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Acronym	Meaning
REC	Renewable Energy Community
NBS	Natural Base Solution
KPIs	Key Performance Indicators
UHI	Urban Heat Island
HVAC	Heating, Ventilation, and Air Conditioning
SuDS	Sustainable Drainage Systems
CEW	Circular Economy of Water

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1 Introduction

1.1 Objectives of the Report

The primary objective of this report is to present a comprehensive portfolio of small-scale Nature-Based Solutions (NBS) tailored to enhance climate resilience and mitigate the Urban Heat Island (UHI) effect in the pilot cities of Genova, Valencia, Patras, and Pula. These cities face unique environmental challenges that necessitate tailored solutions to mitigate the adverse impacts of climate change and urbanization.

This report aims to:

i. Outline a clear framework for the planning, design, implementation, and monitoring of NBS.
ii. Highlight various NBS sourced from successful HORIZON projects and other relevant initiatives.
iii. Customize the selected NBS to fit the unique urban dimensions and climatic conditions of each city.
iv. Encourage collaboration among technical partners, local authorities, and communities. Sharing best practices and lessons learned to facilitate the replication of successful NBS in other MED cities.

Ultimately, this report aims to enhance urban resilience, reduce energy consumption, and improve the quality of life for residents in the pilot cities through the strategic implementation of NBS.

1.2 Importance of Nature-Based Solutions (NBS)

NBS are strategies inspired by natural systems that use plants, animals, and ecological processes efficiently and sustainably. These solutions are adapted to local environments and can be applied in cities, rural areas, and natural landscapes. NBS aim to tackle social, environmental, and economic challenges, providing multiple benefits and promoting sustainable development and resilience. (D. Kolokotsa et al.,2020). NBS leverage natural processes to enhance climate resilience, improve urban environments, and mitigate the effects of climate change (Frantzeskaki *et al.*, 2019).

The concept of NBS is multifaceted, integrating a range of ecosystem-based approaches to address societal challenges. Implementing NBS involves managing trade-offs between functions, and across temporal and spatial scales, while considering social equity dimensions (Bush and Doyon, 2019). By incorporating natural elements into urban planning, NBS create more liveable and resilient cities, capable of withstanding and adapting to the impacts of climate change.

NBS can be viewed as an additional asset for development projects by incorporating alternative and innovative methods that provide sustainable solutions to address the challenges of climate change mitigation and adaptation (Zahra Amirzada et al.,2023).

1.3 Overview of Climate Resilience and Urban Heat Island Phenomena

Climate resilience refers to the capacity of communities, ecosystems, and infrastructure to anticipate, prepare for, respond to, and recover from climate-related hazards. It involves reducing vulnerability and enhancing the ability to adapt to changing climate conditions. In urban areas, climate resilience is critical due to the high concentration of people, assets, and infrastructure that can be affected by extreme weather events such as heatwaves, floods, and storms.

One of the major challenges faced by urban areas is the UHI phenomenon. UHI occurs when urban environments experience significantly higher temperatures than their rural surroundings. This effect is primarily due to human activities, dense built environments, and limited vegetation. This temperature difference is caused by the extensive use of heat-absorbing materials like concrete and asphalt, the lack of green spaces, and the heat generated from vehicles, industries, and buildings. The UHI effect exacerbates the impacts of heatwaves, leading to increased energy demand for cooling, higher emissions of air pollutants, and adverse health effects on urban populations. Vulnerable groups, such as the elderly, children, and individuals with pre-existing health conditions, are particularly at risk during extreme heat events. Therefore, addressing the UHI phenomenon is crucial for improving urban climate resilience and enhancing the quality of life in cities (Lafortezza and Sanesi, 2019).

The UHI not only impacts thermal comfort and citizens' health and well-being but also influences energy demand for building space cooling and heating. Even in northern European countries with cooler climates, understanding energy use in residential buildings for cooling is becoming increasingly relevant in terms of climate change. The increasing energy demand for cooling sustains the endless loop of climate change, with Heating, Ventilation and Air Conditioning (HVAC) systems transferring indoor heat to the outdoor environment.

By incorporating NBS into urban planning, cities can enhance their resilience to climate change, reduce the adverse effects of UHI, and improve the overall quality of life for their residents. The EnerCmed project aims to implement these solutions in the pilot cities of Genoa, Valencia, Patras, and Pula, demonstrating their effectiveness in Mediterranean port hinterlands.

1.4 Specific Impacts on Pilot Cities

1.4.1 Genova

Genoa shows a very complex morphology due to the distribution of urban agglomerations, a highly variable orography and proximity to the sea, consequently the different areas of the municipality have different average temperatures and, in general, a wide range of climatic conditions.

Due to the UHI phenomenon, whereby the temperature of the more built-up urban areas is higher than in natural and rural areas, the temperature difference is particularly significant during the nighttime, that is the very hours that, at least in summer, should be able to ensure that we can "breathe a little." This phenomenon is not just a nuisance. It can, instead, be a real detriment: high temperatures cause heat stress, which can lead to heat strokes and other ailments such as heat exhaustion and cramps, dehydration, and so on. In addition, UHIs can increase the concentration of air pollutants, and worsen the air quality. Finally, according to some studies, they may also affect convective precipitation, making city thunderstorms more intense and frequent than in the surrounding rural areas.

In Genoa, the effects of UHI are particularly relevant in more urbanized and therefore more densely populated areas, as shown respectively in figure A and figure B.

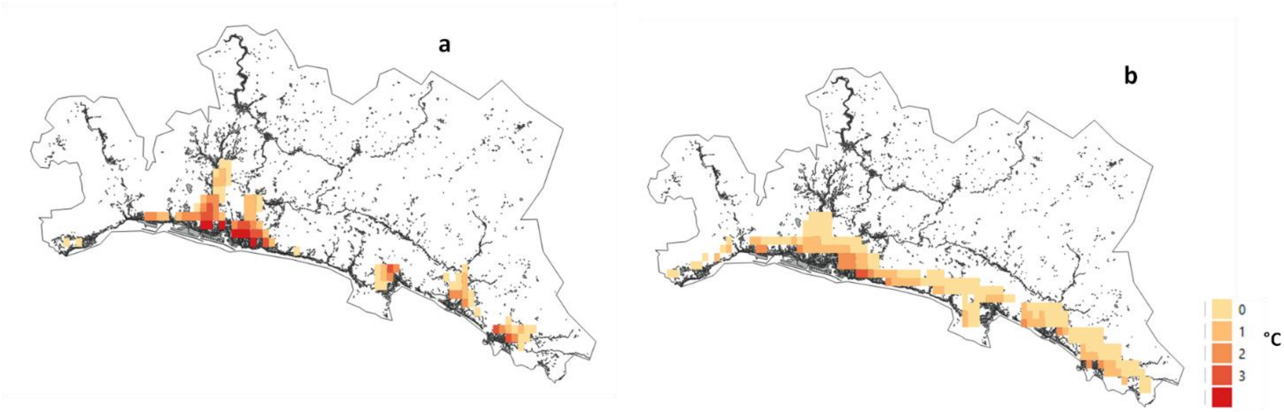
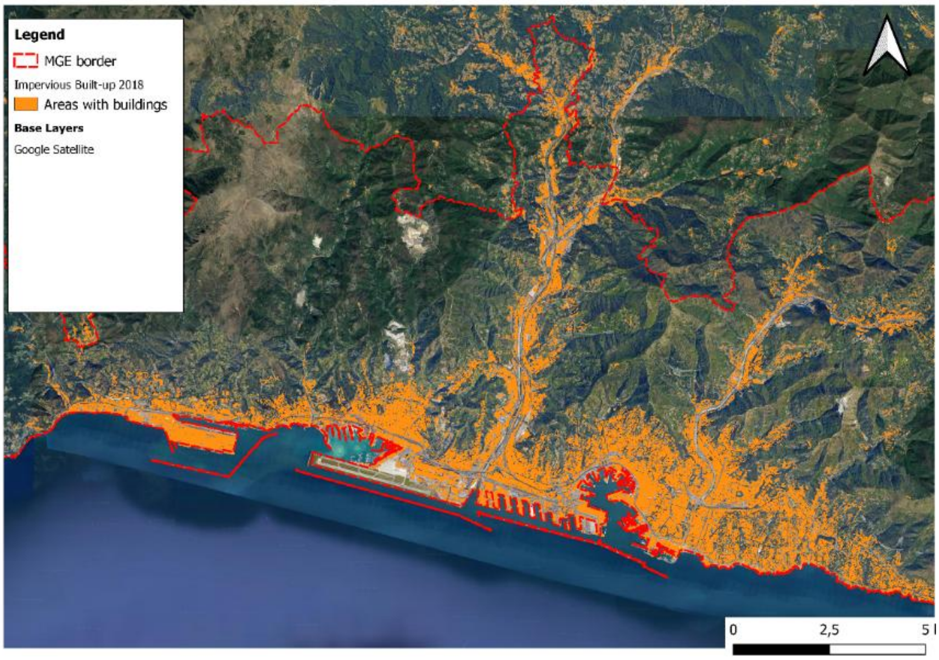


Figure A - UHI daily (a) and nightly (b) average for summer 2020 in Genoa metropolitan area[1].

This last Figure shows the areas most affected by the presence of impervious buildings and surfaces. Buildings in the central areas of most neighborhoods of the city reach significant heights (> 5 or more floors). The presence of large cemented surfaces, especially if arranged in patterns or "textures," is one of the most important determinants of the UHI effect of a city[2]. In Genoa there are several neighborhoods, both in the port areas and in the most residential areas, where this phenomenon occurs.

[1] https://link.springer.com/book/10.1007/978-3-030-86611-2

[2] https://umi.mit.edu/urban-heat-island-effects-depend-city%E2%80%99s-layout



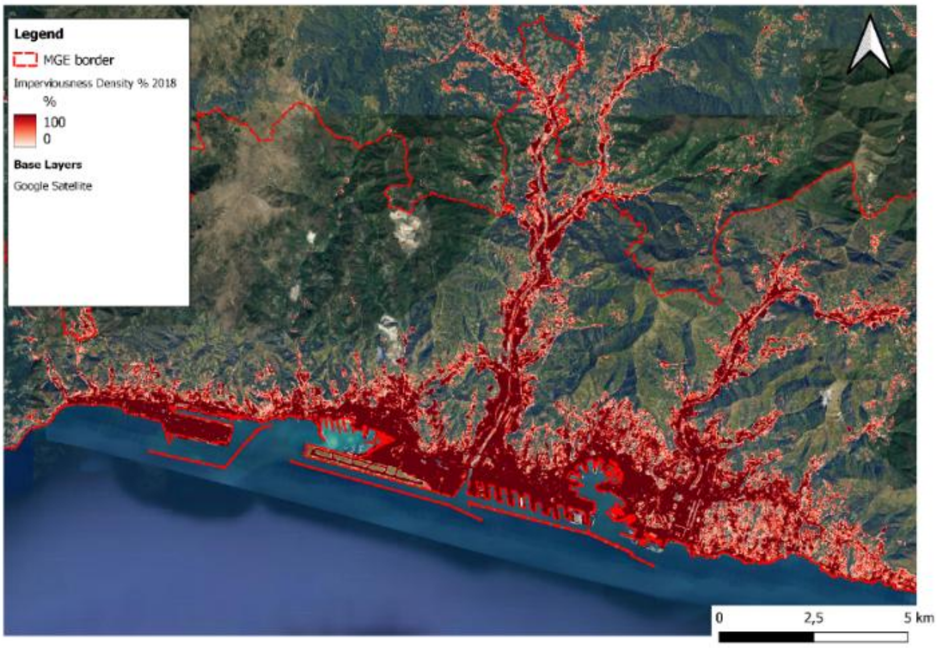


Figure B- Buildings distribution and Imperviousness density, source CLMS.

Heat waves are extreme weather conditions which occur when very high temperatures are recorded for several consecutive days, often associated with high humidity rates, strong solar radiation and no ventilation, conditions that pose a risk to the health of the population.

The city of Genoa is subject to prolonged periods of heat wave risk, mainly due to high humidity, although only rarely recorded temperature values above 35°C. These meteorological parameters increase the perception of temperature, generating physiological discomfort and risk conditions for the population.

Every summer from May to September the Ministry of Health activates the National System of Forecast Alarm to communicate the possible effects on health of heat waves, through the publication of daily bulletins for 27 cities, with forecasts at 24, 48 and 72 hours, sent to the local centres identified by the competent Administrations, for activation in case of need of intervention plans in favor of the vulnerable population.

The city of Genoa is among the 27 cities for which heat wave forecasts are being prepared, in which level 0 represents weather conditions that do not pose a risk to the health of the population:

- Pre-alert level 1 indicates weather conditions that may precede a heat wave. Means that in the following days it is probable that health risk conditions may occur
- Level 2 indicates weather conditions that may pose a health risk, especially in the most susceptible subgroups of population (elderly, children, people with chronic diseases)
- Level 3 indicates emergency conditions (heat wave) with possible adverse health effects on healthy and active people, not only on the sub-groups at risk[3]

During the summer of 2024, the alerts shown in Figure C were issued. Most of the events were perpetrated for several consecutive days, reaching the maximum alert level for five consecutive days in mid-August.

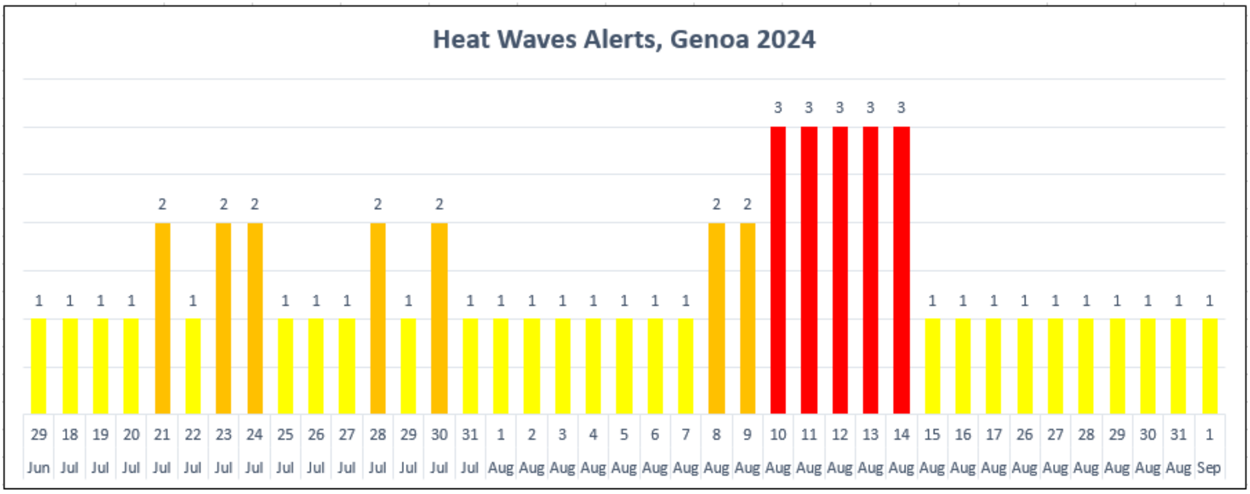


Figure C, heat wave forecasts for Genova, Summer 2024. Source https://www.arpal.liguria.it/.

[3] https://www.comune.genova.it/tutti-gli-argomenti/protezione-civile/rischio-ondata-di-calore

The population is on average very old and therefore suffers greatly from the thermal changes and physiological discomfort conditions that extreme heat and UHI effect, entail.

The consequences of these phenomena are particularly damaging to parameters such as mortality. As in the summer of 2003, when Europe was hit by a massive heat wave, which reached its peak during the first fortnight of August. This phenomenon was exceptional both in duration and intensity, made particularly unbearable by the high humidity of the air; indeed, numerous temperature records were broken in several European cities. In Italy, where temperatures peaked at around 40°C for weeks in many cities, according to the National Institute For Statistics (**ISTAT**), deaths during the summer of 2003 were 18,000 more than in the previous year[4].

More recently, in 2022 in Italy the highest mortality in Europe with 18 thousand deaths; Italy was also the most affected country in terms of population, with 295 heat-related deaths per million inhabitants, well above the European average, estimated at 114 deaths per million[5].

1.4.2 Valencia

Valencia, is the third most populated city in Spain, located by the Mediterranean coast. According to the Köppen climate classification, the city has a Mediterranean climate type characterized by hot and dry summers and mild winters. However, the city is currently facing significant climate change challenges particularly in the form of rising temperatures and hotter summers – with temperatures often reaching 40 degrees during heatwaves– more frequent extreme weather events and erratic rainfall patterns. These are contributing to the intensification of the urban heat island effect impacting as well over infrastructure, water resources, biodiversity, population's health and quality of life in the city overall.

The UHI effect in Valencia is exacerbated by the concentration of asphalt and buildings that absorb and retain heat, significantly raising local temperatures compared to surrounding rural areas.

In addition, the city experiences high humidity levels due to its proximity to the sea - around 65% throughout the whole year reaching higher levels during summer and heatwaves. This is particularly relevant as humidity can raise the feeling of heat and generate respiratory problems and discomfort, especially at night. At this point it is also worth mentioning the progressive increase of the minimum temperatures and the consequent reduction of the range between maximum and minimum temperatures -

[4] Plan B Updates - 56: Setting the Record Straight - More than 52,000 Europeans Died from Heat in Summer 2003

[5] https://www.nature.com/articles/s41591-023-02419-z

which is particularly noticeable during nighttime hours. Thus, the city experiences high levels of thermal stress during the whole day for quite prolonged periods of time.

