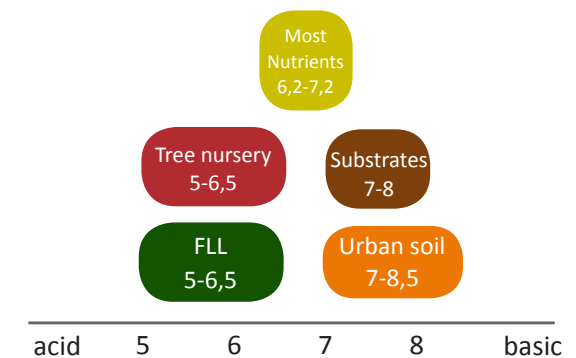


Fig. 2.10 pH of different soils and substrates

Underground services

There is another factor inhibiting urban trees: the underground utilities for drainage and sewer pipes, electric and telephone cables, power lines and local heat network occupy the soil needed by vegetation. Despite the pressure tightness of pipe joints (according to DIN 4060 / EN 681), roots are able to grow into pipelines, occupy the free space and reduce their functionality considerably.

According to ATV-damage classification (Standard terms and conditions (ATV): ATV 1989-1), roots of trees cause the most frequently occurring cases of damage to cables. These have to be cleaned from the roots and soil particles, which is a labor and cost intensive work to further guarantee a safe discharge of water (Brennerscheidt 2011 p.7).

Climate change

Based on weather observations from different time periods (over the past 30 and 60 years) there are numerous scenarios which show changes in temperatures and rainfall. This concerns in particular the observations of regional and local

weather changes and the displacement of seasonal characteristics. The decisive factors are an increase in extreme weather, temperature extremes and of heavy rain events (BMUB 2015b p.11). The number of summer days with extreme temperatures ($> 30^{\circ}\text{C}$) is increasing, while the number of frost days significantly decreases. Predictions assume that precipitation will be shifted from the summer (June-August) into the winter months (December-February) and that precipitation in the summer will decrease by up to 10 percent while increasing in the winter by 10 percent (Schrader 2016).

A strong increase on the frequency of heavy rainfall of 10 mm within one hour to 20 mm within six hours, and in extreme rainfall with a precipitation of up to 50 mm per hour (BBSR 2015 p.17), can be seen (DWD 2016).

Especially for cities, this increase in weather extremes is difficult to cope with (NDKB 2016). The urban heat island effect is already present but will have major consequences on the urban microclimate due to the extreme temperatures and

heating up of surfaces. Trees also have to deal with higher temperature and transpiration rates. Water scarcity for trees will develop into a larger problem, which cannot be compensated by the natural water table of the soil (BBSR 2015 p.10). The problem cannot even be solved by the higher amount of rainwater of the heavy rainfalls because the water must be infiltrated into the soil but not be discharged.

Conclusion

To sum up, the analysis clearly shows that trees and urban environment have different and opposite needs and demands.

While urban environment needs a high load bearing capacity with a pressure strength (E_{v2}) of 45 MN/m^2 on the existing soil and $100\text{-}180 \text{ MN/m}^2$ on the base course and frost blanket course, depending on the type of surface and the subbase (FGSV RSTO 2012). In contrast to that, the FLL requires for tree pits a lower pressure strength on the substrate (45 MN/m^2) (FLL 2010). On the other hand, the analysis demonstrated that trees actually need a completely uncompact soil

without any load pressure nor load bearing capacity for a high amount of pores for a good soil for growing.

If the existing soil and the base course is compact to meet these demands, the required infiltration capacity for tree pits of $\geq 5,0 \times 10^{-6}$ cannot be met (FLL 2010 p.13).

Surface stormwater must be discharged from urban surfaces (FGSV RSTO 2012 P.8) but trees need water in the soil to grow.

In addition, by the sealing of surfaces there is no continuously natural entry of nutrients into the soil through organic material and decomposing of microorganisms like in forests (Bartsch and Röhrig 2016 p.275f). The tree development and vitality depends on nutrients.

The required salt content for tree pits is quite low (150mg/100g) (FLL 2010 p.41), however, the use of de-icing salt on sidewalks and streets increases immensely the salt content in the tree pit (GALK 2011a).

The more needs of the urban environment are satisfied, the more trees suffer in cities and the current human life styles exacerbate their conditions. The structure of the tree pit has to be designed

to accomplish both needs and demands: trees have to be able to grow within an urban environment while an intensive urban use is possible.

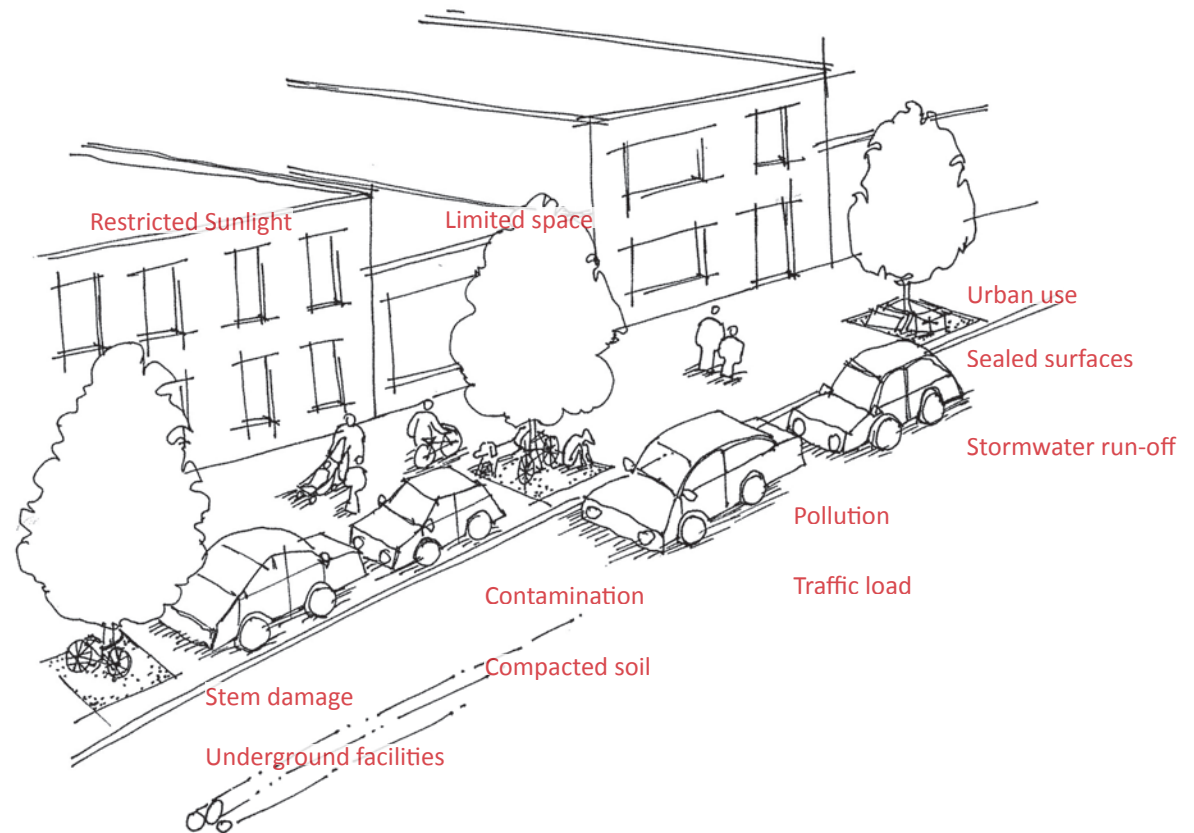


Fig. 2.11 Influences on Trees in a Urban Environment

2.2.3 Climate adapted trees

Choosing the right tree does not seem to be difficult, since there are already many lists of recommendations of species which are said to be adapted and resistant to the urban conditions and the climate change. These lists display trees that are evaluated, assessed and categorized by various criteria.

The lists are developed by numerous research projects with scientists, tree nurseries and practical experiments dedicated to the search for the perfect urban tree. In times of urban development, climate change and tree mortality caused by parasites and pests, it is important to look for suitable trees and test them in the urban environment.

In the following paragraph, a few of these lists and their authors are mentioned.

- **Citree by Technische Universität Dresden:** This is a database-planning tool for woody species for urban spaces (TUD 2016).

- **Climate Species matrix for urban tree species (Klimaartenmatrix für Stadtbaumarten):** is a research study by Prof. Dr. Andreas Roloff, Dr. Stephan Bonn and Dipl.-Forstw. Sten Gillner where over 250 woody species used European-wide are classified and assessed based on different criteria (Roloff, Bonn, and Gillner 2010).

- **Galk List of Street Tree (Straßenbaumliste) :** Since 1994 the work group of Municipal Gardens and Parks Heads Conference is testing and evaluating street trees at nationwide locations in German cities with different tree species. The results are available online (GALK 2016d).

- **The climate tree catalogue (Der Klimabaum-Katalog):** The catalogue is a list of trees which are suitable for urban environment published by the tree nursery E. Sander in Tornesch (Sander 2016)

- **Urban Greenspace (Stadtgrün) 2021:** The Bavarian State Institute for Viticulture and Horticulture performs a street tree test at three locations in Bavaria (Germany), including the test of mycorrhiza treatment (LWG 2016).

- **Urban trees- Fit for the future (Stadt-bäume- Fit für die Zukunft):** An evaluation of trees which seem to be suitable for urban environment, published by the tree nursery Lorenz von Ehren in Hamburg (LVE 2016)

The selection of trees are based on different weighted criteria, such as:

- drought and heat resistance,
- soil moisture,
- late frost risk,
- pH-value,
- de-icing salt stress,
- maximum tree height or
- crown radius.

The location of the city, and in particularly along the street is a location with extreme conditions and requirements for trees (BBSR 2015 p.40). "The less demanding the tree is in relation to soil, nutrients and climate, the better suitable it is for the urban environment" (Dr. Bauer 2015 p.4).

These lists serve as a good basis for decisions of tree species. It is also important to mention tree species that have not been proven as good street trees to be able to select the right tree Species; these are clearly shown by the GALK list. Numerous tree species have already been excluded.

The discussion of non-indigenous species has been ongoing for years, especially with the foundation of nature conservation (Naturschutzbund). It is important to clarify exactly what the differences are between indigenous, non-indigenous and autochthonous trees and to where to start in history to define the terms (GALK 2011b).

Having a higher variety of tree species and an increasing biodiversity in the cities is recommended by many experts (GALK 2016a; LWG 2014a).

A 100 percent security of growing by the selection of a right tree is hard to guarantee. Further research, experimentation and experience are still needed to know how resilient trees really are (Kühne

2016). In the end, it is always difficult to select the ideal tree as every tree is a living organism and responds differently to various urban influences.

2.3 Key actors for new street tree plantings

A tree is passed through several hands until it actually arrives and is planted at its determined location. The figure 2.12 shows the involved key actors and their interrelations.

It explains in general who and what is involved into the process of planning, implementing and planting a new urban tree. There are three groups:

- *the administrative (orange),*
- *the specialist planners (green) and*
- *the executers (brown).*

The orange group which represents the city as the administrative part and the green group (specialist planners) are particularly shown very simplified. Depending on the size of the city and the ad-

ministrative part, different and more or less key actors and departments can be involved in the process of new tree plantings.

The political vision (administrative group) is not a direct key actor but an influencing instrument. It is usually developed by the current government during each parliament term. A vision describes the present political, economic, and social situation of the city and is intended to serve as a guide for sustainable growth and development. In terms of tree planting, it defines the importance of green infrastructure and further development (FHH 2014a).

The group of executers also depends on the size of the city and the structure. The company for maintenance can either be contracted externally or be a part of the city's municipality services (Wahli, Geiger, and Kahle 2016).

In the following paragraph the individual tasks of each key actor are described.

CITY POLITICAL STATEMENT (INSTRUMENT)

- Political vision: as an instrument it sets the frame for urban development and green network

CITY DEPARTMENT OF ROADSIDE GREENERY AS CONSULTANT

- Advising other specialist planners
- Communication with citizens
- Contracting specialist planners and executer for construction, maintenance and tree inspector

SPECIALIST PLANNERS AND CITY DEPARTMENT OF ROADSIDE GREENERY AS PLANNER

- Planning and tendering tree projects
- Definition of requirements concerning materials and construction process
- Monitoring of planning, requirements and construction process
- High knowledge about legal framework and other guidelines
- Instruction/ admonition of contractors
- Cooperating among other specialist planners
- Documentation of construction site including delivery, treatment and installation of all materials

TREE INSPECTOR

- Inspections for tree safety
- Advise/ instruction for maintenance

CONTRACTOR FOR MAINTENANCE, ARBORIST

- Professional knowledge for tree pruning
- Documentation and proof of correct pruning
- Feedback to the city about vitality of trees

CONTRACTOR FOR CONSTRUCTION, LANDSCAPING COMPANY

- Monitoring and inspecting tree delivery on required quality
- Monitoring and inspecting all the other material on required quality
- Planting and initial tree pruning
- Maintenance in first, second and third year (tree establishment/ development)
- Documentation and proof of correct construction

TREE NURSERY

The tree nursery sets the base of a tree's life which depends on vitality and quality of the tree and its root ball. The tree must be in perfect condition for urban use.

- Cultivating and growing trees
- Transplanting and pruning trees regularly

- Breed trees with strong vitality and a good architecture of the root ball
- Preparation for transportation and delivery to the site
- Adapt tree selection based on economic and ecological influences
- Advising in tree selection and maintenance

CITIZEN

The residents are only involved indirectly in the process of planting new trees. Information should be supplied by the city to help with understanding the function and benefits of street trees. The construction process especially can cause troubles if a tree needs to be pruned or planted. The city must provide information and contact persons for communication to avoid misunderstandings. Nevertheless, citizens can support the city with information about the condition of the trees, for example through daily monitoring of the trees near their house or quarter.



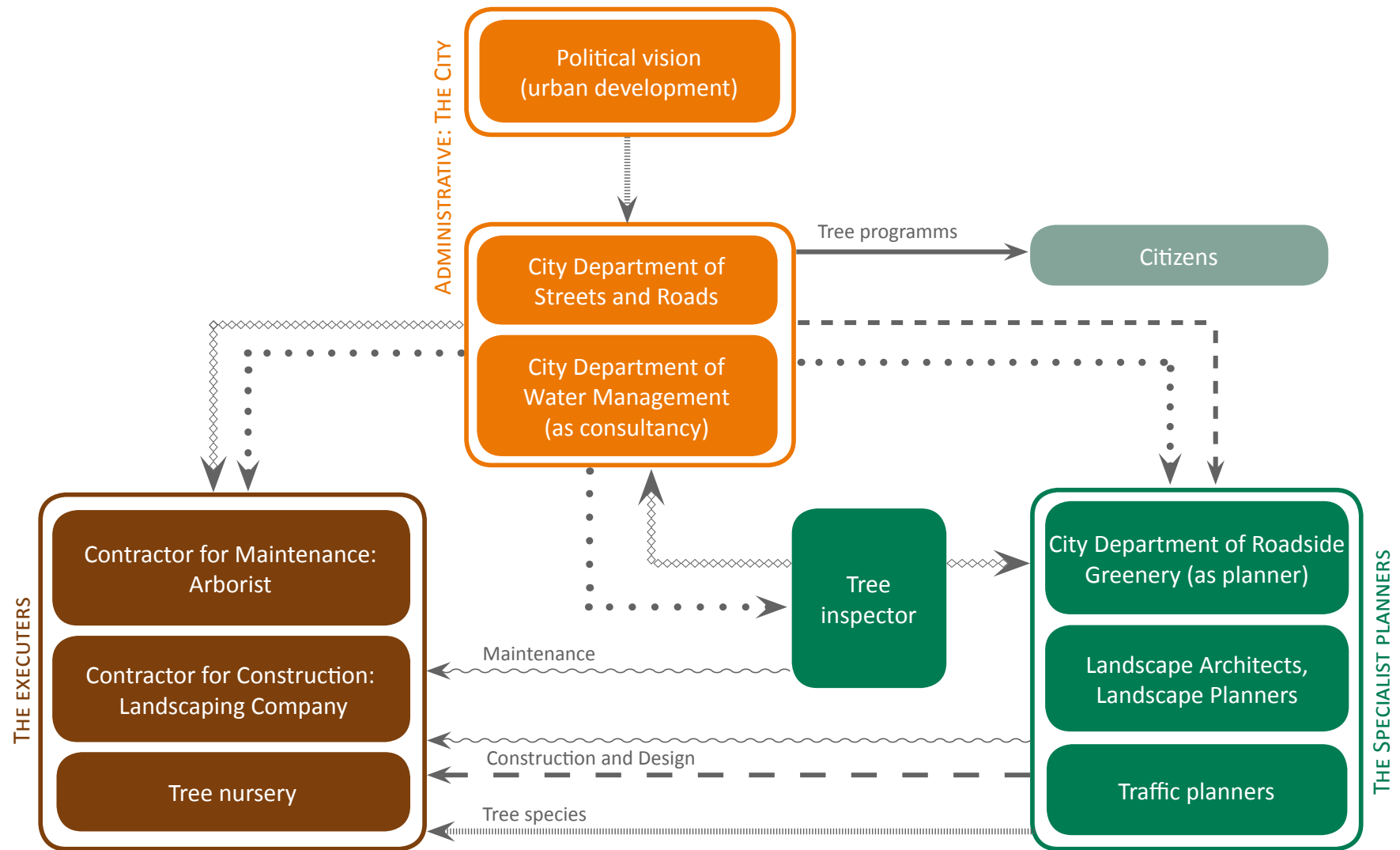


Fig. 2.12 Key actors for the planting process of new street trees (simplified)

2.4 Legal Framework and guidelines for tree plantings and urban environment in Germany and Hamburg

In the following paragraph the legal framework for Germany is displayed, which is completed by the laws released by the city of Hamburg. They are official laws and legally binding.

Federal Act for the Protection of Nature (BNatSchG) (2009) sets regulations and targets for “protection and security of diversity, uniqueness, beauty and recreational value of nature and landscape, in particular such as avenues, one-sided rows of trees” (BNatSchG §1, cl. 1). It especially refers to the protection period and the authorized and prohibited maintenance for the different types of vegetation within the specific time.

Based on that, the **Hamburg Act of Execution of the Federal Act for the Protection of Nature** (2010) sets further details on the protection of nature and landscape within the city of Hamburg.

By the **Tree preservation order of Hamburg** (1948) all trees and hedges are protected. Damage and felling is possible only under certain conditions.

In addition, there is the **Practical Guidance of Execution of Tree preservation order of Hamburg** (2015). This provides the basic demands for quality and quantity of substitute planting of trees after felling, with the target of restoring the landscape. It also gives more requirements for the maintenance of trees.

In addition, the Hamburg district offices summarize the key points of these laws on the **Datasheet of Tree preservation** (2011).

The development of the following standards and guidelines is based on describes laws. These publications and guidelines are not legally binding. They are based and developed on technical and scientific know-how, experience and results. The application is not binding but they represent the current state of the art. They are continuously reviewed and adjusted to include new findings and standards. If they are included in the tendering, the executing company must meet their requirements. In the following paragraph, several guidelines are listed that have a direct impact

on the development of an *advanced system of urban tree pits*. It does not exclude other laws and regulations in terms of tree planting and maintenance.

The main norm in Germany is the German Industry Norm (DIN). For **Vegetation technology in landscaping** two main norms are applicable: The norm **DIN 18915: Soil working** (2002) which gives regulations for the treatment and handling of the soil to retain and improve its properties (DIN 2016).

In addition, **DIN 18916: Plants and plant care** (2002) provides a framework for plants and plant care. It regulates the treatment of the plants before, during and after the planting process and the demands for the materials, especially the soil and the substrate for the tree pit.

The **FLL** (Landscape Research, Development and Construction Society) is a German organization with various working groups of environmental planning and construction. It publishes standards for different topics of green environment (e.g. green roofs, maintenance of greenery,

decentralized stormwater treatment). The organization, founded in 1975, works independently and non-profit based on professionals with their knowledge and experiences from practical work. The publications are rulebooks and guidelines and provide technical standards for planners and executors (FLL 2016).

The ***FLL part 1 recommendations for tree planting: Planning, planting and maintenance*** (2015) provides information about laws to be involved in tree planning and general information about tree size. It is explained how to proceed and what to include into the tendering and contracting companies. The process of planting and maintenance is described.

The ***FLL part 2 recommendations for tree planting: Preparation of the planting bed, structure and substrates*** (2010) gives general information about tree pit preparation regarding size, soil mixture (substrate) and its properties. It provides detailed technical drawings for different sites (e.g. within greenery or sealed surfaces).

The ***FGSV*** (Road and Transportation Research Association) was founded in 1924 and is technical-scientific society. Numerous working groups specified on different topics develop guidelines for the planning and construction process of roads and traffic (FGSV 2016).

FGSV 232 instructions for road planting in built-up areas (2006) provides the same information as the FLL recommendations for tree planting including extra information about (street) trees in the urban environment.

FGSV 939 data sheet for trees, underground pipes and sewers (2013) provides information about the distances to trees and underground utilities and the process of planning. It also includes the protection of underground utilities of tree roots.

The ***FGSV RSTO 499 guidelines for the standardization of the superstructure of traffic areas*** (2012) regulate the dimensioning of the superstructure of traffic areas inside and outside of built-up areas. It depends on the use and the expected

traffic load. According to different materials for the surface and the sub-base it determines the different materials of each layer and the degree of compaction.

The listed guidelines refer to each other and have the similar information depending on the focus (traffic or trees).

2.5 Implementation criteria

Tree conversation, new and compensation planting

In general, trees in Hamburg are protected if they have a circumference of more than 25 cm (measured at 1.00 m height of the trunk). The felling of street trees due to street construction requires a special permit and can only be carried out by the district office. Pruning may only be done from October to March (BNatSchG § 39, cl. 5) and for street trees also from July to October, as they have a small habitat function due to their location (FHH 2015b p.24).

Tree pit

The required size of tree pits should be a volume of at least 12 m³ with a minimum depth of 1.50 m (FLL 2010 p.33), or at least 16 m³ (DIN 18916 2002 p.6). At the same time, it should also be 1.5 times bigger than the size of the root ball. The tree pit should be aerated with aeration and irrigation pipes to a depth of 1.50 to 3.00 m to encourage root growth into deeper layers. To enlarge the rooting volume, the tree pits should be connected with each other by trenches (width of minimum 30 cm) which are filled with coarse gravel of

8 to 22 mm. To avoid excess water in clayey soils, the tree pit has to be drained by a drainage pipe at the bottom of the tree pit (FLL 2010; DIN 18916 2002).

Urban surfaces and tree protection

The urban surfaces, which also includes the tree basement, must meet the load bearing capacity of each specific location. It must be calculated and planned according to the expected use. The main target is to achieve a walkable and safe surface over the tree pit without risk of tripping and to protect the tree base from damage. Therefore, it is suggested to install a tree grade above the open soil of the basement on the same level as the bordering pavement with a size of 6 m². To protect the trunk, a tree guard is useful as a long-term solution (FGSV 2012; FLL 2010 p.40). The trunk should also be protected against solar radiation with, for example, trunk whitening or reed mats (Schneidewind 2010).

To avoid root growth in the superstructure and the pavement, a one-piece component should be installed (e.g. concrete bunker) to direct the roots downwards

(FGSV 2006 p.30).

Trees delivery and planting

If the tree is delivered it must be proven regarding:

- loading conditions on the truck,
- quality of the tree: height, trunk circumference, crown size and structure as required in the order/ tendering,
- the root ball: moisture content, soil quality and quantity,
- damages by heat or cold at the crown like broken off branches or the trunk damages like broken off bark (FLL 2004; FLL 2015; DIN 18916 2002 p.23f, p.5ff).

A documentation based on photographs is recommended (Balder 2012) to clarify the sources of possible damages.

The responsible person (planner and executor) is in charge of supervising and monitoring the process of delivery and planting. The planner must have a professional knowledge and must be able to recognize and criticize insufficient properties. In such a case, the tree delivery should be refused and sent back (FLL 2015 p.34).

When transplanting, the root ball is reduced and the root mass is minimized significantly. For the balance and the vitality of the tree, the crown should be pruned to encourage the growth of roots and new branches. The tree thereby grows out new shoots, which start anchoring in the ground and has a better overall vitality (Balder 1998).

Onsite and during transportation, the root ball should always be kept moist. Longer periods where the tree is not in the soil should be avoided and therefore be planted as fast as possible. This prevents the root ball from drying out and roots become damaged (DIN 18916 2002 p.5f).

A young tree in good shape and with high vitality can save costs for maintenance and pruning within the first years after planting.

Planting soil (substrate)

Soil work must be carried out according to different soil types to avoid the loss of soil properties such as soil pores due to mechanical compaction. Soil with unsuit-

able properties for vegetation should be improved with specific aggregates or be replaced. Soil properties must be proven by test certificates and reports (DIN 18915 2002; FLL 2010 p. 5f; 12f; p.34).

There are high demands on tree substrates. The right composition of different soil types can meet the demands of root growth. Particularly angular materials such as lava ensure high position stability with high compressive strength (FLL 2010 p. 33). It must meet the technical vegetation demands and the load bearing capacity at the same time. The grain size is said to be between 0 and 32 mm and the distribution should have a constant grading curve to prevent material displacement and high compaction. Tree pits in urban environment should have an organic matter of 1 to 2 percent of mass, 25 percent of water holding capacity, 10 percent of areal capacity and a pH between 5.0-pH 8.5 (FLL 2010 p.34ff).

Planting, maintenance and pruning

Planting must be supervised in detail. Initial pruning and watering should be carried out right after planting. Main-

tenance during the first year, until the tree is established, should be followed by monitoring of development in the second and third year after planting. This maintenance processes includes pruning, irrigation and weeding (DIN 18916 2002 p.9f). Especially for street trees, the vehicle clearance (4.50 m) must be guaranteed by regular pruning (FGSV 2006 p.12). Watering should be done with the help of a circular mound of earth at the edge of the root ball (FLL 2010 p.40). A layer of mulch should only be applied if the soil properties/substrates are calling for an extra nutrient source (DIN 18916 2002 p.8).

Costs and time can be saved by specifying trained staff and suitable equipment with proper technical function. Maintenance should be minimized as much as possible because it requires machineries, which produce carbon dioxide, and therefore can harm the environment. Trees, which require less intensive maintenance should be planted to save emission, as this is important for the overall balance of carbon-dioxide-storage by trees.

Underground utilities

Underground utilities must be protected by technical solutions such as root resistant pipes or geomembranes. The most effective protection is achieved by providing large rooting volume in layers (Reichwein 2009) which are specific aerated and not connected with the layer where the pipelines lie. Interdisciplinary cooperation for tree planting and construction of any kind of underground utilities must be carried out to avoid root damage and decrease of tree vitality (FLL 2010; FGSV 2006 p.20; p.14).

Choice of tree species

The choice of the tree species depends on the location and its influences (FLL 2015 p.20). Due to the climatic conditions and the failure of the native tree species due to parasites and pests, non-native trees have to be used in the future (GALK 2016c). However, further study is needed to test the effects of indigenous species to the flora and fauna, like feed for insects and microorganisms. A problem with the selection of more exotic trees is the availability in the tree nurseries, which would need to be increased over time (Dr. Bauer 2015 p.3).

When planning new trees, these lists should be included in any case, since they are based on established knowledge. The following list shows a selection of trees which could be possible as tree species. This list does not exclude other suitable trees. The selection was made based on the list referred to in Section 2.2.3 and the following criteria: drought risk, heat risk, de-icing salt stress, soil moisture, soil compaction and mature tree size.

- *Dutch elm* (*Ulmus x hollandica* Mill. Sorte Lobel)
- *Japanese zelkova* (*Zelkova serrata* Makino Sorte Green Vase)
- *Japanese honey locust* (*Gleditsia japonica* Micq.)
- *Field maple* (*Acer campestre* L. subsp. *campestre*)
- *Azarole* (*Crataegus azarolus* L. var. *azarolus*)
- *Western catalpa* (*Catalpa speciosa* (Warder ex Barney) Engelm.)
- *Black tupelo* (*Nyssa sylvatica* Marshall)
- *Semisour cherry* (*Prunus x eminens* Beck Sorte Umbraculifera)
- *Sweet gum* (*Liquidambar styraciflura* L.)



Fig. 2.13 Semisour cherry



Fig. 2.14 Sweet gum



Fig. 2.15 Field maple



Fig. 2.16 Japanese honey locust

3 STORMWATER MANAGEMENT AND TREATMENT

In both natural and urban environments, rainwater falls on surfaces. In nature, stormwater is brought back into the natural water cycle through infiltration into the soil, evaporation of water bodies and transpiration by plants. In the urban environment, stormwater reaches primarily sealed surfaces where infiltration is almost impossible (TEEB 2016 p. 87).

Stormwater can be discharged quickly and almost invisible from urban surfaces by central wastewater and stormwater management. Due to historical urban development in many German cities, wastewater and stormwater are discharged and transported to wastewater treatment plants in a combined sewer system (HW 2016c).

During heavy stormwater events, it can occur that the capacity of the stormwater system is overloaded quickly due to the high amount of discharged stormwater. As a consequence, mixed storm and wastewater can flow back through gutters and flood streets, which is a risk for

citizens and buildings (TEEB 2016 p.90). In addition, to prevent such flooding, the untreated mixed water is discharged through emergency overflows into close water bodies like nearby rivers and lakes. This can lead to strong biological and hydrological damage to the water through the highly contaminated mixed wastewater (F. Sieker, Kaiser, and Sieker 2006 p.24ff).

In a separated sewer system, stormwater and wastewater are discharged into separate drainage pipes (RISA 2015 p.16). Thus, the sewage system is not overloaded with stormwater during heavy rainfalls and the negative effects described above can be reduced or prevented. Stormwater is discharged separately and sometimes also pre-cleaned before it is discharged into water bodies (BBSR 2015 S.17).

This system seems to be a more natural way of treating stormwater as it leads the water back into the natural water cycle. However, this return does not happen at the point where the rainwater hits the

surface, which still contradicts the natural water cycle (FHH 2006a p.6).

In 2000, the European Water Framework Directive (EG-WRRL) was passed. It includes mainly targets to protect water bodies and groundwater by reducing the pollution, especially by stormwater discharge (EG-WRRL 2000).

Due to the continuous surface sealing because of urban densification and growth, there are areas urgently needed which absorb, retain and infiltrate stormwater. Surface sealing must be minimized and already sealed surfaces should be restored to (natural) permeable surfaces (FHH 2006a p.22ff).

There is a precarious situation with climate change through the increase of extreme weather in terms of heavy rainfalls (see figures 3.01 and 3.02). To meet these challenges, it requires an urban concept for decentralized stormwater management as an alternative to conventional stormwater discharge from urban areas.

This can be dealt with in a sustainable and more natural approach of treating and using stormwater.

An advanced system of urban trees pits could become a part of decentralized stormwater management. They can work as a new method of stormwater treatment combining different methods such as infiltration, retention, cleaning and transpiration. The development of the new method must meet German requirements according to the legal framework including the involved key actors of stormwater management.

In Section 3.1 the general concept and the implementation of a decentralized stormwater management, and in Section 3.2. the main actors involved in the process are explained. The policies and guidelines for handling stormwater are discussed in Section 3.3. In the last Section, the main implementation criteria are explained for the development of an *advanced system of urban trees pits*.

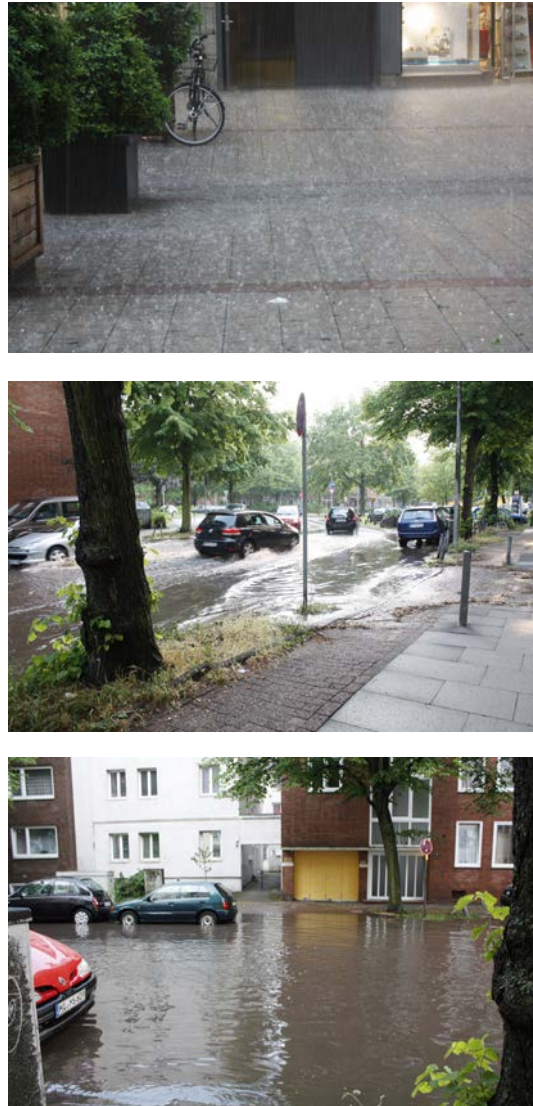


Fig. 3.01 Heavy rainfall in June 2011, Hamburg



Fig. 3.02 Heavy rainfall in October 2016, Hamburg

3.1 Decentralized Stormwater Management: definition of different terms and methods

In an international context there are different terms for Stormwater Management:

Best Management Practice or Low Impact Development (USA), Sustainable Urban Drainage System (UK), Water Sensitive Urban Design (Australia), BlueGreen Solutions (UK / EU), Decentralized Stormwater Management (German: Regenwasserbewirtschaftung) (D) (Sieker et al. 2009).

All these terms describe a sustainable use and treatment of stormwater on the basis of the natural water cycle and balance. There are differences in content and importance of the individual issues. For this report, the German term Decentralized Stormwater Management (DSM) has been chosen considering the main target to develop an *advanced system for urban tree pits* for the city of Hamburg, Germany.

Decentralized stormwater management comes along with different strategies for dealing with stormwater. The priority is that the stormwater is directed back into the natural water balance on-site where the runoff is generated (Sieker

2016). As a result, the on-site treatment and use shall reduce the runoff and with it the peak flow of the sewer systems caused by heavy rainfalls (FHH 2006a). This improves particularly the flow dy-

namics within the settlement area, the groundwater recharge, the cleaning performance of sewage treatment plants and urban waters and the ecological status of urban quarters (TEEB 2016 p.184).

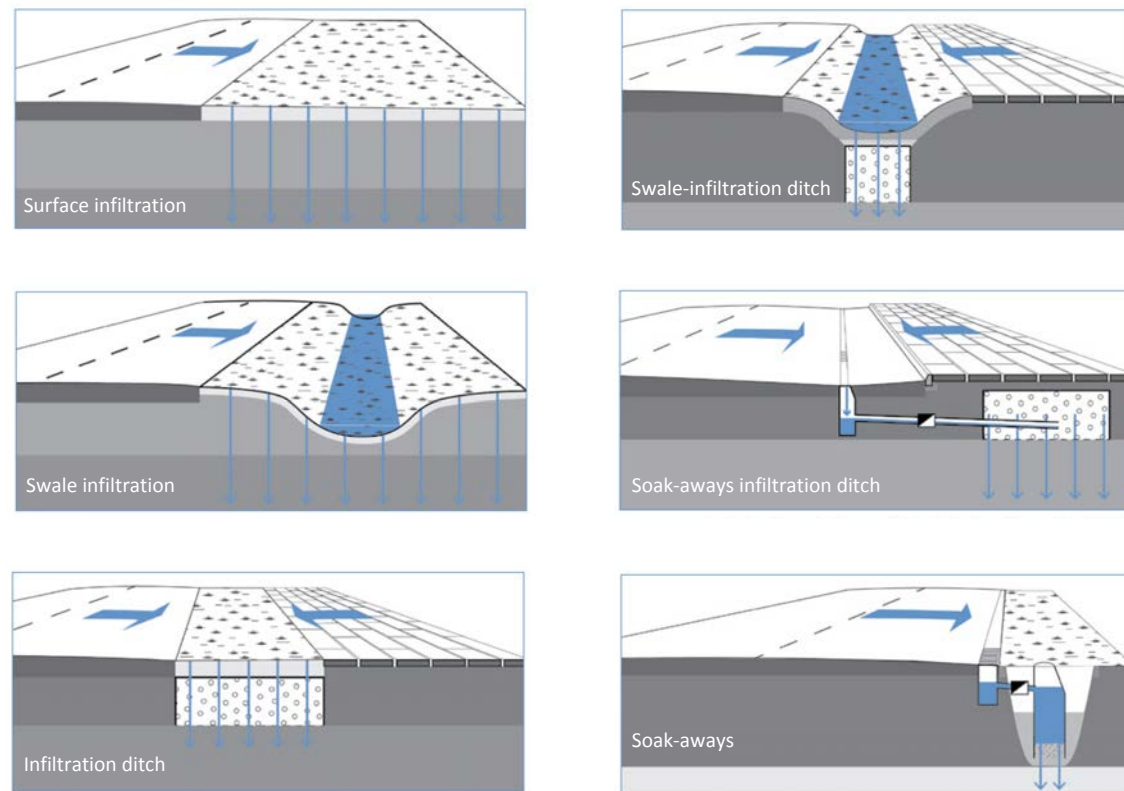


Fig. 3.03 Different strategies of decentralized stormwater management

Different Methods of Dezentralized Stormwater Management

The different processes of retention, infiltration, evaporation, storage and use of stormwater can be performed as single methods or combined at the same site (DWA-138 2005 p.24ff).

