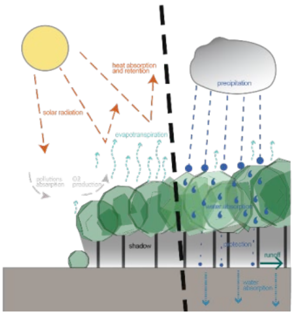
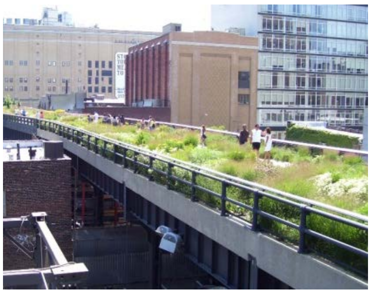
Nature Based Solutions – Technical Handbook

Part II





Version February 2019

NBS catalogue

Introduction - *How to use the NBS catalogue?* The **NBS catalogue** groups a range of nature based solutions by categories according to planning and construction terminology. In total, the following eight categories were identified and will be explained in detail in this document:

1) Greening interventions
2) Public Green Space
3) Vertical Greening
4) Green Roofs
5) Water sensitive urban design measure
6) (River) Restoration
7) Measure of Bioengineering
8) Other NBS

Each category starts with a general description and an explanation of main functions of the associated NBS types as well as *how* the considered NBS type is inspired by nature.

<u>Example:</u> When describing *Green Roofs*, an overview of the structure and services of natural soils – as the feature of nature that is adopted – is given. Additionally, the structure of green roof and its services are specified.

Every thematic group contains a bundle of different nature based solutions. In some cases, nature based solutions are further divided into different subtypes.

<u>Example:</u> The category *Vertical Greening* contains six nature based solutions. One of them *free standing living wall* is sub-divided into *noise protection walls* and *mobile green walls*.

For every nature based solution the information is structured in a table

The structure of the table is as follows:

i. **basic information**
   - *What kind of NBS is considered?*
ii. **general description**
   - *What is it and what does it consist of?*
iii. **role of nature**
   - *How it works? How it makes use and/or gets inspired by nature?*
iv. **technical and design parameters**
   - *Which are the main technical/design considerations?*
v. **conditions for implementation**
   - *Which site conditions should be considered?*
vi. **benefits and limitations**
   - *How does it contribute to/ limit the urban ecosystems*
vii. **Performance**
   - *What is the performance of the NBS? (P = performance of NBS with regard to ecological services; P1 = cooling service; P2: water regulation service; P3: water purification service; P4: air purification service; P5: biodiversity; P6: amenity value service.*

Performance of NBS is significantly/largely dependent on geographic (climate, geomorphology) conditions. Ideally, a location specific evaluation of NBS, considering all factors that are relevant for performance, is conducted. Such an endeavour is, however, not feasible for all the three UNaLab front-runner cities, and the five follower cities for each permutation of conditions. Therefore for the performance evaluation of NBS in the catalogue a generalized approach was chosen, evaluating the potential performance in suitable conditions. The performance in those conditions should be at least good (1) or very good (2). If a performance criteria is not applicable this is also indicated (-).

The overview table lists NBS types with their performance ratings on one page, in order to facilitate the selection of suitable NBS with specific ecological services. The overview table also contains further criteria for categorizing NBS according to the "NBS Case Study Template powered by OPPLA" of the Horizon 2020 coordination and support action Think Nature.

During the internal consultation phase with partners additional issues, that should be incorporated, were raised. Costs and maintenance are, for instance, very important when decision makers need to decide on investing in NBS. These considerations will be part of the Replication Framework in WP6.

List of NBS

1. Greening interventions

The NBS catalogue enlists greening interventions, employing the use of trees, aimed at imparting several positive effects on the urban ecosystems. Some main benefits are the provision of habitats for urban wildlife, regulation of air temperature, pollution control, shading, CO_2 absorption, and human recreation. Some more direct and indirect benefits of urban trees are represented in **Figure 1**.

Greening interventions are described in the catalogue focusing on two different types of street trees as well as on grouped trees represented by several trees. Single tree planting is not considered because the positive effects of single trees on the environment are often local, and limited to the immediate surroundings of a tree. Despite the local effects, the protection and conservation of all urban trees is a very important issue.

The following greening interventions refer to the conservation of existing tree stocks and also to the establishment of new trees within cities. The conservation and professional maintenance of larger, older trees is even more important because positive effects on the environment are generally greater in comparison to small, newly planted trees. Further benefits of existing trees stocks are e.g. the improvement of microclimate, air and quality of life for people within the city reflecting the need to protect them. Effective measures for conservation may be tree protecting statutes on public and private property (Coutts n.d.; Norton et al. 2015).

Further greening options - e.g. shrubs, grassland, meadows or flowerbeds - that also have multiple ecosystem benefits (infiltration, delayed runoff, biodiversity) are not considered as individual NBS types in the catalogue. The main reason is that they often only differentiate other NBS as well. For instance, intensive green roofs with shrubs or bio swales with flower rich meadows.

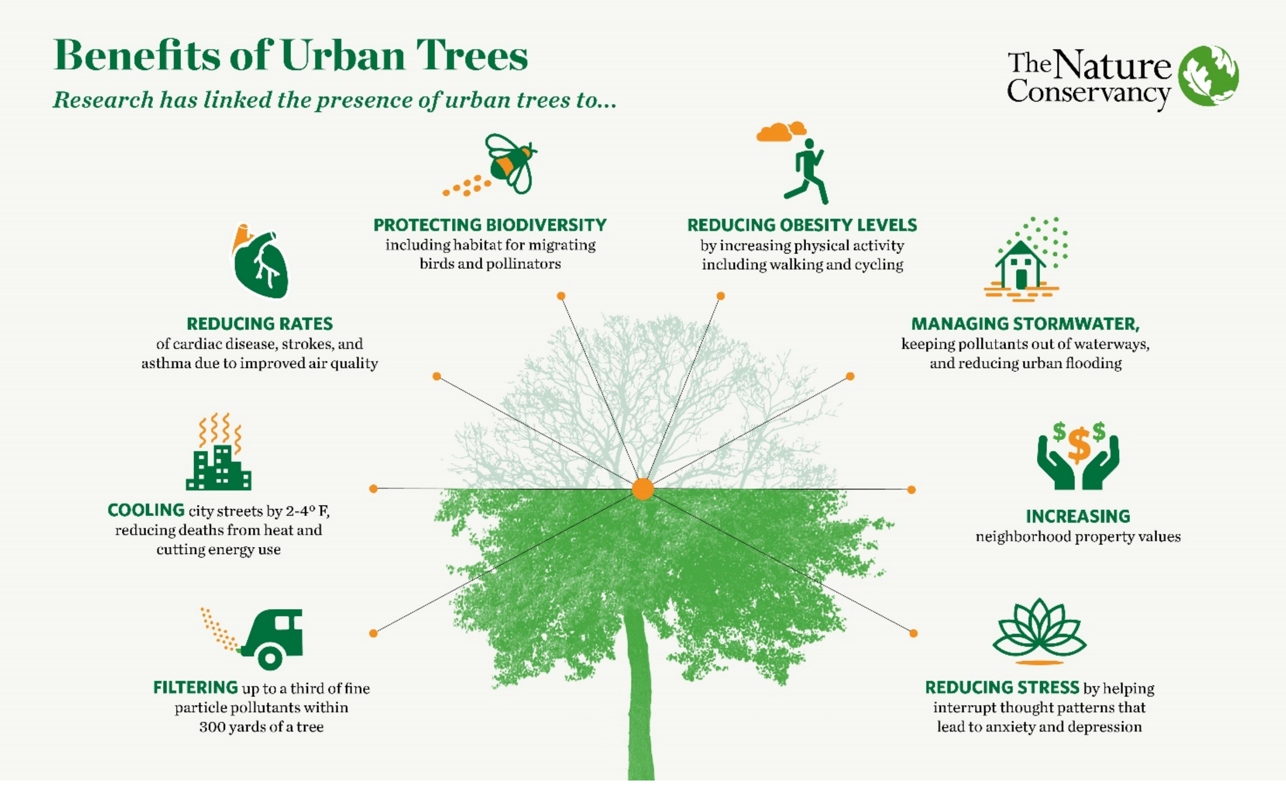


Fig. 1: Benefits of Urban Trees (source: https://thought-leadership-production.s3.amazonaws.com/2017/09/25/13/34/04/fab4e7a8-2d03-4a7d-83d8-bdcff6d0ce22/Cities_Tree_Infographic-02.jpg

Although trees are very often “The Nature Solution” it has to be stated that there are potentially ecological disservices related to (large scale) tree planting in urban areas because they have also an effect on ventilation in street canyons and may therefore lead to higher concentrations of pollutants. Furthermore, there are some tree species that cause negative effects such as BVOC emissions or have a high allergenic potential (Grote et al. 2016).

Biogenic volatile organic compounds (BVOC), emitted from some tree species in high quantities, together with NO_x and high solar radiation play a role in the formation of Ozone. BVOC release from vegetation is governed by environmental conditions (e.g. sunlight, temperature, and water availability) and is highly species-specific. Presently, the problem is primarily relevant for the Mediterranean context but may increase in magnitude there and elsewhere due to climate change (Grote et al. 2016). The allergenic potential of some tree species is well known but not always considered when selecting plant species in urban areas.

Regardless, the interventions involving trees highlighted in the NBS catalogue possess promising potentials. Many of the potential disservices are due to traffic related pollution, which may be less relevant in the coming decades because of electrification of individual and public transport. Stopping or slowing down the schemes for planting and raising trees is therefore not an option. Still the careful selection of suitable tree species for urban environments should take new scientific evidence on disservices into account, in order to make the tree planting schemes – the challenge for a generation - a real success for all.

1.1 Street trees

1.1.1 Single line trees

Fig. 2: Townhall Square Eindhoven (source: Eisenberg)

Fig. 3: Tree lined street (source: LAND; https://www.landsrl.com/)

i. basic information

Type	1	2	**3**	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
			x	x		x	x	x
reference to key studies								

ii. general description

Single line trees represent one possibility to establish several trees in urban areas. As the name implies, single line trees are arranged along e.g. streets, bicycle paths and sidewalks and the trees are situated on one side.

Trees have multiple effects on the local micro-climate conditions, absorb particular matter and provide shade for people as well as for buildings. One of the main positive effects for the human well-being in periods with high temperatures is the air cooling effect. The mentioned effect of street trees in general depends on different factors such as tree size, canopy coverage, planting density, tree species, tree health, location, availability of root water or leaf area index.

iii. role of nature

Single line trees simulate those trees growing at the edge of the woods and their effects on the surrounding environment outside the tree-covered area. The trees shade adjoining land uses. As a result the shaded surface is cooler than surfaces without a protecting tree cover.

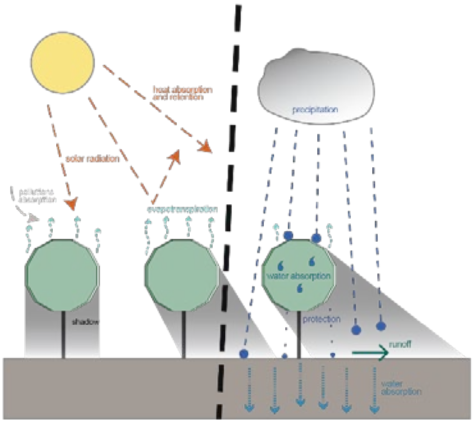


Fig. 4: Role of single trees (source: ILPOE, 2018)

	The shading effect is determined by the characteristics of the trees (tree and canopy density, season). Other effects are a reduced wind velocity; transpiration/air cooling, air purification/absorption of particular matter.
iv.	**technical and design parameters**
	The most important aspect is the selection of suitable trees that serve the intended purpose and are fit for the geobotanical conditions (see Annex 1) The area of the root space for neighbouring trees can be connected in suitable conditions and if separated root space should be 12 m³ with a minimum depth of 1.5 m (FLL 2015). Depending on local climatic conditions, permanent or temporary irrigation facilities need to be considered. The distance between the trees depend on the maximum size of adult tree but also on the size of the planted tree and design ideas. Protection measures (e.g. poles, wire mesh against animals) may be needed as well.
v.	**conditions for implementation**
	Local circumstances (e.g. topography, route characteristics, surrounding land use, and underground uses) need to be considered when planning and establishing new single line trees. Suitable location for the establishment of trees should offer enough space for trees to grow. Depending on the site conditions and available space, suitable tree species have to be selected. The consideration of 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 peoples 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 by standard soils if necessary. The selection of suitable tree species should also consider local conditions like topography: 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.
vi.	**benefits and limitations**
	Benefits: Single trees are associated with diverse benefits for urban ecosystems: - Microclimate regulation - Habitat provision - Aesthetics/recreation - Rainwater regulation (delayed runoff) It takes decades until newly planted trees fulfil the services of adult trees, individually as well as in combination. Therefore initiatives to protect existing trees are very important. *Potential limitations/disservices:* Disservices of trees may be the allergenic potential of its pollen and BVOC emissions, resulting in high O3 concentrations in summer.
vii.	**Performance**

P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	Population/User	1
		Surface	1
	Insolation of building		-
P2	water conveyance		-
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		1

P5	habitat provision	1
	connectivity	1
P6	beauty/appearance	2
	usability/functionality	1
	social interaction	1

literature/source: (Burden 2006); (Kadir, Mohd Akmal Abd and Noriah Othman 2012); (Patterson n.d.); (Pearlmutter et al. 2017); (McDonald et al. 2016)
further reading: (Armson und Stringer, P. and A. R. Ennos 2013); (Grote et al. 2016)

1.1.2 Boulevards

Fig. 5: Boulevards between streetcar tracks Stuttgart (source: Eisenberg)

Fig. 6: Kingsway, London circa 1950 (Photo: London County Council) (source: Administrative County of London Development Plan 1951, Analysis)

Fig. 7: Boulevard with three tree lines (source: LAND; https://www.landsrl.com/)

Fig. 8: Kingsway as it is today (Photo: Jim C. Smith, Forestry Commission) (source: Forestry Commission England 2009)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding		water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
				x	x			x	x
reference to key studies	*Case Study: Boulevard de Magenta; Paris, France* (source: Global Designing Cities Initiative (c/o NACTO). ; globaldesigningcities.org/)								

ii. general description

Boulevards represent a possibility to establish several trees in cities amongst others to mitigate urban heat stress. Within boulevards, trees are commonly arranged along streets, bicycle paths and sidewalks and - if circumstances allow - established on both sides of the route. The treetops of opposite trees often form a (nearly) closed canopy. As a result the street in die middle of two tree lines is protected, shaded and the air temperature is lowered.

iii. role of nature

Boulevards simulate those trees growing at the edge of the woods (fringe area) and their effects on the surrounding environment outside the tree-covered area. The trees shade adjoining land uses - in natural forest commonly vegetated areas like fields, meadow or water surfaces. As a result the shaded surface is cooler than surfaces without protection/tree cover). The shading effect is determined by the characteristics of the trees (tree density, canopy density and season). Other effects are a reduced wind velocity; transpiration/air cooling, air purification.

iv.	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 m³ with a minimum depth of 1.5 m. In most urban conditions the root space need to be prepared with soil substrates for trees. Depending on local climatic conditions, permanent or temporary irrigation facilities need to be considered. The distance between the trees depend on road width, the maximum size of adult trees, on the size of the tree when planted, and further design ideas. Protection measures (e.g. poles, wire mesh against animals) may be needed as well.
v.	**conditions for implementation**
	Local circumstances (e.g. topography, route characteristics, surrounding land use, underground occupation with cables etc.) need to be considered when planning and establishing new boulevards. Suitable location for the establishment of trees should offer enough space for trees to grow. Depending on the site conditions and available space, suitable tree species have to be selected. The consideration of 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 need to be, replaced by standard soils. Species and sub species that are suitable for urban conditions should be planted.
vi.	**benefits and limitations**
	Benefits: Boulevards are associated with diverse benefits for urban ecosystems: - Microclimate regulation - Habitat provision - Aesthetics/recreation - Rainwater regulation (delayed runoff) *Potential limitations/disservices:* - Reduced airflow →Higher pollution in street canyon - Disservices of trees may be the allergenic potential of its pollen and BVOC emissions.

vii.	performance		
P1	evapotranspiration	Transpiration	2
		Evaporation	1
	shading	Population/User	2
		Surface	2
	Insolation of building		-
P2	water conveyance		-
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		1
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		2
	usability/functionality		1
	social interaction		1

literature/source: (Burden 2006); (Pearlmutter et al. 2017; McDonald et al. 2016)
further reading:

1.2 Group of trees (Arboretum)

Fig. 9: Arboretum - A group of adult trees creates a microclimatic environment that mitigates heat stress on hot summer days (source: LAND; https://www.landsrl.com/)

Fig. 10: Small Arboretum with seats *(source: LAND; https://www.landsrl.com/)*

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding			water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
					x	x		x	x	x
reference to key studies									

ii. general description

Group of trees mimicking the gestalt of a forest in an urban setting. They may be an option for the design of shaded squares and places or as a contrasting element in densely built up areas or for court yard design.

iii. role of nature

The group of trees create a shaded environment in summer which is similar to a small patch of forest or the fringe area of larger forests.

iv. technical and design parameters

In order to create a sufficient microclimate right from the start, mature trees from nurseries are needed. Trees are planted in a rather dense grid and need to be irrigated during the first years and possibly throughout the whole life time. Water for irrigation comes ideally from surfaces and roofs.