Moreover, the increased demand for air conditioning contributes to increased energy consumption and higher carbon emissions. At this stage, access to cooling systems and well-insulated homes increases the gap in social inequality, especially among the most vulnerable households experiencing energy poverty, who do not have the same resources to cope with the heat. The Valencia EnerCMed pilot will focus in two of these vulnerable neighbourhoods: Natzaret and La Malva-Rosa, close to the port and the sea. Both face challenges regarding socio-economical vulnerability, high levels of energy poverty, high rates of air pollution, poor housing conditions, progressive deterioration, limited access to city services, lack of green spaces exacerbating UHI, environmental vulnerability and sea level threats.

To address the escalating effects of climate change and the UHI phenomenon, Valencia is making several efforts to work within natural processes to enhance urban resilience, improve sustainability, foster innovation and mitigate the effects of climate change and heat waves. Through the Municipality's participation in different European projects and the adoption of climate agreements and urban plans, the city is paving the framework for the energy transition and the progressive adoption of NBS, being Valencia the European Green Capital 2024.

Overall, the EnerCMed pilot actions can be a key opportunity to implement strategies against UHI to improve the area's resilience and reduce social and economic inequalities.

1.4.3 Patras

The Municipality of Patras presents a complex interplay of urban and natural environments, significantly influencing its microclimate and the Urban Heat Island (UHI) effect. The city's densely populated zones, characterized by predominant concrete structures, asphalt roads, and limited vegetation within urban neighborhoods, are juxtaposed with extensive green areas such as Dasyllio, Eschatovouni, and Kavoukaki, which collectively span 352,892 m². Monitoring data from 2015 and 2018 reveal distinct spatial and temporal variations in UHI intensity. Longitudinal streets like Korinthou exhibit higher temperature peaks compared to transversal streets such as Patreos due to limited natural ventilation and exposure to urban materials with high solar absorptivity and emissivity properties. Comparisons between urban, suburban (e.g., Pantokratoros), and rural areas (e.g., Ag. Vasilios) further demonstrate that while rural regions exhibit higher daytime temperatures, their nighttime cooling capacity remains superior. Additionally, urban zones showed a 19.2% reduction in Heating Degree Hours (HDHs) and a 9% increase in Cooling Degree Hours (CDHs) compared to rural counterparts, emphasizing UHI's role in elevating local temperatures. To mitigate these impacts and enhance climate resilience, strategic integration of Renewable Energy Communities (RECs) with Nature-Based Solutions (NBS) could leverage existing green spaces and expand vegetation coverage to offset UHI effects, cool urban areas, and foster sustainable urban planning practices.

1.4.4 Pula

The City of Pula, situated at the southern tip of the Istrian peninsula in Croatia, offers a compelling case study for the examination of Urban Heat Island (UHI) effects and microclimatic dynamics. UHI, where urban areas experience significantly elevated temperatures compared to their rural surroundings, is exacerbated by dense urban structures, limited vegetation, and high-energy activities. Pula's unique geography includes seven hills, the Adriatic coastline, and historically rich architecture, such as the Roman Pula Arena. Monte Zaro, a primarily residential district with notable green space in Monte Zaro Park, exemplifies areas where UHI impacts converge with urban and environmental factors.

Temperature data from the Pula Airport meteorological station (2008–2021) reveals pronounced summer heatwaves with peak temperatures in July and August, accompanied by minimal precipitation during these months. Satellite measurements from the Copernicus S-3 Thermal IR Fire Emission bands (2021–2024) highlight that Pula's coastal areas and valley floors, especially regions near the port, exhibit the highest temperatures. Monte Zaro consistently emerges as a thermal hotspot, signifying the localized presence of UHI effects. Additionally, a noticeable upward trend in annual air temperatures from 2008 to 2021 suggests that Pula's summers are becoming increasingly warm, intensifying the UHI effect and forming persistent heat pockets.

The convergence of historical structures, demographic growth, and rising temperatures underscores the urgent need for sustainable urban planning in Pula. By analyzing atmospheric and land surface temperature patterns, the study aims to map UHI intensity and understand the interplay between built environments, coastal influence, and green spaces. This comprehensive analysis will guide strategies for mitigating heat risks, enhancing urban resilience, and ensuring sustainable development for this historic city.

1.4.5 Novigrad

Novigrad, a town situated on the western coast of Istria in Croatia, offers a unique setting to analyze Urban Heat Island (UHI) effects and their interplay with microclimatic and geographic factors. Located on a small peninsula 2 km north of the Mirna River's mouth, Novigrad has preserved its medieval layout with narrow, winding streets and fortifications, giving it a historical and architectural significance. Notable structures include Venetian Gothic buildings and the Saint Pelagius Basilica, reflecting its rich cultural heritage.

Bikokere District serves as a focal point for this study, particularly as the site for a planned photovoltaic (PV) power plant. This residential neighborhood lies on the western edge of Novigrad and blends proximity to urban amenities with access to natural areas, including the river Mirna and low hills. It is primarily residential, featuring mid-century modern apartments, detached houses, and newer residential blocks, along with elderly citizen housing. Meanwhile, the adjacent **Marketi District**, home to Novigrad's sports and recreational center, houses 277 parking spaces and an electric vehicle charging station. This area has been identified as the nearest urban heat island to Bikokere.

UHI effects in Novigrad, as with other urban settings, are characterized by elevated temperatures in developed areas compared to rural surroundings. These effects peak during the summer, particularly in August, when temperatures reach their highest annual values. The phenomenon results from factors such as limited vegetation, closely packed urban structures, and waste heat from cooling systems. Satellite data from the Copernicus S-3 program highlights that the coastal and valley areas of Novigrad, particularly in Bikokere and Marketi, experience higher land surface temperatures (LST) compared to surrounding rural areas, creating heat pockets and amplifying UHI effects.

Analysis of 2023 meteorological data shows that heatwaves are prominent during summer, with minimal precipitation in July and August. Conversely, autumn months like September, October, and November experience the highest precipitation levels. Satellite thermal imaging from 2021 to 2024 further confirms a rising trend in temperatures, suggesting that the UHI effect will intensify over time.

2 Nature-Based Solutions Overview

2.1 Definition and Categories of NBS

NBS can be categorized into several types based on their primary focus and the specific challenges they address, such as climate change, biodiversity loss, and water security.

NBS can be categorized into three main types:

- **Vegetation-Based Solutions:** These include green roofs, green walls, urban forests, parks and community gardens. Vegetation-based solutions enhance biodiversity, reduce UHI effects and improve air quality by filtering pollutants. They also provide recreational spaces and aesthetic benefits to urban areas. (Liu, Jay and Chen, 2021).
- **Urban Design Solutions:** These involve the integration of nature with built environments through the use of sustainable materials, energy-efficient designs, and innovative architectural approaches (Widera, 2020).
- **Water Management Solutions:** These include the restoration and creation of wetlands, rain gardens, bioswales, and the implementation of permeable pavements. Water-based solutions help manage stormwater, reduce flood risks, and improve water quality while also mitigating UHI (Beceiro, Galvão and Brito, 2020).

By incorporating NBS into planning and development, cities and regions can address multiple environmental and social challenges simultaneously. The EnerCmed project aims to implement a variety of NBS in the pilot cities of Genoa, Valencia, Patras, and Pula to enhance climate resilience and improve urban sustainability.

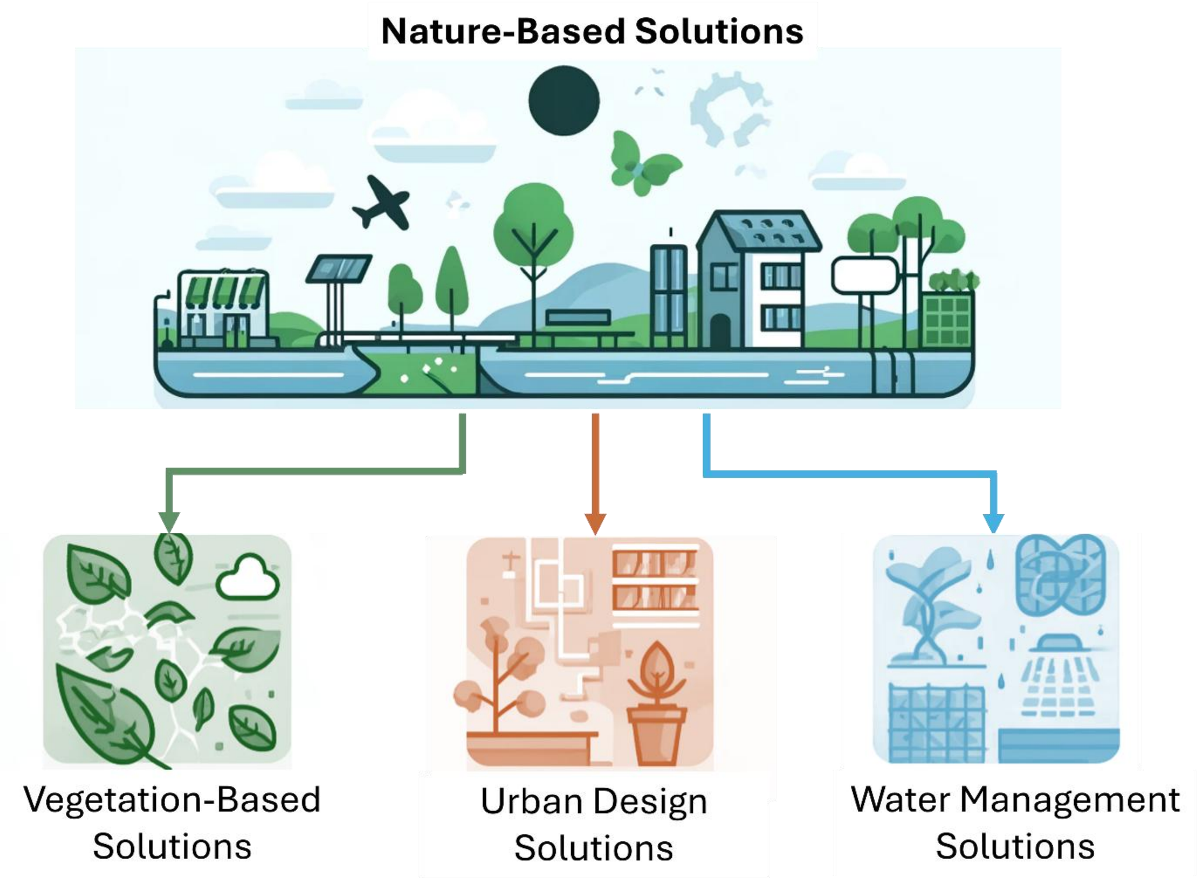


Figure 1 A simplified diagram of Nature-Based Solutions (NBS) types. The three sections illustrate: Vegetation-Based Solutions, Urban Design Solutions and Water Management Solutions.

In this report, we present a comprehensive review of various NBS, highlighting their potential applications, benefits, and challenges in enhancing urban resilience and addressing the UHI phenomenon. Each NBS will be described in detail, illustrating how these innovative approaches contribute to sustainable urban development and climate adaptation.

2.1.1 Vegetation-Based Solutions

Vegetation-based solutions are a critical component of NBS, focusing on the use of plants and green infrastructure to tackle urban and environmental challenges (Freer, 1991). These solutions offer numerous benefits, including cooling urban areas, improving air quality, and enhancing biodiversity. They play a significant role in mitigating the UHI effect by leveraging natural processes such as evapotranspiration and shading to reduce surface temperatures and improve thermal comfort in cities. By cooling urban areas, they directly address one of the primary factors contributing to UHI, making cities more liveable during extreme heat events.

The integration of vegetation into urban settings involves a variety of approaches, from small-scale interventions to larger, systemic changes. Effective implementation requires selecting suitable plant species, ensuring proper maintenance, and integrating green spaces with existing urban infrastructure (Kyropoulou, Subramaniam and Hoffmann, 2021). These solutions not only provide ecological benefits but also enhance the aesthetic and recreational value of urban environments, contributing to the overall well-being of residents.

Vegetation-based solutions can be categorized into several subtypes, each offering unique advantages and addressing specific urban challenges. In the following subsections, various types of vegetation-based solutions are detailed, highlighting their applications, benefits, and the challenges involved in their implementation.

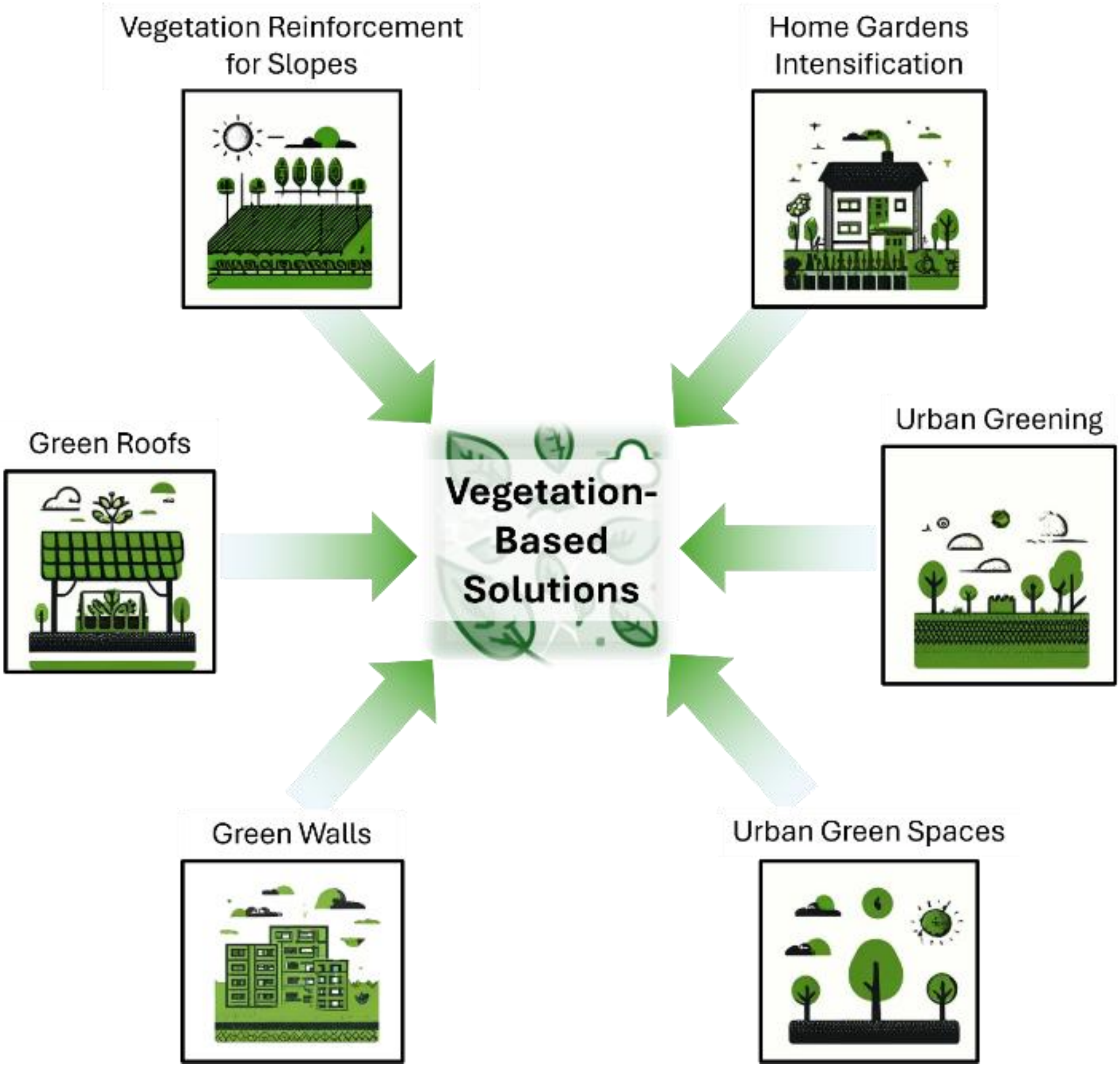


Figure 2 Various types of vegetation-based solutions used to enhance urban resilience and environmental quality. Categories include Urban Greening, Urban Green Spaces, Green Roofs, Green Walls, Vegetation Reinforcement for Slopes, and Home Gardens Intensification.

2.1.1.1 Urban Greening (Trees/Grass/Sharps)

Urban greening, which includes planting trees, grass, and shrubs along streets and in public spaces, is an essential strategy for municipalities aiming to enhance urban resilience. This approach provides significant environmental, social, and economic benefits. Trees and other vegetation in urban areas help reduce the UHI effect, improve air quality, and support biodiversity (Tan, Lau and Ng, 2016). They also offer shading and cooling through evapotranspiration, which helps to lower ambient temperatures and improve thermal comfort in urban environments (Cheung and Jim, 2018).

Trees and other vegetation reduce the UHI effect by providing shade that decreases the amount of solar radiation reaching the surface. This reduction in solar radiation lowers the surface temperature, causing the surface to absorb less energy and emit less heat back into the atmosphere. Additionally, plants release moisture through evapotranspiration, which cools the air and further reduces the UHI effect. Urban greening contributes to better stormwater management by absorbing rainwater and reducing runoff, which helps to prevent flooding. Urban areas face deteriorating air quality due to high concentrations of pollutants and recurrent dust phenomena. Increasing urban greening and introducing vegetation capable of filtering airborne particulates can significantly enhance air quality and improve overall urban living conditions.

