# Nature-based Solutions

## Technical Handbook Factsheets

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INSTITUT FÜR
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UND ÖKOLOGIE

# Content

# List of abbreviations

| | |
|---|---|
| BVOC | Biogenic volatile organic compound |
| CWR | Constructed wet roof |
| EC | European Commission |
| Fig. | Figure |
| FHG | Fraunhofer |
| ha | Hectar |
| m | Meter |
| NBS | Nature-based solutions |
| P1-P8 | Performance indicator 1 - Performance indicator 8 |
| STU | University of Stuttgart |
| SUDS | Sustainable drainage systems |
| UAV | University of Aveiro |
| UNaLab | Urban Nature Labs project |
| VTT | Technical research center of Finland |

# List of icons

Climate resilience, performance indicator P1: Cooling services


Public health and well being

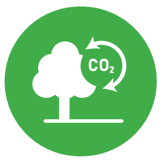

Water management, performance indicators P2 & P3: Water balance and purification services


Social justice, cohesion and performance indicator P6: Amenity value services


Natural hazards and other related impacts


Performance indicator P7: Food, energy and materials


Air quality and performance indicator P4: Air purification services



Performance indicator P8: Carbon sequestration


Biodiversity and performance indicator P5: Biodiversity services

# About the Urban Nature Labs (UNaLab) Project

The UNaLab project is contributing to the development of smarter, more inclusive, more resilient, and more sustainable urban communities through the implementation of nature-based solutions (NBS) co-created with and for local stakeholders and citizens. UNaLab's three Front-Runner Cities – Eindhoven (The Netherlands), Genova (Italy), and Tampere (Finland) – have a strong commitment to smart, citizen-driven solutions for sustainable urban development. The establishment of Urban Living Lab innovation spaces in Eindhoven, Genova, and Tampere supports on-going co-creation, demonstration, experimentation, and evaluation of a range of different NBS targeting climate change mitigation and adaptation, along with the sustainable management of water resources.

The Front-Runner Cities actively promote knowledge- and capacity-building in the use of NBS to enhance urban climate and water resilience within a network of committed partner cities, including seven Follower Cities – Stavanger (Norway), Prague (Czech Republic), Castellón (Spain), Cannes (France), Başakşehir (Turkey), Hong Kong, and Buenos Aires (Argentina) – and the Observers, Guangzhou (China) and the Brazilian Network of Smart Cities. Collaborative knowledge production among this wide network of cities enables UNaLab project results to reflect diverse urban socio-economic realities, along with differences in the size and density of urban populations, local ecosystem characteristics, and climate conditions.

# Introduction

The following Nature-based Solutions (NBS) Factsheets were originally developed for UNaLab's Nature Based Solutions Technical Handbook. The original version of the handbook was created at the beginning of the UNaLab project in 2018 by University of Stuttgart's Institute for Landscape Planning and Ecology (STU, ILPÖ) in an iterative process together with the University of Aveiro (UAV), the Technical Research Centre of Finland (VTT), Fraunhofer (FHG), and the front-runner cities of Eindhoven, Genova, and Tampere [1]. Its main objective was to provide front-runner cities with accurate information about potentially applicable NBS to support climate and water resilience, and therefore facilitate informed decision making during the NBS co-creation process.

Since the publication of the first version of the NBS Technical Handbook in 2018, the European Commission (EC) has adopted a more robust definition of NBS with a greater emphasis on biodiversity. The EC currently defines NBS as follows:

> "Nature-based solutions to societal challenges are solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systematic interventions. Nature-based solutions must therefore benefit biodiversity and support the delivery of a range of ecosystem services" [2].

The NBS Technical Handbook was periodically updated throughout the UNaLab project as the field of NBS and the project itself progressed. Rather than offer an exhaustive catalogue and summaries of all existing NBS, the NBS Technical Handbook Factsheets aim to provide inspiration and easily digestible information directed towards practitioners. Because of this focus on practitioners, the NBS Factsheets were originally organized according to planning and construction terminology. However, since the publication of the first version of the NBS Technical Handbook in 2018, a unified classification system for NBS has been adopted by the European Commission [3], and is used in other recent UNaLab documents. Therefore, the following NBS Factsheets are now organized following this unified classification system.

According to this new classification system, there are three main types of NBS that are categorized by function and increasing level of ecosystem intervention, with Type 1 involving the least intervention, and Type 3 the greatest amount of ecosystem intervention [3]. All NBS described in the Technical Handbook Factsheets are Type 3: Highly intensive ecosystem management or the creation of new ecosystems. Type 3 NBS are further subdivided into seven main categories: Green space, trees and shrubs, soil conservation and quality management, blue-green space establishment or restoration, green built environment, natural or semi-natural water storage and transport structures, and infiltration, filtration and biofiltration structures. Six of these categories are represented in the NBS Technical Handbook Factsheets and are organized into the following chapters:

01 Green space
02 Trees and shrubs
03 Soil conservation and quality management
04 Green built environment
05 Natural or semi-natural water storage and transport structures
06 Infiltration, filtration and biofiltration structures

For the final version of the Technical Handbook Factsheets, each NBS Factsheet is structured in a semi-tabular layout to ensure comparability between methods, general benefits, and performances. Each NBS Factsheet is structured as follows:

i. Basic information
   *What kind of NBS is considered and what challenges does it address?*
ii. Role of nature
   *How is the NBS inspired by or make use of nature?*
iii. Technical and design parameters
   *What are the main technical and design considerations?*
iv. Conditions for implementation
   *Which site conditions should be considered?*

v. Benefits and limitations
*How does it contribute to or limit the functionality of urban ecosystems?*

vi. Performance
*What is the performance of the NBS with regard to the following performance indicators established according to ecological services: P1 cooling service; P2 water balance and regulation service; P3 water purification service; P4 air purification service; P5 biodiversity service; P6 amenity value service; P7 food /energy/ material services; P8 carbon sequestration service.*

vii. References and further reading
*Which sources were used to develop the factsheet?*

Workpackages 3 and 5 of the UNaLab project developed a set of indicators for measuring the performance of NBS in general, as well as on the city and neighborhood or project level. The general NBS indicators try to ascertain what can be measured in different cities to compare overall performance. For example, the indicator "heat reduction" at the city scale is measured by the temperature difference between the inner city heat island effect and the surrounding rural areas. After implementation of the NBS, effectiveness can be measured by comparing the temperature difference of city and rural areas before and after implementation [4].

Evaluating the overall success of NBS in a city can be done with these performance indicators, however, a different form of evaluation is needed to identify differences between various NBS. Therefore, a detailed performance evaluation was created for the NBS Technical Handbook Factsheets based on ecological services and processes. Eight relevant ecological services in terms of NBS performance indicators (see P1-P8 above) with 23 specifications were selected for the performance evaluation. For example, P5 biodiversity service has two associated specifications: Habitat provision and connectivity. While slightly different than the previously mentioned general indicators for measuring NBS performance, each of the services and specifications can be related back to the key performance indicators [4] at the city or neighborhood level.

As NBS performance is dependent on the climate and geomorphological conditions (e.g., soil conditions, slope and aspect of a surface, etc.) of each city or even site, a location-specific evaluation of NBS considering all relevant factors would be ideal. However, this is not feasible for all three UNaLab front-runner cities and five follower cities for each permutation of conditions, and is outside the scope of the NBS Technical Handbook Factsheets. Therefore, a panel of experts, following a general approach, evaluated the potential performance of each NBS in suitable conditions. The performance under suitable conditions is rated as very good (●●), good ( ●○), or is not applicable ( ○○).

The NBS Technical Handbook Factsheets were fundamentally a "living document" whose purpose and construction continued to evolve with the progression of the UNaLab project. For example, while its original intent was to provide information about potentially applicable NBS to front-runner cities, so called "Inspiration Cards" were developed from the NBS Technical Handbook and used in Road Mapping Workshops to inform follower cities about NBS relevant to their identified challenges. The NBS Technical Handbook Factsheets are now publically available in their final form to move beyond the UNaLab cities and offer inspiration to other cities and practitioners interested in NBS. To this end, information from the NBS Technical Handbook Factsheets was also used in the production of the NBS Replication Framework - an online resource built using the knowledge produced within the UNaLab project to support the continued implementation and upscaling of NBS in cities and municipalities after the culmination of the UNaLab project (www.unalab.eu).

# 1. Green space

Fig 1.0 Residential park in Stuttgart, Germany.

The importance of rus in urbe (translated: country in the city) has been recognized since the ancient Romans began incorporating natural elements and green spaces into their cities for recreation and leisure [5]. For many centuries, however, urban green spaces were largely private with restricted access. While some European cities began opening palace gardens and parks to the general public in the 16th and 17th centuries [6], public green spaces were relatively uncommon until the rise of the urban park in the 19th century. Although the design and objectives of parks have evolved over the past centuries, they remain a fundamental part of the urban green infrastructure and are an essential component of healthy and resilient cities.

In an integrated system, often connected by tree lined streets or green corridors, green spaces serve as the backbone of urban green infrastructure and support many of the beneficial services that nature can provide in cities including positive effects for urban climate, human health, recreation, and biodiversity. Urban green spaces are categorized according to size, catchment area, services provided, and urban design aspects. Three examples of green spaces (i.e., residential parks, green corridors, and urban gardens) are described in more detail below.

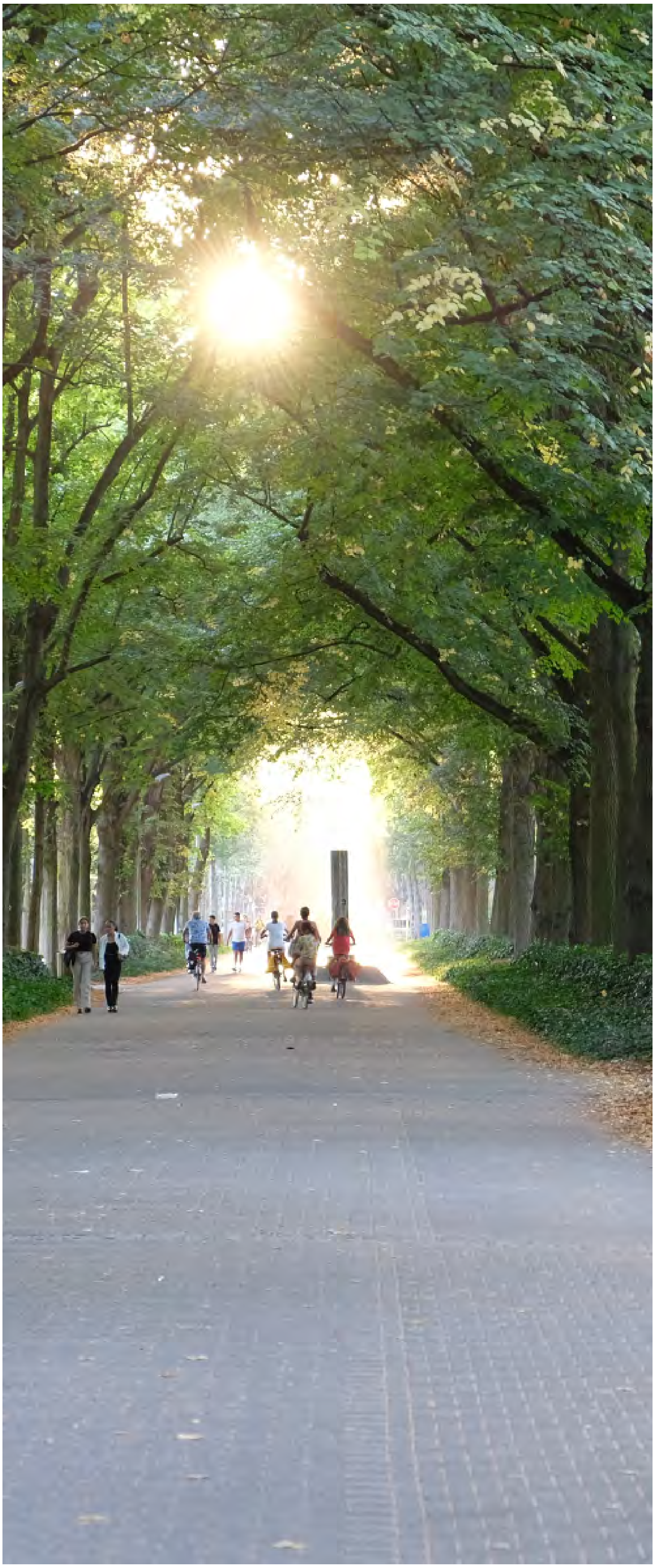


Fig 1.1 Residential park in Antwerp, Belgium.

# 1.1 Residential park

Residential and urban parks are essential components of the green infrastructure of cities. For many people, they are often the nearest and most convenient green space for nature interaction and nature-based recreation. Larger spatial elements of green infrastructre are district parks that often have greater multifuntionality by combining various uses (e.g., sport fields or other NBS like water retention basins). Playgrounds, connecting green strips of land, and pocket parks are examples of smaller spatial elements of green infrastructure that can also be classified as residential parks.

## I. Basic information

Synonyms: Urban park; Pocket park; Parklet

Addressed challenges:

Climatic resilience | Water management | Natural & climatic hazards | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

## II. Role of nature

The residential park acts like an oasis in an urban environment, with positive effects for urban climate, recreation, and biodiversity that extend into the neighbouring residential areas.

## III. Technical and design parameters

The design of residential parks is relatively flexible, but they should be well connected with other natural areas or natural elements, and be easily accessible to residents and pedestrians. Typically, parks are at least 1.5 ha size and have a compact form (e.g., 120 m x 20 m) with a high proportion of trees or a small forest (> 50 % canopy cover), and few sealed surfaces. The layout of the typical London Residential Park with a central open area surrounded by trees and shrub lined streets and paths can be seen as a model, however, the specific ecological conditions, as well as the needs and desires of the community, should be considered in the design process.

Pocket parks are a good alternative where space is limited. These urban parks are typically around 1200 $m^2$ (no greater than 5000 $m^2$) and can offer similar, although smaller-scale, benefits as larger urban parks.

## IV. Conditions for implementation

New urban development areas allow for the establishment of residential parks at the most suitable location, thereby maximizing the effects on urban climate, storm water management, and biodiversity. However, the establishment of new parks or improving existing parks (e.g., in urban regeneration projects) can also provide many benefits with proper planning. Spatially equal distribution of high-qualtiy parks is important to maximize their impact on the urban climate, biodiversity, and residents.

## V. Benefits and limitations

⊕ Potential benefits:

- Residential parks are multifunctional and deliver all benefits of green infrastructure.

⊖ Potential limitations / disservices:

- Accessibility and equitable distribution is a key factor for the success of residential parks.

## VI. Performance

### P1 Cooling service

| | |
|---|---|
| Transpiration | ● ● |
| Shading | ● ● |
| Evaporation | ● ● |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ● ● |

### P2 Water balance regulation service

| | |
|---|---|
| Water conveyance | ● ● |
| Water infiltration | ● ● |
| Water retention | ● ● |
| Water storage | ● ● |
| Water reuse | ○ ○ |

### P3 Water purification service

| | |
|---|---|
| Water filtering | ● ● |
| Water bio-remediation | ○ ○ |

### P4 Air purification service

| | |
|---|---|
| Deposition | ● ● |
| Air biofiltration | ● ● |
| Noise reduction | ○ ○ |

### P5 Biodiversity service

| | |
|---|---|
| Habitat provision | ● ● |
| Connectivity | ● ● |

### P6 Amenity value service

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ● |
| Social interaction | ● ● |
| Education | ○ ○ |

### P7 Food / Energy / Material

| | |
|---|---|
| Food / Energy / Material | ● ○ |

### P8 $CO_2$ Sequestration

| | |
|---|---|
| $CO_2$ Sequestration | ● ○ |

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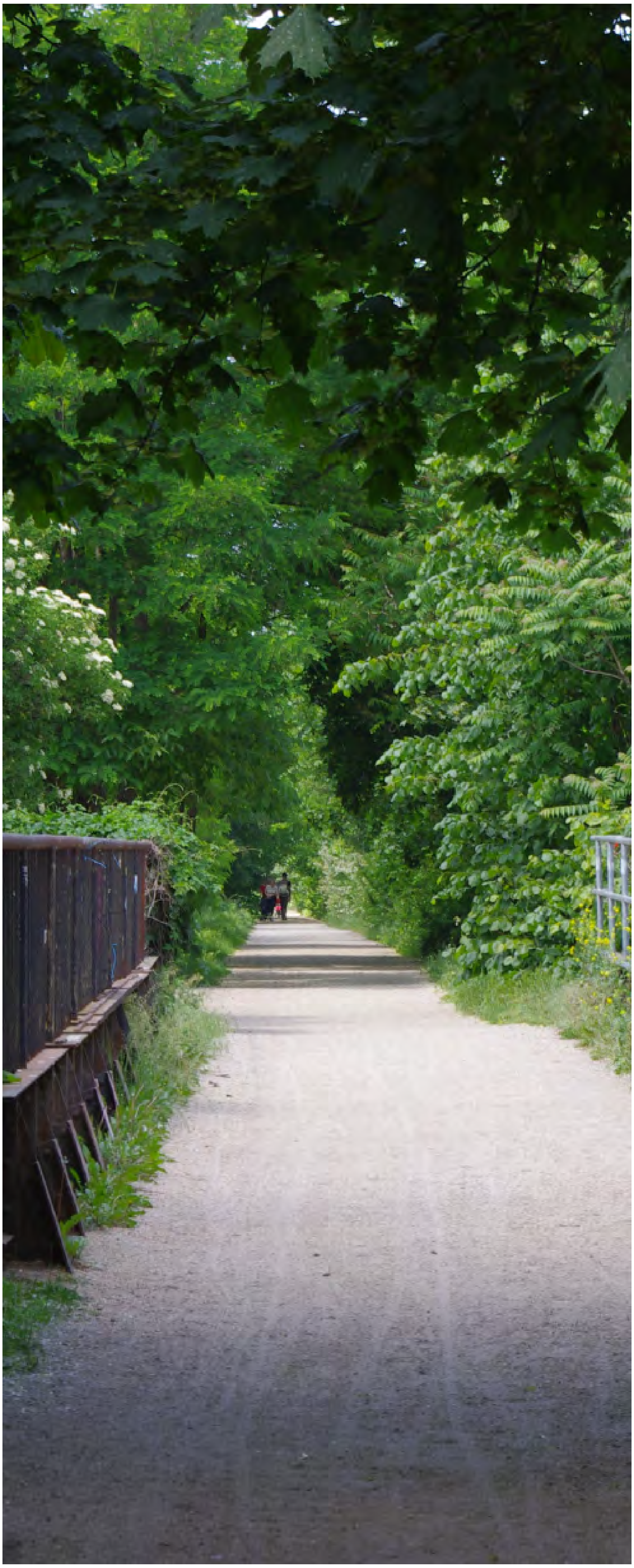

Fig 1.2 Green corridor in Berlin, Germany.

## 1.2 Green corridor

Areas of derelict infrastructure, e.g., railway lines, that are transformed into green corridors play an important role in urban green infrastructure networks and help to re-nature cities. Regeneration along waterways and rivers can also result in linear interconnecting parks. Green corridors can increase accessibility to green spaces while promoting environmentally sustainable transportation like walking and cycling. Additionally, they support biodiversity through improved ecological networks and habitat connectivity.

## I. Basic information

Synonyms: Linear park; Green belt

Addressed challenges:

Climatic resilience | Water management | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

## II. Role of nature

Transition areas between biomes are called ecotones. Green corridors with their linear, natural elements can be seen as ecotones that connect neighbouring and distant areas. Ecotones are often rich in biodiversity because they are connected to two or more different biotopes.

## III. Technical and design parameters

When green corridors are based on derelict infrastructure, the location and network properties are more or less fixed. However, green corridors can also be designed as connecting elements or active transportation corridors within new developments.

## IV. Conditions for implementation

Abandoned and transformed traffic infrastructure may be the most convenient way to establish linear parks and green corridors. The lack of care and sustained neglect of the area often results in spontaneous vegetation, but these areas can also be intentionally designed.

## V. Benefits and limitations

⊕ Potential benefits:

- Linear elements help improve green infrastructure and habitat connectivity.
- The re-use of old grey infrastructure opens up a great potential for creating an interconnected system.

⊖ Potential limitations / disservices:

- Depending on the previous use, the green corridor may need a high level of maintenance (e.g., bridges).