A new project must be examined individually regarding whether decentralized rainwater management is the preferable alternative solution compared to the conventional stormwater discharge system. It must be discussed with which system the highest economic and ecological benefit can be achieved in terms of materials, construction, maintenance and treatment (RISA 2015 p.7).

The second step is to identify the suitable method for each individual site according to local conditions. The parameters of the soil, the groundwater level, space availability and requirement, the quantity and quality of the discharged water, design possibilities and the financial aspects influence the decision.

The dimensioning is based on calculation formulas specified in the relevant regulations and standards (see Section 3.3).

Stormwater can be infiltrated through infiltration ditches, perforated pipes and soak-aways and evaporated over detention areas, swales, drainage ditches and combined swale-infiltration ditches. Stormwater can also be retained and

stored for a time-delayed infiltration or discharge into the stormwater system (DWA-138 2005 p.24ff). For example, stored stormwater can be used for irrigation. This may require filters or settling tanks for cleaning the polluted stormwater. The regular maintenance is also set by the regulations and standards, or by the manufacturer of each individual system (FHH 2006a p.28ff).

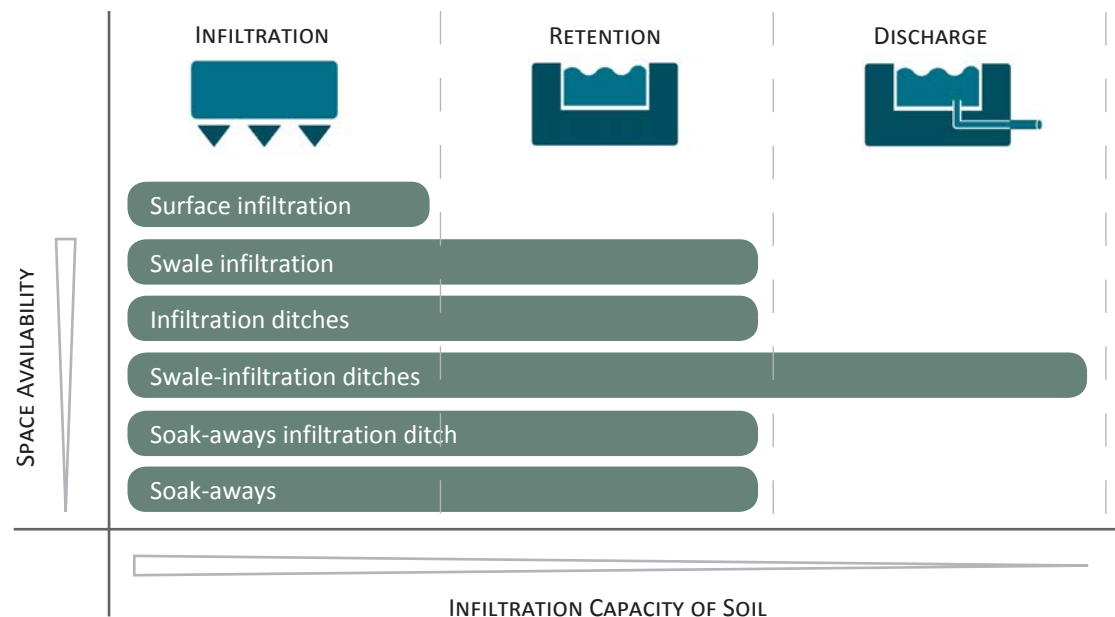


Fig. 3.04 Different strategies of decentralized stormwater management

3.2 Key actors for new street tree plantings

The key actors for (decentralized) stormwater management in Germany are displayed similarly to the key actors for tree plantings in Chapter 2.

Hereby, three main groups exist:

- *the administrative (orange)*
- *the specialist planners (blue) and*
- *the executers (brown)*

In regards to stormwater management, an additional key actor is included:

- *the Water Supplier and Wastewater Disposal Company (blue).*

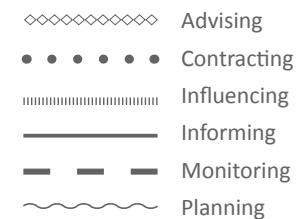
Depending on the administrative structure of the city, there are different systems of organization. In most German cities however, the Water Supplier and Wastewater Disposal Company are a city-owned companies (Spehl and Gensheimer 2006 p.9ff).

Also for the figure 3.05, the orange group which represents the city as the administrative part and the green group (specialist planners) are particularly shown very simplified. Depending on the size of the city and with it of the administrative part,

different and more or less key actors and departments can be involved in the process.

The political vision (administrative group) is not a direct key actor but an influencing instrument. It is developed by the current government during each parliament term. A vision describes the present political, economic, and social situation of the city and is intended to serve as a guide for sustainable growth and development. In detail, it defines the general stormwater treatment, if decentralized and the main directive of the development (FHH 2014a).

In the following paragraph the individual tasks of each key actor are describes.



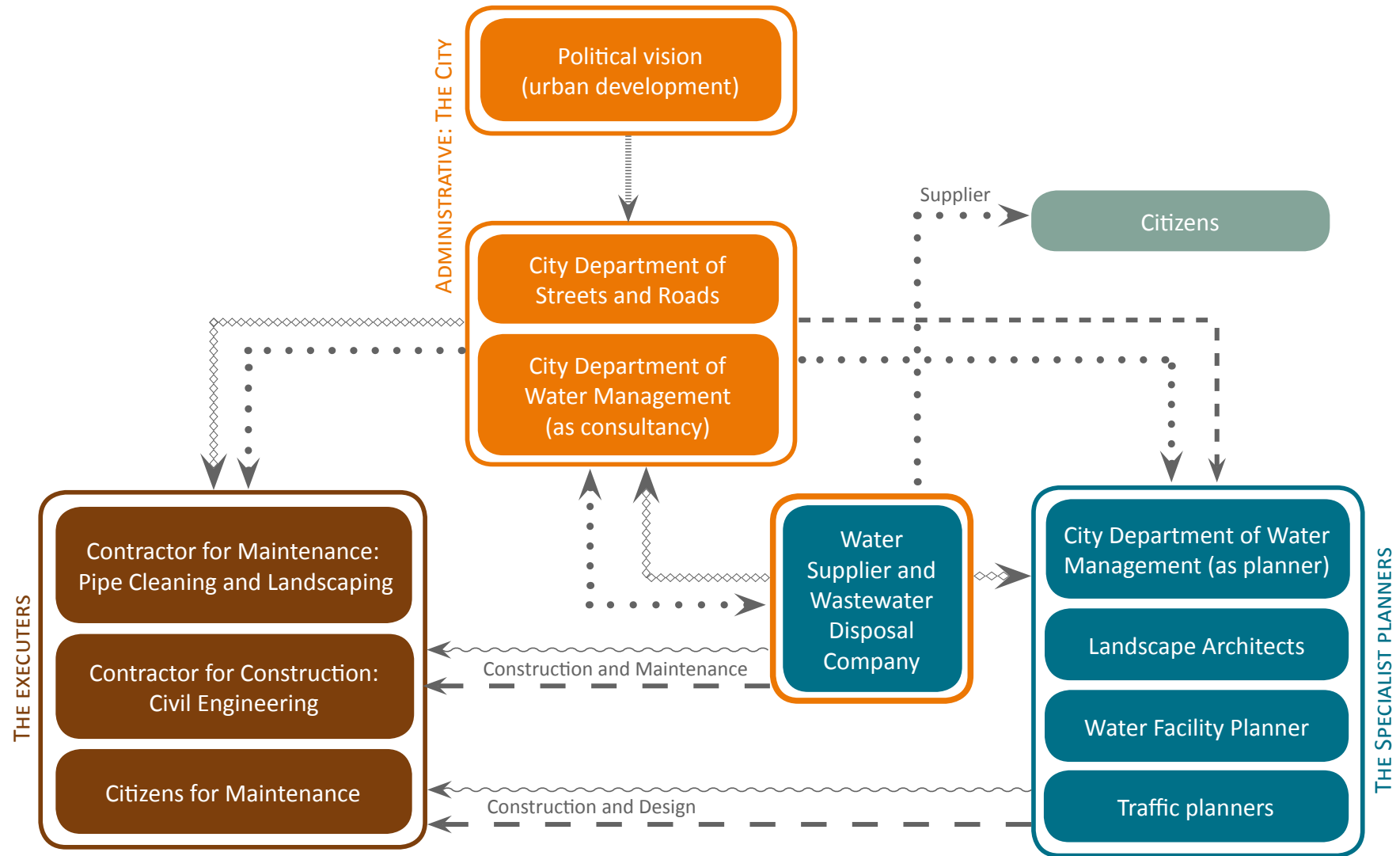


Fig. 3.05 Key actors for stormwater and wastewater management (simplified)

CITY POLITICAL STATEMENT

- Political vision: as an instrument it sets the frame for urban development and green network and sustainable stormwater management

CITY DEPARTMENT OF WATER MANAGEMENT AS CONSULTANCY

- Advising other specialist planners
- Contracting specialist planners and executor for construction and maintenance
- Communication with citizens/residents

CITY DEPARTMENT OF STREETS AND ROADS

- Cooperating with the Department of Stormwater Management for planning and construction of street drainage

SPECIALIST PLANNERS AND CITY DEPARTMENT OF WATER MANAGEMENT AS PLANNER

- Planning and tendering tree projects
- Definition of requirements concerning materials and construction process
- Monitoring of planning, requirements and construction processes
- Instruction/ admonition of contractors
- Cooperating among other specialist planners

- Knowledge about legal framework and other guidelines
- Documentation of construction site including delivery, treatment and installation of all materials

WATER SUPPLIER AND WASTEWATER DISPOSAL COMPANY

- Supplying Drinking Water and coordinating wastewater/stormwater system
- Monitoring of maintenance, planning, construction
- Contracts with citizens (service fee)

CONTRACTOR FOR CONSTRUCTION, CIVIL ENGINEERING

- Procurement, installation and construction of materials
- Monitoring and inspecting all the other material of required quality
- Documentation of construction
- Proof of functionality of stormwater system

CONTRACTOR FOR MAINTENANCE, PIPE CLEANING AND LANDSCAPING

- Cleaning Stormwater devices
- Maintaining greenery
- Documentation of maintenance

CITIZENS FOR MAINTENANCE

- Decentralized Stormwater Management on private property
- Meet obligations of function of DSM-System
- Regular maintenance
- Provided with information and support by the city

CITIZENS

- Consumer of drinking water and producers of wastewater
- Payment of service fees

3.3 Legal framework and guidelines for Stormwater Treatment and Management in Germany and Hamburg

Numerous guidelines and recommendations for dealing with stormwater exist worldwide. This section describes the guidelines which form a legally binding basis for the production of systems for stormwater management in Germany.

Federal Soil Protection Act (2015) sets the framework for the protection of the soil and groundwater against contamination, the high-level features (e.g. filter media) and drinking water precautions have the highest priority.

The **EU Water Framework Directive** (WFD) passed in 2000 aims “to achieve good status in all surface waters and groundwater” (WFD, cl. 25, p.5). It is the environmental background of decentralized stormwater management: The protection of all waters and groundwater, and to restore the ecological function of waters. By separating the stormwater from the combined sewer system and by the reduction of the discharged amount of stormwater, overflows of the combined sewer and wastewater system though emergency overflows shall be minimized.

The **Water Act** (WHG) (2016) is the legal basis for the decentralized stormwater management at the federal level. According to the Water Act and the **Hamburg Sewage Act** (HmbAbwG) (2013) stormwater is legally considered as wastewater when collected and drained from built-up or sealed areas (WHG §54, cl. 1, no. 2). Since wastewater must be disposed properly (WHG §56), consequently also stormwater has to be discharged but “should be infiltrated {...} on the property where it hits the ground and not be discharged or mixed with wastewater” (WHG §55, cl. 2). Discharging wastewater can be achieved by various methods, as long as it is “for the public good” (WHG §55 cl. 1) and not a risk, due to contamination and hazard substances for example for the groundwater. It is stated, that instead of discharging the clean stormwater into the rainwater system it can be infiltrated on the property, on public green space or discharged into a surface water (HmbAbwG §9, cl. 3).

Through the **Building Code**, which is based on the **land-use plan** and **binding land-use plans** principles for soil and wa-

ter conservation in terms of water drainage as by infiltration or retention (green roofs), can be imposed on (new) settlements.

These laws can be supplemented in the legislation at the state level. For example, in the Free and Hanseatic City of Hamburg under the Water Act and **Stormwater Infiltration Regulation** (2003), infiltration of stormwater on private property is possible without permission in accordance with certain specifications. The **Water Conversation Regulation** by the City of Hamburg sets further regulations for infiltration within water protection areas. It determines which type of infiltration systems may be built under which site conditions.

The development of the following standards and guidelines is based on described laws. These publications and guidelines are not legally binding. They are based and developed on technical and scientific know-how, experience and results. They do not have to be used but they represent the current state of the art. They are continuously reviewed and adjusted

to include new findings and standards. If they are included in the tendering, the executing company must meet the requirements.

In the following paragraph, there are guidelines listed that have a direct impact on the development of an advanced system of street tree pits. It does not exclude other laws and regulations in terms of decentralized stormwater management.

DIN 1986-100: 2016-09: Drainage systems on private ground - Part 100 (2016): Specifications in relation to DIN EN 752 and DIN EN 12056: For the planning process of drainage of private properties, all the possibilities of decentralized stormwater management should be taken into consideration. This standard explains the basics for the calculation of stormwater retention areas. It mainly refers to the DWA-A 138.

FLL-Requirement for stormwater infiltration and retention (2004): This guideline explains the different methods of decentralized stormwater management and the requirements of function in terms of soil,

groundwater, load bearing capacity and traffic load including specific information about the dimensioning of the different systems.

The categorization of the outflows, dimensioning and maintenance of the different types of infiltration systems are defined by the **DWA-A 138: Planning, construction and operation of stormwater infiltration systems** (2005). This involves the infiltration of precipitation from permeable and impermeable surfaces. It serves as a basis for calculating the stormwater runoff from different areas and the dimensioning of the inflow to the infiltration systems.

If stormwater of streets is discharged within water protection areas, the **FGSV 514 Guidelines for constructions on streets in water protection areas** (2002) and the **FGSV 548 Notes for construction on existing roads in water protection areas** (1993) must be applied. These two guidelines regulate the treatment and process of infiltration.

The evaluation of the quality of stormwa-

ter runoff and the demands on the quality of the discharged stormwater is given by the **DWA-A 153 Recommendations for handling with stormwater** (2012).

The **FGSV 950 Instructions for infiltration of stormwater in street space** (2002) points out the requirement of load bearing capacity for streets. In addition to the hydrological properties of the system, the distances to buildings has to be examined. There are information given about the maintenance and monitoring of the system.

The Hamburg planning notes for city streets **PLAST** (2013) serve as a supplementary basis of the **FGSV RSTO 499** for the construction of roads in the City of Hamburg. It includes design and technical specifications, as well as the derivation of surface water. For the infiltration of stormwater of streets it refers to the DWA-A 138. An individual analysis of the design and installation of the systems is recommended in every law and guideline due to the different site conditions, and the individual parameters, which need to be assessed in each single case.

3.4 Implementation criteria

To sum up, this section lists the main requirements of the guidelines listed above, which are relevant for the dimensioning and construction of an *advanced system of urban tree pits*.

Dimensioning of decentralized stormwater systems

To calculate the hydrological properties of the infiltration system, the connected area, inflows, infiltration rate of the soil and the storage capacity need to be considered. Depending on the location and size of the system, the individual parameters must be adjusted. The site-spe-

cific rainfall data (KOSTRA DWD) and the amount of rainfall in the predetermined duration of the rain need to be analyzed for each individual site. For the calculation, it is recommended to consider a rainfall event of 5-years frequency with a duration of 15 minutes (DWA-138 2005 p.20). All the formulas and parameters for the calculation are included in the DWA-A 138.

Run-off of different types of surfaces

Depending on the surface type (level of sealing) and slope of the surface, the percentage of stormwater running off

surfaces can be calculated with the run-off coefficient. Based on precipitation data of a specific location, the amount of stormwater is defined. This data must be included in the calculation of the total run-off for the chosen system (DWA-138 2005). Stormwater gutters along the street should not be placed close to trees to prevent clogging by leaves and dirt (FHH 2006b ER4 p.8). For the implementation of an *advanced system*, this is a fact which clearly cannot be followed and needs to be changed.

Source of stormwater

Even when the stormwater is still in the air as rain, it accumulates particulate matter. From the surface, when the rain hits the ground, it takes up further substances. The resulting contamination depends on the use of the surface and its material. In addition to organic solids, such as waste, road building materials, parts of plants or fuels, chemical and heavy metal components can adversely affect stormwater quality (DWA-138 2005 p.11).

According to DWA-A138, stormwater runoff of paved areas is divided into three

TYPE OF SURFACES	TYPE OF SURFACES	ψ
Pitches and flat roof	Metal, tiled, tar paper	0.8 -1.0
Green roof (slope 15-25°)	Vegetation soil < 10 cm	0.3
	Vegetation soil $\geq$ 10 cm	0.5
Streets, pathways, plazas	Asphalt, concrete without joints	0.9
	Pavement stones with narrow joints	0.75
	Pavements stones with open joints	0.5
	Interlocking Pavement with large joints	0.25
	Turf stones	0.15
Lawn, grassland, natural surfaces	Steep or flat terrain	0.1 -0.3

Fig. 3.06 Runoff coefficient of different surfaces

categories depending on the concentration of pollution and the possible resulting impact on the groundwater:

- Harmless (infiltration possible without pretreatment),
- Tolerable (infiltration possible after pretreatment or purification process) and
- Intolerable (discharged into the sewer, infiltration only after intensive pretreatment).

The division into these three categories is based on the use and the motorized traffic load. The classification refers to the *average of daily traffic* (DTV). Traffic flow, proportion of parked cars, ve-

hicle weight classes and intensity of street cleaning must be included in the analysis. Other factors such as winter maintenance and accidents also have an impact on the pollution of stormwater. The type of infiltration system also plays a decisive role. The discharge of tolerable stormwater in underground infiltration systems is either partially admissible or admissible only in exceptional situations. Stormwater from residential building roofs (fertilizers and pesticides prohibited), terraces and courtyards are harmless and could be infiltrated without treatment (DWA-138 2005 p.12ff).

Treatment of polluted Stormwater

To protect the groundwater, infiltrated stormwater has to be passed through a vegetated topsoil zone. It is proven that a topsoil zone can be used for the removal of pollutants by infiltration (FGSV 2002 p.5). The target is to effectively remove key pollutants from stormwater, such as total suspended solids, phosphorus, nitrogen, metals, oil and grease. If pollutants cannot be removed from the stormwater in a natural way, manufactured systems such as sedimentation and absorption filters must be used (e.g. Funke Gruppe). The type of filter and its exact function should be adapted to the level of pollution (DWA-153 2007).

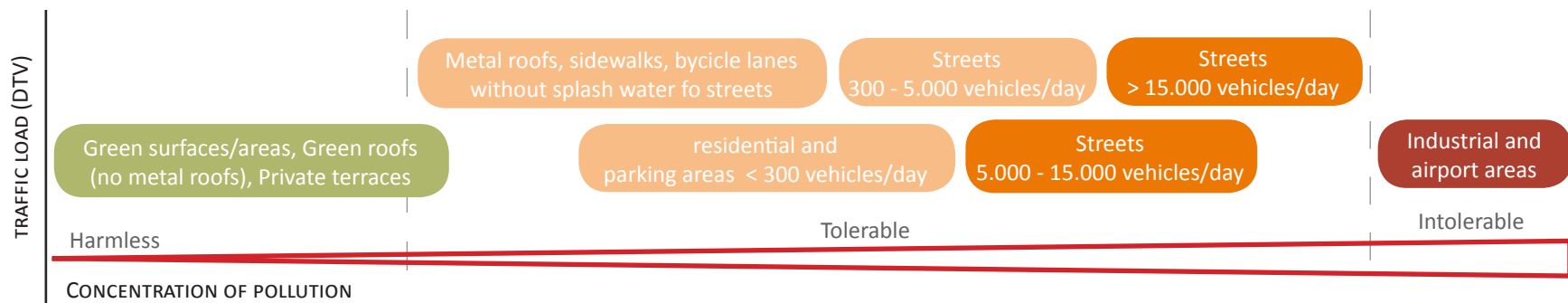


Fig. 3.07 Type of surfaces of stormwater run-off and the concentration of the pollution

Load bearing capacity

The surface and bearing layers must meet the requirements of load bearing capacity. These can be achieved through the use of suitable material, for example only a small amount of fine material (material smaller than 0,063 mm less than 3 percent of mass) (FLL 2005 p.28ff).

Composition and properties of soil

The condition for infiltration of stormwater is the sufficient permeability of the soil, which is defined by the k_f -coefficient (water permeability value, see Section 3.4). This is based on the properties of the different types of soil, such as grain size, storage density and water holding capacity. These components determine the size, number, shape and distribution of the pores in the soil that allow infiltration of water (DWA-138 2005 p.15ff).

The composition of the soil also affects the cleaning quantity of stormwater. For ideal cleaning properties, the humus or compost content should not exceed 1 to 3 percent by mass. The clay content should not exceed 10 percent by mass in order to ensure a uniform flow through

the soil and prevent clogging (DWA-138 2005 p.16ff).

It must be prevented that excessive stormwater is gathering in the infiltration system due to a high difference of grain size distribution of the existing and installed soil layers (German: kapillarer

Bruch) (FLL 2005 p.29). This means, for example, that the correct proportion of clay in the planting soil must be selected. A lower clay content in the planting soil than in the prevailing soil may cause a water accumulation at the bottom of the tree pit.

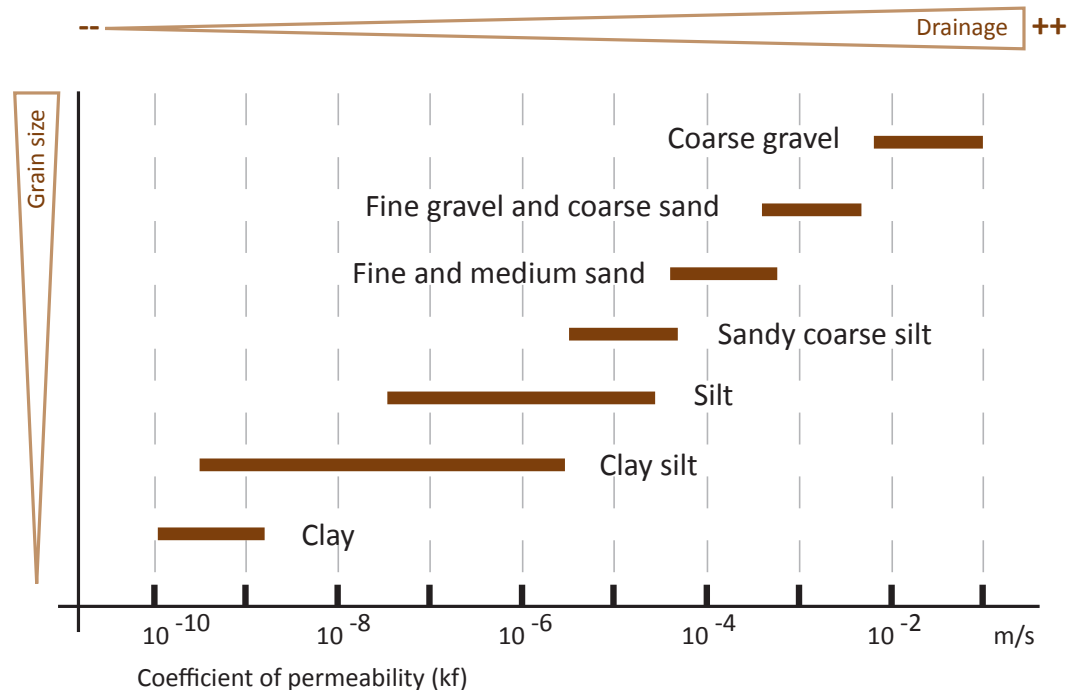


Fig. 3.08 Soil distribution, drainage capability and permeability coefficient (k_f)

Distance to buildings

Damage to buildings by stormwater infiltration systems must be prevented. The distance to the buildings is crucial if the building foundation is not provided with a water pressure-bearing sealing. If the groundwater level is below the basement floor, the distance between the infiltration system to the building should be at

least 1.5 times the depth plus 50 cm of the building excavation pit, or in general at least 6 m in distance from the building (DWA-138 2005 p. 19; FGSV 2002 p.10). If such a sealing protects the building foundation it must be decided in each individual case whether the distance can be reduced.

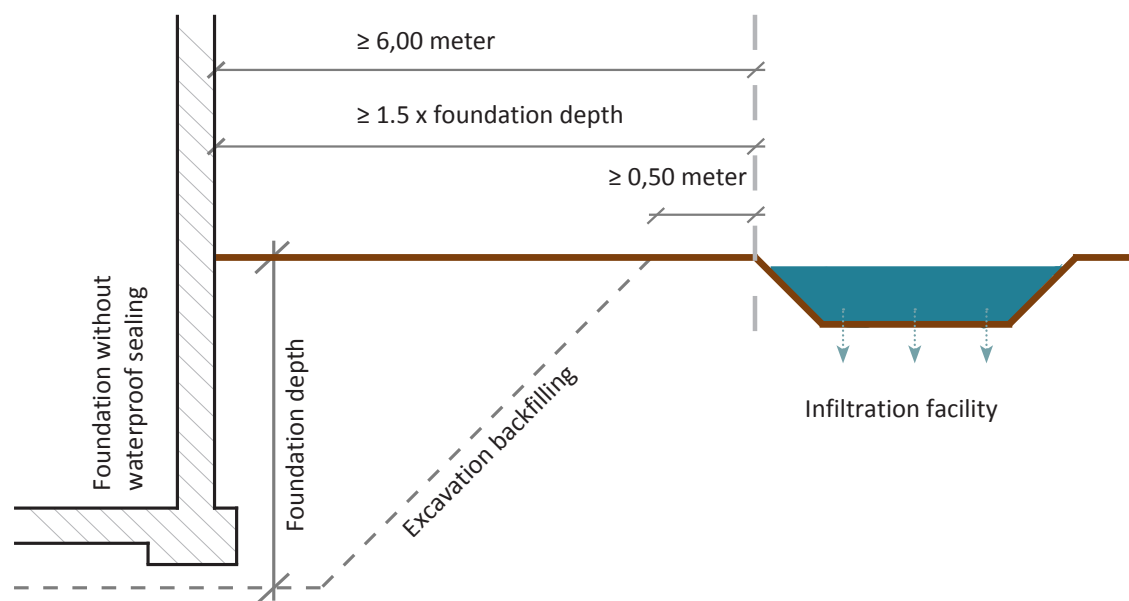


Fig. 3.09 Distance to non-waterproof building foundation

Water/drinking water protection areas

Stormwater infiltration within water and drinking water protection areas must be discussed in each individual case, depending on the level of pollution and the type of stormwater infiltration system. If an *advanced system of urban tree pits* cannot meet these requirements it should not be applied in such areas unless a specific investigation and adaptation is carried out (DWA-138 2005 p.6ff). At sites with contaminated soil, infiltration of stormwater should not be installed due to the high risk of hazardous pollution of groundwater (FGSV 2002 p.5f).

Infiltration and emergency overflow

It has to be ensured that there is no hydraulic overload of the infiltration system. To prevent overflows, an emergency overflow pipe should be installed (FGSV 2002 p.11).

Surface infiltration facilities water should be infiltrated within 24 hours. If not possible in a natural way due to subsoil conditions or properties, a drainage pipe should be connected to the sewer system (DWA-138 2005 p.23).

Maintenance and monitoring

Regular inspection and maintenance must be carried out to guarantee proper functioning of the systems (FGSV 2002 p.16). This includes cleaning, changing of filters and, if needed, other construction materials. The function of the systems should be monitored, especially the water inflow and outflow (DWA-138 2005 p.36f).

4 INTERNATIONAL CASE STUDIES

Worldwide, numerous systems of tree pits have been developed by research projects, contractors or cities. For this report, different systems in various cities have been investigated and evaluated in detail. Therefore, the following chapter will give a deeper understanding of case studies, which will provide the basis for the empirical research of this report.

During the intensive analysis, a classification of four categories was evolved to compare the systems. These categories are based on the particle sizes of the structural substrate, which is used for the construction of the tree pits (compare (TDAG 2014 p.96ff):

- 1. Large-size stones,
- 2. Medium-size particles,
- 3. Fine particles and
- 4. Crate/cell system.

Each category was investigated by different case studies. Due to the amount of data, one case study of each category was chosen to explain in detail. The systems had to met the five main requirement criteria:

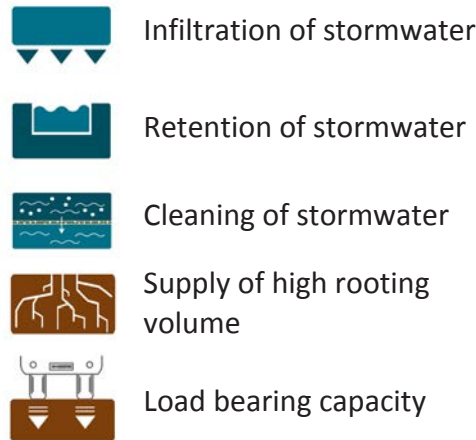


Fig. 4.01 Selection criteria of case studies

Furthermore, information about the systems had to be available online including detailed drawings, pictures or videos about construction and implementation processes and the used materials.

The case studies also must be applied under real conditions in urban and dense space and not only carried out as a research project in the open field where the decisive factors such as lack of space through infrastructure, heat or pollutants would be missing. The chosen cities should have the similar climate indicators as the city of Hamburg. Furthermore, the

systems should already have been applied between five to ten years, with evaluation and monitoring reports.

Best Practice:

1. LARGE-SIZE STONES: STRUCTURAL SOIL IN STOCKHOLM, SWEDEN

The Best Practice Example is the City of Stockholm with the Stockholm Solution which belongs to the first category. It is a skeleton system that uses rocks of the size up to 150 mm (Embrén et al. 2009). The numerous online available information and further reports, offered an ideal basis for a detailed analysis. A personal interview with the responsible people from the City of Stockholm, site visits to the trees and construction sites in Stockholm completed the analysis.

CLIMATE INDICATORS: STOCKHOLM, SWEDEN

Rainfall		
Σ annual:	650 mm	
Ø monthly lowest: January:	46 mm	
Ø monthly highest: August:	77 mm	
Temperatures		
Ø monthly lowest: January:	- 5°C	
Ø monthly highest: July:	22°C	

(SMHI 2016c)

The other Case Studies:

2. MEDIUM-SIZED PARTICLES:

CU-STRUCTURAL SOIL IN NYC, NEW YORK

In New York, City the system of structural soil is used, which is based on material that has a particle size up to 20 mm (medium size) (Bassuk, Grabosky, and Trowbridge 2005).

CLIMATE INDICATORS: NEW YORK CITY, USA

Rainfall	
Σ annual:	1,056 mm
Ø monthly lowest: October:	73 mm
Ø monthly highest: April:	99 mm
Temperatures	
Ø monthly lowest: January:	- 4°C
Ø monthly highest: July:	28°C

(NWSFO-NY 2010)

3. FINE PARTICLES:

RAINGARDEN TREE PITS IN MELBOURNE, AUSTRALIA

Significantly smaller (fine) particle sizes are used in the Raingarden tree pits in Melbourne. This system uses coarse sand with a grain size of maximum 0.22 mm (CM 2016a).

CLIMATE INDICATORS: MELBOURNE, AUSTRALIA

Rainfall	
Σ annual:	650 mm
Ø monthly lowest: January:	47 mm
Ø monthly highest: October:	66 mm
Temperatures	
Ø monthly lowest: July:	6 °C
Ø monthly highest: January:	26°C

(AG 2016)

4. CELL/CRATE SYSTEM:

SILVA CELLS IN TORONTO, CANADA

The fourth system is made of prefabricated components like plastic cells, which are filled with fine material up to 2 mm of grain size. Toronto is chosen as a case study, which uses the products Silva Cells (DeepRoot 2011a).

CLIMATE INDICATORS: TORONTO, CANADA

Rainfall	
Σ annual:	782 mm
Ø monthly lowest: January:	46 mm
Ø monthly highest: August:	84 mm
Temperatures	
Ø monthly lowest: January:	- 8°C
Ø monthly highest: July:	27°C

(GC 2013)

Each following section describes one of the four categories with its case study within the operating city: In Section 4.1 the structural soil in Stockholm, in Section 4.2 the CU-Structural Soil in New York City, in Section 4.3 the Raingarden tree pits in Melbourne and in Section 4.4 the Silva Cells in Toronto are explained in detail. The implementation criteria for every system are pointed out in Section 4.5 which will display the best growing conditions for urban trees according to the overall analysis and research.

4.1 Large-size stones: Structural Soil in Stockholm, Sweden

Since 2004 the City of Stockholm uses their system *Stockholm Solution* for urban tree pits in public space but mainly for street trees. Over the last fifteen years, the system has been adapted and further developed. In 2009, the City of Stockholm published the Handbook „Planting Beds in the City of Stockholm“ (Embrén et al. 2009) which is available online.

Björn Embrén and in collaboration with Britt-Marie Alvem, Örjan Stål and Alf Orvesten, are working for the City of Stockholm. They developed a standard design, planting and renovation methods for trees in Stockholm. In general it describes the techniques to improve the growing conditions for urban trees in different locations such as vegetation and paved areas. Beside the description of planting bed renovation, several examples of planting beds for new trees are described.

A personal interview with Ms. Almen and Mr. Embrén and a tour guided by them to numerous tree locations, renovations and construction sites in the City of Stockholm, provided the latest insights into the developed system and their daily work.

Björn Embrén is the initiator of the Stockholm Solution. Influenced by European research projects, particularly the research project *trees in city streets* of the Institute of landscaping and garden architecture at the University of Hannover, he took over the principle of structural soil and developed it further to the Stockholm Solution.

Over ten years ago, after Mr. Embrén gained the information in Hannover, he

convinced the City of Stockholm to implement the adapted system for tree pits and test their effect. Shortly after the implementation, the new system was a success through rapid growth and enormous development of the trees along streets. Since 2007, Björn Embrén is together with Britt-Marie Alvem the tree specialists (Swedish: träd specialist) and responsible for street trees in the City of Stockholm.

RESULTS OF THE RESEARCH PROJECT OF THE UNIVERSITY OF HANNOVER:

From 1989 to 1994 and 1979 to 1999 the University of Hannover, Institute of landscaping and garden architecture, performed research in different locations within the cities of Hannover and Münster with different soil types on the optimization of rooting volume and site conditions for street trees. Various systems of tree pits for new plantings have been applied: linear aeration ditches between the tree pits, vertical deep drillings for aeration between 1.50 m and 2.30 m and horizontal air-conducting base course of gravel instead of mineral mixture, larger tree pits (1,60 m x 3,10 m x 1,20 m) compared to the normal size of 1,60 m x 1,60 m x 1,20 m.

The results were positive already within three to four growing seasons: The ventilation methods clearly showed that the roots in the area strongly grew and especially deep into the soil, even in very damp/ wet locations, roots were growing into the large-pore structure. The roots were growing quickly out of the normal size of the planting pit and therefore the larger tree pit was more effective. The trees were growing faster and had a larger crown diameter and trunk circumference than in *normal* tree pits within shorter time (Lösken, Schitteck, and Wolschke-Bulmahn 1999).

In their team, they also developed methods for planting bed renovation. For this report, only the planting beds for new plantings are explained.

Before the *Stockholm Solution* was developed, the tree pits were made of a concrete boxes (load-bearing part, about 1,20 m x 1,20 m and 60 cm deep) and filled with planting soil. However, the growth and development of the trees was low. Within a short time, the tree already grew out of the supplied planting hole. With its roots the tree also reached the surrounding underground of the pavement and stopped growing.

“The most important component is uncompressed rooting volume for a good development of the tree in urban space”, clarified Björn Embrén in the interview. This also guarantees water and air in the soil. A simple air inlet simultaneously ensures the water supply in the compressed environment and serves for the gas exchange from the root zone. A good nutrient content can be guaranteed by humus in the planting soil and long-term fertilization. If these properties are avail-

able, trees are able to grow in an urban environment and establish a high vitality. This can be achieved with the Stockholm Solution, because the stone skeleton of the structural soil offers a pore volume of 40 percent for uncompact soil.

There is no legal document by the City of Stockholm which enforces the use the Stockholm Solution. Nevertheless, street tree plantings on public ground are always planned and installed according to the mentioned handbook which used is a guideline and standard. (Embrén and Alvem 2016).



