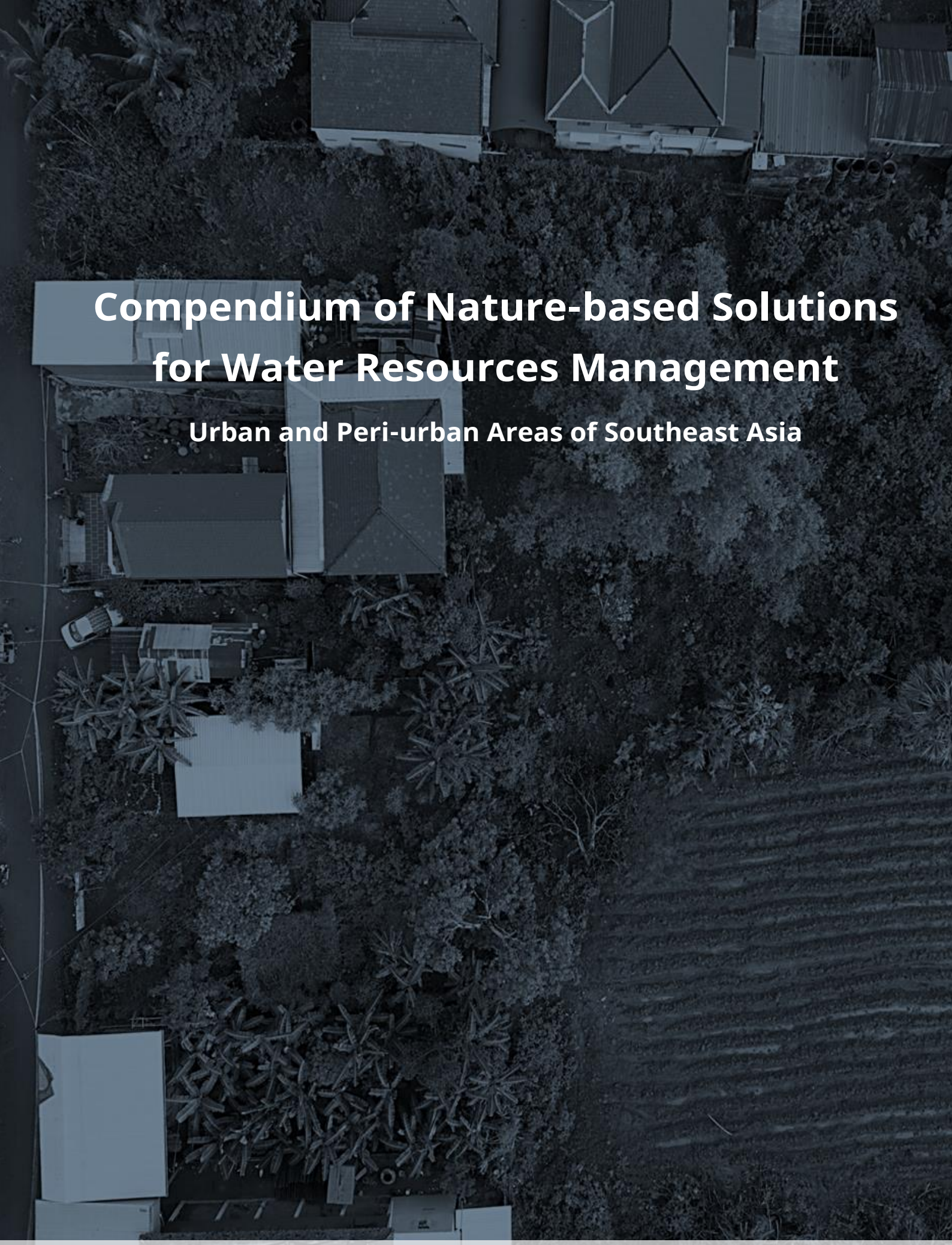

Compendium of Nature-based Solutions for Water Resources Management

Urban and Peri-urban Areas of Southeast Asia

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Spatial Development and
Infrastructure Systems

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The full Compendium is available for download and external access through the Sciebo platform.
Available to download here: https://th-koeln.sciebo.de/s/WdheUS7UrZky6zX

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Technology Arts Sciences TH Köln

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List of Abbreviations

BOD	Biochemical Oxygen Demand
BVOC	Biogenic Volatile Organic Compound
CICES	Common International Classification of Ecosystem Services
ES	Ecosystem Services
KPIs	Key Performance Indicator
NbSs	Nature-based Solution(s)
SEA	Southeast Asia
SuDS	Sustainable Drainage Systems
VB	Vision Building
WSUD	Water-Sensitive Urban Design

Guideline

This document serves as a comprehensive compendium of Nature-based Solutions (NbS) that are vital for enhancing water-sensitive structures and combating environmental changes in South-East Asia (SEA). It provides a framework to address a spectrum of social, economic, and environmental challenges by offering essential ecosystem services. The booklet defines categories and features to better describe problems, propose solutions (NbSs), and outline how these solutions will achieve their targets through ecosystem services. This method streamlines information flow, enabling the selection of optimal solutions for specific problems.

To present this information concisely, the compendium employs an integrated approach, combining visual, mathematical, and textual methods. Each NbS may have distinct information that others do not, making an unstructured combination of data neither practical nor reader friendly. To address this, the booklet organizes information by listing NbSs and evaluating their capabilities against various challenges and ecosystem services. This approach introduces a quantifiable assessment of each NbSs' strengths and limitations, supplemented by standardized evaluation data on how the NbS delivers its ecosystem services.

In this context, the compendium offers visual representations, such as radar charts, to assess the implementation and performance phases of each NbS. These charts allow readers to easily evaluate how well a particular NbS performs across different criteria, facilitating comparisons and aiding in the selection of the most suitable solution(s). However, recognizing that the selection process may not always be definitive, the booklet includes three visual similarity matrices. These matrices quantify the similarities between NbSs based on shared ecosystem services, scales of action, and addressed challenges. This allows readers to explore alternative NbSs if a clear decision cannot be made using the radar charts.

Once suitable NbSs are identified, the compendium provides concise, templated textual descriptions of each solution, complemented by visual illustrations and real-life photographs. These elements ensure that all critical aspects of the NbSs are covered. Additionally, each NbS have its standing alone card which is used as a gamification method during the workshops for the stakeholders (See Appendix 2).

Overall, the compendium provides comprehensive information on challenges, ecosystem services, and global standards relevant to NbSs while maintaining comparability using both conventional metrics and novel calculated metrics presented in visual and tabular formats.

This compendium is designed for two primary audiences, positioned at opposite ends of the spectrum. The first group includes readers and academics seeking to familiarize themselves with the concept of NbSs or delve deeper into the details of assessment and recommendations as subject matter experts. The second group comprises stakeholders directly or indirectly affected by climate-related issues, who play an influential role in decision-making for NbS projects.

Overview

This booklet, titled "Compendium: Nature-based Solutions for Water Resources Management in Urban and Peri-urban Areas of Southeast Asia," has been developed and authored as part of the Vision Building (VB) phase for PolyUrbanWaters project (Website: https://polyurbanwaters.org/) The VB toolset constitutes one of the three core pillars supported by Work Package 4, "Options for Sustainable Water-Sensitive Infrastructure Development and Polycentric Water Management," as illustrated in Figure 1.

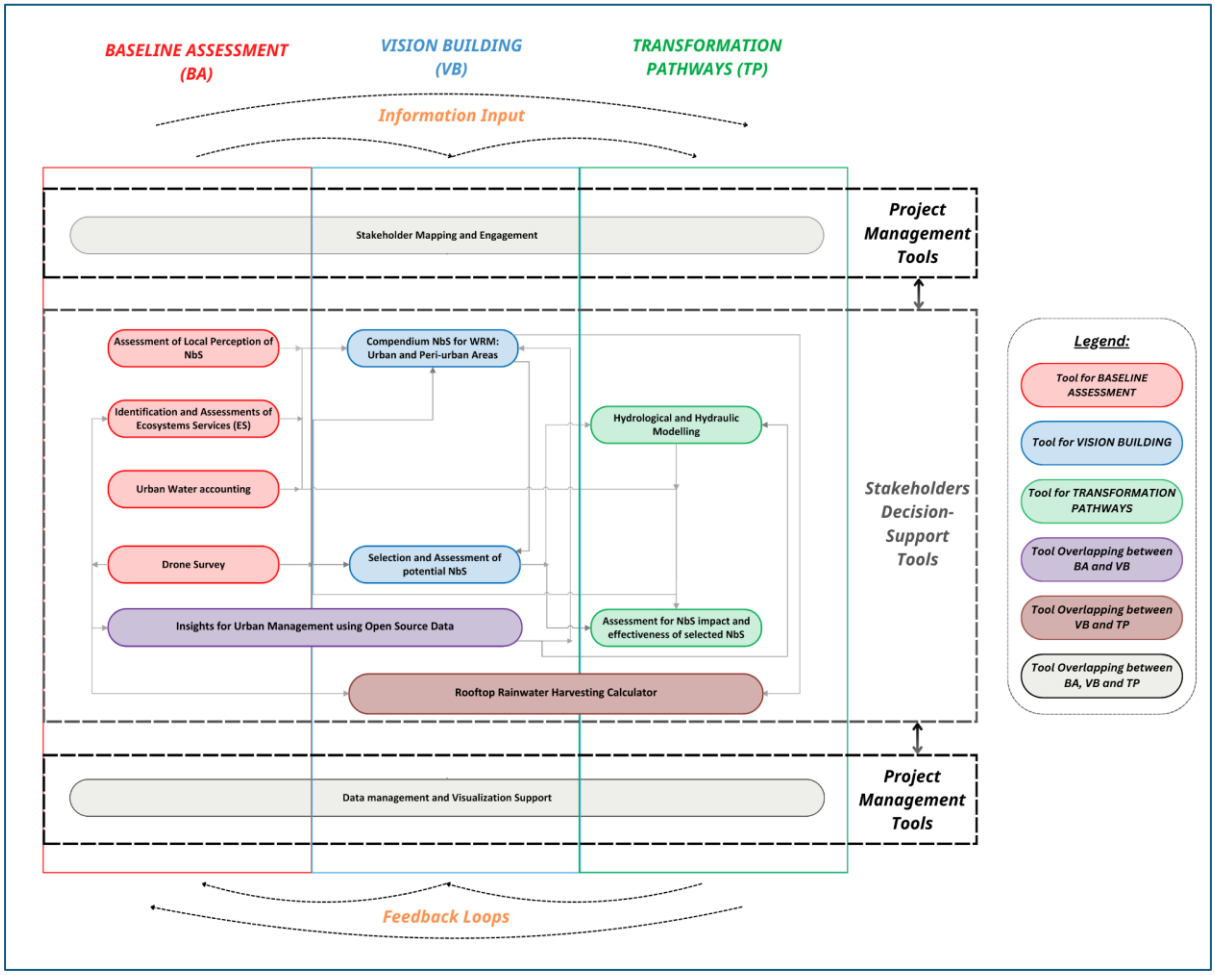


Figure 1 Overview of the Tools

Key objectives are outlined in three sections to achieve our objectives and structure a coherent flow of information for readers across various knowledge levels while addressing key environmental and business cases. The booklet's main objective remains centered on identifying local solutions that can tackle the challenges of urban water resources in secondary and tertiary cities in SEA.

Objective 1: Data Collection and Integrity

Within this objective, data from various sources were compiled, systematically filtered, and rigorously cross-verified with comparable resources to ensure data integrity. The primary aims were to assemble a comprehensive list of Nature-based Solutions (NbS) projects in Southeast

Asia that align with urban project criteria, refine the NbS candidate list, and address any data inconsistencies to ensure the collection of high-quality, reliable data.

Objective 2: Data Compilation and Information Flow

In order to achieve Objective 2, the primary structure of the NbS booklet was designed, and an NbS information summary template was developed to facilitate a systematic exploration of frameworks and Nature-Based Solutions. The objectives included defining distinct NbS attributes by selecting classification frameworks aligned with the core concept of (peri-)urbanism, categorizing NbS structures to support scenario development, and classifying NbS actions to promote sustainable urban water resource management.

Objective 3: Key Use Cases

This objective emphasizes a stakeholder-centered approach by utilizing NbS attributes and comparative data to develop benchmarks that enable stakeholders to evaluate various NbS options for specific scenarios, thereby optimizing cost-to-benefit outcomes. The key objectives include:

1. Developing an NbS ranking system by identifying critical attributes in collaboration with key stakeholders.
2. Standardizing the ranking system through attribute scaling, mapping, and comparison with other compiled NbS datasets to ensure specificity and relevance.
3. Creating visual representations of key performance attributes to support environmental assessments.
4. Developing visual representation for key implementation attributes to facilitate financial planning and project management.
5. Producing visual comparison matrices to optimize the selection of the most suitable NbS for identified challenges.

Section 1

Natural-based Solutions Inception and Concept

1.1. Definitions of NbS

The phrase "nature-based solutions" (NbS) first appeared in the 2000s as a novel concept for addressing and mitigating societal, economic, and environmental concerns simultaneously. The World Bank launched this concept, with backing from the International Union for Conservation of Nature (IUCN) and the European Commission (EC). The following are the definitions according to the institutions:

- **International Union for Conservation of Nature (IUCN):** ''Nature-based Solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people (human well-being) and nature (biodiversity). Nature-based Solutions are underpinned by benefits that flow from healthy ecosystems. They target major challenges like climate change, disaster risk reduction, food and water security, biodiversity loss and human health, and are critical to sustainable economic development'' (Cohen-Shacham et al., 2016).

- European Committee (EC), European Union (EU): ''Solutions to societal challenges that are inspired and supported by nature, which are cost effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource efficient and systemic interventions. Nature based solutions must benefit biodiversity and support the delivery of a range of ecosystem services''. (Maes & Jacobs, 2015).

- UNEA: ''Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits.'' (UNEP/EA.5/Res.5, 2022).
- IPCC: Depended on the IUCN (2016) definition. (Intergovernmental Panel on Climate, 2023).

- European Environment Agency (EEA) (2021): ''Nature-based solutions for climate change adaptation and disaster risk reduction are actions that work with and enhance nature to restore and protect ecosystems and to help society adapt to the impacts of climate change and slow further warming, while providing multiple additional benefits (environmental, social and economic).'' (European Environment Agency, 2021).

- PLANALP –Natural Hazards WG of the Alpine Convention (2022): ''NbS are actions that work with and enhance nature to restore or create a protective function for society from the impacts of natural hazards. NbS are based on and use the power of nature as infrastructure to provide

natural services, to benefit society and environment. Such interventions must be designed to mitigate identified real or anticipated social and environmental challenges, for instance natural hazards that are exacerbated by climate change. At the same time, NbS can have many co-benefits for instance for local biodiversity or increasing the capacity to store carbon.'' (PLANALP, 2022).

- **The Nature-Based Solutions Initiative**: Nature-based solutions (NbS) involve working with nature to address societal challenges, providing benefits for both human well-being and biodiversity. Specifically, they are actions that involve the protection, restoration or management of natural and semi-natural ecosystems; the sustainable management of aquatic systems and working lands such as croplands or timberlands; or the creation of novel ecosystems in and around cities. They are actions that are underpinned biodiversity and are designed and implemented with the full engagement and consent of local communities and Indigenous Peoples. (Nature Based Solutions Initiative, 2022)

Each of the aforementioned definitions identifies the NbS with a different perspective while keeping some shared benefits. Hence, NbS construction is reliant on the environmental and stakeholders' needs. Nonetheless, in this compendium, Nature-Based Solutions (NbS) are considered based on the following definition.

Nature-based Solutions (NbS) are a complementary addition to various ecosystems (urban, suburban, or rural) that address multifaceted problems (social, economic, environmental) by offering a range of ecosystem services. Their physical characteristics (building elements) are defined by our own defined categories (Green-Blue, Green-Gray, Blue-Gray, Green). Where these ecosystem services are characterized by the type of action taken, whether it is the utilization and coexistence within the ecosystem, the optimization of ecosystem use, or the construction of a new ecosystem with a focus on sustainability.

1.2. History of NbS

The entire history of NbS, briefly can be categorized into three sections, as shown in Figure 2. The first section is the Inception phase, where the ideas of ecological modification fused with practical implementation on a limited scale, coined with the projects with the term "NbS", followed by formal approval of the terminology (Liu et al., 2021).

The second phase, Implementation, began in 2008 with the formal adoption of the World Bank group of the concepts, paving a new way for the environmental and societal solution era (Cohen-Shacham et al., 2016; Eisenberg et al., 2018). The last phase, the standardization, was soon after the rapid adoption of the NbS ideas. Hence, the necessity of a standardized usage and assessment frameworks emerged (Cassin, 2021). Consequently, the NbS gained the formal recognition of the countries and marked its success in solving climate change-induced problems (Eisenberg et al., 2018).

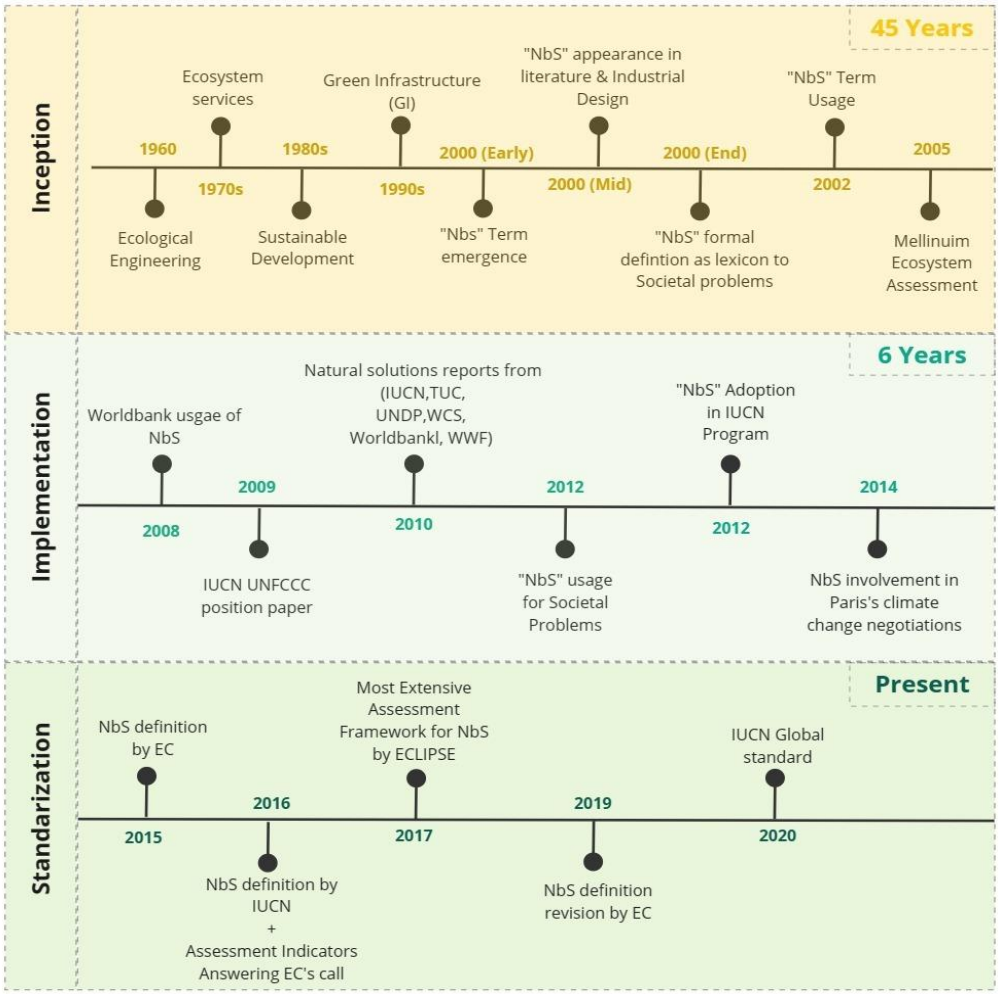


Figure 2 NbS development timeline
Source: (ITT-TH Köln, 2024)

1.3. Key concepts and NbS

A wide range of publications were linking the NbS with Ecosystem concepts (terms and practices). The NbS concept is considered as an evolution of specific used terms to describe a similar idea as the NbS such as: urban forestry (UF); green and blue infrastructure (GI, BI); and ecosystem services (ESS) (Escobedo et al., 2019).

As shown in Figure 3, other terms and practices were described later and included under the umbrella of NbS such as ecosystem-based adaptation (EbA), ecosystem-based disaster risk reduction (Eco-DRR), blue–green infrastructure (BGI), low-impact development (LID), best management practices (BMPs), water-sensitive urban design (WSUD), sustainable urban drainage systems (SuDs), and ecological engineering (EE) (Eisenberg et al., 2018; Ruangpan et al., 2020). However, the aforementioned concepts can be applied to performance, soft engineering, strategic, and spatial planning aspects.

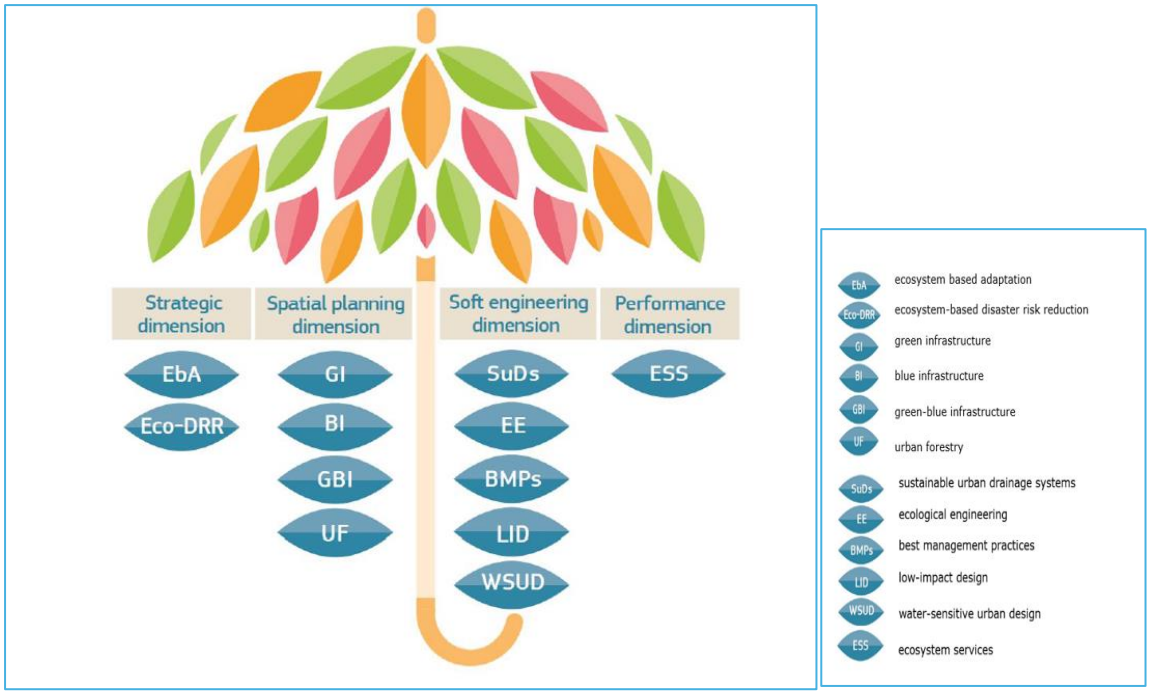


Figure 3 The relation of NbS to key existing concepts
Source: (European Commission & Directorate-General for Research and Innovation, 2021)

1.4. NbS characteristics

The need for creative and long-term solutions is essential more than ever as the globe struggles with before unseen environmental problems. NbSs are a promising strategy that uses ecosystems' potential to address a range of societal, environmental, and economic concerns due to its special characteristics as the following (Lexer, 2023):

- Nature-based: Work with nature, use ecosystem services.

- **Address societal challenges**: joint tackling of the climate and biodiversity crisis (e.x. Mental and physical health, social cohesion, and urban regeneration)

- **Multifunctionality**: delivering multiple benefits such as mitigation, adaptation, environmental, social, economic.

- Resilience: protects, strengthens and enhances ecosystems and biodiversity.

- Climate-Effective: ecosystem-based adaptation approaches such as urban greening, and restoration of wetlands and upstream forest ecosystems have been effective in reducing flood risks and urban heat (high confidence).

- Cost-effectiveness: cost benefits compared to 'standard' / technical solutions, lower life-cycle cost (maintenance, operation, deconstruction), higher price-benefit ratio.

- Stakeholder Engagement: participation is the main characteristic of NbS planning and implementation, co-design and inclusiveness to realize and optimize benefits and avoid trade-offs.

- **Desirable:** often higher public acceptance, aligned with local social, ecological and economic conditions in addition to traditional and cultural, more than technical measures.

The appealing characteristics and benefits of Nature-Based Solutions (NbSs) have been categorized into three primary categories. Afterwords, these categories were dendritically divided and grouped the benefits according to their similar benefits, as shown in Figure 4.

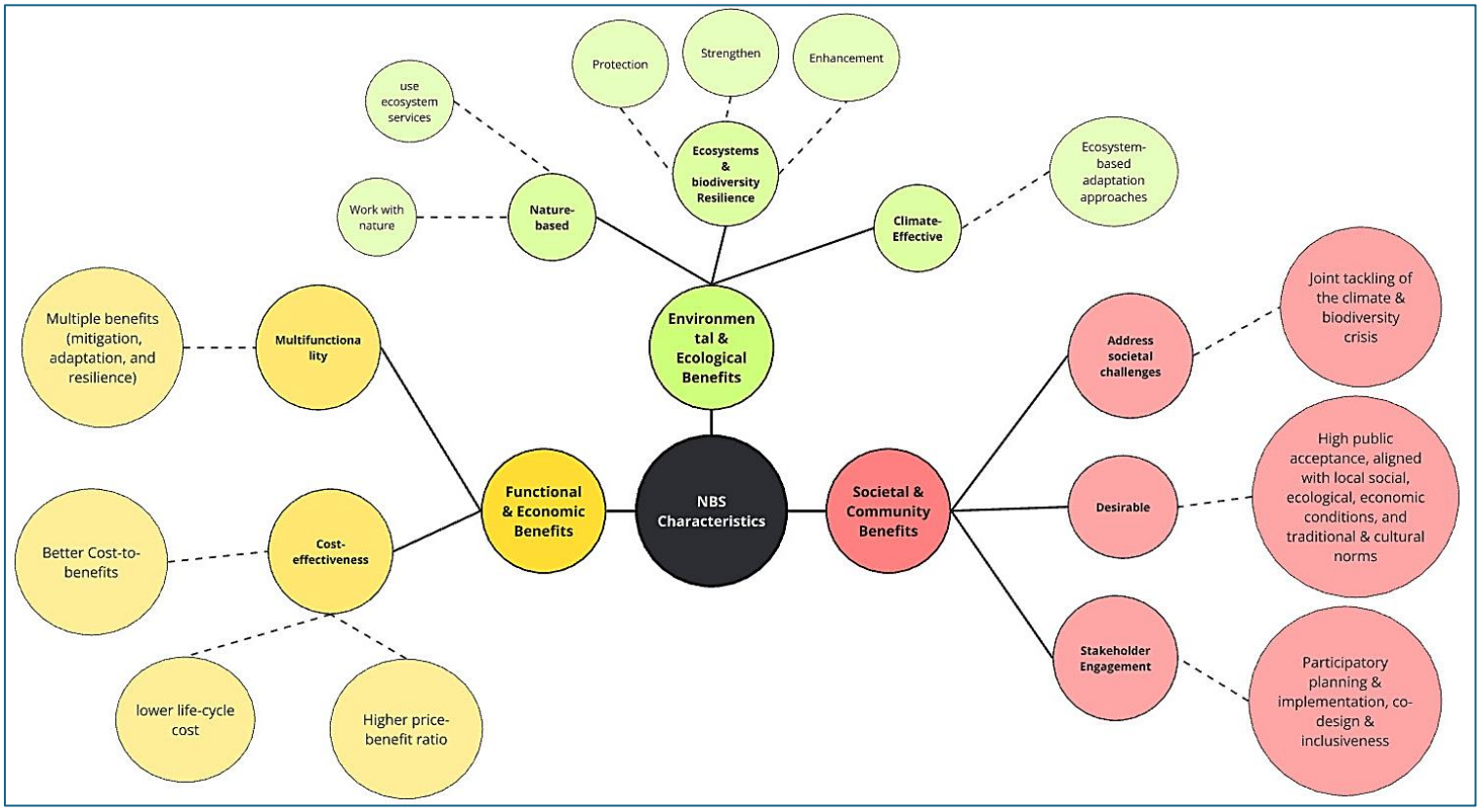


Figure 4 Special characteristics of NbSs
Source: (Lexer, 2023)

Section 2

Natural-based Solutions: Core Challenges and Solutions

2.1. Challenges Categorization

Evidence demonstrates that Nature-Based Solutions (NbSs) can address challenges spanning environmental, social, and economic dimensions. In this compendium, challenges are categorized based on their environmental, social, and economic impacts, with each category further divided into specific sub-challenges that cities may encounter in both the short and long term. For the categorization process, different sources were reviewed to make a decision on the main challenges (Brears, 2021; Cohen-Shacham et al., 2016; European Commission & Directorate-General for Research and Innovation, 2021; Kurdistani et al., 2012; Raymond et al., 2017).

After identifying the challenges, the following questions were answered to fully understand each challenge:

- *What is the challenge? Give a general definition*

- *Why is it considered a challenge?*

- *How to tackle the challenge by introducing NbS?*

Table 1, Table 2, and Table 3, shows the environmental, social, and economical challenges with answering the above questions, respectively.

Table 1 Environmental challenges answering questions

Water Shortage	
What	Supply of water through a network of pipes and pumps, by private companies, public utilities, and community projects
Why	The demand for freshwater worldwide is predicted to exceed supply by 40% by 2030, leaving an estimated 1.6 billion people without access to safely managed drinking water. For this challenge, water provision is utilized for irrigation purposes and others except for drinking water
How	1. water collection and reuse 2. water storage capacity 3. groundwater recharge
Reference	(Water Science School, 2018; World Economic Forum, 2023)
Water Low-Quality	
What	Physical, chemical and biological characteristics of water in relationship to a set of standards.
Why	An estimated 80% of wastewater from municipalities and industry is released untreated, possibly contaminating water and other natural resources.
How	1. wastewater remediation 2. minimize load discharge

	3. capture and removal of pollutants 4. runoff temperature regulation
Reference	(Neo & Jha, 2023; Obilonu et al., 2013)
Flood Hazard	
What	Water inundates land that is usually dry. Flood is the most frequent weather-related disaster where climate change increases the severity and frequency of flooding globally.
Why	Floods devastate homes, displace communities, contaminate water supplies, and disrupt essential services. These impacts lead to prolonged humanitarian crises by elevating disease risks, limiting access to clean water, food, and shelter, and overburdening emergency response and recovery efforts.
How	1. Peak flow control 2. Runoff mitigation 3. Erosion control
Reference	(International Rescue Committee, 2023)
Air Pollution	
What	Refers to the concentration of pollutants in the atmosphere due to emissions from various sources and activities.
Why	Its direct consequences are on human health, plants, animals, infrastructure and historical buildings.
How	1. Carbon sequestration 2. Removal of air pollutants (PM10, NO_2, O_3, CO, SO_2)
Reference	(Paris, 2021; URBAN GreenUP, 2018)
Soil Erosion	
What	The net long-term balance of all processes that detach soil and move it from its original location.
Why	Results in major issues for water quality problems and viable agricultural land.
How	controlling soil erosion by: 1. minimizing load discharge 2. capture and removal of pollutants 3. runoff temperature regulation
Reference	(Al-Kaisi, 2000; FAO, 2019)
Biodiversity Loss	
What	Diversity of species, genes, and ecosystems (natural capital) in the world or in a specific environment.
Why	Local extinction of many species or significant reduction in species population.
How	contributes to biodiversity enhancement through: 1. improved habitat connectivity 2. biological control 3. wildlife and flora habitats provision
Reference	(European Environment Agency, 2020; Fuller et al., 2010)

Table 2 Social challenges answering questions

Public Health Degradation	
What	The tangible and intangible effect of toxic, infectious or allergenic of environment due to perpetual interaction of humans with it.
Why	The rapid adaptability of viruses and microbes to new drugs and environments expedites the outbreak of infectious diseases.
How	1. reduce risk factors 2. provide health benefits 3. recreational benefits
Reference	(Heymann, 2005; Morris et al., 2006)
Mobility Issues	
What	The phrase describes the integration of NbS into conventional transportation infrastructure, which can increase resilience, reduce expenses, and improve community safety.
Why	The "infrastructure gap" that many nations face stems from the need for improved transportation infrastructure, which will only become more acute as a result of climate change.
How	1. make road infrastructure more pleasant. 2. protect it against flooding.
Reference	(Babí Almenar et al., 2021; Transformative Urban Mobility Initiative [TUMI], 2023)
Social Cohesion and Justice	
What	Referring to the selected NbS should fulfil the need of citizens in addition to their engagement processes surrounding NbS delivery.
Why	the need to ensure that benefits are distributed fairly, promote public health, gain support, and steer clear of controversy.
How	1. Accessible public area to everyone 2. Social engagement and empowerment 3. Vulnerable groups protection from environmental crisis
Reference	(Haase et al., 2017; Yip et al., 2016)

Table 3 Economic challenges answering questions

Energy Shortage	
What	Depletion of Fossil fuel reserves, paired with significant increase of prices, necessitate the migration to renewable resources.
Why	The growth of human population and its need for energy, amplify the negative effects of current non-eco-friendly energy sources, resulting in a degradation of life quality and endangerment of living species in vicinity of the energy sources.
How	1. Increase energy savings 2. Sustainable energy generation
Reference	(Pathak, 2014)
Unemployment	
What	Jobs that are associated with the installation and maintenance of NbS in urban settings. These positions may involve design, installation, management, research, or other NbS project-related responsibilities.
Why	The world is turning from casual employment into green ones where the market of green jobs is increasing in a consistent way, which leads to the provision of long-term, secure and sustainable new jobs and opportunities.