## VI. Performance

### P1 Cooling service

| | |
|---|---|
| Transpiration | ● ○ |
| Shading | ● ○ |
| Evaporation | ● ○ |
| Building (Insulation) | ● ○ |
| Reflection (Albedo) | ○ ○ |

### P2 Water balance regulation service

| | |
|---|---|
| Water conveyance | ● ○ |
| Water infiltration | ● ○ |
| Water retention | ● ○ |
| Water storage | ● ○ |
| Water reuse | ○ ○ |

### P3 Water purification service

| | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ○ ○ |

### P4 Air purification service

| | |
|---|---|
| Deposition | ● ● |
| Air biofiltration | ● ○ |
| Noise reduction | ○ ○ |

### P5 Biodiversity service

| | |
|---|---|
| Habitat provision | ● ● |
| Connectivity | ● ● |

### P6 Amenity value service

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ○ |
| Social interaction | ● ● |
| Education | ○ ○ |

### P7 Food / Energy / Material

| | |
|---|---|
| Food / Energy / Material | ● ○ |

### P8 $CO_2$ Sequestration

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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# 1.3 Urban garden

Fig 1.3 Temporary urban garden in Stuttgart, Germany

Urban gardening is a common way to establish garden space and encourage nature interaction for residents. There are many different concepts of urban gardening, but mostly they are semi-private with a possibility to rent or care for individual beds (e.g., within community gardens or urban garden projects) or plots (e.g., allotment gardens). Urban gardens, especially smaller community gardens, can be established in many diverse locations such as courtyards or public spaces. Depending on the size and intent of the garden, they offer a variety of benefits. For example, they can be sources for locally produced food, promote social interaction, and support mental health.

# I. Basic information

Synonyms: Community gardens; Intercultural gardens; Allotment gardens; Urban farming; Urban agriculture

Addressed challenges:

| Climatic resilience | Water management | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion |
|---|---|---|---|---|---|

# III. Role of nature

Urban gardens act as small oases in an urban environment, with positive effects for urban climate, recreation, and biodiversity that extend into the neighbouring residential areas.

# IV. Technical and design parameters

There are many possible designs for urban gardens. They are often constructed according to the space available, and needs or intentions of the organizing community. Often urban gardens are built using raised beds, which allows for flexibility in establishment. However, gardens planted directly in the soil at a site can help mitigate additional challenges like stormwater management. Care must be taken with regard to previous or neighbouring land uses that may have caused soil contamination (e.g., transformed parking lots, industrial sites).

# V. Conditions for implementation

In order to implement urban gardens, an organized, caring community with initiative and an appropriate space are necessary. Urban gardens can be permanent or temporary installations.

# VI. Benefits and limitations

⊕ Potential benefits:

- Urban gardens are multifunctional and deliver many benefits of green infrastructure.
- Provide locally sourced food.
- Encourage social interaction.
- Support pollinators.

⊖ Potential limitations / disservices:

- Accessibility and community engagement are key factors for the success of urban gardens.

# VI. Performance

### P1 Cooling service

| | |
|---|---|
| Transpiration | ● ● |
| Shading | ○ ○ |
| Evaporation | ● ● |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ○ ○ |

### P2 Water balance regulation service

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ● ○ |
| Water retention | ● ○ |
| Water storage | ● ○ |
| Water reuse | ○ ○ |

### P3 Water purification service

| | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ○ ○ |

### P4 Air purification service

| | |
|---|---|
| Deposition | ○ ○ |
| Air biofiltration | ● ● |
| Noise reduction | ○ ○ |

### P5 Biodiversity service

| | |
|---|---|
| Habitat provision | ● ● |
| Connectivity | ○ ○ |

### P6 Amenity value service

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ● |
| Social interaction | ● ● |
| Education | ○ ○ |

### P7 Food / Energy / Material

| | |
|---|---|
| Food / Energy / Material | ● ● |

### P8 $CO_2$ Sequestration

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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# 2. Trees and shrubs

Fig 2.0 Trees and shrubs at the Wilhelma zoological-botanical garden in Stuttgart, Germany.

Planting or protecting existing trees and shrubs are often employed in urban greening interventions and can be important NBS themselves, or elements within other NBS. Some main benefits include the provision of habitat for urban wildlife, temperature and stormwater regulation, and the mitigation of gaseous and particulate air pollutants [7-10]. Urban trees may also be associated with human health benefits like the reduction of stress, obesity, cardiac disease, and asthma [11]. Larger, older trees generally have greater positive environmental effects in comparison to smaller, newly planted trees and therefore their conservation and professional maintenance should be prioritized [12].

Trees are often seen as "the nature solution" and there has been a push in recent decades in many cities to increase tree plantings often in conjunction with lofty goals like planting one million trees [13]. However, while urban trees offer many benefits, there are some potential disservices to consider. For example, some species may increase allergic symptoms in those with hay fever or produce compounds that can react to form ozone under certain conditions [11]. Additionally, if planted without regard to location, street trees can actually trap pollutants at the pedestrian-level in traffic-heavy areas [14]. However, these disservices can be avoided with proper species selection and planning. Single trees or shrubs are not considered NBS themselves, because the positive effects of a single tree on the environment are usually local and limited to the immediate area near the tree. Examples of trees and shrubs as NBS in urban areas include orchards, vineyards, forests (including afforestation), hedges or green fences, and street trees [4]. Three examples of trees and shrubs as NBS (i.e., single line street trees, boulevards, and tree groups) are described in more detail below.

Fig 2.1 Single line street trees in the city center of Magdeburg, Germany.

## 2.1 Single line street trees

Single line street trees represent one possibility to establish several trees in urban areas. As the name implies, single line trees are arranged along one side of streets, bicycle paths, sidewalks, or other pathways.

Trees in general can positively affect local microclimate conditions, absorb gaseous pollutants, intercept particulate matter, and provide shade for people and buildings. One of the main positive effects for human well-being in warmer periods is the mitigation of urban heat stress due to shading and plant transpiration. The potential effects of street trees depend on factors such as tree size, canopy cover, planting density, species, tree health, location, availability of root water, and leaf area index.

## I. Basic information

Synonyms: Street trees

Addressed challenges:

Climatic resilience | Water management | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

## II. Role of nature

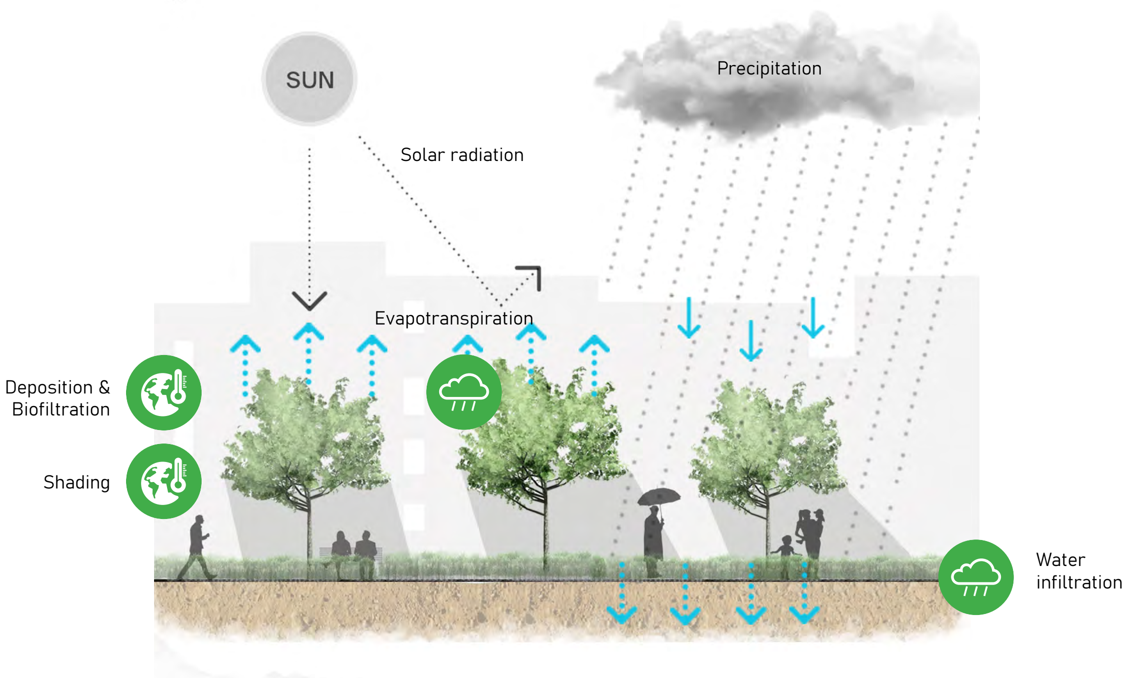


Fig 2.2 Single line street trees and their associated natural processes and benefits.

Single line trees simulate those trees growing at the edge of a forest (i.e. fringe area) and their effects on the surrounding environment outside the tree-covered area. In a natural or semi-natural forest, the edge trees would shade adjoining land uses like fields, meadows, or water surfaces. As a result, those shaded surfaces are cooler than surfaces without the protective tree cover.

The shading effect of single line street trees is determined by the environmental conditions (e.g., season and climate) and structural and species specific characteristics of the trees (e.g., tree canopy cover, crown density, deciduous vs. evergreen, age, height). Other effects are a reduced wind velocity, local temperature reduction due to evapotranspiration, and reduction of air pollution.

## III. Technical and design parameters

The most important aspect is the selection of suitable trees that serve the intended purpose and are fit for the current and future geo-environmental conditions. Additionally, selected trees should have low biogenic volatile organic compound (BVOC) production potential to reduce the possible negative effect of ozone production in warmer months. This is especially important in areas with heavy vehicular traffic. There are tools available that can be useful as a first step in appropriate species selection (for temperate regions, see, e.g., Citree), and suitable species are often recommend by local authorities.

The area of the root space for neighbouring trees can be connected in suitable conditions and, if separated, root space should be 12 $m^3$ with a minimum depth of 1.5 m. Ideally, the available root space should be equal in size to the fully mature crown, but this is often not possible in urban areas. Depending on local climatic conditions, newly planted street trees need about three years of regular watering, often followed by supplemental irrigation thereafter. Therefore, permanent or temporary irrigation facilities need to be considered and sustainable irrigation methods (e.g., using harvested rainwater) should be preferentially used whenever possible. The distance between the trees depends on the maximum size of the adult tree, but also on the size of the planted tree and design ideas. Protection measures (e.g., poles against car parking, wire mesh against animals) may also be necessary. Because it takes decades until newly planted trees fulfil the services of mature trees, individually, as well as in combination, initiatives to protect existing trees are essential.

## IV. Conditions for implementation

Local circumstances (e.g., topography, street characteristics, soil conditions, surrounding land use, and underground uses) need to be considered when planning and establishing new single line trees. A suitable location for the establishment of trees should offer enough space for trees to grow, both below and above ground. For example, considering the maximum height and canopy cover of the trees is important to avoid space problems in the future. Depending on site conditions and available space, appropriate tree species must be selected.

Trees that are not sufficiently rooted may cause accidents and constitute a danger for people on or beside the road. The soil and subsurface should generally be suitable for the establishment of street trees and may need to be replaced with structural soils if necessary. The use of structural soils and permeable pavements may help improve growing conditions for urban street trees and support deeper root growth. The selection of suitable tree species should also consider local conditions like topography. For example, when used for the stabilization of banks or small hills, steadfast trees are necessary.

Species and sub species that are suitable for urban conditions should be planted, and are often suggested by local authorities.

## V. Benefits and limitations

⊕ Potential benefits:

- Microclimate regulation.
- Habitat provision.
- Aesthetics / recreation.
- Rainwater regulation (delayed stormwater runoff).

⊖ Potential limitations / disservices:

- Allergic potential of pollen.
- BVOC emissions, resulting in increased ozone emissions in warmer months.

## VI. Performance

### P1 Cooling service

| | |
|---|---|
| Transpiration | ● ○ |
| Shading | ● ○ |
| Evaporation | ○ ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ● ○ |

### P2 Water balance regulation service

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ● ○ |
| Water retention | ● ○ |
| Water storage | ○ ○ |
| Water reuse | ○ ○ |

### P3 Water purification service

| | |
|---|---|
| Water filtering | ○ ○ |
| Water bio-remediation | ○ ○ |

### P4 Air purification service

| | |
|---|---|
| Deposition | ● ○ |
| Air biofiltration | ● ○ |
| Noise reduction | ○ ○ |

### P5 Biodiversity service

| | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ● ○ |

### P6 Amenity value service

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ○ |
| Social interaction | ● ○ |
| Education | ○ ○ |

### P7 Food / Energy / Material

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

### P8 $CO_2$ Sequestration

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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* See also: Factsheet 2.2 Boulevards, section VII. References and further reading.

## 2.2 Boulevards

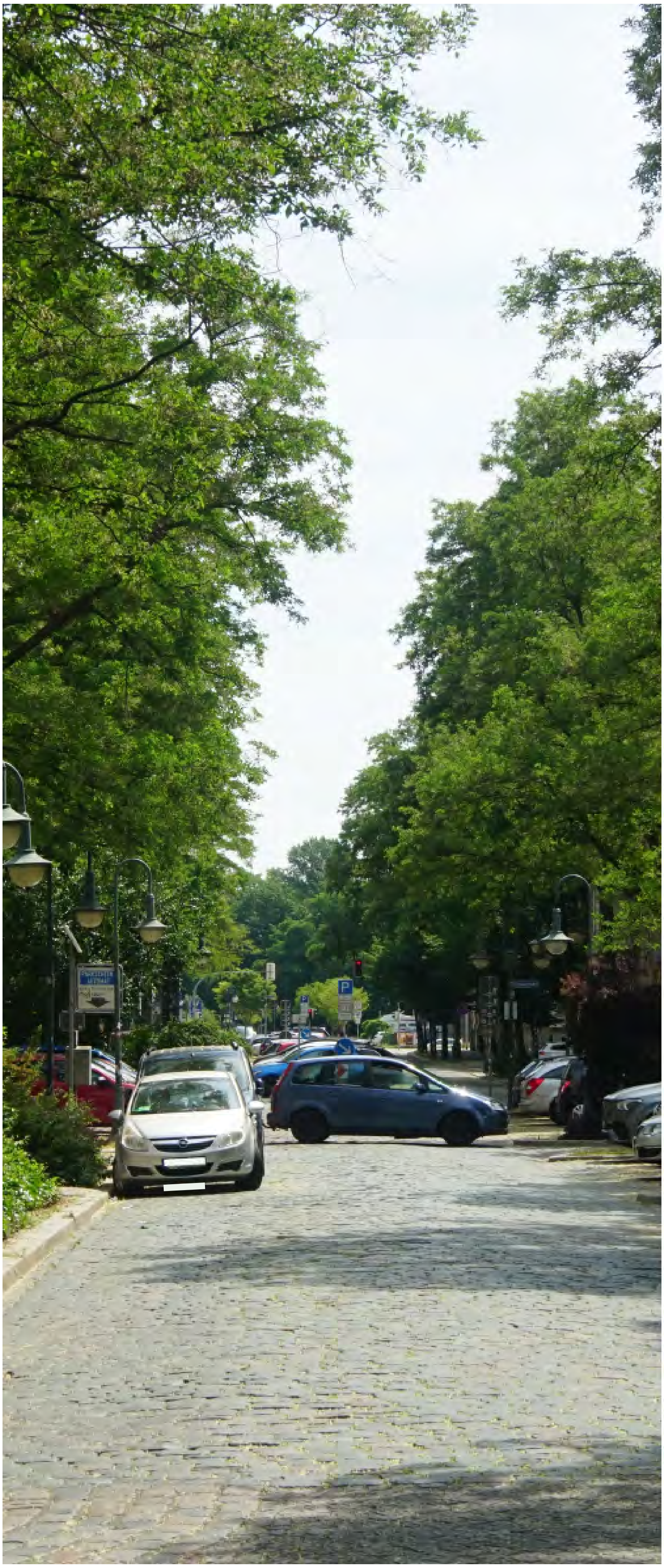


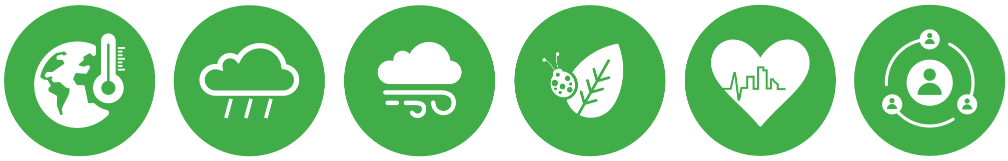
Fig 2.3 Boulevard in the city center of Magdeburg, Germany.

Boulevards represent a possibility to establish several trees in cities to mitigate urban heat stress, while providing additional benefits like improving water management and climate resilience. Within boulevards, trees are commonly arranged along streets, bicycle paths, and sidewalks on both sides of the route. The canopies of opposite trees often form a (nearly) closed canopy. As a result, the area between the two tree lines is shaded and the air temperature cooler.

## I. Basic information

Synonyms: Double line street trees, Double row street trees

Addressed challenges:



Climatic resilience | Water management | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion

## II. Role of nature

Boulevards simulate those trees growing at the edge of a forest (i.e., fringe area) and their effects on the surrounding environment outside the tree-covered area. In a natural or semi-natural forest, the edge trees would shade adjoining land uses like fields, meadows, or water surfaces. As a result, those shaded surfaces are cooler than surfaces without the protective tree cover. The shading effect of boulevards is determined by the environmental conditions (e.g., season and climate) and structural and species specific characteristics of the trees (e.g., tree canopy cover, crown density, deciduous vs. evergreen, age, height). Other effects are a reduced wind velocity, local temperature reduction due to evapotranspiration, and reduction of air pollution.

## III. Technical and design parameters

For boulevards in urban settings, only a limited number of tree species meet the selection criteria based on design principles, durability, and resistance against environmental stress. The area of the root space for neighbouring trees can be connected in suitable conditions and, if separated, root space should be 12 $m^3$ with a minimum depth of 1.5 m. Ideally, the available root space should be equal in size to the fully mature crown, but this is often not possible in urban areas. In most urban conditions, the root space needs to be prepared with soil substrates for trees.

Depending on local climatic conditions, newly planted street trees need about three years of regular watering, often followed by supplemental irrigation thereafter. Therefore, permanent or temporary irrigation facilities need to be considered and sustainable irrigation methods (e.g., using harvested rainwater) should be preferentially used whenever possible. The distance between the trees depend on road width, the maximum size of adult trees, and further design ideas. Protection measures (e.g., poles, wire mesh against animals) may also be needed.

## IV. Conditions for implementation

Local circumstances (e.g., topography, street characteristics, soil conditions, surrounding land use, and underground uses) need to be considered when planning and establishing new boulevards. Planting location for the establishment of trees should offer enough space for trees to grow. Depending on site conditions and available space, suitable tree species must be selected. Considering the maximum height of the trees is important to avoid space problems in the future. Trees that are not sufficiently rooted may cause accidents and constitute a danger for people on or beside the road. The soil and subsurface should generally be suitable for the establishment of street trees and may, if necessary, be replaced by structural soils.

The use of structural soils and pervious pavements may help improve growing conditions for urban street trees and support deeper root growth. Species and sub species that are suitable for urban conditions should be planted, and are often suggested by local authorities. Additionally, special considerations should be made when planning boulevards specifically in areas with heavy vehicular traffic, as structural characteristics like closed or dense canopies could increase pedestrian-level pollution in certain conditions.

## V. Benefits and limitations

⊕ Potential benefits:

- Microclimate regulation.
- Habitat provision.
- Aesthetics / recreation.
- Rainwater regulation (delayed stormwater runoff).

⊖ Potential limitations / disservices:

- Reduced airflow, potentially leading to higher pollution in street canyon.
- Allergenic potential of tree pollen and BVOC emissions.

## VI. Performance

| P1 Cooling service | |
|---|---|
| Transpiration | ● ● |
| Shading | ● ● |
| Evaporation | ● ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ● ● |

| P2 Water balance regulation service | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ● ○ |
| Water retention | ● ○ |
| Water storage | ○ ○ |
| Water reuse | ○ ○ |

| P3 Water purification service | |
|---|---|
| Water filtering | ○ ○ |
| Water bio-remediation | ○ ○ |

| P4 Air purification service | |
|---|---|
| Deposition | ● ○ |
| Air biofiltration | ● ○ |
| Noise reduction | ○ ○ |

| P5 Biodiversity service | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ● ○ |

| P6 Amenity value service | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ○ |
| Social interaction | ● ○ |
| Education | ○ ○ |

| P7 Food / Energy / Material | |
|---|---|
| Food / Energy / Material | ● ○ |

| P8 $CO_2$ Sequestration | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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* See also: Factsheet 2.1 Single line street trees, section VII. References and further reading.