Fig. 4.02 Trees in structural soil in the City of Stockholm with Björn Embrén, Britt-Marie Alvem and Thilo Beeker

The information of the following paragraph are based on the Handbook „Planting Beds in the City of Stockholm“ (Embrén et al. 2009) and the personal interview with Björn Embrén and Britt-Marie Alvem (Embrén and Alvem 2016).

The Stockholm Solution is technically not complex, but it requires a detailed monitoring and control during the construction. The material must be properly installed so that it meets the requirements and can offer appropriate bases for the trees: For example, the air inlet must correspond to the height of the aeration layer, the geotextile needs to be laid on and not under the aeration layer and the use of a premixed structural and planting soil should be avoided.

There is one specialist who is appointed by the City of Stockholm and performs the monitoring of the construction and the maintenance. The system is applied in every street hierarchy besides bus stops and highways.

Structure of the system in general

The system is a multilayer structure. The bottom layer (600 mm) consists of ho-

mogenous angular crushed rock with a stone size of 100-150 mm. The crushed rocks are laid in layers of 250-300 mm and are compressed. By compressing the stones they tilt to one another and form voids. The planting soil is laid in layers of 20 mm and hosed in manually with small amounts of water but high pressure until the voids are saturated. This layer is called structural soil.

A concrete bunker is placed (with foundation) on the crushed rocks and defines the planting hole for the tree, which is filled with planting soil and carries the tree grill. Outside the concrete bunker, the second layer, the aeration layer of angular crushed rock with a grain size of 32-63 mm is laid and compacted. To protect the aeration layer a geotextile is laid, which prevents fine particles from entering and blocking the voids. The air inlet is a drain with perforated base and an air hole with larger holes in the walls. The cover is a simple cover of a street gutter. The inlet reaches from the level of the pavement into the structural soil at the bottom. The subbase and the pavement are installed on top of the system.

Preparation of tree pits

When a new residential area or construction of streets is planned, the locations of new tree plantings are already set in the planning process. The new tree pits will be prepared completely during the construction of the area or the road. The tree pit can be built as large as possible including the area under the sidewalk and part of the street. For the size of the prepared tree pit the size of the tree ball also must be considered.

Tree trenches

With the planning it is always ensured that not an individual tree, but at least three trees are planted in a connected trench. Thus, more natural growth conditions are created, and may arise a natural and vital exchange of nutrients and microorganisms.

Tree size

The trunk circumference of at least 30-35 cm is set as a planting standard. The stem with this size is already stable against wind or sun and more resistant to mechanical damage. Another reason is the visual effect that creates a tree after planting.

Trees that grow on structural soil have a huge growth rate. This is clearly reflected in the increase of the trunk circumference. For example trees (30-35cm), which were planted in 2004 already have a trunk circumference of between 40 and 50 cm after ten years.

Air inlet/ Discharge of stormwater

The air inlet was developed with a drainage company. The stormwater passes through the downspouts of the roofs on the sidewalks, plazas and parking areas. It is then diverted via open drainage channels into the tree pit. From the streets the water is diverted directly into street gutters, which are connected with the air inlet. By the physical effect, stormwater fills up the pores in the planting soil and pushes up the lighter gas (carbon dioxide and nitrogen) out of the tree pit.

There are no additional filters installed in the air inlet. The biological and chemical processes in the planting soil serves as a sufficient media for removal of pollutants. The trees in the City of Stockholm clearly show that their vitality is not affected for example by the de-icing salt.

During winters with high use in de-icing salt, a few trees have marginal brown areas of their leaves, which is the effect of tree necrosis. But the tree regenerate quite fast based on the good growing conditions and the planting soil.

Infiltration

In Stockholm, the water table is generally very low and infiltration is possible. The clay content of the planting soil depends on the existing soil conditions of each individual site. The terrace of the tree pit should be with a small slope (1-2%) for drainage in compacted or very clayey soils. A geomembrane is installed to keep infiltrated water from foundations of buildings.

Costs

The construction of a tree pit (15 m³) with structural soil costs about 120,000 SEK (€ 12,500). Half of the cost is used for the construction of the pavement and the sub-base.

Interdisciplinary and (inter)national cooperation

The cooperation and communication

with other planners of the underground facilities (e.g. water, electricity and telephone department) is important and has been increasing with the implementation of the Stockholm Solution.

Björn Embrén is providing a lot of information (presentations) for other planners to improve the communication and the sensibility of civil engineering companies. Another step is to pass the appreciation of the urban trees on to its own citizens. Furthermore, Björn Embrén and Britt-Marie Alvm are very open to the international interest on the Stockholm Solution and are willing to share information for a good cooperation.

Maintenance

The intensity of the maintenance is quite the same compared to *normal* trees without structural soil. However, while *normal trees* must be periodically restored by e.g. removing old branches for road safety, trees on structural soil need a higher pruning due to the intensive growth rate.

The air inlet must be periodically cleaned of solids such as garbage

or debris to ensure the interception of stormwater into the tree pit. If a tree dies off, it can be replaced by opening easily the tree grill on the concrete bunker. The tree is cut off by the roots, which will rot and serve as organic material. Only the planting soil has to be filled up around the root ball of the new tree. This saves high construction costs.

Irrigation

Watering bags help with the irrigation for the first two years after planting. These are plastic bags which are placed around the trunk and are filled with water once a week with up to 90 liters. The watering bags released the water slowly through micro-holes in the bottom of the bag. The time required of manual irrigation can be significantly minimized. Additionally, watering bags also protect the lower part of the trunk until it is established. They also cover the soil at the bottom of the tree and decrease the evaporation of the soil.

Biochar

In the last four years, biochar has been added in the tree pits. Biochar is charcoal that by the process of pyrolysis (thermal

decomposition) can be used as a carrier for nutrients (Spokas 2016). Thereby, acidification of the soil can be prevented. Biochar can store high amounts of water by its high porosity and makes it available for plants. The biochar is produced locally based on plant and garden residues (garden and park waste). The resulting energy is sustainably fed into the district heating network.

Recycled concrete

An experiment of the City of Stockholm was to replace the granite-crushed rock by recycled concrete. The structure and preparation are identical to the Stockholm Solution. After five to ten years it can be seen that the trees show no differences in vitality and size compared to the granite-crushed rock and therefore can be a cheaper alternative.

(Non)indigenous trees

In Stockholm and in Sweden, the same discussion exists about the use of native and non-native species as in Germany. The number of native trees in Sweden is limited to only 20 species. Hence, a diverse selection compared to Germany is

difficult. According to the tree specialists of the city of Stockholm, in the street tree planting it is important that many different trees in type and species are planted to have a higher stability within the climate change (e.g. against pests). Even though, this increases the use of non-native trees.

Water System of the City of Stockholm

According to the Stockholm Water Department (Stockholm Vatten) the Stockholm Solution of tree pits have a high potential for stormwater infiltration and treatment.

In older parts of the city of Stockholm the stormwater and wastewater are diverted in the same pipe (combined sewer, about 50%) and are treated in the sewage treatment plants before it enters the Baltic Sea. In heavy stormwater events emergency outlets into the sea prevent flooding of basements in the city. The wastewater is directed without treatment into the sea.

In newer areas, which were built after 1960 the waste and stormwater is transported in separate pipes. The stormwater is directed into the nearest lake or to the

sea. In some cases it is treated in ponds or settling tanks, but not intensively cleaned before it is released.

The stormwater from roofs flows onto the sidewalk through open downspouts (heated during the cold period). In the last decades, the downspouts are directly connected to the pipe system. However, Stockholm Vatten is developing a system where the stormwater is directed onto green or permeable areas for retention or infiltration (Sensitive Urban Water Design).

There is a one-time payment when a new building is connected to the pipeline system. It is ca. € 6,000 for connecting water, stormwater and wastewater and only € 3,500 when only water and wastewater is connected. The annual fee for wastewater varies between € 200 for single-family houses up to € 400 for apartment houses. Drinking water costs € 0.50 per m³. The fees for stormwater are fixed for family houses of € 40 per year. For apartment houses and industries as well for the communal ground this fee is based on the size of the property in m².

If water is infiltrated and not directed into the drainage system, there is a possibility of reduction on the connecting fee. Depending on the area where the stormwater will be treated on site and not be discharged, the fee can be reduced between 25-50%. This corresponds to a reduction between € 350-700. In addition, the yearly stormwater fee can be reduced by 50-100% if stormwater is infiltrated on site (Pramsten and Vall 2016).

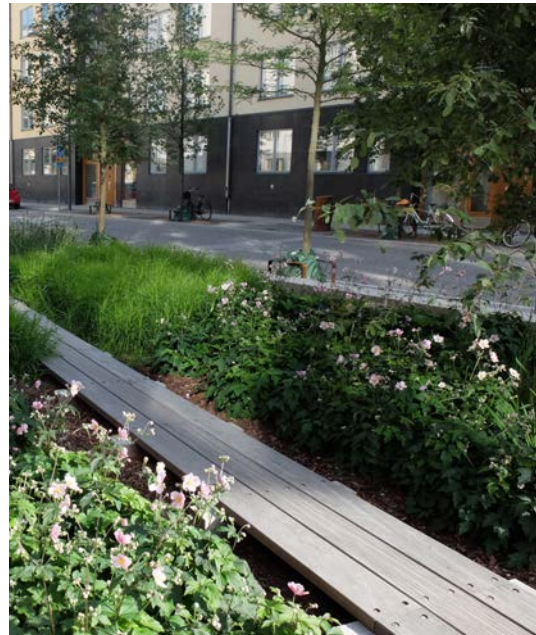


Fig. 4.03 Decentralized Stormwater Management (Infiltration Raindarden) in Norra Djurgårdsstaden, Stockholm

Large-size stones: Structural Soil in Stockholm, Sweden

STORMWATER INTERCEPTION FROM ROOF AND SIDEWALK

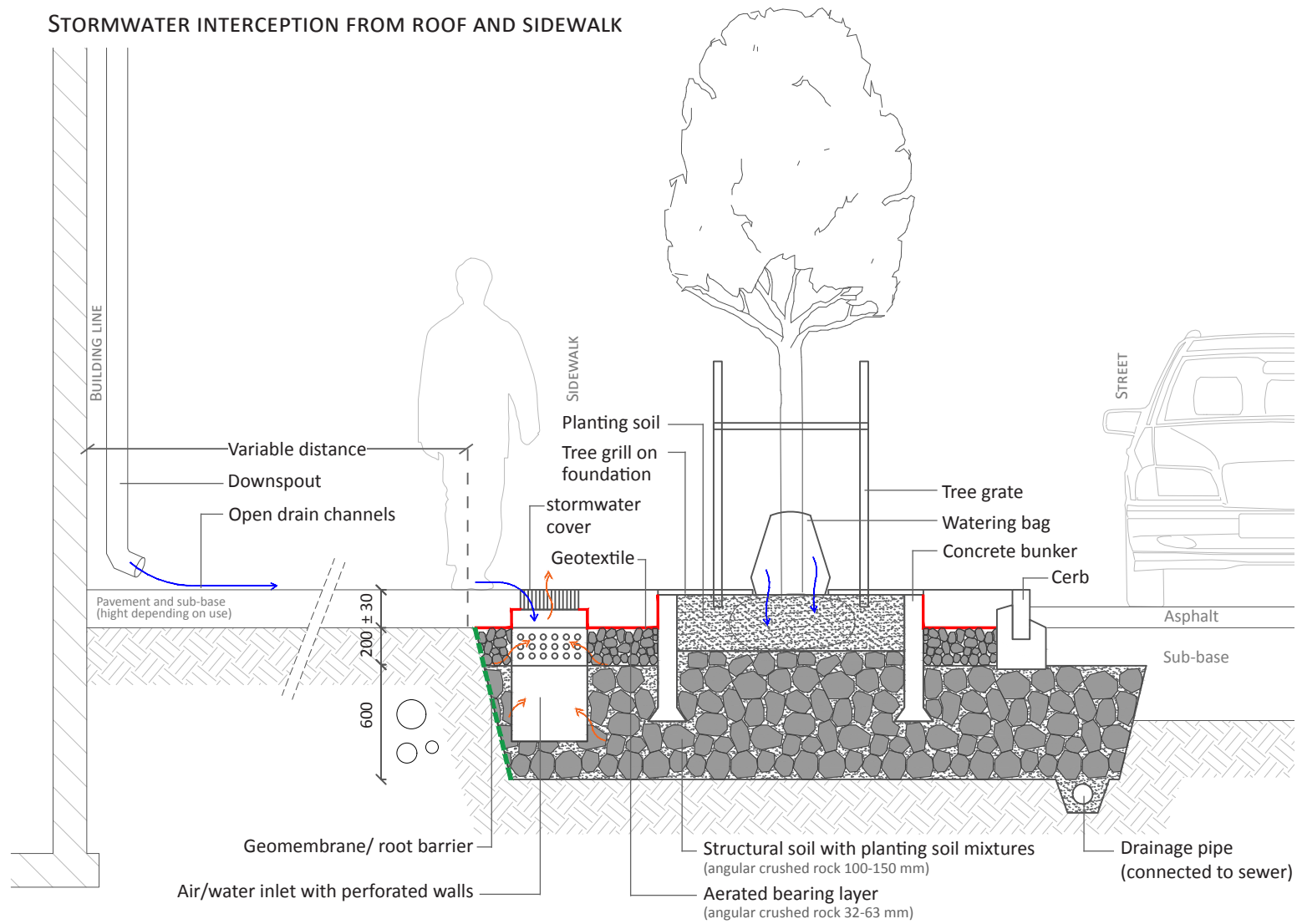


Fig. 4.04 Section of Stockholm Solution: water interception from roofs and sidewalks; without scale, units in centimeter

STORMWATER INTERCEPTION FROM STREETS

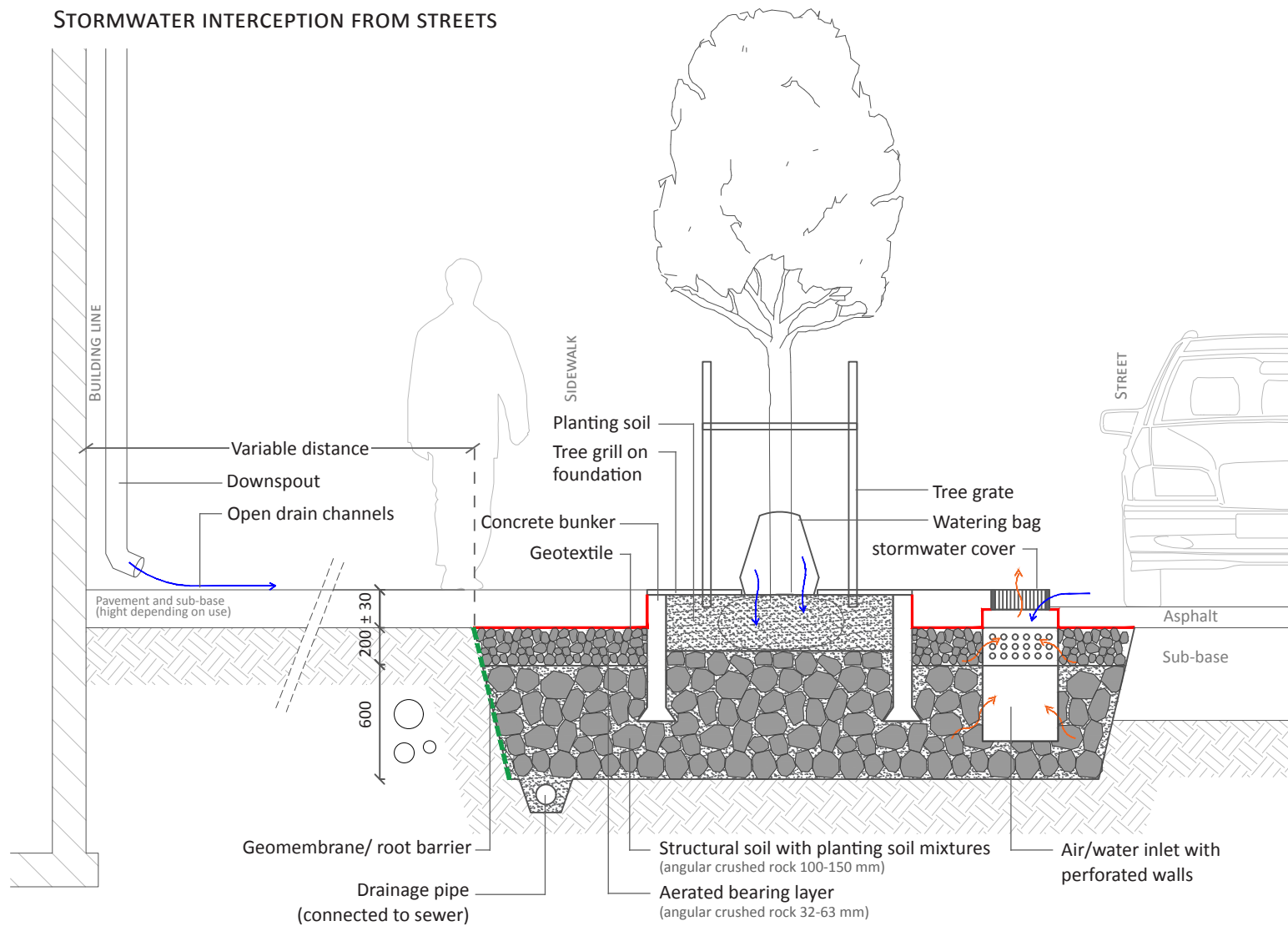


Fig. 4.05 Section of Stockholm Solution: water interception from streets; without scale, units in centimeter

Large-size stones: Structural Soil in Stockholm, Sweden



Fig. 4.06 Air and stormwater inlet



Fig. 4.07 Different types of tree grates

Application Criteria

The Stockholm Solution provides a large rooting volume and load-bearing capacity and meets almost all targets in terms of stormwater management. As the water department already noted, the discharge of stormwater from roofs on public surfaces (sidewalks) is not a mature technology. On the other hand, a high amount of water can be directed into the tree pit through the sidewalk. The city of Stockholm has a variety of impressive vital trees in dense urban areas. The choice of some exotic species, such as *Metasequoia* (Dawn redwood), and *Magnolia* is rare, but by their different habit they conjure a vivid picture in the streets of Stockholm. The system of Stockholm solution is basically produced from a waste product: With each deeper excavation, granite is dug out. The product must be adjusted to the correct size and can then be used directly as a building material for the tree pits. However, the use of recycled concrete is an economical alternative. The openness to implement new systems should be declared as a potential role model for other cities.

Rooting volume

- 80 cm
- Trees trenches
- Tree pit increased under sidewalk and street

Planting soil

- Uncompact planting soil
- Four mixtures for different locations:
- *Planting Soil A*: normal soil conditions high clay content
- *Planting Soil B*: salty environments low clay content
- *Planting Soil C*: pumice-based, light above basements, paved areas used in planting hole
- *Planting Soil D*: for structural soil/ planting hole, normal clay and humus content
- Biochar as a nutrient- and water-holding component
- 1 m³ crushed rock = 0,25 m³ planting soil
- Clay content minimum 4 % by weight
- Organic matter (humus) maximum 3-4 % by weight
- Slow release fertilizer 100 gr/m²

Water interception

- Inlet on streets or on sidewalks
- Water from roofs, sidewalks and streets

Gas exchange

- Air inlet which also serves for gas exchange (CO₂, N, O₂)

Filter

- No extra filter
- Soil functions as filter for pollutants

Adaption in urban space

- All street hierarchies (besides bus stops and highways)
- Open space, plazas, sidewalks
- Variety of tree grates and tree guards

Construction process and planning

- Constructed in layers of 250 -300 mm
- Compact skeleton material before adding planting soil
- Complete tree pit preparation during road constructions until planting
- Geomembrane to protect building foundation of infiltrated water

Maintenance

- Removable tree grill: simple exchange of trees easy
- Irrigation with watering bags

Trees

- High diversity (biological and visual) through indigenous species
- Tree size: trunk circumference 30-35 cm

Large-size stones: Structural Soil in Stockholm, Sweden



Fig. 4.08 Preparation of tree pits in construction process



Fig. 4.09 Biochar in tree pit and planting bed



Fig. 4.10 Aerated bearing layer



Fig. 4.11 Structural soil and aerated bearing layer



Fig. 4.12 Stormwater interception (roof and sidewalk)



Fig. 4.13 Watering bags



Fig. 4.14 *Aesculus hippocastanum* 'Baumannii' in structural soil

4.2 Medium-sized particles: CU-Structural Soil in New York City, New York

In the mid 1990s the Cornell University in Ithaca, New York developed a soil type, which is called CU-Structural Soil™, a mixture which should meet the demands of urban trees and the load-bearing capacity for urban surfaces like streets, parking lots and sidewalks (Day and Dickinson 2008 p.8). The system is similar to the Stockholm principle but differs in the type of installation and the size of the rocks. Therefore, it is classified in the category of medium-sized systems.

Since 1999, the developer Amereq, Inc. “holds the sole patent right to Cornell’s CU-Soil™ Urban Tree Planting Mix” (Amereq Inc. 2016). They provide detailed drawings and construction information on their website. The first trees were planted already in 1993. Until today the system is used worldwide (Amereq Inc. 2016).

The main component is homogeneous angular crushed rock (e.g. granite) with a size of 1,9-3,8 cm (3/4 to 1 1/2 inches), which also serves as the load-bearing layer. With a thickness between 610 mm-910 mm (36 inches) it provides a rooting volume between the stones (stone-on-

stone compaction) (Bassuk, Grabosky, and Trowbridge 2005 p.3) with a 26% porosity, which are filled up with the second component, the planting soil (Day and Dickinson 2008 p.9).

The rocks and the soil are mixed together prior to installation. The amount of planting soil must be accurately calculated. A tackifier (chemical component: increases the stickiness of the planting soil to the rocks) is added in order to guarantee the uniform mixing and to prevent a separation during transport or installation. The amount of organic matter is between 2-5%, the clay content should be at least 20 % to obtain a high water-holding capacity of the planting soil (Bassuk et al. 2015 p.11ff).

Stormwater enters through special openings in the curb into the structural soil and infiltrates inside of the tree pit. In order to drain excess water a perforated drainage pipe at the bottom of the tree pit is installed and connected to the storm water system (Day and Dickinson 2008 p.15). The tree basement can be designed in different ways. The opening

around the trunk should be minimum 180 cm (6 feet) of diameter, which can either be left open with a layer of 7cm (3 inches) of bark mulch on top of the structural soil or covered with a tree grate (Bassuk, Grabosky, and Trowbridge 2005 p.15).

The system has been used and observed for over twenty years. The result is clear: trees develop an enormous root system without lifting pavements and have a high vitality (Bassuk et al. 2015 p.15).

Due to the good infiltration capacity the stormwater can be returned in the natural water cycle and the sewage system can be relieved (Day and Dickinson 2008 p.6).

In accordance with the List of Amereq, Inc. especially in New York City in the US state of New York, the system of CU-Structural soil was used in numerous locations (Amereq Inc. 2016).

In terms of Stormwater Management New York City uses the system of raingardens or enhanced tree pits for the treatment of stormwater. Raingardens

are planted areas along the sidewalks on the streets, which collect stormwater from these surfaces, retain and infiltrate it. The size varies, depending on the available space between 4.0-6.0 m lengths, 1.0-2.0 m width and 1.50 m depth. They are also constructed with a rock layer in the bottom and engineered soil, a type of structural soil (NYC 2012 p.102ff).

The published brochure *Standard designs and guidelines for green infrastructure and practices* provides detailed drawings and descriptions for the construction (NYC 2016).

In the *Guidelines for the Design and Construction of Storm Water Management Systems*, tree pits are mentioned as a system to manage stormwater onsite (NYC 2012 p.7) and raingardens for retaining higher amounts of stormwater (NYC 2012 p.5, 104)



Fig. 4.15 Street Trees in CU-Structural Soil, NYC



Fig. 4.16 Crushed rocks with tackifier and planting soil

Medium-sized particles: CU-Structural Soil in New York City, New York

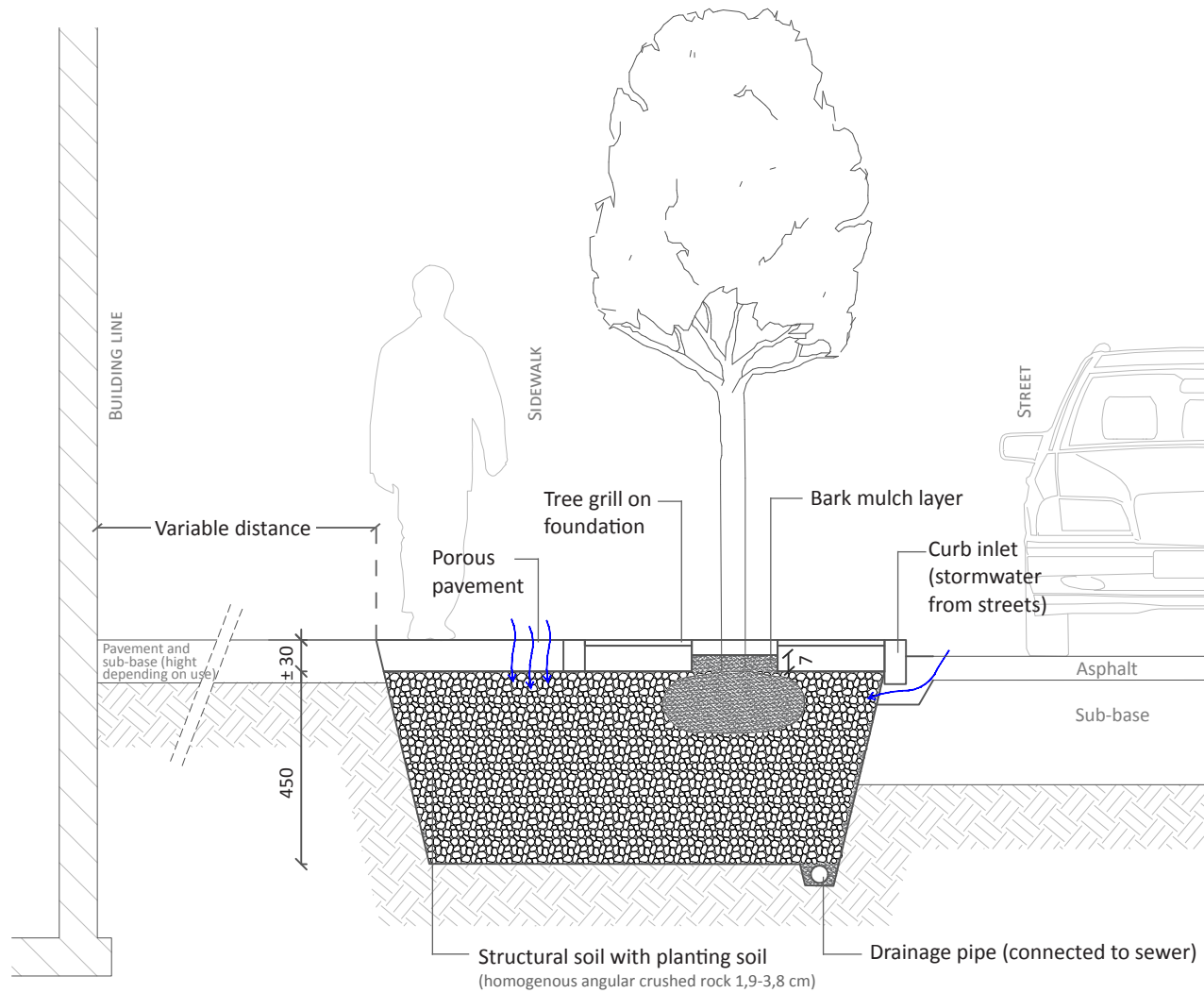


Fig. 4.17 Section of CU-Structural Soil; without scale, units in centimeter

Application Criteria

The New Yorker tree pit design based on structural soil clarifies, like the Stockholm Solution that sufficient root volume can be provided in high-density road space as long as a load-bearing structure such as structural soil is included in the tree pit.

A high amount of stormwater can be absorbed by the applied system of Raingardens, even though that system needs more space. Tree pits based on structural soil can be used much more efficient in space.

Using a premixed soil simplifies the construction process, saves time and storage costs on the construction site. But on the other hand, it is also the limitation of the system. While installation and the mechanical compaction, the pores within the planting soil are becoming compacted densely if not the exact amount of planting soil is added to the rocks. This restricts enormously the rooting volume, the water and air capacity within the tree pit.

Rooting volume

- 60-90 cm
- Trees trenches
- Tree pit under increased under sidewalk

Planting soil

- Clay content minimum 20 wt-%
- Organic matter maximum 2-5 wt-% (Bassuk, Grabosky, and Trowbridge 2005)
- Organic matter maximum 7-12 wt-% (NYC 2014)

Filter

- No extra filter
- Soil functions as filter for pollutants

Water interception

- Inlet on streets
- Water from sidewalks and streets

Adaption in urban space

- All street hierarchies

4.3 Fine particles: Raingarden Tree Pits in Melbourne, Australia

Melbourne is the second largest city in Australia and the state capital of Victoria. Under the term of *Water Sensitive Urban Design* (WSUD) Australia has been developing concepts for stormwater management (MW 2013). With the headline *Discover how water creates a livable city*” on the official website City of Melbourne-Urban Water Melbourne makes it clear that the topics of water and *livable city* and can only be achieved in a common context (CM 2016b).

In Melbourne, based on Sustainable Water Management, each water consumption and water use in public areas is monitored in detail. This intensive monitoring and evaluation process provides accurate data on water quantity and quality, including values for soil quality. This allows precise adjustments to improve the individual processes (CM 2015c).

Through different strategies Melbourne specifies a particular direction to be a *more sustainable city* (e.g. strategies for Open Space, Watermark and Urban Forest) (CM 2016c). The WSUD Guidelines are crucial for the planning and imple-

mentation of stormwater management. They serve as a basis for the implementation of water projects and provide detailed design standards such as drawings and information on the required material (MW 2013).

In 2006, Melbourne launched the Raingarden Tree Pit program. Raingardens are actually larger vegetation areas along streets that can retain and infiltrate high amounts of stormwater. These features were integrated into the smaller system of Raingarden Tree Pits. Besides intercepting, retaining and cleaning stormwater, Raingarden Tree Pits provide improved growing condition for trees. Thus urban cooling and amenity can be improved by transpiration and greenery in the urban environment. In addition, manual watering can be reduced and by minimizing water intersection into the water system the overflow of the sewage system will be minimized (CM 2016d).

The system is optimized for urban locations, particularly along streets. The Raingarden Tree Pits is a sand-based system. The main component is loamy sand

and coarse sand, with a particle size of 0.22 mm. The amount of organic matter is kept small at 4-5 percent by weight, as well as the amount of clay at 2-4 percent (CM 2015a p.5f).

The tree pit is set right on the curb, where the rainwater is discharged into the tree pit by a roadside gutter. Through the multi-layered structure several purposes are met simultaneously (CM 2015b p.2):

The height difference of 50 mm between the adjacent surface and the first layer creates a retention area for stormwater before it infiltrates into the substrate (air void layer). Trash and debris can also accumulate on that area, which can be easily removed by the weekly cleaning. A vertical pipe connected to the drainage pipe controls the water level and prevents from water flowing back on the street. The second layer, a rocky mulch layer retains the moisture in the soil. The third layer, the filtration layer (min. 450mm) removes pollutants like phosphorus and oils. Added compost (in the top 10 cm) supports the biological activity of this layer. Plant roots remove the nitrogen and soil bacteria. It

contains “80 percent loamy sand, 10 percent vermiculite and 10 percent perlite” (CM 2015a p.5f). The materials for this layer should be mixed manually on site. The fourth layer, transition layer (100 mm), composed of coarse sand, provides voids for root growth and good filtration capacity. The drainage layer (100-150 mm) at the bottom of the system ensures infiltration and holds the perforated drainage pipe, which is connected to the sewer system to drain excess water. It is composed of fine and clean washed gravel of a size of 2.5 mm. The basement of the tree can either be made of open soil with vegetation. In more busy urban areas a tree grate including a tree guard should cover it. The City of Melbourne uses growing rings in the tree grate, which can be cut away with the tree growth (CM 2015b).

During the construction it must be ensured that the built-in layers are not contaminated by sediment and debris, or garbage from sidewalks or streets, which are flushed in and remain inside the layers (CM 2015b p.6). Depending on the design and the street hierarchy, the costs

vary between €2,800-5,500 (4,000-8,000 A\$). The main part of the costs are for the tree grate, tree guard and the bollards (CM 2015a p.1).

In Melbourne, a variety of different tree species is planted, such as Turkish hazel (*Corylus Colurna*), Pin oaks (*Quercus palustris*), London planes (*Platanus × acerifolia*) and Waterhousia (*Waterhousia floribunda*), which are not (besides the waterhousia) part of the native trees in Australia. However, the tree species are carefully selected based on the Urban Forest Strategy by the City of Melbourne (CM 2015a p.5).

The periodic maintenance is performed manually or by using suction hoses. Especially the gutter and the surface of the tree pit have to be cleaned to guarantee a proper flow of stormwater into the tree pit (CM 2015a p.7).

According to the City of Melbourne, detailed monitoring construction and maintenance, and regular evaluation with continuously adaption of the processes is the success of the system (CM 2015c).



Fig. 4.18 Raingarden tree pits

Fine particles: Raingarden Tree Pits in Melbourne, Australia

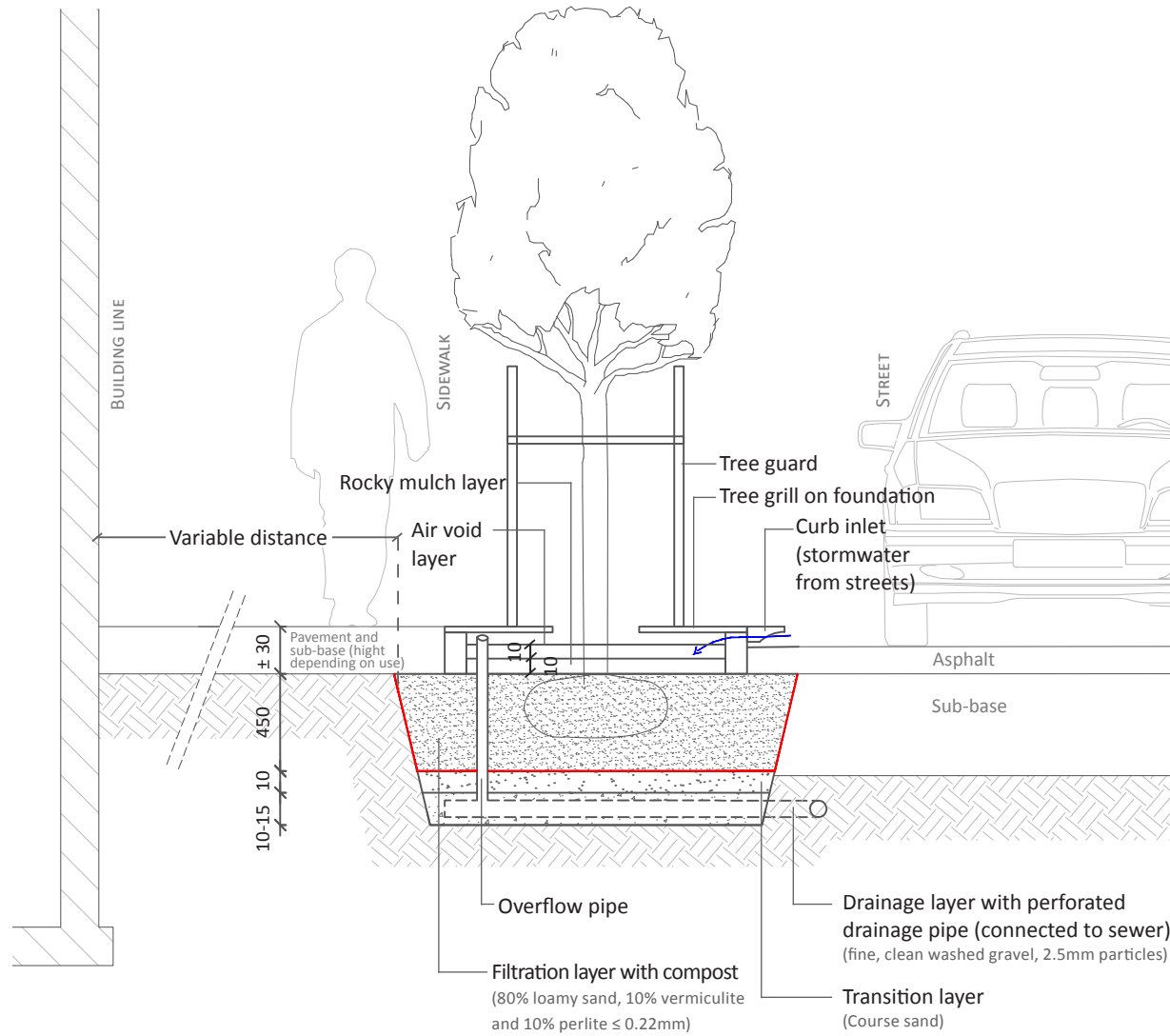


Fig. 4.19 Section of Raingarden tree pit; without scale, units in centimeter

Application Criteria

The City of Melbourne displays that implementation of stormwater management is possible within an urban scope. The inclusion of the Raingarden Tree Pits in urban guidelines and the large amount of information for planners and locals facilitates the planning process is simplified significantly. The air void layer of the system provides an area to accumulate a significant amount of stormwater like in swales. That decreases the amount of discharged stormwater in heavy rainfalls and relieves the pipes of the drainage system. The planting of non-native trees extends the range of species and diversity within the city.