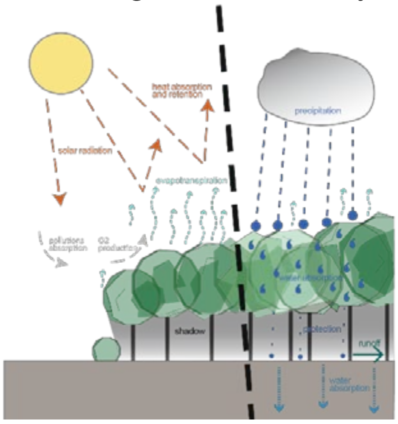


Fig. 11: Role of forests/group of trees (source: ILPOE, 2018)

v. conditions for implementation

Species and sub species that are suitable for urban conditions should be planted. The use of different species (Arboretum) may enhance the chances for establishing more robust living conditions. The group of trees may be planted on natural soils or on top of underground buildings if the soil depth is sufficient.

vi.	**benefits and limitations**			
	Benefits: Biodiversity/Habitat provision (depending on species selection) - Improved aesthetics - Meeting places - Public spaces for heat reduction *Potential limitations/disservices:* Disservices of trees may be the allergenic potential of its pollen and BVOC emissions.			
vii.	**performance**			
P1	evapotranspiration	Transpiration	2	
		Evaporation	1	
	shading	Population/User	2	
		Surface	2	
	Insolation of building		-	
P2	water conveyance		-	
	water infiltration		1	
	water retention		2	
	water storage		-	
	water reuse		-	
P3	water filtering		-	
	water bioremediation		-	
P4	deposition		1	
	biofiltration		1	
P5	habitat provision		2	
	connectivity		2	
P6	beauty/appearance		2	
	usability/functionality		1	
	social interaction		1	

<u>literature/source:</u> (Burden 2006); (Kadir, Mohd Akmal Abd and Noriah Othman 2012); (Patterson n.d.); (Pearlmutter et al. 2017); (McDonald et al. 2016)
<u>further reading:</u> (Armson und Stringer, P. and A. R. Ennos 2013); (Grote et al. 2016)

2. Public Green Space

Public green spaces are categorized according to size, catchment area, services provided and urban design aspects. In an integrated system, often connected through tree lined streets, they serve as the back bone of *urban* green infrastructure and provide many beneficial services for the city.

For the NBS catalogue two types are considered relevant, residential parks and green corridors. They can have extra benefits for urban environments, if designed accordingly and placed well.

2.1 Residential park

Fig. 12: Innocentia Park, Hamburg (source: Bildarchiv der Behörde für Umwelt und Energie Hamburg, Abteilung Stadtgrün)

Fig. 13: Innocentia Park 2, Hamburg (source: BSU, Hamburg.de)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	Flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x	x		x	x	x
reference to key studies								

ii. general description

Residential Parks are part of the Green Infrastructure (GI) of cities and serve the residential areas as the nearest main entry point for nature based recreation. Larger spatial elements of GI are district parks that often deliver more functions and combine various uses (e.g. sport fields). Smaller green spaces are often playgrounds or connecting green strips of land.

iii. role of nature

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

iv. technical and design parameters

Residential parks should be well connected and accessible for pedestrians. The park should be at least 1.5 ha size and have a compact form (120m * 120 m) with high proportion of trees or small forest (> 50%) and a minimum of sealed surfaces. The layout of the typical *London Residential Park* with tree and shrub plantations next to the streets and a central open area can be seen as a model.

v. conditions for implementation

New urban development areas provide the opportunity to locate residential parks at the most suitable location maximising the effects on urban climate. But also in urban regeneration projects the establishment of new parks is possible and may be very beneficial. In order to have a maximised impact on urban climate the spatially equal distribution of parks is important.

vi.	**benefits and limitations**			
	Potentials: Residential parks are multifunctional and deliver all benefits of green infrastructure. *Potential limitations/disservices:* Accessibility is a key factor for the success of residential parks.			
vii.	**performance**			
P1	evapotranspiration	Transpiration		2
		Evaporation		2
	shading	Population/User		2
		Surface		2
	Insolation of building			-
P2	water conveyance			2
	water infiltration			2
	water retention			2
	water storage			2
	water reuse			-
P3	water filtering			2
	water bioremediation			-
P4	deposition			2
	biofiltration			2
P5	habitat provision			2
	connectivity			2
P6	beauty/appearance			2
	usability/functionality			2
	social interaction			2
literature/source: (Pearlmutter et al. 2017) further reading:				

2.2 Green Corridors

Fig. 14: Green Corridor along a cycle path (source: LAND; https://www.landsrl.com/)

Fig. 15: Green Corridor over a bridge (source: LAND; https://www.landsrl.com/)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
			x	x		x	x	x
reference to key studies	High Line Park							

ii. general description

Areas of derelict infrastructure, e.g. railway lines, that are transformed into linear parks play an important role in urban green infrastructure networks and help to re-nature cities. Also regeneration along waterways and rivers often results in linear interconnecting parks.

iii. 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 areas as well as distant areas. Ecotones are often rich in biodiversity because they are connected to two (or more) different biotopes.

iv. technical and design parameters

When green corridors are based on derelict infrastructure the location and the network properties are more or less fixed. For new developments green corridors can be designed as connecting elements.

v. conditions for implementation

Abandoned 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 leads to an automatic development of the natural features in the space. For new urban developments linear elements can also be designed and build

vi. benefits and limitations

Benefits: Linear elements are very important for GI 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).

vii.	performance		
P1	evapotranspiration	Transpiration	1
		Evaporation	1
	shading	Population/User	2
		Building (insolation)	1
	Insolation of building		-
P2	water conveyance		1
	water infiltration		1
	water retention		1
	water storage		1
	water reuse		-
P3	water filtering		1
	water bioremediation		-
P4	deposition		2
	biofiltration		1
P5	habitat provision		2
	connectivity		2
P6	beauty/appearance		2
	usability/functionality		1
	social interaction		2
literature/source: further reading: http://www.fieldoperations.net/project-details/project/highline.html			

3. Vertical greening

Vertical greening is used as the general term for any vegetation cover on vertical surfaces, no matter where the roots are located. Similar to green roofs vertical greening can be differentiated according to the level of technical support that is needed to sustain vegetation. However since vertical soil itself has no model in natural settings, almost all types of vertical greening are “intensive” and therefore different characteristics are used to describe vertical greening. The main differences of vertical greening types are greening of facades (buildings), free standing living walls, moss walls, living plant construction and potentially vertical open spaces. Vertical greening can be build indoor or outdoor. For the catalogue we only consider outdoor solutions.

3.1 Facade-bound greening

Fig. 16: Vertical Garden Patrick Blanc, Paris (*source: Eisenberg)*

Fig. 17: Eindhoven ‚Medina‘ (source: Eisenberg)

Fig. 18: Green facade, Amsterdam (source: City of Tampere)

i. basic information

type	1	2	**3**	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
			x	x			x	x
reference to key studies	*Museé du Quai Branly, Paris* (source: Greenroofs.com)							

ii. general description

Planted walls with controlled cultivation are called green facades. Facade greenings are divided in two types. The facade-bound greening which is a part of the facade or uses the facade for fixing panels and containers to it. The second type is the ground based facade greening (3.2.).

Facade-bound greening is in most cases very intensively using technology for irrigation, and special substrates for reducing the weight of the green facade.

Precultivated panels or special plant pot systems are most often used. For light weight structures special tissues are used. Because of the thinness of the soil/substrate layer temperatures below 0° C may be a problem. Some greening systems allow to remove the panels during winter.

iii. role of nature

Facade-bound greening have similar services like a very thin natural soil which deals as a basis for vegetation. Depending on the level of engineering for irrigation, for nutrition supply and for the substrate the vegetation cover can perform highly.

iv. technical and design parameters

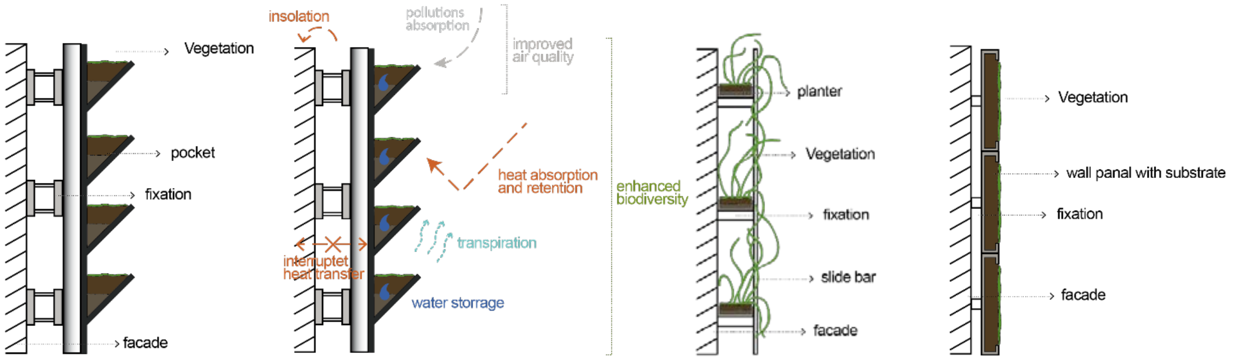


Fig. 19: Facade-bound greening: substrate in planter (a-c); mesh bakets made of plastic or metal (d) (source: ILPOE, 2018 based on Pfoser 2009 provided in: (Pfoser 2016a); page 58 ff.)

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

For regeneration projects a separate scaffolding is often needed.

- Panel: 0.5 – 1.0 m²
- Variety of 10-15 species of plants is most often used
- Irrigation and special substrate is necessary
- Small plants (type depends on environmental factors)

v. conditions for implementation

- Mosses, perennial plants are appropriate
- Not very dry/hot/cold area
- All surfaces are potentially useable, but sun exposed facades perform best potentially due to greatest light exposure (depends on the plants which are used)
- Risk of fire if substrate and / or vegetation dries out
- Temperature resistant material
- Special care of professional gardeners is needed for maintenance

vi. benefits and limitations

Benefits: Air pollution is reduced by plants, they bind high proportions of the particulate matter and polluting gases and green facades additional produce fresh air

- A greened facade reduces the temperature about 2-10 K (compared to natural stone)
- Green facades have good evaporation services
- Evapotranspiration: 5-20 % sunlight is used for photosynthesis, 20-40% is used for evapotranspiration 10-50 % transformed into heat 5-30% reflection
- Water retention: 15-30%
- Biodiversity/Habitat provision: birds, bats (nesting and breeding)
- Natural noise protection
- Improved aesthetics

Potential limitations/disservices:

- High dependency on irrigation system,
- Frost risk

vii.	performance		
P1	evapotranspiration	Transpiration	2
		Evaporation	-
	shading	Population/User	-
		Surface	2
	Insolation of building		-
P2	water conveyance		-
	water infiltration		-
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		2
	usability/functionality		-
	social interaction		-

literature/source: (Blanc n.d.); (Pfoser 2016a) ; (Pfoser 2016b); (Pfoser 2017); (Hancvencl 2013);(Köhler, Manfred and Christian Rares Nistor 2015)
further reading: https://www.murvegetalpatrickblanc.com/; (Ottelé 2011); (Wong et al. 2010a); (Wong et al. 2010b);(Köhler 2008)

3.2 Ground-based greening

Fig. 20: University building, with supporting elements for ground based greening, Berlin-Adlershof (source: Köhler, neuelandschaft.de)

Fig. 21: Ground based greening with climbers (source: Eisenberg)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
			x	x			x	x
reference to key studies								

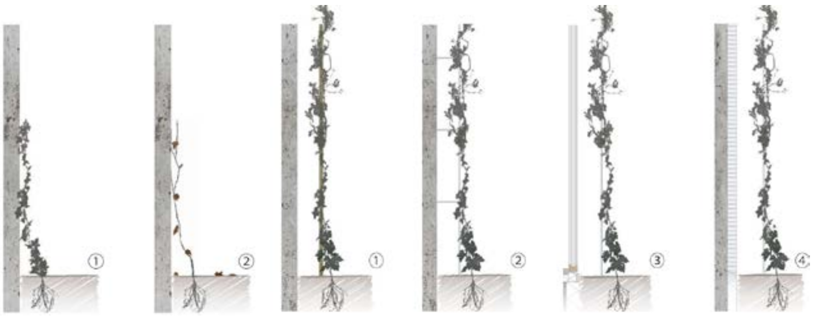
ii. general description

Planted walls with controlled cultivation are called green facades. Ground-based green facades are made of climbing plants. The climber plants get planted in the ground and grow directly on the wall, or climbs on a frame that is connected to the wall and keeps a distance to it. The plants extract water and nutrient from the soil.

iii. role of nature

Climbing plants are part of forests, rocks and shrub areas. The plants grow from rather small areas of natural soil and often need supporting vertical elements or porous surface (roots). Comparable situation are inner areas of forests.

iv. technical and design parameters



(a) (b)

Fig. 22: Ground-based greening: direct vegetation/vegetation without construction (a); vegetation with construction 1. wood, 2. rods, 3./4. ropes (b) (source: Pfoser 2009 provided in: (Pfoser 2016a); page 56 ff.)

- Differentiation of climber plants (self-climbing climbers or climber with supporting system)
- Plant type depends on environmental factors
- Facade without gaps is needed for self-climbers
- Supporting frame is needed for climbers
- Grows up to 25 m high

	- Low number of species can be combined (usually one dominant species)
v.	**conditions for implementation**
	- No very dry/hot/cold area - Good quality of the soil / substrate - Enough sunlight (depends on the plants which are used) - Risk of fire if plants are too dry - Direct growing plants: strong facade (without gaps), moisture - Ground based green facades need 5-20 years to cover a house facade.
vi.	**benefits and limitations**
	Benefits: - Ground-based green facades that are irrigated by surface water runoff replace a part of the surface water regulation service of a naturally soil. - Air purification depending of species, particulate matter and harmful gases - A greened facade reduces the temperature about 2-10 K (compared to natural stone) - Green walls have good evaporation services (65-75 % of the annual rainwater) - Evapotranspiration: 5-20 % sunlight is used for photosynthesis, 20-40% is used for evapotranspiration 10-50 % transformed into heat 5-30% reflection *Potential limitations/disservices:* - Dependent on natural water cycle, drought stress - Climbing plants have origin in forests, often optimum of plants in shaded conditions. Relatively long time span before walls are fully covered
vii.	**performance**

P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	Population/User	-
		Surface	2
	Insolation of building		-
P2	water conveyance		-
	water infiltration		-
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		1
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-

literature/source:(Pfoser 2016b);(Pitha et al. 2013);(Enzi 2010);(Enzi 2010)
further reading:(Köhler 2008);

3.2.1 Noise barrier as ground-based greening

Fig. 23: Ground based greening on noise barrier (source: LAND; https://www.landsrl.com/)

Fig. 24:Green noise barrier along the National Road 405, Århus Denmark (source: Danish Road Directorate (2009) Noise Barrier Design. Danish and some European Examples. Report 174)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x	x		x	x	x
reference to key studies								

ii. general description

Green noise barriers are effective measures to reduce noise emissions along highly frequented roads. They are often designed as walls with a ground based greening. The construction is usually made of concrete, brick or wood and is covered with a vertical plant layer. Ground based green barriers represents a commonly used type of noise barriers along roads, especially in areas with limited space for earth walls.

iii. role of nature

Climbing plants are part of forests, rocks and shrub areas. The plants grow from rather small areas of natural soil and often need supporting vertical elements or porous surface (roots).

iv. technical and design parameters

Ground based green noise barriers need to be equipped with supporting facilities for plants e.g. wires and trellis.

v. conditions for implementation

Sufficient root space at the bottom of the noise barrier is required in order to provide good growing conditions for the plants.

vi. benefits and limitations

Benefits: The plants absorb fine dust and often enhance the visual appearance of noise barriers. Vegetated noise barriers reduce heat, depending on the coverage of the wall elements.

vii.	performance		
P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	Population/User	-
		Surface	2
	Insolation of building		-
P2	water conveyance		-
	water infiltration		-
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		1
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-

literature/source: (Bendtsen 2009)
further reading: (Azkorra et al. 2015)

3.3 Free standing living wall

Fig. 25:Constructing a living wall, Ludwigsburg (souce: (Helix Pflanzensysteme GmbH n.d.)

Fig. 26:Green Living Room Ludwigsburg (souce:(Helix Pflanzensysteme GmbH n.d.)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss	
			x	x	x	x	x	x	
reference to key studies	*Green living room Ludwigsburg, part III*								

ii. general description

Verticalization of green spaces is an adequate way 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 and reduce noise emissions. They are suitable to re-use run-off water and evapotranspirate highly. On the contrary, with extensive vegetation they sustain also longer periods of drought.

iii. role of nature

Natural soil with vegetation cover (perennials and shrubs/trees) is the model for living walls. Vertical layering of soil with plants growing on vertical surface as well as on top of the wall. Depending on the thickness of the living wall (approx. 40 cm) as well as the height normal soil functions can evolve, with filtering along the passage through the soil. Evaporation from vertical soil is one major effect. Transpiration from vegetation depends on plant selection, exposition and level of irrigation.

iv. technical and design parameters

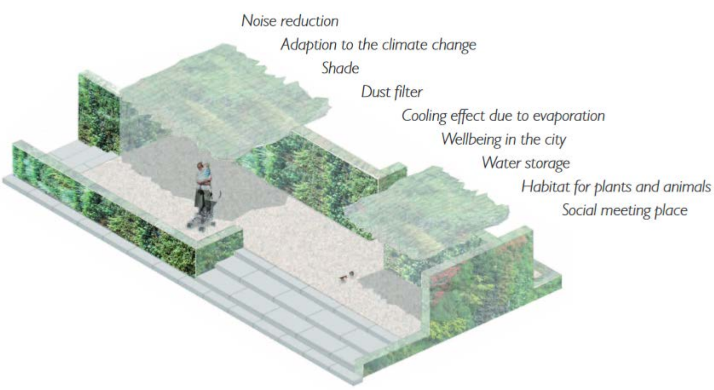


Fig. 27: The functions of the green living room (souce:(Helix Pflanzensysteme GmbH n.d.)

