GREEN ROOFS:
HOW? WHERE? WHY?
A HANDBOOK






GREENO2 - Green Roofs in higher education institutions as sustainable cEnters for research, participation, ENvironmental consciousness and O2 generation

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Developed within Erasmus+ KA220 HED Project

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GREENO2 Project Webpage
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1. Green roofs: a premise

Green roofs (GRs) have emerged as a pioneering solution to numerous environmental challenges, reshaping urban landscapes across Europe. In recent years, Europe has witnessed a surge in the adoption of green roofs, driven by a confluence of factors including the pressing need to mitigate climate change, enhance urban biodiversity, improve air quality, and manage stormwater runoff. This eco-friendly roofing innovation involves the installation of vegetated systems atop buildings, effectively transforming barren rooftops into thriving ecosystems. While the concept of green roofs traces back to ancient times, modern advancements in technology, materials, and design have propelled Europe to the forefront of this green revolution.

At the heart of the GREENO2 project lies the imperative to amplify its impact and reach. This necessitates a concerted effort to engage with key stakeholders and the wider public, fostering a deep understanding, encouraging active participation, and ultimately driving action towards sustainability and the adoption of green roof technologies. Through collaborative initiatives, educational programs, and transparent communication, the GREENO2 project aims to create a cohesive community dedicated to advancing green infrastructure and promoting environmentally responsible urban development.

One of the key drivers behind the widespread acceptance of green roofs in Europe is their unparalleled environmental benefits. By harnessing nature's power, green roofs act as natural insulators, reducing energy consumption for heating and cooling within buildings. This not only translates into significant cost savings for building owners but also contributes to lowering carbon emissions, thus aligning with the European Union's ambitious climate goals. Furthermore, green roofs serve as a critical tool for combating the urban heat island effect, which is particularly pronounced in densely populated cities. By absorbing and dissipating solar radiation, green roofs help to mitigate temperature extremes, fostering a more comfortable and sustainable urban environment for residents.

Moreover, green roofs play a pivotal role in promoting biodiversity and preserving fragile ecosystems in urban areas. These green oases provide habitat and food sources for a diverse array of plant and animal species, including pollinators such as bees and butterflies. As traditional habitats continue to shrink due to urbanisation and habitat fragmentation, green roofs offer a lifeline for struggling wildlife, facilitating the establishment of thriving ecological communities amidst concrete jungles. In recognition of their ecological value, many European cities have implemented policies and incentives to encourage the widespread adoption of green roofs, ranging from financial subsidies to regulatory mandates.

In addition to their environmental benefits, green roofs offer a host of social and economic advantages that are increasingly recognized and valued by European communities. Beyond their aesthetic appeal, green roofs provide opportunities for recreational activities, urban agriculture, and community gardening, fostering a sense of connection with nature in urban dwellers. Moreover, green roofs can enhance property values, attract tenants, and improve the overall livability of buildings, thus contributing to the economic revitalization of urban areas. As cities grapple with the challenges of rapid urbanisation and population growth, green roofs offer a scalable and cost-effective solution for creating sustainable, resilient, and vibrant urban environments.

To realise the full potential of green roofs, European researchers, architects, and policymakers have been actively engaged in advancing the state of the art in green roof technology and implementation practices. A multitude of research initiatives, demonstration projects, and pilot studies have been conducted to assess the performance, feasibility, and cost-effectiveness of green roofs across different climatic regions and building types. Through interdisciplinary collaboration and knowledge exchange, Europe has emerged as a hub of innovation in green roof design, with a plethora of cutting-edge solutions and best practices being developed and disseminated.

One notable area of innovation in green roof technology is the development of modular and pre-vegetated systems, which streamline the installation process and minimise maintenance requirements. These plug-and-play green roof modules are designed to be lightweight, durable, and easy to install, making them suitable for retrofitting existing buildings as well as integrating into new construction projects. Furthermore, advances in substrate formulations, plant selection, and irrigation techniques have contributed to the development of green roofs that are more resilient to environmental stressors such as drought, extreme temperatures, and air pollution.

Another key trend in the evolution of green roofs is the integration of smart technologies and data-driven approaches to optimise their performance and maximise their benefits. By leveraging sensors, actuators, and internet-of-things (IoT) platforms, green roofs can be monitored and managed remotely in real-time, allowing for timely intervention and adaptive management strategies. For instance, automated irrigation systems can adjust watering schedules based on weather forecasts and soil moisture levels, ensuring efficient water use and promoting plant health. Similarly, green roofs equipped with weather stations and air quality sensors can provide valuable data for research purposes and inform urban planning decisions.