Rooting volume

- 80 cm
- Raingardens

Planting soil

- Different layers
- Clay content 2-4 wt-%
- Organic matter 4-5 wt-%
- Rock mulch layer retains moisture in planting soil

Filter

- No extra filter
- Filtration layer: soil functions as filter for pollutants

Water interception

- Inlet on streets
- Stormwater retention layer: air void
- Water from sidewalks and streets

Adaption in urban space

- All street hierarchies
- Open space, plazas, sidewalks
- Removable rings for trunk growth

Maintenance

- Removable tree grill: simple cleaning process

Trees

- High diversity (biological and visual) through indigenous species



Fig. 4.20 Water Inlet and removable rings

4.4 Cell/Crate System: Silva Cells in Toronto, Canada

The crate systems are soil boxes or cell structures made of plastic or concrete in different sizes. They can be modularly stacked into each other, connected with spikes and decks, whereby the system can be extended in height and length. The cells are filled with planting soil but not compressed, so that the soil pores can serve as perfect rooting volume for the trees. Depending on the product, the system can provide up to 90% rooting volume underground. A geotextile prevents other materials (e.g. fine particles, construction materials from streets) to enter into the planting soil. The cells and boxes have a high load bearing capacity and can be used in highly frequented traffic areas. Underground utilities can be integrated into the cells, or cells can also be left out to bypass pipes and cables. The cell system can also be applied in raingardens to reach rooting volume and a higher volume for the retention of water (TDAG 2014 p.105ff).

Stormwater can be directed from the streets through inlets at the curb or directly via downspouts from buildings that are connected to the cell system (Deep-

Root 2011b p.3; 6). The inlets and pipe system require regular maintenance and cleaning, with the aim of correctly intercepting stormwater into the tree pit. At the bottom of the system a perforated pipe drains excess water.

There are numerous suppliers of these soil boxes such as *Silva Cells* or *Stratacell*. The costs vary depending on the provider and the used material. The city or a particular specialist by the company should supervise the installation.

Silva Cells are developed and distributed by the company *DeepRoot Green Infrastructure*. They offer detailed information on their website and detailed descriptions for installation and particularly in terms of stormwater interception. The system is based on a 70-85 vol-percent sand (grain size of 0,05-2,0 mm) and 15-30 vol-percent clay and silt (<0,05 mm). There are no parts of stones with a grain size of 2-20 mm or higher (DeepRoot 2013 p.4).

In Toronto, the largest city in Canada, major projects that are based on the cell systems are implemented. To treat

stormwater from public surfaces, the water authority of Toronto (Toronto Water) tested Silva cells in a small project about their effect in the city. Successfully, water could be introduced into the system, retained and also cleaned using a 20 percent water holding capacity of bioretention soil. The implemented system can handle a 100-year rain event (DeepRoot 2014).

As a result numerous projects have been implemented in Toronto. For example, the redesign of Queens quay, a waterfront boulevard in Toronto. On almost 2 km, the entire upper and underground infrastructure was renewed and a new concept for the public space had been developed. About 200 new trees were planted as tree trenches on Silva Cells (Waterfront Toronto 2014). They also use watering bags for initial irrigation (DeepRoot 2011b p.4).

Nevertheless, tree pits as a solution for stormwater management are not mentioned in any guidelines or information provided by the City of Toronto. However, in 2006 the city published the *Wet*

Weather Flow Management Guidelines. It is a general framework for stormwater management throughout the city and also includes the demands of wastewater management. It mentions to plant trees and bushes on own properties and in open space areas. It also illustrates that „vegetation absorbs water, which will reduce the amount of stormwater runoff“ (CT 2006 p.5).

Toronto has a combined sewer system in the main part of the town, which was built before 1960. In 2011, the City of Toronto launched the initiative of the *Mandatory Downspout Disconnection*. All downspouts on buildings shall be disconnected (until December 2016) from the sewer system to mainly infiltrate the stormwater on the own property. This system shall help, to direct less stormwater into the sewer system and prevent flooding of basement and that wastewater flows into lakes and rivers through emergency overflows (CT 2016). Therefore, the already used system of tree pits on Silva Cells could be included into the initiative for stormwater interception.



Fig. 4.21 Queens quay boulevard, Toronto



Fig. 4.22 Proof of concept: Silva Cell installation



Fig. 4.23 Queens quay boulevard, Toronto

Cell/Crate System: Silva Cells in Toronto, Canada

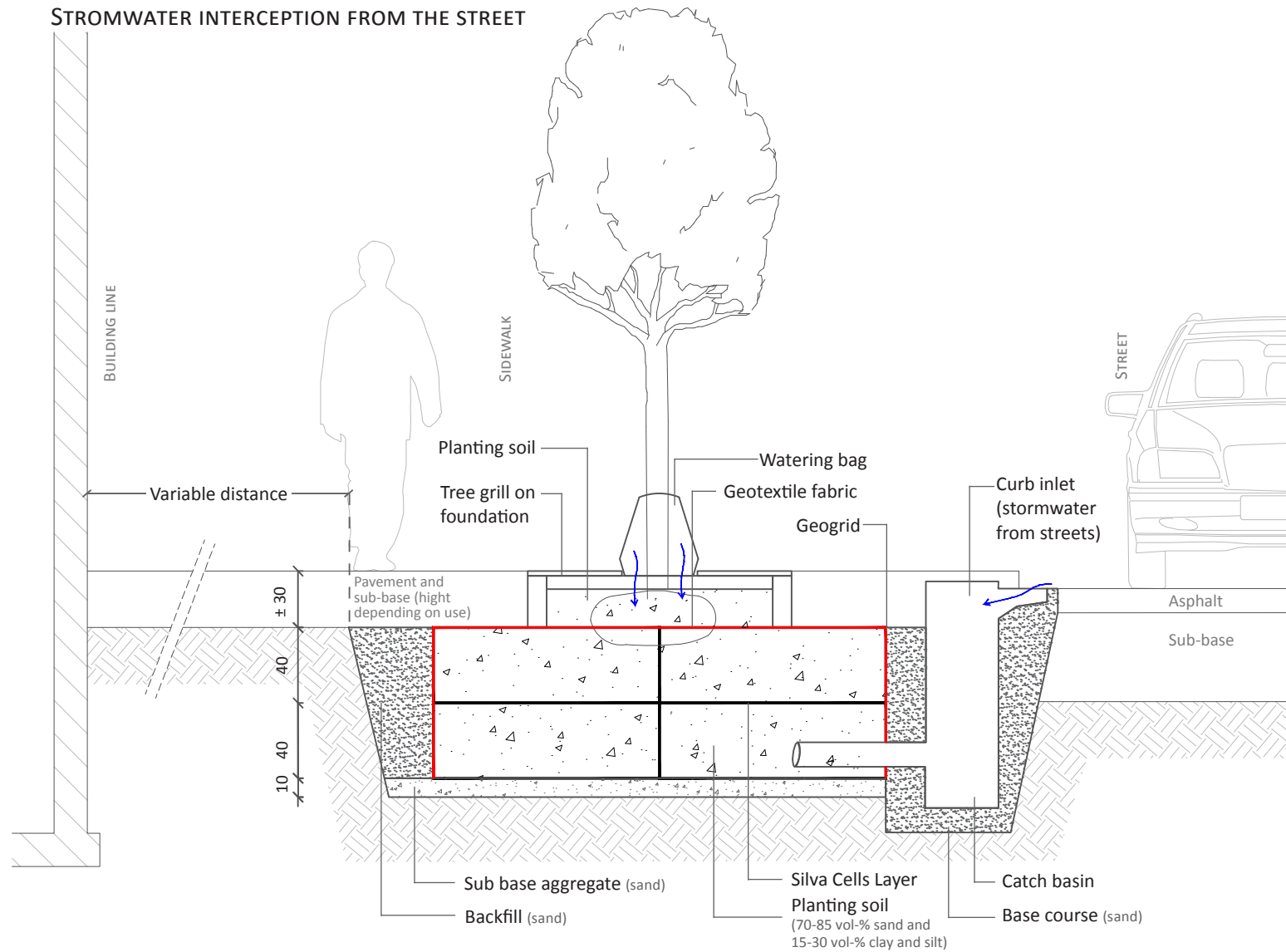


Fig. 4.24 Section of Silva Cells; without scale, units in centimeter

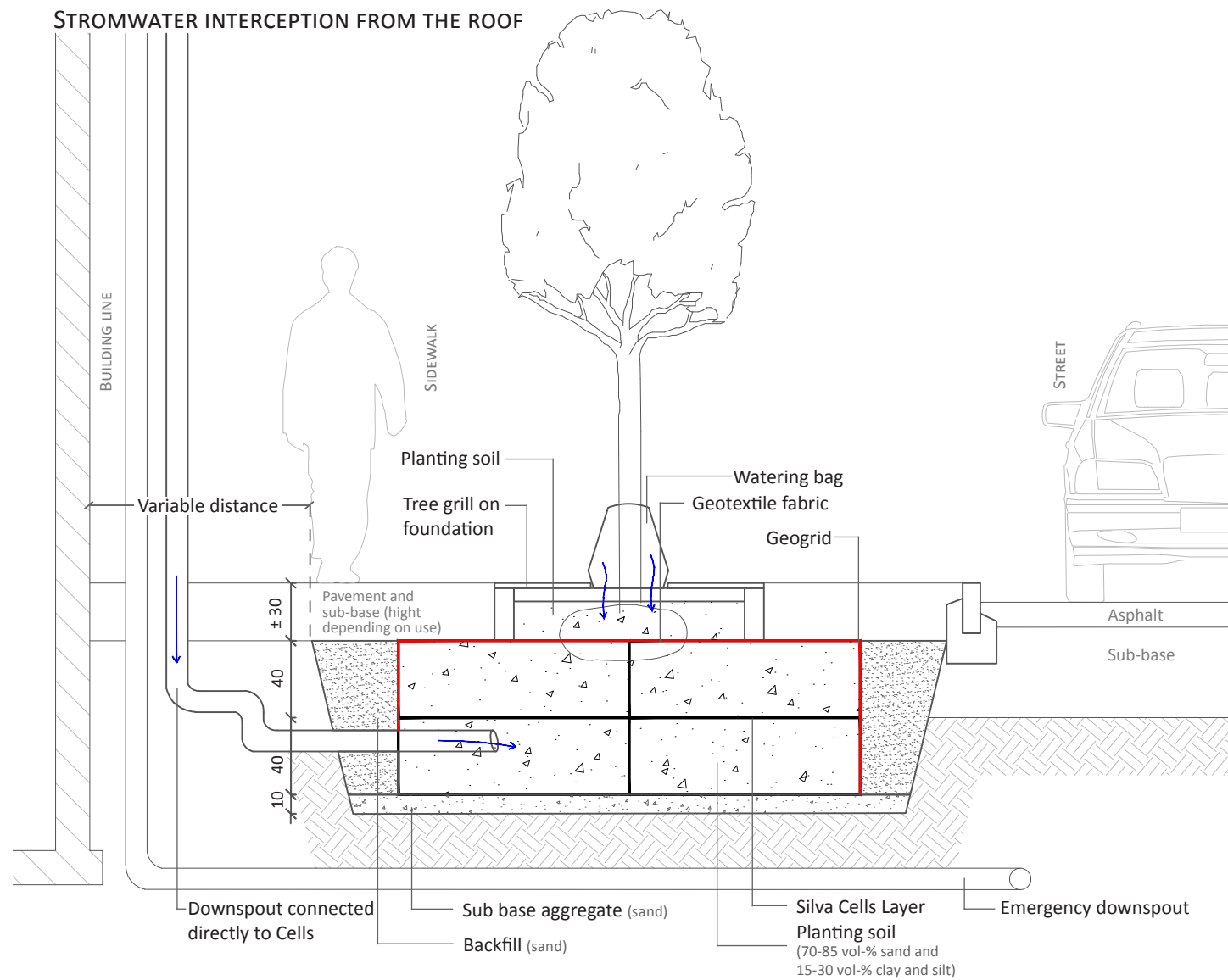


Fig. 4.25 Section Silva Cells in Toronto, Canada; without scale, units in centimeter

Application Criteria

These projects show that even on a large scale, such systems can be used successfully. Through enormous rooting volume in the cell and box structure trees can establish very well and a large amount of stormwater can be intercepted and infiltrated into the ground. It may be questioned, whether these systems, despite their high infiltration capacity can be declared as sustainable due to its materiality. Particularly, the systems of concrete need a large amount of energy to be produced. In addition, it is critical that for the cells more and more plastic is produced and installed into the soil. Re-use and recycling must be considered if such systems are implemented.

Rooting volume

- 40-120 cm
- Trees trenches
- Tree pit under increased under sidewalk and street

Planting soil

- High amount of uncompressed planting soil, 90 %
- Clay and silt (<0.05mm): 15-30 vol-%

Filter

- No extra filter
- Soil functions as filter for pollutants
- Settling tank

Water interception

- Inlet on streets
- Water from roofs, sidewalks and streets
- Watering bag

Adaption in urban space

- All street hierarchies
- Open space, plazas, sidewalks



Fig. 4.26 Construction process of Silva Cells



Fig. 4.27 Silva Cells with planting soil and pipes

4.5 Summary of Implementation criteria

The general conclusion of the analyzed case studies is the importance of trees within the urban development. The individual authorities provide a lot of material about the construction and installation of each system to simplify the implementation.

This shows that urban trees are no longer considered by the municipality only as cost effective urban equipment. The benefits for the cities are much higher. Tree plantings are included as strategies in political guidelines for cooling, infiltration, retention and the green infrastructure network.

A further sustainable step is to integrate specific systems of trees pits into the stormwater management. The discharge of stormwater into the water system could be reduced and urban trees could be watered in a natural way. Thus, the natural water cycle could be closed a little bit more.

Another finding from all case studies is that by connecting individual tree pits to tree trenches creates a more natural en-

vironment by the connection of the roots (compare chapter 2). The tree pit should also be enlarged into the area of the sidewalk and partially under the street to achieve as much rooting volume as possible.

The costs for the construction of these system are mostly more expensive than a regular tree pit. On the other hand, costs can be saved through reducing stormwater in the sewer system and wastewater treatment plants by the interception of stormwater into the tree pit. Furthermore, the benefits increase through large and healthy trees that are not seen as economic value, but as ecological or soft benefit are mentioned in most of the political guidelines of the cities:

- Improvement of air through increased production of oxygen
- Storage of carbon dioxide
- Passive cooling through transpiration
- Amenity value
- Identity for the city
- Cultural and social value

The technical knowledge

Especially from the Stockholm Solution, one of the most important information can be obtained: the gas exchange of the soil. Due to the high percentage of sealed surface in urban areas, a natural gas exchange between soil and the atmosphere is restricted. The solution is the air inlet. The deep level of about half a meter into the rooting zone makes it possible, that the poisoning carbon dioxide can be released.

As long as the air inlet guarantees the gas exchange and water interception the tree base can be completely sealed (pavement or tree grate).

A comparison of the systems demonstrates that the cell system has the highest proportion of uncompressed soil (90 percent), which is the ideal rooting volume and the skeleton system (Stockholm Solution) which provides 40 percent of rooting volume. Compared to the other two systems (sand-based and medium-size particles), the skeleton and cell system are the only two systems, which even contain uncompressed planting soil

because it is not compressed after installation with heavy machines. If roots try to grow in compact soil, they automatically grow superficial under the pavement. There they reach space, oxygen and water. However, root growth can be controlled and directed into deeper soil layers if these resources are supplied in deeper layers.

The only way to provide completely uncompressed planting soil is the use of a load-bearing structure in the tree pit. Besides manufactured elements (e.g. cells), angular crushed rocks achieve a naturally physical load-bearing capacity. The crushed rocks must be homogenous within a small range of size. After compressing, they create a skeleton structure with voids. Compared to the manufactured elements, it is more sustainable to use natural or recycled material (e.g. granite or concrete rocks).

In addition, compressed soil prevents de-icing salt, intercepted by the stormwater, to settle in the dense pores and clogs them. That causes oxygen and water deficiency and prevents the nutrient uptake

of the roots. In large pores within the soil, the de-icing salt is not settled constantly but is flushed out with the stormwater. On the other hand, by the use of filters the de-icing salt can be prevented to enter the tree pit at all.

In all systems it is described that the planting soil operates as a good filter for pollutants. Besides the experiences of the case studies, further studies indicate that stormwater tree pits have high pollution removal rates (CRWA 2009 p.4).

In all systems, the nutrient supply is secured by an initial fertilizing and humus rich soil. But the nutrient content decreases significantly within the first years. In the city of Stockholm biochar has been used successfully for a long-term nutrient and water supply.

An analysis of the existing soil determines the mixture of the planting soil. For example, the clay content must be appropriate for the water holding capacity in correlation of the existing soil to prevent excessive water in the tree pit. In addition a drainage pipe can drain excess water.

Despite the debate about non-indigenous tree species, the cities of the case studies increase the number of planted non-indigenous tree species. These are usually adapted to the rising temperatures and longer dry periods in the city. If different trees are planted in streets, they gain in visual effect and biodiversity. If specific tree species gets infested with pests, the usage of different tree species prevent that an entire street loses its greenery.

Before planning, it is essential to analyze the existing underground utilities. Pipes provide perfect rooting conditions through space, oxygen and water. To prevent root growth into pipes new trees should never be planted above underground facilities unless root growth can be prevented by a geomembrane (root barrier). If constructions on pipes are necessary, roots would get damaged and the tree vitality decreases. In addition during the tree pit construction, unexpected cables and pipes can cause time delays and expensive rescheduling or problems with storage of delivered materials or trees on site.

Civil engineering and maintenance companies of underground facilities should be aware of tree roots during work and should be forced to include and arborist for specific instruction to prevent damage of tree roots. The initiative “dial before you dig” initiated by the City of Melbourne is a good example to locate underground utilities in the city for civil engineer construction companies (CM 2015a p.5).

When a new tree planting is planned, the size of the root ball must be considered, that it corresponds to the size of the tree pit. Larger tree means larger root ball. A subsequent pruning at the construction site to fit the root ball into the already built planting hole has severe consequences to the vitality and the growing conditions of the tree.

It should be achieved to intercept as much stormwater as possible into the tree pit to meet the high water demand of urban trees. Especially in the summer heat a moist soil can be essential for the vitality of the tree. A drainage pipe at the bottom of the system prevents long-term excess

water. The inlet should not be positioned behind (in the direction of the stormwater flow) a connected inlet; otherwise no water would run into the tree.

Continuous irrigation within the first two years is essential. The tree can develop a good root system to anchor itself into the ground and take up sufficient water and nutrients. A watering bag is the most effective and cost-saving type of manual irrigation. In addition the tree should be tied in and be protected by temporary wooden tree stakes. For the long-term solution, a tree guard is the best protection for the stem. The basement of the tree can either be sealed with pavement, or by a tree grate.

All facts and criteria mentioned above must be monitored at all times. Without intense and continuous monitoring, problems will occur during the implementation and construction process. A professional monitoring, evaluation and adaption of processes and materials effects in good growing conditions for urban trees and good vitality from the beginning of the planting.

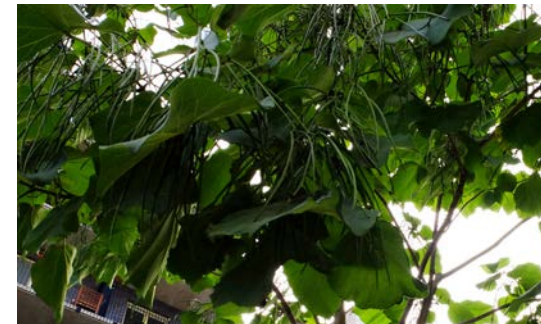


Fig. 4.28 Vital trees in Structural Soil in Stockholm

5 EXISTING CONDITIONS IN THE CITY OF HAMBURG, GERMANY

To specify the general analyzed topics of the previous part of this report, the existing conditions of the City of Hamburg are analyzed in this chapter.

It is clarified, what fundamental parts like materials, soil, water and urban conditions influence the tree (pits) in the City of Hamburg and should be taken into consideration for the development of an *advanced system for urban tree pits*.

Besides the urban conditions such as climate soil and water, the political situation is analyzed to evaluate the need of an advanced system.

In Chapter 5.1 general data is given about the existing trees and their living conditions in the City of Hamburg. The system, which is currently used for tree pits, is displayed and described in detail. The Chapter also includes the political and financial scope with the development for green infrastructure. Chapter 5.2 explains what kind of soils can be found and their effects on urban greenery. The impacts of the climate change specifically for Hamburg is mentioned briefly in chapter 5.3.

The water network and the system including the stormwater management are clarified in chapter 5.4. In the last chapter, the results of the analysis are summed up as implementation criteria.

5.1 Trees: Urban conditions and its effects

Tree stock

Within the history of the City of Hamburg, the number of trees continuously decreased due to urban development and the use of timber as building material (foundation of buildings) for the swampy area of the City of Hamburg. During and after World War 2, trees were destroyed by military attacks and some of the remaining trees were used as firewood during the extremely cold winters in the devastated areas (Vieth 1995 p.21ff).

Today, in 2016 the City of Hamburg owns about 227.000 street trees (FHH 2016h).

On the public website *Geoportal Hamburg*, information can be found of most of the street trees: the specie, planting year, trunk circumference, crown diame-

ter, street name and the responsible borough (FHH 2016c).

The internal database of trees of the district offices offers a variety of additional information. The system has been supplemented with information on the location. For example in 2016, it has been included, if and why a location is not suitable for new tree plantings. Based on this method, these locations are not displayed as a missing tree, but as an unsuitable location, where none tree planting is considered anymore (Drießelmann 2016).

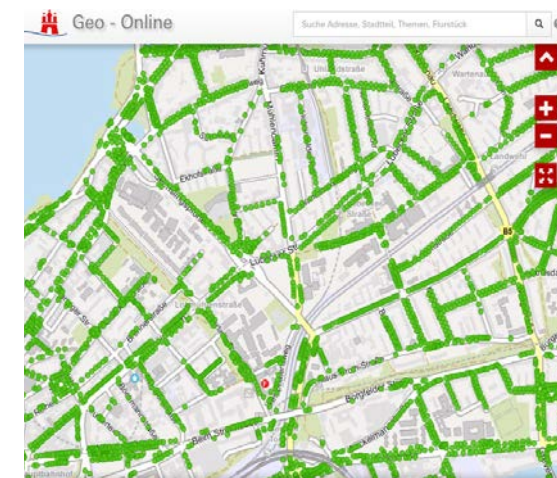


Fig. 5.01 Street Tree online data map

The most common tree species of street trees are *Tilia* (lime), *Quercus* (oak) and *Acer* (maple). Furthermore, there are species like *Carpinus* (hornbeam), *Betula* (birch), *Sorbus* (whitebeam), *Fraxinus* (ash), *Aesculus* (horse chestnut) and *Robinia* (locust tree) (FHH 2016a). There are also non-typical street trees species, which were already planted over 40 years ago and are still growing in very extreme condition. These species are also among the current species selection for adapted street trees (FHH 2016c):

- *Ginkgo* (*Ginkgo*) Luisenweg, planted in 1987/1992/2009 ,
- *Corylus Columna* (Turkish hazel) Döhnerstraße, planted in 1970er/2005,
- *Amelanchier lamarckii* (Juneberry), Große Brunnenstraße, planted in 1986,

Hamburg also has many old trees, particularly in the historical districts of Blankenese, Rotherbaum, Uhlenhorst, Eppendorf and Harvestehude. Beside park trees, also street trees that were planted over 150 years ago are still growing in the dense urban area (FHH 2016a).

- *Platanus acerifolia* (London plane), year of planting. 1865, Loogestieg/Loogestraße
- *Ulmus laevis* (European White Elm), 1894, Kiebitzhof 5
- *Aesculus hippocastanum* (horse-chestnut), 1865, Karlstraße 26
- *Platanus acerifolia* (London plane), 1910, Secshlingspforte
- *Quercus robur* (pedunculate oak) 1891, Heinrich-Barth-Straße 28 (FHH 2016c)

As already mentioned, urban trees grow under tough conditions in urban environments. The same situation can be observed in the City of Hamburg. However, the overall vitality of Hamburg's trees is good (Drießelmann 2016; Wahli, Kahle, and Geiger 2016).

An increasing problem is the spread of pests: The spread of the oak processionary (*Thaumetopoea processionea*), ermine moths (*Yponomeutidae*) and horse chestnut leaf miner (*Cameraria ohridella*) can also be seen in the city of Hamburg. Favored by the climate change, urban trees are particularly vulnerable, since

they are already exposed to a number of stress factors (GALK 2016b).

Urban Development

The general influences on urban trees described in Section 2.2.2 also occur in the City of Hamburg.

Sometimes, a tree is too weak to withstand this urban pressure and must be removed due to safety reasons. The growing conditions for urban trees are declining with the growth of the city and the continuous urban development of infrastructures.

Since 2014, the housing program of Hamburg is implemented (BUE 2014 p.22f). Unused areas are revitalized and built-up. With this process of urban compaction the sealing of surfaces is increasing enormously. Over the years, trees have been able to grow undisturbed within these areas. Within the present situation however, they must be removed for political and social important projects. In addition, the necessary infrastructure is being developed further and expanded. As a consequence the list of tree felling is

extended continuously (FHH 2016g; FHH 2015d).

In 2014 the BUND (the German Federation for Environment and Nature Conservation) published a report, which stated that besides Berlin also Hamburg has a high loss of urban trees. Not only park trees are felled but also street trees with up to 1.000 trees per year. In total, this number of missing trees is not getting replaced by new trees (BUND 2014).

On the other hand, urban development and tree felling always create opportunities for new tree plantings and advanced tree pits for improved growing conditions. However, new plantings must be involved early in the planning process of new developments to provide enough space and good initial conditions for the tree.



Fig. 5.02 Excavation around tree roots



Fig. 5.03 Construction excavation around root ball



Fig. 5.04 Tree roots lifting pavement



Fig. 5.05 Stem damage through cars and bicycles



Fig. 5.06 Failed new tree planting



Compensation planting

In the City of Hamburg replacement plantings are required based on the Tree preservation order of Hamburg (BaumschutzVO § 1) and the Federal Act for the Protection of Nature (BNatSchG§ 29). It is crucial that the “destroyed values and functions of the ecosystem or the natural and urban landscape are restored respecting the local conditions” (FHH 2015b p.17).

To determine the quality and quantity of replacement plantings, there is a data collection form based on a point system (FHH 2015b) attachment 1, p.35ff). The basis on the calculation is the value of the felled tree (tree species, size, health, urban and landscape). The replacement planting also requires the maintenance of development of the first year after planting. In many cases, a replacement planting, which is equal in quantity to the number of felled trees, is not possible due to the lack of space. It is ecologically not reasonable to plant trees too close to each other only to compensate the felled trees on a smaller area. They would compete for rooting space, nutrients, water, sun-

light and space above the surface which results in reduced growth and function (Wahli, Kahle, and Geiger 2016). In such cases a substitute payment is required. The substitute payment is based on the costs of the calculated number of replacement trees. The substitute payments are determined to the Department of Urban Green of the respective District Offices of each borough (FHH 2015b p.18).

For new plantings in the City of Hamburg the use of watering bags for slow release irrigation have already been used in a few locations, for example in the street Ericuspromenade (Gelditsia spec.: locust) in Hafencity.

By detailed analysis of the individual list of street tree felling by the district offices it is striking that more than half of the sites are no longer suitable for new plantings, since the space condition is confined due to the remaining large trees. The replacement tree is planted elsewhere or the substitute payments are invested into the maintenance of the tree stock (FHH 2016g).

In general, the decreasing areas for trees, especially street trees should be minimized. However, if continuously less new trees are planted, the City of Hamburg should invest more in advanced systems of tree pits to provide better growing conditions for new trees and to achieve a higher benefit from the investment.



Fig. 5.07 Watering bags in Ericuspromenade

The current system for tree pits in Hamburg

Based on the interview with Uwe Drießelmann of the roadside greenery in the borough of Wandsbek the system which is currently used in Hamburg can be described in detail in the following paragraph.

The tree pits are installed as large as possible. Usually, there is only a width of 1.00 m available for the tree pit due to underground utilities, parking lots and the street. If a new tree pit is limited in the width, it is then installed with a length as far as possible along the street.

The depth is between 1.00 to 1.50 m. The structure is a two-layer construction with a substrate mixture according to the guideline FLL-part 2 (sand, clay, gravel and topsoil) (FFLL 2010). Some of the district authorities used to have their own substrate mixed according to the requirements. Nowadays however, this process is too time-consuming and external companies provide the substrates. Deep aeration and mechanical irrigation are already integrated as a standard in the tendering of the districts. The tendering is based on the usual specific standards (FLL and DIN, see chapter 2). There are no further requirements given by the districts (Drießelmann 2016).

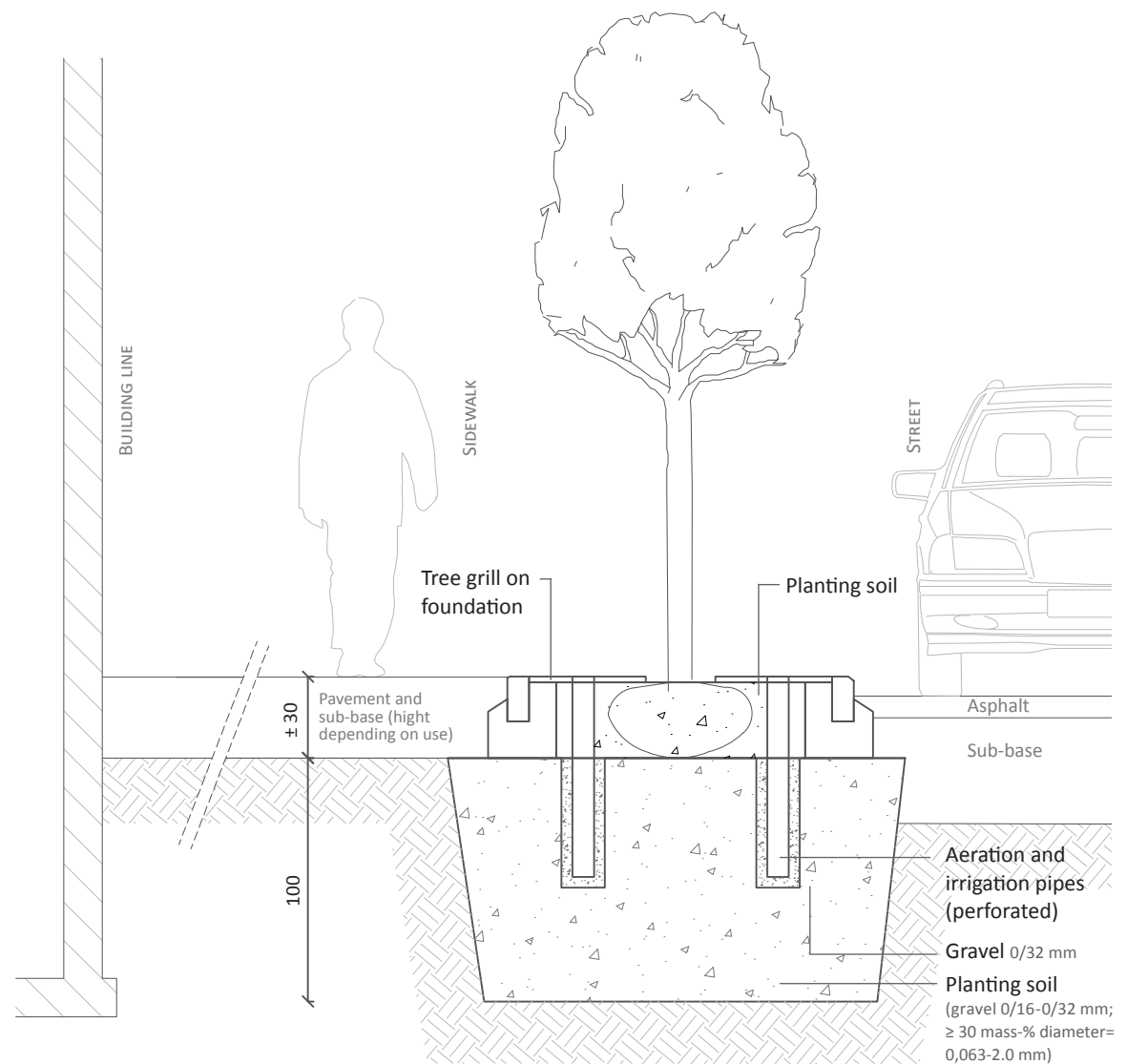


Fig. 5.08 Section of FLL-System; without scale, units in centimeter

Tree planning process

The usual circumference of the trunk of new trees is 18-20 cm. At certain construction projects larger circumferences of 20-25 cm have already been planted. However, in this case, the problem occurred that the root balls did not fit into the tree pits, because of limited space and missing primary planning.

The Department of roadside greenery of the respective district offices are either performers as planners or participants as consultants for a project of new street trees. As performers the office itself plans and manages the entire project, which also includes the selection of tree species, the design of the location and the tendering. As participants, they are called upon for advices where additional specialist planners such as Landscape Architects or Open Space Planners are responsible for the technical and creative planning including tendering and execution of the project (Drießelmann 2016).

Every time new trees are planned, a list with the proposed tree species must be noted and discussed to by District Assem-

bly (political level of the boroughs). The district offices are trying to select a high variety of different species. Also, non-indigenous tree species are included in the planning which sometimes ends up in a political discussion.

Usually, it needs to be pointed out that native species are becoming less suitable for urban environments due to infection by pests or the increasing effects of climate change. The list of suitable native species is becoming shorter. In the end non-native species, which have been proven already in the past, are already planted in Hamburg and will further be in the future (Drießelmann 2016).

Hamburg's political position

In various studies, research reports and the different political visions of the City of Hamburg the importance of green infrastructure within the city is clarified. Through a green network and street trees, urban areas can be reconnected to nature. The reports also conclude that trees contribute to biodiversity within the city, by creating habitat for small and large organisms (FHH 2006a; FHH 2015c;

KLIMZUG-NORD 2014; FHH 2014a; Grüne Stadt 2012). In the current vision *Green, inclusive, growing city by the water: perspectives on urban development in Hamburg* the initiative *My tree- my city* (Mein Baum- Meine Stadt) is considered as a success and will be continued (FHH 2014a p. 24). Since 2011, individuals, companies, associations or schools can donate money to support the planting of new street trees. For this purpose, there is a map available online where a numerous unplanted sites (red trees) are visible (FHH 2012).

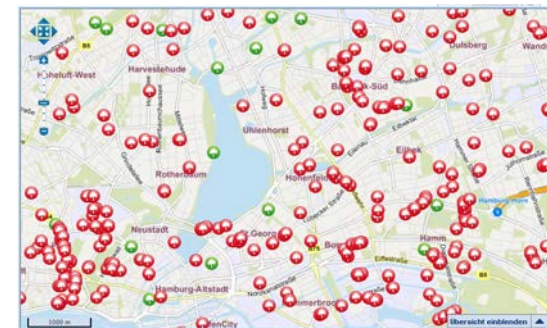


Fig. 5.09 Map of "MeinBaum-MeineStadt"

In the report *KLIMZUG NORD - Strategic adaptation approaches to climate change in the Hamburg Metropolitan Region* published by the city of Hamburg in 2014, green infrastructure and urban trees are

mentioned as important factors, which have a positive impact of the urban ecology (KLIMZUG-NORD 2014 p.35).

Financial scope and investments

According to the *Special investment program 2013/2014* an increasing investment of 1.3 million is set for the initiative *My Tree- my city*, which also includes the maintenance during the first three years after planting for establishing and developing of the tree (FHH 2014b).

The City of Hamburg is investing more in urban greenery, especially in street trees. *More money for street trees* was the headline of the website of the City of Hamburg in March 2016. In 2016, the Ministry of Environment and Energy of the city of Hamburg (BUE) provides up to 1.5 million Euro (2015: EUR 500,000) for new plantings of street trees (FHH 2016f).

Due to high substitute payments from large construction sites, there is enough money available for new plantings of street trees (Drießelmann 2016). Nevertheless, already this year (2016) the Senate of the District Assembly Harburg pro-

posed to contribute another 1.5 million for all districts for new plantings within the roadside greenery (FHH 2016e).

Due to the growing urgency in terms of climate change and the associated plantings of street trees, it can be assumed that the city of Hamburg provides further financial support for the green infrastructure and street trees.

5.2 Urban soil conditions

Anthropogenic soils

Within the urban area in Hamburg, in the upper soil horizons there are no more natural grown soils to be found. During excavations, mainly artificial soils with anthropogenic landfills can be analyzed. There are a high variety of different types of soils, which form a small-scale and heterogeneous urban ground. Due to the large number of underground utilities, the soil is mixed with a lot of sand beds, which serve as a material for pipe bedding. Through permanent sites in streets and housing construction, large amounts of soil are excavated, removed and installed elsewhere (Wiesner et al. 2016; Titel 2016).