How	1. NbS can be adopted and incorporated into production processes and supply chains 2. Private investors in NbS can be important players in increasing investment and the creation of decent jobs. 3. Private sector capacity is also likely to be important for scaling up the implementation of NbS.
Reference	(Enzi et al., 2017; ILO et al., 2022; URBAN GreenUP, 2018)
Food Insecurity	
What	The restricted or unclear availability of safe, nutrient-dense foods, or to obtain acceptable foods in ways that are acceptable to society.
Why	Places a significant financial strain on social and health care expenses in society.
How	NbS maximizing the ability of nature to provide ecosystem services that help address climate change adaptation measures in food security.
Reference	(Bailey et al., 1990; Murthy, 2016; Sonneveld et al., 2018)
Tourism Problems	
What	The alteration of environmental landscape for services provision to suit the tourism attraction, such as potable water.
Why	Mass tourism growth increases the effect of environmental pollution , especially in carbon dioxide emission, in addition to the concept of harming species that co-exist and humans relies on.
How	1. Enhance aesthetical value 2. wildlife habitats Preservation 3. Offer cultural experiences 4. Recreational activities Provision
Reference	(Azam et al., 2018; Holden, 2016)

2.2. NbS Categorization

The available authored categorization of the NbSs is low in count but addresses the core aspect of NbSs selection criterion. The categorization is based on the applicability and objective of the NbS, such as addressing disaster scale problems as in (Nehren et al., 2023) or the process of action and results obtained from the NbS according to (Anderson & Gough, 2022).

The compiled NbS lists are conceptualized as complementary additive units designed to support ecosystems rather than solely eradicating specific challenges. To achieve this, new classifications were developed to reduce the sparsity of NbSs and organize them into meaningful clusters. These clusters implicitly describe the content of NbS structures (e.g., water systems, grey infrastructure) and serve as precursors to the ecosystem services they provide (e.g., Blue-Grey NbSs offering water-related services).

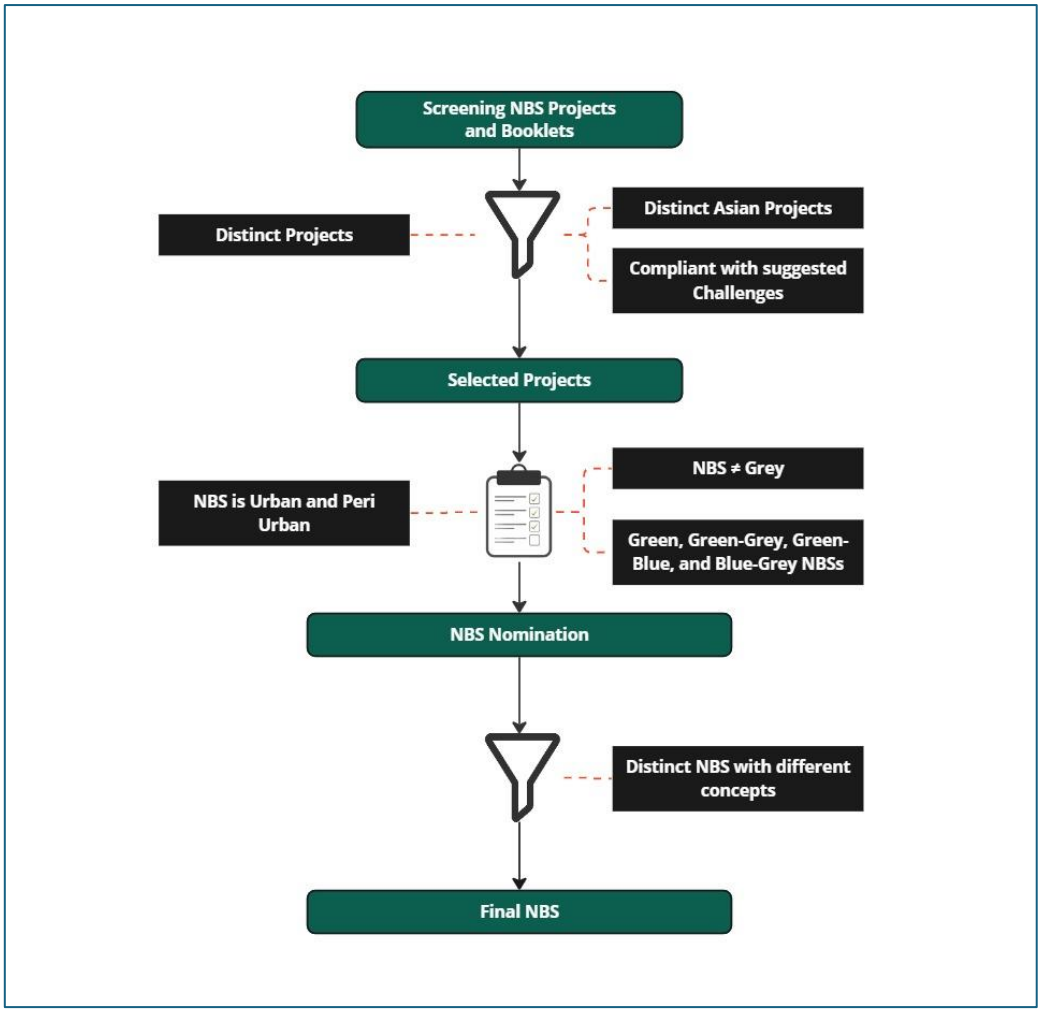


Figure 5 Flow diagram of NbSs selection process
Source: (ITT-TH Köln, 2024)

As shown in Figure 5, the diagram illustrates a structured approach for identifying and nominating NbS projects with a focus on urban and peri-urban areas. Initially, a variety of NbS projects and booklets are reviewed to find those addressing particular challenges, including specific Asian projects. From this pool, relevant projects are selected and further filtered to focus on those suitable for urban and peri-urban settings, excluding projects that solely rely on conventional "grey" infrastructure. Instead, the emphasis is on projects incorporating green, green-grey, green-blue, and blue-grey solutions, which integrate natural elements with traditional infrastructure. Finally, the nominated projects are further refined to ensure uniqueness and avoid redundancy, resulting in a final selection of effective and innovative NbSs tailored to urban and peri-urban challenges specially in the SEA.

2.3. NbS Typology

The typology of NbSs includes three distinct types, based on two main factors: the number of ecosystem services and stakeholder groups involved, and the level of engineering effort required in the planning and construction of the NbS. The relationship between these types and the increase in these factors is linear. A higher-level classification is expected when a greater number

of ecosystem services are provided and the complexity of the NbS design increases, and conversely, a lower classification is associated with fewer ecosystem services and simpler design complexity (Eggermont et al., 2015).

However, the types do not necessarily indicate a better NbS, but rather a more complex structure that suits a specific scenario. This complexity can lead to challenges in maximizing all ecosystem services while meeting the needs of all stakeholders, often necessitating trade-offs by decision-makers. Furthermore, the boundaries between these types can overlap, depending on the specific scenario and goals of the projects, which may result in reassigning a certain NbS to a different type (Eggermont et al., 2015). Despite this, typology serves as a useful preview of the NbS's role in the project.

The three main types are termed Conservation (Type 1), Restoration (Type 2), and Installation (Type 3). Their definitions are shown in Figure 6.

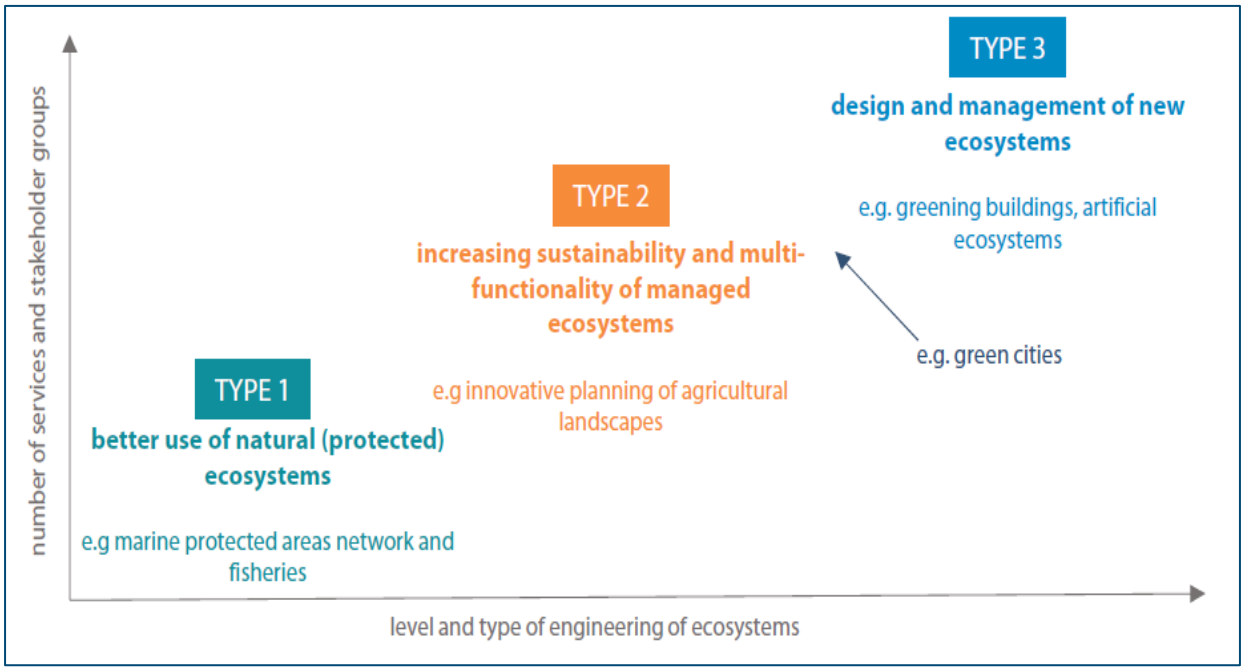


Figure 6 The types of Natural-based Solutions
Source: (Eggermont et al., 2015)

2.4. Ecosystem Services

Ecosystem services (ESS) refer to the advantages that humans derive from ecosystems, which are crucial for sustaining and enhancing human life (Burkhard & Maes, 2017). As per the Common International Classification of Ecosystem Services (CICES) (Haines-Young & Potschin, 2018), these services are divided into three primary categories: Provisioning services (such as the supply of drinking water and Water availability regulation), regulation and maintenance (including the control of damaging floods and land degradation, provision of soil nutrients, and waste recycling like nitrogen and phosphorus), and cultural services (encompassing spiritual and other non-material benefits (Haines-Young & Potschin, 2018).

The "Identification and Assessment of Ecosystem Services" tool, which is developed within the framework of the project, evaluates ecosystem services (ES) in secondary cities within the SEA region. It supports sustainable urban development by mapping the distribution and importance of ES, offering crucial insights for decision-makers. This tool helps prioritize the conservation and enhancement of key ES, tackling water management and urban development challenges. Originating from the PolyUrbanWaters project, it aids in developing water-sensitive urban scenarios by analyzing existing ES related to water resources and ecosystems, thus guiding informed urban planning decisions.

Section 3

Catalogue Structure

How to Read the Booklet?

The booklet consists of 36 NbS where a two-pager factsheet provides the following information:

3.1. Visual Profile

Consists of the name, picture, performance assessment, and implementation assessment of the described NbS

To generate the performance implementation assessment in radar charts, the following section presents all the KPIs and metrics used to evaluate the NbS list compiled in the catalogue. Nonetheless, three notions must be considered while utilizing the metrics and KPIs.

1- The assessment for each metric and KPI is not of the same scale, for example, KPI X, represents count of ecosystem services provision, while KPI Y represents time needed for building the NbS. Hence, each metric requires its own scale all NbS have been assessed, and the metrics have been mapped to a standard scale of 1 to 3, representing poor, medium, and good concepts, respectively. This mapping is based on percentiles, where the first 33% percentile (0 to 33.3%) corresponds to a score of 1, the second 33% percentile (33.3% to 66.6%) corresponds to a score of 2, and the final 33% percentile (66.6% to 100%) corresponds to a score of 3. However, in all the metrics, 3 is desired, and 1 is to be avoided.

2- The assessment is conducted relative to the compiled list of NbS, and comparisons made in subsequent sections do not imply that one NbS is inherently good or bad. Rather, the comparisons highlight the suitability of different NbS for specific use cases. For instance, NbS X may be suitable for scenario A, while NbS Y may not be appropriate for the same scenario. Conversely, reciprocity is not guaranteed; thus, NbS Y may excel in scenario B, whereas NbS X may not be applicable in that scenario.

3- The complicated KPIs calculation is done using the Cosine similarity metric. However, the calculation process is explained in the Appendix 1.

Table 4 and Table 5 illustrates the KPIs (metrics) with their descriptions and the adapted scale.

Table 4 The used metrics in performance radar chart

Metric	Description	Scale
Versatility	The number of challenges that NbS can solve. Where a high number of challenges represents a high versatility. In contrast, low count represents low versatility or adaptability of the NbS to solve many problems.	1= Low 2= Medium 3= High (Higher is better)
Versatility Morphism	A similarity metric indicates the average similarity between a given NbS and all other NbSs, based on the addressed Challenges. Hence, a high similarity count with many NbSs, represents a better NbS that could be replaced with another one, in case any obstacle(s) disrupts the planning and decision process. On the other hand, a low morphism represents a rare NbS that cannot be replaced with another; hence, this NbS will tailor to a specific set of challenges that other NbSs cannot solve.	1= Low 2= Medium 3= High (Higher is better)
Effective Time	The time is needed since the NbS's commissioning until its positive effect on the ecosystem is realized. Thus, high effective time relates to the slow acquisition of an ecosystem service.	1= High 2= Medium 3= Low (Lower is better)
Ecosystem services	The count of ecosystem services and NbS can provide. Where a high number relates to an effective NBS.	1= Low 2= Medium 3= High (Higher is better)
Ecosystem Service Morphism	A similarity metric indicates the average similarity between a given NbS and all other NbS, based on the Ecosystem services. Hence, a high similarity count with many NbS, represents a better NbS that could be replaced with another one, in case any obstacle(s) disrupt the planning and decision process. On the other hand, a low morphism represents a rare NbS that cannot be replaced with another; hence, this NbS will provide a specific set of services that other NbSs cannot provide.	1= Low 2= Medium 3= High (Higher is better)
Type of Action	A classification that classifies the NbS effect on its constructed location. Where the effect is: 1. Installation, built-from-scratch solution for a new or existing problem, while taking into consideration sustainability and future eco value of the NbS. 2. Restoration, a rehabilitation process of the location. 3. Conservation, an optimization of a process or a mitigation of an existing problem.	1= Installation 2= Restoration 3= Conservation (Conservation is better)

Table 5 The used metrics in Implementation radar chart

Metric	Description	Scale
Implementation Time	The time required to implement the NbS	1= High 2= Medium 3= Low (Lower is better)
Budget/ cost	The required budget to implement NbS	1= High 2= Medium 3= Low (Lower is better)
Maintenance	The required activities to maintain the NbS running. High maintenance indicates regular cleaning and/or observation	1= High 2= Medium 3= Low (Lower is better)
Scalability	The scale of area needed for the NbS implementation. A large scale represents a relatively difficult-to-construct NbS while a small scaled NbS is relatively easy to construct but often less ecosystem services are provided.	1= Small 2= Medium 3= Large (Larger is better)
Scalability Morphism	A similarity metric indicates the average similarity between a given NbS to all other NbSs, based on the scale of action. Hence, a high similarity count with many NbS, represents a better NbS that could be replaced with another one, in case any obstacle(s) disrupts the planning and decision process. On the other hand, a low morphism represents a rare NbS that cannot be replaced with another; hence, this NbS will be constructed on a scale that other NbSs cannot be implemented with.	1= Low 2= Medium 3= High (Higher is better)

3.2. Descriptive Profile

Consist of different sections on which each section is described below:

Description

A general description on the NbS, outlining objective and the key characteristics and details in order to present a clear and comprehensive overview on the NbS.

Type of Action

Categories that classify the passive and active actions of the NbS in the applied region. The actions entail protection, sustainable management, restoration or creation (natural, modified or novel) ecosystems. Table 6 illustrates the action types with their description and symbol.

Table 6 Types of action category

Type of Action	Description	Symbol
Conservation	Solutions that involve making better use of existing natural or protected ecosystems (e.g. measures to increase fish stocks in an intact wetland to enhance food security)	
Restoration	Solutions based on developing sustainable management protocols and procedures for managed or restored ecosystems (e.g. re-establishing traditional Agro-forestry systems based on commercial tree species to support poverty alleviation)	
Installation	Solutions that involve creating new ecosystems (e.g. establishing green buildings (green walls, green roofs)).	

Analogy

Due to the existence of myriad terminologies for each NbS, this section mentions possible terminologies which are either used in different handbooks, booklets, and researches, contexts, or from a self-understanding of the NbS.

Naturalistic Design

This section answers the question of ‘‘How is the NbS inspired by or make use of nature?’’ by explaining the natural process and how the NbS simulates the nature, and in-return, benefits the nature.

Ecosystem Services

The classification of the Common International Classification of Ecosystem Services CICES (Haines-Young & Potschin, 2018) is used in the catalogue which categorized ecosystem services as shown in Table 7. A selected subset of ecosystem services relevant to the concept of (peri-)urbanism has been considered, excluding those that do not align with the concept or map to at least one NbS. Additionally, some terminologies of the ecosystem services have been abbreviated for simplicity and ease of reading, while maintaining the integrity of the concepts, in order to reduce the complexity and enhance the readability of this booklet.

Table 7 Ecosystem services categorization and their classes

ES Category	ES Functions
Provisioning	• Food and fiber provisioning• Fuel provisioning • Genetic resources provisioning • Biochemicals, natural medicines, and pharmaceuticals provisioning • Ornamental Resources provisioning • Fresh water provisioning • Habitat provisioning
Cultural	• Enabling of spiritual and religious values • Enabling of Knowledge systems • Enabling of educational values • Enabling of aesthetic values • Enabling of social relations • Enabling of sense of place • Enabling of cultural heritage values• Enabling of recreation and ecotourism
Regulating & Maintenance	• Regulating & maintaining soil formation • Nutrient cycling • Primary production • Air quality maintenance • Climate regulation • Water availability regulation • Erosion control • Water purification and waste treatment • Regulation of human diseases • Biological control • Regulation and maintenance of pollination cycle • Storm protection

Addressed Challenge

This section lists and describes the primary social, environmental, and economic challenges. Each NbS addresses one or more of these challenges; however, only the challenges most effectively addressed are included here. This approach facilitates the selection of NbS based on their efficacy in addressing specific challenges.

Water Shortage

Water Low-Quality

Flood Hazards

Air Pollution

Soil Erosion

Biodiversity Loss

Public Health Degradation

Social Cohesion and Justice

Mobility Issues

Energy Shortage

Tourism Problems

Food Insecurity

Unemployment

Scale of Action

This section lists the possible areas of NbS implementation. These areas are within a city scale which is an urban and peri-urban area. Thus, the areas are:

Households: The individual house (inside and outside; except its garden)

Gardens: A small garden with an area of 20 -1000 m^2 (e.g., Household's gardens)

Buildings: A private or public building which consists of more than three floors.

Parking Spaces: A designated area for parking vehicles (e.g., public parking spaces).

Open Green Area: Open spaces with an area of more than 1000 m^2 (e.g., National parks or public parks)

Streets: Streets which have dense population, residential or commercial buildings.

River course: The route of the river which follows from its upstream to its downstream. The path consists of the whole river length in addition to the banks, turns, bends, and meanders.

Households

Buildings

Parking Spaces

Open Green Area

Streets

Gardens

River courses

Installation and Implementation Requirements

A brief description of the installation and implementation conditions such as the technical & design consideration, site characteristics, and baseline conditions.

Maintenance

This section shows the required regular and long-term maintenance for each NbS.

Benefits / Limitations

Coupling the challenge section, this section lists multiple ways on how NbS can deliver social, economic, and environmental benefits while focusing on the highly weighted benefits in addition

to the limitation. This section also answers the question of ‘How and How much the NbS contributes to the urban ecosystem?”, either a positive contribution (benefits) or negative contribution (limitation).

Sources

This section mentions the sources (handbooks & publications) of the above-mentioned information.

Section 4

Natural-based Solutions Catalogue

4.1. Natural-based Solutions Condensation

4.1.1. Natural-based Solutions and challenges

The NbS booklet groups a range of NbSs which are categorized according to their types (green-blue, green-grey, and blue-grey) and challenges (environmental, social, and economical). Each NbS contains a bundle of different challenges which could be solved by them as described in Table 8.

Table 8 Overview of nature-based solutions and their relevance to tackle challenges

NbS / Challenges	NbS Type	Environmental						Social			Economical			
		Water Shortage	Water Low-Quality	Flood Hazard	Air Pollution	Soil Erosion	Biodiversity Loss	Public Health Degradation	Mobility Issues	Social Cohesion and Justice	Energy Shortage	Unemployment	Food Insecurity	Tourism Problems
Diverting and Deflecting Elements	Blue-Grey	■	■		■			■	■		■	■	■	■
Double Line Trees	Green-Grey	■	■	■							■			■
Green Paths for Cycling	Green-Grey				■	■	■				■	■	■	■
Infiltration Trenches	Green-Blue				■	■		■	■	■	■	■	■	■
Infiltration Wells	Blue-Grey				■		■	■	■	■	■	■	■	■
Natural Pollinatorś Modules	Green-Blue	■	■	■		■			■		■			■
Parklets	Green-Grey	■	■	■		■		■	■		■		■	
Permeable Paving Systems	Green-Grey				■		■	■		■	■		■	■
Planting of Individual Trees	Green-Grey	■	■			■			■		■			■
Raingardens	Green-Blue	■				■			■		■		■	
Rooftop Rainwater Harvesting	Blue-Grey		■		■	■	■	■	■		■	■	■	■
Underground Water Storages	Blue-Grey		■		■	■	■	■	■	■	■		■	■

Urban Parks	Green-Grey													
Windbreaks	Green-Blue													
Channel Renaturing with Terramesh Walls	Blue-Grey													
Floodplain Expansion	Green-Blue													
Floodplain Riparian Woodlands	Green-Blue													
Living Fascine	Green-Blue													
Living Revetments with Cuttings	Green-Blue													
Living Weirs	Green-Blue													
Planted Channels and Rills	Green-Grey													
Planted Embankment Mat	Green-Blue													
Re-Meandering of Rivers	Green-Blue													
Renaturation or Revegetation of Water Courses	Green-Blue													
Reprofiling River Channel Cross Section	Blue-Grey													
River Branching	Blue-Grey													
Bioswales	Green-Blue													
Constructed Wetlands	Green-Blue													
Dry Detention Ponds	Green-Blue													
Electro Wetlands	Green-Blue													
Fishponds	Blue-Grey													
Floating Gardens	Green-Blue													
Green Roofs	Green-Grey													
Green Walls	Green-Grey													
Vertical Mobile Gardens	Green-Grey													
Wet Retention Ponds	Green-Blue													
Able to solve the challenge						**Unable to solve the challenge**								

4.1.2. Similarity Matrices

The use of the heatmap is intuitively designed. Both the horizontal and vertical axes list various NbS types, each color-coded by category (Green-Blue, Blue-Grey, Green, Green-Grey). It could be moved along the other axis to find a target NbS that has a high similarity which is color and size coded. Hence, a good alternative should have the same type and high similarity (Blue colored Circle or Big circle). While the type (color) constraint is subjective and dependent on the decision maker(s), the similarity value is the essence of choice and should be always prioritized.

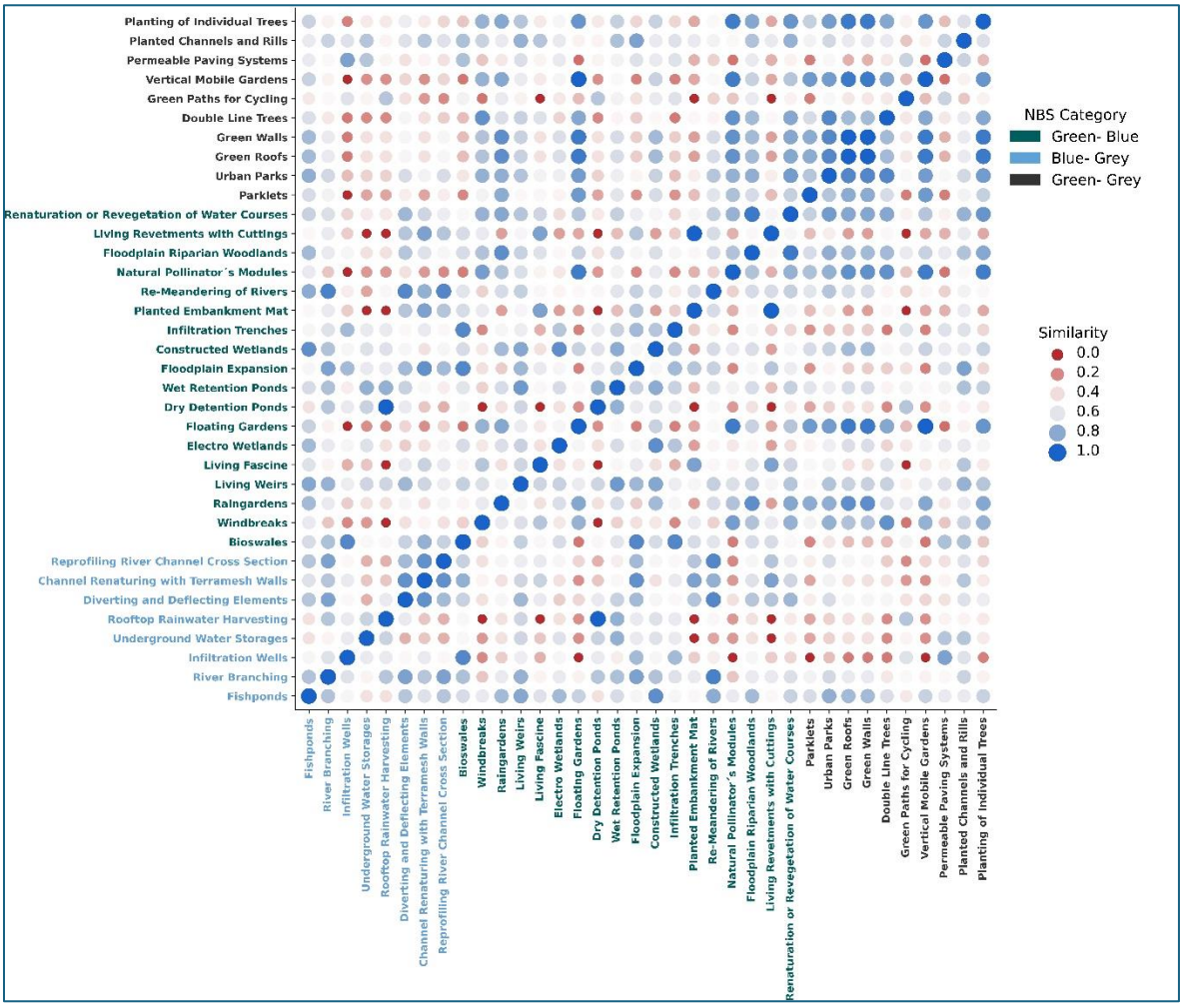


Figure 7 Challenges Similarity Matrix
Source: (ITT-TH Köln, 2024)

As illustrated in similarity matrix for addressing the challenges (Figure 7), it is needed to investigate the similarity in tackling the same challenges between two NbSs (e.g. Parklet and Infiltration Trenches), after crossing the two NbSs, red circle with a similarity value of 0.2 indicates a low similarity between the two interventions. This conceptual example can be applied similarly to the other two desired NbSs.

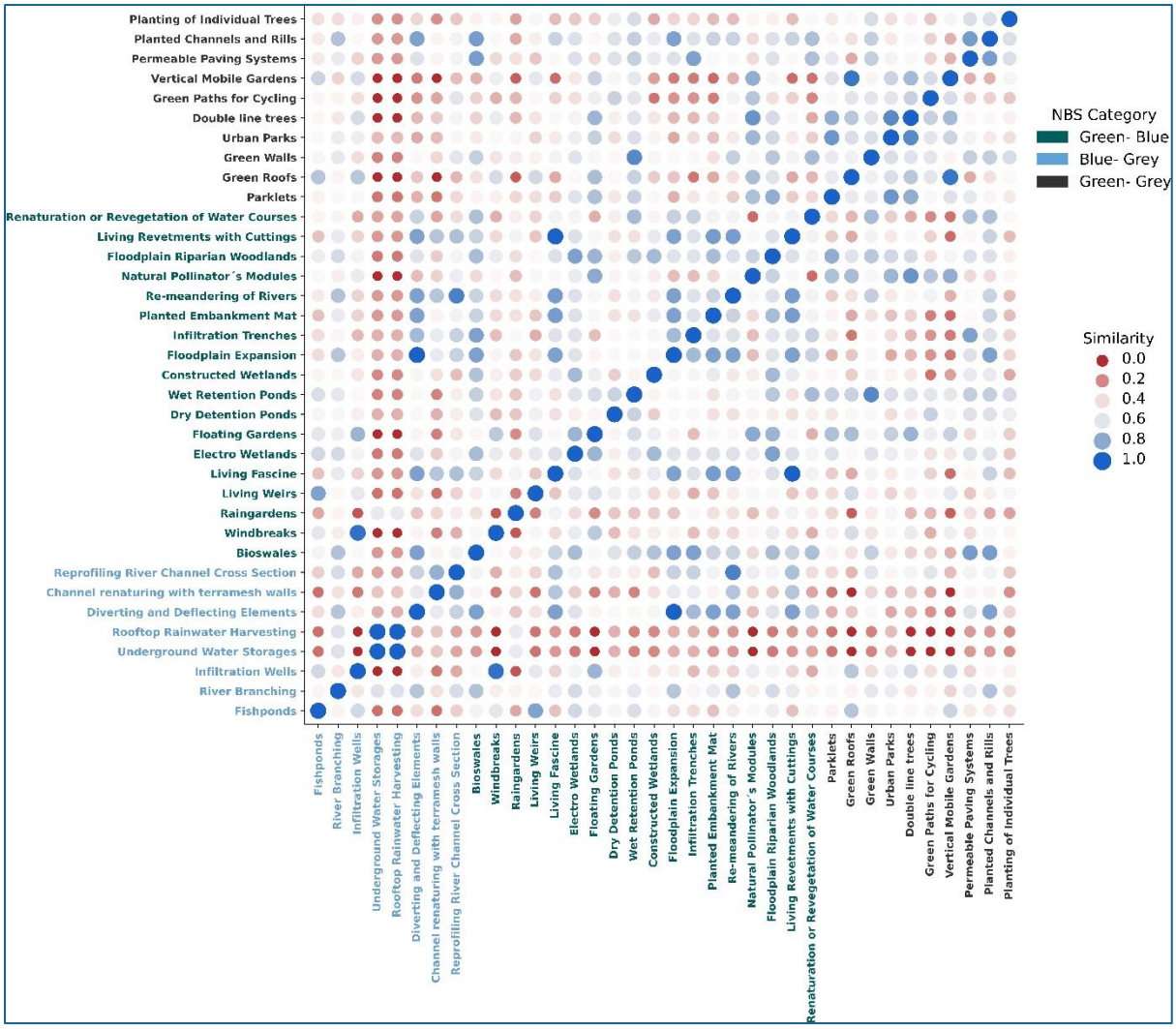


Figure 8 Ecosystem Services Similarity Matrix
Source: (ITT-TH Köln, 2024)

As illustrated in similarity matrix for ecosystem services (Figure 8), if it is needed to investigate the similarity in providing the same ecosystem services between two NbSs (e.g. Parklet and Infiltration Trenches), after crossing the two NbSs, red circle with a similarity value of 0 indicates to no similarity between the two interventions. This conceptual example can be applied similarly to the other two desired NbSs.