	Vertical layering of soil/substrate which is stored in metal cages with supporting elements to create walls of up to 4 m. Fabric (organic or un organic) is used to prevent the substrate / soil from eroding from the cages. Fairly heavy construction which rests on a simple strip foundation. Living wall needs to be constructed in two segments (minimum) that form a right angle in order to stabilize the living wall. Very flexible with regard to plant selection, as long as irrigation and fertilizer can be managed accordingly.
v.	**conditions for implementation**
	Because of the thickness of the living wall there is hardly any problem with central European frost periods Underground needs to be loadable in order to support the wall. Little risk of fire because of constant irrigation
vi.	**benefits and limitations**
	Benefits: Living walls provide direct shelter from the sun and depending on the vegetation indirect shelter (e.g. tree wall with trees growing from the wall). High evapotranspiration of vegetation also helps to decrease heat island effect. - Beneficial for selected species if respective plants are used. - Noise reduction - Surface water can be used for irrigation of living wall. *Potential limitations/disservices:* - Irrigation is needed (summer and winter) but it should not rely on drinking water. - Supporting underground is needed. - Free standing living wall may act as a barrier for pedestrian movement.
viii.	**performance**

P1	evapotranspiration	Transpiration	2
		Evaporation	1
	shading	Population/User	2
		Surface	2
	Insolation of building		-
P2	water conveyance		-
	water infiltration		-
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		1
P5	habitat provision		2
	connectivity		1
P6	beauty/appearance		2
	usability/functionality		1
	social interaction		1

literature/source: (Eisenberg et al. 2016)
further reading:

3.3.1 Noise barrier as free standing living wall

Fig. 28: Noise barrier as free standing living wall (source: www.lueft.de)

Fig. 29: Noise barrier as free standing living wall (source: Helix-Pflanzen)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x	x		x	x	x
reference to key studies								

ii. general description

Noise barrier as free standing living walls are constructions of baskets or different elements covered/filled with soil substrate with the function to reduce noise emissions e.g. along highly frequented roads.

iii. role of nature

Natural soil with vegetation cover (perennials and shrubs/trees) is the model for noise barriers as free standing living wall.

iv. technical and design parameters

The underground soil of noise barrier needs to be suitable for heavy wall elements. The design options are limited.

v. conditions for implementation

Green wall noise barriers need more space than non-vegetated noise barriers and some kind of (natural) water supply is needed.

vi. benefits and limitations

Benefits: Multiple benefits, partly similar to other living walls; great enhancement of visual appearance of noise protection walls; potential for reuse of storm water

Potential limitations/disservices: Success often dependent on natural precipitation

vii.	performance		
P1	evapotranspiration	Transpiration	1
		Evaporation	1
	shading	Population/User	-
		Surface	2
	Insolation of building		-
P2	water conveyance		-
	water infiltration		-
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		1
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-
literature/source: further reading:			

3.3.2 Mobile vertical greening / Mobile Green Living Room

Fig. 30: Mobile Green Living Room (source: Eisenberg)

i. basic information

type	1	2	3	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
				x			x	
reference to key studies								

ii. general description

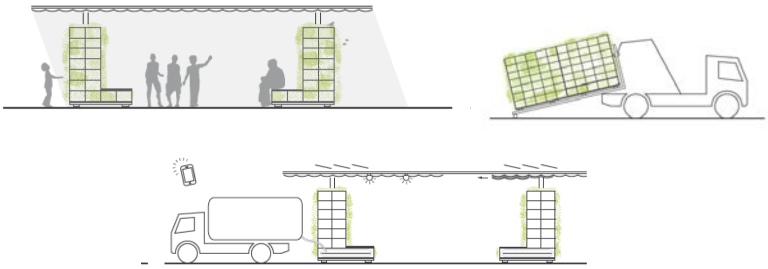


Fig. 31: Mobile green living room (source: Ludwig.Schoenle)

The mobile Green Living Room consists of living wall modules (wire frame cubes) 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. The Green Living Room provides instantly services for clean air provision, cooling and shading, a habitat for urban biodiversity. It can be used as a mobile demonstration for green infrastructure, as a test feature, a temporary green installation or as an open green office for information and communication purposes.

iii. role of nature

Natural soil with vegetation cover (perennials and shrubs/trees) is the model for living walls but for “mobile vegetation” there is no space for loading and unloading example from nature.

iv. technical and design parameters

The Green Living Room can be trucked to any location that has truck access. 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.

v. conditions for implementation

	Space for loading and unloading is needed, surface has to be flat (<3°), permissions needed for installation.		
vi.	**benefits and limitations**		
	Benefits: Mobile vertical elements serve as models for large scale interventions, they can be used for testing the suitability of a location and in participation processes. In combination with more elements the performance increases significantly. The average performance of vertical greening, such as heat reduction, cannot be replicated completely in mobile elements due to the limited space. *Potential limitations/disservices:* The requirements for transporting mobile elements dominate other aspects of vertical greening. The height is limited, also width and length are smaller. Maintenance and supervision is high. Transportation and production produce emissions.		
vii.	**Performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	Population/User	1
		Surface	-
	Insolation of building		-
P2	water conveyance		-
	water infiltration		-
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		1
	social interaction		1

literature/source: (Müller, H. & Eisenberg, B. 2016)
further reading:

3.4. Moss wall

3.4.1 ‚City tree‘

Fig. 32: MoosTex: Test site for pollution absorbing noise protection wall (source: Helix-Pflanzen)

Fig. 33: City tree (source: Eisenberg)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss	
			x	x					
reference to key studies	*City tree* (source: greencitysolutions.de)								

ii. general description

Mosses have compared to other plants a large bio-active surface, they transpire more and also actively reduce some pollutants. There is a range of test sites with open air experiments in order to test the effectiveness for fine dust and reduction and air quality improvement.

To exemplify the potential a product that makes use of the moss capacities is described for this NBS – type: The City Tree. A City Tree is a bio-tech-filter with the aim to improve the air quality in cities. The City Tree is a compact and mobile construction, vertically planted with different species of mosses on its front and back side. The moss surface contribute to improve the air quality through the binding of air pollutants like particulate matter and nitrogen oxide. Due to its large surface (in comparison to many other plants), mosses store a relatively huge amount of water and at the same time provide a relatively large surface area for water transpiration. As a consequence the transpiration of water leads to a reduction of air temperature on a local scale.

iii. role of nature

- Maximizing the ecological function of natural moss capacity
- Mosses have huge surface area → filtering of air pollutants
- Transpiration

iv. technical and design parameters

City trees are equipped with additional technical solutions: Ventilators inside the vertical construction and underneath the moss surface strengthen the air flow through the installation and thus increase the air filtering and the water transpiration. The ventilators are externally controllable.

Furthermore, the city tree is equipped with a technical device that provides real-time information about the city tree as well as the surrounding environment conditions. Depending on the local climate conditions, the city tree has an additional irrigation system. Additional solar panels supply electricity. Otherwise the city tree is connected to the mains.

v. conditions for implementation

	Flat surfaces for installation is needed, also enough space for loading and unloading.
vi.	**benefits and limitations**
	Benefits: - Air filtering - Mitigation against heat stress - Recreation/relaxing *Potential limitations/disservices*: - Real performance is still under discussion, further independent studies needed - Transportation and production produce emissions.

vii.	**performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	Population/User	1
		Surface	-
	Insolation of building		-
P2	water conveyance		-
	water infiltration		-
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		1
P5	habitat provision		-
	connectivity		-
P6	beauty/appearance		1
	usability/functionality		1
	social interaction		1

literature/source: (city tree solutions (n.d.). https://greencitysolutions.de/; (enercity 2017)
further reading:

3.5 Living Plant Constructions *(Baubotanik)*

Fig. 34: Baubotanik (source: Amos Chapple)

Fig. 35: Plane-Tree-Cube, Nagold (source: Ludwig.Schoenle; https://www.baubotanik.org/de/bauten/kubus/)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	(x)		x	x	x	x	x	x

reference to key studies	

ii. general description

For hundreds of years, the Khasi people of the Meghalayan mountains in north-eastern India have built bridges created with living plants by making use of natural growth processes. Roots of rubber trees are used in order to construct a living bridge that regrows constantly and outperforms wooden bridges which would rot away too quickly.

Living plant constructions is inspired by this approach and aims at using living trees with all their biological services also for construction purposes in order to create living architecture.
An essential feature of *Baubotanik* buildings is that they fundamentally change their general shape, appearance and spatial effect from season to season and over time. (Ludwig 2015).

Fig. 36: House of future competition, visualization of facade with living plant construction, winter and summer expression (source: Ludwig.Schoenle)

iii. role of nature

Living plant constructions use the natural process of inosculation, a process that can occur in nature when trunks, roots, or branches in close proximity slowly fuse together. This process also known as approach grafting, can arise within a single tree or neighbouring trees of same or different species. Over time, as the limbs grow, they exert increasing pressure on each other, similar to the friction between two palms rubbed together. This causes the outer bark to slough off, exposing the inner tissue and allowing the vasculature of both trees to intermingle, in essence joining their lifeblood (Oommen 2015).

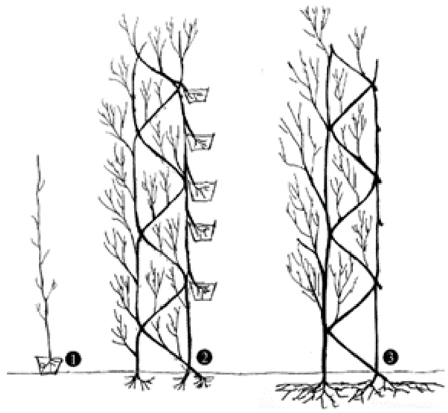


Fig. 37: Principle sketch of plant addition (source: Ludwig.Schoenle)

Plant addition is one application of *Baubotanik*: Only the lowest plants are put in the ground, all others are planted into special containers on a scaffolding or into living wall segments. The containers are fitted with an automated system, which continuously supplies them with water and nutrients and allows them to grow roots. As this network of plants develops, the roots embedded in the ground grow more vigorously than those placed in containers because the ground provides more root space, which plants can exploit for additional resources. Once the inosculations have developed, the artificially created plant structure can transport water and nutrients from the roots in the ground to the upmost leaves, and the roots of the container plants become obsolete.

Gradually, these high-level roots can be cut off, the automated watering system can be removed and, finally, the living structure becomes self-sufficient. At the same time, the secondary growth in circumference increases the strength of the plant structure and eventually it becomes self-supporting so that the scaffolding, initially required to support the containers and young plants, can be removed.

Ultimately, this approach entails a completely new understanding of plants: the plant is no longer seen as a single biological entity with a naturally determined development path (from sapling to tree), but rather as a living construction material, materiality or element that is fused with other living material and technical construction elements to form a unified whole. This process allows the creation of living buildings at the scale of a fully-grown tree in a comparatively short time, or – if seen from another perspective – it permits the construction of trees. The result is not only an amalgamation of the elements “house” and “tree” but also an integration of the processes of building and growing (Ludwig 2015).

iv. technical and design parameters

Living plant construction can be implemented on any site, also on top of buildings. For the upper containers of the plants supporting structure is needed that either has a function in itself (e.g. staircase), is a living wall (example Green Living Room), or a separate structure.

v. conditions for implementation

Due to regulations living plant construction may need special building permissions for implementation.

vi. benefits and limitations

Benefits: The performance that adult trees deliver after decades can be achieved within a couple of years by living plant construction. Depending on the implementation living plant constructions serve as green facades or three dimensional open spaces and deliver respective services like heat reduction for buildings, shading for people, cooling ambient temperature as well as improving the amenity value.

Potential limitations/disservices: Living plant constructions have a certain demand for maintenance and supervision, also irrigation systems are essential in the initial phase. Retrofitting buildings with living plant constructions is fairly difficult, for new constructions all required elements (supporting structures, access etc.) can be integrated right from the beginning.

A Standardized procedure for building and maintaining needs to be developed.

vii.	performance		
P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	Population/User	2
		Surface	1
	Insolation of building		-
P2	water conveyance		-
	water infiltration		-
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		1
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		1
	social interaction		1
literature/source: (Ludwig 2015), (Oommen 2015), (Ludwig, F; Schönle, D. Bellers, M. 2013) further reading:			

4. Green Roof

Green roofs are vegetative layers implemented on rooftops - especially in urban areas - with the aim to provide green space for different purposes and mitigate against urban heat islands. Several types of green roofs with varying coverings, complexity and scopes can be implemented on rooftops. Main positive effects associated with green roofs are for instance *cooling* and *evapotranspiration*, which lead to a reduction of the roofs temperature itself as well as of the surrounding air (= air cooling). As a result, green roofs contribute to mitigating negative effects in urban areas, in particular caused by urban sealing, buildings and heat emissions. The natural process, that green roofs are associated with, are evapotranspiration, temporary storing and buffering rain as well as sunlight absorption. The main functions of each green roof will be explained briefly below (see Figure 2) and will be addressed again in chapter iii/role of nature for each green roof type. The NBS catalogue focusses on intensive and extensive green roof types, but intermediate systems (semi/simple-intensive) also exist. The complete description of the different types of green roofs is given below in chapter 4.1 to 4.4.
For the NBS Catalogue a performance threshold is set for extensive green roofs. They should have at least 25 l/m² storing capacity and 95% coverage after three years. More extensive roof are not considered as NBS types.

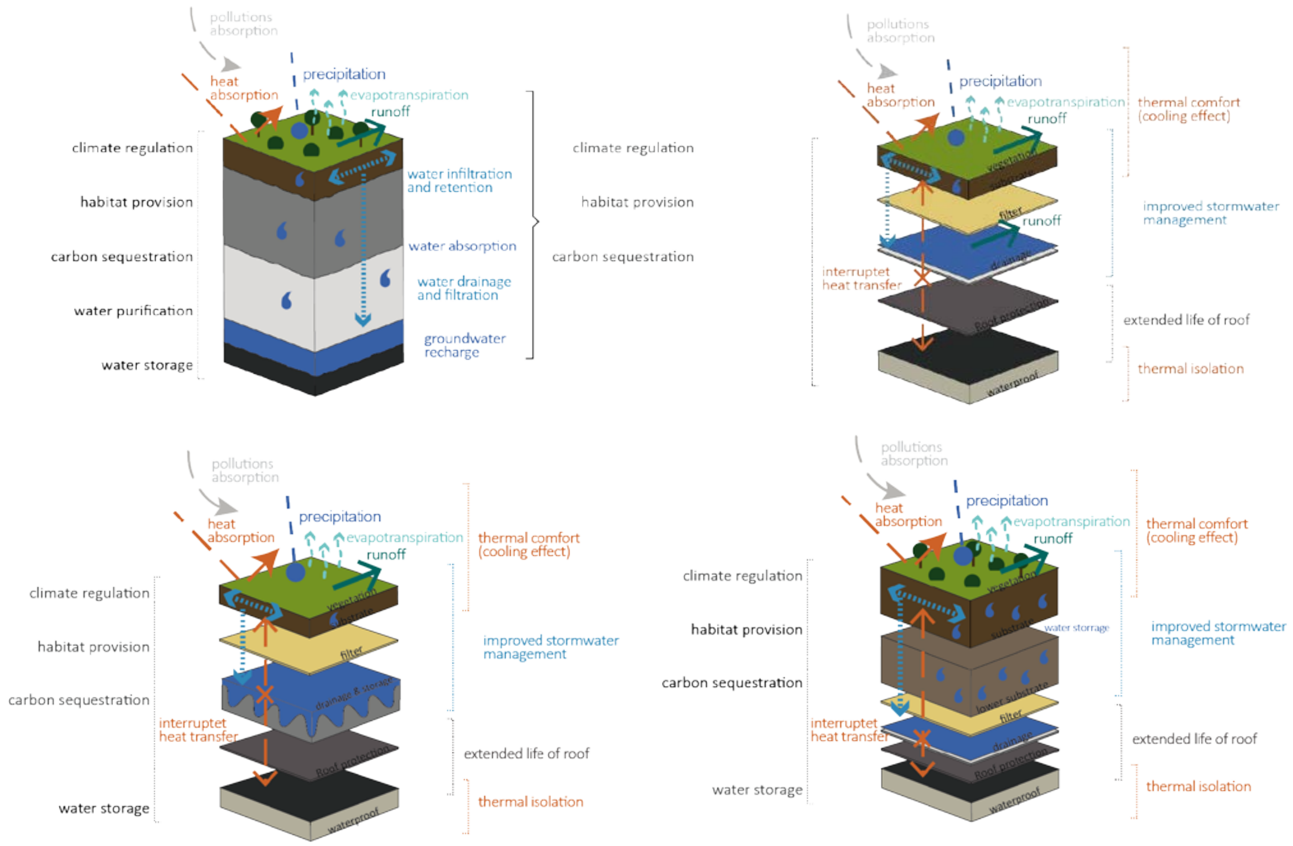


Fig. 38: Upper row, comparison of the structure of natural soils (left) and extensive green roofs (right), lower row, smart roof with extra water storing capacity (left) and intensive green roof (right) (source: ILPOE, 2018)

4.1 Intensive green roof

Fig. 39: Intensive green roof (source: LAND; https://www.landsrl.com/)

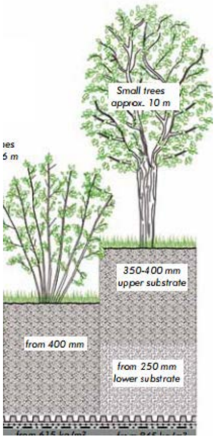


Fig. 40: Intensive green roof Illustration (source: myrooff.com)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x	x	x	x	x	x
reference to key studies								

ii. general description

Intensive green roofs* are often associated with residential buildings, hotels or underground parkings. The more complex and heavier greening systems are characterized by a higher installation, maintenance, management effort (regular irrigation and fertilization) which leads to higher costs for the mentioned system type compared to extensive green roofs (chapter 3.2). Intensive green vegetation is often established on roofs that are accessible for public or recreation purposes and also for regular maintenance measures. The intensive green roof type is regularly frequented by humans: Different activities including gardening, relaxing and socializing are designated for intensive green roofs. To enable human activities on green roofs and the integration of larger plants, trees and architectural elements, suitable rooftops need to be relatively flat.