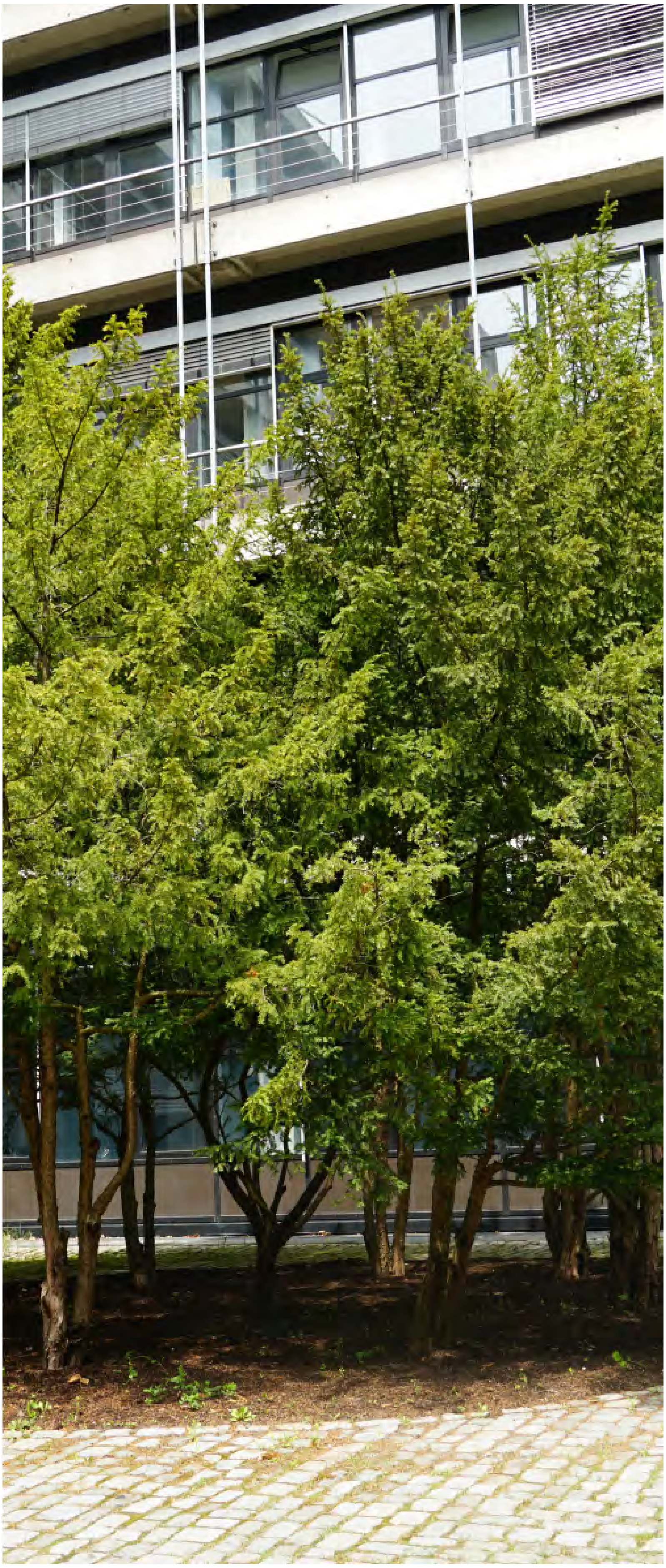

Fig 2.4 Group of trees in a courtyard in Stuttgart, Germany.

## 2.3 Group of trees

Groups of trees mimic the gestalt of a forest in an urban setting. They may be an option for the design of shaded squares, as a contrasting element in densely built areas, or for courtyard design. In some urban areas, groups of trees may also be developed from existing, wild growing trees that established spontaneously and are typical pioneer species of urban forests. Urban groups of trees offer many benefits like improved water management and climate resilience and contribute to the mitigation of urban heat stress. Additionally, selection of diverse native species, especially in combination with understory vegetation, can help support and enhance biodiversity.

# I. Basic information

Synonyms: Arboretum; Tree groups; Sustainable urban groves

Addressed challenges:


# II. Role of nature

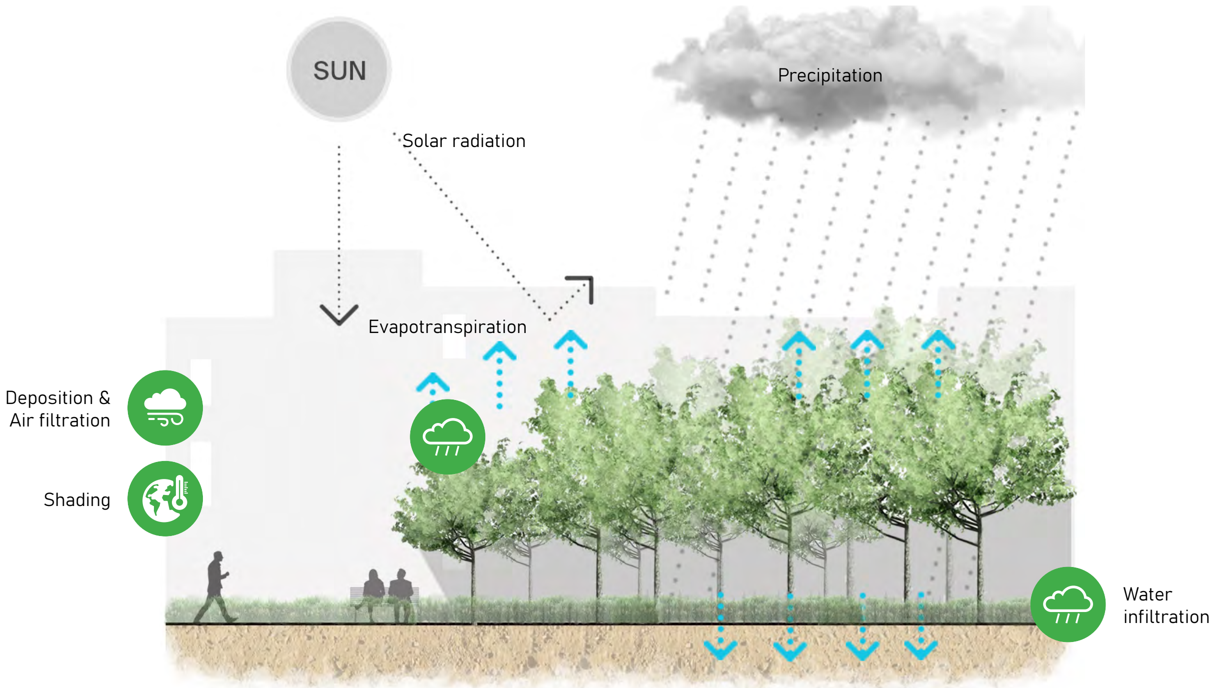


Fig 2.5 Group of trees and their associated natural processes and benefits. A shaded environment in summer, which is similar to a small patch of forest or the fringe area of larger forests..

# III. Technical and design parameters

If improvements to the microclimate are desired shortly after implementation, mature trees from nurseries should be planted. If saplings are planted, it will take longer for the maximum benefit of the group of trees to be achieved. If younger trees are used, their mature height and density need to be considered when planting to avoid future above and below ground spatial issues. The trees should be planted in a rather dense grid and need to be irrigated during their first years and possibly throughout their whole lifetime. Ideally, sustainable irrigation methods, like watering with collected rainwater from surfaces and roofs, should be used for the maintenance of tree groups.

## IV. Conditions for implementation

Species and sub species that are suitable for urban conditions should be planted (see factsheets 2.1 Single line street trees and 2.2 Boulevards). Selection of diverse, native species, especially in combination with understory vegetation, improves the likelihood of establishing more robust living conditions for urban wildlife, thereby supporting biodiversity. The group of trees may be planted on natural soils or in other locations, such as above underground buildings with sufficient soil depth and structural support.

## V. Benefits and limitations

⊕ Potential benefits:

- Habitat provision (depending on species selection).
- Improved aesthetics.
- Meeting places.
- Public spaces for heat reduction.

⊖ Potential limitations / disservices:

- Allergic potential of pollen.
- Possible BVOC emissions, resulting in increased ozone emissions in warmer months.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ● ● |
| Shading | ● ● |
| Evaporation | ● ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ● ● |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ● ○ |
| Water retention | ● ● |
| Water storage | ○ ○ |
| Water reuse | ○ ○ |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ○ ○ |
| Water bio-remediation | ○ ○ |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ● ○ |
| Air biofiltration | ● ○ |
| Noise reduction | ○ ○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ● ● |
| Connectivity | ● ● |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ○ |
| Social interaction | ● ○ |
| Education | ○ ○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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* See also: section VII. References and further reading of factsheets 2.1 Single line street trees and 2.2 Boulevards.

# 3. Soil conservation & quality management

Fig 3.0 Stream banks in Lübars, Germany.

Soil is an important natural resource in urban areas. Soils support above and below ground biodiversity, increase stormwater infiltration, improve water quality, and can help regulate the microclimate [15]. Additionally, soils mitigate climate change through carbon sequestration and the reduction of carbon dioxide ($CO_2$), methane ($CH_4$), and nitrogen nioxide ($N_2O$) emissions [4]. However, these benefits are reduced with common urban environmental stressors like pollution, erosion, compaction, and sealing [16,17]. As of 2015, it is estimated that about one-third of land is moderately to highly degraded due to stressors such as these [18,19]. Additionally, the formation of just one centimeter of fertile soil can take hundreds of years, making it a finite, non-renewable resource. Therefore, the protection of existing soils through soil conservation and quality management is essential. Examples of NBS and actions that involve soil conservation and quality management include slope revegetation, permaculture, organic matter enrichment, establishing windbreaks, using conservation-based tillage practices, and planting deep-rooted perennials [4]. Three examples of NBS that are used to stabilize soil and prevent erosion (i.e., living fascine, revetment with cuttings, and planted embankment mat) are described in more detail below.

# 3.1 Living fascine

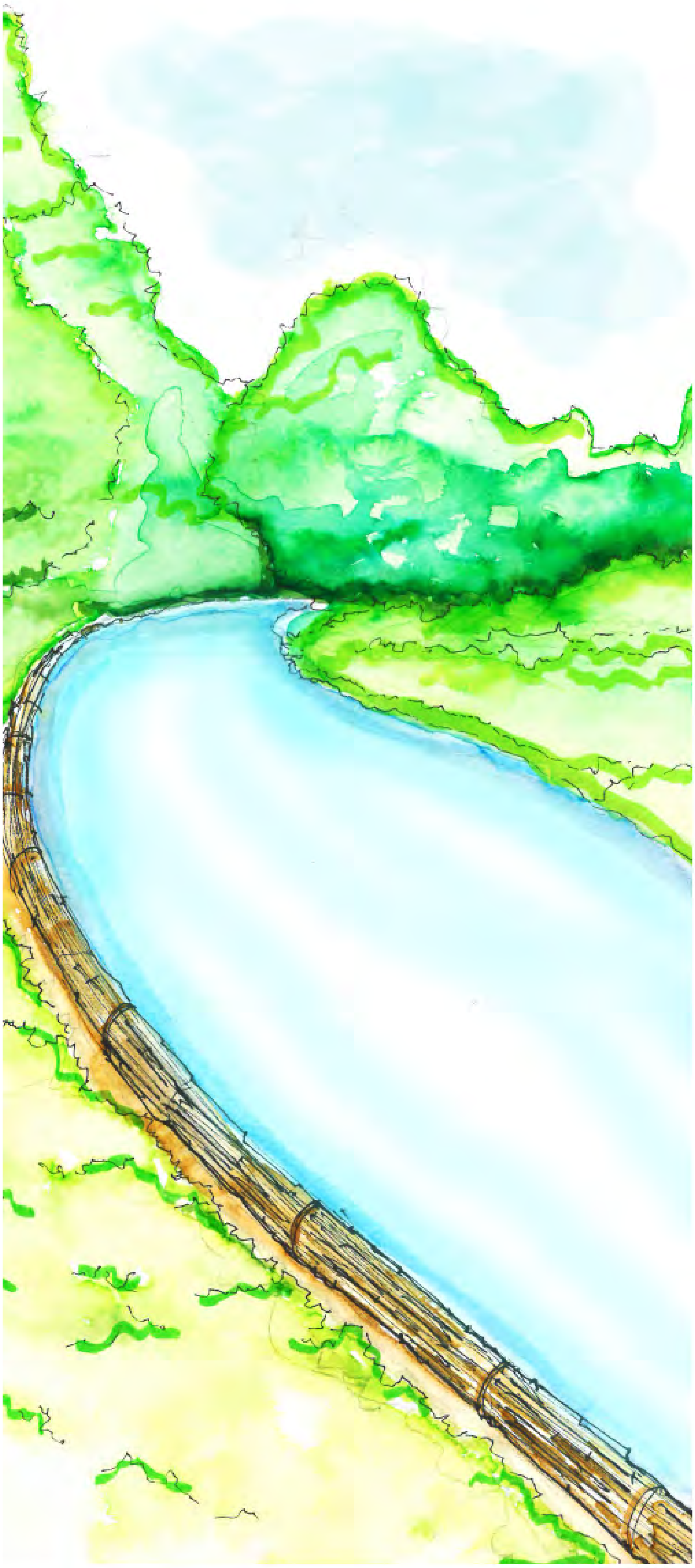

Fig 3.1 Sketch of a living fascine at a stream bank.

Living fascines are used for the stabilization of riversides and hills. By using bundles of living wood, sometimes mixed with dead wood, living fascines can also provide habitat for plants and animals.
For example, implementing living fascines, rather than their “hard” engineering counterparts, provides better structural connectivity of natural habitats, thereby supporting biodiversity. Additionally, when established near stream banks, fascines can provide food and shelter for aquatic organisms. In terms of stabilization, living fascines are superior in comparison to “dead” fascines, as plants readily develop from the living wood (vegetative growth) and developing roots provide soil protection. Additional species may also settle later into this new microhabitat.

# I. Basic information

Synonyms: Live fascines

Addressed challenges:

Climatic resilience | Water management | Air quality | Biodiversity

# II. Role of nature

Living fascines imitate and then stimulate natural vegetation layers with strong, branched root networks, with aboveground biomass that provides habitat structures.

# III. Technical and design parameters

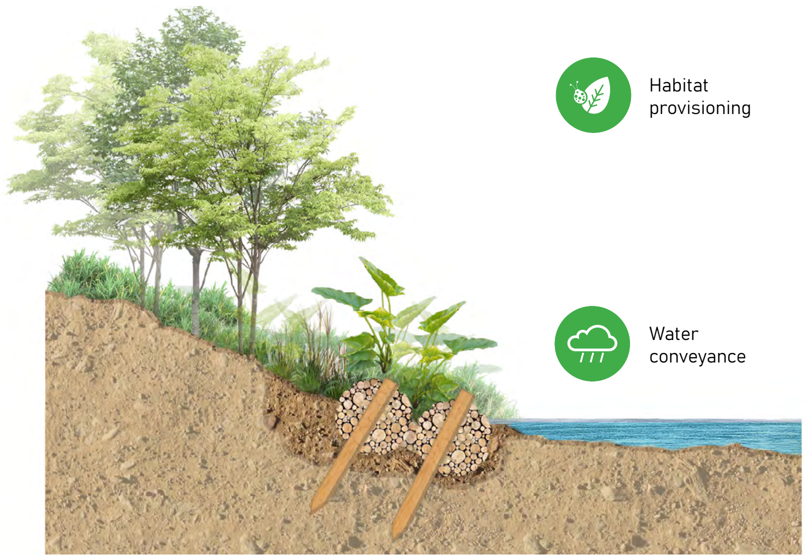


Fig 3.2 An example of a living fascine and its associated benefits.

Living fascines are traditional bioengineering elements that are mainly used outside of urban areas to restore riversides and hilly terrain. Living fascines consist of living tree branches and twigs, but may comprise up to 50% dead wood. The wood is bundled with steel cables or rope made from natural materials like jute; fast-rooting plants and cuttings should be used. Bundles usually have about a 15-20 cm diameter and are about 2-3 m long, depending on site conditions and purpose. The prepared bundles are then installed horizontally in trenches along the water bank or hillside using hardwood cuttings or dowels as fixation. Rooting fascines are covered with bushes or other plants to provide additional stabilisation and reduce the risk of erosion.

Willow is commonly used because of its favourable characteristics: Length, flexibility, elasticity and form, but species selection depends on the objective. For example, common bundle materials for hydraulic engineering are hazel and willow branches (e.g., *Salix viminalis*, *S. purpurea*), whereas for earthwork / hillside stabilization shrub branches from other species (e.g., *S. fragilis*, *S. alba*) are used. Choice of species may also depend on the local context, as species occurring on site may provide plant material for the fascines.

## V. Conditions for implementation

Good timing for construction (e.g., low water flow, no rainfall) is needed, and vegetation material should be established during suitable weather and seasonal conditions to allow for vegetation development.

## VI. Benefits and limitations

⊕ Potential benefits:

- Near-natural protection of hillsides and river banks.
- Benefits for biodiversity through habitat creation.

⊖ Potential limitations / disservices:

- Stability of the river bank is difficult to calculate and foresee.

## VI. Performance

**P1 Cooling service**

| | | |
|---|---|---|
| Transpiration | ● | ○ |
| Shading | ○ | ○ |
| Evaporation | ○ | ○ |
| Building (Insulation) | ○ | ○ |
| Reflection (Albedo) | ○ | ○ |

**P2 Water balance regulation service**

| | | |
|---|---|---|
| Water conveyance | ○ | ○ |
| Water infiltration | ● | ○ |
| Water retention | ● | ○ |
| Water storage | ○ | ○ |
| Water reuse | ○ | ○ |

**P3 Water purification service**

| | | |
|---|---|---|
| Water filtering | ● | ○ |
| Water bio-remediation | ○ | ○ |

**P4 Air purification service**

| | | |
|---|---|---|
| Deposition | ○ | ○ |
| Air biofiltration | ○ | ○ |
| Noise reduction | ○ | ○ |

**P5 Biodiversity service**

| | | |
|---|---|---|
| Habitat provision | ● | ● |
| Connectivity | ● | ○ |

**P6 Amenity value service**

| | | |
|---|---|---|
| Beauty / Appearance | ● | ○ |
| Usability / Functionality | ○ | ○ |
| Social interaction | ○ | ○ |
| Education | ○ | ○ |

**P7 Food / Energy / Material**

| | | |
|---|---|---|
| Food / Energy / Material | ○ | ○ |

**P8 $CO_2$ Sequestration**

| | | |
|---|---|---|
| $CO_2$ Sequestration | ● | ○ |

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## 3.2 Revetment with cuttings

A revetment with cuttings covers eroded riverbanks with, for example, willow (able to root) or brushwood (not able to root). This is a simple method using local material that stabilizes riverbanks against further erosion and leads to long-term stabilization by allowing plants to re-cultivate naturally. This method is often used in combination with other soil bioengineering techniques like living fascines to maximize stabilization potential.

Fig 3.3 Sketch of a revetment with cuttings alongside a little stream.

# I. Basic information

Synonyms: Spreitlage; Brush mattress; Brush and hedge layers; Dormant cuttings

Addressed challenges:

Water management | Air quality | Biodiversity

# II. Role of nature

A revetment with cuttings imitates natural vegetation layers with strong and branched root networks, thereby offering natural production against erosion compared to bare hillsides that have a high risk of water, wind, and soil erosion. Eventually, as the revetment with cuttings matures, it should function more similarly to a restored riparian habitat.