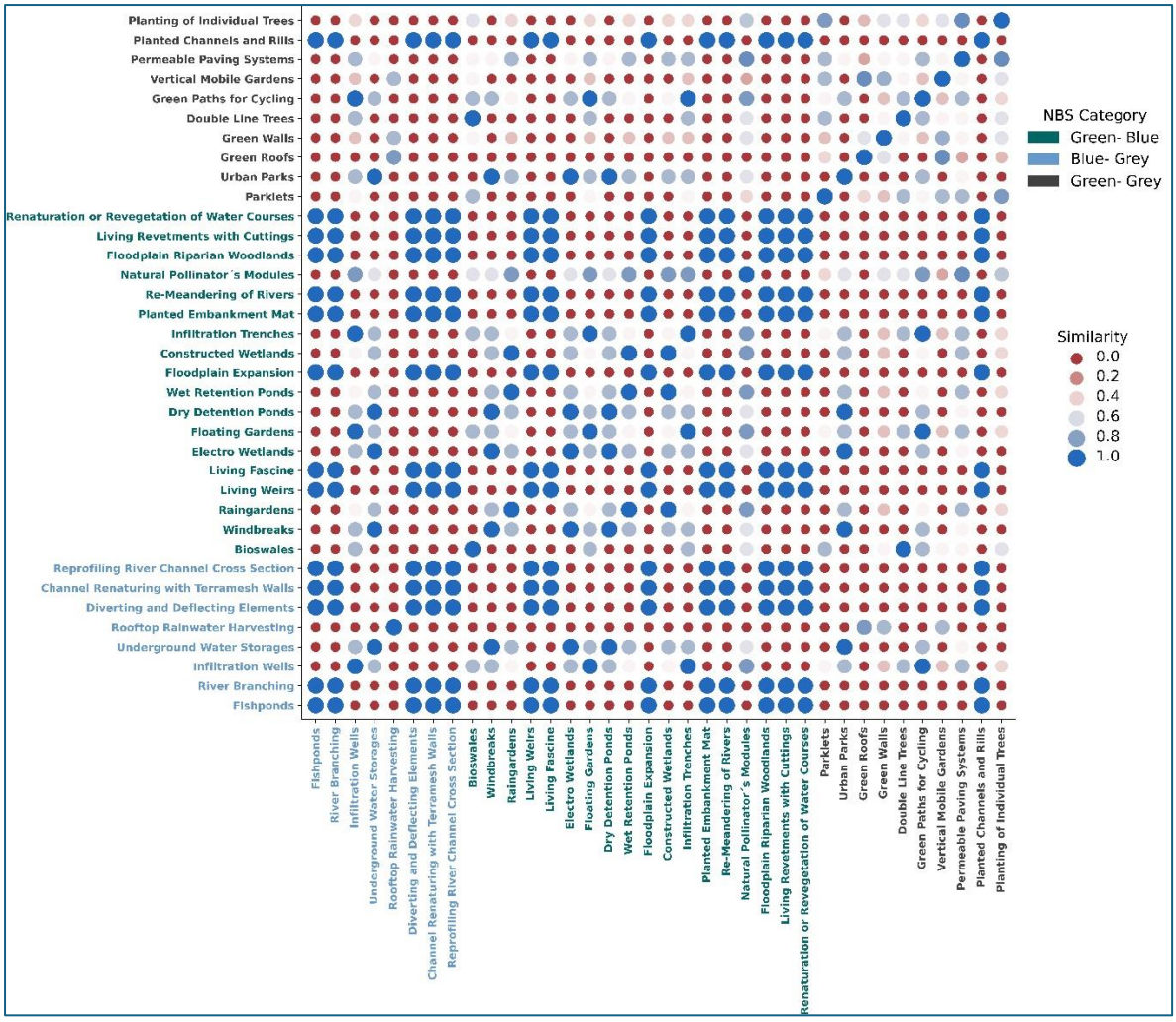


Figure 9 Scale of Action Similarity Matrix
Source: (ITT-TH Köln, 2024)

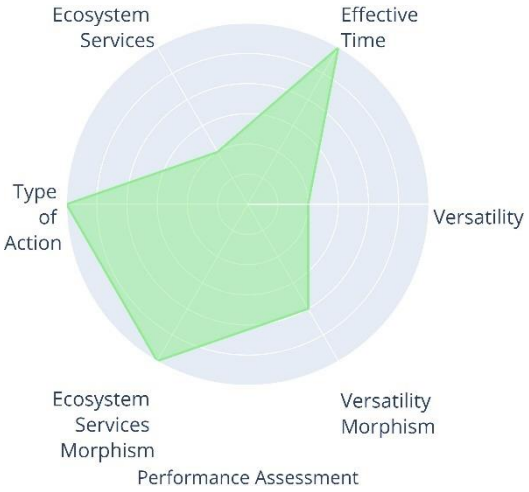
As illustrated in similarity matrix for the scale of action (Figure 9), if it is needed to investigate the similarity in applying the two NbSs in a same scale (e.g. Parklet and Infiltration Trenches), after crossing the two NbSs, an orange circle with a similarity value of 0.4 which indicates a medium similarity between the two interventions. This conceptual example can be applied in the same manner as the other two desired NbSs.

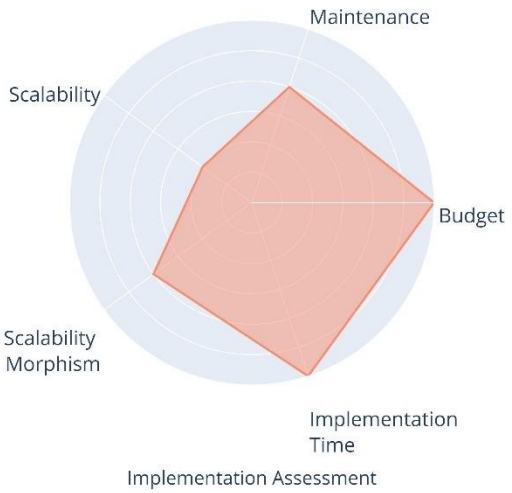
4.2. Natural-based Solutions Lists

The following section illustrates different types of NbSs according to their type of action (conservation, restoration, and installation) with a visual and descriptive profile.

Diverting and Deflecting Elements

Source: ITT-TH Köln, Sleman, Indonesia, 2023





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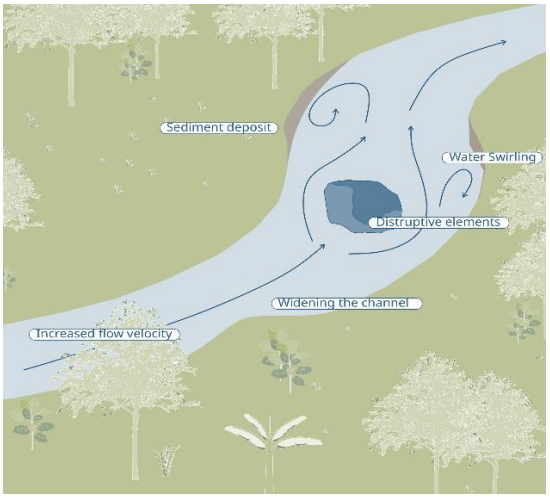
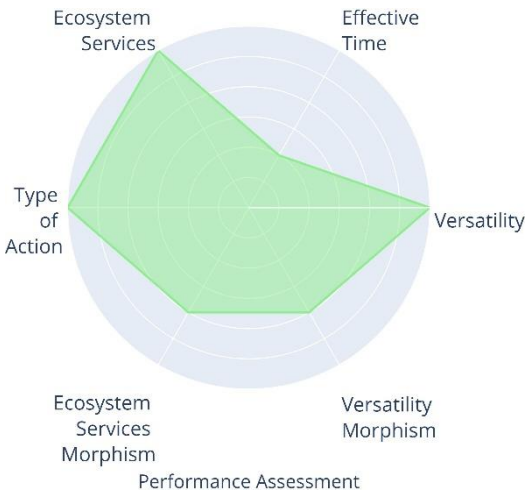
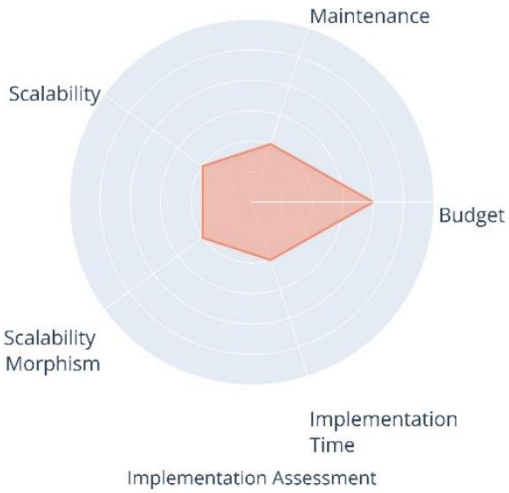
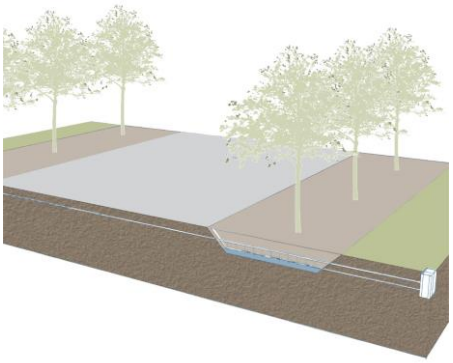
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Placement of disruptive and diverting elements to redirect, disturb, divert and the river current and to initiate water dynamics. Modified river channels are often lacking natural flow variation due to a lack of natural disturbance of the stream.		 Source: (Kota Kita, 2024)
Analogy	Usually have the mentioned name only.		
Naturalistic Design	Natural river streams have varying depths and widths. Natural elements such as tree trunks and rocks as well as vegetation are within and at the riverside. They slow down water velocity, stabilize the soil, protect the river zone from erosion and provide habitat as well as water quality through filtering. Through placement of diverting and deflecting elements, the current is altered to recreate natural water dynamics.	**Installation & Implementation Requirements**	• Construction type of groynes depends on strength of the current and the size of the groynes (e.g. living plants, additional stones). • Possible elements: tree trunks, stones (single rock or group of rocks), willow- Groynes. • The placement of the elements in the middle of the river or near the riverbank as well as the orientation in relation to the flow direction have different effects.
Maintenance	• Low maintenance required. • Periodical observation of elements.		
Benefits/ Limitations	(+) Current deflection and redirection. (+) Provide habitat for organisms, birds and aquatic animals. (+) Water velocity reduction. (-) Disruptive elements can block the river flow if placed without proper analysis. (-) Conflict may arise with potential boat traffic demanding disturbance free river.	**Ecosystem Services**	• Water availability regulation. • Enabling of aesthetic value. • Erosion control. • Habitat provisioning.
Sources	(Prominski et al., 2017; UNaLab, 2019)		

Source: Ti Gong, Guiping Road, China, 2022

Double Line Trees

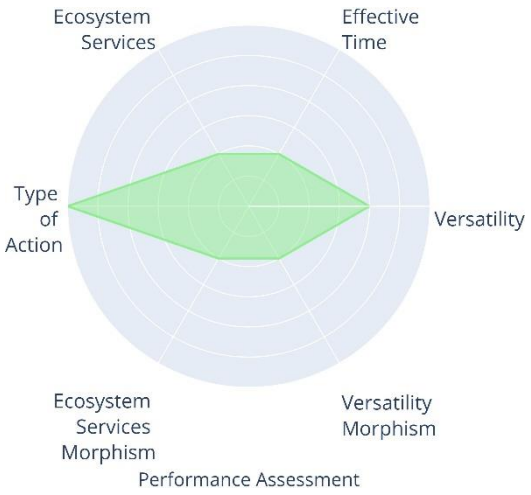


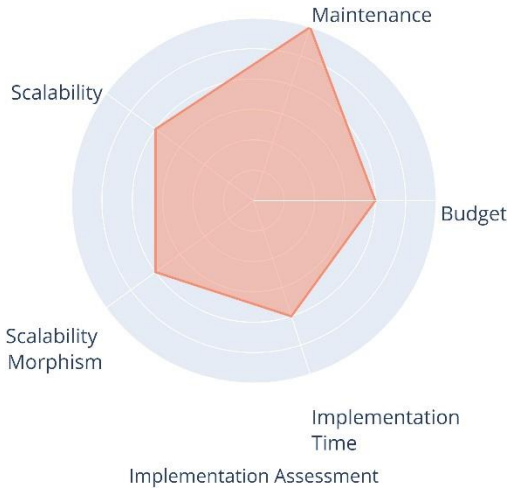


Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Double line trees are represented by several trees used mainly for mitigating urban heat stress. The trees could be arranged in the shape of a line along streets, bicycle paths, or sidewalks. By planting two lines of trees, it would represent a canopy shape where the middle area is shaded or protected from heat and pollution.		 Source: (Kota Kita, 2024)
Analogy	• Boulevards • Urban Forest or Arboreal areas around urban areas • Double-blind Street trees • Double row street trees • Arboretum • Tree groups • Sustainable urban groves • Green avenues.		
Naturalistic Design	Boulevards mimic the natural effects of trees found at the forest edge (fringe area) on their surrounding environment. These trees provide shade to adjacent areas, such as fields, meadows, or water surfaces, similar to those in natural forests. This shading results in cooler temperatures for the shaded surfaces compared to those without tree cover. Additional benefits include reduced wind speeds, cooling of the air through transpiration, and air purification.	**Installation & Implementation Requirements**	• Only a few tree species meet the selection criteria due to design principles, durability, and resistance to environmental stress. • Consideration should be given to both permanent and temporary irrigation facilities. The distance between trees depends on the road width, the maximum size of the mature trees, the size of the trees at planting. • Considering the future size of the tree • Trees that are not properly rooted can cause accidents and pose a danger to people on or near the road.
Maintenance	• Regular irrigation depending on plant types, the soil, and climatic conditions. • Regular trimming, especially in high traffic area.		
Benefits/ Limitations	(+) Provide a place for the public for recreation, social interaction, exercise and connection to nature. (+) Provide cooling and reduce surface runoff and thus mitigate the risk of urban surface flooding. (-) Reducing the air flow especially in the street canopy. (-) Potential to cause harm to human health by increasing allergens and trees pollen and BVOC emissions.	**Ecosystem Services**	•Food and fiber provisioning • Storm protection • Enabling of aesthetic values • Air quality maintenance • Enabling of social relations • Climate regulation • Enabling of recreation and ecotourism • Erosion control • Regulating & maintaining soil formation • Nutrient cycling • Primary production
Sources	(Eisenberg et al., 2022; World Bank, 2021)		

Green Paths for Cycling

Source: ITT-TH Köln, Bali, Indonesia, 2022





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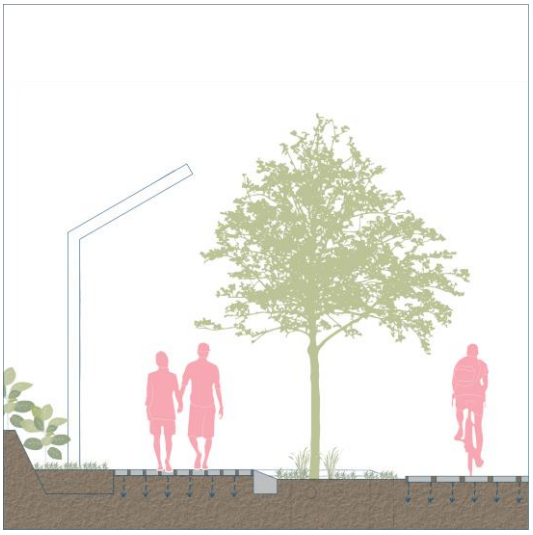
Addressed Challenge	
Description	Involves green pavements with special filtering properties suitable for pedestrians and cyclists. These pavements manage water runoff and are designed for use in cycle-pedestrian areas. By reducing the speed of cyclists in busy pedestrian zones, these pavements help prevent small flood accumulations. Additionally, the collected water can be used to irrigate other NbS, such as resting areas and pollinator modules, thus integrating multiple green infrastructures for various users.
Analogy	• Cycle-Pedestrian Green Paths • Cycle and Pedestrian Green Route
Naturalistic Design	Transition areas between biomes, known as ecotones, are characterized by their linear, natural elements and can be represented by green corridors that link adjacent and distant areas. Ecotones are often rich in biodiversity due to their connection to multiple biotopes.
Maintenance	A high standard of design and construction results in reduced maintenance over time. Cycle and pedestrian routes typically recover their investment within approximately 10 years.
Benefits/ Limitations	(+) Can be applied in streets, sidewalk, and entire roadway. (+) Don't require big maintenance. (+) Suitable place for cycling which could lead to less car accidents. (-) The lack of care and sustained neglect of the area often leads to the growth of spontaneous vegetation.
Sources	(Eisenberg et al., 2022; URBAN GreenUP, 2018)

Type of Action	
Scale of Action	

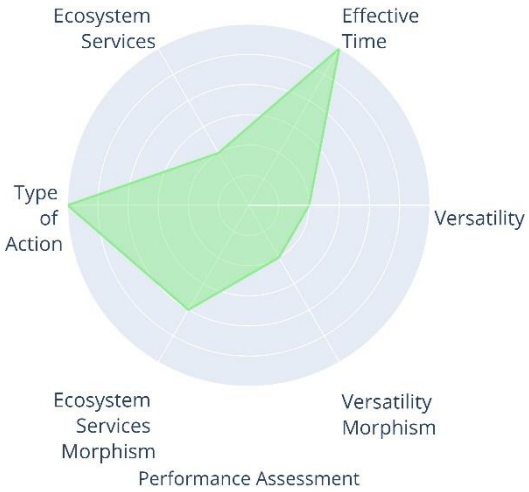


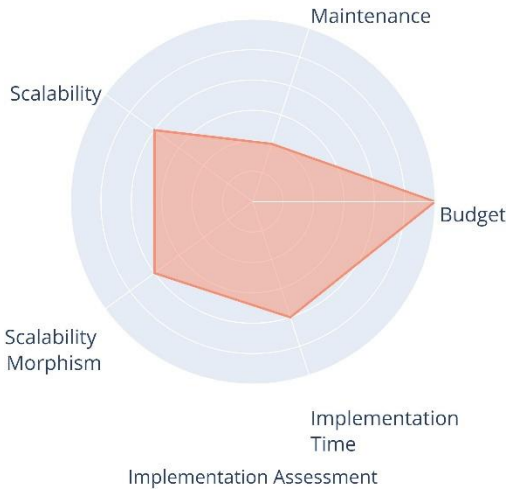
Source: (Kota Kita, 2024)

Installation & Implementation Requirements	• Pavements selection, including permeable pavers, permeable concrete, permeable asphalt, or other materials, should be guided by engineering constraints and the context of the surrounding street. • Using of underdrain system to treat overflow
Ecosystem Services	• Enabling of aesthetic values. • Enabling social relations. • Climate regulation. • Enabling recreation and ecotourism. • Regulating & maintaining soil formation.

Infiltration Trenches

Source: ITT-TH Köln, Indonesia, 2022





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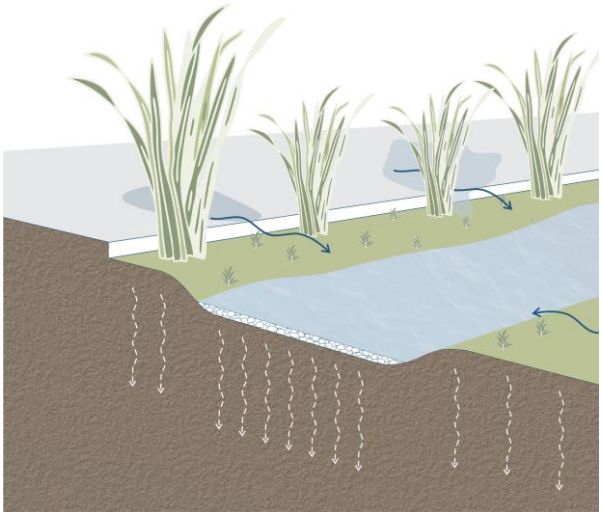
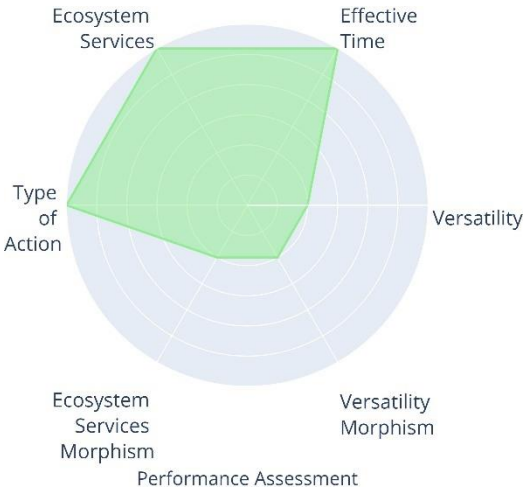
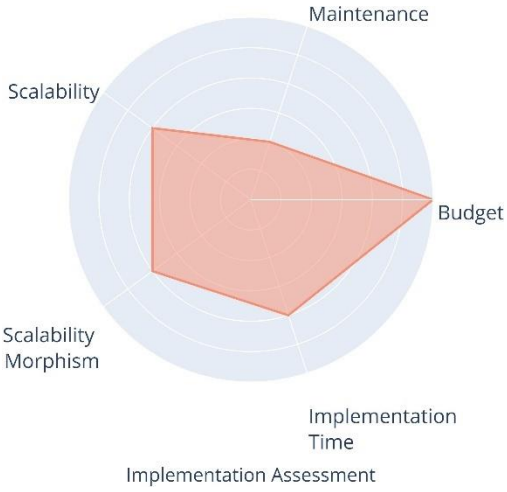
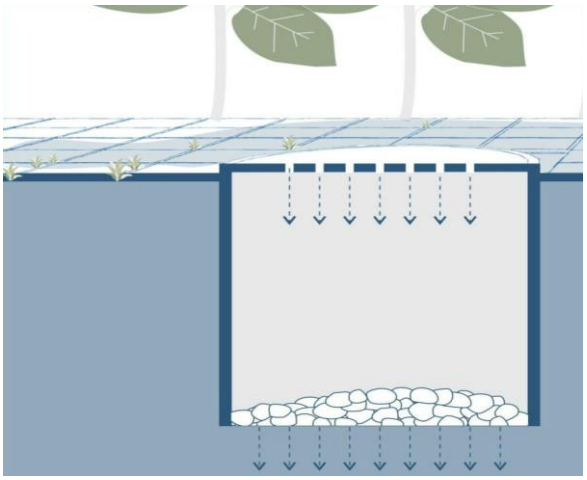
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Infiltration trenches are shallow excavations filled with rubble or stone which allow water to infiltrate into the surrounding soils from the bottom and sides of the trench. The basins are flat areas planted with grass and normally dry.		 Source: (Kota Kita, 2024)
Analogy	Rock Swales.		
Naturalistic Design	Filtration of surface water by different soil layers, for example sand.	**Installation & Implementation Requirements**	• Infiltration trenches are generally restricted to relatively flat sites. • To avoid sediment loading during construction, the contributing drainage area should be stabilized, or flows should be diverted.
Maintenance	• Regular inspection and cleaning of silt and other sediments to maintain infiltration capacity and prevent risk of long-term clogging and weed growth.		
Benefits/ Limitations	(+) Add aesthetic value. (+) Reduction of pollutant load discharged to surface waters. (-) Risk of introducing pollutants to groundwater (low risk if not used to drain pollution hotspots). (-) Not suitable for sites with fine particle soils (clay/silts) in the upstream catchment because of the risk of clogging.	**Ecosystem Services**	• Water availability regulation. • Erosion control. • Enabling of aesthetic value. • Water purification and Wastewater treatment.
Sources	(California Stormwater Quality Association, 2003; NWRM, 2015; Petsinaris et al., 2020; UNaLab, 2019)		

Source: JPNN, East Jakarta, Indonesia, 2021

Infiltration Wells

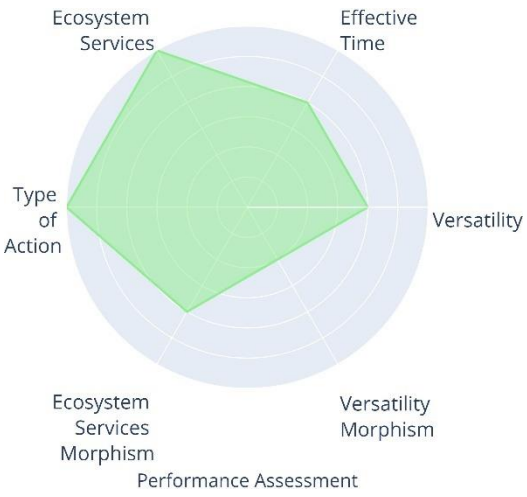


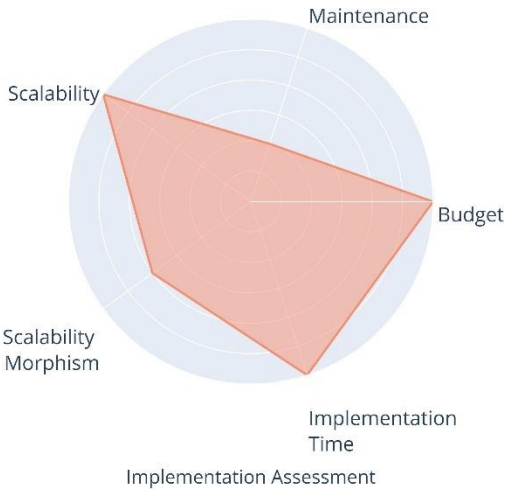


Addressed Challenge		**Type of Action**	
Description	Interception wells are designed to redirect surface runoff into underground piping systems. Unlike traditional drainage wells, these structures do not have a direct water entry point at the surface. Instead, they improve the soil's water absorption by utilizing porous materials and a coiled drainage system located between the surface and the pipes below. This design often permits soil management activities above the wells. To enhance water filtration, materials such as stones, coarse wood chips, or straw are commonly used.	**Scale of Action**	
Analogy	• Interception Wells. • Infiltration pits. • Absorption Wells.		 Source: (Kota Kita, 2024)
Naturalistic Design	Infiltration wells could be cylindrical in shape and vary in depth, these structures may be filled with permeable materials such as gravel or stone. They are designed to enable rainwater to either infiltrate directly into the soil or be stored for future use, even in confined spaces.	**Installation & Implementation Requirements**	• For the backfilling purposes, coarse wood chips are an economical and relatively durable material. • The chips must be sufficiently large to allow water to infiltrate. • In case of installing drainage pipe, it should measure 10 cm in diameter. • Infiltration wells could be connected to an existing drainage system. • If there are no drainages, a drain with a minimum 0.1% slope must direct surface runoff to the nearest outflow.
Maintenance	• Regular inspections for inlets and outlets are required. • If the wells are filled with any material (wood chips), they should be replaced or add more for at least every 10 years.		
Benefits/ Limitations	(+) Natural recharging for the groundwater. (+) Reducing the flood risks. (+) Reduce the load on downstream drainage channels. (-) May be subjected to clogging issues. (-) inefficient if they are applied in small numbers.	**Ecosystem Services**	• Habitat provisioning • Food and fiber provisioning • Climate regulation • Enabling of aesthetic values • Enabling of social relations • Air quality maintenance • Primary production • Enabling of sense of place • Erosion control.
Sources	(California Stormwater Quality Association, 2003; NWRM, 2015; Petsinaris et al., 2020; UNaLab, 2019)		

Source: iStock, Japanese Garden, 2008

Natural pollinator’s modules





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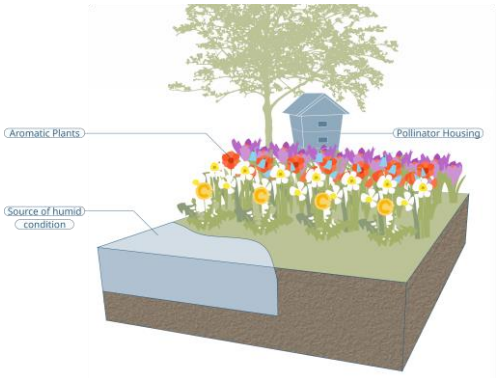
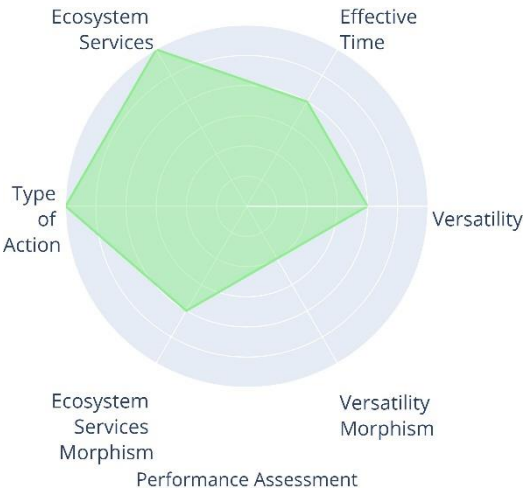
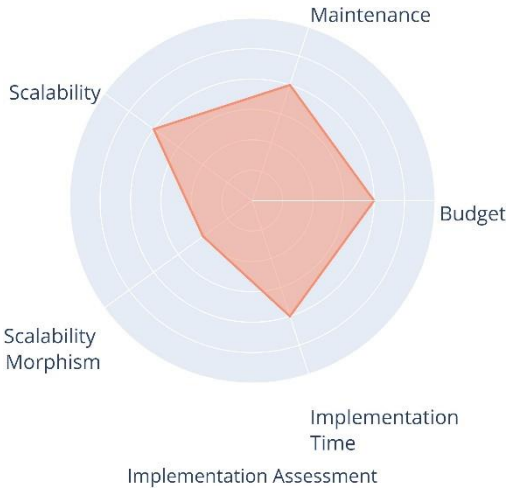
POLYURBAN WATERS