The choice of suitable plants has to be greater (than on extensive green roofs) because of the different requirements and applications e.g. Aesthetic and ecological requirements. Appropriate plants for intensive green roofs are mainly trees, shrubs and perennials. The growth media is relatively thick and notably deeper than for extensive systems with integrated low-growing plants (see 3.2). The growth media of intensive green roofs needs to be relatively deep and nutrient rich to support the growth of plants or bigger trees. Beside a variety of plants, different kinds of architectural elements (buildings, solar panels) can be established on intensive green roofs.

*different terms for intensive green roofs used in literature are high-profile/ roof gardens (source: "Green Roofs." Provided in: Reducing Urban Heat Islands: Compendium of Strategies. Draft. https://www.epa.gov/heat-islands/heat-island-compendium)

iii. role of nature

As illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.** the model for a green roof is natural soil with its vegetation cover. Through the establishment of (intensive) green roofs on buildings, different services of natural vegetation layers are replicated. As a result, the potential to mitigate the urban heat island effect is higher compared to sealed surfaces without any vegetation (black roof).

Intensive green roofs can provide a variety of ecosystem services and benefits for the surrounding environment and microclimate. To enable these services, a natural, grown soil cover needs to be replicated.

The vegetation layer absorbs solar radiation for photosynthesis. Large trees and plants covering the buildings surface and thus providing shade for resting user. Plants and trees as well protect from heat transmission into the building.

	Through the integration of vegetation, the 1) transpiration and 2) evaporation is increased (in comparison to black roofs), reducing the surrounding air temperature (=cooling effect). The retention of precipitation is a fundamental service of natural soils. Especially coarse-pored soils can store storm water for a longer period before it is transported into receiving water. A green roof temporarily stores rain-/wastewater, filters and binds impurities. The thick growing medium of intensive green roofs is positive in the context of water filtration, storage and water retaining.
iv.	**technical and design parameters**
	Different greening systems for intensive green roofs - and therefore no uniform construction - exist (a) substrate fill → substrate mix that varies in height on drainage layer (b) planters → substrate on drainage layer in plant Beside the mentioned systems other/special constructions for intensive green roofs exist. - <u>plants:</u> huge variety (trees, shrubs and perennials) - <u>water requirement:</u> irrigation necessary - <u>growing medium:</u> 6-15” (~ 15-38 cm) - <u>slope gradient:</u> flat, 0-5° (a-b) - <u>weight:</u> 190-680 kg/m (a); depends on plant and planters selection (b) - <u>water retention capacity:</u> 30-160 l/m² (a) - <u>investment:</u> 5 Euro/m²/cm substrate (a); > 500 Euro/m² - <u>investment:</u> median to high - <u>maintenance:</u> 3,50-5,00 Euro/m²a (a, b); medium to high (Exemplary data source: Forschungsgesellschat Landschaftsentwicklung Landschaftsbau e.V., 2015; U.S. Environmental Protection Agency. 2008. „Green Roofs“. In: Reducing Urban Heat Islands: Compendium of Strategies. Draft. https://www.epa.gov/heat-island/heaut-idsland-compendium.)
v.	**conditions for implementation**
	- site characteristics often depend on project objectives → e.g. objective = improving aesthetics; high density areas are preferred that are visible from surrounding buildings - solid, stable concrete buildings/bearing capacity - flat or relatively flat concrete rooftops and underground concrete structures - artificial irrigation but at least (rainwater) watering facility in critical/dry periods - in some cases special plates distribute pressure on rooftop are needed (for planters)
vi.	**benefits and limitations**
	Benefits: - human health an quality of life - storm water/rainwater management and quality - improves air quality (reduction of greenhouse gas emissions) - aesthetic value/visual attractiveness - food production - additional space (intensive roof) - thermal performance/temperature reduction - energy reduction for buildings (heating/cooling) - reduction of noise/sound transmission - habitat provision for urban wildlife *Potential limitations/disservices:* - limited development of undisturbed habitats because of human activities/public purposes - limited spread of flora and fauna because of regular maintenance and management - limited space for rooting (although the growing media is relatively thick)

vii.	performance		
P1	evapotranspiration	Transpiration	2
		Evaporation	1
	shading	Population/User	1
		Surface	1
	Insolation of building		2
P2	water conveyance		2
	water infiltration		-
	water retention		2
	water storage		1
	water reuse		-
P3	water filtering		1
	water bioremediation		-
P4	deposition		1
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		2
	usability/functionality		1
	social interaction		1

literature/source: (International Green Roof Association e.V. (IGRA) 2018); (U.S. Environmental Protection Agency 2008)
McIntyre, L. & E. C. Snodgrass (2010): *The Green Roof Manual: A Professional Guide to Design, Installation, and Maintenance*. Timber Press. Portland. London.
Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2014 (FLL) – The landscaping and landscape development Research Society), Guidelines for Planning, Executing and Upkeep of Green Roof Sites, 2002 edition.
further reading:

4.2 Extensive green roof

Fig. 41: Extensive green roof Oversum- Winterberg (source: Optigrün)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x	x		x		x

reference to key studies	*Green roofs in Basel, Switzerland: combining mitigation and adaptation measures (2015); Urban storm water management in Augustenborg, Malmö (2014).*(source (a, b): http://climate-adapt.eea.europa.eu/)

ii. general description

Extensive green roofs* are basic, light weight systems, characterized by minimum maintenance and management (artificial irrigation, fertilization) after establishment of the system. According to the NBS catalogue, a minimum performance of 25 l/m² storing capacity and at least 95 % of vegetation coverage after three years is needed. The installation and management/maintenance of extensive green roofs is less expensive than that of intensive systems. Extensive green vegetation is often established on roofs that are not accessible or with limited access for public or recreation purposes (but annual maintenance) and partially characterized by steep slopes.

Appropriate plants for extensive green roofs are low growing, rapidly spreading and shallow-rooting plants/hardy perennials (succulents such as sedums, herbs, wildflowers, grasses, mosses) that are able to survive with minimum nutrient uptakes and without additional nutrient supply. The selected plants for extensive green roofs are generally well adapted to alpine environments/climate and tolerate different climate conditions (e.g. drought) and temperature fluctuations. The number of different plant species is limited on extensive roofs, yet the biodiversity on extensive green roofs is generally greater than on other (intensive) green roof types.

Through the establishment of (extensive) green roofs on rooftops, different services of natural vegetation layers are replicated. As a result, the potential to mitigate the urban heat island effect is increased compared to sealed surfaces without any vegetation.

Extensive green roofs provide limited services and benefits for the surrounding environment. As described above, it is characterized by a low vegetation surface that covers the buildings surface. Although the surface covering is the main service of extensive roofs, it also leads to positive effects on microclimate: Evaporation is increased in comparison to black roofs and leads to a heat reduction of the surrounding air temperature (=air cooling). Furthermore, the vegetation binds particular matter.

The growth medium is relatively thin compared to intensive green roofs. As a result the service of water buffering, temporary storage, retention and filtration albeit lower than for intensive green roofs, yet exists.

*different terms for extensive green roofs used in literature are low-profile/Ecoroofs (source: "Green Roofs." Provided n: Reducing Urban Heat Islands: Compendium of Strategies. Draft. https://www.epa.gov/heat-islands/heat-island-compendium)

iii. role of nature

	As illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.** 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.
iv.	**technical and design parameters**
	Different greening systems for extensive green roofs - and therefore no uniform technical/design construction - exists. a) direct → vegetation grows direct on concrete (special “biological concrete”) b) textile systems → vegetation is established on synthetic fibre mats c) textile-substrate-systems → vegetation is precultured on organic fibre mats + underlying substrate d) substrate fill → substrate mix that varies in height on drainage layer - plants: less variety (moss, sedum, herbs, grasses) - water requirement: low - growing medium: 2-6” (~ 5-15 cm); reservoir board for extensive roofs is needed - slope gradient: 0-35° (a-d) (steeper slopes up to 85° (a-c)/ 45° (d) are possible with technical devise) - weight: 20 kg/m (b); 30-90 kg/m² (c); 50-190 kg/m² (d) - water retention capacity: up to 20 l/m² (a, c), up to 24 l/m² (b); 30-50 l/m² - investment: low (a); 45-60 Euro/m² (b), 55-70 E/m²; 15-35 Euro/m² (d) → low to medium maintenance: low (a), 0,50 Euro/m²a (b), 1 Euro/m²a (c); 1,50-3,00 Euro/m²a (exemplary data source: Forschungsgesellschat Landschaftsentwicklung Landschaftsbau e.V., 2014; U.S. Environmental Protection Agency. 2008. „Green Roofs“. Provided in: *Reducing Urban Heat Islands: Compendium of Strategies. Draft.* https://www.epa.gov/heat-island/heaut-idsland-compendium.)
v.	**conditions for implementation**
	- site characteristics often depend on project objectives → e.g. objective = improving aesthetics high density areas are preferred that are visible from surrounding buildings - solid, stable concrete buildings/bearing capacity - flat or relatively flat concrete rooftops and underground concrete structures - artificial irrigation but at least (rainwater) watering facility in critical/dry periods - in some cases special plates are needed to distribute pressure on rooftop (for planters)
vi.	**benefits and limitations**
	Benefits: - human health and quality of life - storm water/rainwater management and quality - improved air quality - aesthetic value/visual attractiveness - thermal performance/temperature reduction - energy reduction for buildings (heating/cooling) - reduction of noise/sound transmission - habitat provision for urban wildlife *Potential limitations/disservices:* - limited development of undisturbed habitats because of human activities/public purposes - limited spread of flora and fauna because of regular maintenance and management limited space for roots

vii.	performance		
P1	evapotranspiration	Transpiration	-
		Evaporation	1
	shading	Population/User	-
		Surface	1
	Insolation of building		1
P2	water conveyance		1
	water infiltration		-
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		-
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-

literature/source: (U.S. Environmental Protection Agency 2008)
McIntyre, L. & E. C. Snodgrass (2010): *The Green Roof Manual: A Professional Guide to Design, Installation, and Maintenance*. Timber Press. Portland. London.
Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2014
further reading:
(Elliott et al. 2016)

4.3 Smart roof

Fig. 42:"Polderdaken" (smart retention roof (source: Amsterdam Rainroof ; www.rainproof.nl)

Fig. 43: Smart roof, Amsterdam (source: City of Tampere)

i. basic information

type	1	2	**3**	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x	x		x				x

reference to key studies	*Case Study: ABG blue roof installed for a green extensive roof* (source: ABG Ltd.; http://www.abg-geosynthetics.com/)

ii. general description

Smart roofs are a special type of extensive green roofs that fulfil different services to protect ecosystems in cities: (Capillar) 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 storm water. Through capillary fibre cylinders water is naturally returned to the vegetation layer during dry periods. Capillar smart roofs represent a cyclic water management where an additional plant irrigation is not needed (100% of the storm water can be reused for irrigation). Furthermore technical devices (pumps, tanks, valves) are redundant.

iii. role of nature

As illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.** 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.

iv. technical and design parameters

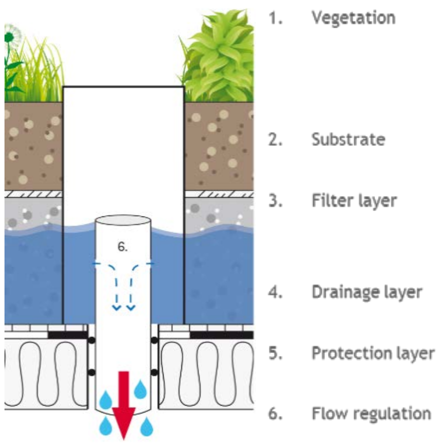


Fig. 44:"Polderdaken" Illustration (smart retention roof (source: www.rainproof.nl)

v.	**conditions for implementation**		
	- Waterproofing surface/roof - sufficient roof load-bearing capacity		
vi.	**benefits and limitations**		
	Benefits: - Reduced flood risk - Water scarcity - Loss of biodiversity		
vii.	**performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	1
	shading	Population/User	-
		Surface	1
	Insolation of building		2
P2	water conveyance		2
	water infiltration		-
	water retention		2
	water storage		2
	water reuse		1
P3	water filtering		1
	water bioremediation		-
P4	deposition		1
	biofiltration		-
P5	habitat provision		-
	connectivity		-
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-

literature/source: Amsterdam Rainproof. https://www.rainproof.nl/project-smartroof-20.
ABG. http://www.abg-geosynthetics.com/case-studies/blueroof-green-extensive-roof-Huddersfield.
further reading:

4.4 Constructed wet roof

Fig. 45: Constrcuted wet roof (source: Rhizotech; www.rhizotech.com)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
			x	x		x		x
reference to key studies								

ii. general description

The idea of constructed wet roofs CWR is to connect (extensive) green roofs and constructed wetlands for domestic wastewater (so-called grey water) treatment. Besides, constructed wet roofs retain storm water for a certain period of time, gradually releasing rainwater and reducing the overall runoff. Furthermore, CWRs have positive impacts on the microclimate.

Constructed wet roofs consists of precultured mats with evergreen vegetation that are installed on rooftops. The plants are irrigated with storm- and wastewater to ensure the surface layer remains moist. Water impurities are filtered during their way through the vegetation layer and absorbed as plant nutrients. Roofs need to have a moderate to high slope gradient to enable the water runoff. The processed water is used for irrigation as well as for disposal into receiving water or for toilet flushing. Besides the wastewater maintains the green space on the rooftop.

*different term for constructed wet roofs used in literature is wetland roofs
(source: http://rhizotech.com/de/107/dachbegruenung)

iii. role of nature

Constructed wet roofs can provide a variety of benefits, replicated from natural processes especially in soils. The most important service in the context of constructed wet roofs is the treatment of wastewater e.g. domestic or industrial wastewater. Water impurities in grey water are filtered during their way through the vegetation layer and absorbed as plant nutrients. Another important service is “storm and wastewater storage and retention”. As a result, the risk for flooding during or after a storm water event is lowered. Water evaporates from the water surface and transpires from the plants surface and stomata. This process leads to a decrease of the air temperature.

iv. technical and design parameters

- horizontal flow constructed wet roof (depth: 9 cm: shallow bed depth corresponds to an extensive green roof) with four beds (3,0 x 25,5 m)
- roof slope: 14,3 degrees
- half retention time (HRT): 3,8 days
- CW construction (top - down):
- turf mats (height: 1,5 cm): sandy, highly fertilized soil (here: organic soil) and grass roots/seed (3 mixture of 3 types)

- stabilization plates (height: 3,5 cm)
- substratum (height: 7,5 cm): sand, light expanded clay aggregates (LECA), polylactic acid beads (PLA)
- (Waterproofing surface (bituminous waterproofing))
- type of wastewater: domestic wastewater (effluent of kitchen-, bathroom-, toilets sink and dishwater from considered building)
- additional technical devices (tanks and pumps): septic tank, inlet tank, pumps for each bed, pressure pipes (influent and effluent pipe), infiltration pond

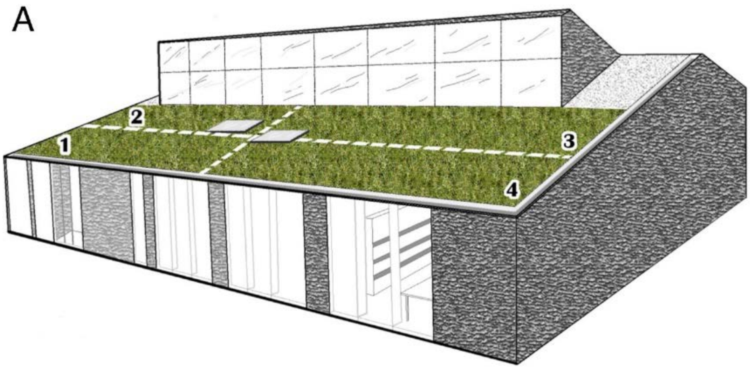


Fig. 46: Constrcuted wet roof (Zapater-Pereyra et al. 2016)

Exemplary technical design: Zapater-Perezra, M., Lavrnic, S., van Dien, F. van Bruggen, J.J.A. and P.N.L. Lens (2016): Constructed wetroofs: A novel approach for the treatment and reuse of domestic wastewater (2016).

v.	conditions for implementation
	- Waterproofing surface/roof - sufficient roof load-bearing capacity - slope gradient to water outlets - (emergency) overflows
vi.	**benefits and limitations**
	Benefits: - effect on microclimate: cooling of air temperature - decreased probability and consequential effects of flooding (water retention) - habitat for insects and birds/urban wildlife - improves water quality - (relative) water quantity (water can be used for different purposes after natural treatment)

vii.	performance		
P1	evapotranspiration	Transpiration	2
		Evaporation	1
	shading	Population/User	-
		Surface	1
	Insolation of building		2
P2	water conveyance		1
	water infiltration		-
	water retention		1
	water storage		1
	water reuse		1
P3	water filtering		1
	water bioremediation		1
P4	deposition		1
	biofiltration		-
P5	habitat provision		-
	connectivity		-
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-
literature/source: http://rhizotech.com/de/107/dachbegruenung; (Zapater-Pereyra et al. 2016) further reading:			

5. Water sensitive urban design measure

The urban water cycle differs greatly from the natural water cycle with regard to the main components evapotranspiration, water run-off and infiltration (see Fehler! Verweisquelle konnte nicht gefunden werden.). This has severe consequences with regard to urban climate, ground water recharge, and risk management. The NBS that are listed in the catalogue aim to mitigate the effects and try to re-establish a more natural water cycle.