# III. Technical and design parameters

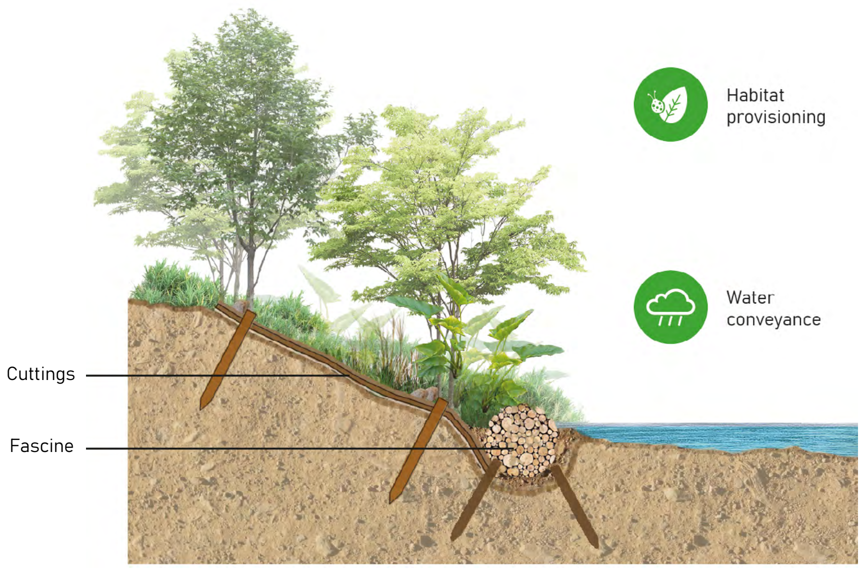


Fig 3.4 An example of a revetment with cuttings and its associated benefits, combined with a fascine.

Two to five year old shrub branches with a length of 1.5 m are typically used for construction. The stake length is usually 3-5 m, with a diameter of 4-8 cm. Native and typical plants for the specific location should be selected, both with regard to supporting local biodiversity and decreasing transportation costs.

# IV. Conditions for implementation

Good timing for construction (e.g., low water flow, no rainfall) and planting is necessary.

## V. Benefits and limitations

⊕ Potential benefits:

- Hillside stabilization.
- Protection against erosion.
- Riverbank protection.
- Habitat for wildlife.

⊖ Potential limitations / disservices:

- Stability of the river bank is difficult to calculate and foresee.

## VI. Performance

### P1 Cooling service

| | |
|---|---|
| Transpiration | ● ○ |
| Shading | ○ ○ |
| Evaporation | ○ ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ○ ○ |

### P2 Water balance regulation service

| | |
|---|---|
| Water conveyance | ● ○ |
| Water infiltration | ● ○ |
| Water retention | ● ○ |
| Water storage | ● ○ |
| Water reuse | ● ○ |

### P3 Water purification service

| | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ● ○ |

### P4 Air purification service

| | |
|---|---|
| Deposition | ○ ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ○ ○ |

### P5 Biodiversity service

| | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ● ○ |

### P6 Amenity value service

| | |
|---|---|
| Beauty / Appearance | ● ○ |
| Usability / Functionality | ○ ○ |
| Social interaction | ○ ○ |
| Education | ○ ○ |

### P7 Food / Energy / Material

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

### P8 $CO_2$ Sequestration

| | |
|---|---|
| $CO_2$ Sequestration | ● ○ |

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Fig 3.5 Planted embankment mat along the Danube river in Fridingen, Germany.

# 3.3 Planted embankment mat

Planted embankment mats are a combination of biodegradable mats with a vegetation layer. These mats are used to re-cultivate riverbanks and prevent erosion by reducing water velocity and promoting sedimentation. The biodegradable mats themselves provide temporary erosion control, while the vegetation develops and produces strong root networks, which then support longer-term erosion prevention. Using local vegetation can create or restore habitats and promote biodiversity. Construction is simple and fast, and combination with other soil bioengineering techniques like living fascines or live stakes is possible.

## I. Basic information

Synonyms: Vegetated erosion-control mat; Vegetated erosion control blanket

Addressed challenges:

Water management

Air quality

Biodiversity

## II. Role of nature

Planted embankment mats imitate natural vegetation layers with strong and branched root networks, thereby offering natural protection against erosion compared to bare hillsides that have a high risk of water, wind, and soil erosion. Eventually, as the vegetation on the planted embankment mat matures, it should function more similarly to a restored (e.g., riparian) habitat.

## III. Technical and design parameters

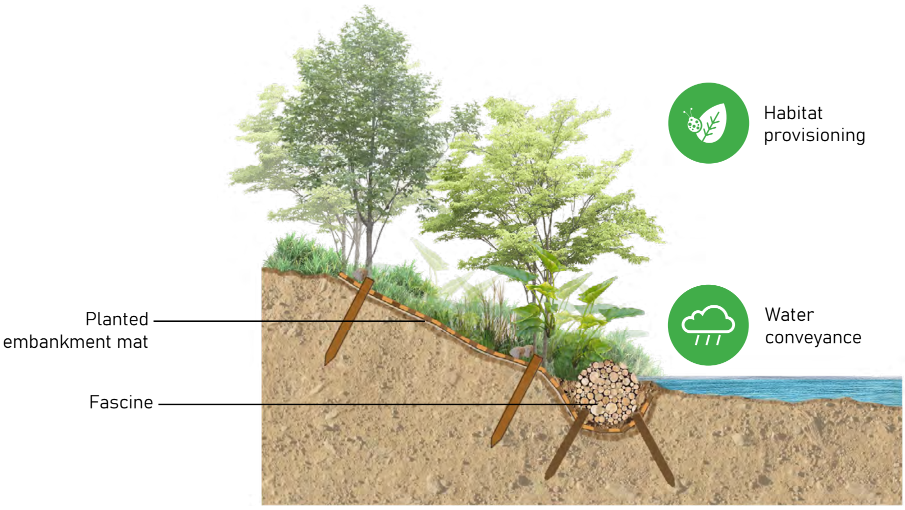


Fig 3.6 An example of a planted Embankment mat and its associated benefits, combined with a fascine.

The mats are simply constructed using biodegradable, plant-based materials such as coir (coconut fiber) or jute, and installation is simple and fast. Appropriate, steadfast species that develop strong rooting systems should be selected to best improve long-term erosion control potential. Addionally, local, native vegetation should be preferentially planted to support habitat restoration and biodiversity enhancement.

## IV. Conditions for implementation

Good timing for construction (e.g., low water flow, no rainfall) and planting (e.g., suitable weather and seasonal conditions) is necessary.

## V. Benefits and limitations

⊕ Potential benefits:

- Protection against erosion.
- Habitat for wildlife.

⊖ Potential limitations / disservices:

- Stability of the river bank is difficult to calculate and foresee.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ● ○ |
| Shading | ○ ○ |
| Evaporation | ○ ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ○ ○ |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ● ○ |
| Water retention | ● ○ |
| Water storage | ○ ○ |
| Water reuse | ○ ○ |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ● ○ |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ○ ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ○ ○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ● ○ |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ● ○ |
| Usability / Functionality | ○ ○ |
| Social interaction | ○ ○ |
| Education | ○ ○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ● ○ |

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# 4. Green built environment

Fig 4.0 Planted stone gabions constructed using rubble from a demolished building in Berlin, Germany.

The green built environment includes structural elements of the urban environment that incorporate vegetation into their design [4]. This can include areas that were conventionally grey spaces like rooftops and façades.

NBS in this category are extremely diverse. Examples include green roofs, green walls and façades, green alleys and parking lots, and even small-scale or temporary structures like green living rooms. Additionally, elements of the same typology, for example green roofs, can be highly variable due to design, structural differences, selected species, and growing media [4]. Because of this diversity, there is a large range of benefits that can be supported by the green built environment including pollution mitigation, microclimate and stormwater regulation, biodiversity enhancement, as well as social and educational benefits. While smaller scale elements of the green built environment are beneficial on their own, potential benefits may be maximized when many of these NBS are integrated into a larger nature-based framework or masterplan focused on addressing urban challenges.

Examples of NBS as part of the green built environment (i.e., extensive and intensive green roofs, constructed wet roofs, smart roofs, green façades, free standing living walls, mobile green living rooms, and moss walls) are described in more detail below.

# 4.1 Extensive green roof

Fig 4.1 Extensive green roof on a mixed use building complex in Stuttgart, Germany.

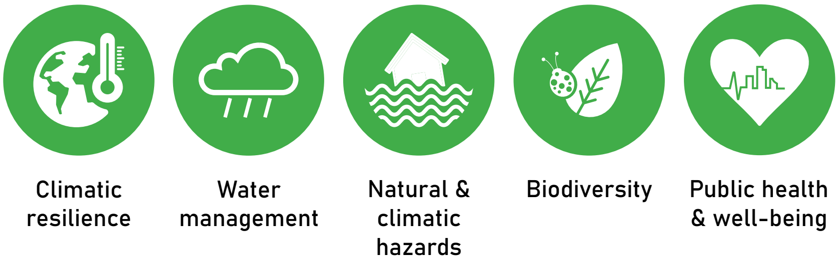
Extensive green roofs are lightweight systems that consist of a thin substrate layer with shallow-rooted, low growing, and often rapidly spreading vegetation. Typical groups of vegetation for extensive green roofs include sedums, herbs, wildflowers, grasses, and mosses, since they are relatively hardy and can often survive in low-nutrient conditions. Once established, extensive green roofs are characterized by their minimal maintenance and management requirements. However, they are often only accessible for maintenance purposes and not open to the public.

Compared to typical grey roofs, extensive green roofs can offer benefits like localized air temperature and pollution reduction, and contribute to water management. These benefits, however, tend to be less extensive than those associated with their more complex and expensive counterparts – intensive green roofs.

# I. Basic information

Synonyms: Low-Profile; Eco-Roofs; Extensive roof greening

Addressed challenges:




# II. Role of nature

Through the establishment of green roofs on buildings, different services of natural vegetation layers are replicated. These include habitat creation (e.g., dry grassland types) or more generally, the establishment of stepping stone biotopes in an urban area.

# III. Technical and design parameters

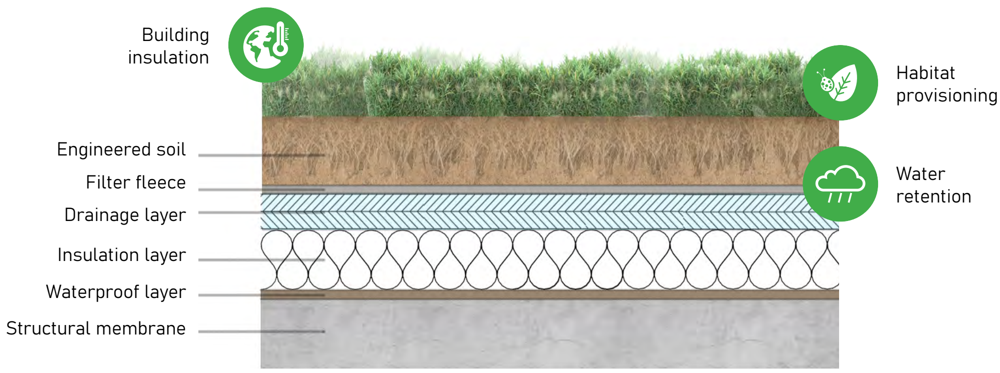



Fig 4.2 Typical layers of an extensive roof and its associated benefits.

There are many different systems for extensive green roofs, and therefore no uniform design exists. For example, vegetation can be planted directly on special "biological" concrete, established on a variety of substrate mixes, or on synthetic fiber mats, alone or in combination with an underlying substrate. If a substrate is included, then it is thin, typically under 20 cm. Despite this thin substrate, extensive green roofs should have a minimum water storage capacity of 25 L/m² and at least 95% vegetation coverage three years after implementation.

Although vegetation is usually restricted to non-woody plants (e.g., moss, sedum, herbs, grasses), there is still a great variety possible. Appropriate plants for extensive green roofs are low-growing, rapidly spreading, and shallow-rooting plants or hardy perennials including succulents that are able to survive with minimal nutrient uptake and without additional nutrient supply. The selected plants for extensive green roofs are generally well adapted to alpine or rocky environments and tolerate different climatic conditions like drought and temperature fluctuations.

Extensive green roofs typically bear less weight, require less water and investment, and can be planted on more steeply pitched surfaces (up to 85° possible with technical devices) than intensive green roofs. Therefore, existing buildings tend to be retrofitted with extensive, rather than intensive, green roofs. Regular maintenance (but less than for intensive green roofs) is necessary, and special care is needed to regularly remove spontaneous woody vegetation.

## IV. Conditions for implementation

Site characteristics are often dependent on project objectives. For example, if the objective is to improve aesthetics, then high-density, visible sights are preferable. Regardless of location, solid, stable concrete buildings with a high bearing capacity, and flat or relatively flat rooftops with underground support structures are necessary.

## V. Benefits and limitations

⊕ Potential benefits:

- Supports human health and good quality of life.
- Stormwater management and quality.
- Improved air quality.
- Aesthetic value
- Localized air temperature reduction (less than intensive green roofs).
- Energy reduction for buildings (less than intensive green roofs).
- Reduction of noise pollution.
- Habitat provision for urban wildlife.

⊖ Potential limitations / disservices:

- Limited development of undisturbed habitats because of human activities (if publically accessible).
- Limited space for roots.
- Often not publicly accessible.

# VI. Performance

### P1 Cooling service

| | | |
|---|---|---|
| Transpiration | ○ | ○ |
| Shading | ● | ○ |
| Evaporation | ● | ○ |
| Building (Insulation) | ● | ○ |
| Reflection (Albedo) | ● | ○ |

### P2 Water balance regulation service

| | | |
|---|---|---|
| Water conveyance | ● | ○ |
| Water infiltration | ○ | ○ |
| Water retention | ● | ○ |
| Water storage | ○ | ○ |
| Water reuse | ○ | ○ |

### P3 Water purification service

| | | |
|---|---|---|
| Water filtering | ○ | ○ |
| Water bio-remediation | ○ | ○ |

### P4 Air purification service

| | | |
|---|---|---|
| Deposition | ○ | ○ |
| Air biofiltration | ○ | ○ |
| Noise reduction | ○ | ○ |

### P5 Biodiversity service

| | | |
|---|---|---|
| Habitat provision | ● | ○ |
| Connectivity | ● | ○ |

### P6 Amenity value service

| | | |
|---|---|---|
| Beauty / Appearance | ● | ○ |
| Usability / Functionality | ● | ○ |
| Social interaction | ○ | ○ |
| Education | ○ | ○ |

### P7 Food / Energy / Material

| | | |
|---|---|---|
| Food / Energy / Material | ○ | ○ |

### P8 $CO_2$ Sequestration

| | | |
|---|---|---|
| $CO_2$ Sequestration | ● | ○ |

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## 4.2 Intensive green roof

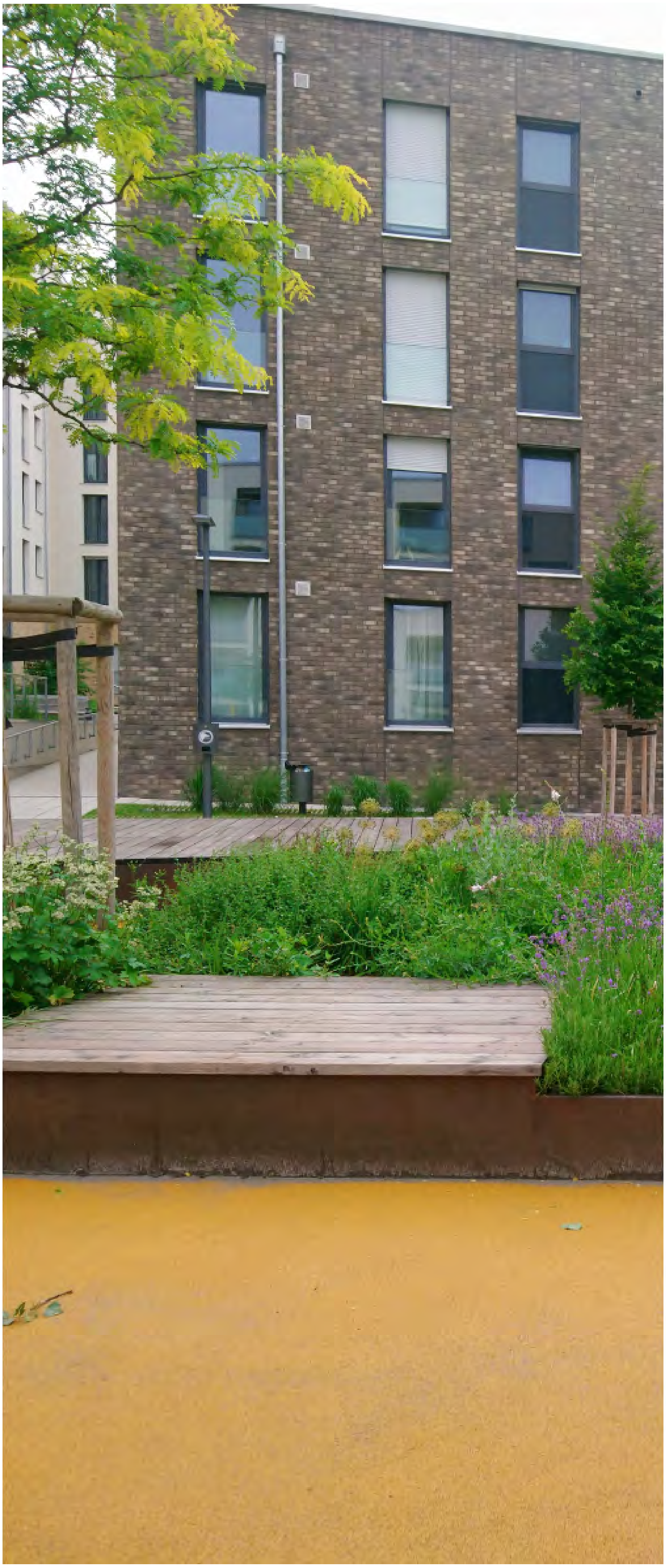

Fig 4.3 Intensive green roof used as a community courtyard in Stuttgart, Germany.

Intensive green roofs are heavier greening systems characterized by a thicker growing medium with more varied vegetation types (compared to extensive green roofs). Common plants used for intensive green roofs include a variety of smaller trees, shrubs, and perennials. Depending on design, intensive green roofs provide many benefits like stormwater storage, reduction of air and water pollution, reduction of localized air temperature, and biodiversity enhancement. They are commonly found on residential buildings, hotels, and parking structures and are often multifunctional areas that can be used for many activites including gardening, relaxing, and socializing. To enable activities for people and the integration of larger plants, trees, and architectural elements on green roofs, suitable rooftops need to be relatively flat and fulfil more complex technical requirements e.g., regarding weight.

## I. Basic information

Synonyms: High-Profile; Roof gardens; Roof greening

Addressed challenges:

| Climatic resilience | Water management | Natural & climatic hazards | Air quality | Biodiversity | Public health & well-being | Social justice & cohesion |
|---|---|---|---|---|---|---|

## II. Role of nature

The model for a green roof is soil with its vegetation cover. Intensive green roofs on buildings provide services similar to natural vegetation layers, and can provide a variety of ecosystem services that benefit the surrounding environment. For example, retention of precipitation in the growing medium and mitigation of the urban heat island through vegetation shading and transpiration are fundamental services of intensive green roofs.

## III. Technical and design parameters

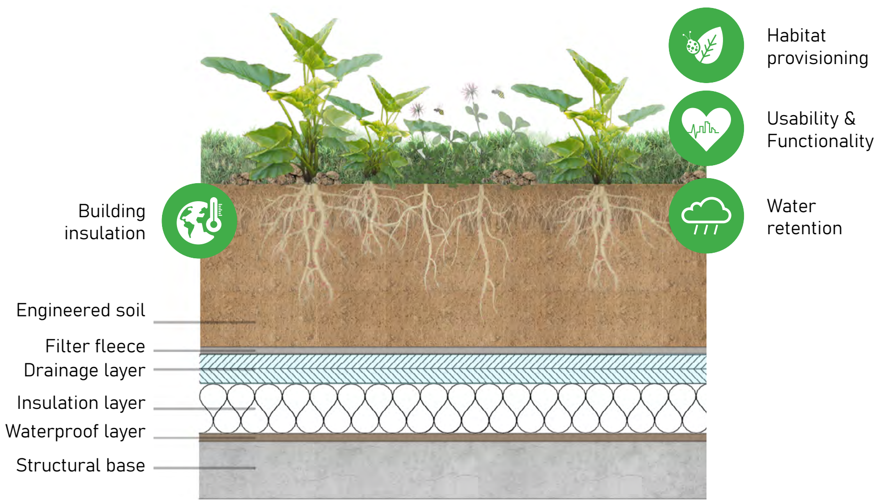


Fig 4.4 Typical layers of an intensive roof and its associated benefits.