Fig. 5.10 Bore-hole: Anthropogenic soils

Within the layers of the urban soil, there is a lot of debris of war damage like bricks, crushed concrete or industrial soil (residues). Crushed material, particularly concrete and also whole bricks increase the structure of the soil. By leaching carbon compounds off the mineral residues (concrete and bricks), the soil has a higher pH value (alkaline) as a naturally grown soil (Lehmann and Stahr 2007 p.294).

Soil Hydrology

The existing soil types and external influences determine the water balance. Soil properties are decisive for the long-term soil hydrology. Short-term effects occur through the infiltration of stormwater and existing vegetation (Wiesner et al. 2016 sect.5).

The water table is generally high in Hamburg. On the website of the Geoportal Hamburg a map exists with daily updating information about the water table. The highest groundwater levels are expected especially in the months of February to June. The level varies depending on the amount of precipitation in the winter months (November to April) (FHH 2016i).

In construction projects, there are often short-term water table drawdowns, which can lead to low soil moisture. Therefore, it must be ensured that the process of drawdown is proceed in accordance to the surrounding vegetation (FHH 2015f p.3).

Due to the differences in soil and soil hydrology on a small scale, the selected locations for new tree plantings should always be analyzed in detail to determine the correct properties of the tree pits.

Infiltration

In general, infiltration of stormwater in Hamburg is possible. The Geoportal Hamburg provides a map that shows where infiltration is possible (infiltration potential map) (FHH 2016d). The potential is divided into four categories: possible, most likely, limited and unlikely displayed in colors from green to red. The infiltration capacity mainly depends on the soil composition and on level of the groundwater. In addition, the archive of bore-holes provided online by the city of Hamburg serves as a further basis for the analysis of soil types (FHH 2016b).

Numerous projects have been successfully implemented. Even at sites where the infiltration capacity was limited according to the infiltration potential map (FHH 2015e p.108). It shows, that this map serves as a good basis but individual locations must be analyzed more detailed to proof the infiltration capacity and to implement the suitable infiltration method.

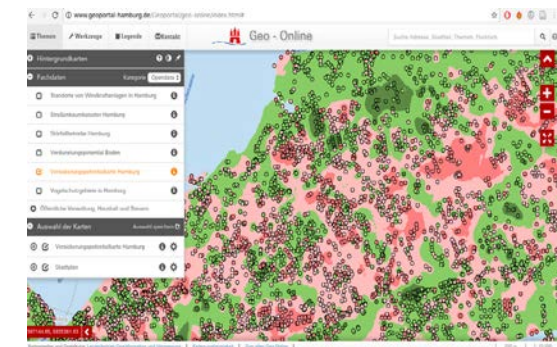


Fig. 5.11 Infiltration potential map (FHH 2016d)

5.3 Climate change

Climate change is a global phenomenon and it also affects the city of Hamburg. Numerous reports clarify that climate change must be considered as a regional phenomenon. Therefore, the change of the weather for the City of Hamburg must be analyzed and evaluated locally.

The analyzed results of climate change from Section 2.2.2 can be transferred to Hamburg. Different forecasts for Hamburg indicate an increase in temperature and especially an increase of days with heavy rain events (Meinke and Klepgen 2016; RKB 2016).

These changes also have a significant impact on the street trees. With the increasing summer drought, the vitality of street trees is continuously impaired. It infers a high maintenance effort with intensive cost (KLIMZUG-NORD 2014 p.34f).

CLIMATE INDICATORS: HAMBURG, GERMANY

Rainfall	
Annual:	650 mm
January: Ø monthly lowest:	46 mm
August: Ø monthly highest:	77 mm
Temperatures	
January: Ø monthly lowest:	17°C
July: Ø monthly highest:	- 3°C

(DWD 2016)

5.4 Stormwater system and sustainable strategies

In the City of Hamburg, the group *HAMBURG WASSER* combines the supply of drinking water by the company *Hamburger Wasserwerke GmbH (HWW)* and the sewage disposal by the company *Hamburg Water (HSE)*. In the more historical areas of the city of Hamburg (e.g. downtown, the boroughs of Altona and Bergedorf) the sewer system works as a combined sewer system. In the remaining districts, the stormwater is discharged in separate systems (HW 2016d).

The main line of sewer, storm and drinking water pipes, including district heating are lying in the streets. The supply lines to the buildings go through the sidewalks, parking strips or tree pits. Within the sidewalk, there are cables for electric and communication services. In Hamburg, there are no clearly defined pipeline routes which combine the entire underground utilities (Drießelmann 2016).

Service fee

Sewage and stormwater fees are combined in the use of water/stormwater pipes (*Sielbenutzungsgebühr*). In 2012, the city of Hamburg released the *split*

wastewater fee (*Gesplittete Abwassergebühr*). That means that the discharged stormwater is not charged together with wastewater anymore. The amount of wastewater (2.09 € / m³) is determined by the quantity of consumed drinking water. The fee for stormwater is calculated according to the sealed surface of the property in m² (e.g. roof, parking area), which is 0.73 €/m²/year (HW 2016a).

By this system of split fees, the city of Hamburg tries to create a financial incentive to avoid sealing of surfaces, especially on private properties. The main target is to reduce the amount of stormwater being discharged from sealed surfaces and the overloads the sewer system. The reduction of the fees is calculated by differentiated tables by Hamburg Wasser based on different types of surfaces. Thus, the decentralized treatment like retention and infiltration of stormwater is supported. Due to financial reasons, the city wants to include the citizens into the process of decentralized stormwater management. (HW 2016b).

Decentralized Stormwater Management

In 2016, there are 1,685 stormwater outlets into surface waters, 145 overflow outlets for mixed water and 72 emergency overflows for sewage water (HW 2016d).

Particularly, the overflow of mixed water and sewage water cause immense hydraulic and ecological problems of the water bodies, which results in a decreasing water quality and biodiversity (compare Chapter 3).

Since the 90s, many projects evolved in the City of Hamburg (FHH 2015e p.41) which reduce the overflow of combined water systems by using mixed water retention basins and retention shafts renovation of transport Pipes. The main target is to improve the hydraulic property of water bodies (FHH 2015e p.9).

Besides decentralized stormwater management, the City of Hamburg is working on strategies of the *Water Sensitive Urban Development (WSUD)*. In addition to the economic treatment of stormwater,

WSUD integrates the architectural design and the ecological value into the urban development (FHH 2015e p.44). It means that rainwater should not only be treated but can also be used to design the urban space.

In 2015, the city of Hamburg published the *Guidelines for water sensitive Design of street areas*. They provide information and design strategies for the integration of decentralized stormwater management within the road space. Specifically street trees are pointed to intercept stormwater into the tree pit for retention and infiltration (FHH 2015a Section 3-9;4-2).

In 2015, the *RISA Structural Plan of stormwater* was published by the cooperative project of Hamburg Wasser (HW) and the Ministry of Environment and Energy of the city of Hamburg (BUE). It serves as a “planning and decision-making basis for a sustainable and modern urban development in the Hamburg Metropolitan Region” (FHH 2015e).

Based on the integrated stormwater management urban planning shall be performed interdisciplinary and include all stakeholders of the water management, urban, landscape and traffic planning in order to develop sustainable cities and water bodies of high quality (FHH 2015e p.7). Top priority is to achieve a natural water balance. Individual strategies and recommendations for the city of Hamburg are described in the dissertation of Elke Kruse as well as in the already mentioned *Guidelines for water sensitive Design of street space*. Street trees are pointed out as a specific solution for the green network to infiltrate stormwater into the tree pit (FHH 2015a; Kruse 2014 p.181).

The report of KLIMZUG likewise recommends to create additional natural green area, to re-open sealed surfaces and to increase the size of the tree base of street trees to promote decentralized infiltration of rainwater (KLIMZUG-NORD 2014 p.35).

5.5 Implementation criteria

With the beginning of the planning process of new street trees, the most important fact is that each location is analyzed in detail. Numerous factors influence each location in different ways and therefore have varying properties: soil types and anthropogenic structures. Since natural soils are no longer present in the City of Hamburg, it is particularly important to establish an advanced system of tree pits, which provides natural growing condition. The specific mixture of the planting soil must be adapted according to root volume, nutrients and microorganisms to the influence of each location.

Through the increasing development of infrastructure and heavy traffic in Hamburg, (hereby especially heavy-duty traffic) the bulk density (level of compression) of the soil is influenced. By mechanical forces (e.g. heavy construction machines, traffic) the soil is compacted and loses its technical vegetation characteristics (Lehmann and Stahr 2007 p.250).

A high groundwater level can display a good accessibility of water for the roots,

but on the other hand, a high risk of waterlogging in the tree pit exists. A constant low groundwater table provides more uniform conditions with respect to the soil moistures (Wiesner et al. 2016) Section 4.1). The infiltration capacity of the existing and the new planting soil must also correspond with each other. According to the groundwater level, the composition of the tree pit must provide constant water properties.

Within the project RISA a digitally available basis is to be created, which illustrates the potential contamination of rainwater of each street in the city of Hamburg. On the basis of a city map the pollutant content can be determined and required treatment for the infiltration of stormwater can be defined.

The climatic conditions demonstrate that decentralized stormwater management is one of the most important programs due to increased heavy rain events to minimize overloading of the pipe systems and to prevent uncontrolled flooding. A general master plan for urban street trees should be developed to include their con-

tribution to stormwater management.

To conclude, particularly important insights can be derived from the analysis of the existing condition: The City of Hamburg points out the significance of the street trees within the green network in the political visions and the urban development. Besides the financial basis through continuously higher investments, the street trees are becoming part of urban strategies to improve the microclimate.

In addition to economical aspects, decentralized stormwater management has an even higher priority in terms of ecological value for the City of Hamburg. The overflows of the urban water systems due to increasing heavy rainfalls (climate change) must be reduced to improve the quality of water bodies. Therefore, stormwater should be handled decentralized.

These values should be used as a chance and opportunity to develop an *advanced system of urban tree pits*, which meets the requirements of the City of Hamburg and make it part of the decentralized water management.

6 ADVANCED URBAN TREES

The entire research and analysis of this report demonstrate the importance of the topic of *Green infrastructure* worldwide and in the City of Hamburg. In terms of climate change and urban development, so far, also the City of Hamburg has been developing new strategies. Implementation in terms of involved stakeholders can often be difficult and time-consuming. Despite of an intensive planning process, interdisciplinary strategies support in particular the ecological value in addition to the economic and aesthetic factor of the city.

In cities, trees should be planted not only to create quantity. It requires an intensive considering of conditions and requirements to create quality. Park and street trees should be treated like a building, which needs a good foundation for all the years of its existence and to keep up with its demands that it can provide benefits for its users. The tree pit is the foundation for a tree.

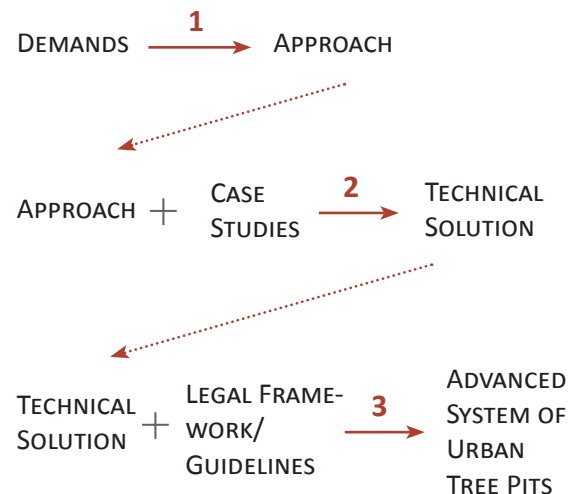
With the understanding of the materials and the construction process, suitable conditions can be created. If the different

existing urban conditions are included into the approach, the advanced system can start to be developed, evaluated and implemented.

Therefore, the implementation criteria of each chapter provide the concluded information. They will be displayed in the following sections as figures.

6.1 The approach and development of the advanced system

The **advanced system of urban tree pits** is developed in three steps:



Step 1: DEMANDS $\xrightarrow{1}$ APPROACH

The first bases for the development of the advanced system are the *demands* of all three components: *trees (green)*, *urban environment (red)* and *decentralized stormwater management (blue)* summarized in the implementation criteria in Chapter 2 and 3. The approaches are defined to meet the demands more practically. In the end, the demands are combined and form a clear structure.

The space of each of the three components is defined clearly and secured, above the surface. The natural resources must be protected, in particular the groundwater, vegetation and the overall soil properties through the removal of pollutants of the intercepted stormwater. Likewise, the adjacent facilities such as buildings and underground utilities must be protected by natural pressure (water and root penetration). Moreover, natural resources especially water must be available sufficiently to the system. Therefore the surface stormwater is drained and intercepted into the system, which also ensures a safe living space for humans (flood protection). In addition, a suitable surface is installed to meet the

requirements of urban use (e.g. traffic, pedestrians and bicycles) and stormwater treatment (runoff) and the vegetation (soil protection). A load-bearing structure takes up forces from the surfaces

and a suitable uncompact soil mixture provides volume of pores for vegetation and stormwater treatment. More natural condition can be achieved by connected systems according to vegetation growing

conditions (soil fungi) and water cycle (distribution of stormwater). Furthermore, the entire system is based on the adaption of urban space to the change of the climate.

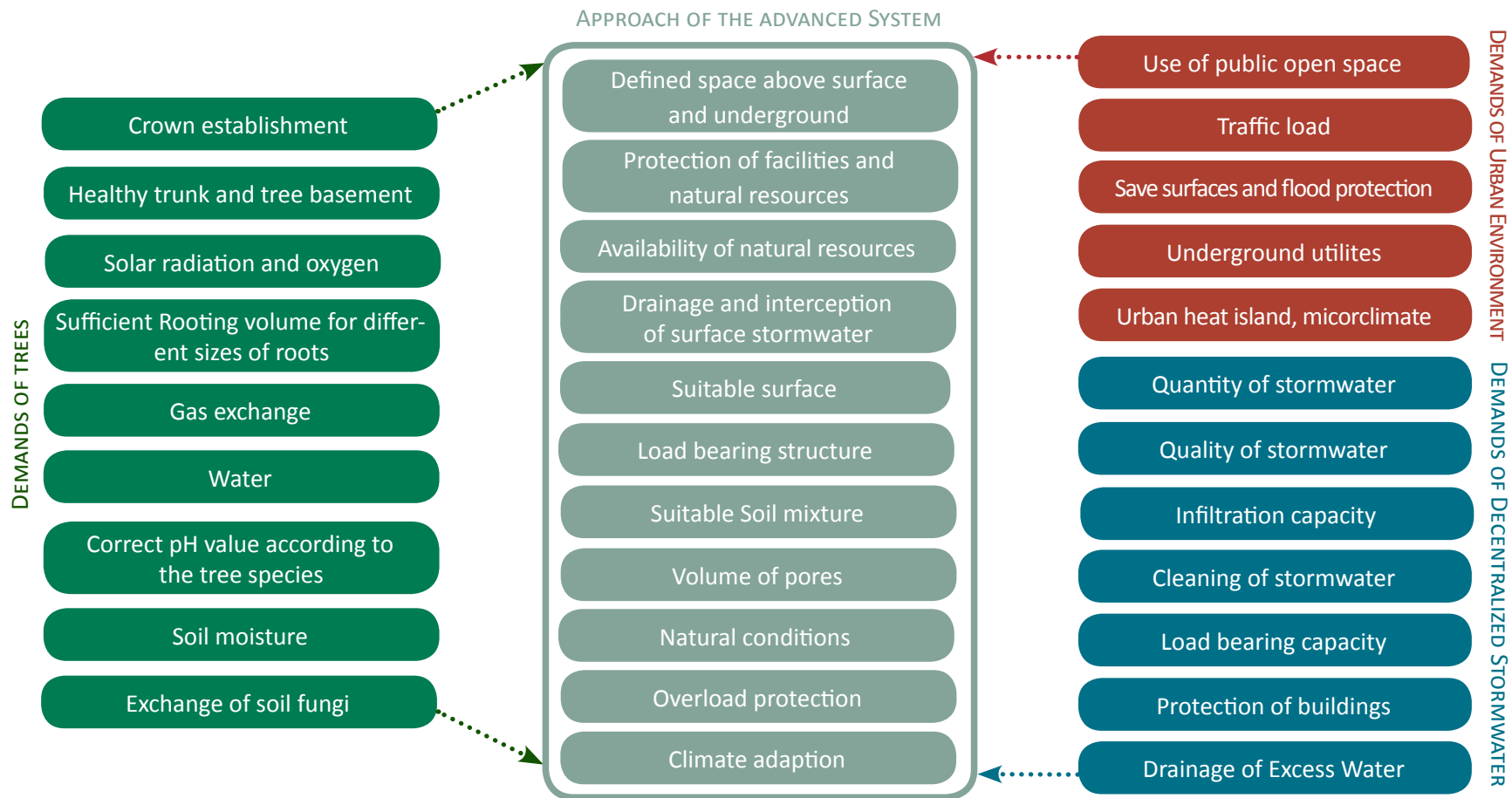


Fig. 6.01 Approach of the advanced system: Step 1

Step 2: APPROACH + CASE STUDIES ² → TECHNICAL SOLUTION

The approaches serve as the first practical concept of the advanced system. For the second step, the implementation criteria of the analyzed systems in the case studies of Chapter 4 including the currently used system in Hamburg/ Germany of Chapter 5 are involved. These selected components of the systems are transferred to the approaches of step one. As a result technical solutions can be defined, which partly have already been implemented by the international case studies (detailed selection see Appendix Section 8.1).

The main components of the technical solutions are based on the Stockholm Solution devised by the City of Stockholm. One of the key finding is the gas exchange of the soil with the atmosphere, which can be provided by a simple construction. The same component also serves for the stormwater interception, either of the sidewalk or the street, which is also used in the systems of the Raingarden Tree Pits by the City of Melbourne and the CU-Structural soil in New York City.

A direct connection to the system via pipes can be installed as shown in the

Silva Cells by the city of Toronto. A similar system of vertical aeration is used in the German System (FLL), which reaches an even deeper rooting volume of 1,50 m. The horizontal aeration is ensured by voids in the aerated bearing layer protected of debris by a geotextile (Stockholm Solution).

The other key finding from the Stockholm Solution, is the availability of rooting volume by a location-specific mixture of uncompact soil, which can take up (storm) water and work as a biological and chemical processor. The structural soil with the defined rock sizes forms a skeleton structure (angular crushed rock) that provides voids for the uncompact planting soil. The structural soil is highly compacted and prevents from further compaction through to urban use. Therefore the installed uncompact planting soil will not be compressed after implementation.

The air void *layer* is included from the system of Raingarden Tree Pits. However, in the advanced system, it does not serve as stormwater retention but for accumulation of dust and debris.

In addition the Raingarden Tree Pits, (partially) the German System and the Stockholm Solution install their tree pits as tree trench to connect the rooting volumes with each other.

To simplify the initial irrigation (two years), the Stockholm Solution and the Silva Cells suggest the use of watering bags. A concrete bunker prevents from superficial roots. To protect underground utilities from root penetration, the Stockholm Solution and the Silva Cells use geomembranes as a root barrier.

All four case studies enlarge the tree pit under the sidewalk and the street. Furthermore, a drainage pipe is installed at the bottom of the systems to prevent an overload of the system and to drain excess water. To protect the upper part of the tree, every system includes a tree grate and most of the a tree grate.

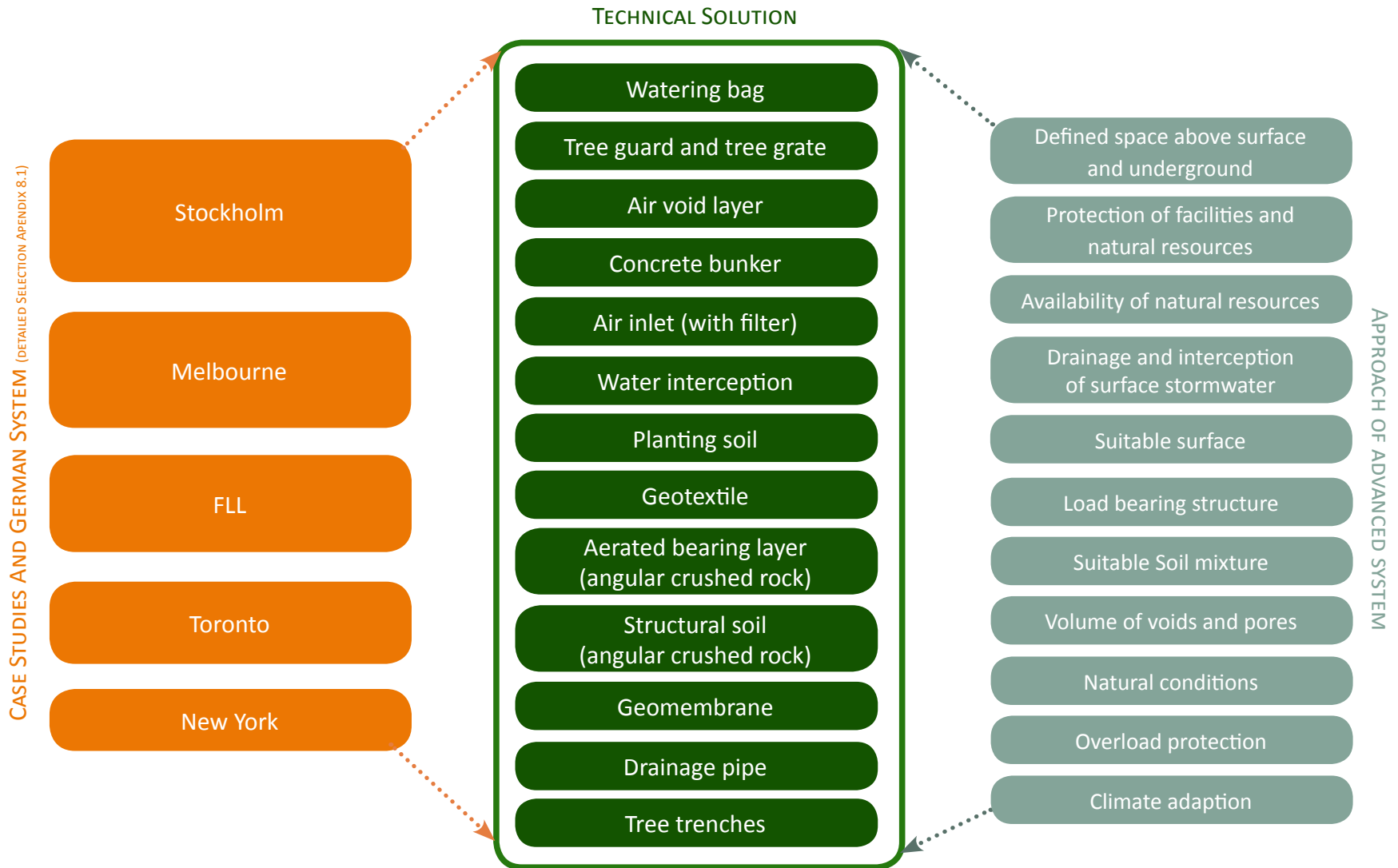


Fig. 6.02 Approach of the advanced system: Step 2

Step 3: TECHNICAL SOLUTION + LEGAL FRAMEWORK/ GUIDELINES ³ → ADVANCED SYSTEM OF URBAN TREE PITS

The implementation criteria of Chapter 5 demonstrate the small-scale condition of urban environments (e.g. soil, water table and building structure) like analyzed for the City of Hamburg. As already mentioned, the conditions and properties of each location must be analyzed and evaluated individually to adapt the advanced system specifically to each location.

The third step consolidates the technical solution on the given legal framework and guidelines summarized in the implementation criteria of Chapter 2 and 3.

Top priority for the advanced system is to protect the soil, the groundwater (Federal Soil Protection Act) and the water bodies (EU Water Framework Directive).

Therefore, the intercepted stormwater must be treated to remove pollutants. Besides infiltrating stormwater through a biological active soil horizon, different kind of filters must be installed in the air inlet (Water Act, Hamburg Sewage Act, Stormwater Infiltration Regulation, DWA-A 138, DWA-A 153, FGSV 514, FGSV 548)

The planting soil of the advanced system serves for the physical, chemical and biological processes and has to have a specific mixture of different soil types to meet the requirements of water holding capacity, nutrients availability, infiltration and retention capacity. Therefore, the size of the tree pit has to be calculated according to the collection area (type of surface) and the amount of intercepted stormwater (DWA-A 138, FLL 2004, FGSV 950, DIN 18916).

The treatment of both *materials* the soil and the tree, must be carried out in consideration to protect their individual properties (DIN 18915, FLL 2010, FLL 2015)

The level load bearing capacity of the urban use (compaction of structural soil) is determined by the use of the surfaces (FGSV RSTO 499, PLAST).

The surfaces of the tree and the adjacent area should be installed according to the urban use and also protected to ensure safety (FLL 2010, FGSV 2006).

Furthermore, the adjacent buildings and underground facilities must be protected as well against roots and water penetration by the distance to the advanced system, geomembranes and concrete bunkers (DWA-A 138, FGSV, 939, FGSV 950).

This is the last step of the development, which finalizes the **advanced system of urban tree pits**. The following figures (6.04-6.07) show the detailed technical drawings of the advanced system and the specific materials.

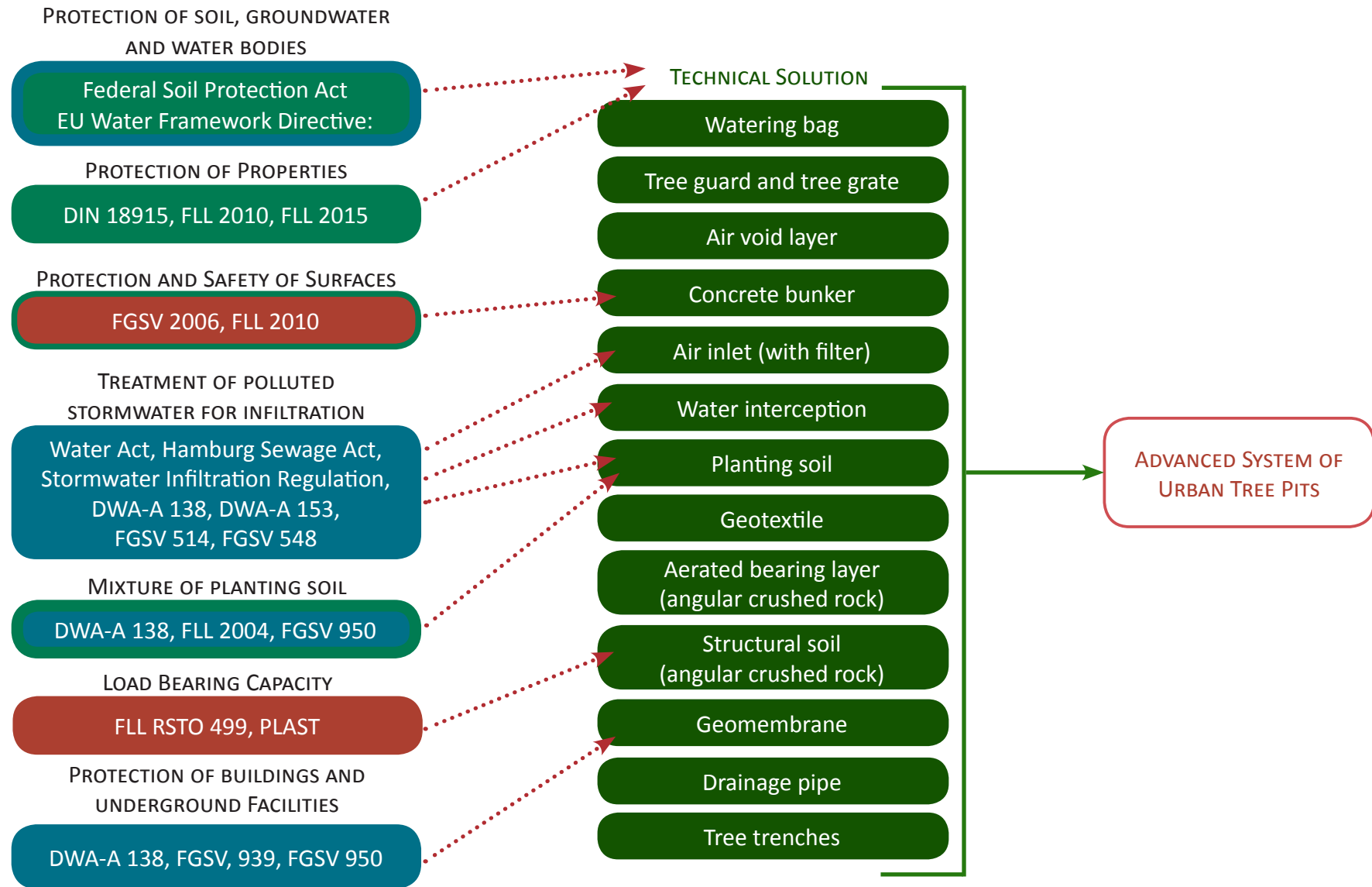


Fig. 6.03 Approach of the advanced system: Step 3

Advanced system of urban tree pit

STORMWATER INTERCEPTION FROM ROOFS AND SIDEWALK

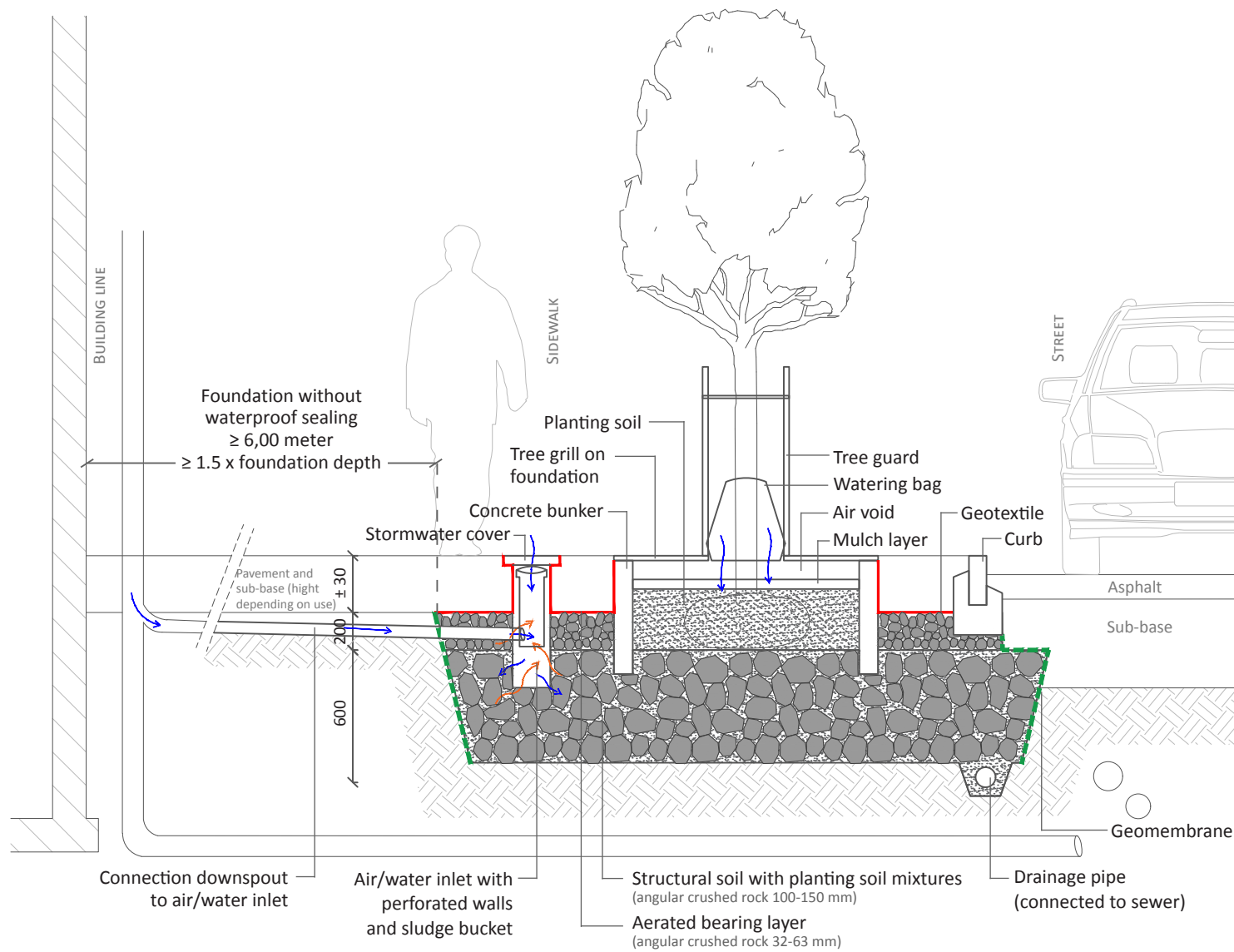


Fig. 6.04 Section of the advanced system of urban tree pits: water interception from the roof and sidewalk; without scale, units in centimeter

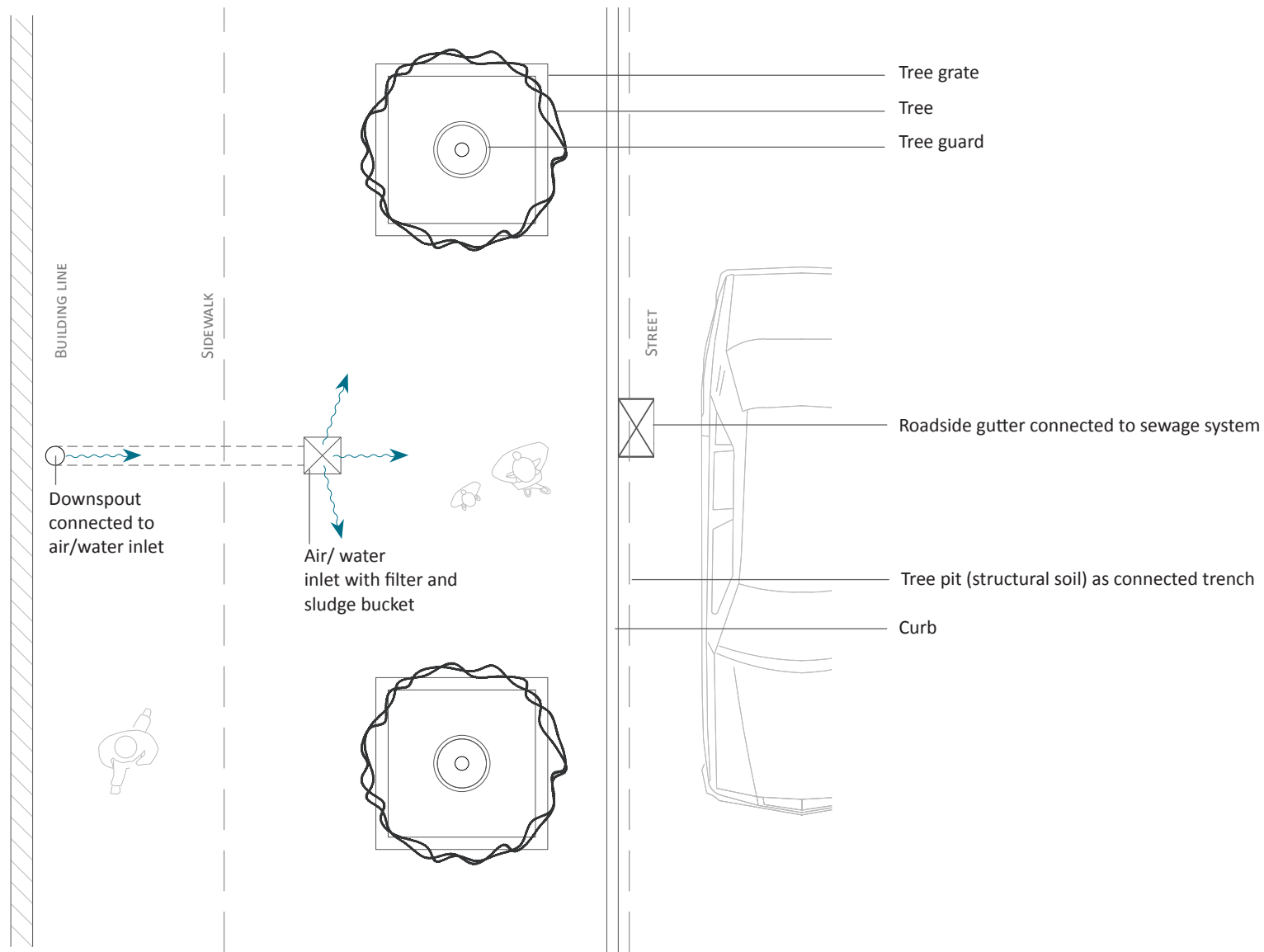


Fig. 6.05 Site plan of the advanced system of urban tree pits: water interception from the street; without scale, units in centimeter