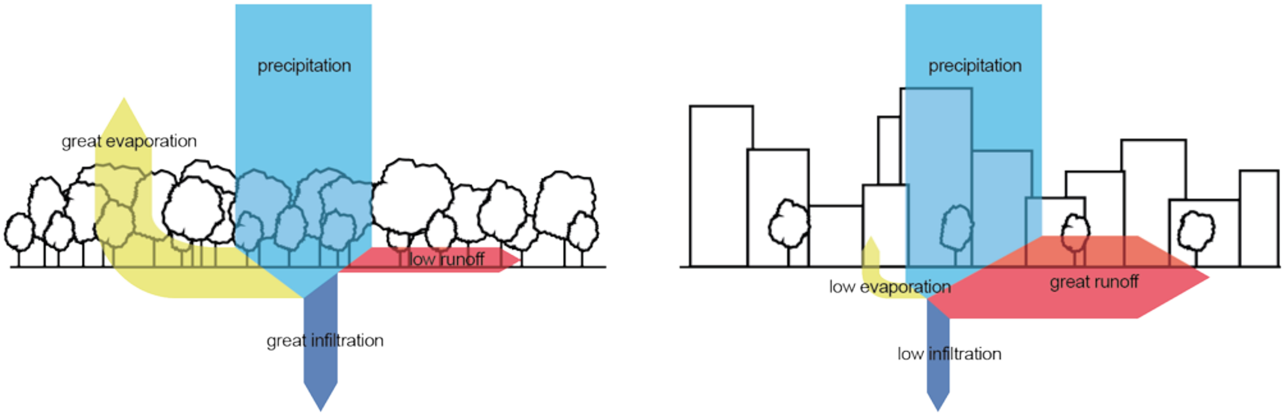


Fig. 47: Comparison between natural and urban water cycle. Main components differ greatly
(source: freely adapted from SAMUWA)

Many of the NBS are integral part of concepts dealing with water such as water sensitive urban design or sustainable drainage systems.

5.1 Bioswale

Fig. 48: Eindhoven, Bioswale (source: Eisenberg)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x					x

reference to key studies	*Case study: Queen Mary´s Walk, Llanelli,* *Case study: Houndsden Road Rain Gardens, Enfield. www.susdrain.org*

ii. general description

A bioswale* is a vegetated, linear and low sloped pit often established in urban areas near/between roads with the objective to reduce flood risk during or after heavy rain events. The intention of bioswales is comparable to rain gardens. Bioswales absorb, store and convey surface water runoff (mainly draining from roadways) and also remove pollutants and sediments, when the water trickles through the vegetation and soil layer. The choice of vegetation for bioswales is variable but deep-rooted native plants are common and preferred. To support infiltration of water runoff, some swales are equipped with dams or similar constructions.

Bioswales are not limited to a certain region/country. If properly planned and planted with native plants, a bioswale is a reasonable contribution to local storm water management and control.

* In literature refers to as swale (source: http://nwrm.eu/sites/default/files/nwrm_ressources/u4_-_swales.pdf)

iii. role of nature

- Processes in bioswales (vegetation, soil) that are inspired by nature:
- water retention and storage (vegetation and soil layer retains and stores water)
- water infiltration (water infiltrates into natural soils (soil substance has an influence on infiltration rate)
- water filtering (plants and soil are natural filters for organic pollutants, sediments and other substances)
- water conveyance (natural riverbed conveys water)
- water evapotranspiration (plants take up and transpires water)

iv. technical and design parameters

- Medium to larger scale installations (larger than rain gardens)
- native deep-rooted plants that withstand occasional flooding (often grass, + other plants for esthetical reasons)

- relatively dense vegetation (positive for slowing water; too dense vegetation would be negative for water conveyance)
- regular maintenance and inspection (grass cutting and removal; removal of sediment)
- access for maintenance and management necessary
- combination with other SUDs (e.g. rainwater harvesting and permeable paving)
- For planting suggestions see: (Bray et al. 2018)

v. conditions for implementation

Storm water from roofs or paved areas need to be collected in order to lead them into a bio swale. Space for implementation is needed, multifunctional uses if possible.

vi. benefits and limitations

Benefits:

- storm water management and control
- reduced flood risk
- improvement of water quality
- habitat provision for wildlife
- improvement of amenity value

Potential limitations/disservices:

- trees are limited → habitat provision limited on ground level

vii. performance

P1	evapotranspiration	Transpiration	-
		Evaporation	1
	shading	Population/User	-
		Surface	-
	Insolation of building		-
P2	water conveyance		1
	water infiltration		2
	water retention		1
	water storage		1
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		2
	usability/functionality		-
	social interaction		-

literature/source: (European Commission n.d.b); (Natural Resources Conservation Service 2005); http://www.susdrain.org/delivering-suds/using-suds/suds-components/swales-and-conveyance-channels/swales.html
further reading:

5.2 Infiltration basin


Fig. 49: Infiltration basin (source: www.susdrain.org)


Fig. 50: Infiltration basin (source: SuDS Wales; www.sudswales.com)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss

reference to key studies	*Case study: Queen Mary´s Walk, Llanelli,* *Case study: Houndsden Road Rain Gardens, Enfield. www.susdrain.org*

ii. general description

Infiltration basins are flat areas planted with grass and normally dry. After a heavy rain the water fills up the basin and soaks into the ground.

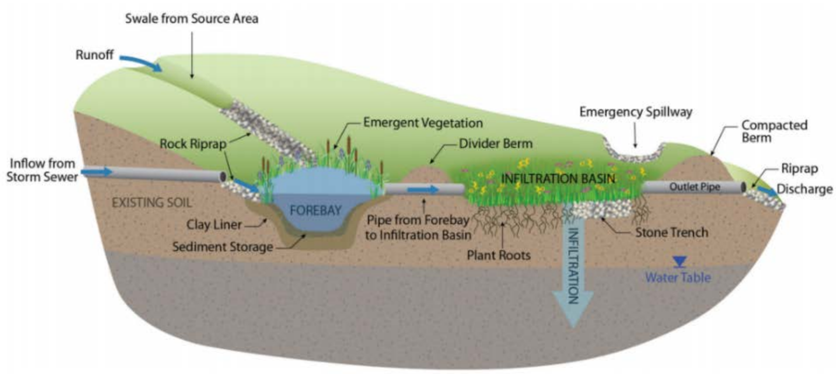


Fig. 51: Infiltration basin *Illustration (source: provided in: Massachusetts Department of Environmental Protection; geosyntec.com/)*

iii. role of nature

Filtration of surface water by different soil layers (for example sand)

iv. technical and design parameters

- Have to be lower than the ground level.
- Simple to construct
- Basin should be flat (water have to soaks equal)
- Grass should be longer than 3 inches (otherwise it will not survive flooding)
- Infiltrate 50% of their storage volume within 24 hours of filling

v. conditions for implementation

<table>
<tr><td></td><td colspan="3">- Available space
- Local soil conditions
- Highly specific rainwater intensities
- Can be integrated in personal gardens, parks, driveways
- Should not be directly connected with aquifers (even if there are permeable layer in between)</td></tr>
<tr><td>vi.</td><td colspan="3">benefits and limitations</td></tr>
<tr><td></td><td colspan="3">Benefits:
- Remove pollution from the rainwater</td></tr>
<tr><td>vii.</td><td colspan="3">performance</td></tr>
<tr><td rowspan="5">P1</td><td rowspan="2">evapotranspiration</td><td>Transpiration</td><td>-</td></tr>
<tr><td>Evaporation</td><td>1</td></tr>
<tr><td rowspan="2">shading</td><td>Population/User</td><td>-</td></tr>
<tr><td>Surface</td><td>-</td></tr>
<tr><td colspan="2">Insolation of building</td><td>-</td></tr>
<tr><td rowspan="5">P2</td><td colspan="2">water conveyance</td><td>-</td></tr>
<tr><td colspan="2">water infiltration</td><td>2</td></tr>
<tr><td colspan="2">water retention</td><td>1</td></tr>
<tr><td colspan="2">water storage</td><td>-</td></tr>
<tr><td colspan="2">water reuse</td><td>-</td></tr>
<tr><td rowspan="2">P3</td><td colspan="2">water filtering</td><td>1</td></tr>
<tr><td colspan="2">water bioremediation</td><td>-</td></tr>
<tr><td rowspan="2">P4</td><td colspan="2">deposition</td><td>-</td></tr>
<tr><td colspan="2">biofiltration</td><td>-</td></tr>
<tr><td rowspan="2">P5</td><td colspan="2">habitat provision</td><td>1</td></tr>
<tr><td colspan="2">connectivity</td><td>1</td></tr>
<tr><td rowspan="3">P6</td><td colspan="2">beauty/appearance</td><td>1</td></tr>
<tr><td colspan="2">usability/functionality</td><td>-</td></tr>
<tr><td colspan="2">social interaction</td><td>-</td></tr>
<tr><td colspan="4">literature/source:
further reading:</td></tr>
</table>

5.2.1 (Dry) Detention Pond

Fig. 52: Detention Pond (source: www.susdrain.org)

Fig. 53: Detention Pond (source: www.sudswales.com)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
reference to key studies								

ii. general description

Dry detention ponds are surface storage basins that retain storm water. During periods of heavy rain, the area gets flooded and could lead to filling up of the detention pond in cases of longer duration of rainfall. After the rain ends, the water flows in the sewer system. If there is no event of heavy rainfall the detention ponds are dry and could be used as a green area.

iii. role of nature

A natural landscape contains a heterogeneous surface with slightly elevated areas and lower parts in close proximity, forming a mosaic of micro conditions. Water stays in the lower parts for some time until it infiltrates or evaporates.

iv. technical and design parameters

- Detention ponds can be part of public spaces (playground, sports field, …)
- Have to be at the lowest part of the park, green space

v. conditions for implementation

- could be considered into park planning (area can be used otherwise)
- Enough space to get flooded

vi. benefits and limitations

Benefits:

- Regulates heavy rain
- Multifunctional use of detention pond is possible

Limitations/ disservice:

- Limited design options
- Green space with too many functions => reduced recreation space

vii. performance

P1	evapotranspiration	Transpiration	-
		Evaporation	-
	shading	Population/User	-
		Surface	-
	Insolation of building		-

P2	water conveyance	-
	water infiltration	1
	water retention	2
	water storage	1
	water reuse	-
P3	water filtering	1
	water bioremediation	1
P4	deposition	-
	biofiltration	-
P5	habitat provision	1
	connectivity	1
P6	beauty/appearance	2
	usability/functionality	1
	social interaction	1
literature/source: further reading:		

5.2.2 (Wet) Retention Pond

Fig. 54: Wet Retention Pond in Vuores, Tampere(source: City of Tampere)

Fig. 55: Wet Retention Pond in Vuores, Tampere(source: City of Tampere)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding			water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
reference to key studies									

ii. general description

Retention ponds retain storm water continuously. In dry periods they also hold water. The detention ponds can improve the water quality (for example with downstream infiltration).

iii. role of nature

A natural landscape contains of a heterogeneous surface with slightly elevated areas and lower parts in close proximity, forming a mosaic of micro conditions. Water stays in the lower parts for some time until it infiltrates or evaporates.

iv. technical and design parameters

- Water available within the city
- Has to be located at lowest point
- Area cannot be used otherwise

v. conditions for implementation

- Enough space to get flood
- Included in parks

vi. benefits and limitations

Benefits:

- Retention of storm water
- Potentially re-use of water for irrigation

Limitations/ disservices:

- Green space with too many functions => reduced recreation space

vii. performance

P1	evapotranspiration	Transpiration	-
		Evaporation	1
	shading	Population/User	-
		Surface	-
	Insolation of building		-
P2	water conveyance		-
	water infiltration		1

	water retention	2
	water storage	2
	water reuse	-
P3	water filtering	1
	water bioremediation	-
P4	deposition	-
	biofiltration	-
P5	habitat provision	1
	connectivity	1
P6	beauty/appearance	1
	usability/functionality	-
	social interaction	1
literature/source: further reading:		

5.3 Rain garden

Fig. 56:Small scale Raingarden (source: Andreas Kis provided in: (European Commission n.d.a)

i. basic information

type	1	2	**3**	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x					x

reference to key studies	*Case study: Greening streets, retrofit rain gardens, Nottingham.* *Ashby Grove residential retrofit rain garden, London. www.susdrain.org*

ii. general description

A rain garden* is a kind of garden that primarily serves as area for water control (storage and infiltration) on a small-scale especially in urban areas. Rain gardens are established in artificial surroundings and catches water runoff from roofs, roads and other (sealed) surfaces. Storm water runoff is drained into rain gardens, where it is stored for a certain period, and infiltrates either into the ground soil or flows into the sewage system. A certain amount of water is taken up and transpired by plants.

Different designs/arrangements of rain gardens are established and a variety of elements is used to create a rain garden such as grass filter strips, water ponds, mulch areas, planting soil, plants (e.g. herbaceous plants) or sand beds. All the mentioned elements have a particular function for example slow down, reduce, filter and store water runoff or increase evapotranspiration. Beside their function to store and infiltrate storm water, rain gardens have esthetical functions (amenity value).

Raingardens are not restricted to a certain climate condition and can be found in different European countries. But, the selected components (plants) should be native and well adapted to local climate conditions.

* In literature refers to as bioretention area (source: (European Commission n.d.a)

iii. role of nature

- Processes in rain gardens (vegetation, soil) that are inspired by nature:
- vegetation and soil layer retains and stores water, water infiltrates into natural soils (soil substance has an influence on infiltration rate)
- plants and soil are natural filters for organic pollutants, sediments and other substances
- natural riverbed conveys water
- plants take up and transpires water

iv. technical and design parameters

- small-scale installation (private gardens or public space)
- native plants that withstand occasional flooding
- relatively dense vegetation
- gentle slope is positive for infiltration
- regular maintenance and inspection
- access for maintenance and management

<table>
<tr><td></td><td colspan="3">- can be combined e.g. with rainwater harvesting and permeable paving</td></tr>
<tr><td>v.</td><td colspan="3">conditions for implementation</td></tr>
<tr><td></td><td colspan="3">- Space</td></tr>
<tr><td>vi.</td><td colspan="3">benefits and limitations</td></tr>
<tr><td></td><td colspan="3">Benefits:
- water retention and storage
- water infiltration
- water filtering
- water conveyance
- water evapotranspiration</td></tr>
<tr><td>vii.</td><td colspan="3">Performance</td></tr>
<tr><td rowspan="5">P1</td><td rowspan="2">evapotranspiration</td><td>Transpiration</td><td>1</td></tr>
<tr><td>Evaporation</td><td>1</td></tr>
<tr><td rowspan="2">shading</td><td>Population/User</td><td>-</td></tr>
<tr><td>Surface</td><td>-</td></tr>
<tr><td colspan="2">Insolation of building</td><td>-</td></tr>
<tr><td rowspan="5">P2</td><td colspan="2">water conveyance</td><td>-</td></tr>
<tr><td colspan="2">water infiltration</td><td>1</td></tr>
<tr><td colspan="2">water retention</td><td>1</td></tr>
<tr><td colspan="2">water storage</td><td>1</td></tr>
<tr><td colspan="2">water reuse</td><td>2</td></tr>
<tr><td rowspan="2">P3</td><td colspan="2">water filtering</td><td>1</td></tr>
<tr><td colspan="2">water bioremediation</td><td>1</td></tr>
<tr><td rowspan="2">P4</td><td colspan="2">deposition</td><td>-</td></tr>
<tr><td colspan="2">biofiltration</td><td>-</td></tr>
<tr><td rowspan="2">P5</td><td colspan="2">habitat provision</td><td>2</td></tr>
<tr><td colspan="2">connectivity</td><td>1</td></tr>
<tr><td rowspan="3">P6</td><td colspan="2">beauty/appearance</td><td>2</td></tr>
<tr><td colspan="2">usability/functionality</td><td>1</td></tr>
<tr><td colspan="2">social interaction</td><td>1</td></tr>
<tr><td colspan="4"><u>literature/source:</u>(Braskerund, Bent, C. 2015); (European Commission n.d.a); (Bray et al. 2018); http://www.susdrain.org/delivering-suds/using-suds/suds-components/infiltration/rain-gardens.html
<u>further reading:</u></td></tr>
</table>

5.4 Permeable paving system

5.4.1 Permeable pavement

Fig. 57: Permeable pavement (source: LAND; https://www.landsrl.com/)

Fig. 58: Eindhoven, permeable pavement (source: Eisenberg)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x	x	x					
reference to key studies								

ii. general description

Permeable paving systems are known as surfaces that are able to absorb storm water and thus, minimize the surface water runoff. Different systems of permeable pavement surfaces exist. They are commonly installed on car parks, residential streets or sidewalks.