Implementing urban greening projects presents several challenges. These include securing sufficient funding, ensuring proper maintenance, and overcoming spatial constraints in densely built urban areas. It is also crucial to select plant species that are well-suited to the local climate and soil conditions to ensure their survival and effectiveness (Jellinek *et al.*, 2020). Additionally, a recent study has shown that strategic placement and maintenance of urban trees can significantly improve thermal comfort and reduce temperatures in urban areas, especially during late afternoons (Tochaiwat *et al.*, 2023). Furthermore, the size and type of trees play a significant role in determining their effectiveness in urban microclimates (Alexandrou *et al.*, 2023; Zhao *et al.*, 2023). Urban areas face significant challenges in implementing urban greening and vegetation-based solutions, particularly due to climate mitigation and adaptation issues. Many regions are experiencing rising temperatures and frequent, intense dust events. To address these conditions effectively, it is crucial to conduct expert studies to identify the specific species of flora that are best suited to the varying climatic conditions across different regions. This tailored approach will enhance the resilience of local ecosystems and help mitigate the adverse effects of climate change. Effective water management remains a critical challenge in urban greening, particularly in areas experiencing severe drought conditions and a scarcity of precipitation. The challenge lies in ensuring a sustainable water supply to support these green infrastructures. Strategies need to include the adoption of advanced water-saving technologies, the development of infrastructure for rainwater harvesting, and the recycling of wastewater.

Effective urban greening requires coordinated efforts from municipal authorities, urban planners, and the community to ensure that these green spaces are well-integrated into the urban landscape and provide maximum benefits. In REC, urban greening plays a pivotal role in mitigating UHI and reducing extreme heat stress. By incorporating vegetation into the design and layout of REC, these communities can create cooler microclimates, reducing the need for energy-intensive air conditioning and improving overall thermal comfort for residents.

2.1.1.2 Urban Green Spaces

According to (Raparthi, 2020), urban green spaces such as parks and community gardens are a crucial component of NBS aimed at enhancing urban resilience. These green spaces provide essential areas for recreation, social interaction, and ecological functions. They play a key role in cooling urban areas, improving air quality, and supporting biodiversity. Urban green spaces mitigate the UHI effect by offering shaded areas and facilitating evapotranspiration, which helps to reduce surface temperatures (Toparlar *et al.*, 2018).

The benefits of urban green spaces extend beyond environmental impacts. These spaces enhance the quality of life for urban residents by providing areas for physical activity, relaxation, and community engagement. Additionally, urban green spaces contribute to mental well-being by offering natural settings that reduce stress and promote psychological health (Lee and Maheswaran, 2011). The presence of green spaces in urban areas has been associated with lower levels of pollution and higher biodiversity.

Compared to urban greening, which often focuses on individual trees and small patches of vegetation, urban green spaces offer larger, contiguous areas that can provide more substantial cooling and recreational benefits. Parks and community gardens can create extensive shaded areas that significantly lower surface temperatures, reducing the overall urban heat load more effectively than scattered trees. The larger green areas also support more diverse plant and animal species, enhancing urban biodiversity and ecological functions.

Implementing urban green spaces involve several challenges (Khoshkar, Balfors and Wärnbäck, 2018). One significant challenge is the availability of land in densely populated urban areas, where space is often limited. Moreover, maintaining these green spaces requires continuous effort and resources, including water, fertilizers, and labor. Additionally, urban regeneration projects present unique challenges. Regeneration efforts should focus on creating mixed-use developments that promote walkability, reduce carbon footprints, and enhance urban biodiversity. This balance is often constrained by the need to preserve cultural heritage and other socioeconomical factors. Another challenge pertains to social justice and cohesion, requiring the creation of green parks that are accessible and beneficial to all socioeconomic groups, thereby enhancing overall social cohesion (Kolokotsa *et al.*, 2020) .

Effective implementation of urban green spaces requires collaborative efforts from urban planners, local authorities, and community members. Addressing these challenges is crucial for the successful integration of green spaces in urban areas. As NBS, urban green spaces help to mitigate the impacts of heatwaves, the UHI effect, and other environmental challenges, ultimately enhancing urban resilience and improving the quality of life for city dwellers.

In REC, urban green spaces are particularly important for mitigating UHI and extreme heat stress. By incorporating parks, gardens, and other green areas into the urban fabric, REC can create cooler microclimates that reduce the reliance on energy-intensive cooling systems, thus conserving energy and enhancing sustainability. The strategic placement and maintenance of these green spaces not only improve thermal comfort for residents but also contribute to the overall resilience and liveability of REC.

2.1.1.3 Green Roofs

Green roofs are a sustainable practice that mitigates the adverse effects of urbanization. These solutions involve the installation of vegetation on rooftops, offering multiple benefits such as stormwater management, energy cost reduction, and improved air quality (Shafique, Kim and Rafiq, 2018).

Green roofs mitigate the UHI effect by covering building rooftop surfaces with vegetation, which absorbs less heat than traditional roofing materials. This helps in reducing the overall heat absorbed by buildings, leading to cooler indoor environments. The process of evapotranspiration, where plants release moisture into the air, further cools the surrounding environment and lowers ambient temperatures. This dual cooling effect can lead to substantial energy savings by reducing the demand for air conditioning, particularly during hot summer months. This cooling effect not only enhances the thermal comfort within buildings but also contributes to energy savings by reducing the need for air conditioning. The integration of green roofs has been shown to significantly lower surface temperatures and improve energy efficiency in urban areas (Sharma *et al.*, 2016).

Implementing green roofs presents several challenges, including high initial construction costs, maintenance requirements, and potential issues with roof leakage (Van der Meulen, 2019). The construction of green roofs requires a significant upfront investment, as it involves reinforcing the existing roof structure to support the additional weight of soil and vegetation. Ongoing maintenance is essential to ensure the health and longevity of the plants, which includes regular watering, fertilizing, and weeding. Additionally, there is a risk of roof leakage if the waterproofing membrane is not properly installed or maintained. The extensive green roof, according to Y. Qiu, et al.2021, has a construction cost of €35 per square meter, annual operation and maintenance costs of €1.75 per square meter, and an expected lifespan of 40 years. Meanwhile, the semi-intensive green roof is priced at €120 per square meter for construction, with annual maintenance costs of €1.91 per square meter, a lifespan of 40 years.

As a NBS, green roofs significantly contribute to urban resilience by managing stormwater, enhancing biodiversity, and improving air quality. Effective implementation of green roofs requires collaborative efforts from architects, urban planners, and community members to ensure these green infrastructures are integrated seamlessly into urban environments. By addressing the impacts of heatwaves, the UHI effect, and other environmental challenges, green roofs promote sustainable urban development and enhance the quality of life for city dwellers. Additionally, advancements in green roof technology, such as lightweight growing media and efficient irrigation systems, can help reduce costs and maintenance burdens.

Within the context of REC, green roofs are instrumental in alleviating UHI and managing extreme heat conditions. These installations foster cooler building environments, thereby minimizing the reliance on air conditioning systems and boosting energy conservation. This practice aligns with the sustainability objectives of RECs, enhancing both energy efficiency and environmental quality. By improving thermal comfort for inhabitants and bolstering urban resilience, green roofs provide a comprehensive solution to the climatic and energy challenges faced by these communities.

2.1.1.4 Green Walls

Green walls, also known as vertical gardens, are an innovative NBS that involves growing plants on vertical surfaces, such as building facades and walls (Li *et al.*, 2022). These systems provide multiple environmental, economic, and social benefits, making them an effective tool for enhancing urban resilience. Green walls help to reduce UHI effect by cooling the surrounding air through evapotranspiration and shading, which lowers ambient temperatures and improves indoor thermal comfort (Koch *et al.*, 2020).

Green walls mitigate the UHI effect by providing a layer of vegetation that shades building surfaces, reducing the amount of solar radiation absorbed by the walls. This shading effect lowers the surface temperature of the building, decreasing the heat that is emitted back into the environment. Additionally, the plants' process of evapotranspiration cools the air as water is absorbed by the roots and released as vapor through the leaves, further reducing ambient temperatures. This dual cooling mechanism helps to create a more comfortable and cooler microclimate in urban areas.

Indoors, green walls contribute to thermal comfort by providing insulation and reducing heat transfer through building walls. The vegetation layer acts as an insulating barrier, which helps to keep buildings cooler in the summer and warmer in the winter. This insulation reduces the need for heating and cooling systems, leading to significant energy savings and lower utility bills. The cooling effect of green walls can reduce the reliance on air conditioning, which in turn lowers energy consumption and decreases greenhouse gas emissions. This contributes to a more sustainable and energy-efficient building environment.

Green walls also improve air quality by filtering pollutants and producing oxygen, contributing to healthier urban environments. They can also absorb and manage stormwater, reducing the risk of flooding (Assimakopoulos *et al.*, 2020). Additionally, green walls reduce noise, enhancing the aesthetic value of urban spaces, contributing to the mental well-being of residents, and increasing property values (Paull *et al.*, 2020)

However, implementing green walls presents several challenges. These include installation and maintenance costs, potential issues with structural integrity and water leakage, and the need for careful selection of plant species that can thrive in vertical environments. The initial costs of installing green walls can be high due to the need for specialized structures and materials to support the vegetation. Ongoing maintenance is essential to ensure the health and longevity of the plants, which includes regular watering, fertilizing, pruning, and pest control (Gunawardena and Steemers, 2020).

In REC, green walls offer a strategic advantage in combating UHI and managing extreme heat. By integrating these vertical gardens into building designs, RECs can benefit from cooler ambient temperatures, which reduces the dependency on air conditioning and lowers overall energy consumption. This approach not only promotes energy efficiency but also supports the overarching sustainability objectives of RECs. Moreover, green walls contribute to creating comfortable living conditions and enhancing urban resilience, making them a vital element in the holistic development of these communities.

Green walls offer a valuable opportunity to boost urban resilience. Achieving successful implementation requires the combined efforts of architects, urban planners, and community members. Effective collaboration and planning are essential to ensure that green walls are integrated seamlessly into urban environments and provide maximum benefits. Green walls can play a crucial role in promoting sustainable urban development and enhancing the quality of life for city residents by addressing environmental challenges such as heatwaves, the UHI effect, air pollution, and stormwater management.

2.1.1.5 Home Gardens Intensification

Home gardens intensification refers to enhancing the use and productivity of domestic garden spaces to support urban resilience. These small-scale nature-based solutions can significantly enhance climate resilience and help mitigate the UHI effect. Home gardens provide numerous benefits, including food production, improved mental health, and increased biodiversity (Santos *et al.*, 2022).

Home gardens help mitigate the UHI effect by offering shade, which reduces the amount of solar radiation absorbed by buildings and surfaces, thus lowering surface temperatures. The process of evapotranspiration, where plants release moisture into the air, further cools the surrounding environment. This combination of shading and evapotranspiration creates a cooler microclimate, reducing the heat load on buildings and lowering the need for air conditioning. The reduced energy consumption for cooling translates into decreased greenhouse gas emissions and more sustainable urban living. By mitigating extreme heat, home gardens improve the thermal comfort of residents and contribute to a more sustainable urban environment.

The intensification of home gardens can help mitigate the effects of urbanization by providing local food sources, which can reduce the carbon footprint associated with food transportation. Additionally, home gardens serve as ecological corridors for wildlife, contributing to biodiversity conservation. Moreover, home gardens act as carbon sinks, absorbing carbon dioxide from the atmosphere and helping to combat climate change (Ghosh, 2021).

Despite these benefits, there are challenges associated with the previous vegetation-based solutions. Additionally, limitations include limited space in densely populated urban areas, lack of gardening knowledge, and insufficient access to resources such as quality soil and water (Saroinsong *et al.*, 2021). The limited space in urban settings can restrict the size and diversity of home gardens. Lack of gardening knowledge among urban residents can hinder the effective cultivation and maintenance of home gardens. Additionally, access to resources like quality soil, water, and gardening tools can be limited in urban areas. Effective strategies to address these challenges involve community engagement, educational programs, and policy support to encourage the widespread adoption of home gardening practices.

Home gardens can significantly contribute to urban resilience by enhancing food security, providing green spaces that improve mental health, and fostering stronger community ties. Their successful implementation relies on efforts from residents. By addressing the impacts of heatwaves, the UHI effect, and other environmental challenges, home gardens intensification can play a crucial role in the portfolio of small-scale nature-based solutions tailored to the urban dimensions of the four pilot cities in this project.

In REC, the integration of home gardens can further enhance energy efficiency by reducing the need for cooling systems, thereby aligning with the sustainability goals of REC. By addressing the impacts of heatwaves, the UHI effect, and other environmental challenges, home gardens intensification can serve as a key strategy in the portfolio of small-scale nature-based solutions tailored to the urban dimensions of the four pilot cities in this project.

2.1.1.6 Vegetation Reinforcement for Slopes

Vegetation reinforcement for slopes is a critical strategy in stabilizing slopes and preventing erosion. Although not a direct solution to the UHI effect, this NBS addresses problems that are correlated with the impacts of UHI and climate change, such as increased erosion and soil degradation. High urban temperatures can exacerbate these issues, making slope stabilization essential for maintaining urban resilience. This NBS involves the use of plant roots to reinforce soil and enhance slope stability. Vegetation such as trees, shrubs, and grasses can significantly improve the mechanical properties of the soil through root reinforcement, which helps bind soil particles together and prevent landslides (Masi, Segoni and Tofani, 2021).

The benefits of using vegetation for slope reinforcement include reducing surface runoff, improving soil structure, and increasing the infiltration capacity of the soil, which helps in managing stormwater and reducing the risk of floods (Patil *et al.*, 2022). Furthermore, vegetation can provide aesthetic value and enhance biodiversity in the area

Figure 3 Illustration of plant roots stabilizing slopes and preventing erosion. (Source: (Masi, Segoni and Tofani, 2021))

However, the implementation of vegetation reinforcement on slopes faces several challenges. These include selecting the appropriate plant species that can thrive in the local conditions, ensuring proper maintenance, and dealing with potential issues such as plant die-off during extreme weather conditions. Additionally, the effectiveness of vegetation in stabilizing slopes can vary significantly depending on factors such as soil type, slope gradient, and climatic conditions (Kim *et al.*, 2017). The study by Liu *et al.*, 2021 highlights that while vegetation can significantly increase slope stability under both dry and wet conditions, the proportion of safety improvement due to vegetation is relatively limited. Other limitations include the time required for vegetation to mature and become effective, which can be a critical factor in urgent erosion control situations. There is also a potential for invasive species to spread, which can disrupt local ecosystems. Additionally, the initial costs and long-term financial investments for planting and maintaining vegetation can be substantial.

Despite these challenges, vegetation reinforcement for slopes remains a promising approach to enhancing urban resilience, particularly in areas facing erosion problems or needing to address climate change impacts. While this strategy does not directly address the UHI problem, it mitigates issues that are correlated with UHI effects, such as increased erosion due to the changing climate. High urban temperatures can exacerbate soil degradation and erosion, making these measures essential for maintaining urban resilience.

Moreover, the use of trees and other vegetation in slope reinforcement can contribute to broader climate mitigation efforts. Trees sequester carbon, provide shade, and reduce ambient temperatures through evapotranspiration. This ancillary cooling effect helps to moderate microclimates and can indirectly support efforts to combat UHI.

Implementing these solutions requires coordinated efforts from environmental engineers, urban planners, and local authorities to ensure successful implementation and maintenance. By effectively mitigating the risks of landslides and erosion, vegetation reinforcement for slopes contributes to sustainable urban development and improves the overall safety and quality of life in urban areas.

2.1.2 Urban Design Solutions

Urban Design Solutions integrate natural elements with built environments to create resilient and sustainable urban landscapes. These solutions focus on enhancing the urban environment's sustainability by using materials, designs, and architectural approaches that minimize environmental impact and promote ecological balance. This approach emphasizes the integration of natural elements and sustainable technologies to create resilient urban environments capable of adapting to climate change and reducing their ecological footprint (Sanseverino *et al.*, 1AD).

This approach leverages a combination of traditional architectural practices and modern sustainable technologies to create urban spaces that are both functional and environmentally friendly. Key elements of sustainable urban design include the use of renewable materials and energy-efficient construction techniques. By prioritizing sustainability in urban planning and design, cities can reduce their carbon footprint, improve air quality, and enhance the overall quality of life for residents (Bettencourt, 2019).

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Sustainable urban design solutions are particularly important in densely populated areas where space is limited, and the environmental impact of urbanization is significant. These solutions provide multiple co-benefits, including reduced energy consumption and improved thermal comfort. Effective implementation of urban design requires collaboration among architects, urban planners and the community to ensure that these solutions are integrated seamlessly into the urban fabric (Puchol-Salort *et al.*, 2021).

The absence of comprehensive and cohesive institutional, policy, and legal frameworks poses a significant barrier to addressing environmental challenge. Effective governance structures are crucial for the implementation and enforcement of sustainable urban design solutions. All the urban design solutions face the same three problems that includes the lack of supportive and systematic institutional and policy and legal frameworks. The lack of supportive and systematic institutional, policy, and legal frameworks is a significant barrier to effective urban design management. Addressing this challenge requires strengthening institutions, developing comprehensive policies, and enhancing legal frameworks to promote sustainable urban management practices. By doing so, it is possible to build a sustainable urban environment in cities (Tsatsou *et al.*, 2023).