Advanced system of urban tree pit

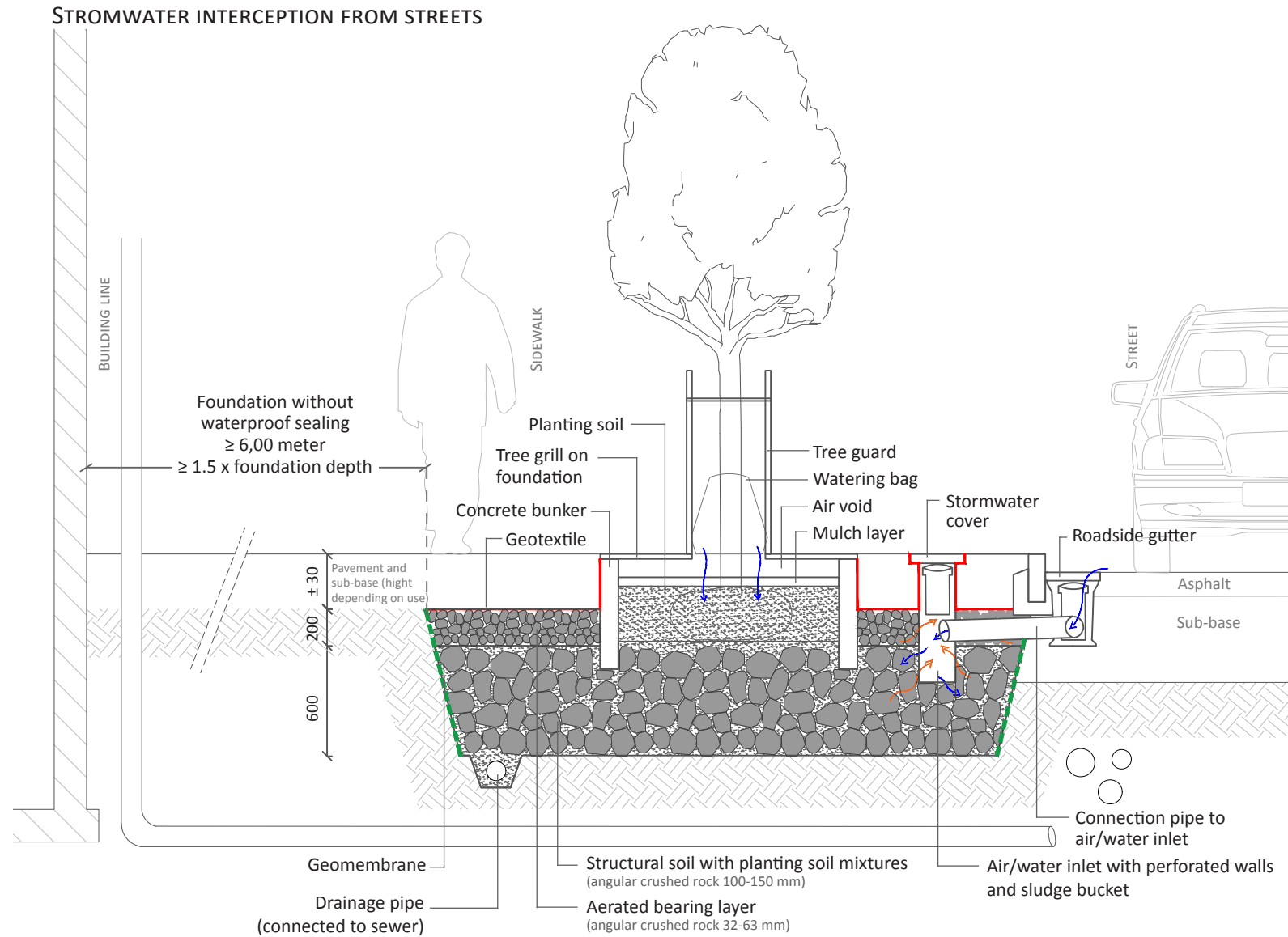


Fig. 6.06 Section of the advanced system of urban tree pits: water interception from streets; without scale, units in centimeter

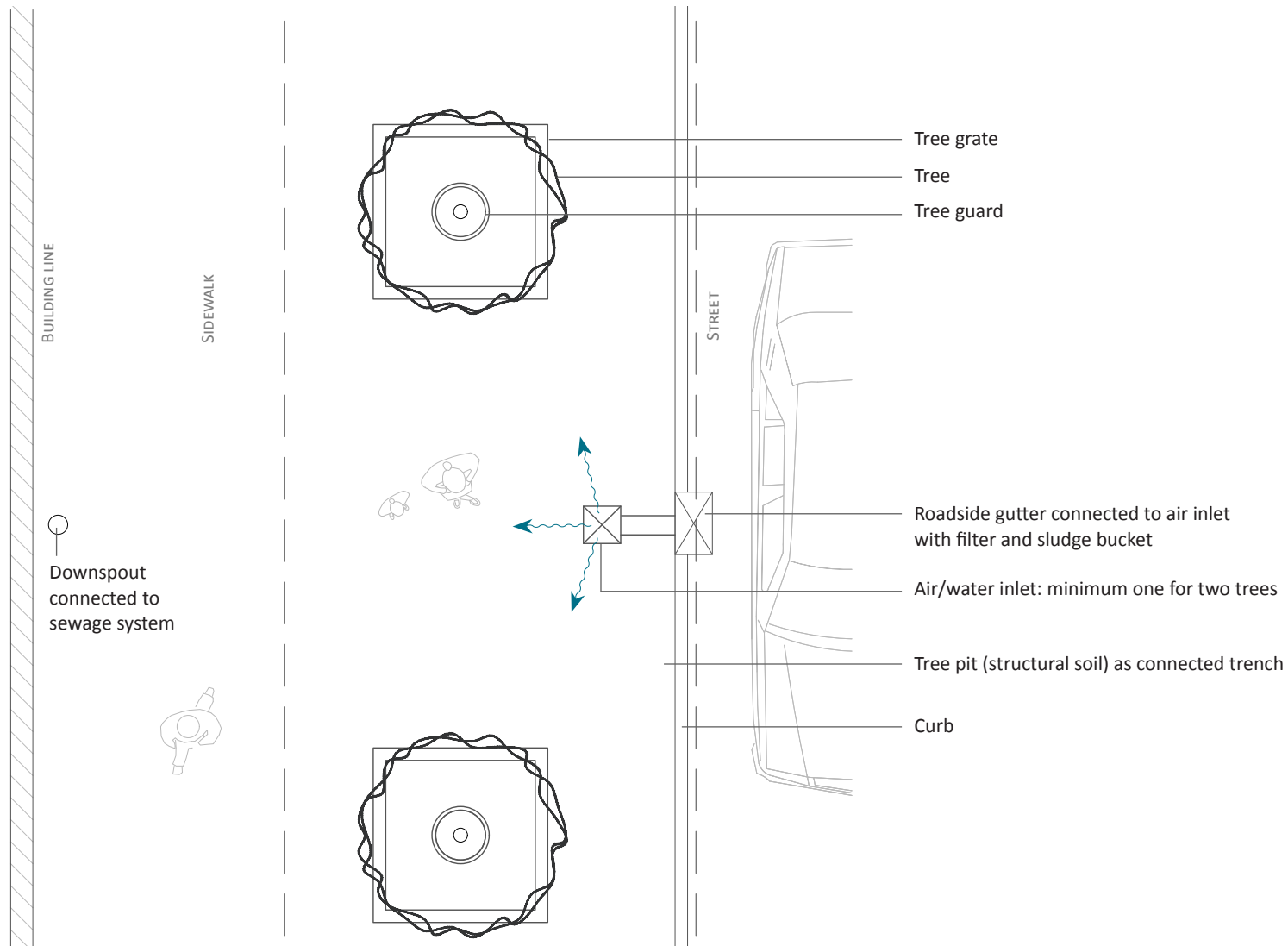


Fig. 6.07 Site plan of the advanced system of urban tree pits: water interception from the roof and sidewalk; without scale, units in centimeter

6.2 Technical details

The components and the different layers of the **advanced system of urban tree pits** are explained in the following chapter. It also describes the individual materials and further technical details.

6.1.1 Layers, components and their materials

The *advanced system of urban tree pits* meets all requirements in terms of vegetation, stormwater management and urban environment:

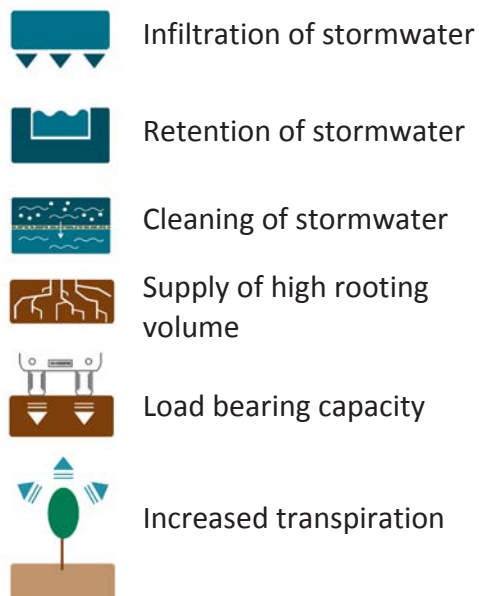


Fig. 6.08 Criteria of the new system

Watering bag

Watering bags are wrapped around the trunk and filled with water (~ 90 Liters/bag) serve for slow release irrigation (5-10 h) through the micro release points at the bottom. They must be filled regularly (1-2x per week) according to the weather and soil conditions of the site.

Tree guard

During the first years the tree must be tied in with a rubber tree strap to a double or triple staking with a height of 1,20m as a temporary protection. Otherwise, an underground anchorage system can be installed, which serves as a short- and long-term protection. In addition a tree guard (cast iron) should be installed to protect the stem as a bumper buffer against vehicles and locked bicycles.

Tree grate

The tree grate is at the same height level as the pavement. It can be manufactured of different materials (cast or galvanized iron) or a self-supporting grate, which can be paved with natural/concrete stones or slabs. The rollover capacity must be adapted to the use of the area. A specific cover

can reduce the grate opening, which is removable with the trunk growth.

Sub-base and pavement

The sub-base and pavement has to be calculated to the load class of the urban use according to the guidelines PLAST and FGSV RSTO 499. The pavement is at the same height level as the tree grate.

Air void layer

The air void *layer* is open space between the tree grate and the mulch layer, which is positioned 100 mm below the grate. Within that space, debris from the surface can accumulate, which sometimes heaves the tree grate if it is placed directly on the planting soil. With the air void, the debris and dust causes no uneven pavement anymore and can be cleaned regularly. Nevertheless, the opening of the tree grate should be closed as much as possible (e.g. with tree rings) that it is not used as a trash bin. In addition the air void is a protection for the exposed root collar (transition of root system and stem).

Concrete bunker

The concrete bunker is a square curbstone

between the base and the adjacent pavement, which directs roots downwards to prevent from growing into the sub-base and heaving of pavement. The root ball is positioned in the concrete bunker and filled with planting soil.

Air and water inlet

The air inlet guarantees the gas exchange of oxygen and the release of carbon dioxide and nitrogen between the soil and the atmosphere. To guarantee the vertical ventilation it must reach into the structural soil. The horizontal exchange operates through the two layers, aerated bearing layer and structural soil. The air inlet can be a specific manufactured component or an extended road gully, a pipe (diameter of 200-300mm) installed vertically or an extended drain, which is used for green roofs. In any case, the air inlet must be perforated to guarantee the gas exchange. It should also meet the requirements of the load-bearing capacity. Additionally it serves as a water inlet, which directs and distributes stormwater into the layers. A filter must be installed if stormwater from streets is intercepted to remove pollutants and other contamina-

tions such as de-icing salt.

Planting soil

The planting soil is hosed into the compacted structural soil. The mixture of different soil types depends on the location conditions and the requirements of the infiltration capacity to prevent a too high infiltration capacity and on the other hand excess water. The organic matter should be between 1-3 percent in order to secure an initial nutrient content. A slow-release fertilizer should be added during construction. The use of biochar is a good possibility to increase the nutrient and water holding capacity.

Geotextile

The Geotextile is laid on the aerated layer to prevent fines (e.g. debris, waste) from entering the voids of the aerated layer and block them. It must be wrapped around the air inlet and the concrete bunker.

Aerated bearing layer (200mm)

The aerated bearing layer constructed of 32-62 mm angular crushed rocks (e.g. granite, recycled concrete) is laid on the

structural soil and compacted after installation. It serves for the upper load bearing layer and the horizontal gas exchange.

Structural soil (600mm)

The structural soil constructed of 100-150 mm angular crushed rocks (e.g. granite, recycled concrete) is laid and compacted in layers of 200 mm. It serves as the main load-bearing layer and provides voids for the planting soil and root growth.

Geomembrane/ root barrier

The geomembrane must be installed vertically between the advanced system and the existing underground utilities (especially water pipes) to prevent roots from growing into the pipes. If new pipes are installed the geomembrane should be wrapped around the pipes including a warning tape.

Drainage pipe

The drainage pipe must be installed at the bottom of the tree pit to discharge excess water, especially in soil conditions with a high clay content, where infiltration is limited. The terrace should have a slight slop of 1-2 percent towards the pipe.

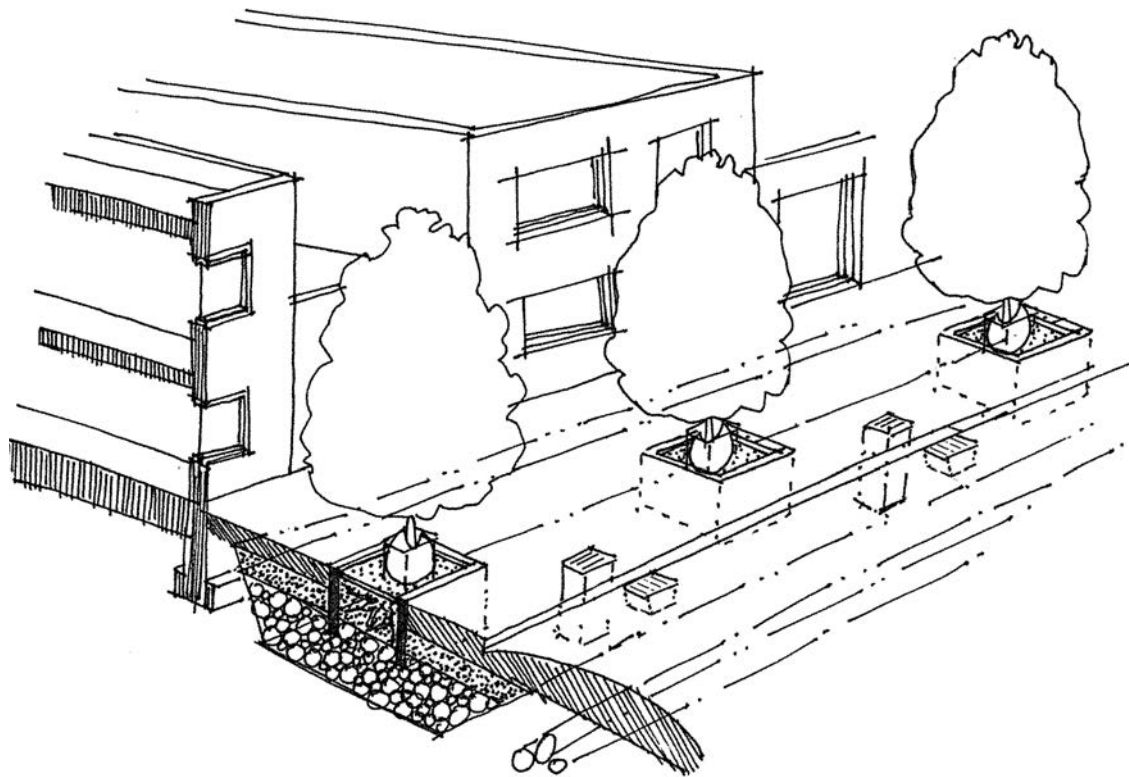


Fig. 6.09 The advanced system of urban tree pits

6.2.1 Further technical details

Rooting volume

The multilayer structure provides a rooting volume of minimum 80 cm depth. The deeper the tree pit is, the more rooting volume is available for the tree. Therefore the depth of the structural soil could also be increased. To create a natural rooting volume, the individual tree pits should be enlarged and connected as tree trenches. Furthermore, the rooting volume should be extended below the sidewalk and the street as far as possible.

Infiltration

If the foundation of the nearest building is not sealed waterproof, the distance to the tree pits must be 1,5 times of the depth of the foundation plus 50 cm, but at least 6 m.

Crushed rocks

The layer of crushed rock must be angular crushed rock and not round to achieve better interlocking and larger voids. The rocks can be natural quarry stone such as granite or limestone. It is also possible to use mineral construction materials like recycled concrete or bricks. Crushed into the right size the recycled materials can

provide the same pores for rooting purposes.

Water interception

The stormwater from roofs, sidewalks and streets (with filter) can be intercepted. If downspouts were disconnected from the sewer system, they could be connected directly to the tree pit otherwise the stormwater can run over the sidewalk into the tree pit. To direct the stormwater from surfaces into the tree pit, simple open drain channels in the sidewalk can be used. If stormwater from streets is intercepted, the usually roadside gutter should be disconnected from the water system and connected to the air inlet of the tree pit. In each case, the connected area should be calculated to reach a sufficient amount of collected stormwater.

There should still be a roadside gutter, which is connected to the stormwater/sewer system, if the system is saturated with water and no further water can be intercepted into the tree pit.

Adaptation in Urban Space

In terms of space requirement and design

the system can be adapted in every street hierarchy and in the public open space (e.g. plazas). Despite, it always must be considered the pollution of the intercepted stormwater. There are a variety of tree grills and grades provided by numerous producers. If the air inlet is included in the system for the gas exchange, the tree base can be completely closed, besides the opening for the growing trunk.

Filter

For specific street hierarchies (more than 300 vehicles per day) a filter medium inside the air inlet has to be installed to prevent pollutants being infiltrated into the soil and washed into the groundwater. If stormwater is contaminated by fuels, petroleum or similar products, oil traps must be used in the air inlet or in case of water interception from streets inside the roadside gutter.

In addition, a sludge bucket inside of the air inlet, collects debris, sediments and other materials with the flush of the stormwater. It is accessible through the usually removable stormwater cover and can be cleaned regularly.

Trees

Due to climate change, non-indigenous species need to be planted. It can achieve a high biological and visual diversity in the city. Trees should be planted with a trunk circumference of minimum 20-25 cm. If the size of the tree pit allows larger tree sizes, it should definitely be considered to plant a trunk circumference of 30-35 cm. The pH may be affected by the used material and must be considered for the tree species selection. If recycled materials such as concrete or bricks are used tree species should be planted which can grow in more alkaline environment. The tree species selection must also be adapted to the groundwater table. Where the groundwater table in general is low, trees should be planted which tolerate dry soils.

In general, the trunk whitening for locations in cities is a good possibility to protect the tree trunk against solar radiation. Within the tree nursery, trees stand relatively close to each other, compared to the street, where the distance between trees is wider with the result of trunks being highly exposed.

Construction Costs

Due to the longer construction process (laying and compaction in layers, hosing in of planting soil) the costs for the installations are higher for the *advanced system of urban tree pits* than for normal tree pits. Nevertheless, the materials, which are needed for the advanced system are common materials such as gravel layers for frost blanket course and bearing layers, which are used in everyday construction sites in the City of Hamburg, only with the difference of none zero-components. Therefore, the procurement of these materials is possible.

6.3 Maintenance

By combining street trees and stormwater management in one system both parts must be maintained equally. It is really important to have a capable and skilled company, which is contracted to carry out the maintenance for pruning, watering and cleaning. Especially pruning must be supervised in detail and done only by professionals with the required certificates. Documentation and evaluation of

time, costs and results can help to adapt the processes to achieve an economical maintenance.

During the first two years, the trees must be irrigated at least once a week until the root system of the tree is established. It can be accomplished manually on the tree base by means of a circular mound of earth at the edge of the root ball or with water bags for automatic slow delivery irrigation. Irrigation with slow release water bags is easier, faster and more efficient compared to manual irrigation on the tree base. More water can be spread over a longer period of time into the pit, while filling the tree bag is done fast.

The irrigation will always be adjusted to the temperatures, the wind and the rainfall. If there are persistent droughts and high temperatures during the summer it is recommended that irrigation is done twice a week

Regular monitoring for maintaining road safety must be carried out. It can be expected that due to the good vitality and growth capacity, the trees must be

pruned more often to ensure the vehicle clearance on streets.

The air inlet and the air void layer must be cleaned regularly of debris, dust and waste to prevent clogging. Especially during autumn: leaves start to fall and can clog the drains. The filters used for suspended solids have to be replaced regularly depending on the product. The devices should be easily accessible for inspection and maintenance. The tree grate should be removable in order to clean the air void layer and to plant a new tree if needed.

6.4 Key actors

To implement the *advanced system of urban tree pits*, the individual key actors of both urban trees and stormwater management have to cooperate with each other in the planning and implementation process.

The figure 6.10 was developed to show that with the implementation of advanced system, there is a need of change within the administrative, executive and planning processes.

Planting new trees is the task of the department of Roadside greenery but with the interception of stormwater the department of Water management has to be involved.

The same issue can occur for the construction and maintenance of the advanced system.

The figure shows how the key actors should be networked for the advanced system. In the following paragraph the changes and the further development of interdisciplinary work of the key actors for an implementation of the advanced

system are described in detail.

City's Responsibility

By combining two groups of key actors, the city does not only advise and consult the planning and the implementation but has especially to be in charge of coordinating the different actors.

Besides having a specialist planner for both scopes, there could be introduced one general planner, who combines the targets of the urban tree and the stormwater management with an overall professional knowledge could be introduced. On the municipal level, a specific department could serve for the inclusion. Especially for the monitoring and evaluation of the advanced systems such professional employees should be included into the process.

The city should provide information for them, such as tender specifications for the advanced system.

Public relations

As the city has already been doing, it should continue to intensively inform the

citizens about the street trees, to increase recognition and appreciation. However, not only the city is responsible for public relations but also the specialist planners, working groups and associations.

Executive Companies and Planners: Interdisciplinary Cooperation

The tasks and requirements of the key actors correspond to those of Section 2.3 and 3.2. To meet the demands of the trees and the stormwater management together, the respective specialist planners must work together in an interdisciplinary interaction and exchange expertise.

To simplify the planning process, the concerns could be assigned on one specialist planner. For example Landscape architects could play a central role, as they have knowledge, understanding and technical basics, regarding vegetation and are also familiar with the design and engineering of drainage and stormwater management. Training, set precisely with respect to both topics could be funded by the city.

Construction within roads, including the construction of rainwater devices may only be performed by certified companies, which are mostly road and civil engineering companies.

Landscaping companies deal with hard and soft landscape and are often not certified for construction within the street, especially in terms of stormwater devices. However, there are (landscaping) companies that are allowed to cover and run both sectors. These companies should be in charge of construction of the *advanced system of urban tree pits*.

The maintenance (pruning) of the trees should remain in the hands of professional arborists.

Monitoring and Evaluation

Primarily, the city's department is responsible for monitoring and evaluation. However, they can outsource these tasks to external specialist planners.

Besides monitoring, it is more important to observe the planning and the construction process in order to secure the technical function of the system.

For example professionals specialized on tree planting should be supervising the process of construction.

The certifications of each executive and maintenance companies have to be proven. Moreover, the arborist has to proof the professional knowledge through certificates and experiences.

The amount of infiltrated stormwater could should be evaluated corresponding to the growth rate of the tree. The infiltrated stormwater should also be tested on pollutants regularly.

With a technical evaluation done by all stakeholders, including a detailed documentation, the advanced system can be gradually adapted and optimized gradually.



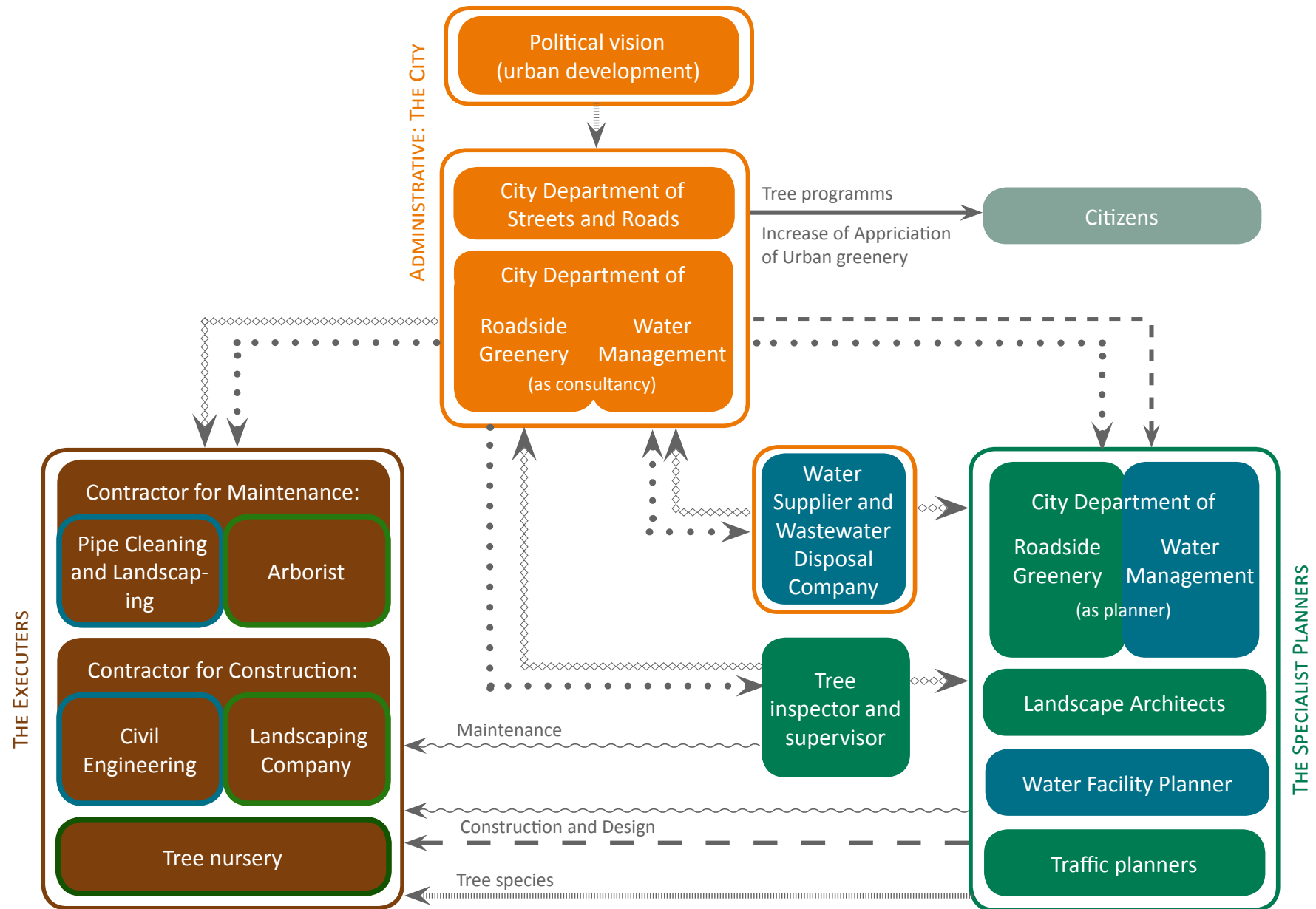


Fig. 6.10 Combined key actors of Advanced Urban Trees

7 RESULTS AND DISCUSSION

The main target of this research was to develop an advanced system, which includes both topics *tree pits and decentralized stormwater management* in a dense urban area like the City of Hamburg.

The three components trees, stormwater management and urban environment were analyzed and evaluated equally. Only by including all three components on the same level, all demands could be included in one system.

International systems that have already succeeded in long-term implementation, served as a basis for the development of the advanced system. The findings could be combined in a technical approach to the ***advanced system of urban tree pits***.

The overall analysis showed, that the currently used system for tree pits does not provide ideal growing conditions for urban trees. The main issue of compact soil can be solved with extensive technical adaptations and structural changes by an advanced system. Therefore, urban trees and especially street trees can be offered an improvement of growing conditions.

With the application of proper materials, trees can also be part of the solution for stormwater management by intercepting stormwater into the tree pit. Therefore multiple effects can be achieved: cleaning of stormwater, natural irrigation, stormwater retention and delayed discharge.

In addition, urban trees growing in the advanced system can also be part of the solution within the climate change through for example shade, living space and transpiration.

7.1 Results and research questions

As a result of good growing conditions in advanced tree pits, trees will continuously be shaping the urban landscape over decades.

Looking back, the result of the *advanced system of urban tree pits* it provides facts and answers of the assumption and the research question of the first chapter.

1. How can street trees be offered species-specific growth conditions in highly dense urban space?

The advanced system displays that trees can be offered good growing conditions within the urban area. With the use of the correct material and construction method, the natural demands of trees can be met. Based on the analysis, the main issue of urban trees is the compressed soil/substrate, which effects many properties: moist and water content, infiltration capacity, gas content and nutrient availability of the soil. The installation of a skeleton system can provide the needed load-bearing capacity for traffic and open space use, as well as voids with loose planting soil for root growth.

In addition, each location is different and therefore the numerous conditions such as climatic impact (sun, wind, rain), urban use, adjacent buildings and vegetation, underground facilities, existing soil composition, the pH-value and the water table have to be analyzed in detail. Only then, a specific adapted mixture of different soil types (sand, clay) and organic

content can be created and installed as planting medium/ substrate in the tree pit.

Furthermore, different tree species can tolerate and withstand diverse conditions, especially within the climate change. A careful selection of species based on knowledge about plant science and experiences of researches (*climate trees*) will show a long-term success in growth.

Finally, the use of stormwater can minimize the lack of water in urban soils and at the same time become a part of stormwater management by treating (infiltrate, retain and clean) stormwater on site in a natural way within the urban environment. In an advanced system of urban tree pit, trees can be offered naturalistic growing condition in dense urban areas.

2. What technical requirements must be met in order to intercept stormwater in the street tree pit?

First of all, the interception of stormwa-

ter itself is technically simple. Stormwater from roofs, sidewalks and streets can be used. The stormwater from roofs can be directed into the tree pit through a pipe connected to the downspout. If the stormwater from downspouts is flushed on the sidewalk, it can also be collected from these surfaces by open drain channels and intercepted into a drain gutter cover. The existing roadside gutter should be disconnected from the sewer network and connected to the air inlet of the tree pit.

The distribution of the intercepted stormwater is solved through the air inlet and the use of structural soil and uncompact-planting soil. After the stormwater enters the perforated air inlet, it runs through the holes into the planting soil in the structural soil and gets naturally distributed by infiltration. A perforated pipe at the bottom of the tree pit drains excess water.

If the system is filled up and saturated with water during a (heavy) rainfall, the stormwater, which cannot be intercepted will be intercepted by the roadside

gutters, which are still connected to the stormwater/ sewer system. Due to the geotextile, no soil or other materials, can be flushed out of the tree pit system.

It is important to remove debris and waste from the stormwater through a sludge bucket in the air inlet. Furthermore, specific filters must be installed inside the air inlet and the connected roadside gutter to remove pollutants and contamination. These filters must be exchanged regularly.

3. Which components of international implemented systems of tree pits can meet the demands of street trees, the decentralized stormwater management and the urban conditions in Hamburg?

The international case studies supported the development of the advanced system of Advanced Tree Pits. Several components such as layers and their materials could serve as a basis and were also integrated into the advanced system.

The study of the Stockholm Solution has many useful technical components. In addition, the currently used German system by the FLL, already offered a very good structure, which was improved combining the results of the Raingardens in Melbourne, the structural soil in New York and the Cell system in Toronto.

The results of all case studies brought up two main (theoretical) elements: Gas exchange and water. These two elements were transformed into technical solutions and gave a start for the development of the advanced system. The systems, shown in the case studies provided different conclusions about the functionality of the various components. The evaluation of the different components made it clear, that some parts were not useful for the specific demands in the urban use. On the other hand, most of the components were useful and supported the development of the advanced system.

The technical components integrated in the advanced system are connected with each other. Through the load bearing layer (structural soil) uncompact plant-

ing soil can be offered for roots growth and stormwater infiltration. The vertical and horizontal gas exchange functions through the air inlet and the aerated bearing layer. Stormwater is intercepted by the air inlet and distributed in these layers. The geotextile and the geomembranes protect the system and adjacent underground facilities. The tree guard, tree grate and the concrete bunker serve as protection for a safe urban use. The watering bag simplifies the manual irrigation.

Through the integration of all the demands, the system was not developed into one direction but adapted to achieve best conditions for all three topics: trees, urban environment and stormwater management.

4. What legal framework and German guidelines must be applied to the advanced system of tree pits for street trees?

The main framework is set by the federal laws to protect the soil, the groundwater

and the water bodies.

- Federal Soil Protection Act (2015)
- EU Water Framework Directive 2000 Water Act (2016)
- Federal Act for the Protection of Nature (2009)

Furthermore, the laws given by the municipality, in this case of the City of Hamburg must be applied as well. They mainly regulate the treatment of stormwater for infiltration to protect the natural resources (soil, groundwater, water bodies).

- Hamburg Sewage Act (2013)
- Hamburg Act of Execution of the Federal Act for the Protection of Nature (2010)

In addition, there are several guidelines, which are not legally binding. But the development of the system is also based on these guidelines (see attachment) because they display know-how, which has been gained over years of experience. The work especially with soil and plants including the maintenance is regulated and the technical requirements for stormwater infiltration are specified. The main guidelines, which influenced the *ad-*

vanced system of urban tree pits are:

- DIN 18915: Vegetation technology in landscaping: Soil working (2002)
- DIN 18916: Vegetation technology in landscaping: Plants and plant care (2002)
- DWA-A 138: Planning, construction and operation of stormwater infiltration systems (2005)
- FGSV 950: Instructions for infiltration of stormwater in street space (2002)
- FGSV 939: Data sheet for trees, underground pipes and sewers (2013)
- FLL part 1: Recommendations for tree planting: Planning, planting and maintenance (2015)
- FLL part 2: Recommendations for tree planting: Preparation of the planting bed, structure and substrates (2010)
- FLL: Requirement for stormwater infiltration and retention (2004)

5. Who is involved and which responsibility do these actors assume in the planning and implementation process of advanced tree pits?

To implement and integrate the *advanced system of urban tree pits* four groups of

key actors have to work interdisciplinary: The administrative part, which displays the city/municipality, the executors, the specialist planners for the urban trees and for stormwater management.

The city as the main key actor has the highest responsibility. On the one hand, it is in charge of as a planner or as a consultancy, but especially through the political statement. The promotion of the importance of trees and green urban network enables the financial background and the public awareness.

The city should also coordinate the different departments and specialist planners or even introduce a specific department including planners with overall technical knowledge about trees and stormwater management. For a proper process of planning, construction, monitoring and evaluation, a combined understanding of both topics must be required and achieved.

Especially the executors must hold the certificates to be allowed to carry out construction on both vegetation and

stormwater devices within the street. It is important, that they have the understanding and the sensibility for the materials, especially for the trees and how to handle and protect their properties.

Furthermore, the *advanced system of urban tree pits* must be especially promoted to the planners of urban trees.

7.2 Limits, possibilities and benefits

Trees in the urban environments will remain a challenge. The quantity of planted trees is not the essential criteria; the most important aspect is the actual quality of each tree and the success of planting and growing.

Planting additional trees should not be enforced. In an environment where the above surface space is confined and the underground space is highly populated by pipes, tree plantings should be reconsidered in every case. Even the *advanced system of urban tree pits* cannot serve as solution for such locations.

Green infrastructure, like street tree plantings should be rather included in the initial phase of the municipal development plans. Therefore, the demands and benefits of street trees should always be the priority and be reflected by all stakeholders in the planning phase.

The installation of the *advanced system of urban tree pits* can be particularly intensive. Due to the size in width and length the construction sites can be time-consuming with temporary restrictions for traffic. However, when tree pits are planned in advance, they should not

be implemented and installed as individual tree pits, but as tree trenches. As a result, there would only be one construction site at once with less restriction for traffic, instead of several sites in different time periods. This can save costs, simplifies the construction process including the material delivery and installation in larger quantities.

The underground facilities in the soil have been an obstacle for the currently used system of tree pits and also are for the advanced tree pits. If pipelines, which lie within the tree pit construction, have to be maintained or repaired the excavation of the overlying materials is labor intensive. Each layer must be removed individually and also must be reinstalled appropriately. The risk of compaction of the different layers (e.g. planting soil) can probably not be avoided. It is important to ensure that pipelines are actually laid in pipeline routes outside the tree pit. Already during the planning process for tree pits, it should be considered not to extend the tree pit towards or even into pipelines.

The filter in the street inlets must be

changed regularly (depending on the product), which increases the maintenance. Skilled employees must change the filters to guarantee a proper function, which arises costs. A detailed concept based on the different street hierarchies can plan the maintenance (change of filters) sustainable and more efficient.