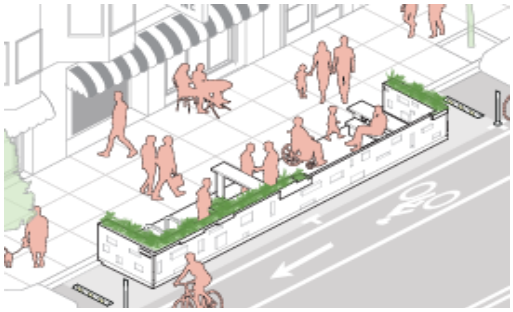
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	These areas are intended to attract pollinators and overall biodiversity by offering favorable weather conditions, such as cooler spots during hot periods and shelters for winter. They will also provide water and food sources for pollinators.		 Source: (Kota Kita, 2024)
Analogy	Pollination gardens.		
Naturalistic Design	Involves in creating an environment which is similar to natural habitats in order to support biodiversity and pollinators.	**Installation & Implementation Requirements**	• The surface area is between 10-20 m^2 (standard but also depends on the available space) with adaptable shape to the available land. • Try to connect the green area in the city. • Two distinct types of modules: one featuring a high variety of flowering plants and the other designed for monitoring purposes. • Pollinator nesting blocks should be installed (e.g. pollinator houses, bee houses, or bee hotels) which promote biodiversity by establishing wildlife-friendly spaces, contributing to the preservation and enhancement of local biodiversity in urban areas. • Some protection elements such as fences could be included. • installation of irrigation or a water source (lake) is important. • Other NbS could be included such as wet/dry detention ponds, raingardens and others.
Maintenance	The garden should be regularly cleaned.		
Benefits/ Limitations	(+) Emitting pleasant aromas. (+) Indirect provider for the food such as contributing in the pollination process. (-) Insecure to the people especially with the presence of bees. (-) The installation and maintenance are costly.	**Ecosystem Services**	• Aesthetic values •Regulation and maintenance of pollination cycle • Air quality maintenance • Enabling of social relations • Climate regulation • Enabling of recreation and ecotourism • Erosion Control • Regulating & maintaining soil formation • Nutrient cycling • Primary production.
Sources	(URBAN GreenUP, 2018)		

Source: MOTU, Cherry Streets, China, 2013

Parklets

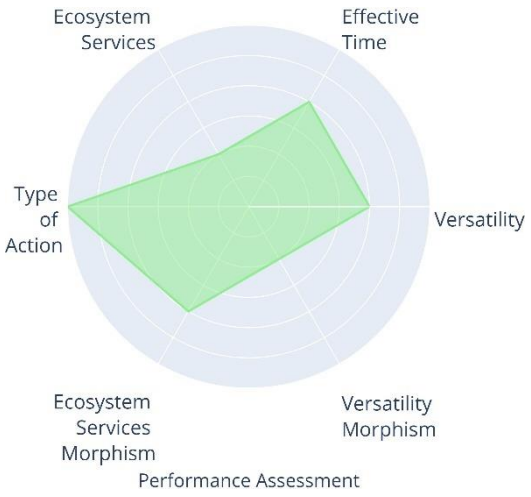


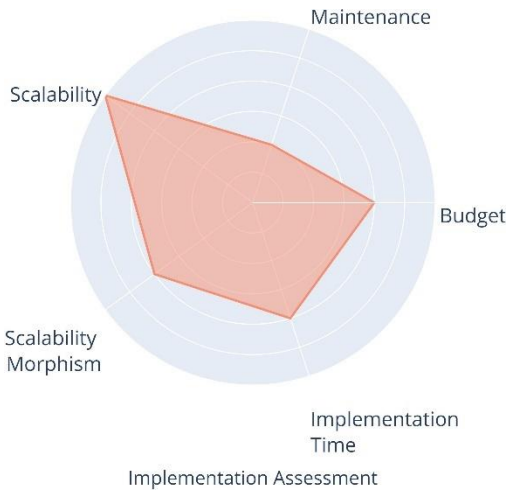


Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Parklet provides opportunities for people to create small but important public spaces in the street or neighborhood. It also turns a portion of the street beside the sidewalk into a people-only area and offers features including benches, vegetation, bike parking, and artwork. In another words, parklets promotes walking and bicycling.		 Source: (San Francisco Planning Department, 2015)
Analogy	• Pocket Park • Mini Parks • Green Resting Area.		
Naturalistic Design	Parklets are supporting biodiversity and green infrastructure by incorporating native plants and using natural woods and stones as a resting place which add both social benefits and aesthetical value.	**Installation & Implementation Requirements**	• Built in areas alongside urban roads, often the shopping streets. • Maintaining visual connections to the street by avoiding opaque walls above 1 meter and extending the sidewalk with multiple entry points. • Overhead elements should not span the sidewalk unless they meet a minimum vertical clearance of 2 meters. • Amenities like seating should be integrated into the parklet structure, and any movable furniture should be distinct from nearby business furniture. • Lighting is preferably to be solar powered. • Encouraged to plant native vegetations and drought tolerance. • Incorporated bicycle parking is possible.
Maintenance	Regular cleaning the parklet area.		
Benefits/ Limitations	(+) multifunctional specially when it is integrated with other NbS such as planting of individual tree. (-) Dangerous due to its location near the street. (-) Not accessible during very hot and cold seasons. (-) Could be considered as a hotspot for homelessness, illegal activity. (-) Impact of noise. (-) Problems of waste dumping.	**Ecosystem Services**	• Storm protection • Fresh water provisioning • Enabling of aesthetic values • Air quality maintenance • Enabling of social relations • Climate regulation • Enabling of recreation and ecotourism • Erosion control • Regulating & maintaining soil formation • Water purification and waste treatment • Nutrient cycling • Primary production.
Sources	(Albury Business Connect, 2021; San Francisco Planning Department, 2015; URBAN GreenUP, 2018)		

Permeable Paving System

Source: ITT-TH Köln, Sleman, Indonesia, 2023





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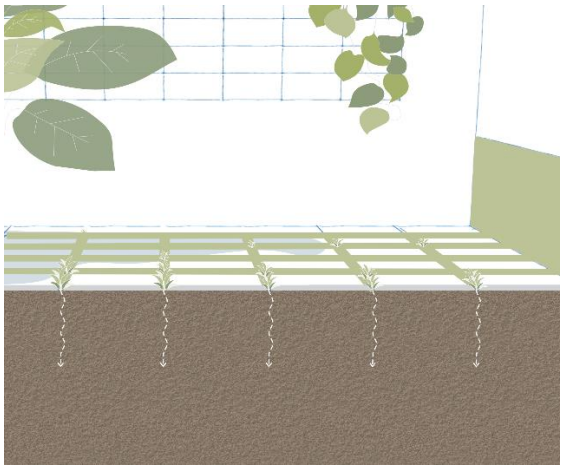
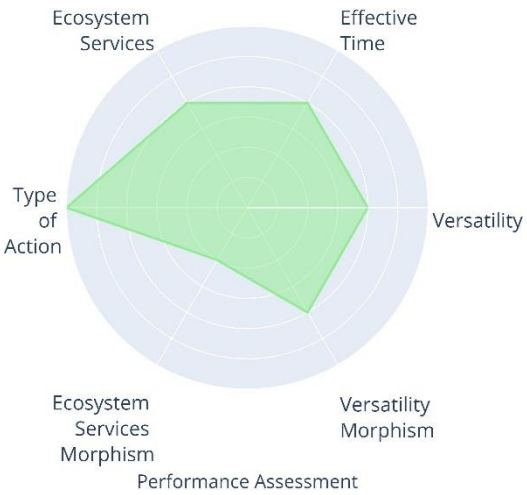
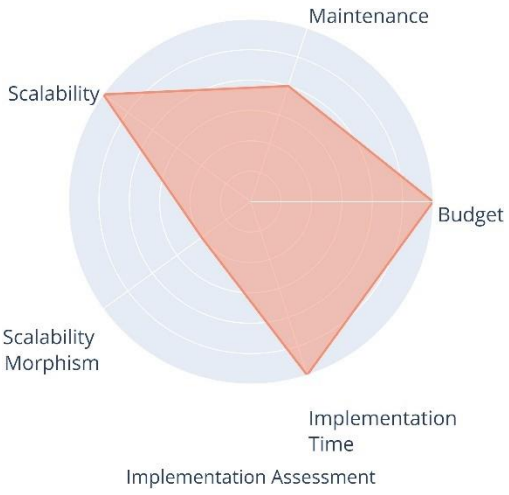
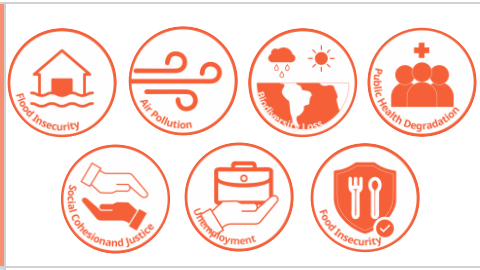
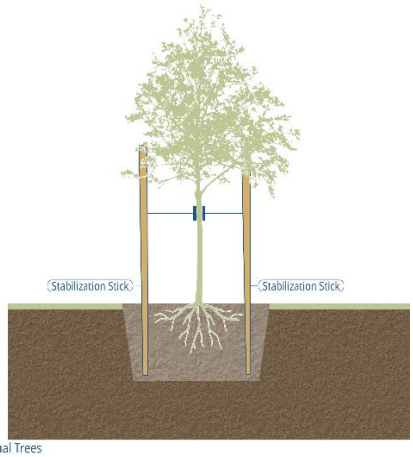
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Green paving systems replace grey urban pavements with up to 50% vegetal soil with high drainage capacity. Several implementation designs exist such as paving bricks containing a certain share of space for vegetation growth space, or grass-bricks that replace certain bricks of conventional pavements.		 Source: (Kota Kita, 2024)
Analogy	• Green Paving System • Permeable Pavement • Draining Pavements • Cycle-Pedestrian Green Pavement.		
Naturalistic Design	The natural elements of green pavements allow water infiltration and evapotranspiration.	**Installation & Implementation Requirements**	• Prior analysis of the soil is necessary. • Implementation on new or existing building sites possible. • Building sites that are newly constructed or that have previously existed can use permeable pavements. • Compatibility with all types of street traffic should be taken into consideration, and a prior investigation of the soil is required.
Maintenance	• Maintenance includes cleaning of silt and other sediments to maintain infiltration capacity and prevent risk of long-term clogging and weed growth which would decrease the infiltration capacity significantly. • Vegetation requires regular cutting.		
Benefits/ Limitations	(+) Reducing surface runoff. (+) They infiltrate, treat, and store rainwater and reduce runoff by allowing rain and snowmelt to seep to underlying layers. (-) Not appropriate for busy or fast-moving roads; stay away from spill areas as they block the pavement. (-) Cannot be used where large sediment loads may be washed or carried onto the surface. (-) Not recommended in areas where the soil or geology has low permeability, groundwater levels are high, or the underlying substrate is contaminated.	**Ecosystem Services**	• Climate regulation. • Water availability regulation. • Water purification and wastewater treatment. • Erosion control. • Storm protection. • Enabling of aesthetic value.
Sources	(Gallacher, 2017; Petsinaris et al., 2020; UNaLab, 2019; URBAN GreenUP, 2018)		

Source: ITT-TH Köln, On the way to Kratite, 2022

Planting of Individual Trees

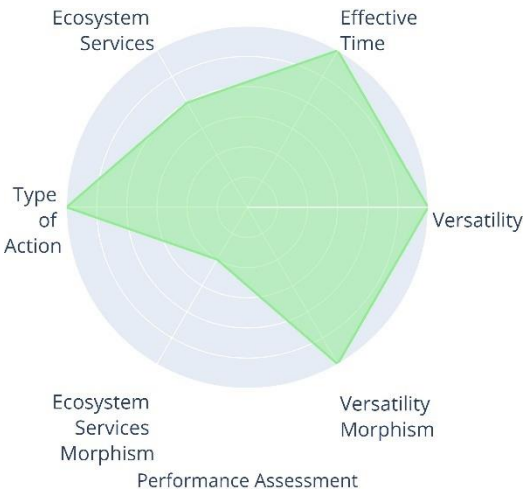


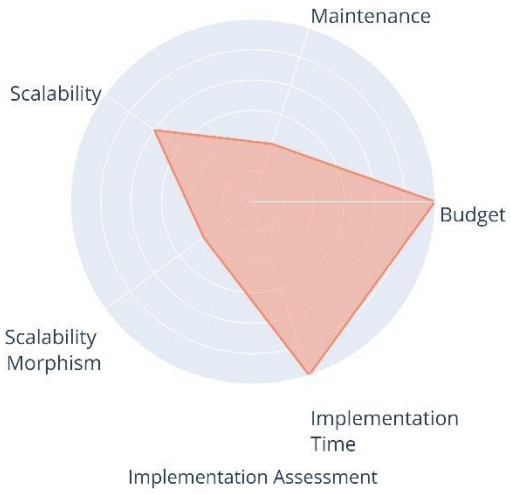


Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Strategic planning of individual trees or series of trees in urban areas to provide shade, reduce urban heat and reduce urban runoff.		 Planting of Individual Trees Source: (Kota Kita, 2024)
Analogy	• Street Trees. • Renewal of Urban Trees. • Trees Re-Naturing Parking.		
Naturalistic Design	Single trees simulate trees growing at the edge of the forests. Their effect on the surrounding environment includes the shading of the direct surrounding and reduced wind velocity. Planting of urban and peri-urban trees can reduce urban heat and mitigate urban air pollution. A single, young tree planted in a small pit over an impermeable asphalt surface has been shown to reduce surface water runoff by 60 %.	**Installation & Implementation Requirements**	• For cooling: species selected include those that are resistant to disease, and which transpire at high rates to maximize their cooling effect. • For shade: strategic positioning and selection of species with sizable canopy is important. • It is important to consider the endemic character of the tree species planted which should also fit for the long and short term, the geo-environmental conditions. • Selection of low biogenic volatile organic compound (BVOC) production trees to avoid the possible negative effect of ozone production in the summer season. • The root of trees can be connected or separated under the following conditions: root space should be 12 m³ with a minimum depth of 1.5 m.
Maintenance	• Pruning and potential irrigation. • Regular trimming of the trees.		
Benefits/ Limitations	(+) Provide shade for citizens and reduce urban heat. (+) Provide habitat for urban animals such as birds and insects. (+) Reduce urban runoff and heat islands. (-) Some tree species can have negative effects on human health (allergies, BVOC emissions in warmer months). (-) Some trees grow extensive root networks that can harm urban infrastructure.	**Ecosystem Services**	• Air quality maintenance • Storm protection • Climate regulation • Enabling of aesthetic values • Water availability regulation • Enabling of sense of place • Regulation and maintenance of pollination cycle.
Sources	(Armson et al., 2013; Gago et al., 2013; Scharenbroch, 2012; URBAN GreenUP, 2018)		

Source: ITT-TH Köln, Suwon, South Korea, 2023

Raingardens





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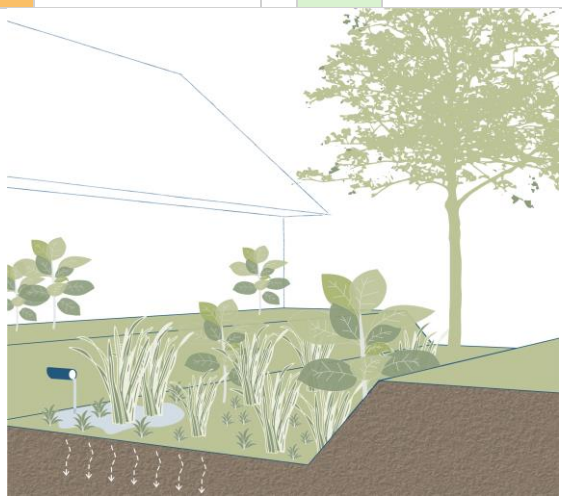
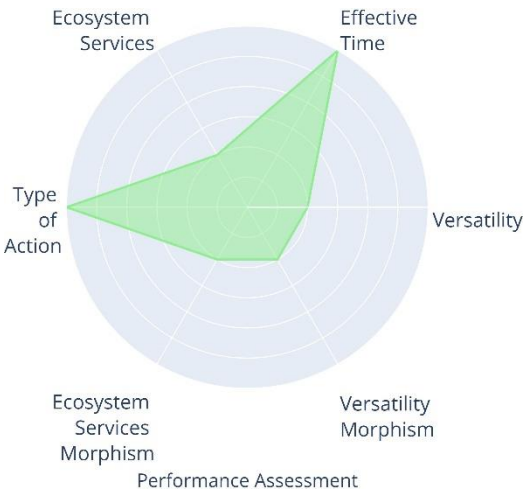
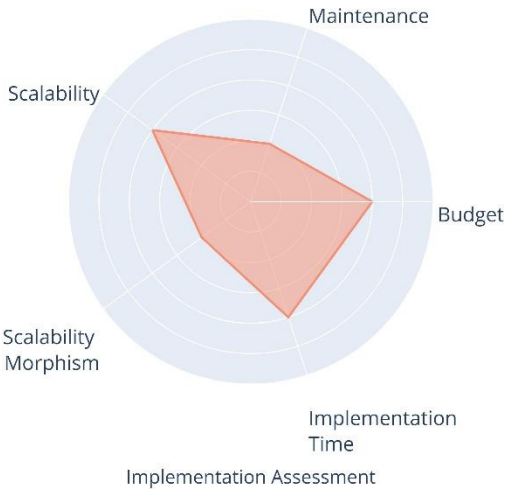
Addressed Challenge	
Description	Shallow bio-retention basins are established in artificial surroundings. They are designed to collect, store, filter and treat water runoff. A variety of elements are used such as grass filter strips, water ponds, mulch areas, planting soil, plants. They are not restricted to certain climate conditions and can be combined with e.g. with rainwater harvesting measures and permeable paving. They also catch water runoff from roofs, roads and other surfaces.
Analogy	• Bioretention Planter • Lined Bioretention Planters • Infiltrating Stormwater Planters • Bioretention Cells • Vegetated Filters • Biotreatment.
Naturalistic Design	Vegetation and soil layer retain and store water. Water infiltrates into natural soils (soil substances have an influence on infiltration rate). Plants and soil are natural filters for organic pollutants, sediments and other substances. While water infiltrates in soil, plants can take up and transpire water.
Maintenance	• Maintenance operations must be done on a regular basis including watering, pruning, pollarding, substitution of mulching and periodic review of the irrigation system (if present). • The appropriate cycle of inspection is 1-2 years.
Benefits/ Limitations	(+) Rain gardens can be both inexpensive and add aesthetic appeal. (+) Create habitat. (+) used in areas with limited space. (-) Not suitable for areas with steep slopes. (-) Risk of pollution to groundwater depending on site. (-) Plants must cope with dry and wet conditions.
Sources	(California Stormwater Quality Association, 2003; Petsinaris et al., 2020; UNaLab, 2019; URBAN GreenUP, 2018)

Type of Action	
Scale of Action	
	 Source: (Kota Kita, 2024)
Installation & Implementation Requirements	• Best to be located at gentle slope which is positive for infiltration. • Relatively dense vegetation of native plants that withstand occasional flooding. • Access for maintenance and management space must be ensured.
Ecosystem Services	• Fresh water provisioning. • Enabling of aesthetic value. • Water availability regulation. • Regulating & maintaining soil formation. • Water purification and wastewater. • Nutrient cycling treatment. • Primary formation.

Source: LinkedIn, Maung Khong, Thailand, 2019

Rooftop Rainwater Harvesting





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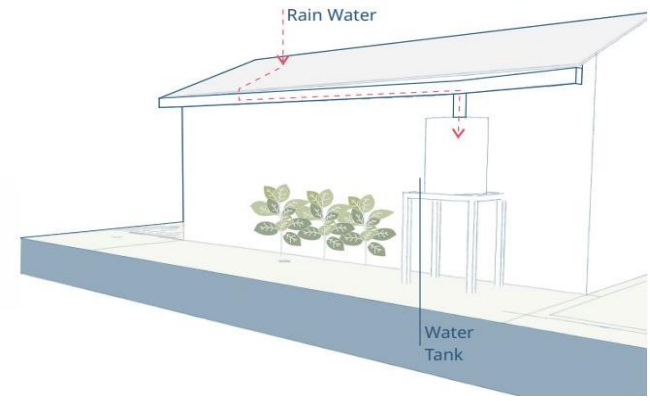
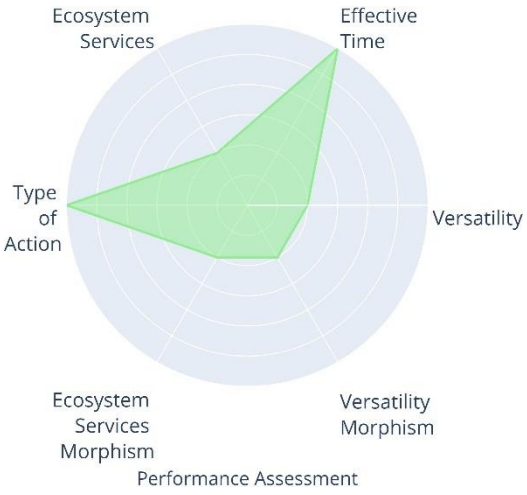
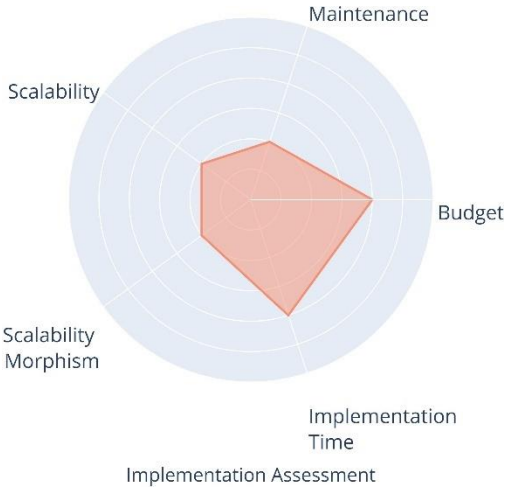
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Rainwater is caught and collected from rooftops and other impermeable surfaces. It can be stored and then be used for non-potable uses such as watering of green spaces and parks or non-potable uses at household level.		 Source: (Kota Kita, 2024)
Analogy	Roof Water Harvesting.		
Naturalistic Design	Storing available rainwater for uses that don't require costly water treatment.	**Installation & Implementation Requirements**	• Systems need to apply progressive layers of protection to prevent contamination and deliver clear, colorless and odorless water. • Require substantial investment in infrastructure to collect, connect, store and treat the water and finally feed into the water supply system. • Availability of space for large tanks in dense urban settings can be a challenge. • Requires having an alternative water supply due to inconsistency of water supply. • 3 categories of rainwater harvest systems: water supply only (small-scale), water supply and passive surface water control, and water supply and active surface water control Often part of SUDS component.
Maintenance	Required regular maintenance.		
Benefits/ Limitations	(+) Collected water for irrigation purposes. (-) Limited control over the water availability. (-) Measure might meet resistance in households due to fear of hygienic reasons or insecure water availability (double-water distribution system needs to be installed). (-) Potential contamination: runoff from roofs made up of materials containing copper or zinc, or treated with fungicides or herbicides, may not be suitable.	**Ecosystem Services**	• Freshwater provisioning. • Water availability regulation.
Sources	(NWRM, 2015; Petsinaris et al., 2020; Woods Ballard et al., 2015)		

Source: Aggeres, Roeselare city, Belgium, 2021

Underground Water Storages





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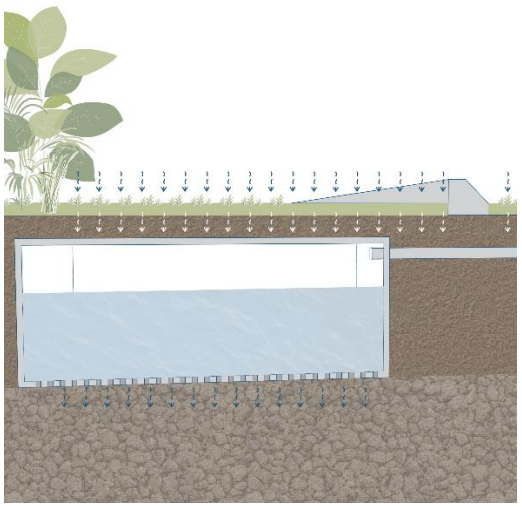
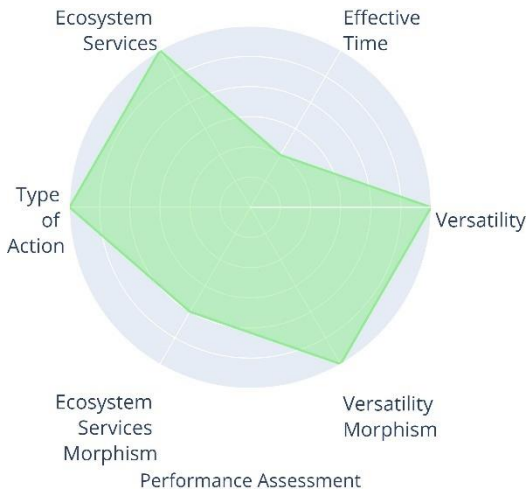
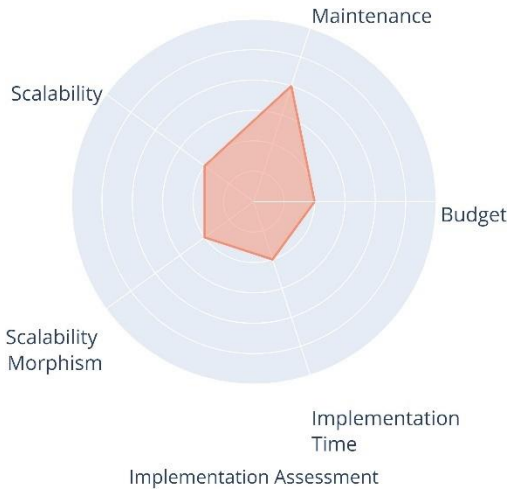
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Underground systems such as installations below public open spaces (sport fields) composed of modular elements where the stormwater enters a vault or a basin through a surface inlet and is temporarily stored, allowing sediments and particles to settle. If the water level reaches a certain height, it is discharged as overflow for further use for irrigation purposes.		 Source: (Kota Kita, 2024)
Analogy	• Underground Storage Vault • Underground Storage System.		
Naturalistic Design	Use of the underground area for water storage and green infrastructure for increased natural infiltration.	**Installation & Implementation Requirements**	• Installation of modular elements below public open spaces. • The following parameters should be considered: - Contributing to drainage area. - Vault volume. - Dead and live loading capacity. - Maintenance drain. - Mosquito access prevention.
Maintenance	• Regular inspection and monitoring of modular elements. • Regular inspection for trash and debris to be removed.		
Benefits/ Limitations	(+) Store water that can be used for irrigation purposes. (+) Increases water security. (+) Reduced urban runoff. (-) Maximum water quality is needed for storage. (-) Due to the designed permanent of stagnant water, vector breeding is the issue. (-) Heavy machinery is required during the implementation phase.	**Ecosystem Services**	• Freshwater provisioning. • Water availability regulation.
Sources	(ICLEI, 2019; UNaLab, 2019)		

Source: VinWonders, Ho Chi Minh City, Vietnam, 2023

Urban Parks





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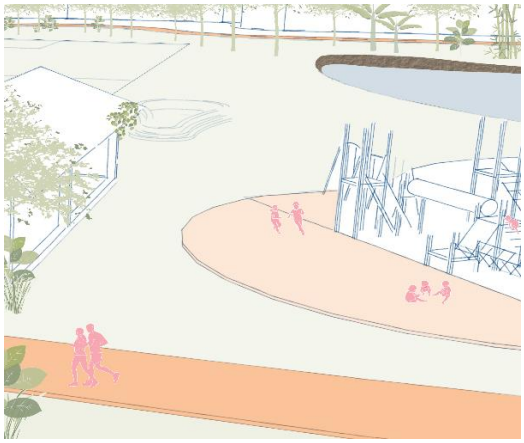
Addressed Challenge	
Description	Parks and forests in urban or peri-urban areas provide several environmental benefits while serving as a public space for recreation, social interaction, exercise and connection to nature. Parks could have multifunctionality by combining various uses such as sport fields or other NbS (e.g. water retention basins).
Analogy	• (Peri-)Urban Park. • Residential Park.
Naturalistic Design	Parks and forests provide shade and enhance evapotranspiration, thus cool down temperatures. Appropriately designed green corridors allow cooler air from outside the city to enter the dense urban areas leading to improved urban ventilation and reduction of the urban heat effect. Natural surfaces enable water to infiltrate into the soil and filter the water before it enters the groundwater.
Maintenance	Periodical inspections and maintenance, such as removal of broken branches, cutting of gras etc.
Benefits/ Limitations	(+) Provide a place for the public for recreation, social interaction, exercise and connection to nature. (+) To provide cooling and reduce surface runoff and thus mitigate the risk of urban surface flooding. (-) Depending on location, urban parks might be considered a non-safe space at night. (-) Potential to cause harm to human health by increasing numbers of mosquitos and/or allergens.
Sources	(Armson et al., 2013; Bowler et al., 2010; Petsinaris et al., 2020; Philadelphia Parks Alliance, 2008)

Type of Action	
Scale of Action	

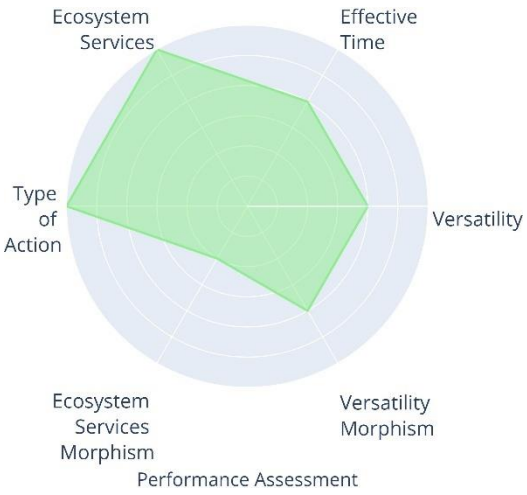


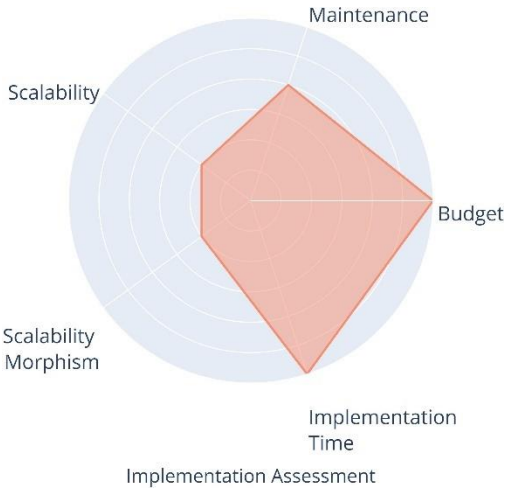
Source: (Kota Kita, 2024)

Installation & Implementation Requirements	• Should have an area of at least 1.5 ha and a compact form (e.g., 120 m x 20 m). • Should have a high proportion of trees or a small forest (> 50 % canopy cover), and few sealed surfaces. • Cooling properties depend on the area size and the composition of vegetation, such as the number of trees and grass cover. • Urban parks and forests can incorporate other NbS elements such as retention ponds and pervious surfaces. • Large space is needed which means that it is dependent on land availability. • Important to plant species that are adapted to local conditions to prevent introduction of new species with potential negative effects. • For safety reasons, the installation of lighting can be considered.
Ecosystem Services	• Food and fiber provisioning • Storm protection • Freshwater provisioning • Enabling of aesthetic values • Air quality maintenance • Enabling of social relations • Climate regulation • Enabling recreation and ecotourism • Erosion Control • Regulating & maintaining soil formation • Water purification and waste treatment • Nutrient cycling • Primary production.