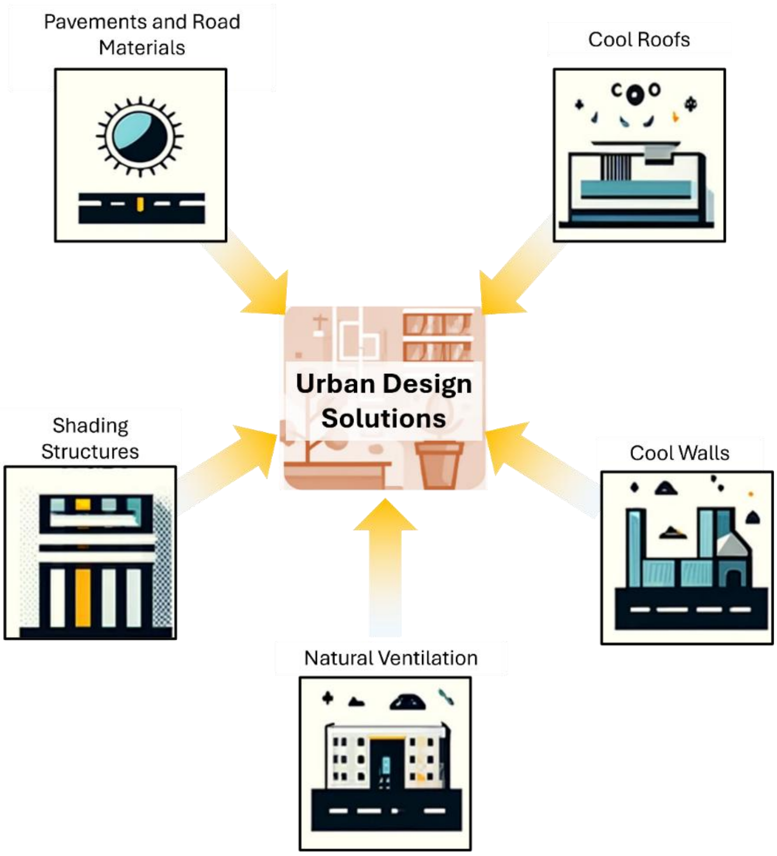

Figure 4 various types of urban design solutions used to enhance sustainability and resilience in urban environments. The categories include Pavements and Road Materials, Reflective and Cool Surfaces, Natural Ventilation Measures, and Shading Structures for Walls

In the following subsections, various types of urban design solutions are detailed, highlighting their applications, benefits, and the challenges involved in their implementation.

2.1.2.1 Pavements and Road Materials

Cool pavements are an innovative urban design approach that addresses the UHI effect by reducing the temperature of paved surfaces. These pavements employ materials and technologies that increase reflectivity, enhance evaporative cooling, and lower heat absorption. By reflecting more sunlight and allowing for water infiltration, cool pavements help to keep urban areas cooler (Kappou *et al.*, 2022).

Different types of cool pavements include reflective pavements, which use materials with high albedo to reflect sunlight. Reflective pavements can significantly lower surface temperatures (Figure 5). Reflective pavements, by utilizing materials with high albedo, reflect a greater portion of sunlight compared to traditional asphalt. This reflection reduces the amount of heat absorbed by the pavement, leading to cooler surface temperatures and subsequently cooler surrounding air.

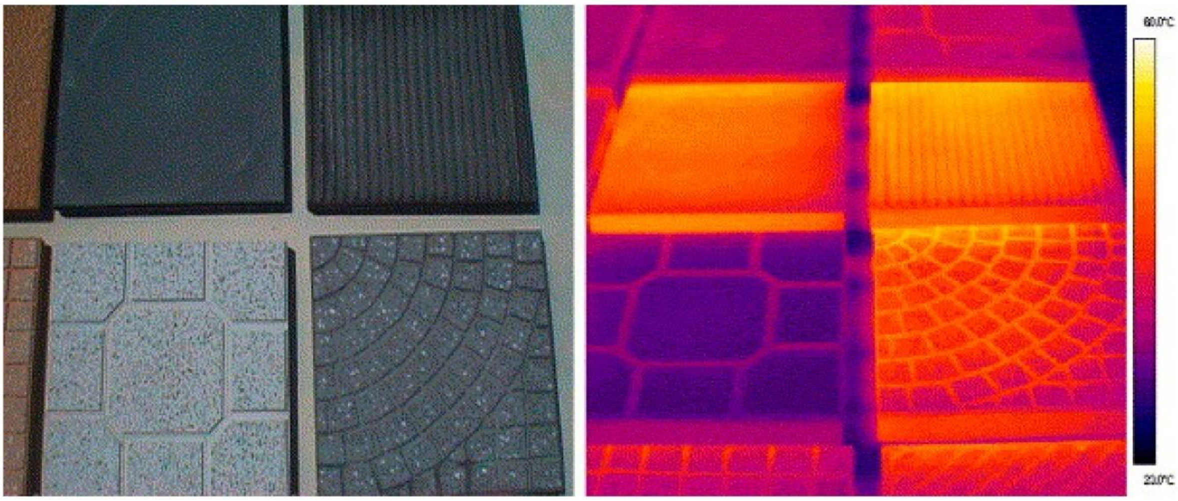

Figure 5 Visible and infrared image for various materials used for road surfaces (Kappou et al.*, 2022)*

The advantages of cool pavements go beyond temperature control. They contribute to better thermal comfort for residents, reduce energy consumption by lowering the need for air conditioning, and decrease greenhouse gas emissions (Xu *et al.*, 2021).

Sustainable road materials are an essential component of nature-based solutions aimed at reducing the UHI effect. By replacing conventional asphalt with sustainable alternatives, cities can significantly lower surface temperatures, improve air quality, and contribute to overall environmental sustainability (Moretti *et al.*, 2022). Studies have shown that replacing traditional asphalt with light concrete or grass pavement can lower surface temperatures by several degrees (Pasetto *et al.*, 2019). Light-colored concrete, due to its higher reflectivity, absorbs less heat compared to dark asphalt. Grass pavements, which integrate vegetation into the pavement structure, provide natural cooling through shading and evapotranspiration.

The use of bio-oils and other sustainable binders in road and pavement construction is another promising technique. These materials can reduce the environmental impact by lowering greenhouse gas emissions and improving the durability and performance of pavements and roads. A study demonstrated that binders made with waste bio-oils can significantly reduce the UHI effect and noise pollution, making them a viable green solution for urban infrastructure (Kousis *et al.*, 2020).

Despite their benefits, the adoption of new pavements and roads faces challenges such as higher initial costs, maintenance requirements, and the need for careful urban planning to ensure compatibility with existing infrastructure. Cool pavements and sustainable road materials often have higher upfront costs compared to traditional materials, which can be a barrier to widespread adoption. Additionally, these innovative materials may require specialized maintenance practices to ensure their longevity and performance. Effective urban planning is crucial to integrate cool pavements and sustainable road materials into existing urban environments without disrupting transportation networks or other infrastructure systems.

Overcoming these challenges requires coordinated efforts from urban planners, engineers, policymakers, and the community to ensure effective implementation and long-term maintenance. Cool pavements and sustainable road materials are vital components of urban strategies to combat the UHI effect and promote sustainable development. In REC, these innovative solutions can play a crucial role by enhancing energy efficiency and reducing reliance on cooling systems, thereby aligning with REC's sustainability objectives.

2.1.2.2 Reflective and Cool Surfaces

Reflective and cool surfaces, including cool roofs and cool walls, provide an effective strategy for enhancing urban resilience by mitigating excessive heat absorption and lowering surface temperatures.

2.1.2.3 Cool Roofs

These roofs utilize materials with high solar reflectance and thermal emittance, which helps in keeping the building and surrounding environment cooler. The implementation of cool roofs can significantly lower rooftop temperatures, enhance thermal comfort, and reduce energy consumption for cooling. Recent advancements have led to the development of super-cool technologies with albedo values greater than 0.96, which significantly improve their cooling efficiency (Baniassadi, Sailor and Ban-Weiss, 2019). For instance, a study in the Kansas City Metropolitan area found that cool roofs could reduce daytime air temperatures by an average of 0.08°C during typical summer conditions, aiding in overall urban cooling (Jeong, Millstein and Levinson, 2021).

Cool roofs not only help in mitigating the UHI effect but also contribute to improved urban air quality by reducing the formation of ground-level ozone, a harmful air pollutant. The high reflectivity of cool roofs prevents the absorption of solar radiation, thereby lowering the surface temperature of the roofs. This reduction in heat absorption translates into lower indoor temperatures, which reduces the need for air conditioning. Consequently, this leads to significant energy savings and reduced greenhouse gas emissions. Studies have shown that cool roofs can decrease daytime air temperatures, leading to energy savings and reduced greenhouse gas emissions (Zhang *et al.*, 2019).

2.1.2.4 Cool Walls

Cool walls, similar to cool roofs, use high-albedo materials to reflect solar radiation and reduce heat absorption by buildings. This strategy is particularly effective in areas with high urban density and tall buildings, where wall surfaces can significantly contribute to the urban thermal environment. By increasing the albedo of walls, cool walls can lower the surrounding air temperature and reduce the energy needed for air conditioning. A study in Los Angeles found that increasing wall albedo by 0.80 could reduce urban air temperatures by up to 0.64 K during peak times (Zhang *et al.*, 2018).

Cool walls also provide additional benefits such as improved indoor thermal comfort and reduced cooling loads for buildings. The high reflectivity of cool walls prevents the absorption of heat, keeping indoor spaces cooler and reducing the demand for air conditioning. The effectiveness of cool walls depends on various factors, including urban density, wall orientation, and the material properties used. Innovative materials such as fluorescent cool pigments have been developed to enhance the reflectivity and cooling potential of wall surfaces, further contributing to urban heat mitigation (Levinson *et al.*, 2019).

These reflective and cool surfaces contribute to a reduction in the overall urban heat load, making urban areas more comfortable and reducing the energy demand for cooling. By reflecting a significant portion of solar radiation, cool walls can help lower the ambient temperature in urban environments, improving the overall thermal comfort for residents. The adoption of cool walls represents a cost-effective and efficient solution to combat the UHI effect, reduce energy consumption, and improve environmental quality.

2.1.2.5 Natural Ventilation Measures

Natural ventilation measures are a sustainable and energy-efficient approach to improving indoor air quality and thermal comfort in urban buildings. These measures harness natural forces such as wind and buoyancy to facilitate air circulation, reducing the need for mechanical ventilation and cooling systems (Pan *et al.*, 2019).

Natural ventilation in urban buildings can be achieved through various strategies, including single-sided and cross ventilation. These methods rely on the strategic placement of openings like windows and vents to maximize airflow and enhance indoor environments (Costanzo *et al.*, 2019). Effective natural ventilation design involves considering factors such as building orientation, window placement, and local wind conditions to optimize air exchange rates. For instance, research has shown that combining buoyancy and wind-driven forces can significantly enhance ventilation rates, particularly in high-rise buildings (Weerasuriya *et al.*, 2019).

The implementation of natural ventilation measures faces challenges such as ensuring adequate ventilation rates in densely built urban areas and managing indoor air quality in the presence of outdoor pollutants. Studies have highlighted the importance of integrating environmental sensors and smart controls to monitor and optimize ventilation performance in real-time (Luo, Hong and Pantelic, 2021). Overall, natural ventilation measures contribute to sustainable urban development by reducing energy consumption and enhancing the health and well-being of urban residents. Effective implementation requires a holistic approach that combines architectural design, environmental monitoring, and stakeholder engagement.

2.1.2.6 Shading Structures for Walls

Shading structures for walls are an effective urban design solution that can significantly reduce solar heat gain and enhance thermal comfort in urban buildings. These structures, which include elements such as external louvers and shading screens are designed to block direct sunlight while allowing natural light to enter buildings. By mitigating the heat absorbed by building facades, shading structures help lower indoor temperatures, reduce the need for air conditioning, and contribute to energy savings (Kirimtat *et al.*, 2019).

One of the primary benefits of shading structures is their ability to improve the energy efficiency of buildings. By reducing the amount of heat entering the building, these structures decrease the cooling load on HVAC systems, leading to lower energy consumption and reduced greenhouse gas emissions. Additionally, shading structures enhance the aesthetic appeal of buildings and urban landscapes, creating more visually attractive and pleasant environments.

Shading structures can be designed to be static or dynamic. Static shading devices, such as fixed louvers and pergolas, provide constant protection from solar radiation. In contrast, dynamic shading systems, such as motorized louvers and retractable awnings, can adjust their position based on the sun's angle, optimizing shading throughout the day and seasons (Kim, Yang and Moon, 2019). This adaptability further improves their efficiency in managing solar heat gain and enhancing indoor comfort.

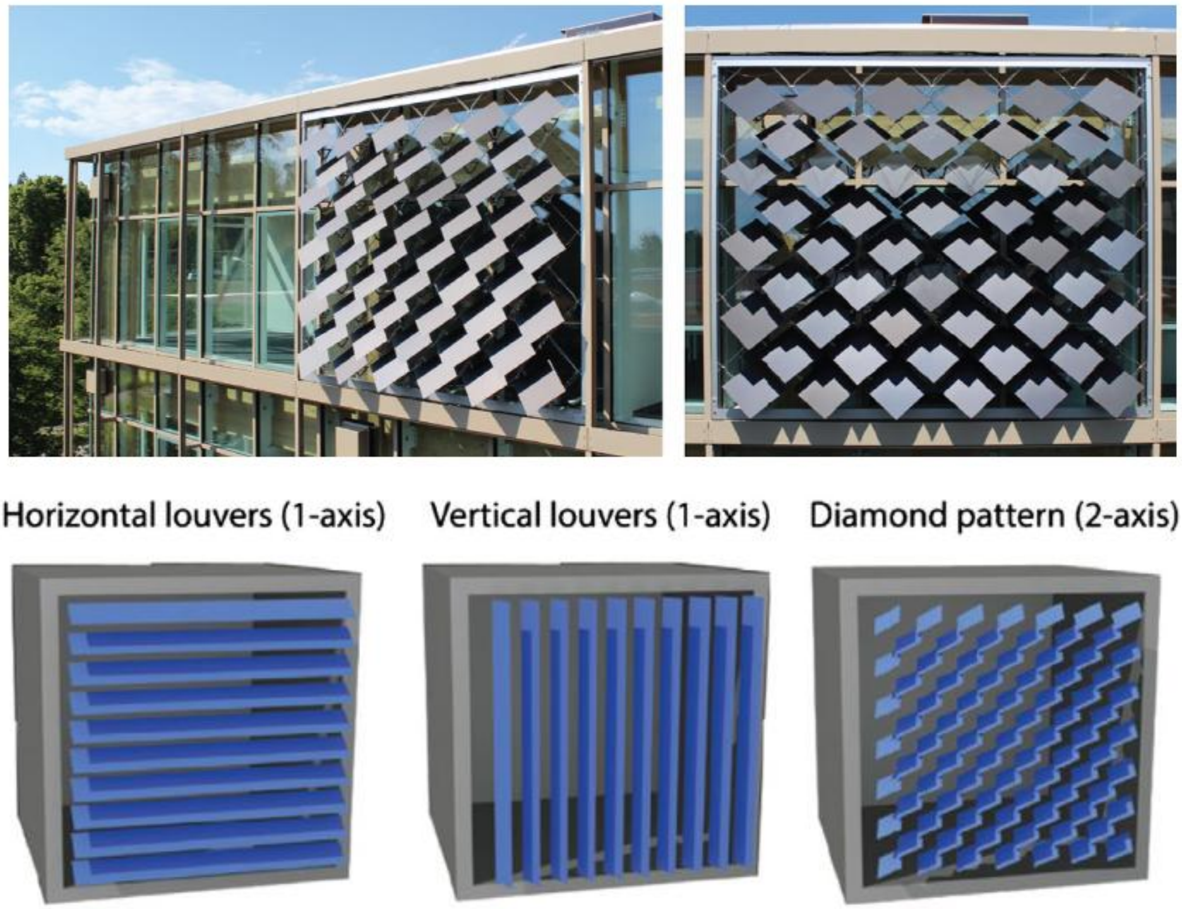

Figure 6 Adaptive Solar Façade installed at ETH House of Natural Resources and illustration of different types of louvers: Horizontal louvers (1-axis), Vertical louvers (1-axis), and Diamond pattern (2-axis) (Source: Hofer et al.*, 2016)*

Implementing shading structures in urban environments faces challenges such as the initial cost of installation, maintenance requirements, and ensuring compatibility with existing building designs. However, advancements in materials and technology, such as the use of lightweight and durable materials and automated control systems, are making shading structures more accessible and effective.

Effective implementation of these structures requires collaboration between architects, urban planners, and building owners to ensure they are integrated seamlessly into the urban fabric and provide maximum benefits.

2.1.3 Water-Based Solutions

Water-based solutions are an essential category of NBS that utilize natural water processes to manage urban challenges and enhance resilience (Kalantari, Gadnert and Ferreira, 2020). These solutions are also pivotal in alleviating the UHI effect by leveraging natural hydrological cycles and processes to reduce ambient temperatures and improve thermal comfort. These solutions also address issues such as stormwater management, flood mitigation, and water quality improvement, which are increasingly critical due to the impacts of climate change, providing a sustainable approach to urban water management. By leveraging natural hydrological cycles and processes, water-based NBS help communities adapt to climate change impacts, reduce the risk of flooding, and improve overall urban water quality.