There are many different greening systems for intensive green roofs, and therefore no uniform construction exists. The roof itself must be relatively flat (0-5°), and it is important to consider the weight load, irrigation system, growing medium, and maintenance. Because of their structural design, the choice of suitable plants is greater than for extensive green roofs. Appropriate plants for intensive green roofs include a variety of smaller trees, shrubs, and perennials. The growth media is relatively thick and notably deeper than for extensive systems with integrated low-growing plants (see Factsheet 5.1). The growth media of intensive green roofs needs to be relatively deep and nutrient rich to support the growth

of plants such as trees.
Based on the technical construction itself and the choice growing media, intensive green roofs can be designed to temporarily store stormwater and wastewater, and reduce impurities. The thicker substrates used for intensive green roofs can increase the potential of services like building insulation and water filtration, storage, and retention. Additionally, using a biodiversity sensitive design (e.g., including a variety of substrate depths, incorporating local soils into the growing substrate, planting structurally diverse vegetation) may help improve the biodiversity enhancement potential of intensive green roofs.

## IV. Conditions for implementation

Site characteristics are often dependent on project objectives. For example, if the objective is to improve aesthetics, then high-density, visible sights are preferable. Regardless of location, solid, stable concrete buildings with a high bearing capacity, and flat or relatively flat rooftops with underground support structures are necessary. Additionally, an artificial irrigation system or, preferably, rainwater irrigation facilities, are needed for dry periods. In some cases, special plates that distribute pressure on the rooftop are needed for planter-based intensive green roofs.

## V. Benefits and limitations

⊕ Potential benefits:

- Supports human health and good quality of life.
- Stormwater management and quality.
- Improved air quality.
- Aesthetic and recreational value.
- Food production (e.g., through urban gardening).
- Additional (public) green space.
- Localized air temperature reduction.
- Energy reduction for buildings (heating / cooling).
- Reduction of noise pollution.
- Habitat provision for urban wildlife.

⊖ Potential limitations / disservices:

- Limited development of undisturbed habitats because of human activity.

## VI. Performance

### P1 Cooling service

| | |
|---|---|
| Transpiration | ● ● |
| Shading | ● ○ |
| Evaporation | ● ○ |
| Building (Insulation) | ● ● |
| Reflection (Albedo) | ● ○ |

### P2 Water balance regulation service

| | |
|---|---|
| Water conveyance | ● ● |
| Water infiltration | ○ ○ |
| Water retention | ● ● |
| Water storage | ● ○ |
| Water reuse | ○ ○ |

### P3 Water purification service

| | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ○ ○ |

### P4 Air purification service

| | |
|---|---|
| Deposition | ● ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ○ ○ |

### P5 Biodiversity service

| | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ● ○ |

### P6 Amenity value service

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ○ |
| Social interaction | ● ○ |
| Education | ○ ○ |

### P7 Food / Energy / Material

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

### P8 $CO_2$ Sequestration

| | |
|---|---|
| $CO_2$ Sequestration | ● ○ |

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Fig 4.5 Sketch of a constructed wet roof.

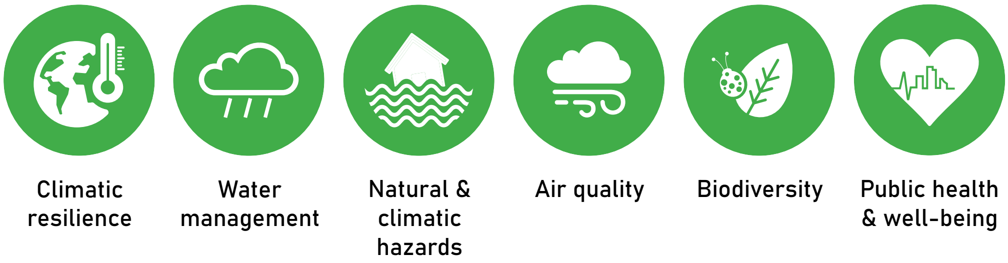
# 4.3 Constructed wet roof

The idea of constructed wet roofs (CWR) is to combine extensive green roofs and constructed wetlands for domestic wastewater (i.e., grey water) treatment. Constructed wet roofs temporarily retain stormwater and gradually release it, thereby reducing peak runoff flow. CWRs offer many of the same benefits as extensive green roofs, but are more physiologically active than extensive green roofs, especially in hot, dry periods, contributing to stronger positive impacts on microclimate, air quality, and biodiversity. Additionally, the treated water from the CWR can be reused for irrigation or, for example, in toilets.

# I. Basic information

Synonyms: Wetland roofs

Addressed challenges:




# II. Role of nature

Constructed wet roofs are inspired by, and mimic the processes of natural wetlands, especially wetland soils. CWRs can provide a variety of benefits, with stormwater management often being the most targeted. CWRs collect and temporarily retain stormwater, thereby reducing flood risk during and shortly after a storm event. As in nature, the water then evaporates directly from the water surface and transpires from plant surfaces and stomata, decreasing the air temperature. Additionally, CWRs harness the ability of natural wetlands to reduce impurities in stormwater or potentially domestic or industrial grey water, as it filters through the system.

# III. Technical and design parameters

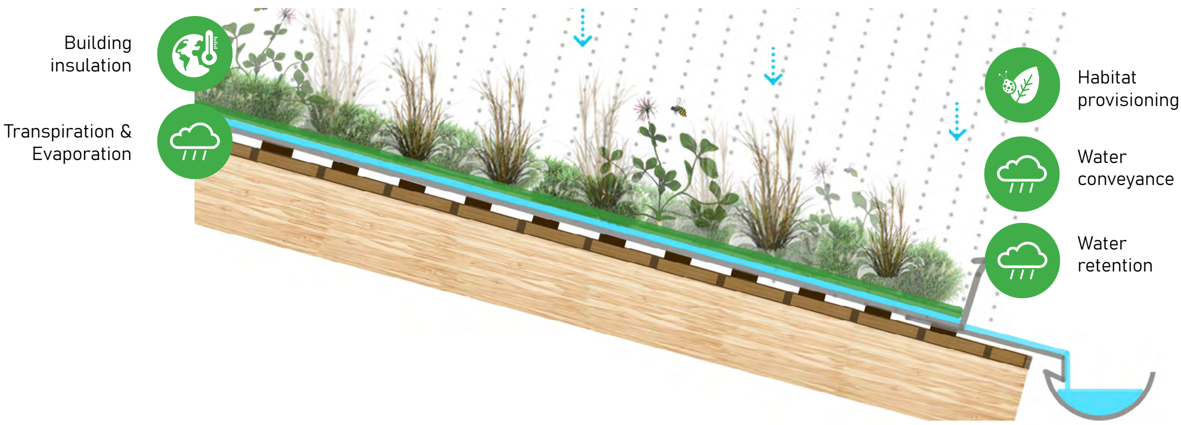



Fig 4.6 An example of a constructed wet roof and its associated benefits.

From the top down, a horizontal flow constructed wet roof typically consists of turf mats with sandy, fertilized soil, and vegetation rooting in stabilization plates on a substratum of sand, light expanded clay aggregates, and polyactic acid beads. The wetland-suitable plants are irrigated with storm and wastewater to ensure the surface remains moist and maintains the green space. Types of wastewater that can be used in CWRs include domestic wastewater, for example, from kitchen or bathroom sinks. CWRs are usually constructed on moderately to high-pitched roofs, with a waterproof (e.g., bituminous waterproofing) surface. Construction on flat roofs is also possible, in which case about 10 to 30 cm of water is retained with floating, vegetative mats.

Some of the technical devices that need to be considered in construction and maintenance include septic and inlet tanks, pumps for each bed, pressure pipes (influent and effluent pipe), and an infiltration pond.

## IV. Conditions for implementation

Like with all green roofs, it is necessary that the roof is waterproofed and has a sufficient load-bearing capacity. The roof must also have a slope gradient to water outlets and emergency overflows.

## V. Benefits and limitations

⊕ Potential benefits:

- Effect on microclimate: Cooling of air temperature.
- Reduced flood risk due to water retention.
- Habitat for wildlife.
- Improves water quality.
- Re-use of water (water can be used for different purposes after natural treatment).

⊖ Potential limitations / disservices:

- Greater maintenance effort and cost than traditional extensive green roofs.

## VI. Performance

| P1 Cooling service | |
|---|---|
| Transpiration | ● ● |
| Shading | ● ○ |
| Evaporation | ● ○ |
| Building (Insulation) | ● ● |
| Reflection (Albedo) | ● ○ |

| P2 Water balance regulation service | |
|---|---|
| Water conveyance | ● ○ |
| Water infiltration | ○ ○ |
| Water retention | ● ○ |
| Water storage | ● ○ |
| Water reuse | ● ○ |

| P3 Water purification service | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ● ○ |

| P4 Air purification service | |
|---|---|
| Deposition | ● ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ○ ○ |

| P5 Biodiversity service | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ○ ○ |

| P6 Amenity value service | |
|---|---|
| Beauty / Appearance | ● ○ |
| Usability / Functionality | ● ○ |
| Social interaction | ○ ○ |
| Education | ○ ○ |

| P7 Food / Energy / Material | |
|---|---|
| Food / Energy / Material | ○ ○ |

| P8 $CO_2$ Sequestration | |
|---|---|
| $CO_2$ Sequestration | ● ○ |

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Fig 4.7 A complex roof greening design with capillary fibre cylinders at Clausplein in Eindhoven, Netherlands.

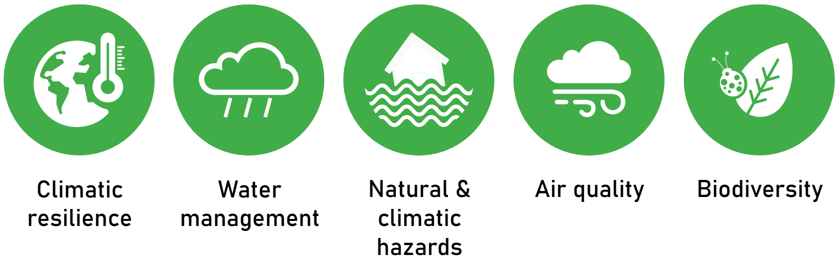
## 4.4 Smart roof

Smart roofs are a unique type of intensive or extensive green roof that provide several services to protect ecosystems in cities. Many of the benefits are similar to other green roofs (e.g., basic habitat provision, reduction of localized air temperature, stormwater management). However, capillary smart roofs represent an extension of conventional green roofs because the system is equipped with a drainage system under the vegetation layer. The drainage layer retains stormwater, thereby reducing flood risk more so than a typical green roof. Through capillary fiber cylinders, water is naturally returned to the vegetation layer during dry periods. Capillary smart roofs represent cyclic water management where additional plant irrigation is not needed (100% of the stormwater can be reused for irrigation).

# I. Basic information

Synonyms: Capillary smart roof; Blue-green roof

Addressed challenges:




# II. Role of nature

The model for a green roof is natural soil with its vegetation cover. Through the establishment of green roofs on buildings, different services of natural vegetation layers are replicated. Capillary smart roofs use the process of capillary action (also the process plants use to move water from their roots and stems to the rest of the plant) to slowly transfer water from a storage layer to the soil layer, making it available for the vegetation.

# III. Technical and design parameters

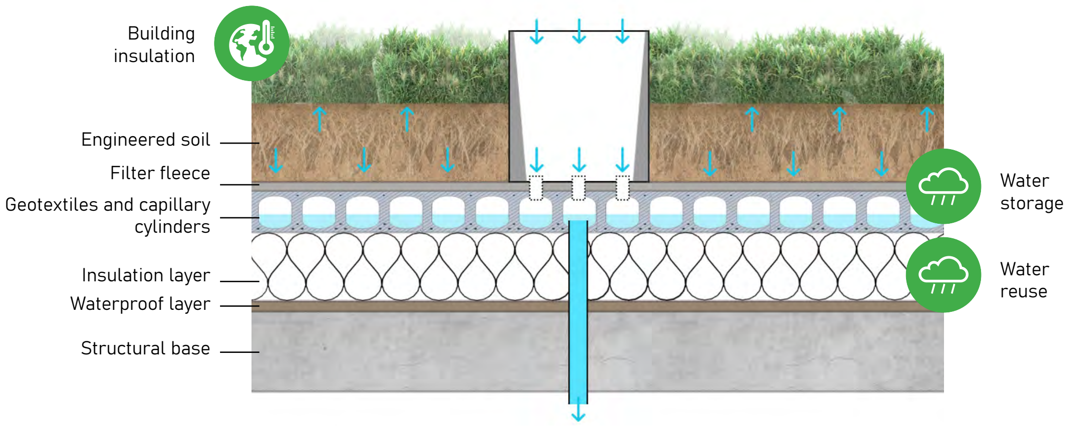



Fig 4.8 Typical layers of a smart roof and its associated benefits.

Capillary smart roofs have a layered construction. The basic construction starting from the bottom up begins with a protective layer and waterproof membrane, followed by drainage and storage layers of capillary geotextiles and capillary cylinders, and topped off with a lightweight substrate and vegetation. An emergency overflow system should be included, but in general, additional technical devices like pumps, tanks, and valves are unnecessary.

## IV. Conditions for implementation

The roof or surface must have sufficient load-bearing capacity and waterproofing.

## V. Benefits and limitations

⊕ Potential benefits:

- Reduced flood risk.
- Re-use of water.
- Habitat for wildlife.

## VI. Performance

**P1 Cooling service**

| | | |
|---|---|---|
| Transpiration | ● | ○ |
| Shading | ● | ○ |
| Evaporation | ● | ○ |
| Building (Insulation) | ● | ● |
| Reflection (Albedo) | ● | ○ |

**P2 Water balance regulation service**

| | | |
|---|---|---|
| Water conveyance | ● | ● |
| Water infiltration | ○ | ○ |
| Water retention | ● | ● |
| Water storage | ● | ● |
| Water reuse | ● | ○ |

**P3 Water purification service**

| | | |
|---|---|---|
| Water filtering | ● | ○ |
| Water bio-remediation | ○ | ○ |

| | | |
|---|---|---|
| Deposition | ● | ○ |
| Air biofiltration | ○ | ○ |
| Noise reduction | ○ | ○ |

**P5 Biodiversity service**

| | | |
|---|---|---|
| Habitat provision | ○ | ○ |
| Connectivity | ○ | ○ |

**P6 Amenity value service**

| | | |
|---|---|---|
| Beauty / Appearance | ● | ○ |
| Usability / Functionality | ○ | ○ |
| Social interaction | ○ | ○ |
| Education | ○ | ○ |

**P7 Food / Energy / Material**

| | | |
|---|---|---|
| Food / Energy / Material | ○ | ○ |

**P8 $CO_2$ Sequestration**

| | | |
|---|---|---|
| $CO_2$ Sequestration | ● | ○ |

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Fig 4.9 Green façade with a façade-bound greening in Reutlingen, Germany.

# 4.5 Green façades

Planted façades with controlled cultivation are called green façades. Green façades offer many benefits including reduction of air pollution, thermal insulation for buildings, and biodiversity support via habitat provision and connectivity improvement. Façade greenings are divided into two types: façade-bound greening and ground-based greening.

Façade-bound greening uses panels or containers that are fixed to the façade or is part of the façade itself. Vegetation is usually planted directly in the thin substrate of the panel and then elevated. Therefore, façade-bound greening systems do not rely on climbing plants, and can be removed during winter.

Ground-based green façades are established using climbing plants. The climbing vegetation is planted in the ground and therefore extracts water and nutrients directly from the soil. The vegetation grows directly on the wall, or climbs on a frame that is connected to, but keeps a small distance from the wall.

# I. Basic information

Synonyms: Façade-Bound greening; Ground-Based greening; Green wall; Living wall; Vertical greening systems

Addressed challenges:

Climatic resilience | Water management | Air quality | Biodiversity

# II. Role of nature

Façade-bound greening provides services similar to a very thin natural soil, which is used to support vegetation. Depending on the type and level of engineering for irrigation, nutrient supply, and substrate, façade-bound greening can perform highly. Integrated vegetation can range from plants of rather wet environments to very dry environments.

Climbing plants used in ground-based greening grow from rather small areas of natural soil and often need supporting vertical elements or a porous surface the plant can attach to (species dependent). A comparable natural situation may be bright areas of forests and their fringes (e.g., *Clematis* species).

# III. Technical and design parameters

**Façade-bound greening**

In most cases, façade-bound greening intensively uses technology for irrigation and special substrates for reducing the weight of the green façade. Pre-cultivated panels or special plant pot systems are most frequently used. For lightweight structures, special tissues are used. Because of the thinness of the soil or substrate layer, temperatures below 0°C may be a problem. Therefore, some greening systems have panels that can be removed during winter. Façade-bound greening does not usually rely on climbing plants, as vegetation is usually first planted in the panel and then elevated.

Options depend highly on the character of the building (new construction, refurbishment, restoration) and on structural engineering. For new constructions, integrated façade systems can be used with vegetation panels (0.5 m²-1 m²).

For regeneration projects, a separate scaffolding is often needed. Typical specifications include:

- Panel: 0.5-1.0 m²
- Selection of 10-15 (usually small) plant species, mainly perennial species.
- Regular irrigation and special substrate is necessary

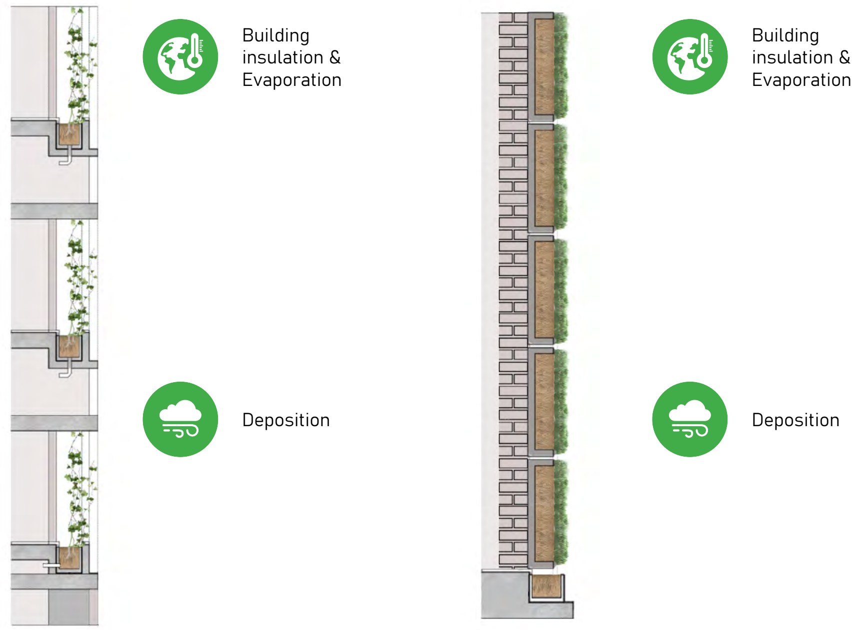


Fig 4.10 Two types of façade-bound greening. Planter-based with climbers (left) and a modular greening system (right).

**Ground-based greening**

It is important to differentiate between self-climbing plants and climbers that need a support system. A façade without gaps is necessary for self-climbers to avoid intrusion of roots into the façade, whereas a supporting frame is needed for climbers. Climbing plants can grow up to 25 meters high, however plant selection depends on environmental factors, and usually only few of species can be combined. Depending on the desired outcomes (e.g., shading in the summer with light in the winter, or year-round insulation), evergreen or deciduous vegetation may be selected.