Source: LANDOV, Sanjiang Plain, China, 2013

Windbreaks





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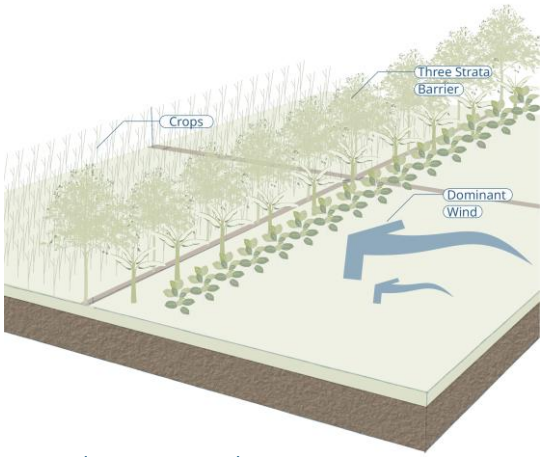
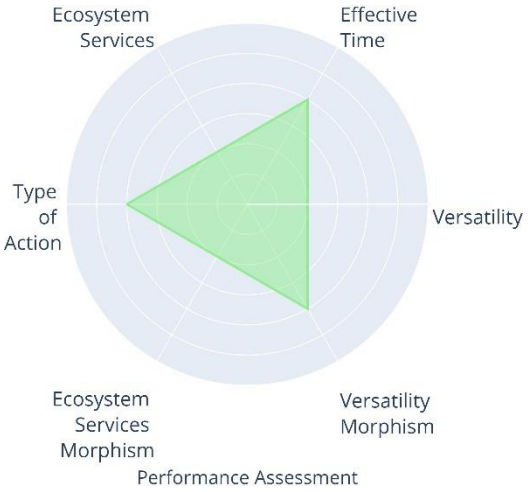
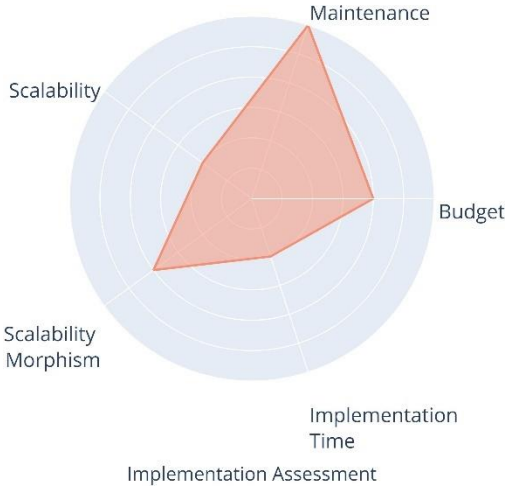
POLYURBAN WATERS

Addressed Challenge		**Type of Action**	
Description	Windbreaks are structures designed and implemented in agricultural lands to reduce wind speed. They consist of tree belts, and they help control erosion, boost agricultural yields, and minimize evaporation by modifying wind direction and turbulence. Their effectiveness is influenced by their height, porosity, and placement relative to the wind.	**Scale of Action**	
Analogy	Agricultural Tree Belt.		 Source: (Kota Kita, 2024)
Naturalistic Design	The trees or shrubs work by modifying wind flow to decrease its speed and turbulence. These windbreaks are dynamic and grow over time, requiring regular management to remain effective, control pests and diseases, and maximize benefits.	**Installation & Implementation Requirements**	• Efficiency of a windbreak is affected by tree type, height, width, tree arrangement, etc. • Windbreaks should be perpendicular to the main wind direction for the best results. • Spacing between rows of windbreaks should be optimized. • Should be positioned to face the dominant wind direction for maximum effectiveness.
Maintenance	Requires regular inspections and maintenance including pests and diseases control and ensuring optimal growth and coverage.		
Benefits/ Limitations	(+) Efficient and effective barriers to high-velocity winds. (+) Controlling evaporation and erosion. (+) Creating shadows and lowering temperatures, particularly when used with other methods like solar panels. (-) Trees requiring water which may affect the water table. (-) In some cases, and to increase the efficiency of the windbreaks, they need to be combined with other solutions.	**Ecosystem Services**	• Habitat provisioning • Food and fiber provisioning • Climate regulation • Enabling of aesthetic values • Air quality maintenance • Primary production • Enabling of sense of place • Erosion control.
Sources	(Bajsanski et al., 2017; Bitog et al., 2011; Pang-ue, 2018; Monfared et al., 2019; Thevs et al., 2019)		

Source: Maccaferri, Indonesia, 2017

Channel Renaturing with Terramesh Walls





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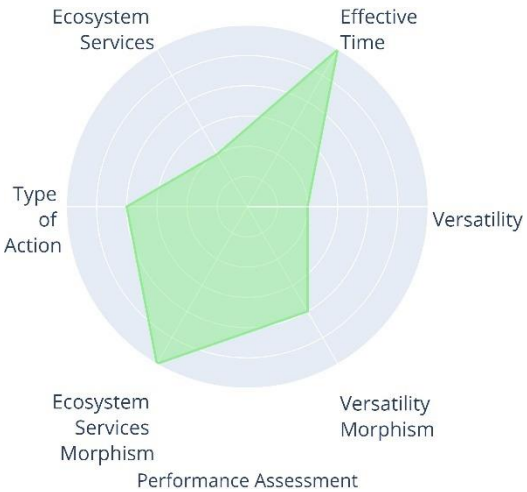
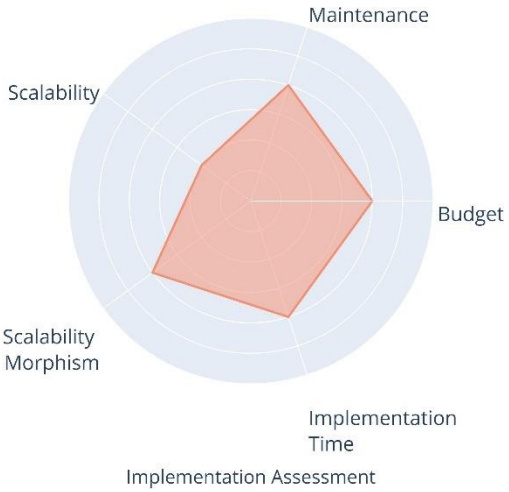
POLYURBAN WATERS

Addressed Challenge		**Type of Action**	
		Scale of Action	
Description	Removal of concrete riverbanks and replacement of Terramesh walls. Terramesh is a wire mesh used as a soil reinforcement system to stabilize slopes.		 Source: (Kota Kita, 2024)
Analogy	• Riverbanks Restoration • Embankments Restoration/Renaturalization.		
Naturalistic Design	The terramesh walls provide good drainage and stabilize the riverbank. The creation of green slopes enables infiltration and creates aesthetic value.	**Installation & Implementation Requirements**	• Technical knowledge Implementation. • Access to material is needed.
Maintenance	Annual maintenance includes pruning and potentially irrigation of vegetation cover.		
Benefits/ Limitations	(+) stabilize slopes along the riverbanks and prevent erosion and provide flood protection. (-) Cost-intensive and no amortization of costs.	**Ecosystem Services**	• Water availability regulation • Erosion control • Regulating & maintaining soil formation.
Sources	(URBAN GreenUP, 2018; Geofabrics, 2023)		

Source: Dutch Water Sector, Arnhem, the Netherlands, 2014

Floodplain Expansion





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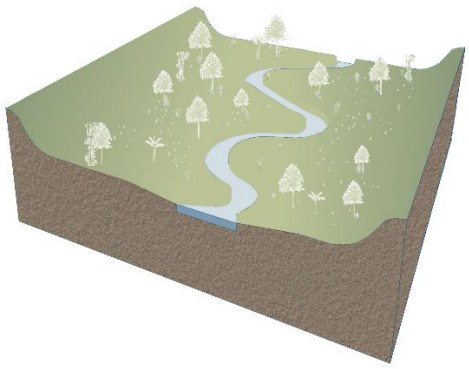
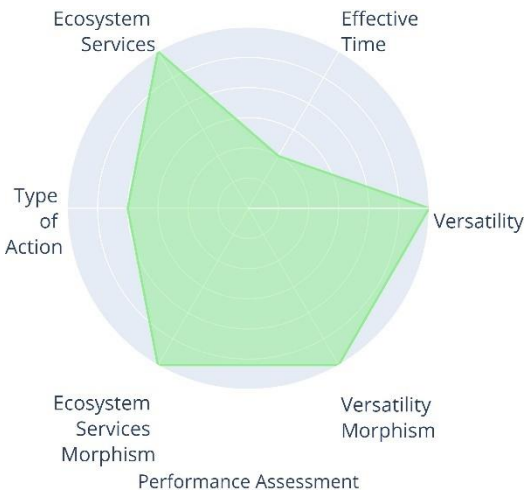
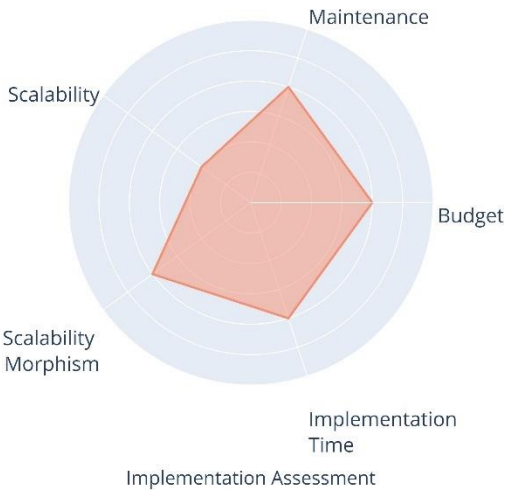
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Expansion of the river flood plain area to temporarily increase the water storage capacity and increase infiltration to reduce risk of river flooding. The expansion process could be through dechannelizing the river in order to increase the floodplain which is the area on both sides of the river.		 Source: (Kota Kita, 2024)
Analogy	• Floodplain Enlargement • Floodplain Widening		
Naturalistic Design	Inspired by natural river landscapes with low-lying, vegetated areas adjacent to river that provide important ecosystem services, including flood protection and water infiltration.	**Installation & Implementation Requirements**	• Large space for additional branch required implementation: • Heavy machinery needed
Maintenance	Periodical monitoring and inspection as well as cutting of vegetation.		
Benefits/ Limitations	(+) Provide additional flood space which increases the temporary water storage capacity during flood events (+) Allows higher water (-) Significant land use changes (i.e. loss of agricultural land, resettlement etc.) (-) Limitation for river restoration if there is a need for preservation of existing infrastructure (-) Possible conflict between habitat provision for wildlife and human recreation.	**Ecosystem Services**	• Water availability regulation • Enabling of aesthetic values • Erosion control • Habitat provisioning
Sources	(Gallacher, 2017; UNaLab, 2019; URBAN GreenUP, 2018; Wesenbeeck et al., 2021)		

Source: BROZ archive, Danube Floodplain Forests, Slovakia, 2020

Floodplain Riparian Woodland





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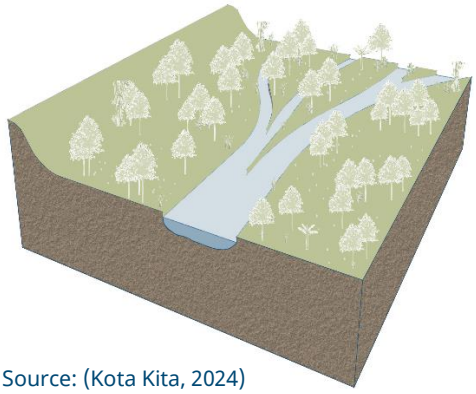
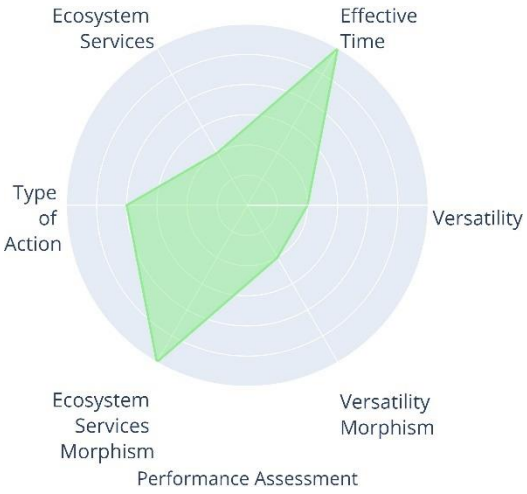
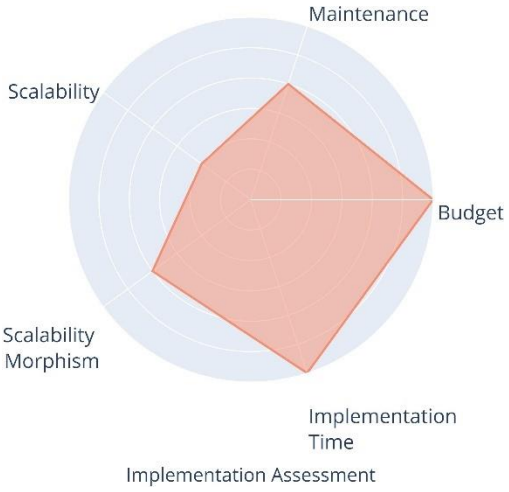
Addressed Challenge		**Type of Action**	
Description	Floodplain riparian woodlands are forests along the regularly flooded areas. The forest can act as a shelterbelt along the floodplain and reduce peak flows by 13 - 48%.	**Scale of Action**	
Analogy	Floodplain Riparian Forest.		 Source: (Kota Kita, 2024)
Naturalistic Design	Imitation of natural river landscapes with low lying, vegetated areas adjacent to river that provide important ecosystem services. Woodlands contribute to alleviation of flooding in three ways: • Trees use more water than shorter types of vegetation. • Woodland soils can hold back and delay rainwater that flows to streams and rivers, due to their more open structures that result in higher infiltration rates. • The hydraulic roughness created by the trees, shrubs, and deadwood in river and on floodplains causes delay of the progression of flood flows.	**Installation & Implementation Requirements**	• Floodplain riparian woodlands are much wider than riparian buffers. The width of wood is highly important for effectiveness of flood. • Large space required. • Important factors to be considered are: Native species, structural diversity, and balance of forest cover and open space
Maintenance	• Maintenance includes periodical removal of waste and natural material. • Management of woods to prevent illegal felling.		
Benefits/ Limitations	(+) Reduce risk of river flooding. (+) protect aquatic ecology by providing shade and preventing too high-water temperatures. (-) Riparian woods can overgrow the river and cause blockage creating natural dams. (-) Branches and trunks can cause damage to downstream infrastructure. (-) The shadow over water provided by the forest can lead to lower productivity of fish growth.	**Ecosystem Services**	• Air quality maintenance. • Enabling of aesthetic values. • Climate regulation. • Enabling of recreation and ecotourism. • Water availability regulation. • Regulating & maintaining soil formation. • Erosion control. • Nutrient cycling. • Water purification and waste treatment. • Primary production. • Habitat provisioning.
Sources	(Nisbet et al., 2011; Nisbet & Thomas, 2006; Petsinaris et al., 2020; Soman et al., 2007)		

Source: Giverny News, Giverny, France, 2014

Living Fascine





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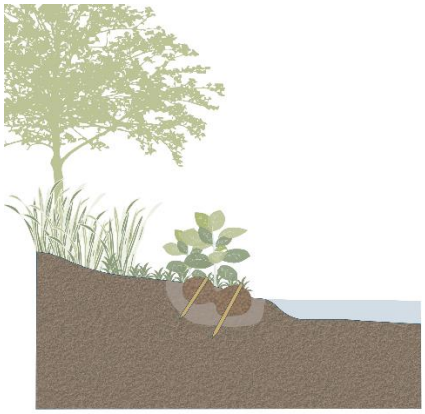
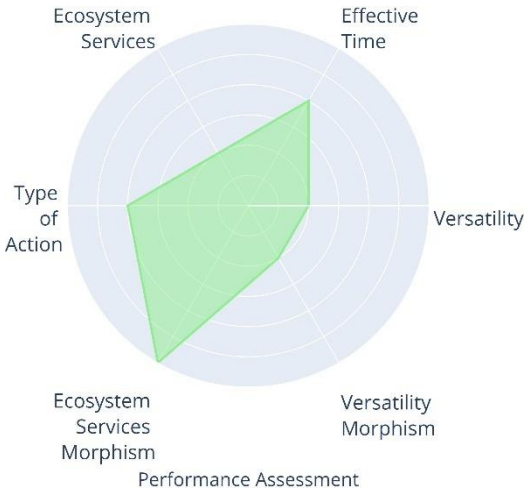
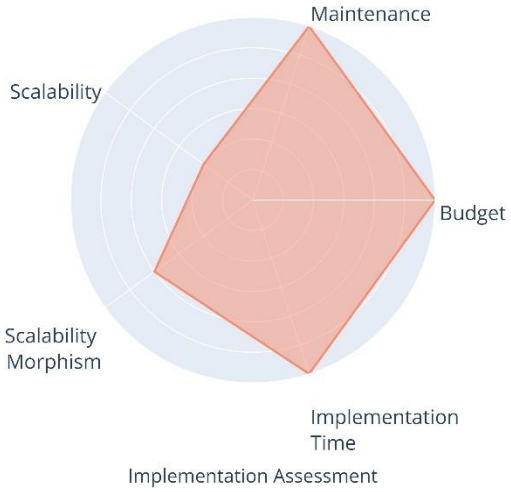
POLYURBAN WATERS

Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Fascines are tubular bundles of brunches and twigs that are installed in trenches along hillsides or riverbanks for stabilization.		 Source: (Kota Kita, 2024)
Analogy	Live Fascines.		
Naturalistic Design	The fascines sprout and root. The vegetation cover protects the surface and the root mass traps sediments and reinforces the soil. The fascines disrupt the hillside, shortening each slope segment and reducing the energy available for erosion. Fascines alongside the riverbed break up the erosion force of small waves and prevent water erosion.	**Installation & Implementation Requirements**	• Should be used outside of urban areas. • The fascines consist of living tree branches and twigs and could comprise up to 50% dead wood. • Timing of installation/planting is important (low water flow, no rainfall). • Bundled of wood made from steel cables or rope which area made from natural materials (jute) • Robust local plant species. • Suitable weather and seasonal conditions are important for the establishment of vegetation material.
Maintenance	Periodical inspections and monitoring.		
Benefits/ Limitations	(+) Waterside reinforcement. (+) Protect hillsides and riverbanks from erosion. (+) biodiversity Benefits by habitat creation. (-) Stability of hillside is hard to determine/foresee.	**Ecosystem Services**	• Water availability regulation • Regulating & maintaining soil formation • Erosion control • Nutrient cycling • esthetic value • Habitat provisioning
Sources	(Larimit, 2016; UNaLab, 2019)		

Source: Vietnam Vetiver Network, Thanh Mai, Vietnam, 2018

Living Revetment with Cuttings





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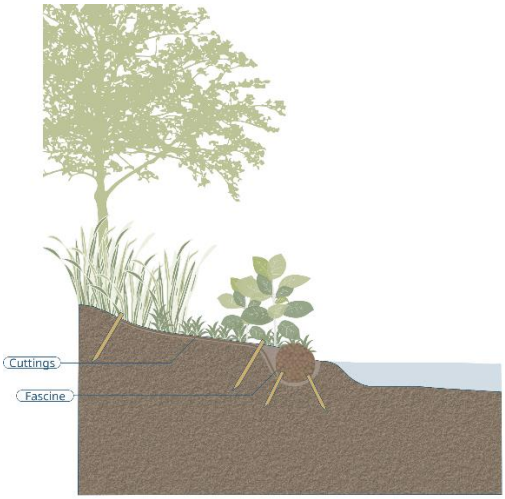
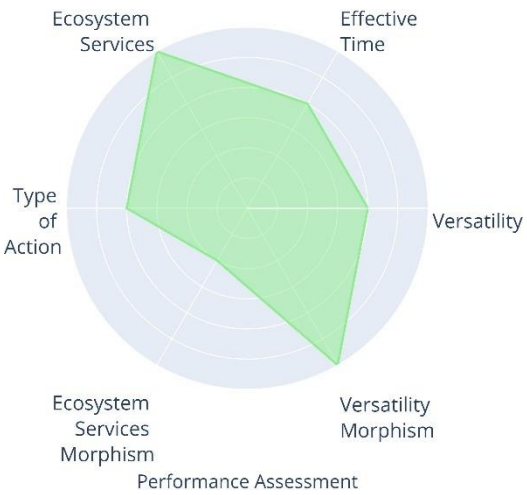
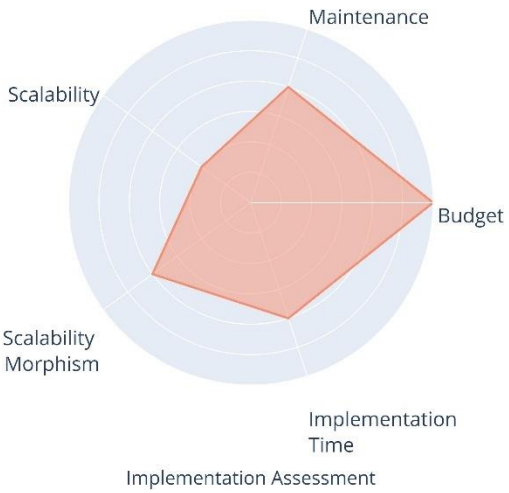
Addressed Challenge	 	**Type of Action**	
Description	Living revetments are a constructed layer of a mix of alive/dead vegetation that is used to cover the riverbank and prevent erosion. Often in combination with living fascines.	**Scale of Action**	
Analogy	• Spreitlage • Brush Mattress • Brush And Hedge Layers • Dormant Cuttings • Live Brush Mats.	 Source: (Kota Kita, 2024)	
Naturalistic Design	The revetments simulate a natural vegetation layer with extensive root network that provide protection against erosion and stabilize the river embankment.	**Installation & Implementation Requirements**	• Branches: 2,5 years old, 1.5 m long, local species. • Common material: non-rooting: shrub branches, rooting: willow. • Installation along hillside, fixation along embankment with wooden stakes (3-5 m length, 4-8 cm diameter). • Timing of installation/planting important. • Willow revetments are suitable for large channels. • Native plants should be selected.
Maintenance	If no flooding occurs, no maintenance is required		
Benefits/ Limitations	(+) Stabilizing the hillside and providing erosion control and water bank. (+) Provides habitats near the riverbanks. (-) Needs a certain growing time until living revetment is fully developed (-) Difficulties in calculating riverbanks stability.	**Ecosystem Services**	• Water availability regulation • Regulating & maintaining soil formation • Erosion control • Nutrient cycling • Enabling of aesthetic value • Habitat provisioning
Sources	(UNaLab, 2019, 2022)		

Source: GIZ, Thailand, 2020

Living Weir





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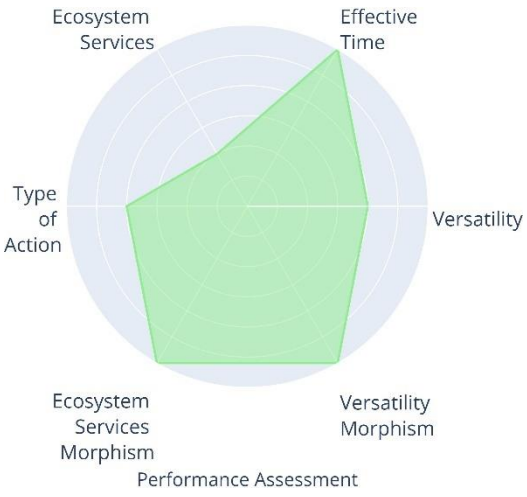
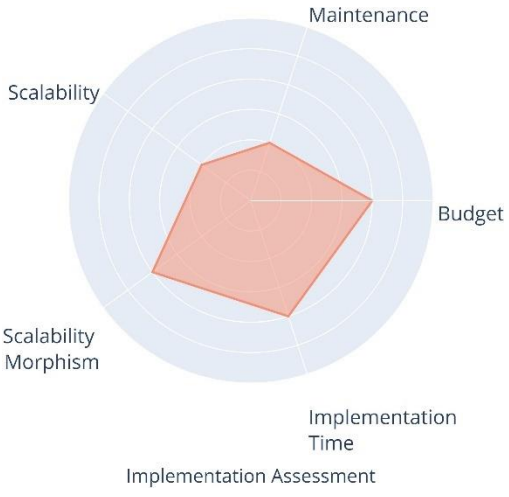
POLYURBAN WATERS

Addressed Challenge		**Type of Action**	
Description	Living weirs are created by constructing a bamboo grid across a river and filling it with sandbags that contain natural materials like sand, coconut coir, and manure. Various trees and plants are planted along the riverbanks to stabilize the soil, with banyan trees specifically planted on either side of the weir. Over time, these banyan trees grow and integrate into the structure, forming the living weirs.	**Scale of Action**	
Analogy	Bambo Weirs.		 Source: (Hicks & Mills, 2022)
Naturalistic Design	The bamboo grid and sandbags decrease the water flow in the river or stream, causing the water to disperse and be absorbed by the adjacent soil. By slowing the water's movement, living weirs aid in preventing soil erection.	**Installation & Implementation Requirements**	• Cement weirs could be used despite it is not NbS • Management can be enhanced and made more systematic by establishing local living wires and/or forming water management committees. • Building cascades of living weirs can provide greater benefits from hydrological ecosystem services compared to individual weirs.
Maintenance	Requires regular inspections and maintenance		
Benefits/ Limitations	(+) mitigating flood and drought impacts by enhancing groundwater recharge (+) benefits for biodiversity. (+) slow the speed of streamflow (+) Increase the sub-surface water storage (+) Increase cultural and leisure activities around living weirs sites (-) decreased fish abundance downstream of the flood detention area (-) downstream villages may face water shortages. (-) May results in contaminated water resulting in odors due to stagnant water in the canal.	**Ecosystem Services**	• Habitat provisioning • Climate regulation • Water availability regulation • Regulation & maintenance of pollination cycle • Enabling of knowledge systems • Enabling of educational values • Enabling of aesthetic values • Enabling of social relations • Enabling of recreation and ecotourism • Primary production • Enabling of sense of place • Enabling of cultural heritage values
Sources	(Hicks & Mills, 2022)		

Source: ITT-TH Köln, Vientiane, Laos, 2022

Planted Channels and Rills





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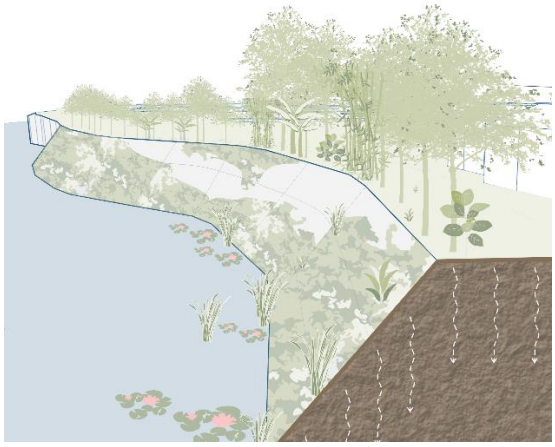
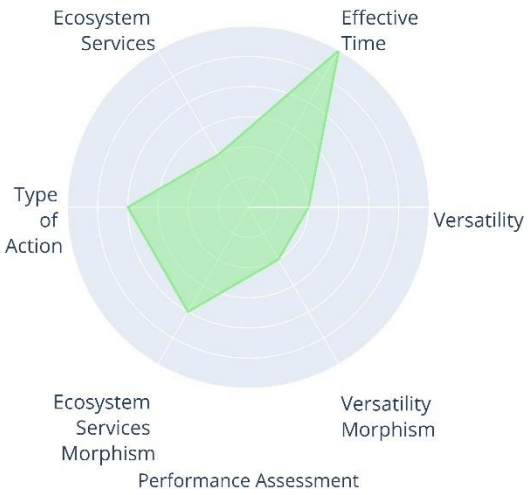
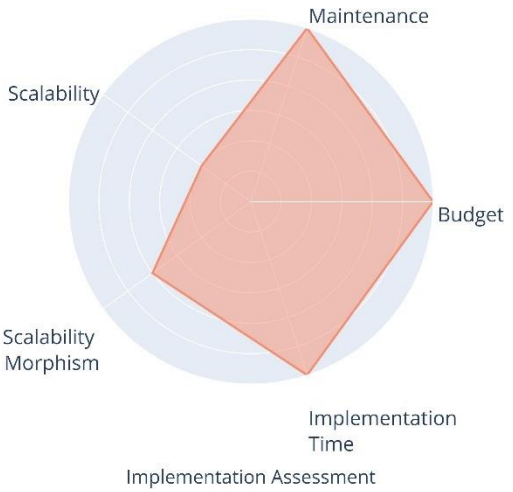
POLYURBAN WATERS

Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Shallow open surface water channels collect water, slow down the velocity and provide storage for silt deposited from runoff. Can be incorporated into the upper parts of a chain of NbS. Greening of the channels enhances amenity and biodiversity.	 Source: (Kota Kita, 2024)	
Analogy	Planted trenches.		
Naturalistic Design	Natural processes enhanced by channels and rills in combination with planted surroundings are the slow-down and storage of runoff, soil conservation and the reduction of surface temperatures.	**Installation & Implementation Requirements**	• Channels and rills require minimal land take. • Most effective when draining from a catchment with a small impermeable area. • The design is highly adaptable, allowing an easy integration with architectural and landscape choices. • Shallow depth: max. 15-30 cm.
Maintenance	• Regular inspection and maintenance to ensure effective ongoing operation. • Maintenance includes removal of sediment, litter, and debris. • If vegetation is deliberately incorporated, it will need to be maintained, any vegetation growth should be regularly removed.		
Benefits/ Limitations	(+) capture of runoff at the beginning of a SuDS train, allowing the deposition of sediment and conveying the runoff to downstream SuDS features. (+) Planting in channels and rills can visually enhance the urban landscape and offer biodiversity and amenity values. (-) Incorrect planting can cause silt build up. (-) Careful consideration to crossings should be given.	**Ecosystem Services**	• Climate regulation • Storm protection • Water availability regulation • Enabling of aesthetic value. • Erosion control • Habitat provisioning
Sources	(NWRM, 2013-2015, 2015; Petsinaris et al., 2020)		

Planted Embankment Mat

Source: ITT-TH Köln, South Korea, 2022





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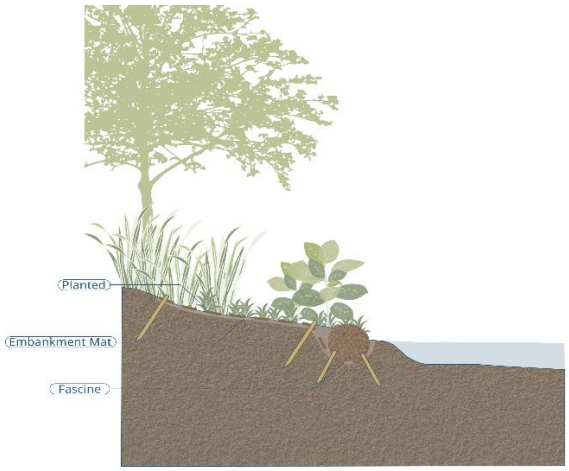
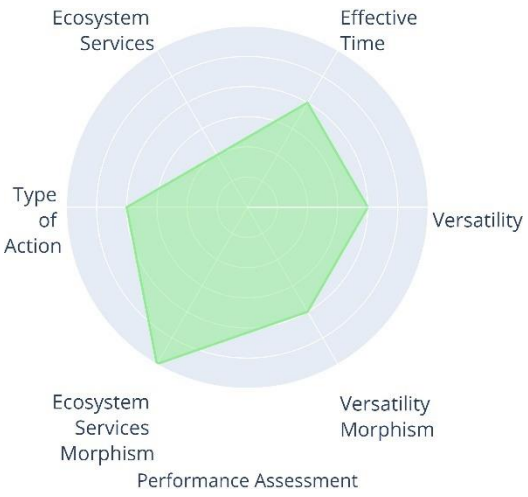
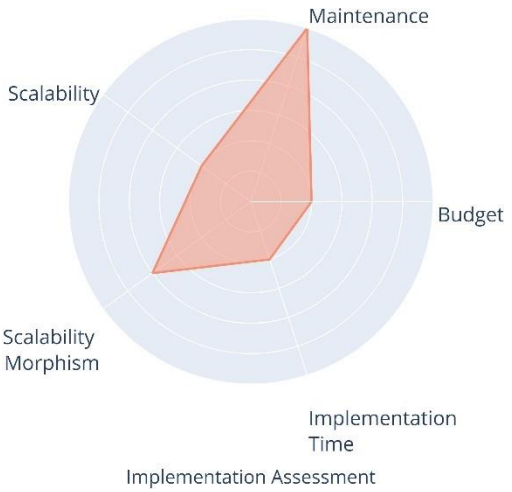
POLYURBAN WATERS