The integration of water-based solutions into urban settings involves various strategies, like rain gardens, constructed urban wetlands and sustainable drainage systems (SuDS). Effective implementation requires careful planning, proper maintenance, and the integration of these systems with existing urban infrastructure. These solutions not only manage water resources efficiently but also create cooler microclimates, enhance the ecological and recreational value of urban environments, and contribute to the overall well-being of residents by reducing heat stress.

In the context of Renewable Energy Communities (REC), water-based NBS can further support energy efficiency and sustainability goals. But to implement this is required a circular economy of water (CEW). This framework involves minimizing water consumption (Reduce), harvesting and reusing rainwater with minimal treatment (Reuse), collecting, treating, and recycling used water for either on-site or off-site applications (Recycle), and recovering valuable resources embedded within the wastewater stream (Recover). By implementing CEW within REC, communities can optimize water usage and enhance the cooling effects of water-based NBS, leading to a significant reduction in energy consumption for cooling purposes. This methodology can be conceptualized through a CEW hierarchy, which prioritizes the efficient and sustainable management of water resources at each stage of the cycle (McCarton and O'Hogain, 2024).

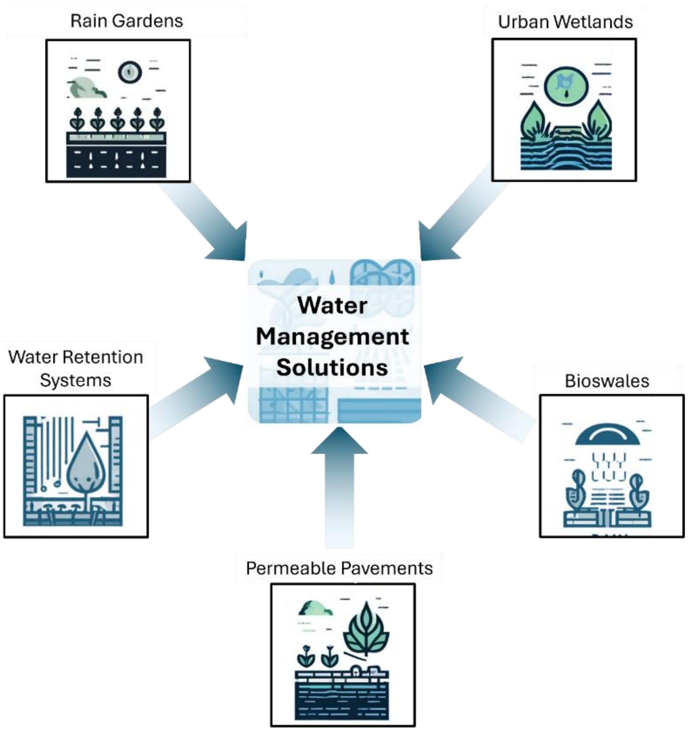

Figure 7 Various types of water-based solutions used to enhance urban resilience and manage water resources sustainably. The categories include Urban Wetlands, Water Retention Systems, Rain Gardens, Bioswales, and Permeable Pavements

Water-based solutions can be categorized into several subtypes, each offering unique advantages and addressing specific urban water challenges.

2.1.3.1 Rain Gardens

Rain gardens, also known as bioretention systems, are designed to capture and infiltrate stormwater runoff from impervious surfaces (Yang *et al.*, 2009). These small-scale green infrastructures help reduce stormwater runoff, improve water quality, and provide aesthetic and ecological benefits to urban areas (Sharma and Malaviya, 2021).

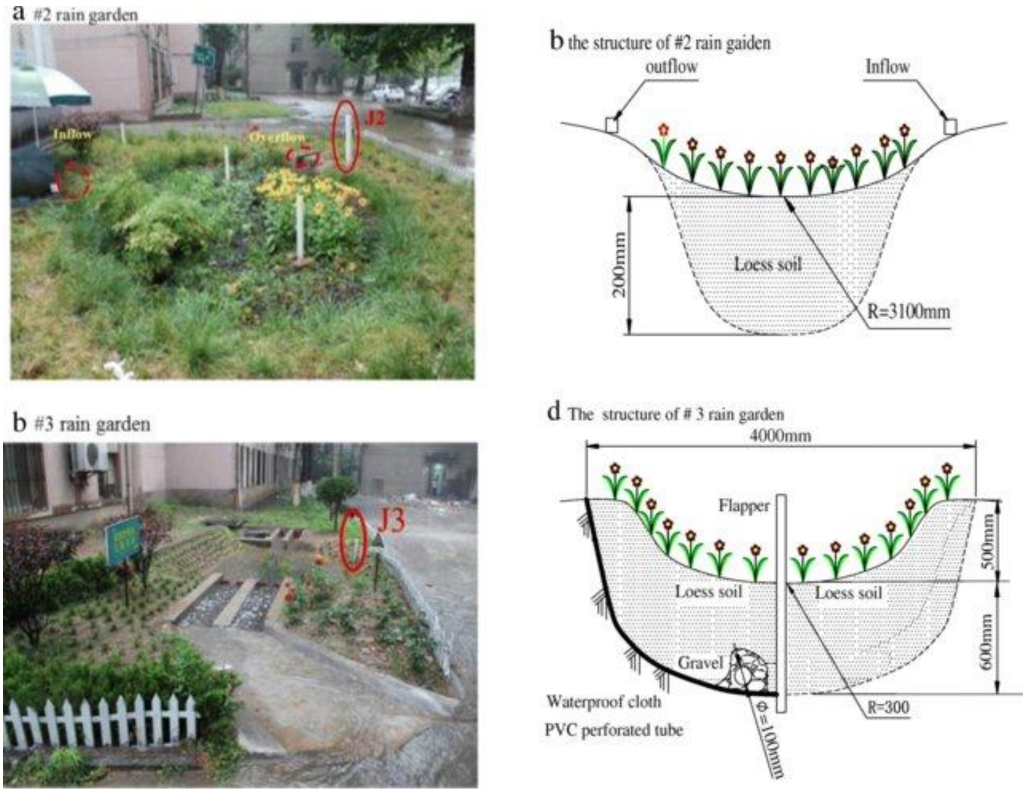

Figure 8 Image shows two rain gardens as studied by Li et al.*, 2019, illustrating their design and function in managing stormwater.*

As described by Palermo *et al.*, 2023, an inflow structure directs runoff from the surrounding areas into the ponding area, while an overflow structure, typically connected to the sewer system, discharges excess water that exceeds the garden's capacity. This setup limits water discharge from impermeable surfaces to the drainage network through natural storage, infiltration, and evapotranspiration processes. These processes contribute to reducing total runoff and its peak by favoring runoff infiltration and short-term storage. In the context of mitigating the UHI effect, rain gardens contribute to cooling urban areas by increasing vegetation cover and maintaining soil moisture, which enhances evapotranspiration and reduces ambient temperatures.

During a storm event, rain gardens retain stormwater within the substrate's micropores until field capacity is reached, followed by evapotranspiration of a portion of the retained water. The soil moisture increases toward saturation, filling larger pores, and allowing ponding once saturation reaches the surface. If the rain garden is unlined, excess moisture infiltrates the ground; if lined, it discharges into the linked sewer. Thus, rain gardens control stormwater through retention, reducing runoff volume, and detention, delaying and attenuating the runoff hydrograph.

In REC, the implementation of rain gardens can enhance urban resilience by not only managing stormwater but also mitigating UHI effects. By keeping the soil moist and promoting vegetation growth, rain gardens help create cooler microclimates. Rain gardens also offer additional benefits such as restoring groundwater recharge, improving water quality by filtering pollutants from stormwater runoff, capturing and storing CO_2 to improve air quality, mitigating local climate, and enhancing biodiversity and visual amenity.

Effective implementation of rain gardens involves addressing challenges like initial costs, regular maintenance, and selecting appropriate plant species for urban environments. Despite these challenges, rain gardens represent a promising approach to enhancing urban resilience. Irrigation is essential for agricultural productivity, especially in regions with variable or insufficient rainfall. Insufficient water for irrigation poses a significant threat to global food security and rural livelihoods (Moosavi, Browne and Bush, 2021).Their successful implementation relies on collaboration among urban planners, local authorities, community members, and environmental engineers. The construction cost for rain gardens is estimated at €30 per square meter with annual operation and maintenance costs of €1.5 per square meter, and they have a projected lifespan of 40 years, as reported by Y. Qiu, et al, 2021

2.1.3.2 Bioswales

Bioswales are vegetated, shallow, and often linear channels designed to manage stormwater runoff (Faraj and Hamaamin, 2023). Bioswales can be in a wide range of scales and types to treat runoff from any surface, but they are typically associated with linear features along roads or parking lots. These green infrastructures not only manage stormwater but also play a significant role in mitigating the UHI effect by enhancing vegetation cover and soil moisture, which contribute to cooling urban environments.

Bioswales can also provide a landscape perspective of green space in a developed environment. By incorporating vegetation, bioswales enhance evapotranspiration helping to lower ambient temperatures and reduce the reliance on energy-intensive cooling systems. They slow, infiltrate, and filter stormwater, improving water quality and reducing flood risks. Bioswales can be integrated along streets and parking lots, providing both functional and aesthetic benefits. They are particularly effective in reducing the burden on conventional rainwater management systems and promoting urban resilience. Bioswales also enhance groundwater recharge by allowing water to infiltrate into the soil, which is crucial for maintaining hydrological balance in urban areas.

The ecohydrological processes within bioswales are influenced by plant characteristics and environmental conditions, which affect their performance and sustainability. For example, plant water use efficiency impacts the ecohydrology within bioswales, and retrofitted bioswales need to be adapted over time to meet environmental demands (Papuga *et al.*, 2022). These processes not only support urban cooling but also foster the growth of vegetation, which further contributes to mitigating UHI.

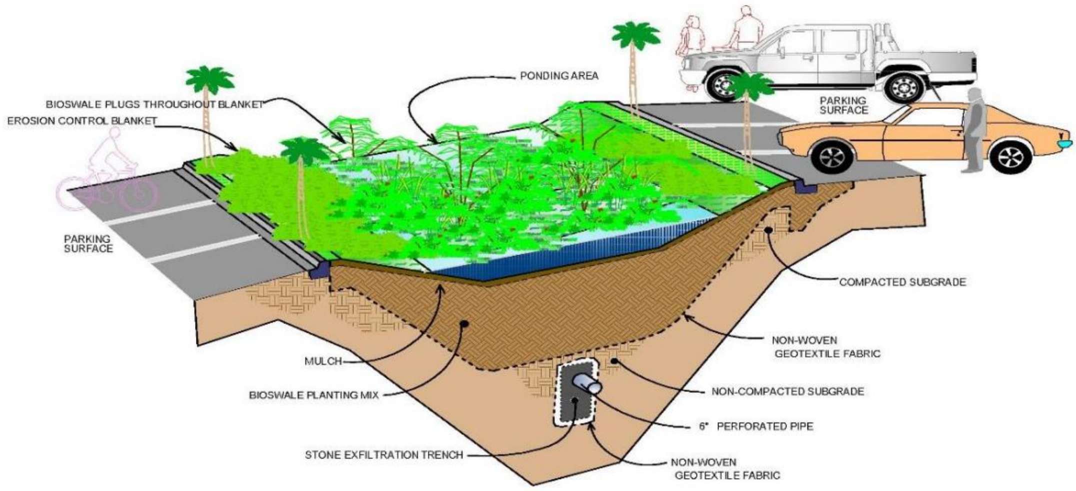

Figure 9 Bioswale concept diagram, structure and operation (Faraj and Hamaamin, 2023)

Challenges associated with bioswales include ensuring proper design and placement to maximize their effectiveness, maintaining vegetation to prevent clogging and degradation, and managing the accumulated pollutants in the soil to prevent secondary contamination. Regular maintenance and monitoring are essential to sustain the functionality and environmental benefits of bioswales (Shetty *et al.*, 2018).

In REC, bioswales offer a dual benefit of managing stormwater and mitigating the UHI effect. By reducing surface temperatures and promoting vegetative growth, bioswales help to create cooler urban microclimates, which in turn decrease the energy demand for cooling. Overall, bioswales represent a promising nature-based solution for urban stormwater management, providing multiple ecological and social benefits. Their role in enhancing vegetation and cooling urban areas makes them a vital component in the strategy to combat UHI and improve the quality of life in urban settings.

2.1.3.3 Permeable pavements

Permeable pavements are a sustainable urban drainage technique designed to manage stormwater by allowing water to infiltrate through the pavement surface into the underlying soil. These systems help reduce surface runoff, mitigate flood risks, and improve water quality by filtering pollutants (Kuruppu, Rahman and Rahman, 2019). Permeable pavements include various types such as permeable interlocking concrete pavements, porous asphalt, and pervious concrete.

In mitigating the UHI effect, permeable pavements are particularly effective due to their ability to facilitate groundwater infiltration (Sanicola, 2018). This process helps cool the surface temperatures, as water infiltrating through the pavement cools the surrounding area, thereby reducing the ambient temperature. This cooling mechanism is crucial in densely built urban areas where traditional pavements contribute to higher temperatures.

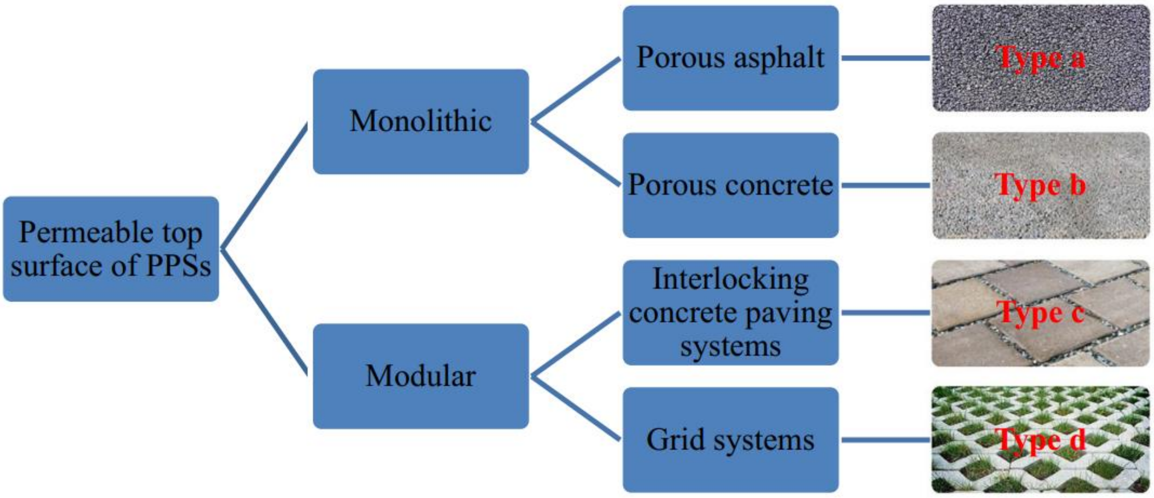

Figure 10 This figure categorizes different types of permeable top surfaces/pavements as sourced by (Kuruppu, Rahman and Rahman, 2019)

Permeable pavements also support natural cooling processes by allowing cooler groundwater to rise to the surface, which helps in reducing heat retention in urban environments. They further aid in stormwater management, reducing peak flow and enhancing water quality by filtering pollutants like sediment, heavy metals, and nutrients (Zhu *et al.*, 2021; Singer *et al.*, 2022). According to Y. Qiu et al, 2021, the construction cost for porous pavement is estimated at €49.4 per square meter, with annual operation and maintenance costs of €1.07 per square meter, and a projected lifespan of 20 years.

One of the main benefits of permeable pavements is their ability to reduce surface runoff and delay peak flows, which helps in mitigating urban flooding. A study on an innovative ceramic permeable pavement demonstrated significant reductions in runoff and peak flow rates, highlighting its effectiveness in stormwater management (Castillo-Rodríguez *et al.*, 2021). Additionally, permeable pavements have been found to improve the quality of infiltrated water by removing suspended solids and pollutants, making them a valuable component of sustainable urban drainage systems (Hernández-Crespo *et al.*, 2019).

In REC permeable pavements contribute to mitigating the UHI effect by enhancing groundwater recharge and supporting vegetation that cools the environment. This approach aligns with REC's sustainability objectives by decreasing heat stress and reducing the overall energy footprint.

However, permeable pavements also face challenges such as clogging, maintenance requirements, and ensuring sufficient load-bearing capacity for vehicular traffic. Clogging, primarily occurring due to sediment accumulation, can significantly reduce the infiltration capacity of permeable pavements. Regular maintenance, such as vacuum sweeping and pressure washing, is essential to mitigate clogging effects. Additionally, the selection of appropriate materials and design considerations are crucial to ensure the durability and functionality of permeable pavements under different traffic loads and environmental conditions (Weiss *et al.*, 2019).

2.1.3.4 Urban Wetlands

Constructed wetlands are engineered systems designed to mimic the functions of natural wetlands. They are an effective water-based NBS for treating wastewater, managing stormwater, and enhancing biodiversity. Constructed wetlands use a combination of physical, chemical, and biological processes to remove pollutants from water, thereby improving water quality and providing habitat for wildlife (Krauze and Wagner, 2019). These systems are particularly beneficial in urban areas where space is limited, as they can be integrated into parks and green spaces to stimulate intensive vegetation growth.