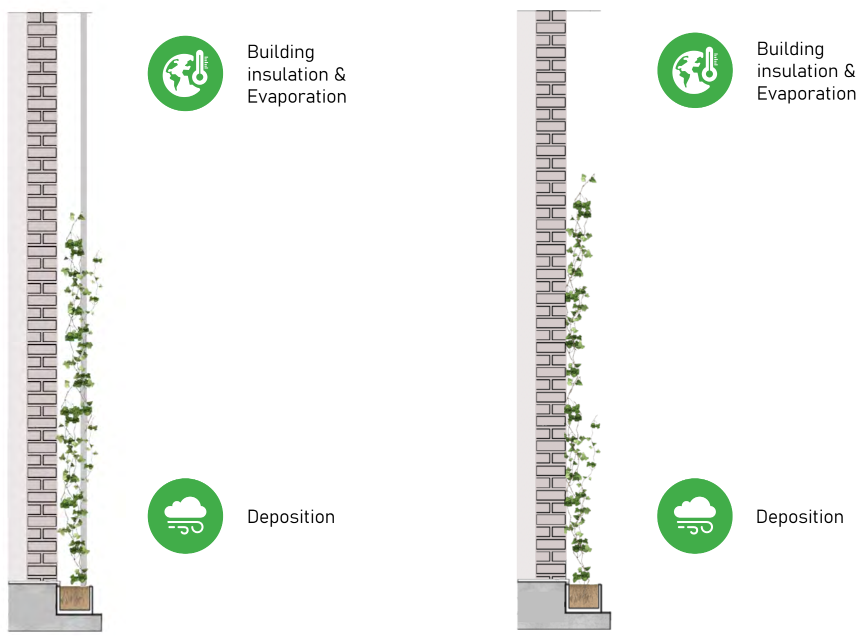


Fig 4.11 Two types of ground-based greening with an external support system (left) and without a support system (right).

## IV. Conditions for implementation

While all surfaces are potentially usable for a green façade, areas with plenty of sun exposure and with mild climatic conditions (e.g., not very dry, hot, or cold) tend to perform best. For façade-bound greening, mosses and small perennial plants are appropriate, but other suitable vegetation can also be selected. For ground-based greening, good soil or substrate, and a strong façade without gaps is necessary. It takes about 5-20 years for ground-based greening to fully cover a medium-sized house façade.

It is important to use material that can withstand high temperatures, and if the substrate or vegetation dries out there is a risk of fire. Special care of professional gardeners (particularly for façade-bound greening) is usually needed for maintenance.

## V. Benefits and limitations

⊕ Potential benefits:

- Air pollution is reduced by plants, they bind high proportions of the particulate matter and polluting gases.
- Reduction of façade surface temperature via shading, evapotranspiration, and reflection.
- Reduction of local air temperature via evapotranspiration.
- Building insulation.
- Water retention.
- Biodiversity support through increased habitat connectivity and provision: For example, habitat for nesting and breeding for birds and potentially for bats.
- Natural noise protection.
- Improved aesthetics.
- Ground-based green façades that are irrigated by surface water runoff replace a part of the surface water regulation service of a natural soil.

⊖ Potential limitations / disservices:

- High dependency on irrigation system (façade-bound types).
- Fire risk – especially if vegetation is dry.
- Frost risk.
- Relatively long time span before walls are fully covered for ground-based greening.

# VI. Performance

### P1 Cooling service

| | |
|---|---|
| Transpiration | ● ● |
| Shading | ○ ○ |
| Evaporation | ○ ○ |
| Building (Insulation) | ● ● |
| Reflection (Albedo) | ○ ○ |

### P2 Water balance regulation service

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ○ ○ |
| Water retention | ○ ○ |
| Water storage | ○ ○ |
| Water reuse | ○ ○ |

### P3 Water purification service

| | |
|---|---|
| Water filtering | ○ ○ |
| Water bio-remediation | ○ ○ |

### P4 Air purification service

| | |
|---|---|
| Deposition | ● ● |
| Air biofiltration | ● ● |
| Noise reduction | ○ ○ |

### P5 Biodiversity service

| | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ● ○ |

### P6 Amenity value service

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ○ |
| Social interaction | ○ ○ |
| Education | ○ ○ |

### P7 Food / Energy / Material

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

### P8 $CO_2$ Sequestration

| | |
|---|---|
| $CO_2$ Sequestration | ● ○ |

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Fig 4.12 Free standing living wall in Ludwigsburg, Germany.

# 4.6 Free standing living wall

Verticalization of green spaces is a method to increase vegetated surfaces with many ecological services in urban environments. Free standing living walls serve as adaptation measures for the urban heat island effect. Furthermore, they create space with high amenity value and potentially high biodiversity. Free standing living walls can also be used as noise barriers along highly frequented roads. They are suitable to re-use stormwater runoff water and have a high rate of evapotranspiration.

# I. Basic information

Synonyms: Living wall; Green wall; Green noise barrier

Addressed challenges:


# II. Role of nature

Natural soil with vegetation cover (perennials, shrubs, and trees) is the model for living walls. They consist of vertical layering of soil with plants growing on a vertical surface as well as on top of the wall. Depending on the construction, thickness (typically at least 40 cm), and height of the living wall, functions of natural soils like water filtration may develop. While dependent on plant selection, exposition, and level of irrigation, evaporation from the vertical soil and vegetative transpiration are also key natural processes that can help reduce the surrounding air temperature.

# III. Technical and design parameters


Fig 4.13 An example of free standing living wall and its associated benefits.

Free standing living walls are constructed by the vertical layering of soil or substrate that is contained in hollow cubes constructed using metal wire with supporting elements to create walls of up to four meters in height. Fabric (organic or inorganic) is used to prevent the erosion of substrate or soil from the cubes. It is a fairly heavy construction that rests on a simple strip foundation. Living walls tend to be at least 40 cm wide and need to be constructed with a minimum of two segments that form a right angle for stabilization (e.g., L-shaped).

Living walls are very flexible with regard to plant selection as long as they are properly maintained. Therefore, living walls can help support biodiversity with proper species selection and a biodiversity-sensitive design. An irrigation system is necessary and should preferentially use collected rainwater or run-off from nearby surfaces.

## IV. Conditions for implementation

Because of the thickness of the living wall, there are few issues with central European frost periods. The ground and underground space needs to be sufficiently loadable to support the living wall. An irrigation system should also be implemented, as regular irrigation supports the vegetation and reduces fire risk.

## V. Benefits and limitations

⊕ Potential benefits:

- Provides direct shelter from the sun, and depending on the vegetation indirect shelter (e.g., living wall with trees).
- Evapotranspiration of vegetation helps to mitigate the heat island effect.
- Can help support biodiversity with proper species selection and biodiversity-sensitive design.
- Noise reduction.
- Surface water can be used for irrigation of living wall (re-use of rainwater or run-off).
- Can be used for way-finding in public space.

⊖ Potential limitations / disservices:

- Irrigation is needed (summer and winter), but should not rely on drinking water.
- Underground support is needed.
- Free standing living walls may act as a barrier for pedestrian movement.

## VI. Performance

### P1 Cooling service

| | |
|---|---|
| Transpiration | ● ● |
| Shading | ● ● |
| Evaporation | ● ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ● ● |

### P2 Water balance regulation service

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ○ ○ |
| Water retention | ○ ○ |
| Water storage | ○ ○ |
| Water reuse | ○ ○ |

### P3 Water purification service

| | |
|---|---|
| Water filtering | ○ ○ |
| Water bio-remediation | ○ ○ |

### P4 Air purification service

| | |
|---|---|
| Deposition | ● ○ |
| Air biofiltration | ● ○ |
| Noise reduction | ○ ○ |

### P5 Biodiversity service

| | |
|---|---|
| Habitat provision | ● ● |
| Connectivity | ● ○ |

### P6 Amenity value service

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ○ |
| Social interaction | ● ○ |
| Education | ○ ○ |

### P7 Food / Energy / Material

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

### P8 $CO_2$ Sequestration

| | |
|---|---|
| $CO_2$ Sequestration | ● ○ |

## VII. References and further reading


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## 4.7 Mobile vertical greening

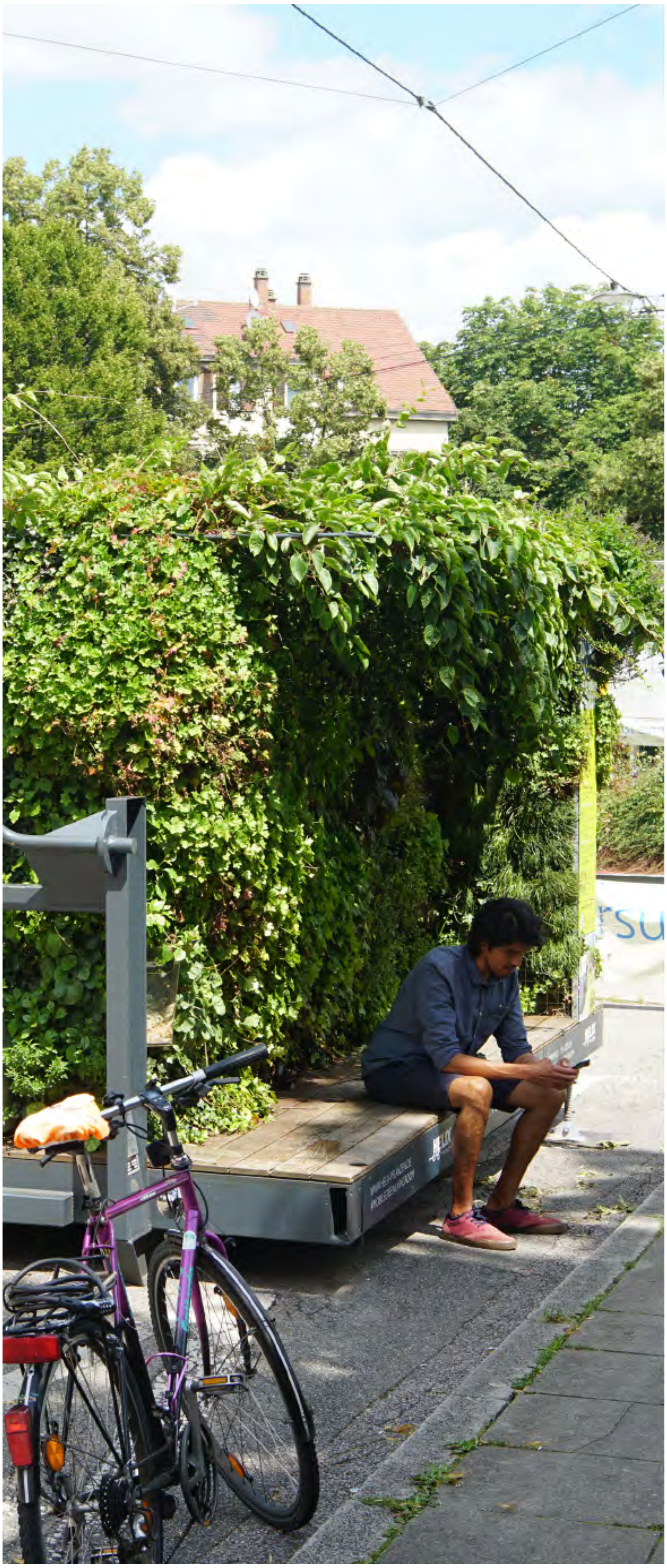


Fig 4.14 Mobile Green Living Room in Stuttgart, Germany.

Mobile vertical greening such as the Mobile Green Living Room consists of living wall modules (Factsheet 5.6 Free standing living wall) that are fixed to a hook lift container platform. The vegetation cover is very diverse in order to illustrate the high potential of living walls to increase amenity value and stimulate biodiversity.
A light, open roof structure partly covered with vegetation provides shade. Mobile vertical greening instantly provides services for clean air provision, cooling and shading, and habitat for urban biodiversity. It can be used for educational purposes, as a mobile demonstration for green infrastructure, a test feature, a temporary green installation, or as an open green office for information and communication purposes.

# I. Basic information

Synonyms: Mobile Green Living Room; Vertical mobile garden

Addressed challenges:


# II. Role of nature

Natural soil with vegetation cover (perennials and shrubs or trees) is the model for living walls. However, there is not an adequate example from nature for the loading and unloading of “mobile vegetation.”

# III. Technical and design parameters

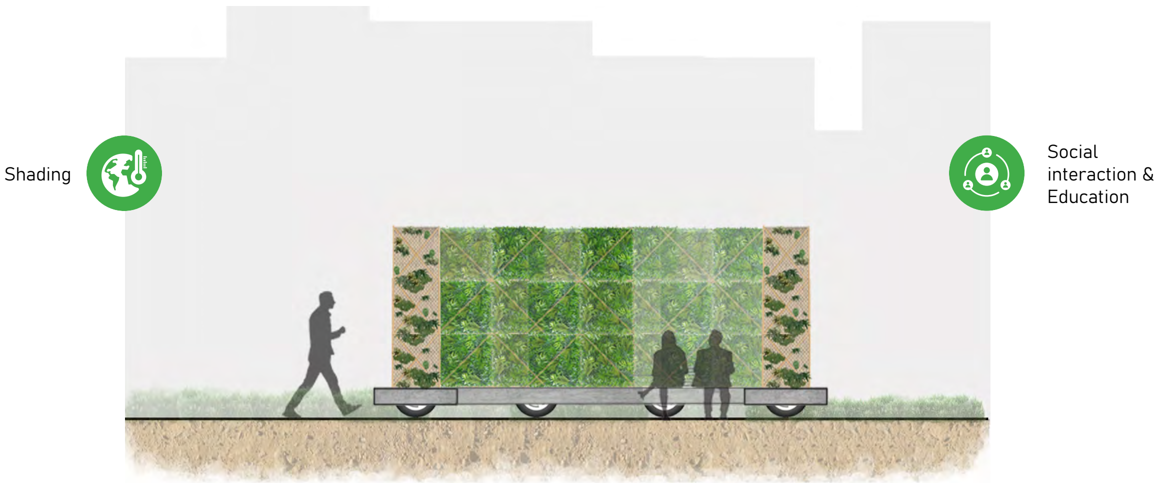


Fig 4.15 Detail of a typical mobile vertical greening unit and its associated benefits.

Mobile vertical greening such as the Mobile Green Living Room can be moved to any location that has truck access. The actual module itself is constructed using substrate filled wire cubes, similar to a free standing living wall (see Factsheet 5.6). It acts as a semi-autonomous unit with an on-board water tank that lasts for up to a week and an irrigation system that needs a temporary energy supply.

# IV. Conditions for implementation

Space for loading and unloading is needed, the surface has to be flat (<3°), and permission is needed before installation.

## V. Benefits and limitations

Potential benefits:

- Mobile vertical elements serve as models for large scale interventions by testing the suitability of a location for permanent vertical greening and in participatory processes.
- In combination with additional green elements, the performance increases significantly.
- Raises awareness and offers educational opportunities for NBS use in urban areas.

Potential limitations / disservices:

- The requirements for transporting mobile elements eclipse the environmental benefits of vertical greening.
- The average performance of vertical greening, such as heat reduction, cannot be replicated completely in mobile elements due to the limited space.
- Size is limited.

## VI. Performance

| **P1 Cooling service** | |
|---|---|
| Transpiration | ● ○ |
| Shading | ● ● |
| Evaporation | ○ ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ● ○ |

| **P2 Water balance regulation service** | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ○ ○ |
| Water retention | ○ ○ |
| Water storage | ○ ○ |
| Water reuse | ○ ○ |

| **P3 Water purification service** | |
|---|---|
| Water filtering | ○ ○ |
| Water bio-remediation | ○ ○ |

| **P4 Air purification service** | |
|---|---|
| Deposition | ● ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ● ○ |

| **P5 Biodiversity service** | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ● ○ |

| **P6 Amenity value service** | |
|---|---|
| Beauty / Appearance | ● ○ |
| Usability / Functionality | ● ● |
| Social interaction | ● ○ |
| Education | ● ● |

| **P7 Food / Energy / Material** | |
|---|---|
| Food / Energy / Material | ○ ○ |

| **P8 $CO_2$ Sequestration** | |
|---|---|
| $CO_2$ Sequestration | ● ○ |

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Fig 4.16 Sketch of a moss wall.

# 4.8 Moss wall

Constructed moss walls use the natural capacities of mosses to reduce air pollution. There is a range of test sites with open-air experiments in order to test the effectiveness for fine dust reduction and air quality improvement using moss walls. Additionally, because mosses can store a relatively large amount of water and a have a large surface area for transpiration, they also contribute to the local reduction of air temperature.

A variety of products based on different concepts are available on the market, but here, the “City Tree” is described to exemplify this NBS. The “City Tree” is a compact and mobile construction, vertically planted with different species of mosses on both its front and backside, with the primary aim to reduce air pollution, especially at the pedestrian level.

# I. Basic information

Synonyms: City tree

Addressed challenges:

Climatic resilience | Air quality | Social justice & cohesion

# II. Role of nature

Mosses, compared to other plants, have a large bioactive surface, transpire more, and actively reduce some pollutants. The “City Tree” and moss walls in general, maximize the ecological function of natural mosses, by utilizing their large surface area to filter air pollutants and cool the surrounding area via transpiration.

# III. Technical and design parameters

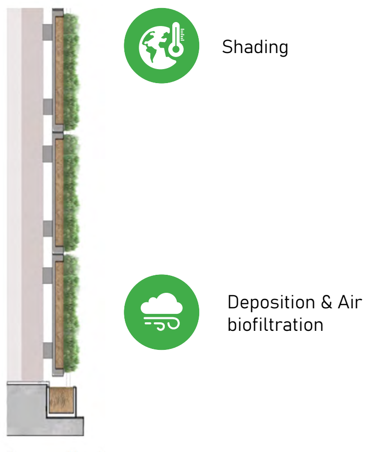


Fig 4.17 An example of moss wall and its associated benefits.

The “City Tree” is a compact, vertical greening element that combines multiple moss species on both sides of a mobile module. “City Trees” are also equipped with additional technical solutions. For example, externally controllable ventilators inside the vertical construction and underneath the moss surface strengthen the airflow through the installation, thereby increasing air filtering and water transpiration capacity.

They are also equipped with a device that provides real-time information about the “City Tree” and the surrounding environmental conditions. Depending on local climate conditions, the “City Tree” may need an additional irrigation system. Solar panels can supply electricity or it may be connected to the main power line.

## IV. Conditions for implementation

Flat surfaces for installation and enough space for loading and unloading is needed for the mobile "City Tree".

## V. Benefits and limitations

⊕ Potential benefits:

- Local reduction of air pollution.
- Local reduction of air temperature: Mitigation against heat stress.
- Relaxation.

⊖ Potential limitations / disservices:

- Non-experimental performance is still under discussion; further independent studies needed.
- Transportation and production produce emissions.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ● ● |
| Shading | ● ○ |
| Evaporation | ● ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ○ ○ |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ○ ○ |
| Water retention | ○ ○ |
| Water storage | ○ ○ |
| Water reuse | ○ ○ |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ○ ○ |
| Water bio-remediation | ○ ○ |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ● ○ |
| Air biofiltration | ● ○ |
| Noise reduction | ● ○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ○ ○ |
| Connectivity | ○ ○ |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ● ○ |
| Usability / Functionality | ● ○ |
| Social interaction | ● ○ |
| Education | ● ○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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# 5. Natural and semi-natural water storage and transport structure

Fig 5.0 Renatured segment of the Lura river in Arese, Italy.

It is projected that many areas of Europe will experience both intensifying rainfall events and longer dry periods due to the effects of climate change [20]. Indeed these trends have already been observed with the frequency and total amount of extreme rainfall increasing in Europe since 1950. Additionally, projections suggest large future increases of extreme rainfall in parts of Europe [21]. The negative consequences of these climate trends include not only increased risk of flooding, including the associated risks of erosion and water pollution, but also drought. Traditional urban areas dominated by grey infrastructure may experience these challenges more intensely, for example with increased flood risk due to heavy runoff from sealed surfaces. Natural and semi-natural water storage and transport structures are natural or constructed waterbodies that help mitigate these challenges by reducing runoff flow, increasing retention capacity, and reducing pollution by facilitating particulate settling [4]. Additionally, these structures may provide a range of recreational opportunities for people and natural habitat for wildlife thereby enhancing biodiversity. Examples of NBS that are natural and semi-natural water storage and transport structures include surface wetlands, floodplains and floodplain reconnection with rivers, restoration of degraded waterbodies and waterways, and retention ponds. Four examples (i.e., constructed wetlands, retention / detention ponds, daylighting, and underground water storage) are described in more detail below.

Fig 5.1 Urban wetland on the University of Stuttgart's Vaihingen campus in Stuttgart, Germany.

# 5.1 Constructed wetland

Constructed wetlands are artificial wetlands with the main objective to harvest, treat, and store grey water or stormwater run-off in urban areas. Constructed wetlands are a cost-effective alternative, as they are often less expensive than conventional wastewater treatment options. Processes and services of natural wetlands are adapted to constructed wetlands focusing on water purification and storage. Wetlands are complex systems where vegetation, soil, microbiological activity, and their interactions, play an important role in their filtering performance. Constructed wetlands can also enhance urban biodiversity, for example, by including design elements such as diverse vegetation and barrier-free shores.