Addressed Challenge	 	**Type of Action**	
Description	Fast rotting mats (jute or coconut) covered with vegetation are installed along the riverbank to prevent erosion.	**Scale of Action**	
Analogy	• Vegetated Erosion-Control Mat • Vegetated Erosion Control Blanket • Erosion Control Planted Mat • Vegetated Geotextile.	 Source: (Kota Kita, 2024)	
Naturalistic Design	Embankment mats simulate natural vegetation layers with extensive root network that provide protection against erosion. The vegetation slows down water velocity while providing sedimentation.	**Installation & Implementation Requirements**	• Mats covered with a vegetation layer e.g. seeding and plants are installed along the riverbank. • Fast rotting mat material: jute/ coconut fiber. • Vegetation layer material: local plants/ trees/ scrubs/ meadow. • Timing of installation/planting important (no rainfall/ low water flow). • Robust local plant species.
Maintenance	No maintenance required.		
Benefits/ Limitations	(+) Stabilize the riverbank and provide erosion control and water bank. (-) Needs a certain growing time until the vegetation is fully developed. (-) Difficulties in calculating riverbanks stability.	**Ecosystem Services**	• Water availability regulation. • Enabling of aesthetic value. • Erosion control. • Regulating & maintaining soil formation. • Nutrient cycling. • Habitat provisioning.
Sources	(NWRM, 2013-2015, 2015; Petsinaris et al., 2020)		

Source: Public Utilities Board, Singapore, 2016

Re-meandering of Rivers





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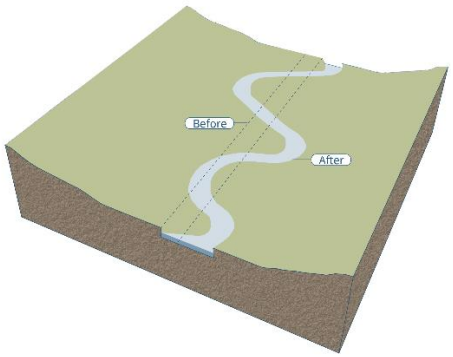
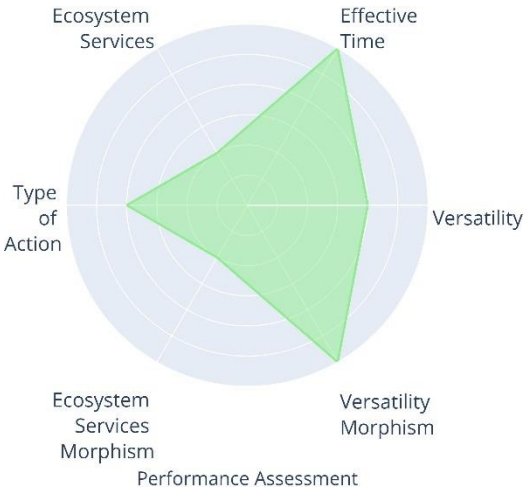
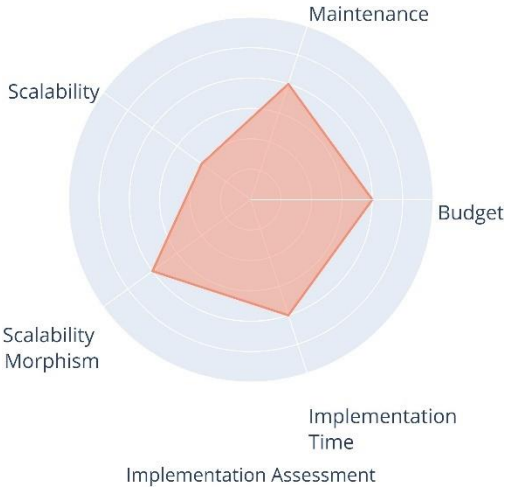
POLYURBAN WATERS

Addressed Challenge		**Type of Action**	
Description	Re-meandering the restoration of original curves of the river course by creating new meanders and reconnecting old cut-off ones. Re-meandering aims at reducing the water flow and increasing the length of the river leading to increased water storage capacity.	**Scale of Action**	
Analogy	• River Restoration-Meandering • Bedway Restoration.		 Source: (Kota Kita, 2024)
Naturalistic Design	A natural curved river course has a slower river flow and is longer and therefore has a higher water capacity.	**Installation & Implementation Requirements**	• Advisable to make research on the natural river behaviour before construction. • Large space required. • Heavy machinery needed.
Maintenance	• Low maintenance required. • maintenance could be an advantage by keeping the entrance open.		
Benefits/ Limitations	(+) Slowing the velocity of the river. (+) Erosion reduction. (+) Aesthetical value. (-) Heavy engineering with high impact on river ecosystem. (-) Significant land use changes (i.e. loss of agricultural land, resettlement etc.).	**Ecosystem Services**	• Water availability regulation. • Enabling of recreation and ecotourism. • Erosion control. • Regulating & maintaining soil formation. • Enabling of aesthetic values. • Habitat provisioning.
Sources	(NWRM, 2015; Petsinaris et al., 2020; Wesenbeeck et al., 2021)		

Source: iStock, UK, 2018

Renaturation/ Revegetation of Water Courses





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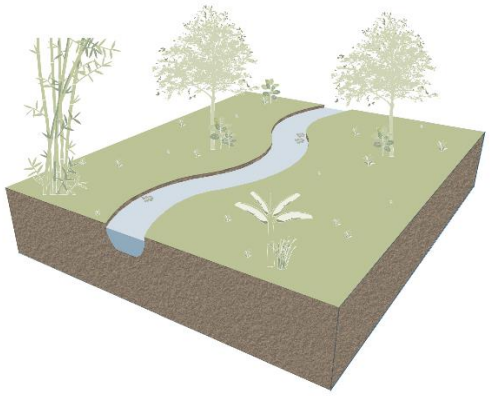
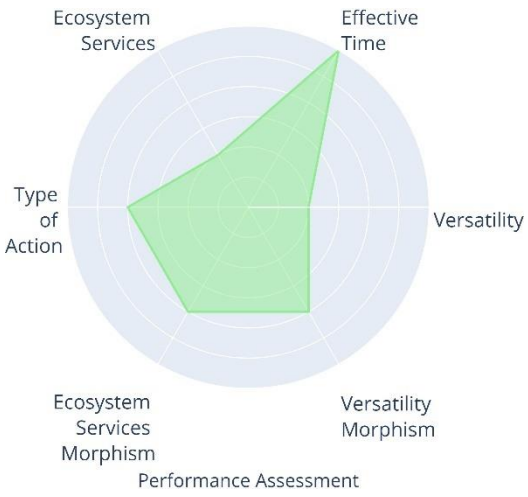
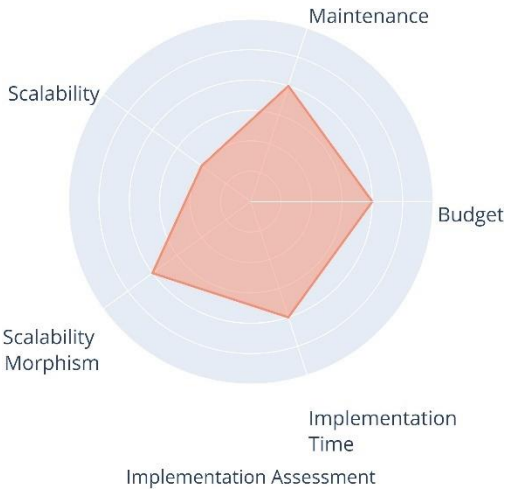
Addressed Challenge		**Type of Action**	
Description	The NbS focuses on the de-culverting of covered watercourses by the removal of concrete layers as culverting watercourses lead to the degradation of habitats and increase water pollution. This process can be combined with a re-naturalization of the channel by opening and allowing natural development of riverbed.	**Scale of Action**	
Analogy	• Bank and bed renaturation. • Stream daylighting. • Unearth water courses.	 Source: (Kota Kita, 2024)	
Naturalistic Design	The exposure of water channels to daylight supports a natural development of water courses that is essential for aquatic life, plants and water quality. The vegetation of riverbed and riparian zone enables water to expand to its riversides and reduces the flow velocity.	**Installation & Implementation Requirements**	• Removal of the entire culverted structure, • Removal of top layer. • Creation of gaps in top layer. • Re-naturization includes removal of entire culverted structure in combination with restoration of the riparian zone to a natural shape with rocks and plants. • Technical expertise and knowledge about soil material is needed. • A natural restoration is associated with greater effort than only removing the top layer of a watercourse and keeping of constructed.
Maintenance	• Periodical removal of sediments to prevent clogging. • Regular inspections after re-naturization process.		
Benefits/ Limitations	(+) Create more space and increase storage capacity enabling a higher uptake of storm water runoff. (-) Potential safety issues for citizens (falling into channels). (-) Open channels within urban areas can present a barrier for citizens with limited mobility. (-) Potential to increase the number of mosquitos that may cause diseases.	**Ecosystem Services**	• Water availability regulation. • Storm protection. • Water purification and waste treatment. • Enabling of aesthetic values. • Habitat provisioning.
Sources	(California Stormwater Quality Association, 2003; Gallacher, 2017; UNaLab, 2019; URBAN GreenUP, 2018)		

Source: SCRT, Staveley, England, 2016

Reprofiling River Channel Cross Section





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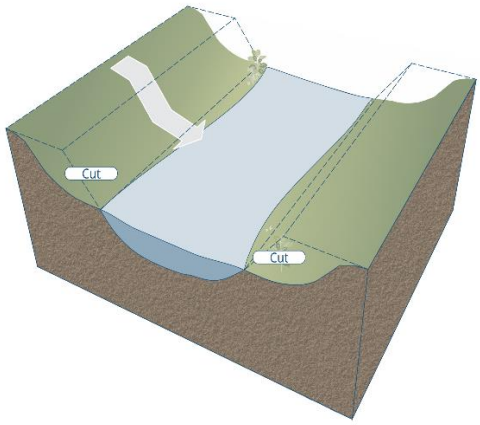
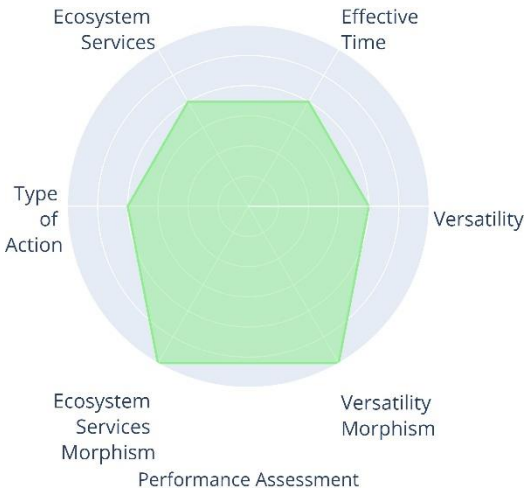
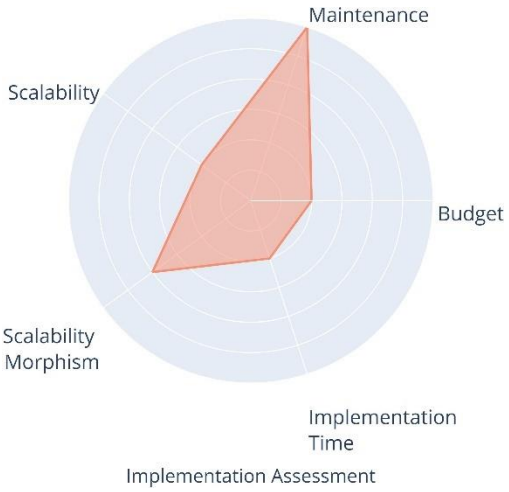
Addressed Challenge		**Type of Action**	
		Scale of Action	
Description	Reprofiling of the river channel cross-section towards a wider and more natural profile including shallow and deep waters and fast and slow flowing areas.		 Source: (Kota Kita, 2024)
Analogy	• Riverbank Removal • Embankment Removal		
Naturalistic Design	Natural river courses have sediment shifting processes and changing depths and widths throughout the cross sectoral profile. Sediments of different size accumulate and natural processes such as filtering, storage and infiltration occur. A natural river cross section with sediment shifting processes allows sedimentation accumulation and prevents erosion of the riverbank.	**Installation & Implementation Requirements**	Enlarging the flood plain, shifting substrate within the river and bottom out banks.
Maintenance	No regular maintenance is required.		
Benefits/ Limitations	(+) Allows sedimentation accumulation and prevent erosion of the riverbank. (+) discharge capacity of floodwater could be increased. (+) Reduce the flood risk. (-) Conflict with the neighboring population interests where the bank removal may affect the agricultural lands during the flooding periods.	**Ecosystem Services**	• Water availability regulation • Enabling of aesthetic values • Erosion control • Enabling of recreation and ecotourism • Regulating & maintaining soil formation
Sources	(UNaLab, 2019; World Bank, 2021)		

Source: MERLIN, Scotland, 2021

River Branching





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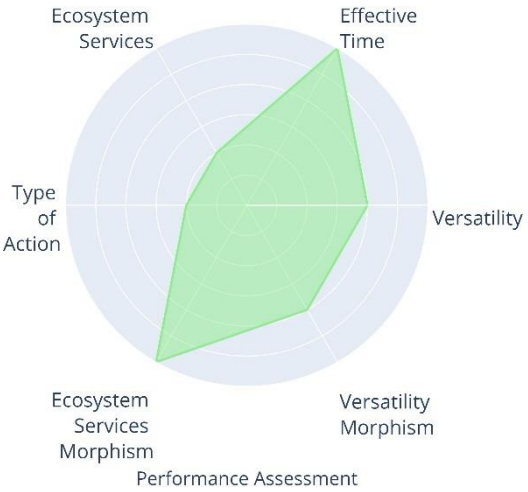
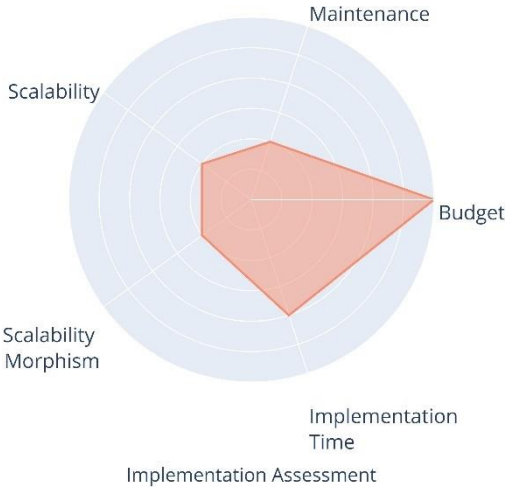
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Creation of a new river branch and flat riverbanks. The second river branch provides additional flood space.	 Source: (Kota Kita, 2024)	
Analogy	• Floodplain Expansion. • Dividing River.		
Naturalistic Design	The additional branch is a replication of natural river courses and river landscapes without sealed and cultivated riverbanks.	**Installation & Implementation Requirements**	• The new river branch created should be characterized by relatively flat flood plains and a surrounding area with space for natural development. • Large space for additional branches required. • Technical effort depends on project design and natural conditions. • Heavy machinery needed. • Water depth/flow must be taken into account. • Heavy machinery needed.
Maintenance	No maintenance is required.		
Benefits/ Limitations	(+) Provide additional water storage capacity. (+) Extra flood space by dividing the discharge into two branches and reducing flood. (-) Significant land use changes (i.e. loss of agricultural land, resettlement etc.). (-) Limitation for river restoration if there is a need for preservation of existing infrastructure. (-) Possible conflict between habitat provision for wildlife and human recreation. (-) Potential to increase the number of mosquitos which may cause diseases.	**Ecosystem Services**	• Fresh water provisioning • Climate regulation • Enabling of aesthetic values • Water availability regulation • Enabling of recreation and ecotourism • Erosion control • Habitat provisioning
Sources	(Addy et al., 2016; Prominski et al., 2017; UNaLab, 2019)		

Bioswales

Source: ITT-TH Köln, Bangkok, 2023





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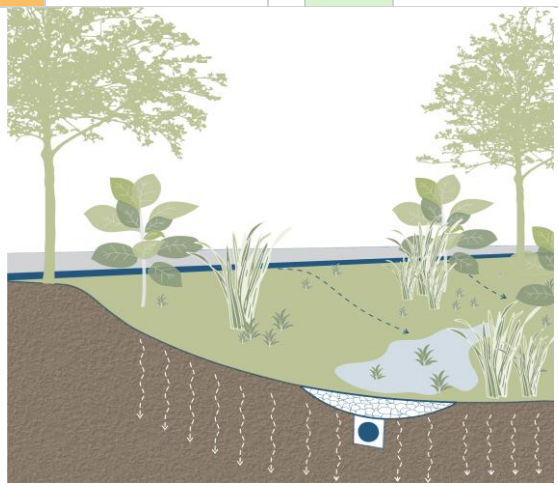
Addressed Challenge	
Description	Swales are vegetated, linear and low-sloped pits (larger than rain gardens) often established in urban areas near and between roads. They absorb, store, and convey surface water runoff (mainly draining from roadways) and remove pollutants and sediments when the water trickles through the vegetation and soil layer. Additionally, swales can serve as traffic harassment and can be implemented in combination with other NbS.
Analogy	• Grassed Swale • Vegetated Filter Strip • Stripswale • Vegetated Swale
Naturalistic Design	The vegetation and soil layer retain and store water, water infiltrates into the soil while plants and soil are natural filters for organic pollutants, sediments and other substances. The natural riverbed conveys water and plants take up and transpire water.
Maintenance	• Regular maintenance and inspection include grass cutting and removal of sediment. • The appropriate cycle of inspection is 1-2 years.
Benefits/ Limitations	(+) Usually vegetated with grass or other low maintenance plants (+) Correctly sizing, will provide adequate drainage and removal of particulate pollutants (+) the required elevation change is minimal (-) Limitation for planting trees: habitat provision is limited to ground level (-) Risk of blockages in connecting pipe work Risk of pollution to groundwater depending on site. (-) Prone to channelization and erosion in the absence of appropriate vegetative cover maintenance.
Sources	(California Stormwater Quality Association, 2003; Petsinaris et al., 2020; UNaLab, 2019; URBAN GreenUP, 2018)

Type of Action	
Scale of Action	

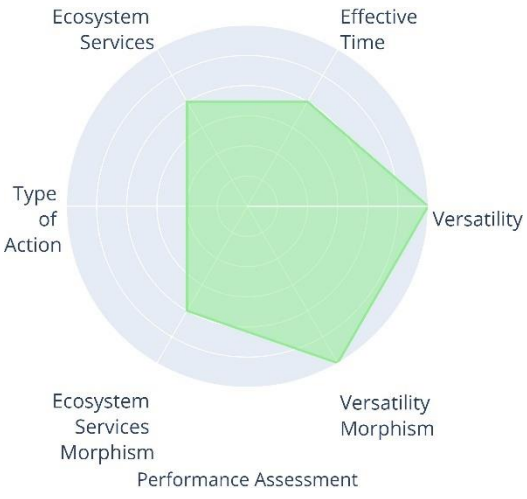


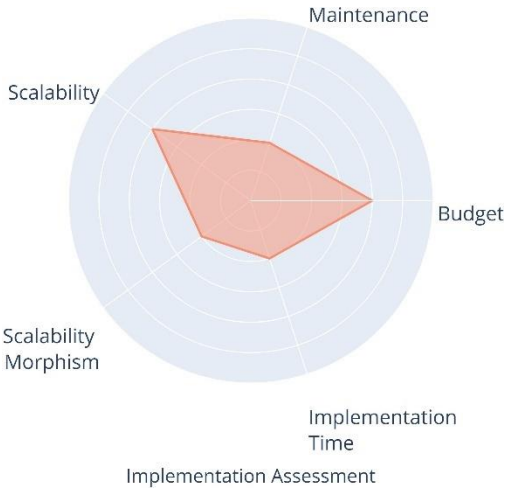
Source: (Kota Kita, 2024)

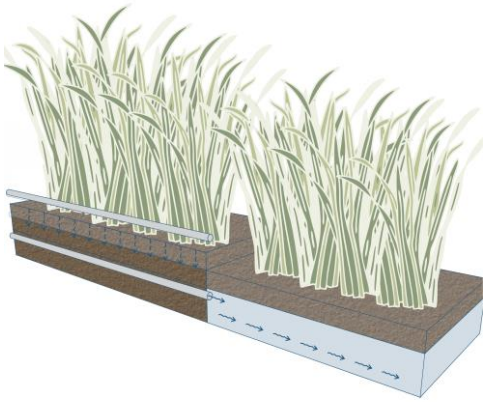
Installation & Implementation Requirements	• Relatively dense vegetation to slow down water, but too dense vegetation would be negative for water conveyance. • Best to use native deep-rooted plants that withstand occasional flooding. Often used is grass in combination with other plants for aesthetic reasons. • Installed only when rains provide enough moisture for plants to establish themselves without the need for irrigation. • Storm water from roofs or paved areas must be led into the bio swale through rills/channels • Standards concerning public safety must be met.
Ecosystem Services	• Climate regulation • Water availability regulation • Enabling of aesthetic values • Erosion control • Habitat provisioning • Water purification and wastewater treatment

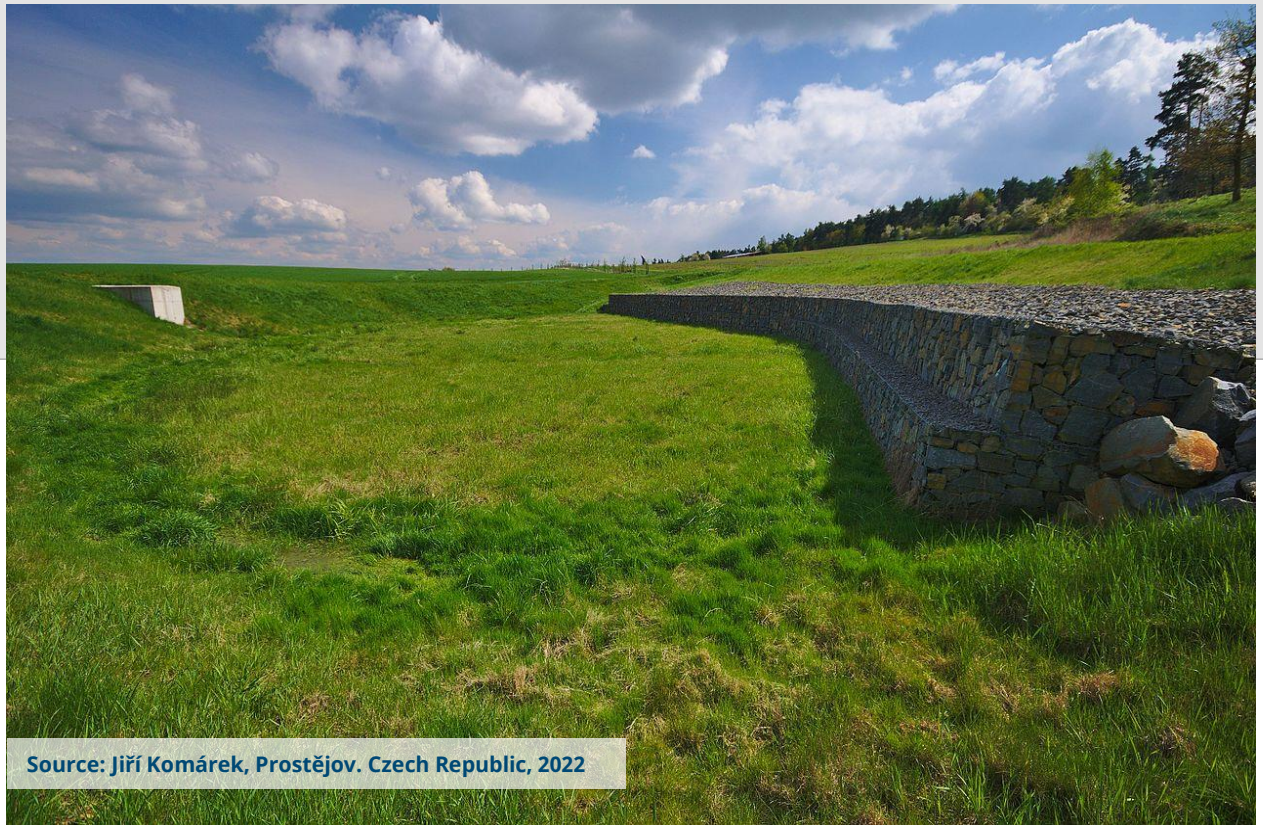
Source: Agaton and Guila, Bayawan City, Philippines, 2024

Constructed Wetlands



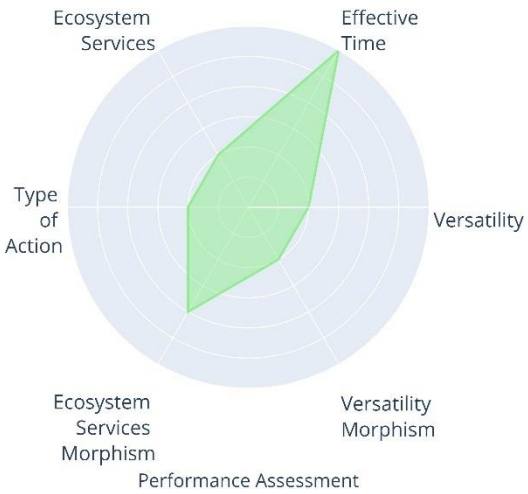


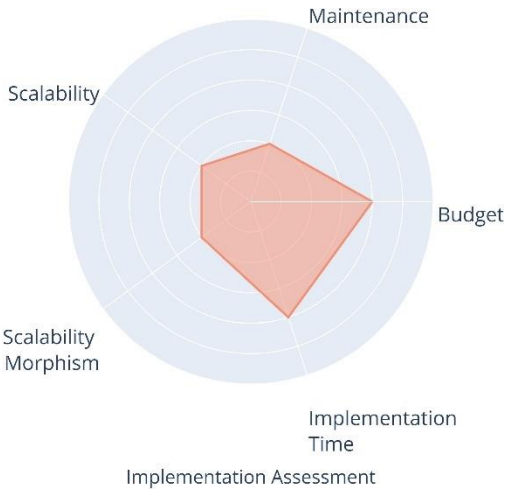
Addressed Challenge	
Type of Action	
Scale of Action	
Description	Constructed wetlands are designed shallow basins used for water treatment such as filtering pollutants from water. The processes and services of natural wetlands are adapted to constructed wetlands and are used as a solution to treatment of combined sewer overflow during heavy rainfall events.
	 Source: (Kota Kita, 2024)
Analogy	• Artificial Wetlands • Planted Wetlands
Naturalistic Design	Constructed wetlands replicate natural wetland processes that include the storage of water and purification: settlement of particles, filtration, chemical transformation, adsorption and ion exchange e.g. on plants and substrates and uptake/ breakdown/ transformation of pollutants and nutrients by microorganisms and plants.
Installation & Implementation Requirements	• Large space required • Suitable locations: outside floodplains, gently sloped location, near wastewater • The substrate type is variable but usually constructed wetlands are filled with sand or gravel. • The substrate layer is planted with vegetation/aquatic plants • According to the type of constructed wetlands, wastewater can flow horizontal over the ground surface, horizontal under the ground surface and through the substrate layer, or vertical through the constructed wetland (hybrid systems) • Relatively simple construction: bricks - underlying gravel layer -drainage layer -filling material (little stones or sand)
Maintenance	• Low maintenance with regular inspection • Seasonal cutting of vegetation
Benefits/ Limitations	(+) Water temperature control and provision. (+) Water quality Improvement. (+) Flood control / mitigation (+) Habitat for wildlife (-) Potential to increase mosquitoes which may cause diseases (-) Requires large area or scattered units
Ecosystem Services	• Climate regulation • Water availability regulation • Recreation and ecotourism • Erosion control • Nutrient cycling • Water purification and wastewater treatment • Primary production • Habitat provisioning
Sources	(Liquete et al., 2016; NWRM, 2015; Petsinaris et al., 2020; UNaLab, 2019)



Source: Jiří Komárek, Prostějov. Czech Republic, 2022

Dry Detention Pond





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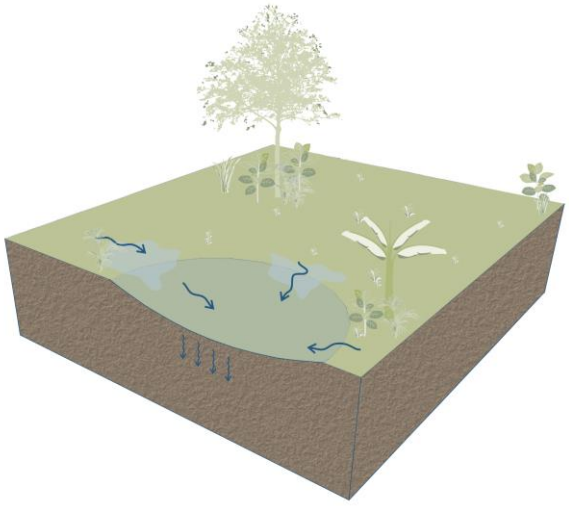
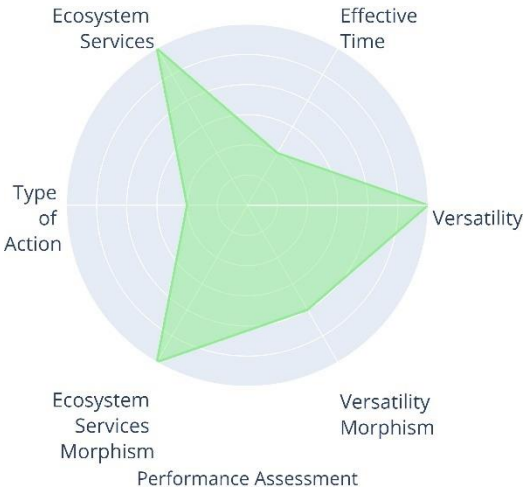
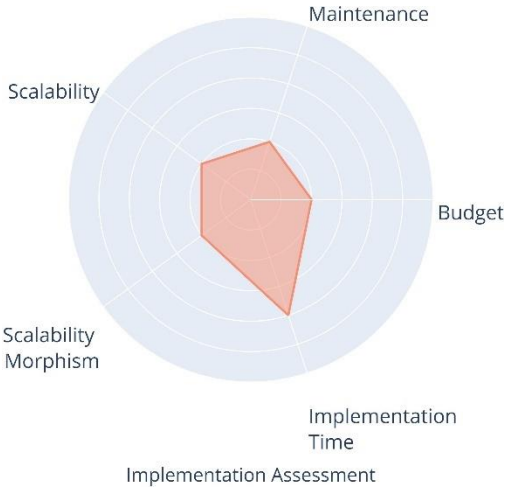
Addressed Challenge		**Type of Action**	
		Scale of Action	
Description	Dry detention ponds are vegetated detention basins designed for short-term temporal water storage during heavy rain occasions. Stormwater fills up the detention pond and detained water then flows into the sewer system. In periods of no heavy rainfall, the detention ponds are dry and can be used as public green areas. The natural landscape in which the detention pond is being implemented contains a heterogeneous surface with slightly elevated areas and lower parts in proximity, forming a mosaic of micro conditions. Water stays in the lower parts for some time until it infiltrates or evaporates.	 Source: (Kota Kita, 2024)	
Analogy	• Bioretention Area • Detention Pond • Dry Detention Pond • Dry Detention Basin • Retention Pond • Dry Retention Pond • Dry Retention Basin		
Naturalistic Design	Detention ponds mimic a natural landscape that contains a heterogeneous surface with slightly elevated areas and lower areas in proximity, forming a mosaic of micro conditions. Water remains in the lower parts for some time until it infiltrates or evaporates. Dry retention ponds, however, mimic natural ponds that have standing water (although at various levels) year-round. Similar to natural ponds, retention ponds store stormwater and run-off and provide habitat for aquatic and semi aquatic species.	**Installation & Implementation Requirements**	• Must always be at the lowest part of the green space. • Traditional dry detention ponds can be used as green areas in times without heavy rainfall events. dry detention ponds can improve biodiversity enhancement potential if designed to have, for example, greater structural diversity (e.g., inclusion of various substrates in dry detention ponds). • Needs to be appropriate available area (enough space to flood) with proper soil and rainfall conditions. • Limited design options, they could be considered in park planning.
Maintenance	• Litter and debris removal. • Vegetation maintenance. • Sediment removal from forebay. • Sediment removal from permanent pond. • Ongoing inspections and monitoring.		
Benefits/ Limitations	(+) Regulates heavy rain. (+) Multifunctional use of detention pond is possible. (-) Limited design options. (-) Green space with too many functions a reduced recreation space.	**Ecosystem Services**	• Enabling of aesthetic values • Climate regulation • Enabling of social relations • Water availability regulation
Sources	(Petsinaris et al., 2020; UNaLab, 2019; URBAN GreenUP, 2018)		