In the context of mitigating the UHI effect, constructed wetlands can help by increasing the local humidity and promoting evaporative cooling. This cooling effect can reduce the ambient temperature in urban areas, making them more comfortable during extreme heat events. Furthermore, the dense vegetation typically found in constructed wetlands can provide shade, further contributing to the reduction of surface temperatures.

Based on the detailed analysis of constructed wetlands from the paper by Masi, Rizzo and Regelsberger, 2018, one of the main advantages of constructed wetlands is their ability to handle variable water flows and pollutant loads, making them highly resilient to changing environmental conditions. They offer benefits such as water reuse, nutrient recovery, and energy production, which align with the principles of a circular economy.

Figure 11 shows different examples of constructed wetlands inside urban cities (Shiba et al.*, 2021)*

However, implementing constructed wetlands involves challenges such as high initial costs, the need for regular maintenance, and potential land use conflicts. Effective planning, stakeholder engagement, and financial incentives are essential to overcome these challenges and promote the widespread adoption of constructed wetlands. Additionally, poor water quality in these wetlands can result from several factors, including pollution, stormwater runoff, and inadequate wastewater management (Croeser *et al.*, 2021).

In REC, especially those close to ports where humidity levels are already high, constructed wetlands can still play a crucial role. By integrating these systems, RECs can enhance local biodiversity and improve water quality, which indirectly supports the cooling of urban areas. The presence of wetlands can mitigate the UHI effect by promoting cooler microclimates. Their successful implementation depends on collaboration among urban planners, environmental engineers, local authorities, and community members. By mitigating flood risks, improving water quality, and providing green spaces, constructed wetlands contribute to the sustainable development of cities and improve the overall quality of life for urban residents.

2.1.3.5 Water Retention Systems

Water retention systems are designed to capture and store excess water below the surface during periods of heavy rainfall, preventing flooding and enhancing water availability during dry periods. These systems include natural water retention ponds, reservoirs, and detention basins, which can be integrated into urban landscapes to manage stormwater and support urban resilience. Water retention systems play a critical role in regulating water flow, maintaining the water balance, and improving water quality by allowing sediments and pollutants to settle before water is released back into the environment (Sitzenfrei *et al.*, 2020; Staccione *et al.*, 2021).

One of the main benefits of water retention systems is their ability to store large volumes of water, which can be used for various purposes, including irrigation, industrial use, and maintaining ecological flows. These systems also help recharge groundwater and reduce the pressure on urban drainage systems. While water retention systems do not directly address the UHI effect, they tackle problems that are exacerbated by UHI and climate change, such as increased flooding and water scarcity during dry periods.

In REC the integration of water retention systems can provide crucial benefits. By managing stormwater effectively and maintaining water availability, these systems support the resilience of urban areas against the adverse effects of climate change, which are often intensified by UHI.

However, implementing water retention systems involves challenges such as land availability, high construction and maintenance costs, and ensuring proper design to prevent structural failures. Additional limitations include need for adequate stuff, time and resources as well as the management of urban runoff and flooding. Effective planning, stakeholder engagement, and financial incentives are essential to overcome these challenges and promote the widespread adoption of water retention systems (Cuthbert *et al.*, 2022).

2.2 Benefits of NBS in Urban Settings

The selection of appropriate NBS must be tailored to address the specific challenges and goals of each pilot project. It is essential to consider the unique environmental, social, and economic contexts of the areas where these solutions will be implemented. By carefully evaluating the problems such as UHIs, stormwater management, air quality, and biodiversity loss, the most effective NBS can be chosen to provide maximum benefits. Collaboration among urban development professionals, local authorities, and community members is crucial to ensure the successful implementation and sustainability of these solutions.

Combining different NBS can amplify their effectiveness in addressing urban challenges. For instance, vegetation-based solutions directly address the UHI effect by providing shade and cooling through evapotranspiration. Trees, shrubs, and other plants can reduce surface temperatures and improve thermal comfort, leading to lower energy consumption for cooling. Additionally, these solutions enhance air quality and support biodiversity.

Water-based solutions, such as rain gardens, constructed wetlands, can indirectly support the mitigation of UHI by enhancing the health and growth of vegetation. These solutions manage stormwater by absorbing and filtering rainwater, which reduces runoff and the risk of flooding. By ensuring that vegetation has adequate water supply, water-based NBS help maintain the cooling effects of plants, thus indirectly contributing to the reduction of urban temperatures.

Urban design solutions also have a key role in addressing the UHI effect directly. Cool roofs and cool walls use materials with high solar reflectance and thermal emittance to reduce the amount of heat absorbed by buildings, thus lowering surface and ambient temperatures. Similarly, cool pavements employ reflective and permeable materials to reduce heat absorption and enhance evaporative cooling. These urban design solutions improve thermal comfort for residents and reduce energy consumption by lowering the need for air conditioning.

By integrating multiple NBS, RECs can create multifunctional urban spaces that address a variety of environmental, social, and economic challenges. This holistic approach ensures that the benefits of NBS are maximized, leading to more sustainable and resilient urban environments.

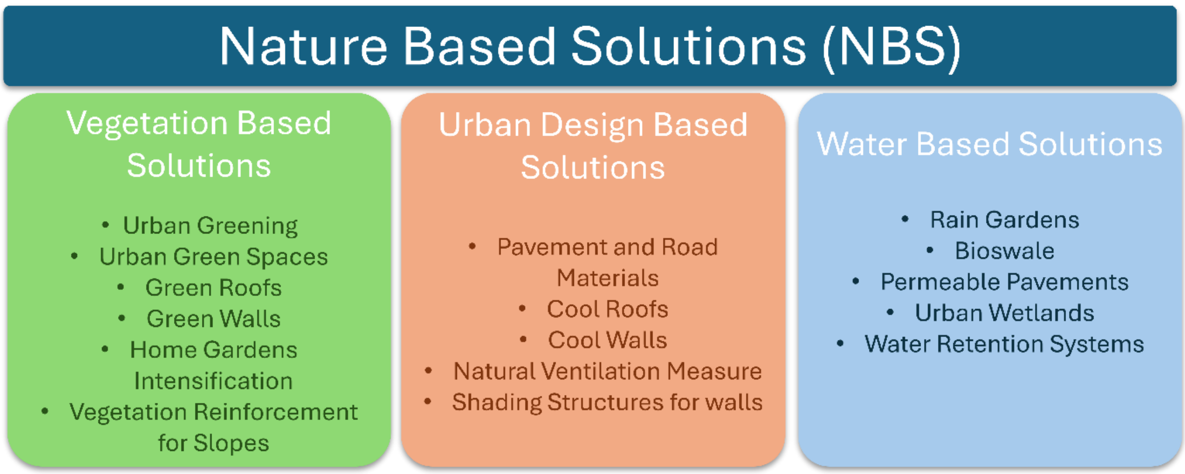

Figure 12: categories of various Nature-Based Solutions into three main types: Vegetation-Based Solutions, Urban Design Based Solutions, and Water-Based Solutions. Each category lists specific solutions aimed at addressing urban environmental challenges

In this section, we summarize the various NBS discussed in the report, categorizing them based on their type, the environmental or social problems they address, and the key participants involved in their implementation. The tables below provide an organized overview, divided into three main categories of participants:

- Urban Development Professionals: This category includes architects, urban planners, environmental engineers, construction companies, and building owners who are instrumental in the design, planning, and implementation of NBS.
- Local Authorities: This category comprises municipalities and local governments responsible for policymaking, regulatory frameworks, and providing support for the implementation of NBS projects.
- Residents and Communities: This category encompasses local communities, residents, and community organizations that participate in and benefit from NBS initiatives, ensuring local engagement and support.

The following tables categorize the NBS into vegetation-based solutions, water-based solutions, and urban design solutions, detailing the type of each NBS, the specific problems they address, and the relevant participants involved.

Table 1This table summarizes the various urban design-related Nature-Based Solutions (NBS), detailing their types, the environmental problems they address, and the key participants involved in their implementation.

Vegetation-Based Solutions					
No.	**NBS**	**Type**	**Problem Address**	**Participants**	**NBS CHALLENGES**
1	Urban Greening	Trees/Grass/Shrubs	UHI, Air pollution, Biodiversity support, Thermal comfort	Urban Development Professionals, Local Authorities, Residents and Communities	Climate mitigation and adaptation, Water management, Space management.
2	Urban Green Spaces	Parks/Community Gardens	UHI, Air pollution, Biodiversity support, Thermal comfort	Urban Development Professionals, Local Authorities	Climate mitigation and adaptation, Water management, Space management, Social justice and social cohesion.
3	Green Roofs	Vegetation on rooftops	UHI, Stormwater management, Air quality, Building insulation, Thermal comfort	Residents and Communities	Climate mitigation and adaptation, Water management, Space management, Urban regeneration, Economical cost.
4	Green Walls	Vertical gardens	UHI, Air pollution, Noise reduction, Building insulation, Thermal comfort	Residents and Communities	Climate mitigation and adaptation, Space management, Urban regeneration, Economical cost.
5	Home Gardens Intensification	Domestic garden spaces	UHI, Air pollution, Food production, Biodiversity support, Thermal comfort	Residents and Communities	Climate mitigation and adaptation, Water management, Space

					management, land usage, Economical cost.
6	Vegetation Reinforcement for Slopes	Trees/Shrubs/Grasses on slopes	Slope stabilization, Erosion prevention, Soil quality improvement	Urban Development Professionals, Local Authorities	Water management, Space management, Climate mitigation and adaptation
Urban Design Solutions					
1	Pavement and Road Materials	Reflective pavement/roads	UHI, Energy efficiency, Thermal comfort	Urban Development Professionals, Local Authorities	Economical cost, Material Compatibility, Maintenance
2	Cool Roofs	Reflective materials	UHI, Energy efficiency, Thermal comfort	Residents and Communities	Economical cost, Material Compatibility, Structural Limitations, Maintenance
3	Cool Walls	Reflective materials	UHI, Energy efficiency, Thermal comfort	Residents and Communities	Economical cost, Material Compatibility, Structural Limitations, Maintenance
4	Natural Ventilation Measures	Design for airflow	Energy efficiency, Air quality improvement, Thermal comfort	Residents and Communities	Economical cost, Material Compatibility, Structural Limitations, Maintenance
5	Shading Structures for Walls	Louvers, shading screens	Solar heat gain reduction, Energy efficiency, Thermal comfort	Residents and Communities	Economical cost, Material Compatibility, Structural Limitations, Maintenance
Water-Based Solutions					
1	Rain Gardens	Small-scale gardens	Stormwater management, Flood mitigation, Biodiversity enhancement	Urban Development Professionals, Local	Climate mitigation and adaptation, Urban run off,

				Authorities, Residents and Communities	drought, insufficient water for irrigation, Space management
2	Bioswales	Vegetated drainage channels	Stormwater management, Water quality improvement, Biodiversity enhancement	Urban Development Professionals, Local Authorities	Climate mitigation and adaptation, Urban run off, drought, insufficient water for irrigation, Space management
3	Permeable Pavements	Permeable surfaces	Stormwater management, Flood risk reduction, Groundwater recharge	Urban Development Professionals, Local Authorities	Economical cost, Material Compatibility, Maintenance
4	Urban Wetlands	Constructed wetlands	Wastewater treatment, Stormwater management, Biodiversity enhancement, Flood risk reduction	Urban Development Professionals, Local Authorities	Climate mitigation and adaptation, Poor water quality, Space management
5	Water Retention Systems	Rainwater harvesting, retention basins	Flood risk reduction, Stormwater management, Water quality improvement,	Urban Development Professionals, Local Authorities	Adequate stuff, Resources, Urban run-off, Flooding, Space management

2.3 Examples from HORIZON Projects

The literature review highlights the necessity for specialized expertise during the design phase of NBS. Enhancing this expertise can be achieved by updating design tools such as protocols, manuals, and guidelines. Additionally, spreading awareness and knowledge about these tools through training courses and conferences will facilitate improved implementation of NBS (P. Kumar et al., 2019). A major concern identified in NBS literature is the lack of specialized knowledge required for the design, on-the-ground implementation, performance evaluation, and understanding of the benefits and co-benefits of NBS. This 'knowledge' barrier has been identified as a major concern across the whole NBS policy cycle (Juliette Martin (IIASA) et al., 2023). This section highlights successful examples of EU Horizon projects from the OPERANDUM (https://www.operandum-project.eu), PHUSICOS (https://www.phusicos.eu), UnaLab (https://unalab.eu/en) and RECONECT (http://www.reconect.eu), showcasing their implementations and evaluations of NBS.

The OPERANDUM (OPEn-Air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks) project aimed to mitigate hydro-meteorological risks through NBS. By establishing open-air laboratories across Europe, OPERANDUM evaluated the effectiveness of interventions such as urban green spaces and vegetative barriers in reducing UHI effects. These solutions were shown to lower ambient temperatures and reduce the severity of heat waves, thereby decreasing energy demand for cooling in urban areas. The project's comprehensive evaluation framework, which included monitoring ecological and socio-economic indicators, highlighted the potential of NBS to enhance urban resilience to heat stress. OPERANDUM concluded that integrating NBS into urban environments effectively mitigated the adverse impacts of UHI and reduced energy consumption.

PHUSICOS (According to Nature) focused on implementing NBS in rural and mountainous areas to address climate change impacts, including heat waves. The project successfully utilized vegetation-based solutions such as tree planting and green corridors to create cooler microclimates, reducing the intensity of heat waves. In addition to lowering local temperatures, these interventions decreased energy demand for air conditioning. PHUSICOS emphasized the role of NBS in enhancing thermal comfort and energy efficiency in communities. The project's participatory approach, which integrated local knowledge and scientific expertise, ensured that the solutions were both effective and sustainable. PHUSICOS concluded that NBS played a crucial role in mitigating heat wave impacts and promoting energy efficiency.

The RECONECT (Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion) project evaluated large-scale NBS for reducing risks like flooding and UHI effects. In the Netherlands, RECONECT implemented floodplain restoration and the creation of green infrastructure, which demonstrated significant reductions in urban temperatures and heat stress. These interventions contributed to lowering energy demand for cooling by enhancing natural shading and evapotranspiration. The project used advanced modeling tools to assess the impacts of NBS on heat waves and energy consumption, providing valuable insights into their effectiveness. RECONECT highlighted the importance of stakeholder collaboration and policy integration to maximize the benefits of NBS in reducing UHI effects and energy demand.

The UNaLab (Urban Nature Labs) project was designed to develop and test innovative NBS to tackle urban challenges such as UHI and climate change adaptation. By implementing green roofs, rain gardens, and permeable pavements in the front-runner cities of Eindhoven, Tampere, and Genova, UNaLab effectively reduced local temperatures and improved stormwater management. These NBS interventions contributed to significant reductions in heat stress and energy demand for cooling. The project emphasized co-creation with local stakeholders, ensuring that the solutions were tailored to the specific needs of each city. UNaLab's success in enhancing urban resilience and sustainability underscores the potential of NBS as practical solutions for climate-related challenges in urban settings. Simulations of nearby buildings have indicated a potential 10% reduction in cooling load due to their proximity to green areas. Additionally, using turf for vertical greening has been shown to reduce interior surface temperatures by more than 2°C. Courtyards with trees that provide shade and grass can lower daytime temperatures by approximately 2.5°C (Wendling et al., 2020).

These Horizon 2020 projects demonstrated that NBS are effective strategies for mitigating UHI effects, reducing the impacts of heat waves, and decreasing energy demand in urban areas. By integrating scientific research with community involvement, OPERANDUM, PHUSICOS, RECONECT, and UNaLab illustrated the potential of NBS to provide sustainable solutions to climate-related challenges across Europe. These projects underscored the importance of continued collaboration and knowledge exchange to expand the adoption of NBS and effectively address the impacts of climate change.

3 Methodology for Selecting and Customizing NBS

The implementation of NBS involves a comprehensive project cycle that ensures these interventions are effectively planned, executed, and evaluated. The NBS Project Cycle includes several key stages: Engaging Stakeholders, Assessing, Project Planning, Action Planning, Implementing, and Monitoring & Evaluating. Each stage is critical for the success and sustainability of NBS projects (Figure 13).