- Permeable pavers consist of concrete bricks with gaps or funnels between the single bricks
- a variety of single rocks create the permeable paver surface
- Gaps and funnels between bricks are commonly filled with stone and sand or grass (vegetated grid pavers are further explained in 5.4.2)
- Concrete bricks are located on stone layer
- Bricks are not pervious! (gaps/funnels allows water infiltration)
- After storm water event: water trickles/infiltrates through gaps/funnels between bricks
- Water is temporary stored in underlying stone layer and infiltrates into the soil or to an additional drainage layer conveys water into sewage system (subsurface drain)
- Water uptake by plants (if plants established in funnels between concrete bricks)
- Application area: parking lots, sidewalks, bike paths, driveways, streets…
- Function:
  - reduced surface/storm water runoff
  - water filtering → reduced amount of pollutants
  - delayed runoff

iii. role of nature

- Imitating natural soils → natural soils are permeable
- Natural drainage effect of soils
- different permeability of soils depending on the soil type and the saturation with water
- different infiltration potential
- soil with large pores absorbs bigger amount of water compared to sealed surfaces
- filling material between bricks enables water infiltration on high level

iv.	technical and design parameters
	- Single bricks create surface paver - Relatively simple construction: bricks; underlying gravel layer; drainage layer; filling material - Filling material: little stones or sand - Maintenance necessary

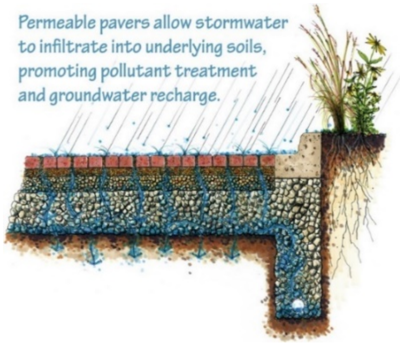


Fig. 59: Permeable pavers
(source: https://www.watershedcouncil.org/permeable-pavers.html)

v.	conditions for implementation
	- Implementation on new or existing building sites - Prior analysis of the soil is necessary
vi.	**benefits and limitations**
	Benefits: - Water quality protection - Storm water management - reduced surface runoff - controlled infiltration - temporary water storage - water filtering *Limitations /disservices* - limited load on paved area

vii.	performance		
P1	evapotranspiration	Transpiration	-
		Evaporation	-
	shading	Population/User	-
		Surface	-
	Insolation of building		-
P2	water conveyance		-
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		-
P4	deposition		-
	biofiltration		-
P5	habitat provision		-
	connectivity		-
P6	beauty/appearance		-
	usability/functionality		1

	social interaction	1

literature/source: (Eisenberg et al. 2015); (Winnebago County Highway Department n.d.); Tip of the Mitt Watershed Council (n.d.): https://www.watershedcouncil.org/permeable-pavers.html
further reading:

5.4.2 Vegetated grid pave

Fig. 60: Eindhoven, vegetated grid pave (source: Eisenberg

Fig. 61: Eindhoven, vegetated grid pave (source: Eisenberg)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x					
reference to key studies								

ii. general description

- Vegetated grid pavers consist of concrete bricks with gaps/funnels between the single bricks
- Use of concrete bricks or plastic grid
- Gaps/grid is filled with soil, grass seeds, rocks
- After storm water event: water trickles/infiltrates through gaps/funnels between bricks into the underlying gravel and then into the soil or groundwater
- Infiltrated water is also taken up by plants
- Water is stored for a certain period in the soil and drainage layer
- Additional drainage conveys water into sewage system
- Used in parking areas and roadways
- Function:
  - reduced surface runoff
  - water filtering
  - water storage

delayed runoff

iii. role of nature

- Imitating natural soils → natural soils are permeable
- Natural drainage effect of soils
- different permeability of soils depending on the soil type and the saturation with water
- different infiltration potential
- soil with large pores absorbs larger amount of water than sealed surface
- filling material between bricks enables water infiltration on high level

iv. technical and design parameters

- Concrete bricks or plastic grids are filled with soil, seeds or stones
- Grass grows in concrete/plastic grid
- Maintenance necessary

v. conditions for implementation

vi. benefits and limitations

	Benefits: - storm water management - reduced surface runoff - controlled infiltration - temporary water storage - water filtering *Limitations /disservices* - visual appearance		
vii.	**performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	Population/User	-
		Surface	-
	Insolation of building		-
P2	water conveyance		-
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		-
P4	deposition		-
	biofiltration		-
P5	habitat provision		1
	connectivity		-
P6	beauty/appearance		1
	usability/functionality		1
	social interaction		-
Literature/source: (Eisenberg et al. 2015); (Winnebago County Highway Department n.d.); Tip of the Mitt Watershed Council (n.d.): https://www.watershedcouncil.org/permeable-pavers.html.; ESCOFET 1886 SA (n.d.).; http://www.escofet.com/pages/productos/ficha_productos.aspx?IdP=288. further reading:			

5.4.3 Permeable concrete

Fig. 62: Permeable concrete (source: LAND; https://www.landsrl.com/)

Fig. 63: Permeable concrete (source: New Dawn Permeable Paving P/L; www. newdawnpermeablepaving.com.au)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x					
reference to key studies								

ii. general description

- Permeable concrete is permeable to water (also described as heavy permeable surface)
- special material/cement mixture with larger stones that allows water to pass through the concrete into the soil beneath the concrete layer
- Permeable concrete looks similar to standard concrete different functionality/construction
- Holes/gaps/voids in the concrete layer enables water infiltration/drainage
- After a storm water event: rainwater soaks through the concrete layer (pores) in contrast to regular concrete where water runs off on the surface and may cause flooding
- A porous medium for example an underground gravel bed, which also filters the water is installed under the permeable concrete layer
- Permeable concrete is a hard surface (roadways/areas with higher traffic)
- Application areas: parking lots, streets, driveways…

iii. role of nature

- Permeable paver are similar to other surfaces

iv. technical and design parameters

- Cavity ≥ 15%
- Water permeability: kf >10^{-3} m/s
- Asperity: at 4m length asperity cannot be more than 1,5 cm
- About 100 l/m² per second water passes

v. conditions for implementation

- Greater effort (→ roads have to be relaid)

vi. benefits and limitations

Benefits:

- Water regulation with space which is used for traffic (no more space is needed)
- Can be used to slow traffic and reduce noise
- Reduces storm runoff by 70-90 %

	- Improves water quality (removes 85-95% suspended solids, 65-85% phosphorus, 80-85% nitrogen 30% nitrate, up to 98% metals)

vii.	**performance**		
P1	evapotranspiration	Transpiration	-
		Evaporation	-
	shading	Population/User	-
		Surface	-
	Insolation of building		-
P2	water conveyance		-
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		-
P4	deposition		-
	biofiltration		-
P5	habitat provision		-
	connectivity		-
P6	beauty/appearance		-
	usability/functionality		1
	social interaction		-

literature/source: (Eisenberg et al. 2015); (Winnebago County Highway Department n.d.);(Breitbüchner 2013); Tip of the Mitt Watershed Council (n.d.): https://www.watershedcouncil.org/permeable-pavers.html.
further reading:

5.4.4 Porous asphalt

Fig. 64: Porous asphalt (source: New Dawn Permeable Paving P/L ; www.newdawnpermeablepaving.com.au)

i. basic information

type	1	2	**3**	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x					
reference to key studies								

ii. general description

- Porous asphalt is permeable to water
- Porous asphalt is similar to permeable/pervious concrete (function)
- Composed of larger stones in comparison to regular asphalt; different asphalt binders
- Material allows water to pass/drain through the asphalt layer
- Underlying open-graded stone bed
- After a storm water event: rainwater drains through the concrete layer into underlying stone bed
- Infiltration through stone bed into soil/groundwater
- Porous asphalt is a hard surface (roadways/areas with higher traffic)
- Application areas: parking lots, streets, driveways…

iii. role of nature

- Permeable concrete → water regulation function
- Porous medium → inspired by natural soils water drains/infiltrates into the soil
- Reduced flood risk compared to typical roads, where water runs off the surface

iv. technical and design parameters

- Quite simple technology
- Porous asphalt consists of larger stones compared to regular asphalt
- Use of different asphalt binders
- Use of standard equipment that is used to build e.g. roads for regular asphalt
- Careful planning of the underlying bed size/depth to avoid that the water level rises into asphalt layer (stone bed depth: 18-36 inches)

v. conditions for implementation

- Greater effort (→ roads have to be repaid)

vi. benefits and limitations

Benefits:

- Water regulation with space which is used for traffic (no more space is needed)
- Can be used to slow traffic and reduce noise
- Reduces storm runoff by 70-90 %

	- Improves water quality (removes 85-95% suspended solids, 65-85% phosphorus, 80-85% nitrogen 30% nitrate, up to 98% metals)		
vii.	**performance**		
P1	evapotranspiration	Transpiration	-
		Evaporation	-
	shading	Population/User	-
		Surface	-
	Insolation of building		-
P2	water conveyance		-
	water infiltration		1
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		-
	biofiltration		-
P5	habitat provision		-
	connectivity		-
P6	beauty/appearance		-
	usability/functionality		1
	social interaction		-

literature/source:
(Eisenberg et al. 2015); (Winnebago County Highway Department n.d.); National Asphalt Pavement Association (n.d.): http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=359&Itemid=863
further reading:

5.4.5 Permeable stone carpet

Fig. 65: Permeable stone carpet *(source: www.drenatech.it/)*

Fig. 66: Permeable stone carpet around a tree *(source: LAND; https://www.landsrl.com/)*

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x					

reference to key studies	

ii. general description

- High permeable material/special material that allows water to pass through into the soil
- underground gravel bed (additional filtering of storm water runoff)
- Flexible material; Application for car parks, parks, public spaces, bicycle path, private gardens…
- Example *(Drenatech)*:
- Innovative flooring option: consists of stones and two-component resin
- Two-component resin □ binds material; natural stones □define appearance
- Use of different stone types
- Esthetical value: more attractive than regular floorings (e.g. asphalt; concrete)
- Frost- and wear-resistant
- High chemical + mechanical strength

iii. role of nature

- Permeable concrete → water regulation function
- Porous medium → inspired by natural soils □ water drains/infiltrates into the soil
- Reduced flood risk compared to typical roads, where water runs off the surface

iv. technical and design parameters

- Example *(Drenatech)*:
- Environmentally friendly
- Resistant to heat and frost
- About 600-1000 l/m² per minute water passes
- Easy to apply (two components to mix)

v. conditions for implementation

vi. benefits and limitations

Benefits:

- Water regulation with space which is normal sealed
- Reduces storm runoff

	- Improves water quality - Mitigating the urban heat island effect			
vii.	**performance**			
P1	evapotranspiration	Transpiration		-
		Evaporation		-
	shading	Population/User		-
		Surface		-
	Insolation of building			-
P2	water conveyance			-
	water infiltration			1
	water retention			-
	water storage			-
	water reuse			-
P3	water filtering			-
	water bioremediation			-
P4	deposition			-
	biofiltration			-
P5	habitat provision			-
	connectivity			-
P6	beauty/appearance			-
	usability/functionality			1
	social interaction			-
literature/source: (drenatech 2017); drenatech (n.d.): http://www.drenatech.it/ further reading:				

5.5 Underground water storage

Fig. 67: Underground water storage *(source: Commune di Genova)*

Fig. 68: Zollhallen Plaza (source: Land8 Media, LLC.; land8.com)

i. basic information

type	1	2	**3**	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x	x	x					

reference to key studies	Zollhallen Plaza

ii. general description

Underground systems below public open spaces (sport fields) composed of modular elements to retain flash floods and to store water for irrigation purposes nearby.

iii. role of nature

Depending on the Geology of an area underground storage capacity retains and stores water after flash floods. Examples from Peru show that already in Pre – Inca time, people made use of these qualities and directed water in channels to storage areas or in order to feed artificial ponds or springs.

Fig. 69: Amuna in the Peruvian Andes (source: image concesa)

"Amunas, or ancient diversion channels, in select upper reaches of Lima's watersheds historically conveyed stream flows to infiltration ditches constructed laterally across mountainsides. Infiltrated water would re-emerge in small, constructed micro-pools or in natural springs downslope, over several weeks or months of lag time." (Gammi & De Bievre 2015).

iv.	**technical and design parameters**
v.	**conditions for implementation**
	Space for underground storage needs to be excavated
vi.	**benefits and limitations**
	Benefits - On site storage of water helps minimizing /delay run-off - Re-use of water on site => irrigation during hot season => more climate active vegetation Limitations - Minimum water quality needed for storage - Space for underground storage required
vii.	**performance**

P1	evapotranspiration	Transpiration	-
		Evaporation	-
	Shading	Population/User	-
		Surface	-
	Insolation of building		-
P2	water conveyance		-
	water infiltration		-
	water retention		1
	water storage		1
	water reuse		2
P3	water filtering		1
	water bioremediation		-
P4	deposition		-
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		-
	usability/functionality		-
	social interaction		-

literature/source:
further reading:

5.6 Constructed wetlands

Fig. 70:Urban Constructed wetland (source: LAND; https://www.landsrl.com/)

Fig. 71: Constructed wetland (source: LAND; https://www.landsrl.com/)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding			water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x			x	x				x	x
reference to key studies	*Case study: Trin Warren Tam-boore wetlands.*(source: *(City of Melbourne 2015)* *Urban wetland, Tanner Springs Park in Portland, Oregon* (source: enclos*ure and Cynthia Goodson; https://enclosuretakerefuge.com/)								

ii. general description

Constructed wetlands represent artificial wetlands with the main objective to harvest, treat and store storm-/grey water runoff in urban areas. Processes/services of natural wetlands are adapted to constructed wetlands focusing on water purification and (underground) storage. Hydrological processes of natural wetlands are simulated in constructed wetlands. Wetlands are complex systems: The established vegetation, the soil and microbiological activity play an important role for the filter performance of constructed wetlands. (salt) Marshes, swamps, peat bogs, coral reefs, mangroves or lagoons represent different types of wetlands.

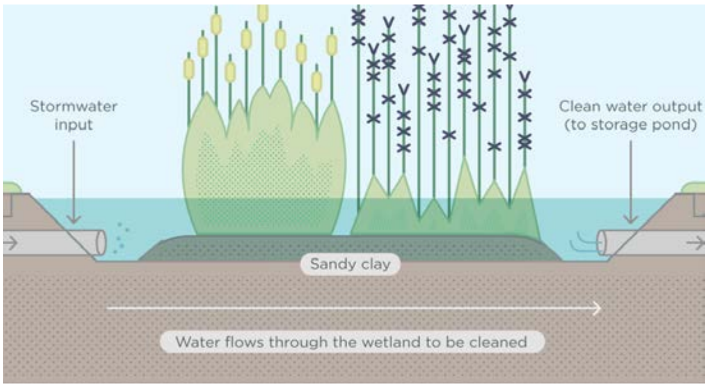
Constructed wetlands are basins (shallow) that are filled with substrate. The substrate type is variable but usually CWs are filled with sand or gravel. The substrate layer is planted with vegetation/aquatic plants. Constructed wetlands have an inlet (pipe) for storm water runoff. The water flows horizontal through the wetland while it is naturally filtered and cleaned. The main processes in a constructed wet roof are: settling of particles, filtration, chemical transformation, adsorption+ ion exchange e.g. on plants and substrates, uptake/breakdown/transformation of pollutants and nutrients by microorganisms and plants.

The storm water runoff can flow over or through the substrate layer. The constructed wetland is equipped with an outlet (pipe, weir) for a controlled water discharge. The purified water flows into another pond where it is stored. The treated storm water can be used for different purposes (e.g. for irrigation within the city in green areas). According to the type of constructed wetlands wastewater flows 1) horizontal over the ground surface or 2) horizontal under the ground surface → through the substrate layer or 3) vertical through the constructed wetland → hybrid systems.

iii. role of nature

Processes in/services of natural wetlands are adapted to constructed wetlands focusing on water purification and storage. The main processes in a constructed wet roof are: settling of particles, filtration, chemical transformation, adsorption+ ion exchange e.g. on plants and substrates, uptake/breakdown/transformation of pollutants and nutrients by microorganisms and plants.

iv. technical and design parameters

	- less expensive than conventional wastewater treatment options - installation of water control measures - regular inspections, monitoring, maintenance - cost-effective  *Fig. 72:*Constructed wetlands *(source: (City of Melbourne 2015)*
v.	**conditions for implementation**
	- suitable locations - outside floodplains - protection of biodiversity - upland location/gently sloped location - water flows by gravity through constructed wetland - near source of wastewater - enough land available - compact soils (minimized water infiltration to groundwater) - no endangered/threatened species - no archaeological or historic resources - accessible land
vi.	**benefits and limitations**
	Benefits: - Water supply regulation - Water temperature control - Improve water quality/water purification - Provide water for different purposes (e.g. irrigation) - Flood control/mitigation - Habitat for wildlife/biodiversity - Recreation (watching birds) - Aesthetic value *Potential limitations/disservices:* - Require relatively large areas → implementation where free space is available

vii.	**performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	2
	shading	Population/User	-
		Surface	-
	Insolation of building		-
P2	water conveyance		1
	water infiltration		1
	water retention		1

	water storage	1
	water reuse	2
P3	water filtering	1
	water bioremediation	2
P4	deposition	-
	biofiltration	-
P5	habitat provision	2
	connectivity	2
P6	beauty/appearance	2
	usability/functionality	1
	social interaction	2

literature/source:(City of Melbourne 2015); (Davis 1994); (Sample und Wang Chih-Yu and Laurie J. Fox 2013); City of Melbourne (n.d.); http://urbanwater.melbourne.vic.gov.au/industry/treatment-types/constructed-wetlands/; Kilian Water (n.d.): http://www.kilianwater.nl/en/constructed-wetlands/solar-powered-water-treatment.html
https://nepis.epa.gov/Exe/ZyPDF.cgi/30005UPS.PDF?Dockey=30005UPS.PDF
further reading: (Andreo-Martínez et al. 2017); (Jácome et al. 2016); (Moinier 2013)

5.7 Biofilter (water purification)

Fig. 73: Biofilter (source: Monash University; https://www.monash.edu)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding			water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x			x	x			x		
reference to key studies	*Monash University: Case study: Biofilter: Providing a fresh approach to storm water.* (source: https://www.monash.edu) *Feng, W., Hatt, B. E., McCarthy, D. T., Fletcher, T.D. and A- Deletic (2012): Biofilters for Stormwater Harvesting: Understanding the Treatment Performance of Key Metals That Pose a Risk for Water Use. Provided In: American Chemical Society*. (Feng et al. 2012)								

ii. general description

Biofilters (water) are developed to collect and purify storm- and wastewater and represent a promising system for storm 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 contaminations in the wastewater (influent) that is piped through the filter material. As mentioned above, the term “filter” is misleading. Biofilters separates/removes nutrients and organic carbons from wastewater/storm water through biodegradation. As a result biofiltration improves the quality of wastewater (reduction of nutrients, metals, sediments) and storm water and at the same time harvests storm water and stores it for a certain period.

iii. role of nature

Biodegradation is a natural process e.g. in soils. This natural degradation is used for different processes for example in anaerobic digestion (biogas production). Microorganisms and bacteria de degrades/removes/ nutrients and contaminations and biological substances.

iv. technical and design parameters

- Biofilter as demonstration for bioretention system
- Biofilter situated at the car park in Clayton Campus
- processed storm water per annum: 1.000.000 litres
- removal: nitrogen, phosphorus, 90% of heavy metals
- water storage in ornamental pond
- reuse of water runoff after treatment

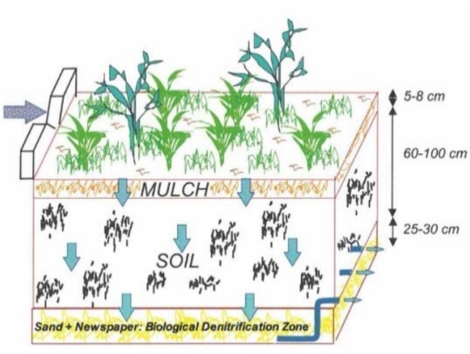


Fig. 74: Innovative bioretention process (Davis et al. 2009) Fig. 75:

- Improves the removal of difficult pollutants such as Nitrate
- Uses shredded newspaper (a synthetic waste material), as it is an effective source of carbon for denitrification
- Shredded newspaper is mixed with coarse sand to create a new layer under the soil media, which is kept continuously saturated with water, to maintain an anaerobic condition
- Can be integrated to any bioretention facility

v. conditions for implementation

Space for construction needed, flat terrain

vi. benefits and limitations

Benefits:
- water purification
- improving quantity of storm- and wastewater
- storm water regulation/management
- quality of live (reduction of odours)
- habitat for wildlife (limited service)

vii. performance

P1	evapotranspiration	Transpiration	-
		Evaporation	-
	shading	Population/User	-
		Surface	-
	Insolation of building		-
P2	water conveyance		1
	water infiltration		2
	water retention		1
	water storage		2
	water reuse		1
P3	water filtering		2
	water bioremediation		2
P4	deposition		-
	biofiltration		-
P5	habitat provision		1
	connectivity		-
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-

Literature/source: (Feng et al. 2012); Monash University (n.d.): https://www.monash.edu/environmental-sustainability/campus-initiative/water/water-harvesting/case-study-biofilter-providing-a-fresh-approach-to-storm-water.