Source: Netherlands Institute of Ecology, Netherlands, 2012

Electro Wetlands





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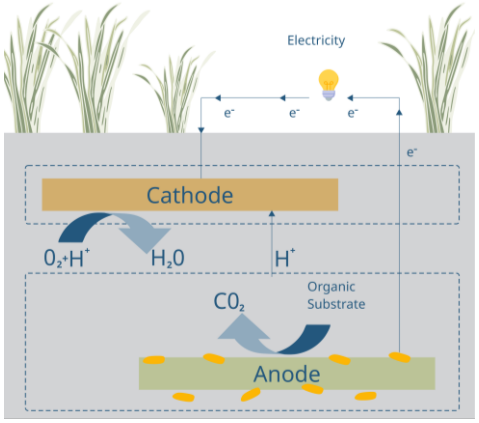
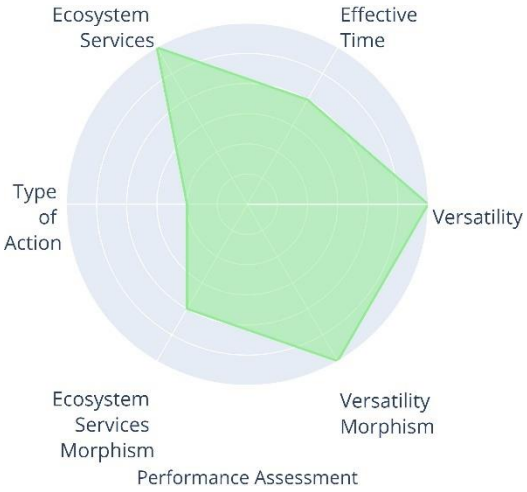
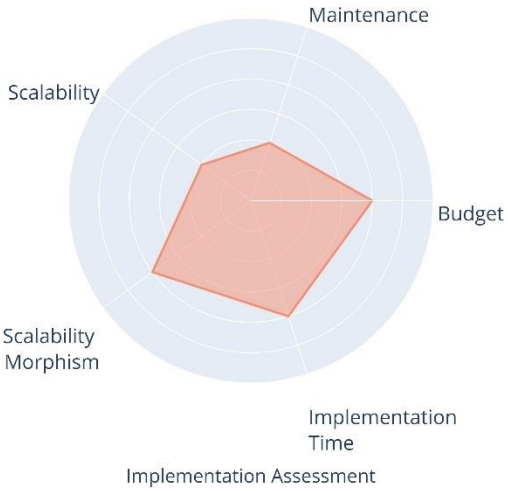
Addressed Challenge		**Type of Action**	
Description	An electro wetland is a natural system for treating wastewater that produces electricity through the oxidation of organic matter. It is built upon a standard Horizontal Subsurface Flow Constructed Wetland (HSSF CW) with the addition of electrodes. (Cathodes and Anodes).		 Source: (Kota Kita, 2024)
Analogy	• Planted Microbial Fuel Cell • Sediment Microbial Fuel Cell • Constructed Wetland Microbial Fuel Cell		
Naturalistic Design	Wetlands are intricate systems characterized by their vegetation, soil, and microbiological activity. The processes and services found in natural wetlands are adapted for use in constructed wetlands, primarily aimed at water purification and storage. Key processes in a constructed wetland include particle settling, filtration, chemical transformation, adsorption, cation exchange, and the uptake, breakdown, or transformation of pollutants and nutrients. When electrodes are incorporated, the biological processes are harnessed to generate electricity.	**Installation & Implementation Requirements**	• Can be built in an area which generates wastewater with a significant content of organic matter • Normally, the electrode layer is crossed horizontally by wastewater flow from one side to the other of the system Conventional design parameters are as following: - Range of application < 2000 he - Surface requirement ~ 5m^2/p.e. - Bed depth is 0.4-0.6 m - Organic loading is 8.7 g BOD/m^2*d
Maintenance	A regular monitoring and cleaning tasks are required.		
Benefits/ Limitations	(+) Electricity generation (+) Water temperature control and provision. (+) Water quality Improvement. (+) Flood control / mitigation (+) Habitat for wildlife (-) Potential to increase mosquitoes which may cause diseases (-) Requires large area or scattered units	**Ecosystem Services**	• Fuel provisioning • Enabling of aesthetic values • Climate regulation • Enabling of recreation and ecotourism • Erosion Control • Nutrient cycling • Primary production • Water availability regulation • Water purification and wastewater treatment • Habitat provisioning
Sources	(Ortega de Miguel, 2010; Patwardhan et al., 2021; UNaLab, 2022; URBAN GreenUP, 2018)		

Fishponds

Source: ITT-TH Köln, Sariharjo Indonesia, 2023





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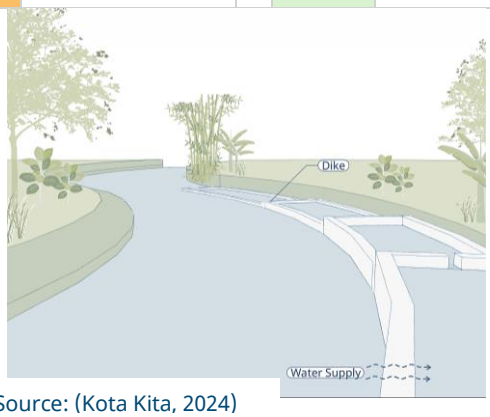
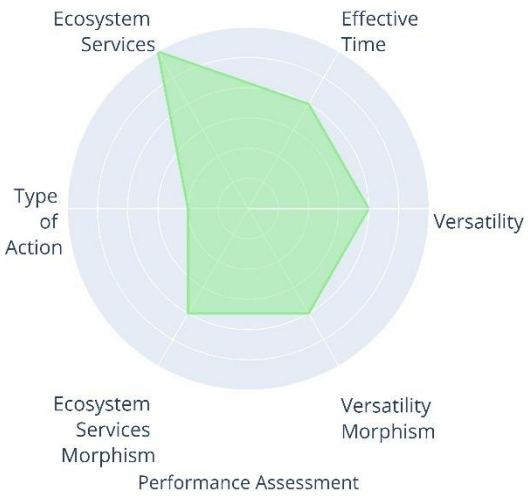
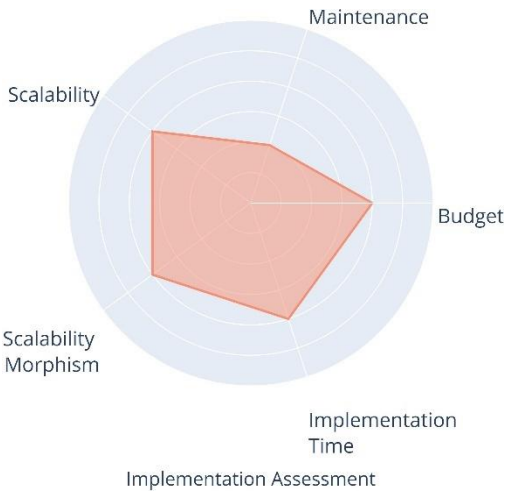
Addressed Challenge		**Type of Action**	
Description	Ponds are considered as small bodies of standing water ranging from 1 m² to 2–5 hectares, which can be permanent or seasonal, and either man-made or naturally formed. In other hand, Pondscape is a network of ponds spread out within a terrestrial matrix, highlighting their spatial distribution and connectivity.	**Scale of Action**	
Analogy	• Pondscapes. • Networks of Ponds.		 Source: (Kota Kita, 2024)
Naturalistic Design	Wetlands are intricate systems characterized by their vegetation, soil, and microbiological activity. The processes and services found in natural wetlands are adapted for use in constructed wetlands, primarily aimed at water purification and storage. Key processes in a constructed wetland include particle settling, filtration, chemical transformation, adsorption, cation exchange, and the uptake, breakdown, or transformation of pollutants and nutrients. When electrodes are incorporated, the biological processes are harnessed to generate electricity.	**Installation & Implementation Requirements**	• Engaging stakeholders is essential to identify the various interests involved in areas where pond and pondscape NbS might be developed, restored, or managed. • Fishponds can be applied with rice fields as an integration for rice-fish production systems. • Fishponds can be linked to land ownership or land use, as it common to take place in a privately owned land • Dike Construction: Dikes must resist water pressure, be impermeable, and have the correct height and slope. • Compaction: Vital for stability, using either manual or mechanical methods. • Foundation Preparation: Treat surfaces, build cut-off trenches, and prepare channels to prevent seepage.
Maintenance	Mimic a natural pond that contains an elevated bank and lower basin with inlet and outlet to keep the pond wet for fishes breeding. A source for water is important during dry season while an outlet is important during the flooding season to discharge the excess water quantities for further uses.		
Benefits/ Limitations	(+) Recreational possibilities. (+) Climate mitigation. (+) Food provision. (-) Lacking sufficient knowledge on managing and restoring ponds to optimize their role in enhancing the resilience of ecosystems and society against climate change. (-) For pond management, different challenges are presented especially in securing funding.	**Ecosystem Services**	Food and fiber provisioning • Habitat provisioning • Climate regulation • Water availability regulation • Water purification and waste treatment • Regulation and maintenance of pollination cycle • Enabling of knowledge systems • Enabling of educational values • Enabling of aesthetic values • Enabling of social relations • Enabling of recreation and ecotourism • Primary production
Sources	(Boothby, 1997; Cuenca-Cambronero et al., 2023; FAO, 2016; Richardson et al., 2022; WorldFish, 2022)		

Source: UN, Inle Lake floating garden, Myanmar, 2023

Floating Gardens





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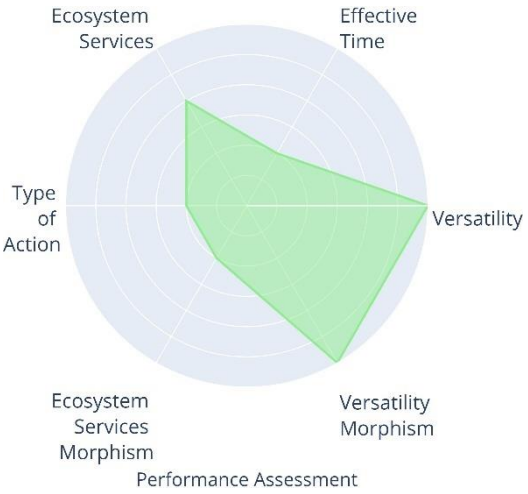
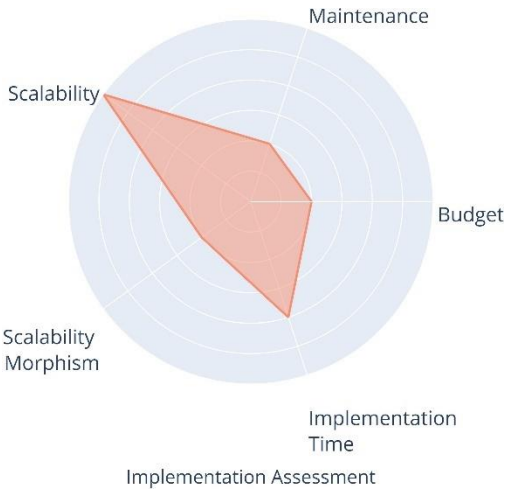
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Floating gardens typically consist of rafts that enable certain plants to be grown hydroponically, with their roots extending into the water. These gardens can be used for growing vegetables, for decorative purposes, or both	 Source: (Kota Kita, 2024)	
Analogy	• Floating Farming • Floating wetland		
Naturalistic Design	Gardens float on flooded land or small ponds and can be utilized year-round for both summer and winter crops, providing families with sufficient vegetables for consumption and sale.	**Installation & Implementation Requirements**	• constructed from a plant material floating • As the sublayer, a floating base is used of plant materials like water hyacinths to support the growth of various plants, animals, or food crops on top. Otherwise, they use materials with a natural buoyancy (plastics or woods) • floating garden strength depends on the raft construction and the material weight which are placed/grown on it. In some cases, several water hyacinth plants are used to construct the floating rafts • he floating garden should stand with all weather conditions • Stainless steel quick connect system with a locking mechanism for effortless garden expansion • Reinforced with full cross-bracing for enhanced durability • Durable UV-resistant, thermo-fused floats • Weighted guide rail-secured concrete anchors
Maintenance	• Regular maintenance • Regular inspections		
Benefits/ Limitations	(+) habitats provision for marine and terrestrial species (+) Considered as habitats linked across urban boundaries (connective features) (+) Climate change mitigation (-) Require extensive areas of land submerged in still water for most of the year (-) water hyacinth plants which is used in some cases to construct the floating rafts is an invasive species (-) Floating gardens' resilience against future climate threats such as drought, temperature increases, or soil salinity due to rising sea levels and storm surges remains uncertain.	**Ecosystem Services**	• Aesthetic values • Air quality maintenance • Enabling of social relations • Climate regulation • Habitat provisioning • Enabling of recreation and ecotourism • Erosion Control • Nutrient cycling • Primary production
Sources	(Chowdhury, 2019; URBAN GreenUP, 2018; Water Environment Federation, 2015)		

Green Roofs

Source: ITT-TH Köln, Suwon, South Korea, 2023





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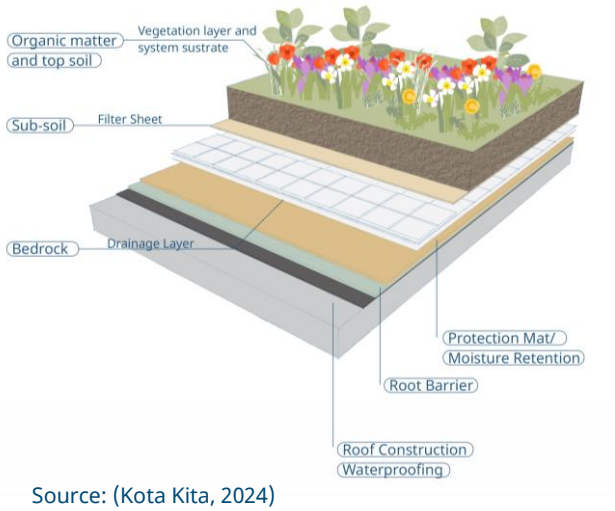
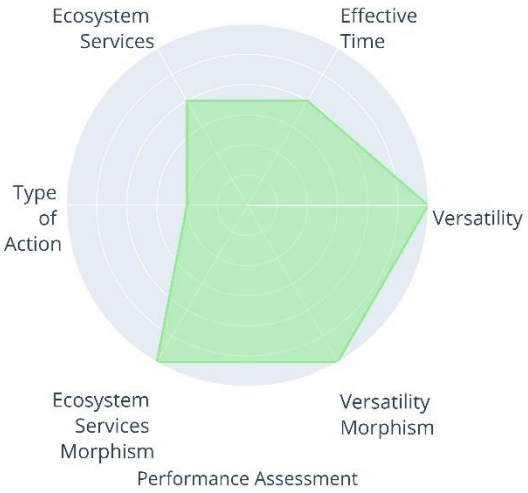
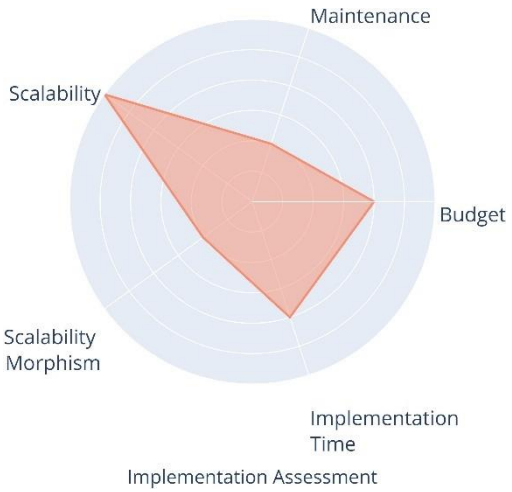
Addressed Challenge		**Type of Action**	
Description	Green roofs are multi-layered systems designed for stormwater management, beginning with a well-insulated, structurally sound roof as the base layer.	**Scale of Action**	
Analogy	• Rooftop Garden. • Eco-roof. • Roof Greening. • Intensive Green Roof.		 Source: (Kota Kita, 2024)
Naturalistic Design	Intensive green roofs mimic natural vegetation layers by consisting of soil and vegetation cover. These roofs offer ecosystem benefits comparable to natural environments, such as retaining rainfall in their soil and mitigating urban heat islands through vegetation shade and transpiration. These features contribute significantly to improving the local environment.	**Installation & Implementation Requirements**	• Installing green roofs on wooden structures may be infeasible due to the moisture and load they impose • Materials of roof structure and design, building load capacity should be taken into consideration • Type of vegetation is important • Planting material and water holding capacity, roof slope, irrigation method, lining, outlet drainage, and overflow drainage should all be considered. • For erosion prevention, mulch Covering or another erosion control method before vegetation is crucial especially during vegetation establishment.
Maintenance	• Regular regulation of vegetation • Regular mowing the frass, trimming the trees, removing the weeds, and harvesting the yields •Inspections for retention water after heavy rainfall		
Benefits/ Limitations	(+) No need for additional land (+) Habitat provision (+) Provide usable green space (-) Requirements for structural support Not applicable for wooden roofs	**Ecosystem Services**	Food and fiber provisioning • Air quality maintenance• Climate regulation • Habitat provisioning• Regulation and maintenance of pollination cycle • Enabling of aesthetic values • Enabling of social relations • Enabling of recreation and ecotourism • Primary production
Sources	(Eisenberg et al., 2022; Sacramento Stormwater Quality Partnership, 2018)		

Green Walls

Source: ITT-TH Köln, Sleman, Indonesia, 2022





Technology Arts Sciences TH Köln
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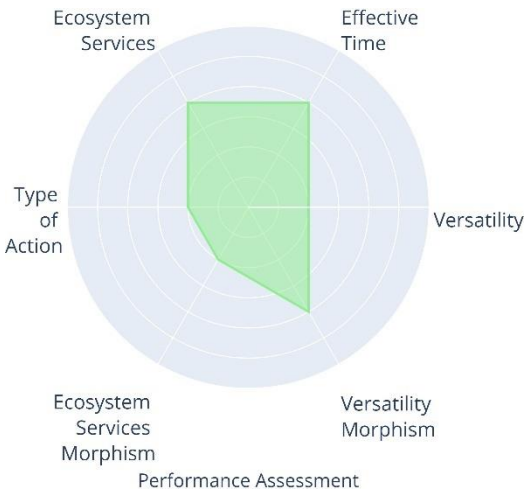
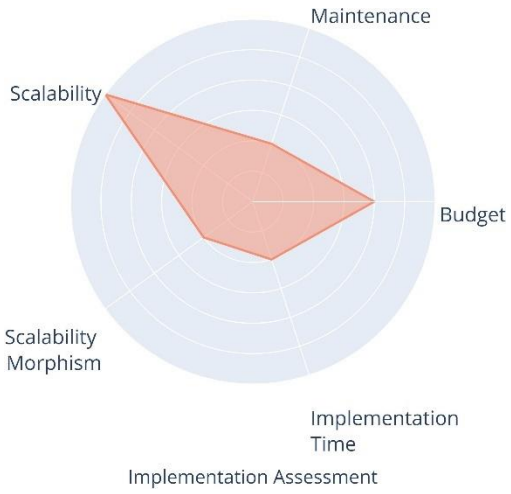
POLYURBAN WATERS

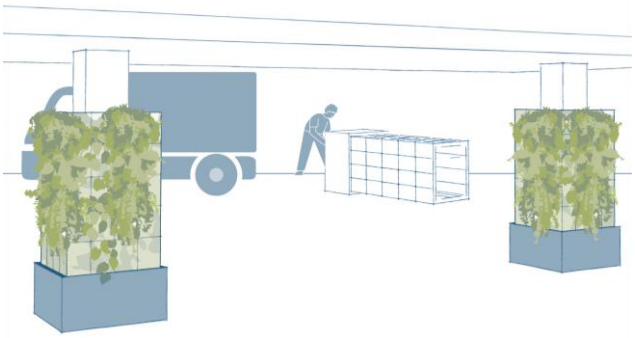
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Green walls are vertical green infrastructure interventions. They provide infiltration areas for water and mainly function as visual and noise barriers between roads/industrial areas and public spaces. The vegetation grows directly on the wall, or climbs on a frame or already structured wall, but keeps a small distance from the wall.	 Source: (Kota Kita, 2024)	
Analogy	• Green Façades • Façade-Bound Greening • Ground-Based Greening • Green Filter • Living Wall • Vertical Greening • Moss Wall • Green Noise Barrier • The City Tree.		
Naturalistic Design	The green filter vegetation is rooted in permeable substrate and enables infiltration of surface water runoff while contributing to reduce the urban heat island effect through evaporation and cooling effects.	**Installation & Implementation Requirements**	• Trees, shrubs, climbers or mosses may be planted directly into the ground or into containers • Can combined with solid barrier construction to reduce noise impact • Increased height (over 5m) and width (10m) will in general increase the effectiveness of green filter areas in reducing concentrations of airborne pollutants • Both density and porosity of low vegetation barriers close to pollution source are important for effective capture of particulate pollutants • Two types of ground-based greening could be either with an external support system and without a support system. • Crucial to use material that can withstand high temperatures • Plenty of sun exposure with mild climatic conditions perform best. • Strong façade with no gaps is important
Maintenance	Maintenance includes regular pruning and irrigation in dry periods and removal and replacement of dead vegetation.		
Benefits/ Limitations	(+) Aesthetically important (+) Heat regulation indoor and outdoor (+) Noise protection (+) Increased habitat connectivity and provision (+) Shelter from the sun radiation (+) Air purification (-) Mostly depended on irrigation (-) When the vegetation is dry, it could be susceptible to fire (-) Requires long time span before walls are fully covered for ground-based greening.	**Ecosystem Services**	• Air quality maintenance • Storm protection • Climate regulation • Enabling of aesthetic values • Water availability regulation • Enabling of recreation and ecotourism • Water purification and waste treatment • Regulating & maintaining soil formation • Habitat provisioning
Sources	(Eisenberg et al., 2022; Pettit et al., 2019; URBAN GreenUP, 2018)		

Source: ITT-TH Köln, Seoul, South Korea, 2023

Vertical Mobile Garden

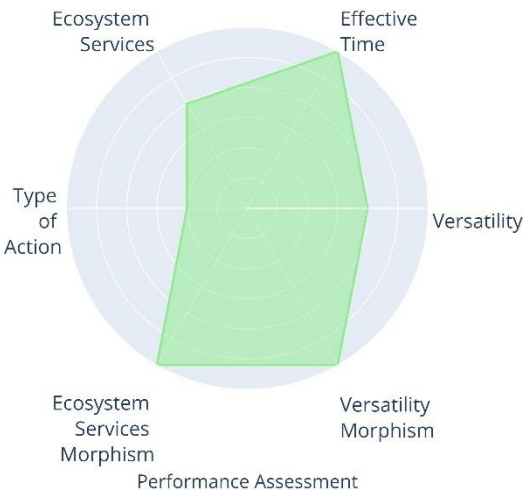


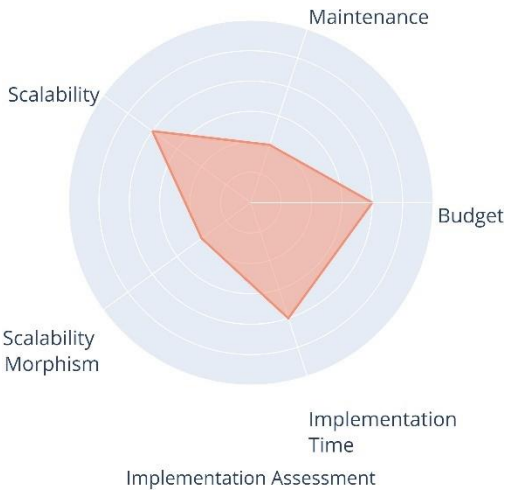


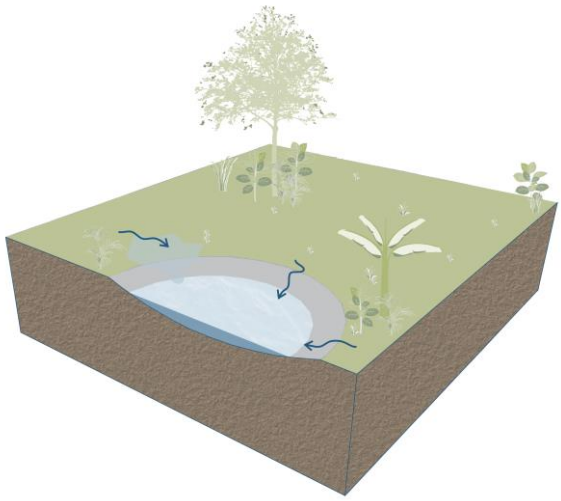
Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Consists of living wall modules, which are wire frame cubes attached to a hook lift container platform. The vegetation cover is highly diverse, showcasing the potential of living walls to enhance amenity value and promote biodiversity. A light, partially vegetated open roof structure provides shade. The Green Living Room offers immediate benefits such as clean air provision, cooling, shading, and creating a habitat for urban biodiversity.	 Source: (Kota Kita, 2024)	
Analogy	• Mobile Green Living Room • Mobile vertical greening.		
Naturalistic Design	Natural soil with vegetation cover, including perennials and shrubs/trees, serves as the model for living walls. However, for "mobile vegetation," there is no natural equivalent for loading and unloading.	**Installation & Implementation Requirements**	• It has an on-board water tank which can irrigate the wall up to a week. • Space for loading and unloading is necessary. • Surface has to be flat (<3°) • Water inlet and outlet are required • Should be constructed from metallic structure which is self-supporting, a water proof layer, foamed PVC panel, Special rock wool panels for vegetation growth • The vegetation should be planted with little nutrient and water requirements and should be climatic resistance • A tank should be placed in the bottom of the mobile garden in case of excess water during irrigation process • The irrigation system consists of horizontal drip irrigation pipes that soak the substrate, two vertical pipes, and a pump connected to the tank.
Maintenance	• Regular maintenance is needed, especially with trimmings and cleanings. • Regular supervision is important to prevent it from the sabotage acts.		
Benefits/ Limitations	(+) Can serve as a mobile demonstration of green infrastructure, a test feature, a temporary green installation, or an open green office for information and communication purposes (+) Biodiversity provision (-) Limited size (-) Can not feel its benefits unless several units are installed (-) Its transportation requires energy and results in emissions (-) Maintenance and supervision are highly required	**Ecosystem Services**	• Food and fiber provisioning • Air quality maintenance • Climate regulation • Regulation and maintenance of pollination cycle • Aesthetic values • Enabling of social relations • Enabling of recreation and ecotourism • Primary production
Sources	(Eisenberg et al., 2022; URBAN GreenUP, 2018)		

Source: ITT-TH Köln, Phnom Penh, 2023

Wet Retention Pond





Addressed Challenge		**Type of Action**	
Scale of Action			
Description	Wet retention ponds are pools that continuously hold water and are designed with additional storage capacity to store surface runoff during heavy rainfall events. They release stormwater at a controlled rate and improve water quality through downstream infiltration. The ponds can be integrated into public recreation areas.	 Source: (Kota Kita, 2024)	
Analogy	• Bioretention Area • Detention Pond • Wet Detention Pond • Wet Detention Basin • Retention Pond • Wet Retention Pond • Wet Retention Basin		
Naturalistic Design	The natural landscape in which the detention pond is being implemented contains a heterogeneous surface with slightly elevated areas and lower parts in proximity, forming a mosaic of micro conditions. During heavy rainfall, water flows to the lowest parts and is stored in the retention.	**Installation & Implementation Requirements**	• Large space needed (e.g. part of park) • Wet retention pond should be in the lowest part of park/green space • Should not be sited in areas where water storage may cause slope instability or foundation problems, e.g. in areas prone to landslides or at the top of slopes. Retention ponds must be appropriately sized according to the catchment area
Maintenance	• Litter and debris removal. • Vegetation maintenance. • Sediment removal from forebay. • Sediment removal from permanent pond. • Ongoing inspections and monitoring.		
Benefits/ Limitations	(+) Regulates heavy rain. (+) Multifunctional use of detention pond is possible. (-) Limited design options. (-) Accumulation of insects	**Ecosystem Services**	• Air quality maintenance • Storm protection • Climate regulation • Enabling of aesthetic values • Water availability regulation • Enabling of social relations • Water purification and wastewater treatment • Enabling of recreation and ecotourism • Habitat provision
Sources	(Petsinaris et al., 2020; UNaLab, 2019; URBAN GreenUP, 2018)		

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Appendices

Appendix 1: Similarity Heat Maps

This section presents an illustration powered by similarity KPIs calculated based on Versatility (the count of addressed challenges), Scale of Action, and Ecosystem Services. As the similarity KPIs are calculated relative to other NbS in this catalogue, they are referred to as "Morphism," a term that reflects their potential to transform into or align with other NbS.

The similarity (morphism) metrics is the cosine similarity, which can be defined algebraically by the angle between two vectors (Gomaa & Fahmy, 2013), and as illustrated in Figure 10. However, it can also be interpreted as a form of derived Euclidean distance between two sets based on their shared elements Acharya et al., 2017; Sohangir & Wang, 2017. One of the cosine similarity main use cases, is the recommendation systems (e.g. recommended videos on YouTube) (Miesle, 2023). In this context, the term "Morphism" is used to ide ntify suitable alternatives for a given NbS based on predefined criteria. For example, the extent to which a selected NbS can address a set of challenges is measured relative to all other NbSs. If the proposed NbS encounters unforeseen issues, a suitable alternative can be suggested based on this comparison.

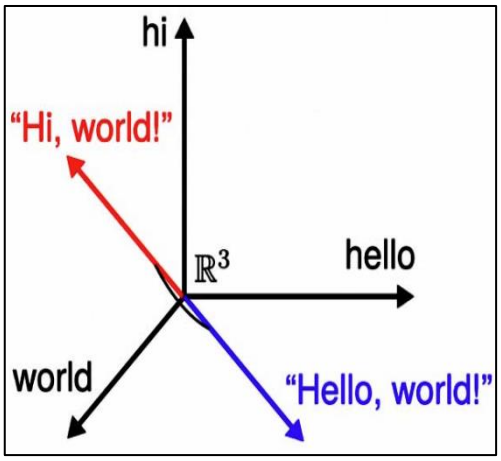


Figure 10 Cohesion Similarity in Vector Presentation
Source: (Engati, n.d.)

The heatmap concept illustrates the similarity between each pair of NbS, where an NbS is compared with all other NbSs, and their similarity or difference is summarized by a number ranging between 0 and 1, where 1 represents a perfect match or similarity, while 0 represents total difference, hence, no mutual benefits between this pair. Then, this pairwise comparison is repeated for each NBS, resulting in a matrix containing all the possible NbSs pairs and their similarities. Then, the matrix is visualized using Python to produce Figure 7, Figure 8, and Figure 9. Additionally, the NbS names have been color-coded based on their type to ensure fairness in comparison. For instance, a Green-Blue NbS should not be compared to a Green-Grey NbS unless the project location and issues permit a change in type. Otherwise, comparisons should be confined to NbS of the same type. Pairwise comparisons are conducted for all NbS, including comparisons of an NbS itself, which will yield a perfect similarity. However, while perfect similarity is ideal, it does not reflect typical real-world scenarios.