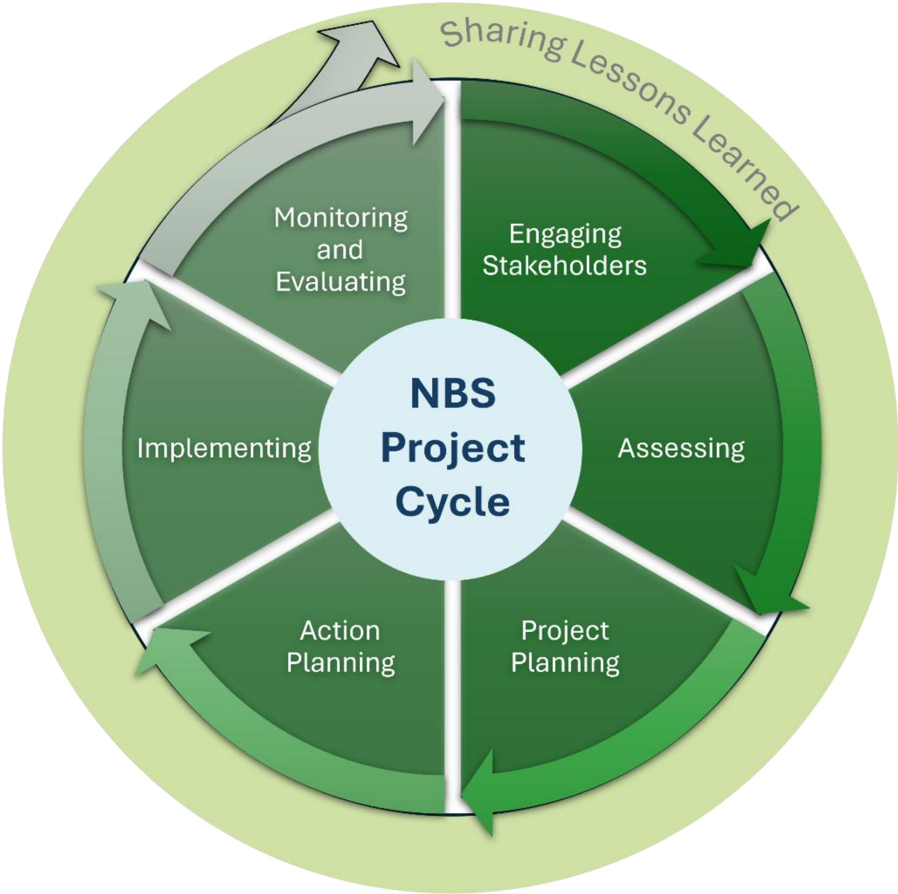

Figure 13: Cycle of Nature-Based Solutions (NBS) involves engaging stakeholders, assessing current issues, project planning, action planning, implementing defined activities, and monitoring & evaluating the outcomes. (Reference: Adapted from Dumitru et al. (2021))

3.1 Criteria for Selection

The selection of NBS for the EnerCmed project is grounded on a comprehensive set of criteria to ensure their suitability and effectiveness in addressing the specific needs of Mediterranean port hinterlands. These criteria are detailed below:

3.1.1 Environmental Criteria

Effectiveness in Reducing UHI: Solutions must demonstrably lower urban temperatures through mechanisms like shading, evapotranspiration, and increasing surface albedo. Specific examples include installing green roofs, green walls, and expanding urban green spaces.

Biodiversity Conservation and Enhancement: NBS should support and increase local biodiversity by providing habitats for flora and fauna. For instance, urban gardens and green corridors should be designed to connect fragmented habitats.

Improvement of Air Quality: Solutions should contribute to the reduction of pollutants and particulate matter in the air. Vegetative barriers and green roofs that filter air pollutants are examples.

3.1.2 Socio-Economic Criteria

Reduction of Energy Poverty: Solutions should be aimed at lowering energy costs for vulnerable populations by enhancing building energy efficiency and offering natural cooling and insulation. Examples include green roofs and walls that provide thermal insulation.

Social Acceptance and Participation: NBS must be designed and implemented with the active involvement of local communities to ensure acceptance and foster a sense of ownership. Public consultations and participatory design workshops are recommended.

Health and Well-being Benefits: Solutions should promote physical and mental health benefits by providing recreational spaces and reducing heat stress. Urban parks and community gardens can serve this purpose.

3.1.3 Technical Criteria

Feasibility of Implementation: Solutions must be technically viable given the local conditions, including soil type, climate, and urban density. An example is the use of drought-resistant plants in arid regions.

Maintenance and Longevity: NBS should require manageable maintenance efforts and be durable. Selecting native plant species that require less water and maintenance is an example.

Scalability and Replicability: Solutions should be scalable and adaptable to other urban areas within the region. Modular green wall systems that can be easily expanded are an example.

3.1.4 Economic Criteria

Cost and Funding: The initial and long-term costs of NBS should be evaluated against the available budget, and potential funding sources should be identified. Public-private partnerships can be explored for funding.

Return on Investment (ROI): Solutions must offer economic benefits such as energy savings, increased property values, and reduced healthcare costs due to improved environmental conditions. For example, studies showing the energy savings from green roofs can help justify their implementation.

3.1.5 Climate Resilience Criteria

Adaptability to Climate Change: Solutions must be resilient to climate change impacts such as increased temperatures, extreme weather events, and changing precipitation patterns. Implementing rain gardens that manage stormwater and reduce flooding risks is an example.

Mitigation of Extreme Weather Events: NBS should help mitigate the effects of extreme weather, such as heatwaves and heavy rainfall. Installing permeable pavements to manage stormwater and reduce flooding is an example.

3.1.6 Integration with Urban Infrastructure

Compatibility with Existing Infrastructure: Solutions must integrate seamlessly with current urban infrastructure without causing disruptions. Rooftop gardens on existing buildings are an example.

Enhancement of Urban Aesthetics: NBS should contribute to the visual appeal of the urban landscape. Green facades and aesthetically designed urban parks are examples.

3.1.7 Policy and Regulatory Criteria

Compliance with Local Regulations: Solutions must adhere to local zoning laws, building codes, and environmental regulations. Ensuring that green roofs meet building codes for load-bearing capacity is an example.

Support from Local Authorities: Solutions should have the backing of local government policies and initiatives. Engaging local authorities in the planning process to align NBS with municipal sustainability goals is crucial.

In summary, the selection criteria for NBS in the EnerCmed project would be designed to ensure environmental effectiveness, socio-economic benefits, technical feasibility, economic viability, climate resilience, integration with urban infrastructure, and compliance with policy and regulatory frameworks. These criteria help tailor solutions to the specific needs and challenges of the pilot areas, ensuring the success and sustainability of the project.

3.2 Stakeholders Engagement and Collaboration

Engaging stakeholders is the critical initial stage in the NBS project cycle for EnerCmed. This process involves identifying and actively involving all relevant stakeholders, including local communities, policymakers, scientists, and businesses, to ensure that the project reflects the diverse needs and perspectives of all groups. Effective stakeholder engagement is essential for raising collaboration and securing broad-based support for NBS initiatives aimed at enhancing climate resilience and reducing energy poverty in Mediterranean port hinterlands.

For the EnerCmed project, stakeholder engagement includes several specific actions. Initially, local community members are consulted to understand their concerns and aspirations related to UHI and energy efficiency. Policymakers and municipal authorities are engaged to align NBS interventions with existing urban plans and regulations. Scientists and technical experts provide insights into the feasibility and effectiveness of various NBS, while businesses, including local enterprises and potential investors, are involved to explore funding opportunities and ensure economic viability.

The engagement process includes forming local monitoring teams that participate in diverse roles, from providing information and feedback to actively co-monitoring the implementation and impact of NBS. This inclusive approach not only ensures the technical success of the project but also builds community resilience and ownership, essential for the long-term sustainability of the solutions implemented under the EnerCmed project.

4 Implementation Framework

4.1 Assessing

The assessing stage involves identifying current environmental and social issues and their root causes. This assessment helps to understand the specific challenges that NBS aims to address. Key activities include collecting baseline data on environmental conditions, community needs, and existing infrastructure, serving as a reference point for measuring the impact of NBS interventions. Engaging stakeholders throughout the assessment process is crucial, involving local communities, policymakers, scientists, and businesses to gather diverse perspectives and ensure a comprehensive assessment. This engagement helps identify potential barriers to implementation and ensures that the interventions are socially acceptable and supported by the community. Using the collected baseline data, clear objectives and targets for the NBS project are established, which are crucial for monitoring progress and evaluating the success of the interventions.

4.2 Project Planning

In the project planning stage, the focus shifts to identifying targets, evaluating options, and estimating the costs and benefits of various NBS strategies. During this stage, stakeholders work together to design a detailed plan that outlines the specific NBS interventions, their expected outcomes, and the resources required. Effective project planning ensures that the NBS are feasible and aligned with the overall goals of urban resilience and sustainability. This involves a thorough evaluation process where different NBS options are assessed for their feasibility and potential impact. By evaluating various options, stakeholders can identify the most effective and sustainable solutions for their specific urban context. Additionally, the project planning stage involves defining the specific NBS interventions, setting clear objectives and targets, and outlining the expected outcomes. Cost-benefit analysis is conducted to ensure the interventions are cost-effective and provide significant value. The resources required for implementation, such as funding, materials, and labour, are identified and allocated during this stage.

4.3 Action Planning

Action planning follows, where roles and resources are assigned to ensure the successful implementation of the NBS project. This involves developing a detailed action plan that specifies the tasks, responsibilities, timelines, and necessary resources. Clear action planning helps in coordinating efforts and ensures that all stakeholders are aware of their roles and responsibilities, which enhances the efficiency of the project.

By carefully outlining the steps involved in action planning, the project team can ensure that the implementation of NBS is systematic and that all potential challenges are anticipated and managed proactively. This approach not only enhances the efficiency of the project but also ensures that the desired environmental and social outcomes are achieved. Thus, action planning serves as a bridge between the theoretical aspects of project planning and the practical realities of NBS implementation

4.4 Implementation Stage

The implementing stage involves the actual execution of the defined project activities. This includes installing green infrastructure, planting vegetation, or other NBS interventions. Effective implementation requires close coordination among all stakeholders and adherence to the planned timelines and processes. This stage is crucial for translating plans into tangible actions that contribute to urban resilience and environmental sustainability.

4.5 Monitoring & Evaluation Stage

Finally, monitoring and evaluating the NBS interventions are critical for measuring their performance and impact. This stage involves regularly assessing changes, analyzing costs and benefits, and sharing lessons learned. Monitoring the performance and impact of NBS is important for understanding their effectiveness and guiding future implementations. Various monitoring methods, including ground-based measurements and remote sensing technologies, can been utilized to assess NBS effectiveness (Kumar *et al.*, 2021). Establishing Key Performance Indicators (KPIs) that measure the success of these interventions is essential. KPIs can include biophysical indicators like soil moisture levels, water quality, and vegetation health, as well as socio-economic indicators such as cost savings, community engagement, and public health improvements. These indicators help in quantifying the benefits of NBS and comparing their performance against traditional grey infrastructure solutions.

Evaluating the impact of NBS involves assessing their effectiveness in mitigating environmental challenges and enhancing urban resilience, focusing on both environmental and socio-economic benefits. Documenting case studies and pilot projects provides valuable insights into the practical application and outcomes of NBS, offering lessons learned and best practices for future projects. Sharing these lessons helps improve future NBS projects and promotes the adoption of successful strategies in different contexts.

5 Roles and Expertise of Technical Partners

The success of the EnerCmed project heavily relies on the collaborative efforts and specialized expertise of its technical partners. This subsection, "Roles and Expertise of Technical Partners," will delineate the distinct roles and contributions of each partner, highlighting their specific areas of expertise and how they align with the project's objectives.

University of Cyprus (UCY): UCY leads the drafting and coordination of the NBS portfolio. Their expertise in environmental engineering and sustainable urban planning ensures that the selected NBS are scientifically sound and tailored to the unique challenges of Mediterranean port hinterlands.

University of Genoa (UNIGE): UNIGE leads the coordination of research activities and provides comprehensive expertise in urban management and infrastructure development. Their experience is crucial for the integration of NBS into existing urban environments and for ensuring that these solutions are scientifically grounded and effective.

SINLOC (SIN): As a specialist in financial and strategic consultancy, SIN offers vital support in the economic evaluation and funding strategies for the NBS implementations. Their role includes conducting cost-benefit analyses and identifying financial resources, ensuring the financial viability and sustainability of the project.

Municipality of Patras (PAT): PAT leverages its extensive experience in local governance and community engagement to foster public support and participation. Their involvement is key to ensuring that the NBS interventions are socially accepted and beneficial to the local residents, promoting active community involvement.

Municipality of Genoa (MGE): MGE plays a pivotal role in the practical implementation of NBS at the local level. Their knowledge in urban management helps in the seamless integration of green infrastructure projects within the city, ensuring that the interventions are effectively realized.

6 Conclusion

This report presents a comprehensive portfolio of small-scale NBS designed to enhanced climate resilience and mitigate UHI in pilot cities of Genoa, Valencia, Patras, and Pula. These cities face unique environmental challenges that necessitate tailored solutions to mitigate the adverse impacts of climate change and urbanization.

Through a detailed assessment process, this report identifies the current environmental and social issues in these cities and proposes specific NBS to address these challenges. While the solutions presented are among the most common, applicable, or well-known, it is crucial to acknowledge that there are further NBS available. Each NBS needs to be tailored to the specific needs and conditions of the pilot areas. Not all NBS are suitable for every situation; therefore, each pilot must identify the specific problems they aim to address and select the most appropriate solutions accordingly.

For example, different types of trees will perform differently in various urban settings, and the success of vegetation-based solutions such as green roofs and urban greening depends on selecting species that are well-suited to local climatic and soil conditions. Similarly, water-based solutions like constructed wetlands and rain gardens must be designed to integrate seamlessly with existing urban infrastructure and address local hydrological challenges effectively.

The implementation framework outlined in this report provides a clear roadmap for planning, executing, and monitoring NBS interventions. This framework ensures that the solutions are not only technically feasible but also socially acceptable and economically viable. Continuous monitoring and evaluation are essential to measure the performance and impact of NBS interventions, allowing for adjustments and improvements over time. The active involvement of stakeholders, including local communities, policymakers, scientists, and businesses, is crucial for the success of these interventions. Their participation ensures that the NBS are well-integrated into the local context and meet the needs of the communities they serve. Monitoring and evaluating the performance and impact of NBS interventions are essential for understanding their effectiveness and for guiding future implementations. Establishing Key Performance Indicators (KPIs) and using both ground-based measurements and remote sensing technologies provide a robust framework for continuous assessment.

In conclusion, the EnerCmed project aims to demonstrate the effectiveness of NBS in enhancing urban resilience and sustainability in Mediterranean port hinterlands. By leveraging the diverse expertise of its technical partners and engaging local stakeholders, the project seeks to create more liveable, sustainable, and resilient urban environments. The lessons learned from this project will be invaluable for scaling up and replicating successful NBS interventions in other cities facing similar challenges.

REFERENCES

Alexandrou, G. et al. (2023) Experimental investigation of the impact of tree-like obstacles on ventilation in street canyons under isothermal and different levels of non-isothermal conditions. EMS2023-89. Copernicus Meetings. Available at: https://doi.org/10.5194/ems2023-89.

Assimakopoulos, M.-N. et al. (2020) 'Green Wall Design Approach Towards Energy Performance and Indoor Comfort Improvement: A Case Study in Athens', Sustainability, 12(9), p. 3772. Available at: https://doi.org/10.3390/su12093772.

Baniassadi, A., Sailor, D.J. and Ban-Weiss, G.A. (2019) 'Potential energy and climate benefits of super-cool materials as a rooftop strategy', Urban Climate, 29, p. 100495. Available at: https://doi.org/10.1016/j.uclim.2019.100495.

Beceiro, P., Galvão, A. and Brito, R.S. (2020) 'Resilience Assessment Framework for Nature Based Solutions in Stormwater Management and Control: Application to Cities with Different Resilience Maturity', Sustainability, 12(23). Available at: https://doi.org/10.3390/su122310040.

Bettencourt, L.M.A. (2019) 'Designing for Complexity: The Challenge to Spatial Design from Sustainable Human Development in Cities', Technology|Architecture + Design, 3(1), pp. 24–32. Available at: https://doi.org/10.1080/24751448.2019.1571793.

Bush, J. and Doyon, A. (2019) 'Building urban resilience with nature-based solutions: How can urban planning contribute?', Cities, 95, p. 102483. Available at: https://doi.org/10.1016/j.cities.2019.102483.

Carla Rodríguez Alonso (CARTIF) (2022) Report on assessment methodologies for planning and monitoring the reduction of GHG emission through the use of urban Nature-based Solutions. Available at: https://netzerocities.eu/wp-content/uploads/2023/05/Report-on-assessment-methodologies-for-planning-and-monitoring-the-reduction-of-GHG-emission-through-urban-Nature-based-Solutions.pdf.

Castillo-Rodríguez, J.T. et al. (2021) 'Quantifying the Impact on Stormwater Management of an Innovative Ceramic Permeable Pavement Solution', Water Resources Management, 35(4), pp. 1251–1271. Available at: https://doi.org/10.1007/s11269-021-02778-7.

Cheung, P.K. and Jim, C.Y. (2018) 'Comparing the cooling effects of a tree and a concrete shelter using PET and UTCI', Building and Environment, 130, pp. 49–61. Available at: https://doi.org/10.1016/j.buildenv.2017.12.013.

Costanzo, V. et al. (2019) 'Natural ventilation potential for residential buildings in a densely built-up and highly polluted environment. A case study', Renewable Energy, 138, pp. 340–353. Available at: https://doi.org/10.1016/j.renene.2019.01.111.

Croeser, T. et al. (2021) 'Choosing the right nature-based solutions to meet diverse urban challenges', Urban Forestry & Urban Greening, 65, p. 127337. Available at: https://doi.org/10.1016/j.ufug.2021.127337.

Cuthbert, M.O. et al. (2022) 'Global climate-driven trade-offs between the water retention and cooling benefits of urban greening', Nature Communications, 13(1), p. 518. Available at: https://doi.org/10.1038/s41467-022-28160-8.

Faraj, B.A. and Hamaamin, Y.A. (2023) 'Optimization of Locations for Bioswales Stormwater Management Using BMP Siting Tool - Case Study of Sulaymaniyah City-KRG-Iraq', Journal of Engineering, 29(01), pp. 76–92. Available at: https://doi.org/10.31026/j.eng.2023.01.05.

Frantzeskaki, N. et al. (2019) 'Nature-Based Solutions for Urban Climate Change Adaptation: Linking Science, Policy, and Practice Communities for Evidence-Based Decision-Making', BioScience, 69(6), pp. 455–466. Available at: https://doi.org/10.1093/biosci/biz042.