Stormwater from street surfaces is part of the municipal water management, which also must be involved, if the stormwater is treated decentralized and intercepted into the tree pit. This could be a difficult process in terms of planning, construction and the cooperation of the individual departments. Specialists must be involved, who are equipped with both fundamental knowledge about tree planting and stormwater devices.

The total construction costs seems to be higher for the advanced system as for a normal tree pit. But since the tree has a longer lifetime with an advanced tree pit, the costs will be paid off in the course of time.

Nevertheless, all these challenges can be handled with specific information, knowl-

edge and consideration in the interdisciplinary planning process by the city and specialists. The advanced system of urban tree pits have many benefits and sustainable effects in terms of ecology, economy and architecture design.

Due to the extended rooting volume with uncompact soil, an almost unrestricted root growth especially in the fine range is possible. By uncompact soil, an adequate supply of nutrients, gases and water is guaranteed for the trees. Advanced tree pits provide very natural growth conditions: If the tree pits are designed as tree trenches, trees are able to communicate and interact with one another like in nature.

Decisive for the good growth is the gas exchange. The guideline FLL already provided such recommendations but a profound aeration is only effective, if it is also distributed in a horizontal layer with the use of angular crushed rock. The aeration is a simple system with highly functional effect for the trees.

Besides the pipes, the air inlet with the filter, the geomembranes/textile and the

concrete bunker, the entire layer structure is based on natural materials. There is no further artificially manufactured product from plastic or concrete installed into the ground. Therefore, the advanced system is sustainable because the raw material can be supplied continuously and there are no further dependencies on individual manufacturers.

The general repair work is diminished significantly. Through deep root growth there is no longer problems with pavements being heaved or broken by superficial roots. Since roots have adequate root volume and existing nutrients in deep layers, also root growth into pipelines can be prevented. Proper water flow is guaranteed and the cost intensive pipe cleaning can be avoided.

The City of Hamburg could include the advanced system as an additional requirement for building permissions. An examination of the various criteria for possible infiltration of stormwater in advanced tree pits should be mandatory included in the planning process.

The good vitality of the trees prevents

from dying and falling branches. Therefore, the regular tree control can be carried out more quickly and save costs, since intensive monitoring and evaluating of damages on the trees is no longer necessary. Advanced urban trees can meet the expectations (e.g. oxygen production, habitat for small creatures, providing shade) and have a significant contribution to the challenge with climate change.

The advanced system is ideal for public spaces and streets with only pedestrians and light traffic (up to 300 vehicles/day). The intercepted stormwater of this street hierarchy has a low pollution and can be removed by filters, which therefore have to be removed less often. For higher pollutions the filter and its exchange have to be adjusted.

The advanced system can also be used without the interception of stormwater. For example, in areas where the stormwater drainage is already attached to a sustainable decentralized stormwater management. The system is built up in the same way only without the drainage pipe at the bottom of the tree pit.

7.3 Outlook and further research

If tree pits are installed during large street constructions, the cost factor is relatively small for the tree pits in comparison to the development and construction of street and underground facilities (Drießelmann 2016). Due to the positive financial situation of the City of Hamburg, it should be invested more in the implementation of street trees. An integration of the system in urban standards would be a step towards sustainable street tree design and planning.

For the advanced system, the grain sizes of the aerated bearing (32-64 mm) and the structural soil (100-150 mm) layer were chosen according to the positive experiences of the Stockholm Solution. The implementation of the advanced system in the City of Hamburg and Germany in general is possible in terms of availability of these grain sizes in German gravel, sand and grit plants. In addition, the grain size for the structural soil still has a good workability and form voids after compaction which are still large enough for growth of strong roots (Moser 2016).

According to the Practical Guidance of Execution of Tree preservation order of Hamburg, street trees have a low habitat function because of their location. In my opinion, this statement is controversial, based on all guidelines, which particularly emphasize street trees and their positive impacts. The general protection times from October to March for maintenance and pruning should also be respected for street trees in terms of species protection (mainly because of the birds). The pruning for safety reasons should remain exclusive.

In the City of Hamburg, within the next decade, there will probably be numerous locations where new trees will be planted. For example, the chestnuts will start to disappear from the cityscape because of the effects of the leafminer (decrease of tree vitality and more vulnerable to other parasites). This will result in replacement plantings in many streets. For example the Amselstraße (residential and access street) in Hamburg Nord: 17 horse chestnut trees (*Aesculus hippocastanum*), planted between 1906 to 1965, are probably infested by the leafminer. If

these trees will be felled in the future due to bad vitality and breaking branches, it will be a serious ecological loss. However, this could also be an opportunity for new trees in an advanced system.

If somewhere in future, a disease or a pest infects lime trees in Hamburg and thousand of trees would start to decrease in health. Particularly old trees with a high ecological value will probably not be replaced fast enough to compensate the ecological loss. Therefore more non-indigenous species should be considered planting.

An interdisciplinary cooperation of professional groups is indispensable at a municipal level. At the international level, an intensive exchange about advanced tree pits should be promoted further on, as well as the sharing of experiences and to promote the further development of the advanced system should be pursued more intensely. For the city of Hamburg, a first implementation could be a start of an experiment of testing the effect under given conditions. This could also clearly determine

the costs of the construction of the advanced system.

In addition, the City of Hamburg could define suitable locations for advanced urban trees based on the tree database. According to the defined conditions, which must be analyzed before planning and installation, this map would already show, where the advanced system could be applied and would simplify the overall planning process.

Further research projects could investigate and document in detail different characteristics of the advanced system like root growth, nutrient availability, water and air capacity in the soil. The following questions could be investigated:

1. How much water can actually be intercepted and taken up depending on the size of the tree pit and the effect it has on the sewage system?

2. What environmental impacts do non-native tree species have on the native flora and fauna?

3. How intense are the positive influences of street trees within the climate change?

4. Which grain size of the structural soil is most suitable for root growth?

Only experiences in practical work including failure lead to gained knowledge whether the *advanced system urban tree pits* requires further adjustments to provide urban trees good growing conditions rich in nutrients, gas and water in extreme locations.

8 APPENDIXES

8.1 Comparison of the chosen case studies and the German system of FLL

Selected components of case studies,
evaluated positive in analysis

NAME OF THE SYSTEM	CITY, COUNTRY	ROOTING VOLUME	MATERIALS (LAYERS FROM TOP TO BOTTOM)	PLANTING SOIL	STORMWATER FILTER
Stockholm Solution	Stockholm, Sweden	80 cm - Tree trenches - Tree pit increased under sidewalk	Two layers: Aerated bearing layer: 32-63 mm angular crushed rock Structural soil: 100-150 mm angular crushed rock filled with planting soil	Uncompact planting soil Different mixtures of planting soil Biochar as a nutrient- and water-holding component • Clay content minimum 4 wt-% • Organic matter (humus) maximum 3-4 wt-% • Slow release fertiliser 100 gr/m ²	- No extra filter - Soil functions as filter for pollutants
CU Structural Soil™	New York City, USA	60-90 cm - Tree trenches - Tree pit increased under sidewalk	Two layers: • Bark mulch layer • 1,9-3,8 cm crushed rock with planting soil and tackifier	• Clay content minimum 20 wt-% • Organic matter maximum 2-5 wt-% (CU 2005) • Organic matter maximum 7-12 wt-% (NYC 2014)	- No extra filter - Soil functions as filter for pollutants
Raingarden Tree Pits	Melbourne, Australia	80 cm - Raingardens	Five layers: Air void layer • Rocky mulch layer • Filtration layer: 80% loamy Sand, 10% vermiculite and 10% perlite by volume+ composte • Transition layer: coarse sand • Drainage layer: fine and clean washed gravel of 2.5 mm	• Clay content 2-4 wt-% • Organic matter 4-5 wt-%	- No extra filter - Filtration layer: soil functions as filter for pollutants
Crate System	Toronto, Canada	40-120 cm - Tree trenches - Tree pit increased under sidewalk	One to three layers of cells filled with 70-85 vol-% sand (grain size of 0,05-2,0 mm and 15-30 vol-% clay and silt (<0,05 mm))	Uncompact planting soil: 90% of system space • Clay and silt: 15-30 vol-%	- No extra filter - Filtration layer: soil functions as filter for pollutants - Settling tank
FLL: Recommendations for tree planting, Part 1 and 2	Hamburg, Germany	150 cm Trench aeration and connection of tree pits	Two layers • mixed crushed rock 0/16 bis 0/32mm with Drainage pipe	• Organic matter 1-4 wt-%	-

Table 8.01 Comparison of the chosen case studies and the German system of FLL

WATER INTERCEPTION	GAS EXCHANGE	ADAPTION IN URBAN SPACE	TREES	CONSTRUCTION PROCESS	COSTS	FURTHER INFORMATION
• Inlet on streets and sidewalks • Water from roofs, sidewalks and streets	Air inlet which serves for gas exchange	• All street hierarchies • Open space, plazas, sidewalks • Variety of tree grates and tree guards	High diversity through indigenous species Tree size: trunk circumference 30- 35cm	• Constructed in layers of 250 -300 mm • Compact structural soil before adding planting soil • Complete tree pit preparation during road construction	In total: € 12,500 • € 6,250 for the tree pit • € 6,250 for the design	Watering bags for irrigation Concrete bunker to direct roots downwards Tree guard and tree grate Geomembrane+ geotextile
From streets	• Through tree base and permeable surface	• All street hierarchies • Open space, plazas, sidewalks	High diversity through indigenous species	• Mixed prior installation	-	Tree guard and tree grate
From streets, sidewalks and roofs • Stormwater retention „layer“	• Through tree base	• All street hierarchies • Open space, plazas, sidewalks Removable rings for trunk growth	• High diversity (biological and visual) through indigenous species	-	• € 2.800-5.500 main part of the costs are for the tree pit lid, bollards and tree guard	Drainage of tree pit through drainage pipe Tree guard and tree grate Geomembrane/ root barrier
• Inlet on streets • Water from roofs, sidewalks and streets	• Perforated pipes up to a depth of 1,50m • Trench aeration up to 5 m length and 30 cm width	• All street hierarchies • Open space, plazas, sidewalks • Variety of tree grates and guards	-	No compaction of planting soil	-	Watering bags for irrigation Drainage of tree pit through drainage pipe
-		• All street hierarchies • Open space, plazas, sidewalks • Variety of tree grates and guards	• Mainly indigenous species, but more and more non-indigenous (climate adapted) trees	• Installed in two layers, compact each layer	• € 2.500-3.500	Vertical aeration Tree guard and grate

8.2 Contact persons

THE CITY OF STOCKHOLM

Björn Embrén

Björn Embrén is a gardener and has been working for the *City of Stockholm*. Since 2001 he is responsible of the urban trees in the city as a tree specialist.

Britt-Marie Alvem

Britt-Marie Alvem is a landscape architect and is working for the *City of Stockholm* since 1997. In the beginning, she was responsible for urban greenery and road design and since 2007 she is in charge of street trees with Björn Embrén.

In Stockholm, on August 24th 2016, I interviewed Britt-Marie Alvem and Björn Embrén. Together, we were visiting numerous locations of street trees, which are growing in structural soil and constructions of street tree retrofits with plant bed renovation.

Thilo Beeker joined our excursion. Together they provided information, which is detailed summarized in Chapter 4 *Case Studies*, Section 1 *Large-size Stones: Structural Soil in Stockholm, Sweden*.

NORDIC TREE CARE

Thilo Beeker

Thilo Beeker is an arborist born in a German tree nursery and is the founder of his company *Nordic Tree Care* in Stockholm which is specialized in tree care, pruning, felling, tree broker and planting, inventory and inspection, as well as education and training. Thilo Beeker has been contracted by the City of Stockholm, for caring and pruning trees, and also for purchasing and choosing trees in tree nurseries in North Germany. He has been working in collaboration with Björn Embrén and Britt-Marie Alvem.



Fig. 6.11 Thilo Beeker, Britt-Marie Alvem and Björn Embrén

STOCKHOLM VATTEN

Joakim Pramsten and Eva Vall

Joakim Pramsten and Eva Vall are working for *Stockholm Vatten*, which is the Water Supplier and Wastewater Disposal Company for the City of Stockholm.

The target of the contact was to understand the function of the water system in the City of Stockholm, especially the water diversion from the roofs through open downspouts on the sidewalks and streets. In addition, the influence of water interception in street trees in context of decentralized stormwater management was pointed out.

They provided information by email (08/30/16 and 09/01/16) about the drinking water and wastewater system, the fees and decentralized stormwater management.

The information is described in detail in Chapter 4 *Case Studies*, Section 1 *Large-size Stones: Structural Soil in Stockholm, Sweden* in the Paragraph *Water System of the City of Stockholm*

CITY OF HAMBURG: BOROUGH OF WANDSBEK

Uwe Drießelmann

Uwe Drießelmann is responsible for the *roadside greenery in the borough of Wandsbek in the City of Hamburg*, in the office for economy, construction and traffic, Management of urban space (Bezirkssamt Wandsbek Dezernat für Wirtschaft, Bauen und Verkehr, Management des öffentlichen Raumes, Straßengrün).

In Hamburg, on September 28th 2016, I interviewed Uwe Drießelmann about the general topic of urban trees and the task of the borough, and in detail of his position. The target of the interview was to constitute the function and task for the boroughs and the offices in the process of planning and implementation of street trees.

The information of the interview are detailed summarized in Chapter 5 *Existing conditions in the City of Hamburg, Germany*, Section 1 *Trees urban conditions and its effects* and Section 4 *(Storm)Water System and sustainable strategies*.

BAUM-MANAGEMENT HAMBURG

Volker Wahli

Volker Wahli is biologist and technical expert for trees. He founded his company *Baum-Management Hamburg* in 2007 and is specialized in tree inspection, inventory, assessment, monitoring and consulting of constructions.

Georg Geiger

Georg Geiger (employee) is a specialized agronomist for trees.

Katja Kahle

Katja Kahle (employee) is an architect and a certified tree inspector.

On August 1st 2016, in Hamburg, I interviewed the team of Baum-Management Hamburg. The purpose of the interview was to work out the existing condition and overall vitality of street trees in the City of Hamburg, especially in regard of climate change. The interview pointed out their responsibility and task in correlation with the City of Hamburg.

The summary of the interview is attached in the following Chapter 8.2.1.



Fig. 6.12 Volker Wahli, Georg Geiger and Katja Kahle

8.2.1 Interview with Baum-Management Hamburg: Volker Wahli, Georg Geiger and Katja Kahle, August 1st 2016

Trees in Hamburg

The office Baum-Management Hamburg is specialized in tree inspection, inventory, assessment, monitoring and consulting of constructions and they are contracted by public institution (e.g. municipality, communes, schools and kinder gardens, fire department) in regard to trees on public space and along streets, and also by the private sector (e.g. private persons, housing associations, companies which/who own properties with trees).

The street trees are controlled mainly for traffic safety and life protection with suggestion for the following treatment such as pruning or felling. The trees are characterized and analyzed in detail about pests and mechanical damage. The second target of tree maintenance is the tree vitality and the design of the tree. Urban trees in the City of Hamburg have a good vitality due to good maintenance.

There are cities in Germany that have their own tree inspectors and arborists but many cities contract external certified professionals according to the required guidelines such as FLL.

In the City of Hamburg, there is a high quality of tree management based on the specialized people working in the district offices. The main guidelines for tree maintenance and inspection are for example FLL 2010 and FLL 2015. The actual pruning of trees is supervised by the city itself or by the tree inspector.

Less trees should be planted but with high growing conditions. If trees are felled, the quantity of the compensation planting is set by

the City of Hamburg. It should be avoided to squeeze all required trees on the property but rather plant less with a higher standard. The trees species are chosen according to the list of the office districts (FHH 2015b attachment 1, p.35ff).

Climate adapted trees

That list displays native tree species which fit in the existing ecosystem in terms of living space and feed for animals. Nevertheless, Baum-Management Hamburg also tries to plant exotic trees in coordination with the offices. More exotic species should be planted to increase the biodiversity. The native species are still suitable for tree planting within cities and if more sensitive trees are planted, it must be provided a better tree pit and surrounding.

Different tree species should be planted within one street to prevent a loss of all trees due to a pest.

Growing conditions for urban trees

In cities, trees are cramped into a tiny tree pit far from natural growing condition compared to the forest.

The sealing around the trees should be reduced and changed into open surface such as soil with plants to achieve a supply of nutrients. The more space, nutrients and water is available for roots underground, the less they grow into pipes.

The main issue for the tree is the sealed basement of the tree. If it is an open tree basement (soil and vegetation), most of the times

it is too small for a sufficient gas exchange with the atmosphere.

Fine roots are mainly growing in deeper layers, after the tree has developed a root system within a few years. Therefore, vegetation at the tree basement is not a competitor for the tree in terms for nutrients and water. The tree takes up these resources from much deeper layers. The vegetation rather loosens up the upper layers of the soil with its roots.

On the other hand, nutrient-rich planting soil should be supplied in deeper layers to encourage them to grow deeper and not superficially. Therefore the tree basement should be constructed for example, as water bound surfaces. But in this case, the tree basement must be compact and the tree pit is compact again. For the urban environment it is not easy to find the best tree basement.

The more natural the tree basement in terms of open soil for gas and water exchange, the better for the tree vitality. In most cases in cities, this area is quite too small.

De-icing salt is a high problem (marginal brown area of leaves) and has to be minimized to sustain the vitality of the urban trees. If water is infiltrated into the tree pit it is important that the tree species is chosen according to their tolerance.

The appreciation of urban trees should be increased in general.

The Stockholm Solution

The size of the tree pit of the Stockholm Solution is immense and could be a problem for implementation in the City of Hamburg.

It could be possible to connect the downspouts directly to the tree pit to intercept the stormwater from the roofs. In addition, it must be ensured that the roots are not growing into the air inlet.

The structural soil serves as a good supply of voids which are filled up with uncompacted planting soil. Nevertheless, the planting soil must be kept in the voids and not washed out through intercepted stormwater.

There are specific soil types, which can hold nutrients and water to ensure a sufficient supply for the roots and the tree. It also must be guaranteed that the intercepted water is not washing out the nutrients with the planting soil.

To conclude, the idea to try out a new system is a good start instead of only installing some compact planting soil in the tree pit like it is done at the moment.

8.3 Legal framework and guidelines for tree planting

LEGALLY BINDING	TITLE (GERMAN)	TITLE (ENGLISH)
	Bundesnaturschutzgesetz (BNatSchG): Gesetz über Naturschutz und Landschaftspflege	Federal Act for the Protection of Nature
	Hamburgisches Gesetz zur Ausführung des Bundesnaturschutzgesetzes (HmbBNatSchAG)	Hamburg Act of Execution of the Federal Act for the Protection of Nature
	Baumschutzverordnung (BaumschutzVO) 1984	Tree preservation order by the City of Hamburg
	FHH. 2015 - Arbeitshinweise zum Vollzug der Baumschutzverordnung und der dabei zu beachtenden artenschutzrechtlichen Vorschriften	Practical Guidance of Execution of Tree preservation order of Hamburg
	FHH. 2000 - Informationen zum Baumschutz	Datasheet of Tree preservation by the City of Hamburg
	DIN 18915. 2002 : DIN 18915- Vegetationstechnik Im Landschaftsbau: Bodenarbeiten.	DIN 18915. 2002 : DIN 18915- Vegetation technology in landscaping- soil working"
	DIN 18916. 2002 : DIN 18916- Vegetationstechnik Im Landschaftsbau: Pflanzen Und Pflanzarbeiten.	DIN 18916. 2002 : DIN 18916- Vegetation technology in landscaping- Plants and plant care
	DIN 18920. 2014 : DIN 18920- Vegetationstechnik Im Landschaftsbau - Schutz von Bäumen, Pflanzenbeständen Und Vegetationsflächen Bei Baumaßnahmen.	DIN 18920. 2014 : DIN 18920- Vegetation technology in landscaping - Protection of trees, plantations and vegetation areas during construction work
	FLL. 2010 : FLL-Empfehlung Für Baumpflanzungen Teil2: Standortvorbereitungen Für Neupflanzungen; Pflanzgruben Und Wurzelraumerweiterung, Bauweisen Und Substrate.	FLL. 2010 : Recommendation for tree planting, part 2: Preparation of the planting bed, structure and substrates
	FLL. 2015 : FLL-Empfehlung Für Baumpflanzungen. Teil1: Planung, Pflanzarbeiten, Pflege.	FLL. 2105 : Recommendation for tree planting, part 1: Planning, planting and maintenance
	FGSV 232. 2006 : Hinweise zur Straßenbepflanzung in bebauten Gebieten	FGSV 232. 2006 : Instructions for road planting in built-up areas
	FGSV RSTO 499. 2012 : FGSV 499 RStO: Richtlinien Für Die Standardisierung Des Oberbaues von Verkehrsflächen.	FGSV RSTO 499. 2012 : Guidelines for the standardisation of pavement structures of traffic areas
	FGSV 939. 2012 : Merkblatt Bäume, unterirdische Leitungen und Kanäle	FGSV 939. 2012 : data sheet for trees, underground pipes and sewers

Table 8.02 Legal framework and guidelines for tree planting

8.4 Legal framework and guidelines for stormwater treatment and management

LEGALLY BINDING	TITLE (GERMAN)	TITLE (ENGLISH)
	Gesetz zum Schutz vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten (Bundes-Bodenschutzgesetz - BBodSchG)	Federal Soil Protection Act
	EG-Wasserrahmenrichtlinie (EG-WRRL)	EU Water Framework Directive (WFR)
	Wasserhaushaltsgesetz (WHG)	Water Act
	Hamburgischen Abwassergesetz (HmAbwG)	Hamburg Sewage Act
	Baugesetzbuch (BauGB)	Building Code by the City of Hamburg
	Verordnung über die erlaubnisfreie Versickerung von Niederschlagswasser auf Wohngrundstücken: Niederschlagswasserversickerungsverordnung	Stormwater Infiltration Regulation by the City of Hamburg
	DIN 1986-100. 2016: Entwässerungsanlagen für Gebäude und Grundstücke - Teil 100: Bestimmungen in Verbindung mit DIN EN 752 und DIN EN 12056	DIN 1986-100. 2016: Drainage systems on private ground - Part 100: Specifications in relation to DIN EN 752 and DIN EN 12056
	FLL. 2004: Empfehlungen zur Versickerung und Wasserrückhaltung	FLL. 2004: Requirement for stormwater infiltration and retention
	DWA-A 138. 2005: Planung, Bau und Betrieb von Anlagen zur Versickerung von Niederschlagswasser	DWA-A 138. 2005: Planning, construction and operation of stormwater infiltration systems
APPENDIX	FGSV 514. 2016: Richtlinien für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten	FGSV 514. 2016: Guidelines for constructions on streets in water protection areas
	FGSV 548. 1993: Hinweise an bestehenden Straßen in Wasserschutzgebieten	FGSV 548. 1993: Notes for constructions on existing roads in water protection areas
	DWA-A 153. 2012: Handlungsempfehlung zum Umgang mit Regenwasser	DWA-A 153. 2012: Recommendations for handling with stormwater
	FGSV 950. 2002: Hinweise zur Versickerung von Niederschlagswasser im Straßenraum	FGSV 950. 2002: Instructions for infiltration of stormwater in street space
	PLAST. 2013: Planungshinweise für Stadtstraßen in Hamburg	PLAST. 2013: The Hamburg planning notes for city street

Table 8.03 Legal framework and guidelines for stormwater treatment and management

8.5 References

AG-Australian Government, Bureau of Meteorology. **2016**: Climate Statistics for Australian Locations. Retrieved 9/25/16 from http://www.bom.gov.au/climate/averages/tables/cw_086071.shtml.

Amereq Inc. **2016**: CU Soil Detailed Drawings - Amereq Inc./CU-Soil Division - CADdetails. Retrieved 9/20/16 from <http://microsite.cad-details.com/Main/Company/ViewProduct?productID=211&company-ID=57µsite=1>.

Balder, Hartmut. **1998**: Die Wurzeln Der Stadtbäume: Ein Handbuch Zum Vorbeugenden Und Nachsorgenden Wurzelschutz. Berlin: Parey.

Balder, Hartmut. **2012**: Leitfaden Für Eine Fachgerechte Baumpflanzung-Baustellen Bezogener Pflanzeinkauf, Ballenbehandlung Und Kronenschnitt. Braunschweig.

Balling, Edwin. **2005**: Die Kulturgeschichte Des Obstbaus. Bayrische Landesanstalt für Landwirtschaft. Retrieved 10/25/16 from https://www.lfl.bayern.de/mam/cms07/iab/dateien/kulturgeschichte_obstbau_extern.pdf.

Bartsch, Norbert and **Röhrig**, Ernst. **2016**: Walddökologie: Einführung Für Mitteleuropa. Berlin, Heidelberg: Springer Spektrum Akademischer Verlag.

Bassuk, Nina; **R. Denig**, Bryan; **Haffner**, Ted; **Grabosky**, Jason and **Trowbridge**, Peter. **2015**: Retrieved 8/7/16 from CU-Structural Soil - A Comprehensive Guide. New York: Urban Horticulture Institute, Cornell University Department of Horticulture. <http://www.hort.cornell.edu/uhi/outreach/pdfs/CU-Structural%20Soil%20-%20A%20Comprehensive%20Guide.pdf>.

Bassuk, Nina; **Grabosky**, Jason and **Trowbridge**, Peter. **2005**: Using CU-Structural Soil in the Urban Environment. New York: Urban Horticulture Institute, Cornell University Department of Horticulture. Retrieved 7/17/16 from <http://www.hort.cornell.edu/uhi/outreach/pdfs/custructuralsoilwebpdf.pdf>.

B. B. C. News. **2016**: Man Injured in Chertsey Falling Tree Car Crash Dies. BBC News. July 14. Retrieved 8/7/16 from <http://www.bbc.co.uk/news/uk-england-surrey-36795884>.

BBSR-Bundesinstitut für Bau-, Stadt- und Raumforschung (editor). **2015**: Ueberflutungs- Und Hitzevorsorge durch Die Stadtentwicklung. Strategien und Maßnahmen zum Regenwassermanagement gegen urbane Sturzfluten und überhitzte Städte.

Beede, Robert H.; **Brown**, Patrick H.; **Kallsen**, Craig and **Weinbaum**, Steven A. **2005**: Diagnosing and Correcting Nutrient Deficiencies. Davis, California, United States. Retrieved 8/2/16 from <http://fruitsandnuts.ucdavis.edu/files/73696.pdf>.

Blume, Hans-Peter; **Brümmer**, Gerhard W.; **Horn**, Rainer; **Kandeler**, Ellen; **Kögel-Knabner**, Ingrid; **Kretzschmar**, Ruben; **Stahr**, Karl and **Wilke**, Berndt-Michael. **2010**: Lehrbuch Der Bodenkunde. 16. Auflage. Berlin, Heidelberg: Springer.

BMUB-Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (editor). **2015a**: Grün in Der Stadt - Für Eine Lebenswerte Zukunft, Grünbuch Stadtgrün. Berlin.

BMUB-Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (editor). **2015b**: Hochwasserschutzfibel - Objektschutz Und Bauliche Vorsorge. Berlin.

BMUB-Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (editor). **2016**: Grün in Der Stadt. Weißbuchprozess. Berlin: Bundesumweltministerium. Retrieved 6/27/16 from <http://www.bmub.bund.de/themen/stadt-wohnen/stadtentwicklung/gruen-in-der-stadt/>.

Brennerscheidt, Christoph. **2011**: Wurzeleinwuch in Abwasserleitungen Und -Kanälen: Von Problemen Zu Gemeinsamen Lösungsansätzen. PRO Baum 3|2011.

BUND- Bund für Umwelt und Naturschutz Deutschland e.V. **2014**: Baumschutz in Hamburg. Retrieved 9/25/16 from http://bund-hamburg.bund.net/themen_projekte/baumschutz_in_hamburg/.

bpb- Bundeszentrale für politische Bildung. **2013**: Träger der öffentlichen Verwaltung. Retrieved 9/28/16 from <http://www.bpb.de/politik/grundfragen/24-deutschland/40472/traeger-der-oeffentlichen-verwaltung>

Callaú Poduje- Paula A. **2016.** Architecta.

Channel New Asia. 2016: 1 Killed, 5 Injured after Car Crashes into Tree on Changi Coast Road. Channel NewsAsia. July 29. Retrieved 8/7/16 from <http://www.channelnewsasia.com/news/singapore/1-killed-5-injured-after/2996506.html>.

CM- City of Melbourne. **2015a:** Raingarden Tree Pit Program, Case Study. Retrieved 8/2/16 from <http://urbanwater.melbourne.vic.gov.au/wp-content/uploads/2015/02/D327828-WSUD-SHEET-2.pdf>.

CM- City of Melbourne. **2015b:** Urban Water Raingarden Tree Pit Program. Retrieved 8/2/16 from http://urbanwater.melbourne.vic.gov.au/wp-content/uploads/2015/02/Urban-Water_Raingarden-treepit-program.pdf.

CM- City of Melbourne. **2015c:** Lessons from the Drought, Melbourne Urban Water. Retrieved 9/21/16 from https://www.youtube.com/watch?time_continue=59&v=Zd8DWwu92No.

CM- City of Melbourne. **2016a:** Design Standards: Engineering Standards and Specifications. Retrieved from 8/11/16 <http://www.melbourne.vic.gov.au/building-and-development/standards-specifications/Pages/design-standards.aspx>.

CM- City of Melbourne. **2016b:** The City of Melbourne, Urban Water. Main website. Retrieved 10/31/16 from <http://urbanwater.melbourne.vic.gov.au/>.

CM- City of Melbourne. **2016c:** The City of Melbourne, Urban Water: Our Strategies. Retrieved 10/31/16 from <http://urbanwater.melbourne.vic.gov.au/industry/our-strategies/>.

CM- City of Melbourne. **2016d:** The City of Melbourne, Urban Water: Raingarden Tree Pit Program. Retrieved 10/31/15 from <http://urbanwater.melbourne.vic.gov.au/projects/raingardens/little-collins-street-tree-pits/>.

CRWA- Charles River Watershed Association. **2009:** Stormwater Trees Urban Environment. A Comparative Analysis of Conventional Street Tree Pits and Stormwater Tree Pits for Stormwater Management in Ultra Urban Environments. Retrieved 8/10/16 from http://www.crwa.org/hs-fs/hub/311892/file-642201447-pdf/Our_Work_/Blue_Cities_Initiative/Resources/CRWA_Stormwater_Trees_Urban_Environment.pdf.

CT- The City of Toronto. **2006:** Wet Weather Flow Management Guidelines. Toronto, Canada. Retrieved from 9/22/16 http://www1.toronto.ca/city_of_toronto/toronto_water/files/pdf/wwfm_guidelines_2006-11.pdf.

CT- The City of Toronto. **2016:** Mandatory Downspout Disconnection - Stormwater Management - Water | City of Toronto. Retrieved 9/22/16 from <http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=d-490ba32db7ce310VgnVCM10000071d60f89RCRD&vgnextfmt=default>.

Day, S.D and Dickinson, S.B. 2008: Managing Stormwater for Urban Sustainability Using Trees and Structural Soils. Blacksburg, VA.: Virginia Polytechnic Institute and State University. Retrieved 8/9/16 from <http://www.hort.cornell.edu/uhi/outreach/pdfs/TreesAndStructuralSoilsManual.pdf>.

DeepRoot. 2011a: Toronto Captures Rain on Downtown Streetscape Silva Cell Case Study: Bloor Street | DeepRoot Blog. Retrieved 8/12/16 from <http://www.deeproot.com/blog/blog-entries/toronto-captures-rain-on-downtown-streetscape-silva-cell-case-study-bloor-street>.

DeepRoot. 2011b: Stormwater and the Silva Cell System, Schematics. San Francisco: DeepRoot Green Infrastructure, LLC. Retrieved 5/31/16 from http://www.deeproot.com/silvapdfs/resources/standardDetails/Stormwater_Schematics.pdf.

DeepRoot. 2013: Planting Soil for Silva Cells. San Francisco: DeepRoot Green Infrastructure, LLC. Retrieved 5/31/16 from <http://www.deeproot.com/silvapdfs/resources/design/UK-PLANTING-SOIL-for-SILVA-CELLS.pdf>.

DeepRoot. 2014: Toronto Pioneers underground bioretention, Stormwater 'proof of Concept' Silva Cell Installation. San Francisco: DeepRoot Green Infrastructure, LLC. Retrieved 8/12/16 from http://www.deeproot.com/silvapdfs/caseStudies/Queens%20Way%20Case%20Study_New.pdf.

DIN- Deutsche Industrienorm. 2016: DIN kurz erklärt. Deutsche Industrienorme. Retrieved 8/21/16 from <http://www.din.de/de/ueber-normen-und-standards/basiswissen>.

Dr. Bauer, Joachim. 2015: Aktuelles Zur GALK-Straßenbaumliste. Deutsche Gartenamtsleiterkonferenz. Retrieved 6/21/16 from http://www.galk.de/arbeitskreise/ak_stadtbaeume/down/v_baumliste_bauer0606.pdf.

Drießelmann, Uwe. 2016: Interview with Uwe Drießelmann. Freie und Hansestadt Hamburg. Bezirksamt Wandsbek Dezernat für Wirtschaft, Bauen und Verkehr, Management des öffentlichen Raumes, Straßen-grün. 9/28/16 in Hamburg.

DWD-Deutscher Wetterdienst. 2016: Wetter Und Klima - Deutscher Wetterdienst - Hamburg (Flugh.). Retrieved 9/29/16 from http://www.dwd.de/DE/wetter/wetterundklima_vorort/schleswig-holstein_hamburg/hamburg/_node.html.

Embrén, Björn and Alvem, Britt-Marie. 2016: Interview with Björn Embrén and Britt-Marie Alvem. Stockholm Stad Trafikkontoret, Park och Stadsmiljö. 8/24/16 in Stockholm.

Embrén, Björn; Alvem, Britt-Marie; Stål, Örjan and Orvesten, Alf 2009: "Planting Beds in the City of Stockholm, A Handbook." Stockholm.

EUC- European Commission. 2016: Green Infrastructure - Environment - European Commission. Retrieved 10/25/16 from <http://ec.europa.eu/environment/nature/ecosystems/>.

Evans, Robert; Cassel, D. K. and Sneed, R. E. 1996: Soil, Water, and Crop Characteristics Important to Irrigation Scheduling. Publication Number: AG 452-1. North Carolina Cooperative Extension Service. Retrieved 10/7/16 from <https://www.bae.ncsu.edu/programs/extension/evans/ag452-1.html>.

FGSV- Forschungsgesellschaft für Straßen- und Verkehrswesen 2016: FGSV: Forschung. Retrieved 11/6/16 from <http://www.fgsv.de/forschung.html>.

FHH- Freie und Hansestadt Hamburg (editor). 2006a: Dezentrale Naturnahe Regenwasserbewirtschaftung. Ein Leitfaden für Planer, Architekten, Ingenieure und Bauunternehmer. Erneuerbare Energien & Umweltschutz. Behörde für Stadtentwicklung und Umwelt.

FHH- Freie und Hansestadt Hamburg (editor). 2006b. PLAST- Planungshinweise Für Stadtstraßen in Hamburg. Hamburg: Freie und Hansestadt Hamburg.

FHH- Freie und Hansestadt Hamburg (editor). 2012: Mein Baum- Meine Stadt. Behörde für Bau und Verkehr, Amt für Bau und Betrieb, Abteilung Gewässer. Retrieved 8/1/16 from http://www.galk.de/projekte/pr_down/Broschuere_MBmS_deutsch_2012.pdf.

FHH- Freie und Hansestadt Hamburg (editor). 2014a: Grüne, gerechte, wachsende Stadt am Wasser Perspektiven der Stadtentwicklung für Hamburg. Retrieved 6/27/16 from <http://www.hamburg.de/contentblob/4309812/data/broschuere-perspektiven.pdf>.

FHH- Freie und Hansestadt Hamburg. 2014b: Haushaltplan 2013/2014, Haushaltsjahr 2014 Sonderinvestitionsprogramm „Hamburg 2010“ (SIP). Niederschrift über Senatssitzung. Retrieved 9/25/11 from <http://suche.transparenz.hamburg.de/dataset/haushaltsplan-2013-2014-haushaltsjahr-2014-sonderinvestitionsprogramm-hamburg-2010-sip-1000-bae>.

FHH- Freie und Hansestadt Hamburg (editor). 2015a: Wissensdokument: Hinweise Für Eine Wassersensible Straßenraumgestaltung. Behörde für Wirtschaft, Verkehr und Innovation. Retrieved 10/23/16 from <http://www.hamburg.de/contentblob/4458538/data/wassersensible-strassenraumgestaltung.pdf>.

FHH- Freie und Hansestadt Hamburg (editor). 2015b: Arbeitshinweise Zum Vollzug Der Baumschutzverordnung und der dabei zu beachtenden artenschutzrechtlichen Vorschriften. Behörde für Stadtentwicklung und Umwelt. Retrieved 6/27/16 from http://www.galk.de/projekte/pr_down/leitfaden_vollzug_baumschutz_20150115.pdf.

FHH- Freie und Hansestadt Hamburg (editor). **2015c:** Gutachten Zur Broschüre 'Steigerung Der Biodiversität Im Städtischen Geschosswohnungsbau in Hamburg.' Behörde für Stadtentwicklung und Umwelt, Abteilung Naturschutz.