The use of the heatmap is intuitively designed, where the reader can choose any NbS from either the x or y axis, then move along the other axis to find a target NbS that has a high similarity which is colour and size coded. Hence, a good alternative should have the same type and high similarity (Blue coloured Circle or Big circle). While the type (colour) constraint is subjective and dependent on the decision maker(s), the similarity value is the essence of choice and should be always prioritized. The main idea and key benefit of the heatmaps is to give the decision maker(s) the ability and flexibility to choose and rank a list of alternatives of their desired NbS, if any obstacle is to be faced along the way of planning the NbS project.

The interpretation and logic of the heatmap use is to have a backup list of alternative NbS(s) that will act as a good replacement for the already chosen NbS. Hence, an NbS that has many alternatives, is to be interpreted as a versatile NbS that addresses many challenges, and/or provides many ecosystem services, and/or can be implemented on different scales. On the other hand, an NbS that has a short or no list of candidates alternative NbS is to be considered rare and specific NbS which tailors to a specific set of problem(s), and/or provides specific ecosystem service(s), and/or can be implemented in a limited selection of scale (s).

Appendix 2: The Cards

The cards are considered as part of the compendium where the cards could be used as a tool during the capacity building for the gamification activities.

The front side of the card includes the name of the Nature-based Solution (NbS) and a corresponding photograph. The back side of the card presents the type of action and Nature-based Solution (NbS) category. Below, a detailed schematic is provided to illustrate the specific aspects of the NbS. Additionally, the challenges tackled by the NbS and the type of scale are presented. Furthermore, a concise description is also included to provide an overview of the NbS. This page also contains other aspects such as the required budget to implement the NbS, required maintenance, and the implementation time which is required to implement the NbS. An example layout of the second page of the card is illustrated in Figure 11.

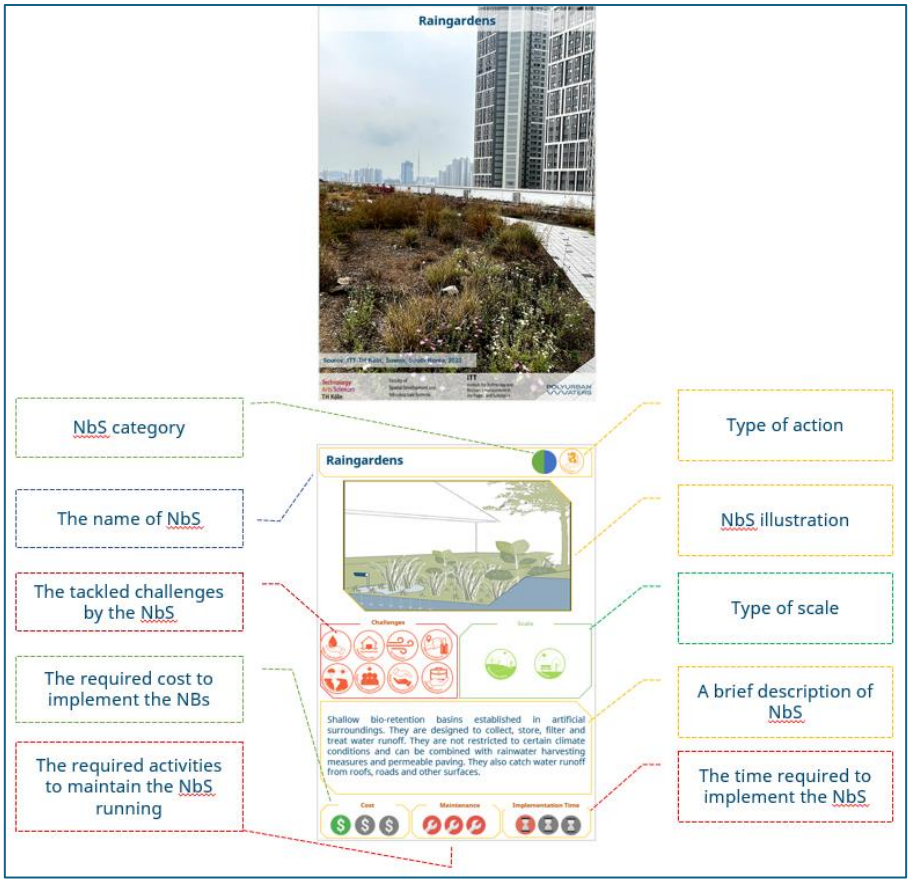
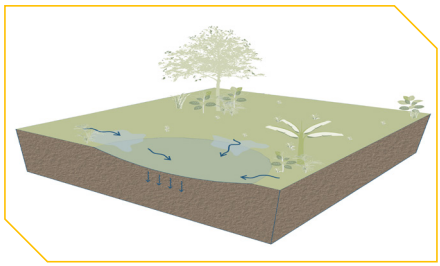


Figure 11 Sample of the front and back sides of the cards

Dry Detention Pond



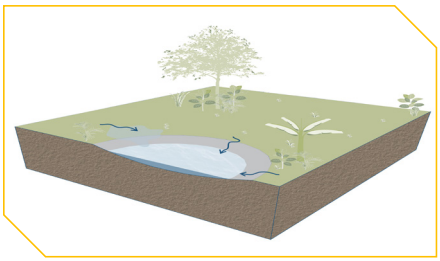
Challenges

Scale

A vegetated detention basins designed for short-term temporal water storage during heavy rain occasions. Stormwater fills up the detention pond and detained water then flows into the sewer system. In periods of no heavy rainfall, the detention ponds are dry and can be used as public green areas.

Cost | Maintenance | Implementation Time

Wet Retention Pond



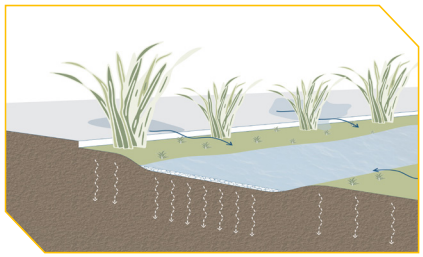
Challenges

Scale

Pools that continuously hold water and are designed with additional storage capacity to store surface runoff during heavy rainfall events. They release the stormwater at a controlled rate and improve water quality through downstream infiltration. The ponds can be integrated into public recreation areas.

Cost | Maintenance | Implementation Time

Infiltration Trenches



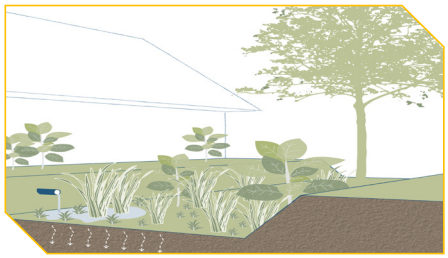
Challenges

Scale

Infiltration trenches are shallow excavations filled with rubble or stone which allow water to infiltrate into the surrounding soils from the bottom and sides of the trench. The basins are flat areas planted with grass and normally dry.

Cost | Maintenance | Implementation Time

Raingardens



Challenges

Scale

Shallow bio-retention basins established in artificial surroundings. They are designed to collect, store, filter and treat water runoff. They are not restricted to certain climate conditions and can be combined with rainwater harvesting measures and permeable paving. They also catch water runoff from roofs, roads and other surfaces.

Cost | Maintenance | Implementation Time

Wet Retention Pond

Source: ITT-TH Köln, Phnom Penh, 2023

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Dry Detention Pond

Source: Jiří Komárek, Prostějov. Czech Republic, 2022

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Raingardens

Source: ITT-TH Köln, Suwon, South Korea, 2023

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Infiltration Trenches

Source: ITT-TH Köln, Indonesia, 2022

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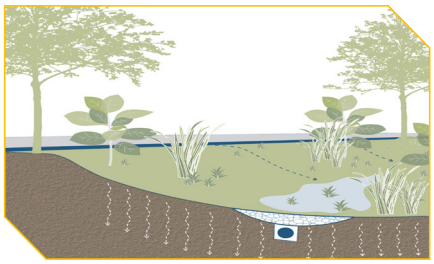
Bioswales



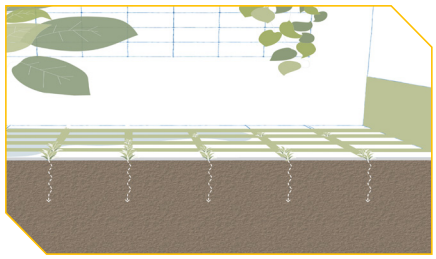
Challenges

Scale

Swales are vegetated, linear and low-sloped pits, often established in urban areas near and between roads. They absorb, store, and convey surface water runoff (mainly draining from roadways) and remove pollutants and sediments when the water trickles through the vegetation and soil layer.

Cost | Maintenance | Implementation Time

Permeable Paving System



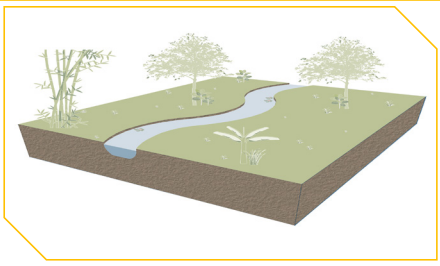
Challenges

Scale

Green paving systems replace grey urban pavements with up to 50% vegetal soil with high drainage capacity, such as paving bricks containing a certain share of space for vegetation growth space, or grass-bricks that replace certain bricks of conventional pavements.

Cost | Maintenance | Implementation Time

Renaturation/ Revegetation of Water Courses



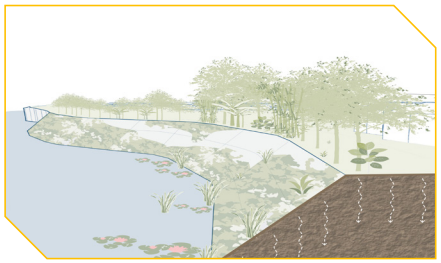
Challenges

Scale

De-culverting of covered watercourses by the removal of concrete layers. This process can be combined with a re-naturalisation of the channel by opening and allowing natural development of riverbed.

Cost | Maintenance | Implementation Time

Planted Channels and Rills



Challenges

Scale

Shallow open surface water channels which collect water, slow down the velocity and provide storage for silt deposited from runoff. Can be incorporated into the upper parts of a chain of NbS. Greening of the channels enhances amenity and biodiversity.

Cost | Maintenance | Implementation Time

Permeable Paving System

Source: ITT-TH Köln, Sleman, Indonesia, 2023

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Bioswales

Source: ITT-TH Köln, Bangkok, 2023

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Planted Channels and Rills

Source: ITT-TH Köln, Vientiane, Laos, 2022

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Renaturation/ Revegetation of Water Courses

Source: iStock, UK, 2018

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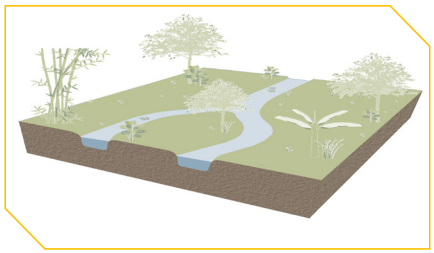
River Branching



Challenges

Scale

Creation of a new river branch and flat riverbanks. The second river branch provides additional flood space.

Cost

Maintenance

Implementation Time

Floodplain Expansion

Challenges

Scale

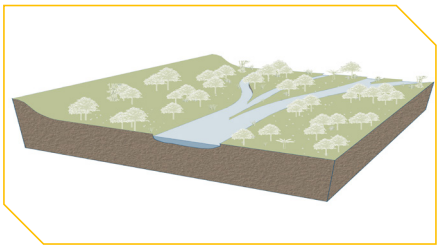
Expansion of the river flood plain area to temporarily increase the water storage capacity and increase infiltration to reduce risk of river flooding. The expansion process could be through dechannelize the river in order to increase the floodplain which are the area on both sides of the river.

Cost

Maintenance

Implementation Time

Floodplain Riparian Woodland



Challenges

Scale

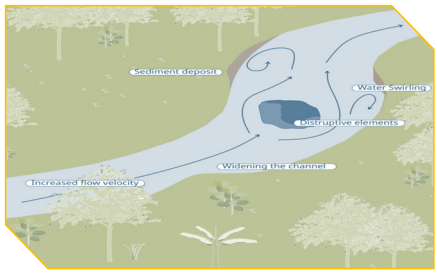
Floodplain riparian woodlands are forests along the regularly flooded areas. The forest can act as a shelterbelt along the floodplain and reduce peak flows by 13 - 48%.

Cost

Maintenance

Implementation Time

Diverting and Deflecting Elements



Challenges

Scale

Placement of disruptive and diverting elements to redirect, disturb, divert and the river current and to initiate water dynamics.

Cost

Maintenance

Implementation Time

Floodplain Expansion

Source: Dutch Water Sector, Arnhem, the Netherlands, 2014

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River Branching

Source: MERLIN, Scotland, 2021

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Diverting and Deflecting Elements

Source: ITT-TH Köln, Sleman, Indonesia, 2023

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Floodplain Riparian Woodland

Source: BROZ archive, Danube Floodplain Forests, Slovakia, 2020

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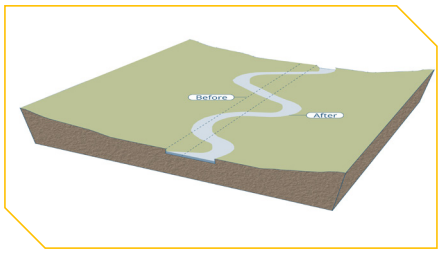
Re-meandering River



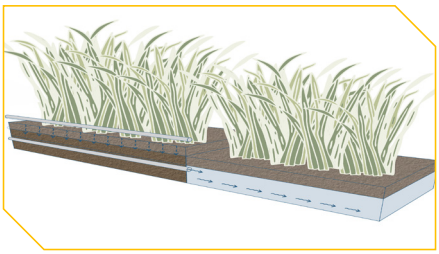
Challenges

Scale

Re-meandering the restoration of original curves of the river course by creating new meanders and reconnecting old cut-off ones. Re-meandering aims at reducing the water flow and increasing the length of the river leading to increased water storage capacity.

Cost | Maintenance | Implementation Time

Constructed Wetlands



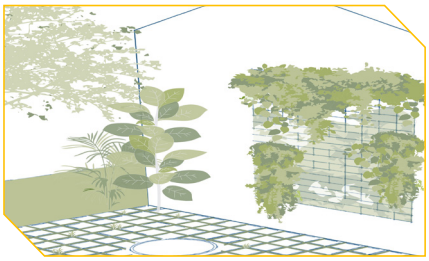
Challenges

Scale

Constructed wetlands are designed shallow basins used for filtering pollutants from water. The processes and services of natural wetlands are adapted to constructed wetlands and are used as a solution to treatment of combined sewer overflow during heavy rainfall events.

Cost | Maintenance | Implementation Time

Green Walls



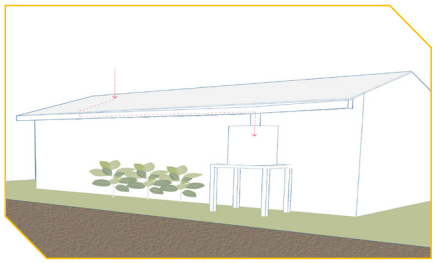
Challenges

Scale

Green wall are vertical green infrastructure interventions. They provide infiltration area for water and mainly function as visual and noise barriers between roads/industrial areas and public spaces. The vegetation grows directly on the wall, or climbs on a frame or already structured wall, but keeps a small distance from the wall.

Cost | Maintenance | Implementation Time

Rooftop Rainwater Harvesting



Challenges

Scale

Rainwater is caught and collected from rooftops and other impermeable surfaces. It can be stored and then be used for non- potable uses such as watering of green spaces and parks or non- potable uses at household level.

Cost | Maintenance | Implementation Time

Constructed Wetlands

Source: Agaton and Guila, Bayawan City, Philippines, 2024

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Re-meandering River

Source: Public Utilities Board, Singapore, 2016

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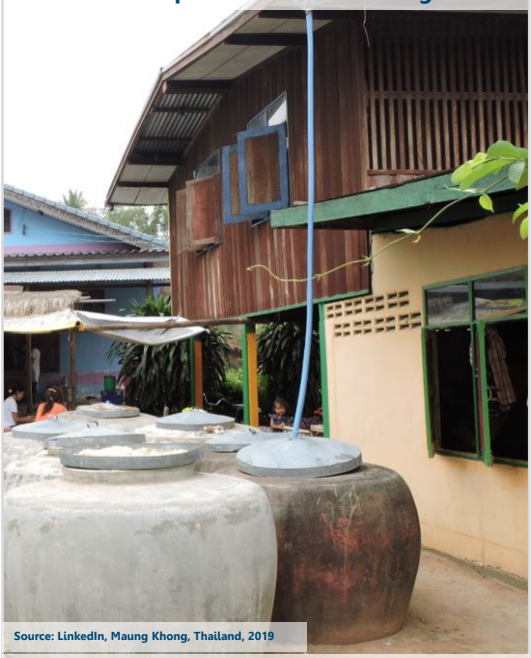
Rooftop Rainwater Harvesting



Source: LinkedIn, Maung Khong, Thailand, 2019

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Green Walls

Source: ITT-TH Köln, Sleman, Indonesia, 2022

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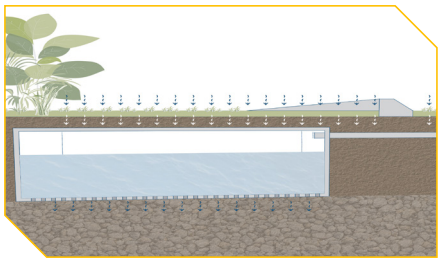
Underground Water Storages



Challenges

Scale

Underground systems such as installations below public open spaces (sport fields) composed of modular elements where the stormwater enters a vault or a basin through a surface inlet and is temporarily stored, allowing sediments and particles to settle. If the water level reaches a certain height, it is discharges as overflow for further uses

Cost

Maintenance

Implementation Time

Channel Renaturing with Terramesh Walls

Challenges

Scale

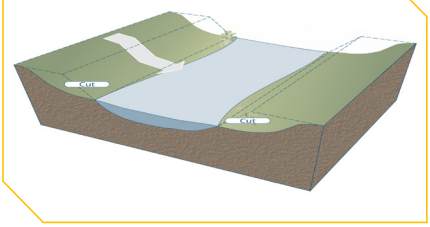
Removal of concrete riverbanks and replacement with Terramesh walls. Terramesh is a wire mesh used as a soil reinforcement system to stabilize slopes.

Cost

Maintenance

Implementation Time

Reprofiling River Channel Cross Section



Challenges

Scale

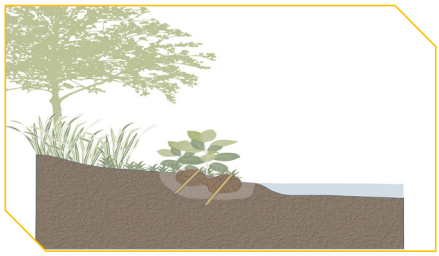
Reprofiling of the river channel cross-section towards a wider and more natural profile including shallow and deep waters and fast and slow flowing areas.

Cost

Maintenance

Implementation Time

Living Fascine



Challenges

Scale

Fascines are tubular bundles of brunches and twigs that are installed in trenches along hillsides or riverbanks for stabilization.

Cost

Maintenance

Implementation Time

Channel Renaturing with Terramesh Walls

ource: Maccaferri, Indonesia, 2017

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Underground Water Storages

Source: Aggeres, Roeselare city, Belgium, 2021

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Living Fascine

Source: Giverny News, Giverny, France, 2014

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Reprofiling River Channel Cross Section

Source: SCRT, Staveley, England, 2016

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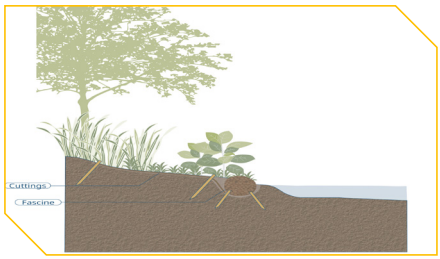
Living Revetment with Cuttings



Challenges

Scale

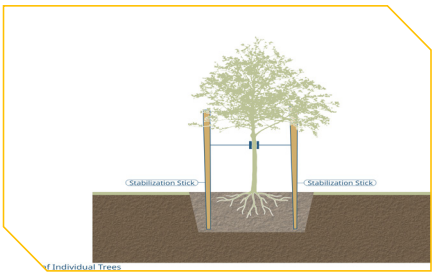
Living revetments are a constructed layer of a mix of alive/dead vegetation that is used to cover the riverbank and prevent erosion and often in combination with living fascines.

Cost

Maintenance

Implementation Time

Planting of Individual Trees



Challenges

Scale

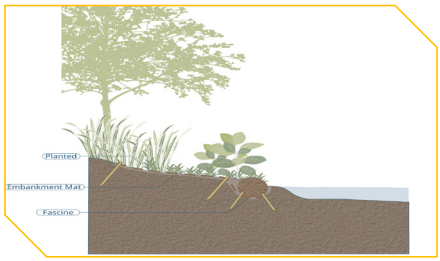
Strategic planning of individual trees or series of trees in urban areas to provide shade, reduce urban heat and reduce urban runoff.

Cost

Maintenance

Implementation Time

Planted Embankment Mat



Challenges

Scale

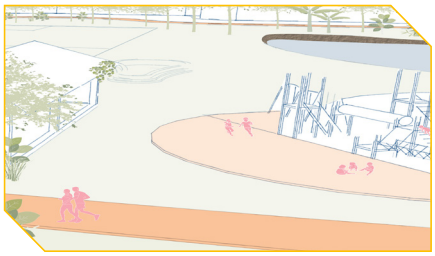
Fast rotting mats (jute or coconut) covered with vegetation which are installed along the riverbank to prevent erosion.

Cost

Maintenance

Implementation Time

Urban Parks



Challenges

Scale

Parks in urban or peri-urban areas provide several environmental benefits while serving as a public space for recreation, social interaction, exercise and connection to nature. Parks could have multifunctionality by combining various uses such as sport fields or other NbS (e.g. water retention basins)

Cost

Maintenance

Implementation Time

Planting of Individual Trees

Source: ITT-TH Köln, On the way to Kratite, 2022

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Living Revetment with Cuttings

Source: Vietnam Vetiver Network, Thanh Mai, Vietnam, 2018

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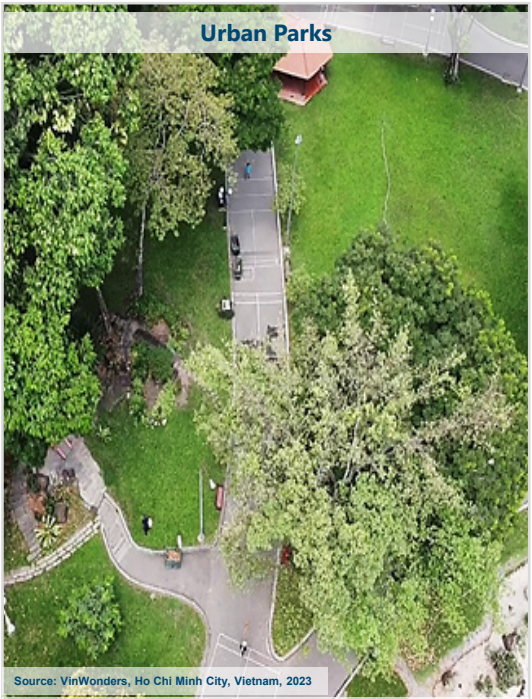
Urban Parks



Source: VinWonders, Ho Chi Minh City, Vietnam, 2023

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Planted Embankment Mat

Source: Vietnam Vetiver Network, Thanh Mai, Vietnam, 2018

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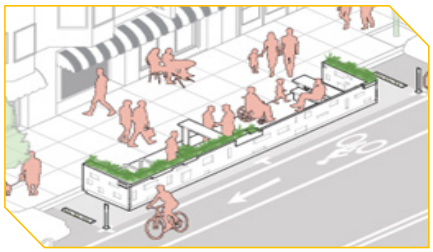
Parklets



Challenges

Scale

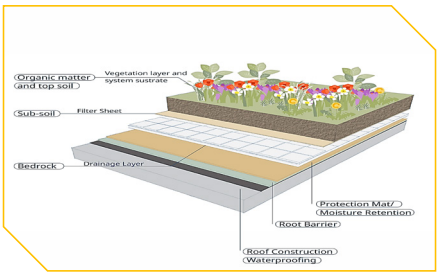
Parklet provides opportunities for people to create small but important public spaces in the street or neighbourhood. It also turns a portion of the street beside the sidewalk into a people-only area and offers features including benches, vegetation, bike parking, and artwork.

Cost

Maintenance

Implementation Time

Green Roofs



Challenges

Scale

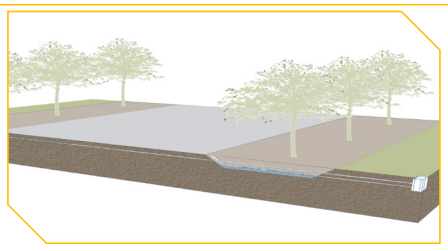
Green roofs are multi-layered systems designed for stormwater management, beginning with a well-insulated, structurally sound roof as the base layer.

Cost

Maintenance

Implementation Time

Double Line Trees



Challenges

Scale

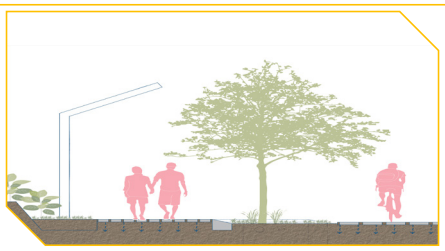
Represented by several trees used mainly for mitigating urban heat stress. The trees could be arranged in a shape of a line along street, bicycle paths, or sidewalk. By planting two lines of trees, it would represent a canopy shape where the middle area is shaded and protected from heat and pollution.

Cost

Maintenance

Implementation Time

Green Paths for Cycling



Challenges

Scale

Green pavements with special filtering properties suitable for pedestrians and cyclists. These pavements manage water runoff by preventing small flood accumulations.

Cost

Maintenance

Implementation Time

Green Roofs

Source: WordPress, Singapore, 2006

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Parklets

Source: MOTU, Cherry Streets, China, 2013

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Green Paths for Cycling

Source: ITT-TH Köln, Bali, Indonesia, 2022

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Double Line Trees

Source: Ti Gong, Guiping Road, China, 2022

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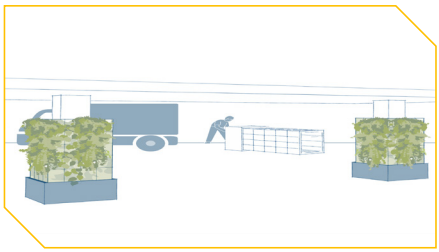
Vertical Mobile Garden



Challenges

Scale

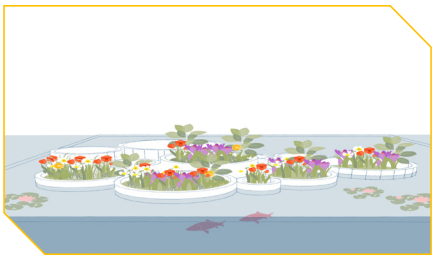
Consists of living wall modules, which are wire frame cubes attached to a hook lift container platform. The vegetation cover is highly diverse, showcasing the potential of living walls to enhance amenity value and promote biodiversity.

Cost

Maintenance

Implementation Time

Floating Garden



Challenges

Scale

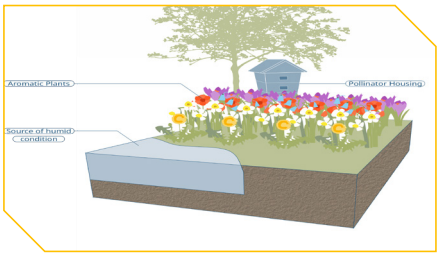
Floating gardens typically consist of rafts that enable certain plants to be grown hydroponically, with their roots extending into the water. These gardens can be used for growing vegetables, for decorative purposes, or both.

Cost

Maintenance

Implementation Time

Natural pollinator´s modules



Challenges

Scale

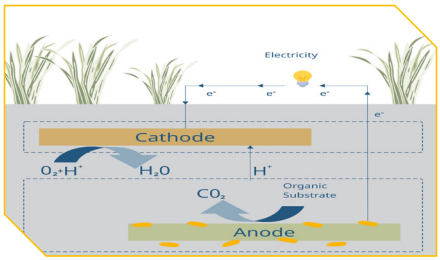
These areas are intended to attract pollinators and overall biodiversity by offering favorable weather conditions, such as cooler spots during hot periods and shelters for winter. They will also provide water and food sources for pollinators.

Cost

Maintenance

Implementation Time

Electro Wetlands



Challenges

Scale

An electro wetland is a natural system for treating wastewater that produces electricity through the oxidation of organic matter. It is built upon a standard Horizontal Subsurface Flow Constructed Wetland with the addition of electrodes. (Cathodes and Anodes).

Cost

Maintenance

Implementation Time

Floating Garden

Source: UN, Inle Lake floating garden, Myanmar, 2023

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Vertical Mobile Garden

Source: ITT-TH Köln, Seoul, South Korea, 2023

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Electro Wetlands

Source: Netherlands Institute of Ecology, Netherlands, 2012

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Natural pollinator´s modules

Source: iStock, Japanese Garden, 2008

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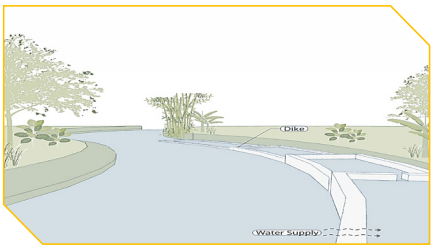
Fish Ponds



Challenges

Scale

Ponds are considered as small bodies of standing water ranging from 1 m² to 2–5 hectares, which can be permanent or seasonal, and either man-made or naturally formed. In other hand, Pondscape is a network of ponds spread out within a terrestrial matrix, highlighting their spatial distribution and connectivity.

Cost

Maintenance

Implementation Time

Living Weir

Challenges

Scale

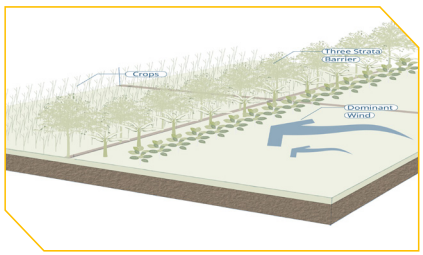
Living weirs are created by constructing a bamboo grid across a river and filling it with sandbags that contain natural materials like sand, coconut coir, and manure. Various trees and plants are planted along the riverbanks to stabilize the soil, with banyan trees specifically planted on either side of the weir. Over time, these banyan trees grow and integrate into the structure, forming the living weirs.

Cost

Maintenance

Implementation Time

Windbreaks



Challenges

Scale

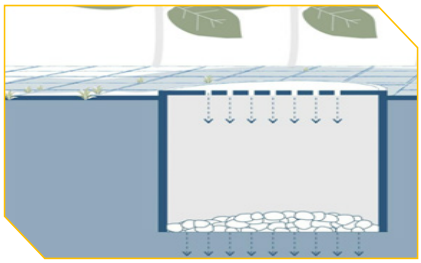
Windbreaks are structures which are implemented in agricultural lands to reduce wind speed. They consist of tree belts, and they help control erosion, boost agricultural yields, and minimize evaporation by modifying wind direction and turbulence. Their effectiveness is influenced by their height, porosity, and placement relative to the wind.

Cost

Maintenance

Implementation Time

Infiltration Wells



Challenges

Scale

Infiltration wells are structures which do not have a direct water entry point at the surface. Instead, they improve the soil's water absorption by utilizing porous materials and a coiled drainage system located between the surface and the pipes below.

Cost

Maintenance

Implementation Time

Living Weir

Source: GIZ, Thailand, 2020

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Fish Ponds

Source: ITT-TH Köln, Kota Kita, 2022

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Infiltration Wells

Source: JPNN, East Jakarta, Indonesia, 2021

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Windbreaks

Source: LANDOV, Sanjiang Plain, China, 2013

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