6. (River) Restoration

The following chapter deals with different measures focusing on the restoration of rivers. The International Union for Conservation of Nature (IUCN) defines River restoration as […] *"the re-establishment of natural physical processes (e.g. variation of flow and sediment movement), features (e.g. sediment sizes and river shape) and physical habitats of a river system (including submerged, bank and floodplain areas)."* (IUCN provided in: (The River Restoration Centre n.d.).

The main aim of restoration is to design rivers towards more near-natural state with the effect, that the reinstated channels fulfil (again) important functions for the environment and for public protection. After restoration the rivers are characterized by dynamic water courses and sediment movements. Some of the mentioned functions are storm water regulation and flood risk reduction, habitat provision, and the provision of public space for recreation. The measures of restoration are diverse and modify different parts of the river e.g. the riverbed, the riverbank or floodplains and include small-scale as well as larger scale interventions. **Figure 4** represents an overview of different restoration measures in and along rivers.

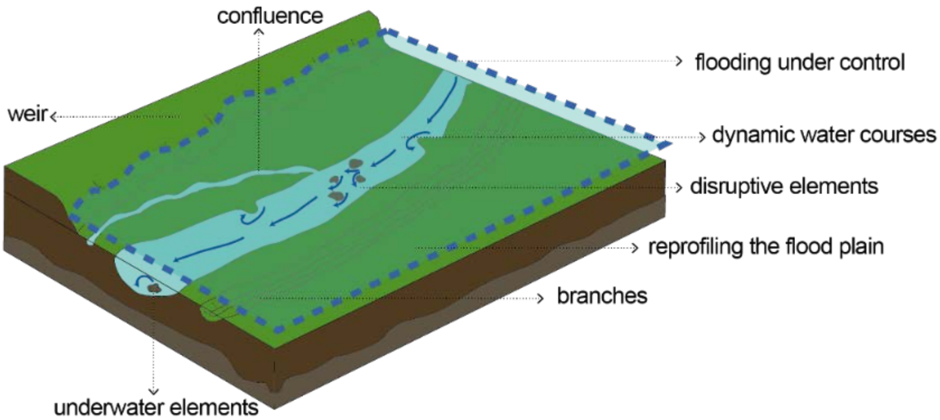


Fig. 76: Overview of restoration measures (source: ILPOE, 2018)

6.1 Daylighting

Fig. 77: Small stream after Daylighting (source: LAND; https://www.landsrl.com/)

Fig. 78: Daylighting of a small stream in work (source: LAND; https://www.landsrl.com/)

i. basic information

type	1	2	**3**	<u>action type:</u> 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x				x	x

reference to key studies	http://daylighting.org.uk/Daylighting/ *Tanners Brook, Southampton.* source: (European Centre for River Restoration (ECRR) n.d.b) *Wandle Park River Restoration* (National Environmental Assessment Service, Solent and South Downs Area, South East Region n.d.a)

ii. general description

- opening of covered/buried watercourses (rivers, drainage systems) by removing concrete layers
- reason for culverting watercourses: need of space for buildings, parking lots, roads
- negative effects of culverting: degradation of habitats, pollution, flood risk
- daylighting leads to more space for the water; increased storage capacity of the channel
- daylighting results in a natural development of the riverbed and riparian zone
- storm water benefits/management; environmental, aesthetic co-benefits
- positive effects: flood risk reduction, amenity value/recreation, habitat quality
- difference between “natural restoration” and “architectural restoration”
- natural restoration refers to the daylighting of channels and a natural development of the riverbed and riparian zone
- architectural restoration describes the daylighting of the channel that still follows a concrete/ constructed channel (less near-natural than channels of the first type)

iii. role of nature

- Daylighting allows the natural development of a water channel that fulfils services of a natural water channel/river e.g. habitat for wildlife and aquatic life and plants; regulation/uptake of storm water runoff
- natural channels enables the water to flow to/expand to its riversides; natural vegetation contributes to slow down the water velocity

iv. technical and design parameters

- Different designs are possible depending on the intention/planned project
- options: Removing whole culverted structure, parts of it (top layer) or making gabs
- a natural restoration is associated with greater effort than only removing the top layer of a watercourse and receiving the constructed channel; the riparian zone gets a natural shape with plants, rocks and a dynamic water channel shaped by nature

v.	**conditions for implementation**
	- restriction/limited possibilities in highly dense and build-up areas because of high cost for shifting of infrastructure/removing of infrastructure - enough space to deculvert the watercourse - certain channel width - need to assimilate knowledge about soil types under/surrounding the channel to guarantee the performance of the daylighting measure
vi.	**benefits and limitations**
	Benefits: - storm water management - benefits for aquatic organism (light plays important role for population movement) - benefits for flora and fauna frequenting the banks/habitat provision for flora and fauna - improving physical habitat conditions of the watercourse, habitat niches - Natural bank development/profile; creating natural watercourses - enables natural processes (erosion; deposition) - aesthetic value; human recreation - 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 is limited
vii.	**performance**

P1	evapotranspiration	Transpiration	1
		Evaporation	1
	shading	Population/User	-
		Surface	-
	reflection		-
P2	water conveyance		1
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		2
	connectivity		1
P6	beauty/appearance		2
	usability/functionality		1
	social interaction		1

literature/source :(Addy et al. 2016) (Trice n.d.) (Parks & Open Spaces, London Borough of Croydon n.d.); (National Environmental Assessment Service, Solent and South Downs Area, South East Region n.d.b); (American Planning Association, the American Society of Civil Engineers, the Association of State Floodplain Managers and the National Association of Counties and The Nature Conservancy n.d.)
European Center for River Restoration (n.d.): http://www.ecrr.org/RiverRestoration/Floodriskmanagement/HealthyCatchments-managingforfloodriskWFD/Environmentalimprovementscasestudies/Removeculverts/tabid/3125/Default.aspx
Miskell, B. (n.d.): http://www.boffamiskell.co.nz/project.php?v=stream-daylighting
Dutchwatersector.com. https://www.dutchwatersector.com/solutions/projects/283-room-for-the-river-programme.html
further reading:

6.2 River space extension

6.2.1 Reprofiling/Extending flood plain area

Fig. 79: Sandbank and flat riverbank, Isar, Munich (source: ILPOE, 2018)

Fig. 80: Extended flood plain area (source: LAND; https://www.landsrl.com/)

viii. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x						x	x

reference to key studies	*Allow the river to flood its floodplain.* (European Centre for River Restoration (ECRR) n.d.a) *Isar-Plan – Water management plan and restoration of the Isar River, Munich (Germany)* (source:(Schaufuß n.d.)

ix. general description

- expansion of the flood plain area
- providing additional flood space by excavating the lateral river bed (flood plain area)
- main purpose: flood/water control and management
- creation of relatively flat and accessible bank areas
- new created space can be used for e.g. public purposes (relaxing, leisure activities) or agricultural purposes (farmland) during low water levels

x. role of nature

- replication of:
  - natural river courses with relatively flat banks and natural floodplains
  - natural river landscapes without sealed and cultivated areas
- temporary water storage and infiltration into the ground
- water filtration

xi. technical and design parameters

- Technical effort depends on project/design considerations and natural conditions of the channel
- Different designs are possible (see picture below) focusing e.g. on ecosystem development or human recreation (or both)

xii. conditions for implementation

- Infrastructure near the river or other types of land use can be seen as an limitation for river restoration, if there is an need for preservation (limited space)

xiii. benefits and limitations

Benefits:

- Flood control
- water storage
- Water conveyance

	- Ecological benefits (habitat for wildlife; vegetation) - Human recreation; Amenity value *Potential limitations/disservices:* - An intensive use of the new floodplain area for recreation (e.g. leisure activity) may restrict the establishment of animals and plants and therefore limits the provision of ecosystems for wildlife - Inversely: if the floodplain area is reserved for the development of ecosystems, the area does not serve (primarily) for human recreation

xiv.	**performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	1
	shading	Population/User	-
		Surface	-
	reflection		-
P2	water conveyance		1
	water infiltration		1
	water retention		2
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		2
	connectivity		2
P6	beauty/appearance		1
	usability/functionality		2
	social interaction		2

literature/source: (Environmental Agency 2006); (London Environment Team and Environment Agency n.d.); (Prominski et al., 2017)
further reading:

6.2.2 Branches

Fig. 81: New created branch for water retention, Neckar in Wernau/Neckar (source: www.pfrommer-roeder.de)

Fig. 82: Vegetated island between side and main branch, Neckar in Wernau/Neckar, 2014 (source: www.pfrommer-roeder.de)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x						x	x
reference to key studies								

ii. general description

- expansion of the flood plain area/water retention area
- providing additional flood space by dividing the discharge into two branches
- new branch is created which is characterized by relatively flat flood plains and e.g. space for natural development
- main purpose: flood event control and management
- creation of relatively flat and accessible bank areas
- new created space can be used for e.g. public purposes (relaxing, leisure activities) or agricultural purposes (farmland) during low water levels
- division and connection of new branch to main stream depends on project/intervention
- planners take water depth and (min) water flow into account

iii. role of nature

- replication of natural river courses
- replication of natural river landscapes without sealed and cultivated areas (river cleaves a natural way through the landscape)

iv. technical and design parameters

- Technical effort depends on project/design considerations and natural conditions of the channel (e.g. length and width of new branch)
- More complex undertaking

v. conditions for implementation

- Enough space for additional branch

vi. benefits and limitations

Benefits:

- flood event control and management
- Ecological benefits (habitat for wildlife; vegetation)

	- amenity value/recreation		
vii.	**performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	1
	shading	population	-
		building itself	-
	reflection		-
P2	water conveyance		2
	water infiltration		1
	water retention		1
	water storage		1
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		2
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		1
	social interaction		-
literature/source: (Prominski et al., 2017); (Addy et al. 2016) further reading:			

6.2.3 Channel widening and length extension

Fig. 83: Alb, Karlsruhe (source: Prominski et al., 2017)

Fig. 84: Ahna, Kassel (source: Prominski et al., 2017)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss	
	x						x	x	
reference to key studies									

ii. general description

- measures lead to flow variation and sediment shifting processes → structural remodelling
- change of appearance → changing the length and depths of the river, current strength
- widening the channel describes the measure to broaden the riverbed at its sides
- as a result flow velocity of the water decreases and sediments accumulate to sand/gravel banks
- additional effort: Relocation of bank reinforcement to allow widening of the channel
- length extension: establishment of elements that alters the current as well as grading in the middle of the current → the result is a curvy course of the channel with an increased length compared to the initial current course
- appearance like a natural river
- cut and slip-off banks arise through the curvy course of the current

iii. role of nature

- replication of natural river courses with sediment shifting processes and changing depth and width of the river
- natural processes occur (filtering, storage, infiltration)

iv. technical and design parameters

- widening can be limited by bank reinforcement that cannot be relocated
- widening can be limited at one side
- protection against erosion is necessary at these parts of the river (length extension)

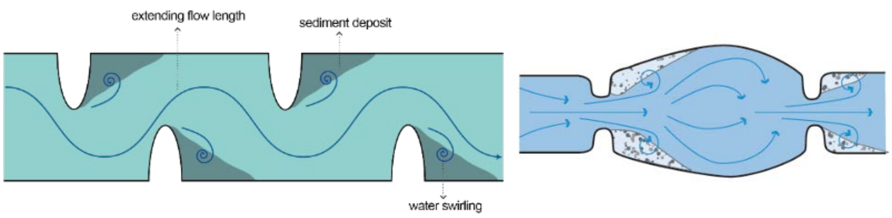


*Fig. 85: Extension of the river length (left) (source: Freely adapted from Prominski et al., 2017)
Widening the channel (middle), extending the flow length (right) (source: Prominski et al., 2017)*

v.	**conditions for implementation**		
	- Enough space for widening and extension of the length		
vi.	**benefits and limitations**		
	Benefits: - Increased floodwater discharge capacity - Reduced flood risk - Ecological benefits (habitat for wildlife; vegetation) *Potential limitations/disservices:* - Limited space - an (urban) surrounding (e.g. streets, public places) near the channel may restrict the establishment of flora/fauna		
vii.	**performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	1
	shading	population	-
		building itself	-
	reflection		-
P2	water conveyance		1
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		2
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-

literature/source: (Prominski et al., 2017); (Addy et al. 2016)
further reading:

6.2.4 Reprofiling the channel cross-section


Fig. 86: Isar, Munich 2018 (source: ILPOE 2017)


Fig. 87: Isar, Munich (source: ILPOE 218)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x						x	x
reference to key studies								

ii. general description

- measure to initiate channel dynamics
- enlarging the flood plain, shifting substrate within the river and bottom out banks
- result: river expansion; sinks; shallow water; fast and slow flowing areas
- sediments with different sizes accumulate (sand, gravel, stones) on the river ground

iii. role of nature

- replication of natural river courses with sediment shifting processes and changing depth and width of the river
- natural processes occur (filtering, storage, infiltration)

iv. technical and design parameters

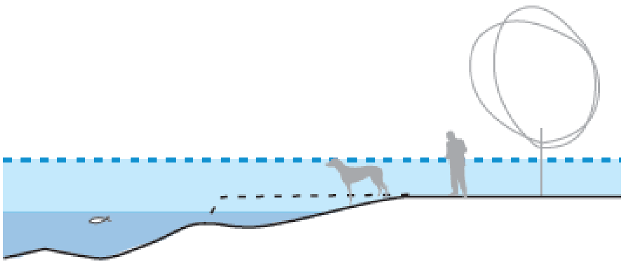


Fig. 88: Reprofiling the channel cross-section (Prominski et al., 2017)

v. conditions for implementation

vi. benefits and limitations

Benefits:
- Increased floodwater discharge capacity
- Reduced flood risk

	- Habitat provision		
vii.	**performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	1
	shading	population	-
		building itself	-
	reflection		-
P2	water conveyance		1
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		2
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		1
	social interaction		1
literature/source: (Prominski et al., 2017); (Addy et al. 2016) further reading:			

6.3 Diverting and deflecting elements

Fig. 89: Group of large rocks, Isar, Munich (source: Prominski et al., 2017)

Fig. 91: Tree trunk, Isar, Munich (source: Prominski et al., 2017)

Fig. 90: Bioengineered groynes in Birs, Basel (source: Prominski et al., 2017)

Fig. 92: Introducing disruptive elements in the Isar, Munich (source: Prominski et al., 2017)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding			water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x								x	x
reference to key studies									

ii. general description

- disruptive and diverting element are placed in a riverbed with the main objective to redirect, disturb, divert and deflect the current and initiate water dynamics
- elements: larger single rocks - sometimes arranged in groups of several rocks, larger tree trunks, willow branches (for groynes)
- the elements can be placed near the river bank or in the middle of a river, depending on the desired effect (deflecting and redirecting the current, one-sided riverbank erosion, sediment accumulation)
- measures lead to flow variation and sediment shifting processes
- disruptive elements influence the development of the channel (length, depth)
- flow sediment variation; development/settlement of water-dependent habitats
- provide space for human interaction/playing/relaxing
- provide habitats for aquatic animals, small animals (bird, insects)

<u>tree trunks and stones</u>

	- Tree trunks with or without branches - either fixed in the riverbed, positioned with piles or steel cables - if trunk is fixed only at one point → free floating of tree trunk in the current - trees pointing downstream or horizontal to flow direction - stones and trees can serve as stepping stones for public purposes and as a place to play - stone type variation; often application of local available stones - aesthetic value of elements <u>bioengineered groynes</u> - general objective of the following measure is to disturb, divert and deflect the current away from the riverside/riparian for riverside protection against erosion - groynes mainly consist of willow (whole plants or branches) or bundles of brushwood (fascines) - roots of living willow and fascines grow vertically as well as horizontally and form relatively stable, natural constructions - initial construction of e.g. willow (pioneer species) is naturally extended through a gradual establishment of other/different shrubs - the naturally grown construction provides a habitat for various organisms and aquatic animals
iii.	**role of nature**
	- Replication of natural river channels with varying depth and width; natural elements (e.g. stones) and vegetation within and at the river and at its riversides. - replication of natural conditions (e.g. bushes or trees with branched roots) at the riverside that stabilizes the soil, protects the river zone from erosion and slowdown water velocity - natural processes occur (filtering, storage, infiltration)
iv.	**technical and design parameters**