## I. Basic information

Synonyms:

Addressed challenges:

Climatic resilience | Water management | Natural & climatic hazards | Biodiversity | Social justice & cohesion

## II. Role of nature

Wetlands are complex systems with their vegetation, soil, microbiological activity, and their interactions, playing an important role for their functionality. Processes and services of natural wetlands are adapted to constructed wetlands focusing on water purification and storage. The main processes in a constructed wetland are: Settling of particles, filtration, chemical transformation, adsorption, positive ion exchange, and the uptake / breakdown / transformation of pollutants and nutrients. Additionally, natural wetlands are among the most biodiverse ecosystems, and therefore constructed wetlands should use an intentional biodiversity-senstive design (e.g., diverse vegetation, native species selection, potential water level fluctuations, and barrier-free shores) to support urban nature as well as water management.

## III. Technical and design parameters

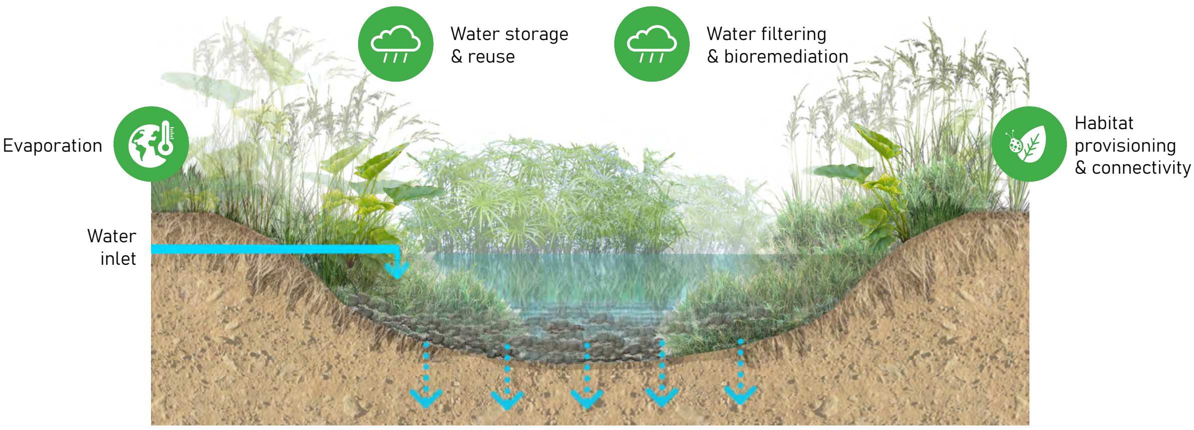


Fig 5.2 An example of a constructed wetland and its associated natural processes and benefits.

Constructed wetlands are shallow basins that are filled with substrate. There are various substrate options, but usually constructed wetlands are filled with sand or gravel. The substrate layer is planted with aquatic or semi-aquatic vegetation. Constructed wetlands have an inlet pipe for grey water or stormwater run-off. The untreated water can then flow over or through the substrate layer and vegetation while it is naturally filtered and cleaned. The constructed wetland is equipped with an outlet (pipe, weir) for controlled water discharge. Often, the treated water flows into another pond where it is stored. The treated stormwater can be used for different purposes (e.g., for green space irrigation). Depending on the type of constructed wetland, wastewater flows 1) horizontally over the ground surface, 2) horizontally under the ground surface and through the substrate layer, or 3) vertically through the constructed wetland (hybrid systems).

## IV. Conditions for implementation

Suitable locations must be selected for constructed wetlands. There needs to be enough accessible land with compact soils to minimize infiltration into groundwater and they should be located upland, near a wastewater source, and outside floodplains. They should also be built on a gentle slope, as water flows by gravity through constructed wetlands. They can also be included in green spaces as landscaping elements. Installation of water control measures, and regular inspections, monitoring, and maintenance are necessary. Furthermore, the protection of biodiversity should be considered, and therefore construction should not displace endangered or threatened species or disturb archaeological or historic resources.

## V. Benefits and limitations

⊕ Potential benefits:

- Water supply regulation.
- Water temperature control.
- Improve water quality.
- Provide water for different purposes (e.g., irrigation).
- Flood control / mitigation.
- Habitat for wildlife supports wetland biodiversity.

⊖ Potential limitations / disservices:

- Traditional constructed wetlands require relatively large areas.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ● ○ |
| Shading | ○ ○ |
| Evaporation | ● ● |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ○ ○ |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ● ○ |
| Water infiltration | ● ○ |
| Water retention | ● ○ |
| Water storage | ● ○ |
| Water reuse | ● ● |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ● ● |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ○ ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ○ ○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ● ● |
| Connectivity | ● ● |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ○ |
| Social interaction | ● ● |
| Education | ● ○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ● ○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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Fig 5.3 Wet retention pond in Tampere, Finland.

# 5.2 Retention / detention pond

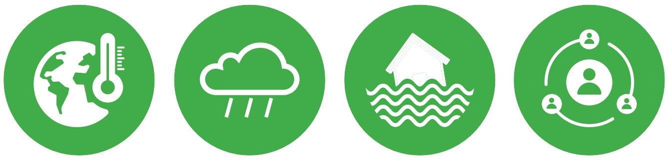
Dry detention ponds are surface storage basins that retain stormwater. During periods of heavy rain, the area gets flooded and could fill the detention pond for several days in cases of heavier or longer rainfall events. After the rain ends, the water flows in the sewer system or, ideally, infiltrates through the soil and recharges the groundwater. If there is no heavy rainfall event, the detention ponds are dry and could be used as a green area.

Retention ponds retain stormwater continuously, holding water also in dry periods. They can also improve the water quality, for example, with downstream infiltration and sedimentation and provide habitat for aquatic and semi-aquatic species.

## I. Basic information

Synonyms: Detention pond: Dry detention pond; Dry detention basin
Retention pond: Wet retention pond; Wet retention basin

Addressed challenges:



Climatic resilience | Water management | Natural & climatic hazards | Social justice & cohesion

## II. Role of nature

Detention ponds mimic a natural landscape that contains a heterogeneous surface with slightly elevated areas and lower areas in close proximity, forming a mosaic of micro conditions. Water remains in the lower parts for some time until it infiltrates or evaporates. Wet retention ponds, however, mimic natural ponds that have standing water (although at various levels) year round. Similar to natural ponds, wet retention ponds store stormwater and run-off and provide habitat for aquatic and semi aquatic species.

## III. Technical and design parameters

Detention and retention ponds can be incorporated into public areas like parks and sports fields, but must always be at the lowest part of the green space. Additionally, traditional dry detention ponds can be used as green areas in times without heavy rainfall events. Both dry detention ponds and wet retention ponds can improve biodiversity enhancement potential if designed to have, for example, greater structural diversity (e.g., larger transition zones between aquatic and terrestrial conditions for wet retention ponds, or the inclusion of various substrates in dry detention ponds).

## IV. Conditions for implementation

There needs to be appropriate available area (enough space to flood) with proper soil and rainfall conditions. While there are limited design options, they could be considered in park planning.

## V. Benefits and limitations

⊕ Potential benefits:

- Reduces flood risk from heavy rain events.
- Multifunctional use of detention pond is possible.
- Retention of stormwater.
- Potential reuse of water for irrigation.
- Recreation and aesthetic value.

⊖ Potential limitations / disservices:

- Usually requires a relatively large area.

## VI. Performance

### P1 Cooling service

| | | |
|---|---|---|
| Transpiration | ○ | ○ |
| Shading | ○ | ○ |
| Evaporation | ● | ○ |
| Building (Insulation) | ○ | ○ |
| Reflection (Albedo) | ○ | ○ |

### P2 Water balance regulation service

| | | |
|---|---|---|
| Water conveyance | ○ | ○ |
| Water infiltration | ○ | ○ |
| Water retention | ● | ● |
| Water storage | ● | ○ |
| Water reuse | ● | ○ |

### P3 Water purification service

| | | |
|---|---|---|
| Water filtering | ● | ○ |
| Water bio-remediation | ○ | ○ |

### P4 Air purification service

| | | |
|---|---|---|
| Deposition | ○ | ○ |
| Air biofiltration | ○ | ○ |
| Noise reduction | ○ | ○ |

### P5 Biodiversity service

| | | |
|---|---|---|
| Habitat provision | ○ | ○ |
| Connectivity | ○ | ○ |

### P6 Amenity value service

| | | |
|---|---|---|
| Beauty / Appearance | ● | ○ |
| Usability / Functionality | ● | ○ |
| Social interaction | ● | ○ |
| Education | ● | ○ |

### P7 Food / Energy / Material

| | | |
|---|---|---|
| Food / Energy / Material | ○ | ○ |

### P8 $CO_2$ Sequestration

| | | |
|---|---|---|
| $CO_2$ Sequestration | ○ | ○ |

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Fig 5.4 Daylighted segment of De grote beek, Eindhoven, Netherlands.

## 5.3 Daylighting

Daylighting describes the opening of buried or covered watercourses, such as rivers and drainage systems, by removing concrete layers. This creates more space for the river, which allows for increased storage capacity of the channel, thus decreasing flood risk. Daylighting also results in a more natural development of the riverbed and riparian zone, thereby enhancing aesthetics and supporting biodiversity through improved habitat quality or habitat creation. Both natural and architectural restoration can be considered when daylighting. Natural restoration refers to the daylighting of channels followed by a natural development of the riverbed and riparian zone, whereas architectural restoration describes the daylighting of a watercourse that still follows a concrete or constructed channel.

# I. Basic information

Synonyms: River daylighting; Stream daylighting; Culvert removal

Addressed challenges:


# II. Role of nature

Daylighting allows the natural development of a water channel that fulfils services of a natural stream. For example, it provides habitat for aquatic or semi-aquatic wildlife and vegetation, and increases the regulation and uptake of stormwater run-off. Natural restoration typically offers benefits more similar to those of a natural stream than architectural restoration. For example, natural channels enable the water to flow and expand to its riverbanks, and vegetation contributes to reducing water velocity.

# III. Technical and design parameters

There are a variety of designs and levels of intervention possible that are dependent upon the intention of the planned project. For example, the completely culverted structure, or parts of it like as the top layer, may be completely removed or gaps created. Natural restoration is associated with more effort than only removing the top layer of a culvert that results in an open constructed channel. However, with natural restoration the water channel is shaped by nature leading to a dynamic water channel and a riparian zone with a natural shape that includes plants and rocks.

# IV. Conditions for implementation

There may be restrictions or limited possibilities in dense and highly built areas because of high costs for shifting or removing infrastructure. Additionally, there needs to be enough space and a sufficient channel width to deculvert the watercourse. Furthermore, information about soil types under and surrounding the channel need to be collected to guarantee the performance of the daylighting measure.

## V. Benefits and limitations

Potential benefits:

- Stormwater management.
- Benefits for many aquatic organisms (light plays a role for population movement).
- Habitat provision for riparian flora and fauna.
- Improving physical habitat conditions of the watercourse, habitat niches arise from structural diversity.
- Natural bank development; creating natural watercourses.
- Enables natural processes (e.g., erosion, deposition).
- Aesthetic and recreational value.
- Educational resource.

Potential limitations / disservices:

- Architectural restoration is less near natural than the natural restoration. As a result the development and establishment of flora and fauna may be limited.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ●○ |
| Shading | ○○ |
| Evaporation | ●○ |
| Building (Insulation) | ○○ |
| Reflection (Albedo) | ○○ |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ●○ |
| Water infiltration | ●○ |
| Water retention | ●○ |
| Water storage | ○○ |
| Water reuse | ○○ |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ●○ |
| Water bio-remediation | ●○ |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ○○ |
| Air biofiltration | ○○ |
| Noise reduction | ○○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ●● |
| Connectivity | ●○ |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ●● |
| Usability / Functionality | ●○ |
| Social interaction | ●○ |
| Education | ●○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ○○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ●○ |

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Fig 5.5 Public square with an Underground water retention basin in Freiburg, Germany.

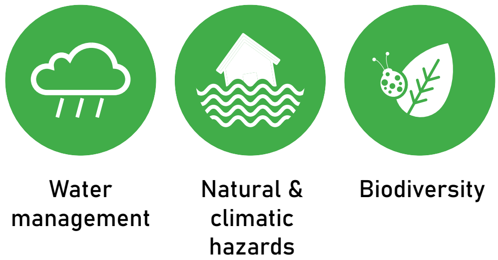
# 5.4 Underground water storage

Underground water retention systems are typically composed of modular elements to retain stormwater from heavy precipitation events and store that water for nearby irrigation purposes. They can be constructed below open spaces such as parks, sports fields, or public squares, and are usually topped with permeable pavements or soil substrates with vegetation that allow water to enter the system. Underground water retention systems can be incorporated into a multifunctional design while simultaneously supporting water management (e.g., flood risk reduction, re-use of water for irrigation).

# I. Basic information

Synonyms: Underground water retention basin

Addressed challenges:




# II. Role of nature

Depending on the geology of an area, underground storage systems retain and store water after heavy precipitation events. Examples from Peru show that already in pre-Inca times, people made use of these qualities and directed water in channels to storage areas or to feed artificial ponds or springs.

# III. Technical and design parameters

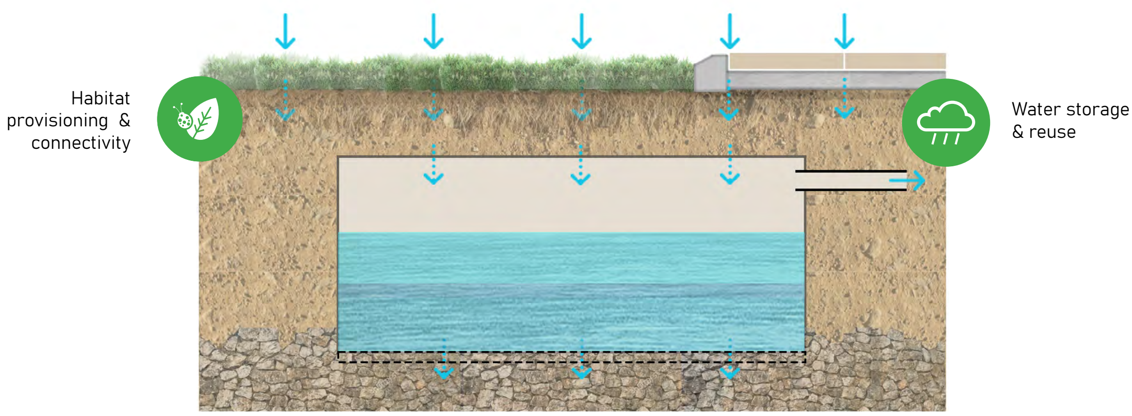



Fig 5.6 An example of an underground water retention basin and its associated and benefits.

Underground water storage can be incorporated into larger water management projects as long as it is disconnected from the sewage system. Above the water storage tanks, there is a top layer consisting of vegetation or a permeable pavement, followed by a load-bearing substrate layer. Underneath the tanks, the lower substrate acts as a filtration layer. Other aspects should also be considered such as the drainage gradient and overflow pipes and systems.

# IV. Conditions for implementation

Space for underground storage needs to be excavated. Therefore, they are relatively difficult to incorporate into already existing infrastructure.

## V. Benefits and limitations

⊕ Potential benefits:

- On-site storage of water helps minimize flood risk by reducing run-off and delaying water flow.
- Reuse of water on site can be used for irrigation during hot, dry seasons.
- Multifunctional use of open space.

⊖ Potential limitations / disservices:

- Minimum water quality needed for storage.
- Space for underground storage required.
- They can be relatively difficult to incorporate into already existing infrastructure.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ○ ○ |
| Shading | ○ ○ |
| Evaporation | ○ ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ○ ○ |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ● ● |
| Water retention | ● ○ |
| Water storage | ● ○ |
| Water reuse | ● ● |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ○ ○ |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ○ ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ○ ○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ● ○ |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ○ ○ |
| Usability / Functionality | ● ○ |
| Social interaction | ○ ○ |
| Education | ○ ○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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# 6. Infiltration, filtration and biofiltration structures

Fig 6.0 Dry bioretention basin near University of Stuttgart's Vaihingen campus, Germany.

The urban water cycle differs greatly from the natural water cycle with regard to evapotranspiration, water run-off, and infiltration. This has severe consequences for the urban climate, groundwater recharge, and risk management [22]. These challenges are likely to increase as Europe is projected to experience more intense precipitation events in the future [20]. Infiltration, filtration, and biofiltration structures as part of a water sensitive urban design or sustainable drainage system, can help mitigate these challenges. These green infrastructures are often areas that are usually dry (excluding during or after precipitation events) and that reduce peak flows by slowing surface runoff, increasing infiltration, and providing water storage [4]. They can also reduce pollutants in run-off water through natural physical, biological, and chemical processes, allowing cleaner water to be discharged, collected, or recharge groundwater [23]. Depending on design, these structures may also support biodiversity by providing habitat for wildlife. Examples of NBS that are infiltration, filtration, and biofiltration structures include infiltration basins, bioretention basins, rain gardens, bioswales, infiltration planters, and subsurface constructed wetlands or filtration systems. Selected examples (i.e. bioswales, raingardens, infiltration basins, permeable paving systems, and biofilters) are described in more detail below.

Fig 6.1 Bioswale in Gartz (Oder), Germany.

# 6.1 Bioswale

A bioswale is a vegetated, linear, and low-sloped structure often established in urban areas, near or between roads, with the objective to reduce flood risk during or after heavy rain events. The intention of bioswales is comparable to rain gardens (see Factsheet 6.2). Bioswales absorb, store, and convey surface water runoff, and also remove pollutants and sediments as the water trickles through the vegetation and substrate layers. If properly planned and planted with native vegetation, a bioswale can contribute to local stormwater management and can help support biodiversity.

## I. Basic information

Synonyms: Swale; Grassed swale; Vegetated filter strip; Stripswale

Addressed challenges:

Water management | Natural & climatic hazards | Biodiversity

## II. Role of nature

There are several processes in bioswales that are inspired by nature. For example, the vegetation and soil within the bioswale can retain and store water, allowing it to slowly infiltrate through the layers as organic pollutants, sediments, and other substances are filtered out of the water. The physical and chemical characteristics of the soil substrate and selected vegetation will have an effect on each of these processes. Other natural processes in bioswales include evapotranspiration as the vegetation takes up and transpires water, and water conveyance that is similar to that of a riverbed.

## III. Technical and design parameters

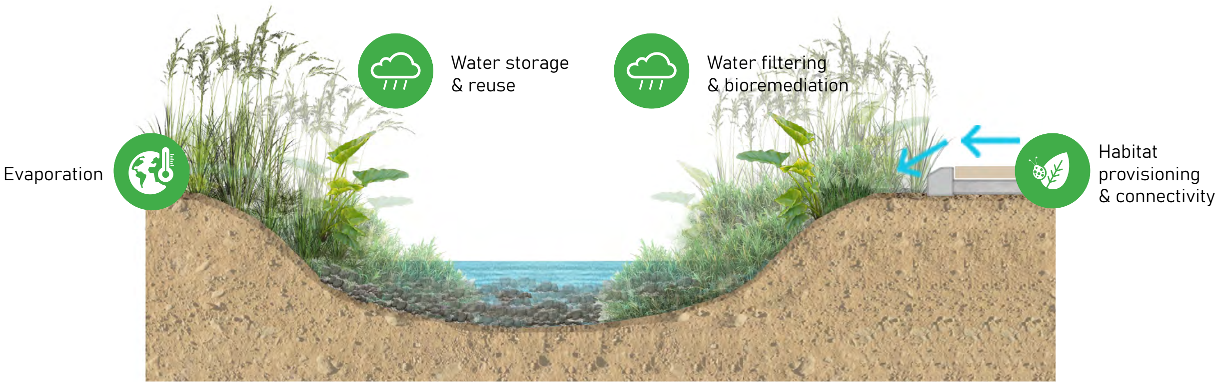


Fig 6.2 An example of a bioswale and its associated natural processes and benefits.