Freer, R. (1991) 'Bio-engineering: the use of vegetation in civil engineering', Construction and Building Materials, 5(1), pp. 23–26. Available at: https://doi.org/10.1016/0950-0618(91)90028-J.

Ghosh, S. (2021) 'Urban agriculture potential of home gardens in residential land uses: A case study of regional City of Dubbo, Australia', Land Use Policy, 109, p. 105686. Available at: https://doi.org/10.1016/j.landusepol.2021.105686.

Gunawardena, K. and Steemers, K. (2020) 'Urban living walls: reporting on maintenance challenges from a review of European installations', Architectural Science Review, 63(6), pp. 526–535. Available at: https://doi.org/10.1080/00038628.2020.1738209.

Hernández-Crespo, C. et al. (2019) 'Influence of rainfall intensity and pollution build-up levels on water quality and quantity response of permeable pavements', Science of The Total Environment, 684, pp. 303–313. Available at: https://doi.org/10.1016/j.scitotenv.2019.05.271.

Jellinek, S. et al. (2020) 'Replanting agricultural landscapes: how well do plants survive after habitat restoration?', Restoration Ecology, 28(6), pp. 1454–1463. Available at: https://doi.org/10.1111/rec.13242.

Jeong, S., Millstein, D. and Levinson, R. (2021) 'Modeling potential air temperature reductions yielded by cool roofs and urban irrigation in the Kansas City Metropolitan Area', Urban Climate, 37, p. 100833. Available at: https://doi.org/10.1016/j.uclim.2021.100833.

JoAnne Linnerooth-Bayer, Juliette Martin, Alberto Fresolone (IIASA), (2023) Learning from NBS implementation barriers.

Juliette Martin (IIASA) (2023) Opportunities and barriers to NBS at the EU, national, regional and local scales, with suggested reforms and innovations. Available at: https://pure.iiasa.ac.at/id/eprint/19281/1/deliverable-d5-2.pdf.

Kalantari, Z., Gadnert, A. and Ferreira, C.S.S. (2020) Nature-based solutions for urban resilience. EGU2020-5963. Copernicus Meetings. Available at: https://doi.org/10.5194/egusphere-egu2020-5963.

Kappou, S. et al. (2022) 'Cool Pavements: State of the Art and New Technologies', Sustainability, 14(9), p. 5159. Available at: https://doi.org/10.3390/su14095159.

Khoshkar, S., Balfors, B. and Wärnbäck, A. (2018) 'Planning for green qualities in the densification of suburban Stockholm – opportunities and challenges', Journal of Environmental Planning and Management, 61(14), pp. 2613–2635. Available at: https://doi.org/10.1080/09640568.2017.1406342.

Kim, H.-J., Yang, C.-S. and Moon, H.J. (2019) 'A Study on Multi-Objective Parametric Design Tool for Surround-Type Movable Shading Device', Sustainability, 11(24), p. 7096. Available at: https://doi.org/10.3390/su11247096.

Kim, J.H. et al. (2017) 'Vegetation as a driver of temporal variations in slope stability: The impact of hydrological processes', Geophysical Research Letters, 44(10), pp. 4897–4907. Available at: https://doi.org/10.1002/2017GL073174.

Kirimtat, A. et al. (2019) 'Multi-objective energy and daylight optimization of amorphous shading devices in buildings', Solar Energy, 185, pp. 100–111. Available at: https://doi.org/10.1016/j.solener.2019.04.048.

Koch, K. et al. (2020) 'Urban heat stress mitigation potential of green walls: A review', Urban Forestry & Urban Greening, 55, p. 126843. Available at: https://doi.org/10.1016/j.ufug.2020.126843.

Kolokotsa, D. et al. (2020) 'On the impact of nature-based solutions on citizens' health & well being', Energy and Buildings, 229, p. 110527. Available at: https://doi.org/10.1016/j.enbuild.2020.110527.

Kousis, I. et al. (2020) 'Using bio-oils for improving environmental performance of an advanced resinous binder for pavement applications with heat and noise island mitigation potential', Sustainable Energy Technologies and Assessments, 39, p. 100706. Available at: https://doi.org/10.1016/j.seta.2020.100706.

Krauze, K. and Wagner, I. (2019) 'From classical water-ecosystem theories to nature-based solutions — Contextualizing nature-based solutions for sustainable city', Science of The Total Environment, 655, pp. 697–706. Available at: https://doi.org/10.1016/j.scitotenv.2018.11.187.

Kumar, P. et al. (2021) ‘An overview of monitoring methods for assessing the performance of nature-based solutions against natural hazards’, Earth-Science Reviews, 217, p. 103603. Available at: https://doi.org/10.1016/j.earscirev.2021.103603.

Kuruppu, U., Rahman, A. and Rahman, M.A. (2019) ‘Permeable pavement as a stormwater best management practice: a review and discussion’, Environmental Earth Sciences, 78(10), p. 327. Available at: https://doi.org/10.1007/s12665-019-8312-2.

Kyropoulou, M., Subramaniam, S. and Hoffmann, S. (2021) ‘An automated workflow for informing urban greening based on photosynthetic radiation modelling’, Journal of Physics: Conference Series, 2069(1), p. 012060. Available at: https://doi.org/10.1088/1742-6596/2069/1/012060.

Lafortezza, R. and Sanesi, G. (2019) ‘Nature-based solutions: Settling the issue of sustainable urbanization’, Environmental Research, 172, pp. 394–398. Available at: https://doi.org/10.1016/j.envres.2018.12.063.

Lee, A.C.K. and Maheswaran, R. (2011) ‘The health benefits of urban green spaces: a review of the evidence’, Journal of Public Health, 33(2), pp. 212–222. Available at: https://doi.org/10.1093/pubmed/fdq068.

Levinson, R. et al. (2019) ‘Solar-Reflective “Cool” Walls: Benefits, Technologies, and Implementation’. Available at: https://doi.org/10.20357/B7SP4H.

Li, H. et al. (2022) ‘Impact of green walls on ventilation and heat removal from street canyons: Coupling of thermal and aerodynamic resistance’, Building and Environment, 214. Available at: https://doi.org/10.1016/j.buildenv.2022.108945.

Li, J. et al. (2019) ‘Analysis of rainfall infiltration and its influence on groundwater in rain gardens’, Environmental Science and Pollution Research, 26, pp. 1–15. Available at: https://doi.org/10.1007/s11356-019-05622-z.

Liu, C. et al. (2021) ‘Stability Reinforcement of Slopes Using Vegetation Considering the Existence of Soft Rock’, Applied Sciences, 11(19), p. 9228. Available at: https://doi.org/10.3390/app11199228.

Liu, H.-Y., Jay, M. and Chen, X. (2021) ‘The Role of Nature-Based Solutions for Improving Environmental Quality, Health and Well-Being’, Sustainability, 13(19), p. 10950. Available at: https://doi.org/10.3390/su131910950.

Luo, M., Hong, Y. and Pantelic, J. (2021) ‘Determining Building Natural Ventilation Potential via IoT-Based Air Quality Sensors’, Frontiers in Environmental Science, 9. Available at: https://doi.org/10.3389/fenvs.2021.634570.

Masi, E.B., Segoni, S. and Tofani, V. (2021) ‘Root Reinforcement in Slope Stability Models: A Review’, Geosciences, 11(5), p. 212. Available at: https://doi.org/10.3390/geosciences11050212.

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Masi, F., Rizzo, A. and Regelsberger, M. (2018) 'The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm', Journal of Environmental Management, 216, pp. 275–284. Available at: https://doi.org/10.1016/j.jenvman.2017.11.086.

McCarton, L. and O'Hogain, S. (2024) 'Editorial special issue: Integrating nature-based solutions (NBS) for resilient cities and communities', Nature-Based Solutions, p. 100105. Available at: https://doi.org/10.1016/j.nbsj.2023.100105.

Meulen, V.D. and H, S. (2019) 'Costs and Benefits of Green Roof Types for Cities and Building Owners', [Journal of Sustainable Development of Energy, Water and Environment Systems], [7]([1]), p. [57]-[71].

Moosavi, S., Browne, G.R. and Bush, J. (2021) 'Perceptions of nature-based solutions for Urban Water challenges: Insights from Australian researchers and practitioners', Urban Forestry & Urban Greening, 57, p. 126937. Available at: https://doi.org/10.1016/j.ufug.2020.126937.

Moretti, L. et al. (2022) 'Investigation of Parking Lot Pavements to Counteract Urban Heat Islands', Sustainability, 14(12), p. 7273. Available at: https://doi.org/10.3390/su14127273.

Palermo, S.A. et al. (2023) 'Nature-based solutions for urban stormwater management: an overview', IOP Conference Series: Earth and Environmental Science, 1196(1), p. 012027. Available at: https://doi.org/10.1088/1755-1315/1196/1/012027.

Pan, W. et al. (2019) 'A model for calculating single-sided natural ventilation rate in an urban residential apartment', Building and Environment, 147, pp. 372–381. Available at: https://doi.org/10.1016/j.buildenv.2018.08.047.

Papuga, S.A. et al. (2022) 'Ecohydrology of Green Stormwater Infrastructure in Shrinking Cities: A Two-Year Case Study of a Retrofitted Bioswale in Detroit, MI', Water, 14(19), p. 3064. Available at: https://doi.org/10.3390/w14193064.

Pasetto, M. et al. (2019) 'Innovative pavement surfaces as urban heat islands mitigation strategy: chromatic, thermal and mechanical characterisation of clear/coloured mixtures', Road Materials and Pavement Design, 20(sup1), pp. S533–S555. Available at: https://doi.org/10.1080/14680629.2019.1593230.

Patil, U.D. et al. (2022) 'Role of vegetation in improving the stability of a tropical hill slope in Guam', Environmental Geotechnics, 9(8), pp. 562–581. Available at: https://doi.org/10.1680/jenge.21.00064.

Paull, N. et al. (2020) 'Can Green Walls Reduce Outdoor Ambient Particulate Matter, Noise Pollution and Temperature?', International Journal of Environmental Research and Public Health, 17(14), p. 5084. Available at: https://doi.org/10.3390/ijerph17145084.

Prashant Kumar (UoS); Sisay E Debele (UoS); Fabrice Renaud (UoG), et al. (2019) Mapping, characterization and critical evaluation of existing NBS.

Puchol-Salort, P. et al. (2021) 'An urban planning sustainability framework: Systems approach to blue green urban design', Sustainable Cities and Society, 66, p. 102677. Available at: https://doi.org/10.1016/j.scs.2020.102677.

Qiu, Y., Schertzer, D. and Tchiguirinskaia, I. (2021) 'Assessing cost-effectiveness of nature-based solutions scenarios: Integrating hydrological impacts and life cycle costs', Journal of Cleaner Production, 329, p. 129740. Available at: https://doi.org/10.1016/j.jclepro.2021.129740.

Raparthi, K. (2020) 'Ability of Nature Based Solutions through Urban Green Space Management in Building Urban Resilience', 3, pp. 46–56. Available at: https://doi.org/10.37628/.V3I2.685.

Sanicola, O. (2018) 'USING PERMEABLE PAVEMENTS TO REDUCE THE ENVIRONMENTAL IMPACTS OF URBANISATION', International Journal of Geomate, 14. Available at: https://doi.org/10.21660/2018.41.KEY3.

Sanseverino, E.R. et al. (1AD) Smart Cities and Municipal Building Regulation for Energy Efficiency, https://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/978-1-5225-7314-2.ch048. IGI Global. Available at: https://www.igi-global.com/gateway/chapter/www.igi-global.com/gateway/chapter/216023 (Accessed: 5 June 2024).

Santos, M. et al. (2022) 'Contribution of Home Gardens to Sustainable Development: Perspectives from A Supported Opinion Essay', International Journal of Environmental Research and Public Health, 19(20), p. 13715. Available at: https://doi.org/10.3390/ijerph192013715.

Saroinsong, F.B. et al. (2021) 'Utilization of Home Gardens as a Community Empowerment-Based Edible Landscape to Combat Stunting', IOP Conference Series: Earth and Environmental Science, 940(1), p. 012093. Available at: https://doi.org/10.1088/1755-1315/940/1/012093.

Shafique, M., Kim, R. and Rafiq, M. (2018) 'Green roof benefits, opportunities and challenges – A review', Renewable and Sustainable Energy Reviews, 90, pp. 757–773. Available at: https://doi.org/10.1016/j.rser.2018.04.006.

Sharma, A. et al. (2016) 'Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: evaluation with a regional climate model', Environmental Research Letters, 11(6), p. 064004. Available at: https://doi.org/10.1088/1748-9326/11/6/064004.

Sharma, R. and Malaviya, P. (2021) 'Management of stormwater pollution using green infrastructure: The role of rain gardens', WIREs Water, 8(2), p. e1507. Available at: https://doi.org/10.1002/wat2.1507.

Shetty, N. et al. (2018) 'Quantifying Urban Bioswale Nitrogen Cycling in the Soil, Gas, and Plant Phases', Water, 10(11), p. 1627. Available at: https://doi.org/10.3390/w10111627.

Shiba, A. et al. (2021) 'Supporting Eco-Cities by Utilizing Green Technologies in Wetlands for On-Site Wastewater Treatment', Design Engineering (Toronto), 2021, pp. 940–954.

Singer, M.N. et al. (2022) 'Permeable Pavement Systems for Effective Management of Stormwater Quantity and Quality: A Bibliometric Analysis and Highlights of Recent Advancements', Sustainability, 14(20), p. 13061. Available at: https://doi.org/10.3390/su142013061.

Sitzenfrei, R. et al. (2020) 'Green Infrastructures for Urban Water System: Balance between Cities and Nature', Water, 12(5), p. 1456. Available at: https://doi.org/10.3390/w12051456.

Staccione, A. et al. (2021) 'Natural water retention ponds for water management in agriculture: A potential scenario in Northern Italy', Journal of Environmental Management, 292, p. 112849. Available at: https://doi.org/10.1016/j.jenvman.2021.112849.

Tan, Z., Lau, K.K.-L. and Ng, E. (2016) 'Urban tree design approaches for mitigating daytime urban heat island effects in a high-density urban environment', Energy and Buildings, 114, pp. 265–274. Available at: https://doi.org/10.1016/j.enbuild.2015.06.031.

Tochaiwat, K. et al. (2023) 'Eco-Efficiency of Green Infrastructure on Thermal Comfort of Outdoor Space Design', Sustainability, 15(3), p. 2566. Available at: https://doi.org/10.3390/su15032566.

Toparlar, Y. et al. (2018) 'The effect of an urban park on the microclimate in its vicinity: a case study for Antwerp, Belgium', International Journal of Climatology, 38(S1), pp. e303–e322. Available at: https://doi.org/10.1002/joc.5371.

Tsatsou, A. et al. (2023) 'Planning nature-based solutions for water management and circularity in Ljubljana, Slovenia: Examining how urban practitioners navigate barriers and perceive institutional readiness', Urban Forestry & Urban Greening, 89, p. 128090. Available at: https://doi.org/10.1016/j.ufug.2023.128090.

Weerasuriya, A.U. et al. (2019) 'A holistic framework to utilize natural ventilation to optimize energy performance of residential high-rise buildings', Building and Environment, 153, pp. 218–232. Available at: https://doi.org/10.1016/j.buildenv.2019.02.027.

Weiss, P.T. et al. (2019) 'Permeable pavement in northern North American urban areas: research review and knowledge gaps', International Journal of Pavement Engineering, 20, pp. 143–162. Available at: https://doi.org/10.1080/10298436.2017.1279482.

Wendling, L. et al. (2020) 'Performance and Impact Monitoring of Nature-Based Solutions'.

Widera, D.B. (no date) 'NATURE-BASED SOLUTIONS FOR CLIMATE RESILIENT BUILDINGS AND CITIES'.

Xu, L. et al. (2021) 'Potential strategies to mitigate the heat island impacts of highway pavement on megacities with considerations of energy uses', Applied Energy, 281, p. 116077. Available at: https://doi.org/10.1016/j.apenergy.2020.116077.

Yang, H. et al. (2009) 'Design and hydraulic characteristics of a field-scale bi-phasic bioretention rain garden system for storm water management', Water Science and Technology, 59(9), pp. 1863–1872. Available at: https://doi.org/10.2166/wst.2009.186.

Zhang, J. et al. (2018) 'Systematic Comparison of the Influence of Cool Wall versus Cool Roof Adoption on Urban Climate in the Los Angeles Basin', Environmental Science & Technology, 52(19), pp. 11188–11197. Available at: https://doi.org/10.1021/acs.est.8b00732.

Zhang, J. et al. (2019) 'Investigating the Urban Air Quality Effects of Cool Walls and Cool Roofs in Southern California', Environmental Science & Technology, 53(13), pp. 7532–7542. Available at: https://doi.org/10.1021/acs.est.9b00626.

Zhao, Y. et al. (2023) 'The time-evolving impact of tree size on nighttime street canyon microclimate: Wind tunnel modeling of aerodynamic effects and heat removal', Urban climate, 49, p. 101528. Available at: https://doi.org/10.1016/j.uclim.2023.101528.

Zhu, Yuxin et al. (2021) 'Permeable pavement design framework for urban stormwater management considering multiple criteria and uncertainty', Journal of Cleaner Production, 293, p. 126114. Available at: https://doi.org/10.1016/j.jclepro.2021.126114.