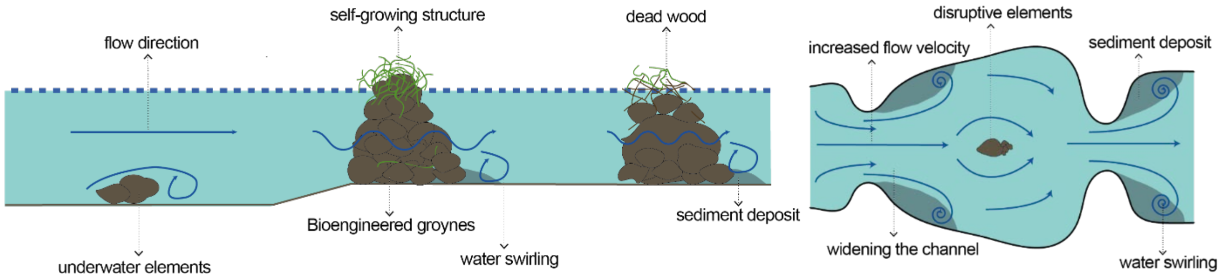


Fig. 93: Diverting and disruptive elements above and under water level (source: Freely adapted from Prominski et al., 2017)

Fig. 94: Large single rocks (left), dead wood (middle), bioengineered groynes) (source: Prominski et al., 2017)

Different elements are possible: stones, tree trunks, willow-groynes

- stones with sufficient size and weight to guarantee their stable position in the riverbed
- often used: local rocks
- Single rocks or group of rocks
- Materials for groynes: living willow, willow branches or fascines (pioneer plants)
- willow branches are arranged diagonally
- extension of the system through a natural establishment of different shrubs
- variable construction: extension of living system with stones and other materials that leads to a higher construction stability → suitable for strong currents and large groynes

	- limited use of living plants/willow because of limited stability in rivers with strong current - different groynes layout and orientation possible (pointing upstream, downstream or to flow direction) - Provide space for human interaction/playing/relaxing - Provide habitats for aquatic animals, small animals (bird, insects)
v.	**conditions for implementation**
	- Construction type of groynes depends on strength of the current and the size of the groynes (e.g. living plants; additional stones)
vi.	**benefits and limitations**
	Benefits: - redirection and deflection of the current - habitat for organisms, birds and aquatic animals - reduction of water velocity (at the shore zone) - protection against flooding - provide space for human interaction/playing/relaxing
vii.	**performance**

P1	evapotranspiration	Transpiration	-
		Evaporation	-
	shading	population	-
		building itself	-
	reflection		-
P2	water conveyance		1
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		2
	social interaction		2

literature/source: (Prominski et al., 2017); (King 2009); (Addy et al. 2016)
further reading:

6.4 Living revetment

Fig. 95: Living revetment (source: Salix; www.salixrw.com)

Fig. 96: Living revetment (source: Salix; www.salixrw.com)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x				x	x
reference to key studies								

ii. general description

- varying the bank reinforcement
- plants/trees are planted along the riverside to stabilize the riverbank and thus avoid and retain erosion
- constructions of living willow, timer, stone
- willow revetments are suitable for large channels

iii. role of nature

- Replication of natural rivers
- Replication of natural conditions (vegetation at the riverside) that stabilizes the soil, protects the river zone from erosion and slowdowns water velocity
- Natural processes occur (filtering, storage, infiltration)

iv. technical and design parameters

- Relatively simple design and technical knowledge

v. conditions for implementation

- Needs a certain time till plants/trees are grown up and living revetment is developed and fulfils its service

vi. benefits and limitations

Benefits:
- Erosion protection
- Filtering of water
- Storm water management
- Habitat provision (flora and fauna)
- Esthetical value/recreation

vii. performance

P1	evapotranspiration	Transpiration	-
		Evaporation	-

	shading	population	-
		building itself	-
	reflection		-
P2	water conveyance		1
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		2
	connectivity		2
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-
literature/source: (Prominski et al., 2017); Salix. https://www.salixrw.com/product/live-willow-revetments/. Further reading:			

7. Measures of bioengineering

The measures of bioengineering that are included in the NBS-handbook focus on the protection of water banks and hillsides with medium to high inclination against water and wind erosion. In total, three different measures are discussed that make use of flexible living as well as dead wood branches (e.g. willow) for the construction.

7.1 Living Fascine

Fig. 97: Preparing a Living Fascine (source: Stowasserplan GmbH & Co. KG; stowasserplan.de)

Fig. 98: Living Fascine (source: freitag-weidenart.com)

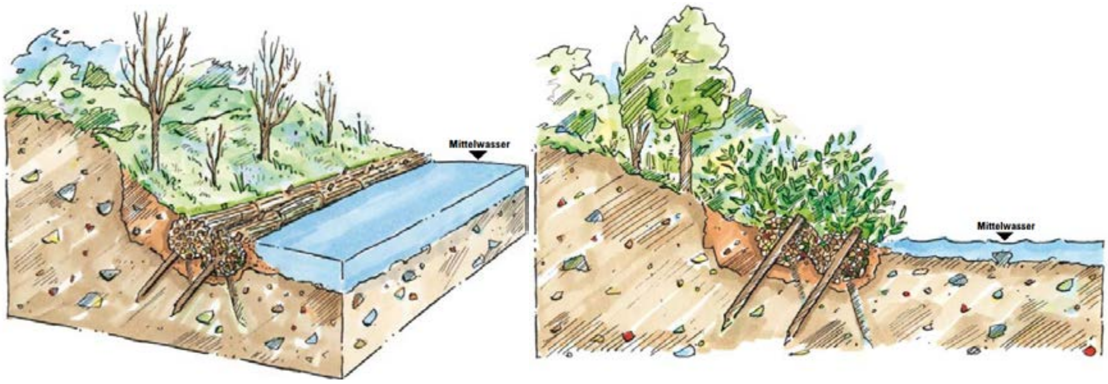
i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x						x	x
reference to key studies								

ii. general description

- natural and careful measure
- application for water bank protection and (strongly inclined) hillside stabilization
- consists of bundled tree brunches and twigs (max. length and diameter see technical and design parameters)
- bundles consist of living wood; additional use of death wood (max. 50 %) possible
- plants/branches are fast rooting
- Common bundle material for hydraulic engineering → hazel, willow (branches): e.g. *S. viminalis*, *S. purpurea*
- common bundle material for earthwork/hillside stabilization → shrub willow (branches): e.g. *S. fragilis*, *S. alba*
- willow is commonly used because of its characteristics → length, flexibility, elasticity, form
- twigs are bundled with steel cables
- hardwood cuttings or dowels serve as fixation for the prepared bundles
- every bundle is fixed with several hardwood cuttings → willow is used for cuttings
- horizontal installation of fascines (see figure - left)
- rooting fascine branches give (additional) stabilization and reduce risk of erosion
- fascines are covered with bushes; bushes grow on fascine and support stability of the water bank or hillside
- simpler forms of hillside stabilization exist
- use of fast rooting plants/cuttings
- Plants are established on hills with strong inclination (hazel, willow…)

iii.	**role of nature**
	imitation/simulation of natural vegetation layers with strong and branched root networks
iv.	**technical and design parameters**
	 *Fig. 99:* Living fascine after implementation (left) and older fascine(source: Jany und Geitz 2013)
v.	**conditions for implementation**
	Good timing for construction, planting is needed (low water flow, no rainfall)
vi.	**benefits and limitations**
	Benefits - Near-natural protection of hillsides and river banks, - benefits for biodiversity Limitations - stability of river bank is difficult to calculate, foresee - pre-selection of only robust species
vii.	**performance**

P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	population	-
		building itself	-
	reflection		
P2	water conveyance		-
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		-
P4	deposition		-
	biofiltration		-
P5	habitat provision		2
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-

literature/source: (Jany, Angeika and Peter Geitz 2013); (Graf et al. 2003)
further reading:

7.2 Revetment with cuttings *(Spreitlage)*

Fig. 100:Revetment under construction (source: (Jany, Angeika and Peter Geitz 2013)

Fig. 101:Revetment with cutting (source: (Jany, Angeika and Peter Geitz 2013)

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation					
addressed challenges	flooding			water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x								x	x
reference to key studies										

ii. general description

- covering construction consisting of willow (able to root) and brushwood (not able to root)
- installation and fixation on embankment
- protection against erosion (wind, water)
- intensive and fast rooting; “direct” effects
- use of simple and local available materials

iii. role of nature

- imitation/simulation of natural vegetation layers with strong and branched root networks
- natural protection against erosion; reduced erosion risk compared to bare hillsides with a high risk of water, wind and soil erosion

iv. technical and design parameters

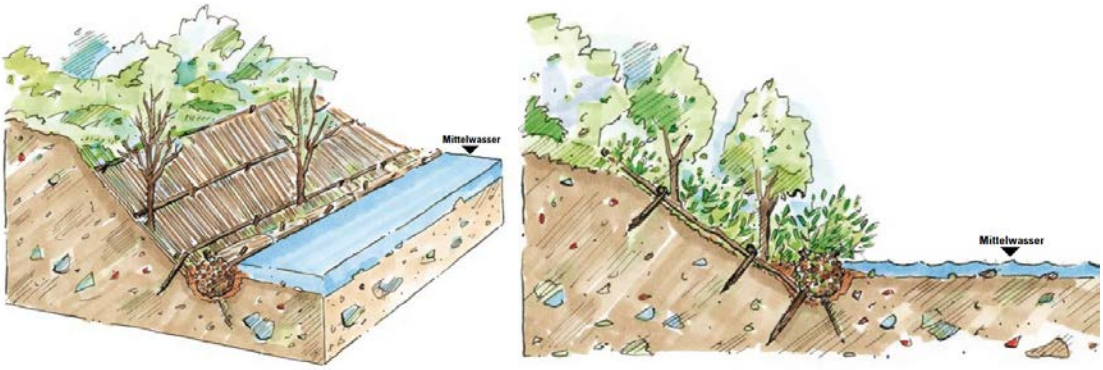


Fig. 102: Rewetment with cuttings after implementation (left) and after a few years) (source: (Jany, Angeika and Peter Geitz 2013)

Material for construction:

	- branches: 2 to 5 years old - commonly used: shrub branches - height: 1,50 m - local and typical plants for the specific location - stake: length: 3 to 5m; diameter: 4 to 8 cm
v.	**conditions for implementation**
	Good timing for construction, planting is needed (low water flow, no rainfall)
vi.	**benefits and limitations**
	Benefits: - hillside stabilization - protection against erosion - water bank protection - habitat for wildlife
vii.	**performance**

P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	population	-
		building itself	-
	reflection		
P2	water conveyance		-
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-

literature/source: (Jany, Angeika and Peter Geitz 2013); (Graf et al. 2003)
further reading:

7.3 Planted embankment mat

*Fig. 103:*Planted embankment mat *(source: (Jany, Angeika and Peter Geitz 2013)*

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x						x	x
reference to key studies								

ii. general description

- protection against erosion
- combination of mats/covering with vegetation layer e.g. seeding and plants
- use of local plants/trees/scrubs/meadow
- simple construction, fast installation
- possible combination with fascines
- slow down water velocity,
- promote sedimentation

iii. role of nature

- imitation/simulation of natural vegetation layers with strong and branched root networks
- natural protection against erosion; reduced erosion risk compared to bare hillsides with a high risk of water, wind and soil erosion

iv. technical and design parameters

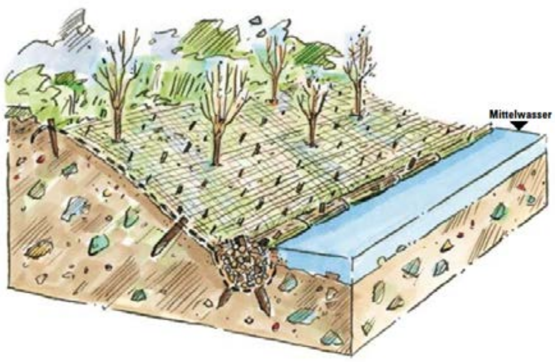


Fig. 104: Planted embankment mat (source: (Jany, Angeika and Peter Geitz 2013)

- mats → fast rotting → coconut fiber, jute
- simple construction

	- fast installation

v.	**conditions for implementation**		
	Good timing for construction, planting is needed (low water flow, no rainfall)		
vi.	**benefits and limitations**		
	Benefits: - protection against erosion - habitat for wildlife		
vii.	**performance**		
P1	evapotranspiration	Transpiration	1
		Evaporation	-
	shading	population	-
		building itself	-
	reflection		-
P2	water conveyance		-
	water infiltration		1
	water retention		1
	water storage		-
	water reuse		-
P3	water filtering		1
	water bioremediation		1
P4	deposition		-
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		-
	social interaction		-
literature/source:(Jany, Angeika and Peter Geitz 2013); (Graf et al. 2003) further reading:			

8. Other NBS

The following chapter is the most open chapter, a collection of NBS that range from technology oriented to long term process oriented. They differ from the other NBS measures and therefore do not match the previous seven categories but represent interesting measures for air purification (8.1) and flood protection (8.2).

8.1 Biofilter (air purification)

Fig. 105: Biofilter *(source: FUCHS Enprotec GmbH; www.fuchs-germany.com)*

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation

addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x		x			x		

reference to key studies	

ii. general description

Biofilters (air) are facilities to control and purify biological waste gas. They are developed to reduce and eliminate biogenic odours and represent a relatively simple technical installation. The application of biofilters is diverse, including for example agriculture, sewage treatment plants, biogas plants, and composting plants. The term "filter" is misleading in terms of their service: Biofilters (air) does not separate solid particles from gas or water but separate gaseous/dissolved substances through bio-degradation. Bacteria and microorganisms are located on a filter medium (breeding ground) that absorbs odours of the air stream (e.g. peat, tree bark, and root wood fibre). The microorganisms on the filter degrade the absorbed, biological substances (biological oxidation) and thus purifies the exhaust air passing the filter material. Biofilters exist in different sizes and structural shapes (often in a box).

iii. role of nature

Biodegradation is a natural process e.g. in soils. This natural degradation is used for different processes for example in anaerobic digestion (biogas production). Microorganisms and bacteria de degrade/remove/ nutrients contaminations, and biological substances.

iv. technical and design parameters

- different sizes → flexible modules (expandable)
- different shapes → container/box as common construction
- low maintenance
- easy handling: easy exchange and disposal of filter material
- domestic filter materials
- ecological process

FUCHS-Biofilter (series: BAC): Air purification (example (FUCHS enprotec GmbH n.d.)

	- different applications - small to medium exhaust air stream (200 to 2.400 m³/h) - integrated facility to pre-damp the air flow (conditioning of exhaust air) - containers made from polyethylene (resistant) - filter covering for protection - natural filter material: bark compost (neutral pH value; balanced moisture → optimal conditions for microorganisms, high degradation rate of organic air impurities)
v.	**conditions for implementation**
	- optimal conditions ensure microbiological activity and reduction of odorous and harmful substances **FUCHS-Biofilter (series: BAC): Air purification** (example (FUCHS enprotec GmbH n.d.) physical and chemical conditions: - Moisture content of filter material (40 % - 60 %) - low pressure loss - high buffering capacity - high biodiversity - (optimal) temperature - (optimal) pH value - (optimal) nutrient supply
vi.	**benefits and limitations**
	Benefits: - air purification - reduced odour nuisance (increase quality of life) *Potential limitations/disservices:* - limited habitat provision for wildlife
vii.	**performance**

P1	evapotranspiration	Transpiration	-
		Evaporation	-
	shading	population	-
		building itself	-
	reflection		-
P2	water conveyance		-
	water infiltration		-
	water retention		-
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		2
	biofiltration		2
P5	habitat provision		-
	connectivity		-
P6	beauty/appearance		-
	usability/functionality		-
	social interaction		-

literature/source: (FUCHS enprotec GmbH 2015); FUCHS http://www.fuchs-germany.com/; bioteg Biofilter Systems GmbH. http://www.bioteg.de/info/definition_biofilter.htm; Anit, S. B. & R. J. Artuz. https://www.rpi.edu/dept/chem-eng/Biotech-Environ/MISC/biofilt/biofiltration.htm
further reading:

8.2 Mounds

Fig. 106: Mound on Mandoe island, Denmark *(source: mandoe.de)*

Fig. 107: Mound on Mandoe island, Denmark *(source: mandoe.de)*

i. basic information

type	1	2	**3**	action type: 1: protection/conservation; 2 = restoration + managing; 3 = retrofitting + creation				
addressed challenges	flooding	water scarcity	water/ air pollution	heat stress	rapid growth	health issues (climate)	habitat loss	biodiversity loss
	x						x	x
reference to key studies	*Mound on Mandoe island, Denmark* (source: mandoe.de)							

ii. general description

Mounds are a very old strategy to make use of natural processes for proving flood protection. They enable settlement and livestock farming in areas that are affected by water/sea-level rises

- mounds represent higher ground above the water level during flood events
- mounds are connected with dikes to guarantee access to the dike
- mounds can be natural or manmade hills
- refuge for farm animals (cows, horses) and wild animals (contribution to nature conservation)

iii. role of nature

Sedimentation is a natural process that leads to increasing, upward "growing" soils. Mounds make use of this natural process.

iv. technical and design parameters

- fast rotting mats (coconut fibre, jute)
- simple construction
- fast installation

v. conditions for implementation

Time is a condition for success, mounds can be initiated through construction but can only develop over decades.

vi. benefits and limitations

- protection against erosion
- habitat for wildlife
- spatially concentrated flood protection has a potential as an alternative to costly dike construction

	performance		
P1	evapotranspiration	Transpiration	-
		Evaporation	-
	shading	population	-
		building itself	-
	reflection		-
P2	water conveyance		-
	water infiltration		1
	water retention		2
	water storage		-
	water reuse		-
P3	water filtering		-
	water bioremediation		-
P4	deposition		-
	biofiltration		-
P5	habitat provision		1
	connectivity		1
P6	beauty/appearance		1
	usability/functionality		2
	social interaction		1

literature/source: (Prominski et al., 2017)
further reading:

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