While similar to raingardens, bioswales are usually medium to larger scale installations. Bioswales are often linear, with a gentle downward slope that facilitates water flow into the base of the bioswale and positively affects infiltration. They must have relatively dense vegetation to slow water flow, without being so dense as to negatively affect water conveyance. It is best to select native, deep-rooted vegetation that can withstand occasional flooding, which is often a mixture of grasses and other vegetative plants. Vegetation should be selected specifically for each zone of the bioswale, with the most water tolerant species being located at the base of the swale. To improve water storage capacity, infiltration or pollutant removal, engineered soils and other substrates could be considered in construction. Access for maintenance (e.g., mowing the grass, leaf litter, and sediment removal), inspection, and management is also necessary. Bioswales can be combined with other sustainable drainage system (SUDS) elements such as rainwater harvesting measures and permeable paving. Trampling or any other soil compaction within bioswales should be avoided to ensure water infiltration capacity.

## IV. Conditions for implementation

A large enough area is necessary so that bioswales can be an effective part of a stormwater management system. To maximize efficiency, stormwater from roofs or paved areas can be collected and intentionally led into a bioswale.

## V. Benefits and limitations

⊕ Potential benefits:

- Stormwater management and control.
- Reduced flood risk.
- Improvement of water quality.
- Habitat provision for wildlife.
- Improvement of amenity value.

⊖ Potential limitations / disservices:

- Trees need to be managed or limited to allow water conveyance.
- The performance and acceptance of bioswales are dependent on regular and appropriate maintenance.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ○○ |
| Shading | ○○ |
| Evaporation | ●○ |
| Building (Insulation) | ○○ |
| Reflection (Albedo) | ○○ |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ●○ |
| Water infiltration | ●● |
| Water retention | ●○ |
| Water storage | ●○ |
| Water reuse | ○○ |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ●○ |
| Water bio-remediation | ●○ |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ○○ |
| Air biofiltration | ○○ |
| Noise reduction | ○○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ●○ |
| Connectivity | ●○ |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ●● |
| Usability / Functionality | ○○ |
| Social interaction | ○○ |
| Education | ○○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ○○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ○○ |

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# 6.2 Rain garden

Fig 6.3 Sketch of a rain garden close to the road.

A rain garden primarily serves as an area for small-scale water management (e.g. storage, infiltration, pollution removal), especially in urban areas. Rain gardens are often established within the built environment and collect water runoff from roofs, roads, and other sealed surfaces. Stormwater runoff is drained into rain gardens, where it is temporarily stored, and then infiltrates through the soil or flows into the sewage system. Rain gardens are not restricted to certain climate conditions and can be found in many countries. However, the selected vegetation should be native and well adapted to local climate conditions.

# I. Basic information

Synonyms: Bioretention area; Biorentention swale

Addressed challenges:

Climatic resilience

Water management

Natural & climatic hazards

Biodiversity

Social justice & cohesion

# II. Role of nature

There are several processes in rain gardens that are inspired by nature. For example, the vegetation and soil within the rain garden can retain and store water, allowing it to slowly infiltrate through the layers as organic pollutants, sediments, and other substances are filtered out of the water. The physical and chemical characteristics of the soil substrate and selected vegetation will have an effect on each of these processes. Other natural processes in rain gardens include evapotranspiration as the vegetation takes up and transpires water, and water conveyance that is similar to that of a river (in larger installations).

# III. Technical and design parameters

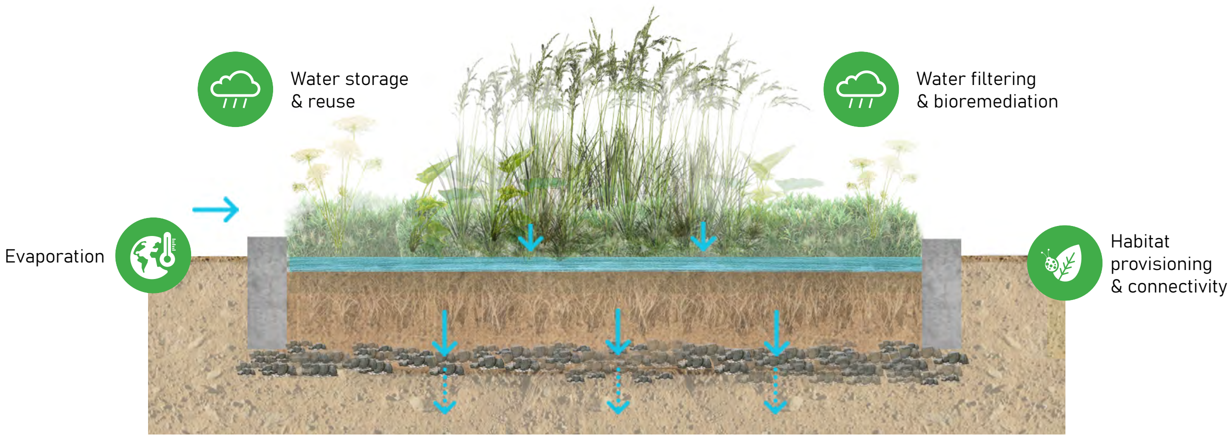


Fig 6.4 An example of a rain garden and its associated natural processes and benefits.

Rain gardens are small-scale, private or public, installations. There are many established designs and arrangements of rain gardens and a variety of elements can be incorporated into their design including grass filter strips, water ponds, mulch areas, soil or other substrates, vegetation, and sand beds. Each of these elements has a particular function (e.g., to slow down, reduce, filter, and store water run-off or increase evapotranspiration), and should therefore be selected according to the local stormwater challenges. Additionally, a gentle downward slope facilitates water flow into the base of the rain garden and positively affects infiltration. In general, rain gardens should be planted with relatively dense, native vegetation that can withstand occasional flooding. Vegetation should be selected specifically for each zone of the rain garden, with the most water tolerant species being located at the base of the garden. Access for regular maintenance, management, and inspection is necessary. Rain gardens can also be combined with other water management solutions like permeable paving and rainwater harvesting.

## IV. Conditions for implementation

The amount of available space, selection of adapted plant species, and maintenance need to be considered for implementation.

## V. Benefits and limitations

Potential benefits:

- Stormwater management and control.
- Reduced flood risk.
- Improvement of water quality.
- Habitat provision for wildlife.
- Aesthetic value and improvement of amenity value.

Potential limitations / disservices:

- The performance and acceptance of rain gardens are dependent on regular and appropriate maintenance.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ● ○ |
| Shading | ○ ○ |
| Evaporation | ● ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ○ ○ |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ● ○ |
| Water retention | ● ○ |
| Water storage | ● ○ |
| Water reuse | ● ● |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ● ○ |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ○ ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ○ ○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ● ● |
| Connectivity | ● ○ |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ● ● |
| Usability / Functionality | ● ○ |
| Social interaction | ● ○ |
| Education | ○ ○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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# 6.3 Infiltration basin

Fig 6.5 Infiltration basin in Berlin - Adlershof, Germany.

Infiltration basins are flat, vegetated areas that are usually dry. After heavy rainfall, the water fills up the basin and soaks into the ground. Infiltration basins are usually built with the additional goal to recharge the water table, which differentiates them from retention basins in general. While often planted with grass, additional vegetation types can be integrated into infiltration basins, creating habitats for wildlife, thereby supporting biodiversity and improving aesthetic appeal.

## I. Basic information

Synonyms: Infiltration planter (see also Factsheet 6.2); Infiltration pond; Recharge basin

Addressed challenges:

Water management | Natural & climatic hazards | Biodiversity

## II. Role of nature

Infiltration basins, similar to dry detention ponds, mimic a natural landscape that contains a heterogeneous surface with slightly elevated and lower areas in close proximity, forming a mosaic of micro conditions. Water is temporarily stored in the lower areas of the basin until it evaporates or infiltrates through the soil, eventually recharging the ground water. Infiltration basins also take advantage of the natural properties of vegetation and soil layers to reduce pollution levels before the stormwater joins the ground water.

## III. Technical and design parameters

Infiltration basins are simple to construct. They must be lower than ground level, should be relatively flat, and grass and other vegetation should be taller than 7.5 cm in order to survive flooding. Infiltration basins should have the capacity to infiltrate 50% of their storage volume within 24 hours of filling.

Some maintenance is required including removal of litter and debris, mowing, and annual removal of sediment from inlets and outlets.

## IV. Conditions for implementation

Local soil conditions (e.g., permeability and infiltration capacity), available space, and highly specific rainwater intensities must be considered when implementing infiltration basins. They can be integrated into private gardens, public green space, and driveways, but should not be directly connected to aquifers (even if there is a permeable layer in between). Trampling or any other soil compaction within infiltration basins should be avoided to ensure water infiltration capacity.

## V. Benefits and limitations

Potential benefits:

- Temporarily stores stormwater and run-off, thereby reducing peak flows and flood risk.
- Reduces pollution from stormwater.

Potential limitations / disservices:

- Performance is dependent on regular and appropriate maintenance.

# VI. Performance

### P1 Cooling service

| | | |
|---|---|---|
| Transpiration | ○ | ○ |
| Shading | ○ | ○ |
| Evaporation | ● | ○ |
| Building (Insulation) | ○ | ○ |
| Reflection (Albedo) | ○ | ○ |

### P2 Water balance regulation service

| | | |
|---|---|---|
| Water conveyance | ○ | ○ |
| Water infiltration | ● | ● |
| Water retention | ● | ○ |
| Water storage | ○ | ○ |
| Water reuse | ○ | ○ |

### P3 Water purification service

| | | |
|---|---|---|
| Water filtering | ● | ○ |
| Water bio-remediation | ○ | ○ |

### P4 Air purification service

| | | |
|---|---|---|
| Deposition | ○ | ○ |
| Air biofiltration | ○ | ○ |
| Noise reduction | ○ | ○ |

### P5 Biodiversity service

| | | |
|---|---|---|
| Habitat provision | ● | ○ |
| Connectivity | ● | ○ |

### P6 Amenity value service

| | | |
|---|---|---|
| Beauty / Appearance | ● | ○ |
| Usability / Functionality | ○ | ○ |
| Social interaction | ○ | ○ |
| Education | ○ | ○ |

### P7 Food / Energy / Material

| | | |
|---|---|---|
| Food / Energy / Material | ○ | ○ |

### P8 $CO_2$ Sequestration

| | | |
|---|---|---|
| $CO_2$ Sequestration | ○ | ○ |

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Fig 6.6 Permeable paving system in Stuttgart, Germany.

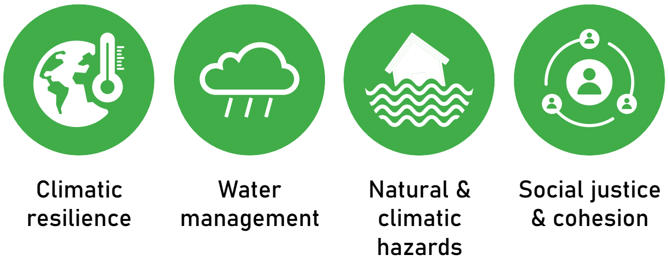
# 6.4 Permeable paving system

Permeable paving systems are surfaces that are able to absorb stormwater, thereby minimizing and delaying surface water run-off, while reducing the amount of some pollutants. After storm events, the water either trickles through the permeable surface itself, or through gaps or funnels between pavers. Water is then temporarily stored in the underlying stone layer and infiltrates into the soil or to an additional drainage layer that conveys water into the sewage system (subsurface drain). They are commonly installed in parking lots, residential streets, and sidewalks. There are many different systems of permeable pavements. For example, porous asphalt and permeable concrete improve infiltration of homogeneous surfaces. Other solutions such as vegetated grid pavers increase the share of substrate or vegetation cover for better infiltration and allow for water uptake by plants. Solutions such as permeable stone carpets provide macropores for gravity-driven percolation.

# I. Basic information

Synonyms: Permeable pavement; Draining pavements

Addressed challenges:




# II. Role of nature

Permeable paving systems imitate the permeability and drainage effect of natural soils. Soil permeability depends on soil type and degree of water saturation, which affects infiltration potential. Soil with large pores absorbs more water compared to sealed surfaces, and filling material between bricks enables a high level of water infiltration.

# III. Technical and design parameters

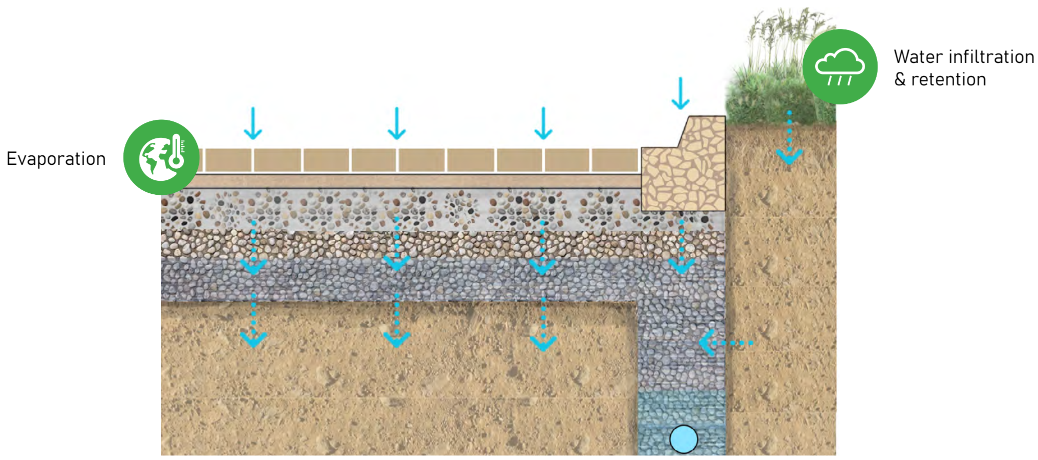



Fig 6.7 An example of a permeable paving system and its associated natural processes and benefits.

Technical and design parameters are dependant upon the specific implemented solution. For example, permeable pavers have a relatively simple construction consisting of a single layer of bricks or stones, followed by an underlying gravel layer, a drainage layer, and filling material that consists of gravel or sand (Fig 6.7). While technical and design parameters differ among permeable paving systems, all require regular maintenance to avoid clogging and maintain functionalitiy.

# IV. Conditions for implementation

Permeable pavements can be implemented on new or previously existing building sites. Prior analysis of the soil is necessary, and compatibility with all kinds of street usage should be considered.

## V. Benefits and limitations

Potential benefits:

- Water quality protection.
- Stormwater management.
- Reduced surface run-off.
- Controlled infiltration.
- Temporary water storage.
- Water filtering.

Potential limitations / disservices:

- Limited load on paved area - often not applicable for high speed or highly trafficked roads.
- Prone to clogging without regular maintenance.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ● ○ |
| Shading | ○ ○ |
| Evaporation | ● ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ● ○ |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ○ ○ |
| Water infiltration | ● ○ |
| Water retention | ● ○ |
| Water storage | ○ ○ |
| Water reuse | ○ ○ |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ● ○ |
| Water bio-remediation | ○ ○ |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ○ ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ○ ○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ○ ○ |
| Connectivity | ○ ○ |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ○ ○ |
| Usability / Functionality | ● ○ |
| Social interaction | ● ○ |
| Education | ○ ○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

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Fig 6.8 Heidanranta biofilter, Finland.

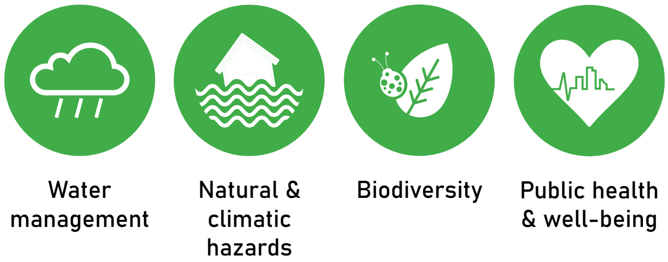
# 6.5 Biofilter (water purification)

Biofilters are developed to collect and treat storm- and wastewater and represent a promising system for grey water treatment. Bacteria and microorganisms are located on a filter medium (biofilm), which often consists of sand or granular activated carbon. The biofilm degrades nutrients and contaminants in the wastewater (influent) that is pumped through the filter material. The term “filter,” however, can be misleading. Biofilters separate and remove nutrients and organic carbons from storm- and wastewater through biodegradation. As a result, biofiltration improves the quality of storm- and wastewater (e.g., the reduction of nutrients, metals, sediments) while temporarily storing stormwater, which can help reduce peak flows.

## I. Basic information

Synonyms:

Addressed challenges:




## II. Role of nature

Biodegradation is a natural process in soils. This natural degradation is used for different processes, for example, in anaerobic digestion (biogas production). Microorganisms and bacteria degrade and therefore remove excess nutrients and contaminants.

## III. Technical and design parameters

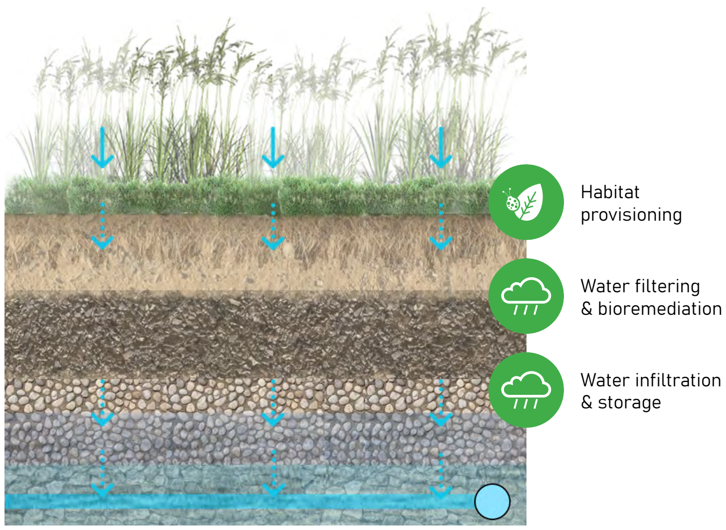



Fig 6.9 An example of a biofilter and its associated natural processes and benefits.

Biofilters consist of layers of different soil types or substrates (e.g., sand, activated carbon) with a biofilm of bacteria and other microorganisms that degrade and remove pollutants (e.g., nitrogen, phosphorus, heavy metals). Typically, anaerobic conditions are necessary for this biodegradation, so the biofilter should be continuously saturated with water. To maintain the proper level of saturation without overwhelming the system, stormwater run-off can be stored in an ornamental pond and slowly guided (or pumped) to the biofilter. Filtered water can then be re-used after treatment.

On top of the biofilter, a vegetation layer should be established. Depending on the design of the filter, suitable species (e.g., water and pollution tolerant) should be selected. Proper selection of native and condition-tolerant species can help support small-scale biodiversity enhancement through habitat establishment.

## IV. Conditions for implementation

Adequate space for construction and flat terrain are needed.

## V. Benefits and limitations

⊕ Potential benefits:

- Water treatment.
- Improves quality of storm- and wastewater.
- Stormwater regulation and management.
- Improve quality of life (e.g., reduction of odours).
- Small-scale habitat establishment.
- Smaller than solutions with similar benefits, e.g., constructed wetlands.

⊖ Potential limitations / disservices:

- High level of maintenance and monitoring necessary to ensure effectiveness.

## VI. Performance

**P1 Cooling service**

| | |
|---|---|
| Transpiration | ○ ○ |
| Shading | ○ ○ |
| Evaporation | ○ ○ |
| Building (Insulation) | ○ ○ |
| Reflection (Albedo) | ○ ○ |

**P2 Water balance regulation service**

| | |
|---|---|
| Water conveyance | ● ○ |
| Water infiltration | ● ● |
| Water retention | ● ○ |
| Water storage | ● ● |
| Water reuse | ● ○ |

**P3 Water purification service**

| | |
|---|---|
| Water filtering | ● ● |
| Water bio-remediation | ● ● |

**P4 Air purification service**

| | |
|---|---|
| Deposition | ○ ○ |
| Air biofiltration | ○ ○ |
| Noise reduction | ○ ○ |

**P5 Biodiversity service**

| | |
|---|---|
| Habitat provision | ● ○ |
| Connectivity | ○ ○ |

**P6 Amenity value service**

| | |
|---|---|
| Beauty / Appearance | ● ○ |
| Usability / Functionality | ○ ○ |
| Social interaction | ○ ○ |
| Education | ○ ○ |

**P7 Food / Energy / Material**

| | |
|---|---|
| Food / Energy / Material | ○ ○ |

**P8 $CO_2$ Sequestration**

| | |
|---|---|
| $CO_2$ Sequestration | ○ ○ |

# VII. References and further reading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# 8. List of Figures

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