FHH- Freie und Hansestadt Hamburg. **2015d:** Fällliste Wandsbek. Bezirksamt Wandsbek. Retrieved 10/31/16 from <http://www.hamburg.de/contentblob/4802302/dd56caef63df5dffa793f2f1e7c867ec/data/download-pdf-baumfaelliste-strasse-2016.pdf>.

FHH- Freie und Hansestadt Hamburg. **2015e:** Strukturplan Regenwasser 2030, Für Ein Integriertes RegenWasserManagement (IRMW) in Hamburg. Ergebnisbericht des Projektes RISA- RegenInfraStrukturAnpassung. Hamburg. Retrieved 7/19/16 from <http://www.risa-hamburg.de/Downloadbereich.html>.

FHH- Freie und Hansestadt Hamburg. **2015f:** Merkblatt Zum Umgang Mit Baugrubenwasser. Behörde für Umwelt und Energie.

FHH- Freie und Hansestadt Hamburg. **2016a:** Fakten Zu Hamburgs Straßenbäumen." Retrieved 10/31/16 from <http://www.hamburg.de/strassenbaeume-online/5421342/strassenbaeume-online-fakten/>.

FHH- Freie und Hansestadt Hamburg. **2016b:** Das Bohrdatenportal Hamburg- Bohrungen GLA. Retrieved 9/29/16 from <http://www.hamburg.de/bohrdaten-geologie/>.

FHH- Freie und Hansestadt Hamburg. **2016c:** Geo-Online-Portal. Fachdaten- Umwelt und Klima- Straßenbaumkataster Hamburg. Retrieved 9/28/16 from <http://geoportal-hamburg.de/geoportal/geo-online/>.

FHH- Freie und Hansestadt Hamburg. **2016d:** Geo-Online- Portal. Fachdaten- Umwelt und Klima- Versickerungspotentialkarte Hamburg. Retrieved 9/27/16 from <http://www.geoportal-hamburg.de/Geoportal/geo-online/index.html>.

FHH- Freie und Hansestadt Hamburg. **2016e:** Stellungnahme Zum Antrag CDU Betr. Zusätzliche Mittel für Straßenbäume. Retrieved 9/25/16 from <https://sitzungsdienst-hamburg.de/bi/vo020.asp?VOLFDNR=1002717>.

FHH- Freie und Hansestadt Hamburg. **2016f:** Hamburg - Mehr Geld Für Straßenbäume. Hamburg.de. Retrieved 6/17/16 from <http://www.hamburg.de/pressearchiv-fhh/5627542/2016-03-29-bue-mehr-geld-fuer-strassenbaeume/>.

FHH- Freie und Hansestadt Hamburg. **2016g:** Fällliste MR Straßenbäume, Eimsbüttel. Bezirksamt Eimsbüttel. Retrieved 9/26/16 from <http://www.hamburg.de/contentblob/78990/e65c577ad68557d380a6876d0207fc08/data/baumfaelliste.pdf>

FHH- Freie und Hansestadt Hamburg. **2016h:** Halbjahresbericht 2016 Bericht Zur Entwicklung Der Hamburger Steuererträge und Schulden uum 2.Quartal 2016 sowie Stellungnahme des Senats. Retrieved 9/26/16 from <http://www.buergerschaft-hh.de/ParlDok/dokument/54038/halbjahresbericht-2016-bericht-zur-entwicklung-der-hamburger-steuerertr%c3%a4ge-und-schulden-zum-2-quartal-2016-sowie-stellungnahme-des-senats-zum.pdf>.

FHH- Freie und Hansestadt Hamburg. **2016i:** Problematik Hoher Grundwasserstände. Retrieved 9/28/16 from <http://www.hamburg.de/hohe-gw-staende/>.

FHH- Freie und Hansestadt Hamburg. **2016j:** Fachbehörden Landesregierung. Die Behörden der Freien Hansestadt Hamburg. Retrieved 9/28/16 from <http://www.hamburg.de/behoerden/3733948/fachbehoerden/>

FHH- Freie und Hansestadt Hamburg. **2016k:** Spendenkarte Mein Baum-Meine Stadt. Retrieved 7/15/16 from <http://www.hamburg.de/karte/>

FLL- Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V **2016:** Leistungsprofil. FLL- viele gute Gründe sichern Qualität für die Grüne Branche. Retrieved 10/28/16 from <http://www.fll.de/leistungsprofil.html>

GALK-Gartenamtsleiterkonferenz. **2011a:** Auswirkungen Des Einsatzes von Streusalz Auf Straßenbäume. Positionspapier. Arbeitskreis Stadtbäume.

GALK-Gartenamtsleiterkonferenz. 2011b: Verwendung von Nicht Heimischen Baumarten Am Innerstädtischen Straßenstandort. Positionspapier. Arbeitskreis Stadtbäume. Retrieved 7/6/16 from http://www.galk.de/projekte/pr_down/pospapier_heimischebaumarten_flyer1104.pdf.

GALK-Gartenamtsleiterkonferenz. 2016a: GALK - Strassenbaumtest II. Arbeitskreis Stadtbäume. Retrieved 7/20/16 from http://www.galk.de/arbeitskreise/ak_stadtbäume/webprojekte/sbtest/.

GALK-Gartenamtsleiterkonferenz. 2016b: Schadinsekten an Bäumen. Arbeitskreis Stadtbäume. Retrieved 9/26/16 from http://www.galk.de/projekte/akstb_schädlinge.htm.

GALK-Gartenamtsleiterkonferenz. 2016c: Sonderseite des Arbeitskreises Stadtbäume. Stadtbäume Im Klimawandel. Wetterextreme. Retrieved 6/20/16 from http://www.galk.de/projekte/akstb_klimabäume_0911.htm.

GALK-Gartenamtsleiterkonferenz. 2016d: GALK Straßenbaumliste. Juli 2016. Retrieved from 7/6/16 http://www.galk.de/arbeitskreise/ak_stadtbäume/webprojekte/sbliste/.

GC- Government of Canada. 2013: Canadian Climate Normals 1981-2010 Station Data - Climate - Environment Canada. Environment and natural resources. September 25. Retrieved 9/25/16 from http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=5051&lang=e&dCode=0&province=ONT&provBut=Go&month1=0&month2=12.

Goldy, Ron. 2016: More Reasons for Soil Testing. MSU Extension. Retrieved from 10/7/16 http://msue.anr.msu.edu/news/more_reasons_for_soil_testing.

Grüne Stadt. 2012: Bäume in Der Stadt, Wervolle Gestalten Im öffentlichen Grün. Stiftung DIE GRÜNE STADT. Retrieved 6/27/16 from <http://www.die-gruene-stadt.de/bäume-in-der-stadt.pdf>.

Hellberg-Rode, PD Dr. Gesine. 2016: Bodenart, Westfälische Wilhelms-Universität Münster. HyperSoil - Entwicklung einer hypermedialen Lern- und Arbeitsumgebung zum Themenfeld "Boden" im (Sach-) Unterricht. Retrieved 10/5/16 from <http://hypersoil.uni-muenster.de/0/03/06.htm>.

Holzapfel, Helmut. 2012: Urbanismus Und Verkehr: Bausteine Für Architekten, Stadt- Und Verkehrsplaner. 2.Auflage ed. Kassel: Springer.

HSH- Nordbank AG. 2015: HSH Nordbank AG | Studie: Hamburg Steht in Fünf Jahren Vor Verkehrs-Kollaps. Retrieved 9/28/16 from https://www.hsh-nordbank.de/de/presse/pressemitteilungen/2015/press_release_detail_6748672.jsp.

HW- Hamburg Wasser. 2016a: Hamburg Wasser - Gebührensplitting. Retrieved 7/30/16 from <http://www.hamburgwasser.de/gebuehrensplitting.html>.

HW- Hamburg Wasser. 2016b: Hamburg Wasser - Gebührensplitting: Abminderung Der Anrechenbaren Flächen Bei Der Erhebung von Niederschlagswassergebühren. Retrieved 9/28/16 from <http://www.hamburgwasser.de/gebuehrensplitting-1.html>.

HW- Hamburg Wasser. 2016c. Hamburg Wasser - Geschichte. Retrieved 10/12/16 from <https://www.hamburgwasser.de/geschichte.html>.

HW- Hamburg Wasser. 2016d. Hamburg Wasser - Abwasserableitung." Retrieved 9/28/16 from <https://www.hamburgwasser.de/abwasserableitung.html>.

Jeschke, Roland. 2011: Thermisch Rindenschäden an Bäumen - Erfahrungen Der Letzten Zehn Jahre. PRO Baum 1|2011. Retrieved from 8/4/16 <https://www.fluegel-gmbh.de/download/ProBaum1-2011.pdf>.

KLIMZUG-NORD (editor). 2014. Kursbuch Klimaangepassung. Handlungsoptionen Für Die Metropolregion Hamburg. Hamburg: TuTech Verlag. Retrieved 6/27/16 from <http://klimzug-nord.de/file.php/2014-03-20-KLIMZUG-NORD-Verbund-Hrsg.-2014-Kursbuch-Klimaangepassu>.

Konijnendijk, Dr. Cecil and Forrest, Mary. 2005: Urban Forests and Trees. Edited by Dr. Kjell Nilsson, Dr. Thomas Randrup, and Dr. Jasper Schipperijn. Heidelberg: Springer.

Kruse, Elke. 2014: Integriertes Regenwassermanagement für den Wassersensiblen Umbau von Städten. Hamburg: Hafencity Universität. Retrieved 6/28/16 from http://edoc.sub.uni-hamburg.de/hcu/volltexte/2015/225/pdf/E_Book_Elke_Kruse_IRWM.pdf.

Kück, Ulrick and Wolff, Gabriele. 2014: Botanisches Grundpraktikum, Die Wurzel. 3.Auflage ed. Heidelberg: Springer Spektrum Akademischer Verlag.

Kühne, Norbert Prof. Dr. 2016: Stadtnortgerechte Pflanzenverwendung Als Antwort Auf Den Klimawandel. presented at the Leitthema "Grün in der Stadt," Fulda, June 24.

Lehmann, Andreas and Stahr, Karl. 2007: Nature and Significance of Anthropogenic Urban Soils. Anthopogenic Urban Soils. Institute of Soil Science and Land Evaluation (310), University of Hohenheim, 70593 Stuttgart, Germany.

Leuzinger, Sebastian; Vogt, Roland and Körner, Christian 2009: Tree Surface Temperature in an Urban Environment. Agric. Forest Meteorol. Retrieved 8/4/16 from https://plantecology.unibas.ch/pdf/2009leuzinger_vogt_koerner.pdf.

Lösken, Prof. Dipl.-Ing. Gilber; Schitteck, Prof. Dipl.-Ing. and Wolschke-Bulmahn, Prof. Dipl.-Ing. J. 1999: Stanortoptimierung Für Die Pflanzung von Straßenbäumen - Zwischenergebnisse von Langzeitversuchen." Jahrbuch der Baumpflege. Jüngbäume: Standort-Pflanzung-Pflege. Institution für Grünplanung und Gartenarchitektur, Universität Hannover.

LVE- Lorenz von Ehren. 2016: Stadtbäume, Fit Für Die Zukunft. Baum-schule Lorenz von Ehren, Hamburg.

LWG-Bayrische Landesanstalt für Weinbau und Gartenamt. 2014a: Abschlussbericht Stadtgrün 2012-2014. Veitshöchheim. Retrieved 7/22/16 from https://www.lwg.bayern.de/mam/cms06/landespflege/dateien/kl_12_02_abschlussbericht_stadtgruen_2014.pdf.

LWG- Bayrische Landesanstalt für Weinbau und Gartenamt. 2014b: Straßenbaumarten Und Ihre Ansprüche an Den pH-Wert. Veitshöchheim. Retrieved 8/2/16 from https://www.lwg.bayern.de/mam/cms06/landespflege/dateien/baeume_phwert.pdf.

LWG- Bayrische Landesanstalt für Weinbau und Gartenamt. 2016: Stadtgrün 2021: Neue Bäume Braucht Das Land!. Retrieved 7/21/16 from https://www.lwg.bayern.de/landespflege/urbanes_gruen/085113/index.php.

LWG- Bayrische Landesanstalt für Weinbau und Gartenamt. 2004: Mirkokosmos Bodenleben: Verteilungskämpfe Oder Miteinander. PRO Baum 2|2004: S. 26.

Mayr, Stefan. 2011: Trockenstree: Bäume Unter Druck. PRO Baum 3|2011.

McMillan, Helen and Small, John. 2016: Impact of Soil Acidity on Crop Yield and Management in Central Western NSW. Retrieved 8/10/16 from <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Soil-acidity-Crop-yield-impacts-and-management-in-Central-Western-NSW>.

Moser, Martin. 2016: Landscape Gardener and Landscape Architect, Hagg-Moser Gardening and Landscaping company. By email and telephone 8/9/2016.

Meinke, Dr. Insa and Klepgen, Jessica. 2016: Stadtklima: Beispiel Hamburg. Regionales Klimabüro. Retrieved 10/9/16 from <http://www.klimanavigator.de/dossier/artikel/035856/index.php>.

MW- Melbourne Water Corporation. 2013: Water Sensitive Urban Design Guidelines South Eastern Councils. Melbourne. Retrieved 10/31/16 from <http://www.melbournewater.com.au/planning-and-building/forms-guidelines-and-standard-drawings/documents/south-eastern-councils-wsud-guidelines.pdf>.

NDKB-Norddeutsches Klimabüro. 2016: Schleswig-Holstein, Hamburg: Mögliche Mittlere Änderung Der Starkregentage (10 Mm) Im Jahr Bis Ende Des 21. Jahrhunderts (2071-2100) Im Vergleich Zu Heute (1961-1990): Unklar | Regionaler Klimaatlas Deutschland. Retrieved 10/9/16 from <http://www.regionaler-klimaatlas.de/klimaatlas/2071-2100/jahr/starkregentage-10-mm/schleswig-holstein-hamburg/mittlereanderung.html>.

NWSFO-NY- National Weather Service Forecast Office, New York. 2010: National Weather Service Climate." National Weather Service Corporate. Retrieved 9/24/16 from <http://w2.weather.gov/climate/xmacis.php?wfo=okx>.

NYC- New York City. 2012: Guidelines for the Design and Construction of Stormwater Management Systems. Developed by the New York City Department of Environmental Protection in consultation with the New York City Department of Buildings. New York: NYC Environmental Protection. Retrieved 8/16/16 from http://www.nyc.gov/html/dep/pdf/green_infrastructure/stormwater_guidelines_2012_final.pdf.

NYC- New York City. 2014: Tree Planting Standards." New York City: City of New York, Parks & Recreation. Retrieved 8/2/16 from <https://www.nycgovparks.org/pagefiles/53/Tree-Planting-Standards.pdf>.

NYC- New York City. 2016: Standard Designs and Guidelines For Green Infrastructure Practice. City of New York, Department of Environmental Protection Office of Green Infrastructure. Retrieved 9/29/16 from http://www.nyc.gov/html/dep/pdf/green_infrastructure/bioswales-standard-designs.pdf.

Pramsten, Joakim and Vall, Eva. 2016: Water System of the City of Stockholm. email contact 08/30/16, 09/01/16.

Reichwein, Dr. Sabine. 2009: Zum Umgang Mit Baumwurzeln Unter Wegebölen Aus Bau- Und Vegetationstechnischer Sicht." Allentagung der BUND Dipl.-Ing. Landschafts- und Freiraumplanung, Hannover. Grüne Tunnel- Lebensader- Haben Die Alleen In Deutschland Eine Zukunft. Potsdam: BUND Mecklenburg-Vorpommern. Retrieved 10/26/16 from http://www.bund-mecklenburg-vorpommern.de/uploads/media/Dr._Sabine_Reichwein.pdf.

RKB-Regionales Klimabüro. 2016: Schleswig-Holstein, Hamburg: Mögliche Mittlere Änderung Der Starkregentage (10 Mm) Im Jahr Bis Ende Des 21. Jahrhunderts (2071-2100) Im Vergleich Zu Heute (1961-1990): Unklar | Regionaler Klimaatlas Deutschland. Retrieved 10/9/16 from <http://www.regionaler-klimaatlas.de/klimaatlas/2071-2100/jahr/starkregentage-10-mm/schleswig-holstein-hamburg/mittlereanderung.html>.

Roloff, Andreas. 2010: Bäume: Lexikon Der Praktischen Baumbiologie. 2.Auflage ed. Weinheim: Wiley-VCH.

Roloff, Andreas. 2013: Bäume In Der Stadt: Besonderheiten, Funktion, Nutzen, Arten, Risiken. Stuttgart: Ulmer UTB.

Roloff, Andreas; Bonn, Stephan and Gillner, Sten. 2010: Klimawandel Und Baumartenwahl In Der Stadt- Entscheidungsfindung Mit Der Klimate-Arten-Matrix (KLAM). Retrieved 7/8/16 from https://www.frankfurt.de/sixcms/media.php/738/klam_stadt.pdf.

Ruschke, Philipp. 2016: Landscape Architect, Hamburg, By telephone 9/9/2016.

Sander. 2016: Der Klimabaum-Katalog. Tornesch: Baumschule E.Sander.

Schneidewind, Dr. Axel. 2010: Stammanstrich Als Thermischer Und Mechanischer Rindenschutz Für Jungbäume Am Endstandort. Quedlinburg: Aktuelles Fachwissen GalaBau.

Schopfer, Peter and Brennicke, Axel. 2010. Pflanzenphysiologie. 7. Auflage. Heidelberg: Springer Spektrum Akademischer Verlag.

Schrader, Meno. 2016: Klima Im Wandel Der Zeit. presented at the ACO Klimawandel: Herausforderung für die Zukunft urbaner Räume, LGS Eutin, Orangerie, June 14.

Sieker. 2016: Begriffe Der RW-Bewirtschaftung. Sieker. Retrieved 8/1/16 from <http://www.sieker.de/de/fachinformationen/umgang-mit-regenwasser/article/begriffe-der-rw-bewirtschaftung-77.html>.

Sieker, Dr. F.; Sieker, Dr. H.; Zweynert, U. and Schlottmann, P. 2009: Konzept Für Bundeseinheitliche Anforderungen And Die Regenwasserbewirtschaftung. Dessau-Roßlau. Retrieved 8/1/16 from <https://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/3815.pdf>.

Sieker, Friedhelm; Kaiser, Mathias and Sieker, Heiko. 2006: Dezentrale Regenwasserbewirtschaftung Im Privaten, Gewerblichen Und Kommunalen Bereich; Grundlagen Und Ausführungsbeispiel. Stuttgart: Fraunhofer IRB Verlag.

SMHI- Swedish Meteorological and Hydrological Institute. 2016a. Climate Indicators - Extreme Areal Precipitation. Retrieved 9/25/16 from <http://www.smhi.se/en/climate/climate-indicators/climate-indicators-extreme-areal-precipitation-1.91476>.

SMHI- Swedish Meteorological and Hydrological Institute. **2016b:** Climate Indicators - Precipitation. Retrieved 9/25/16 from <http://www.smhi.se/en/climate/climate-indicators/climate-indicators-precipitation-1.91462>.

SMHI- Swedish Meteorological and Hydrological Institute. **2016c:** Climate Indicators - Temperature. Retrieved 9/25/16 from <http://www.smhi.se/en/climate/climate-indicators/climate-indicators-temperature-1.91472>.

Spehl, Prof. Dr. H. and **Gensheimer**, Dipl.-Geogr. M. **2006:** Universität Trier. Fachbereich IV - Volkswirtschaftslehre. Materielle und soziale Infrastruktur, WS 2006/2007. Wasserversorgung in Deutschland - staatlich oder privat?. Retrieved 9/10/16 from <https://www.uni-trier.de/fileadmin/fb4/prof/VWL/SUR/Lehre/WS0607/SeminarInfrastruktur/privat/Leistungsnachweise/HA/Wojtalla.pdf>

Spokas, Kurt A. **2016:** Biochar. United States Department of Agriculture, Agricultural Research Service. Retrieved 10/17/16 from <https://www.ars.usda.gov/midwest-area/st-paul-mn/soil-and-water-management-research/people/kurt-spokas/biochar/>.

Stockholms Stad. **2016:** Organisation of the City of Stockholm. Retrieved 15/17/16 from <http://www.stockholm.se/OmStockholm/Forvaltningar-och-bolag/>. and <http://www.stockholm.se/TrafikStadsplanering/>.

TDAG- Trees & Design Action Group. **2014.** Trees in Hard Landscape- A Guide for Delivery. London.

TEEB-Naturkapital Deutschland. **2016:** Ökosystemleistungen in Der Stadt, Gesundheit Schützen Und Lebensqualität Erhöhen. Berlin, Leipzig: Naturkapital Deutschland- TEEB.de. Retrieved 8/7/16 from http://www.naturkapital-teeb.de/fileadmin/Downloads/Projekteigene_Publicationen/TEEB_Broschueren/TEEB_DE_Stadtbericht_Langfassung.pdf.

Titel, Selina. **2016:** Institut für Bodenkunde, Universität Hamburg, Centrum für Erdsystemforschung und Nachhaltigkeit (CEN), Partner im KlimaCampus Hamburg. By email and personal meeting 7/15/16 in Hamburg.

TUD- Technische Universität Dresden. **2016:** Citree - Gehölze Für Urbane Räume. Gehölze Für Urbane Räume, Planungsdatenbank. Retrieved 10/26/16 from <http://citree.ddns.net/>.

US EPA- United States Environmental Protection Agency. **2014:** Green Infrastructure Implementation Strategy for the Town of Franklin, Massachusetts. Retrieved 10/12/16 from <https://www.epa.gov/green-infrastructure>.

Vieth, Harald. **1995:** Hamburger Bäume, Zeitzeugen Der Stadtgeschichte. Hamburg: Selbstverlag Harald Viet.

Wahli, Volker; **Geiger**, Gregor and **Kahle**, Katja. **2016:** Interview mit Baummanagement Hamburg. Dipl. Biol. Volker Gantke - Baumgutachten und Baumkontrolle. 8/1/16 in Hamburg.

Waterfront Toronto. **2014:** Queens Quay Construction Fact Sheet." Toronto. Retrieved 8/9/12 from http://www.waterfronttoronto.ca/uploads/documents/qq_fact_sheet_oct_2014_1.pdf.

WDR. **2016:** Tödlicher Unfall: Auto Kracht Gegen Baum - Nachrichten - WDR. Retrieved 8/7/16 from <http://www1.wdr.de/nachrichten/toedlicher-unfall-hopsten-100.html>.

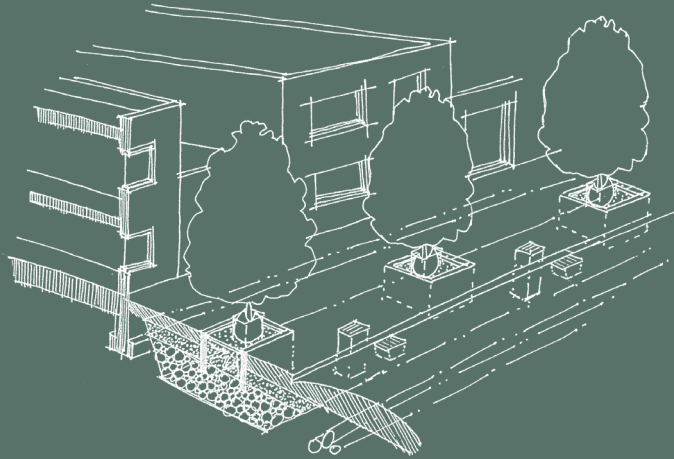
Wiesner, Sara; **Gröngroft**, Alexander; **Ament**, Felix and **Eschenbach**, Anette. **2016:** Spatial and Temporal Variability of Urban Soil Water Dynamics. Hamburg: Springer.

Wilderotter, Hans, and Dormmann, Michael (editors). **1995.** Das Große Sterben: Seuchen Machen Geschichte. Deutsches Hygiene-Museum Dresden: Jovis.

WZ- Westdeutsche Zeitung. **2015:** Unfall: Feuerwehr Birgt Schwerverletzte. Westdeutsche Zeitung. Retrieved 8/7/16 from <http://www.wz.de/lokales/duesseldorf/unfall-feuerwehr-birgt-schwerverletzte-1.1861638>.

Zeitz, Prof. Dr. Jutta. **2003:** Einführung in Die Bodenkunde. Online-Modul. Humboldt Universität. Retrieved 10/20/16 from https://www.bodenkunde-projekte.hu-berlin.de/boku_online/pcboku10.agrar.hu-berlin.de/cocoon/boku/sco_7_chemie_22d03f.html?section=uv100CO.

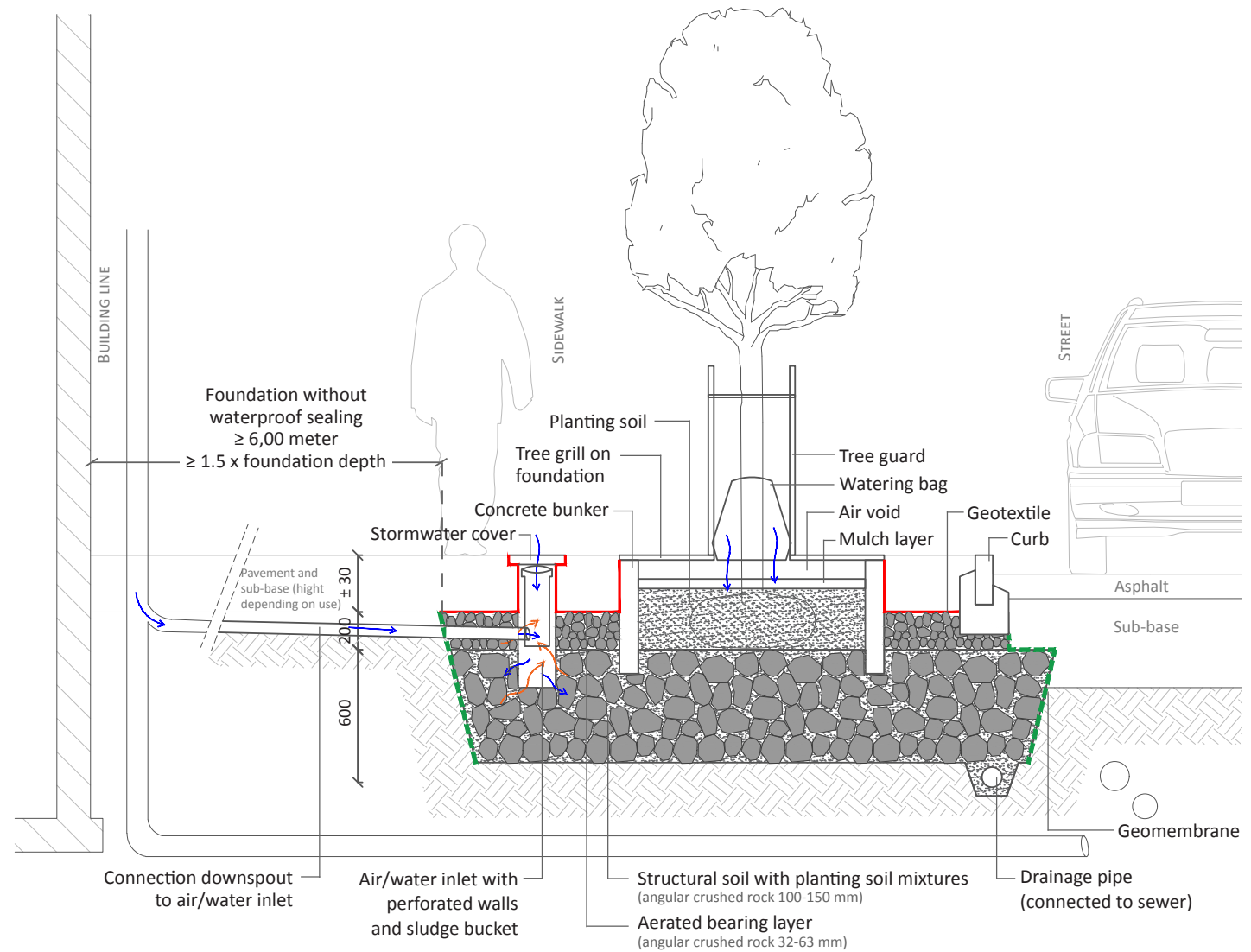
ADVANCED URBAN TREES



An advanced system of urban tree pits

Urban trees as part of the solution for decentralized stormwater management and climate change

Stormwater interception from roofs and sidewalks



Section: Technical drawing of advanced system of tree pit (without scale)

Further information and detailed construction process in the research paper.

Watering bag

Watering bags are wrapped around the trunk and filled with water (~ 90 Liters/bag) serve for slow release irrigation (5-10 h) through the micro release points at the bottom. They must be filled regularly (1-2x per week) according to the weather and soil conditions of the site.

Tree guard

During the first years the tree must be tied in with a rubber tree strap to a double or triple staking with a height of 1,20m as a temporary protection. Otherwise, an underground anchorage system can be installed, which serves as a short- and long-term protection. In addition a tree guard (cast iron) should be installed to protect the stem as a bumper buffer against vehicles and locked bicycles.

Tree grate

The tree grate is at the same height level as the pavement. It can be manufactured of different materials (cast or galvanized iron) or a self-supporting grate, which can be paved with natural/concrete stones or slabs. The rollover capacity must be adapted to the use of the area. A specific cover can reduce the grate opening, which is removable with the trunk growth.

Sub-base and pavement

The sub-base and pavement has to be calculated to the load class of the urban use according to the guidelines PLAST and FGSV RSTO 499. The pavement is at the same height level as the tree grate.

Air void layer

The air void *layer* is open space between the tree grate and the mulch layer, which is positioned 100 mm below the grate. Within that space, debris from the surface can accumulate, which sometimes heaves the tree grate if it is placed directly on the planting soil. With the air void, the debris and dust causes no uneven pavement anymore and can be cleaned regularly. Nevertheless, the opening of the tree grate should be closed as much

as possible (e.g. with tree rings) that it is not used as a trash bin. In addition the air void is a protection for the exposed root collar (transition of root system and stem).

Concrete bunker

The concrete bunker is a square curbstone between the base and the adjacent pavement, which directs roots downwards to prevent from growing into the sub-base and heaving of pavement. The root ball is positioned in the concrete bunker and filled with planting soil.

Air and water inlet

The air inlet guarantees the gas exchange of oxygen and the release of carbon dioxide and nitrogen between the soil and the atmosphere. To guarantee the vertical ventilation it must reach into the structural soil. The horizontal exchange operates through the two layers, aerated bearing layer and structural soil. The air inlet can be a specific manufactured component or an extended road gully, a pipe (diameter of 200-300mm) installed vertically or an extended drain, which is used for green roofs. In any case, the air inlet must be perforated to guarantee the gas exchange. It should also meet the requirements of the load-bearing capacity. Additionally it serves as a water inlet, which directs and distributes stormwater into the layers. A filter must be installed if stormwater from streets is intercepted to remove pollutants and other contaminations such as de-icing salt.

Planting soil

The planting soil is hosed into the compacted structural soil. The mixture of different soil types depends on the location conditions and the requirements of the infiltration capacity to prevent a too high infiltration capacity and on the other hand excess water. The organic matter should be between 1-3 percent in order to secure an initial nutrient content. A slow-release fertilizer should be added during construction. The use of biochar is a good possibility to increase the nutrient and water holding capacity.

Geotextile

The Geotextile is laid on the aerated layer to prevent fines (e.g. debris, waste) from entering the voids of the aerated layer and block them. It must be wrapped around the air inlet and the concrete bunker.

Aerated bearing layer (200mm)

The aerated bearing layer constructed of 32-62 mm angular crushed rocks (e.g. granite, recycled concrete) is laid on the structural soil and compacted after installation. It serves for the upper load bearing layer and the horizontal gas exchange.

Structural soil (600mm)

The structural soil constructed of 100-150 mm angular crushed rocks (e.g. granite, recycled concrete) is laid and compacted in layers of 200 mm. It serves as the main load-bearing layer and provides voids for the planting soil and root growth.

Geomembrane/ root barrier

The geomembrane must be installed vertically between the advanced system and the existing underground utilities (especially water pipes) to prevent roots from growing into the pipes. If new pipes are installed the geomembrane should be wrapped around the pipes including a warning tape.

Drainage pipe

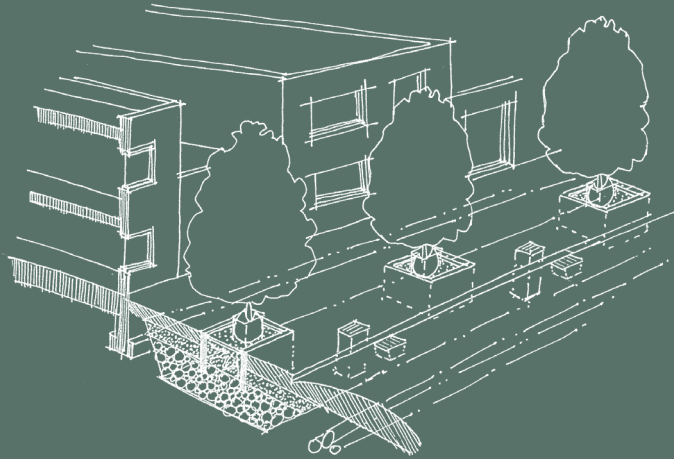
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Master 's thesis by Carmen Biber

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Drawing cover page: Paula A. Callaú Poduje
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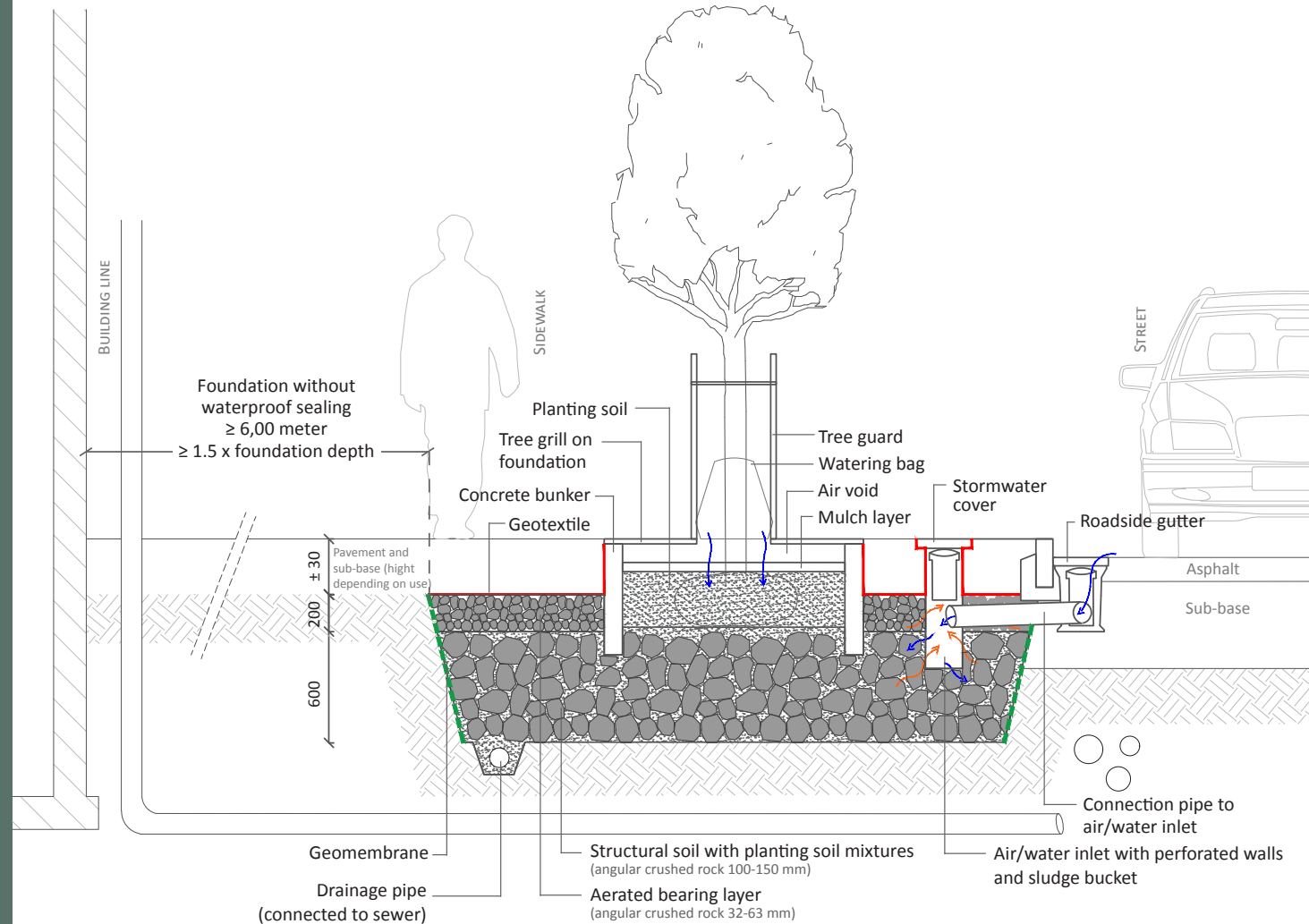
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