Furthermore, there is growing recognition of the importance of interdisciplinary collaboration and stakeholder engagement in the planning, design, and implementation of green roof projects. By involving stakeholders from diverse backgrounds, including architects, engineers, landscape designers, ecologists, policymakers, and community members, green roof projects can benefit from a holistic and inclusive approach that addresses the complex interplay of social, economic, and environmental factors. Participatory design processes, community workshops, and stakeholder consultations are increasingly being used to ensure that green roof projects are responsive to the needs and aspirations of local communities, thereby enhancing their long-term sustainability and resilience. Looking ahead, the future of green roofs in Europe holds great promise as cities continue to embrace sustainable and regenerative approaches to urban development. As the urgency of climate change intensifies and the benefits of green roofs become more widely recognized, it is expected that their adoption will continue to grow exponentially across Europe and beyond. With ongoing advancements in technology, policy support, and public awareness, green roofs are poised to play a pivotal role in shaping the cities of tomorrow, where nature and urban life coexist harmoniously, creating healthier, more resilient, and more equitable communities for generations to come. To summarise the factors influencing green roof implementation among various stakeholders in urban systems, Table 1 provides a compilation of drivers, motivations, and barriers.

Table 1. Factors influencing green roof implementation among various stakeholders (Source: Zhang and He, 2021)

Drivers, motivations and barriers to green roof implementation among different groups of stakeholders.

	Designer	Engineer	Constructor and builders	Contractor	Building operator	Owner	End-user	Government agent
Drivers								
1	✓	✓	✓	✓	✓	✓	✓	✓
2	✓		✓	✓	✓	✓		✓
3	✓	✓	✓	✓	✓			✓
Motivation								
4	✓	✓			✓		✓	✓
5	✓	✓						✓
6	✓	✓	✓	✓	✓	✓	✓	✓
7	✓	✓					✓	✓
8	✓	✓					✓	✓
9	✓	✓					✓	✓
10	✓	✓	✓	✓	✓		✓	✓
11	✓	✓					✓	✓
12	✓	✓		✓				✓
13	✓	✓					✓	✓
14	✓	✓		✓	✓	✓		✓
15			✓	✓	✓			✓
Barriers								
16	✓	✓	✓	✓	✓	✓		✓
17	✓	✓	✓		✓			
18	✓			✓		✓	✓	✓
19	✓	✓		✓	✓	✓	✓	

Note: 1. Policy pressure, 2. Market pressure, 3. Innovation and technology advancement, 4. Energy efficiency, 5. Urban heat island mitigation, 6. Roof longevity prolongation, 7. Air purification, 8. Runoff control, 9. Water purification, 10. Urban infrastructure improvement, 11. Sound insulation and noise reduction, 12. Biodiversity increase 13. Recreation and aesthetics, 14. Property value enhancement, 15. Employment improvement, 16. Lack of government policy, 17. Unsound technological level, 18. Unsound economic benefit assessment, 19, Individual unwillingness.

Leveraging the existing space atop buildings, the integration of green roofs can play a pivotal role in supporting cities' transitions toward circularity and resilience. These roofs offer a myriad of ecosystem services, functioning as versatile and decentralised units. To fully harness these benefits, it is essential to effectively incorporate and replicate green roofs in the urban landscape, with different system configurations considered based on the unique challenges faced by each city, including university buildings. To successfully implement green roofs, it is crucial to (i) identify and overcome barriers, (ii) establish standardisation to ensure reliability, (iii) define and implement policies, incentives, and strategies, (iv) leverage organisations providing Nature-Based Solutions (NBS) services, and (v) promote awareness and dissemination, including investments in education. This comprehensive approach ensures that university buildings, among other urban structures, contribute significantly to the overall implementation and success of green roofs in fostering circular and resilient urban environments (Calheiros and Stefanakis, 2021).

2. Green roofs: an introduction and state of the art

Green roofs (GRs) stand as intricate nature-based solutions (NBS) meticulously crafted to deliver a myriad of ecosystem benefits within urban or peri-urban environments. Their significance reverberates in their profound capacity to diminish runoff, thus alleviating the stress on drainage systems, while simultaneously tempering the urban heat island effect and conserving energy (Krauze and Wagner 2018; Pelorosso et al. 2017). Despite the expansive array of co-benefits ascribed to GRs, they frequently fall short of being engineered to realise their full potential (Cook et al. 2021). Moreover, existing GR design guidelines, such as those posited by Losken et al. (2018), often emphasise aspects like vegetation and substrate characteristics geared towards minimising static loading, maintenance, and cost, sometimes neglecting to ascertain if these recommendations indeed manifest into tangible ecosystem services.

Sedums, as prevalent succulent plants, dominate GR vegetation in the Mediterranean region. However, numerous studies have unearthed instances where they exhibit runoff retention akin to bare soil and provide diminished cooling effects compared to alternative species and solutions (Cook et al. 2021; He et al. 2022; Rocha et al. 2021). For instance, in Mediterranean climates, cool roofs may present a marginal cost/benefit ratio relative to GRs concerning cooling capacity and reduction of the urban heat island (UHI) effect during hot periods (Cook et al. 2021). Indeed, recent revelations by Cuthbert et al. (2022) underscore the challenges that nature-based solutions (NBSs) face in simultaneously addressing UHI and urban flooding issues in most cities. In arid regions, irrigation becomes indispensable for vegetation survival, thereby promoting cooling. Additionally, anticipated climate change-induced precipitation variability may undermine the performance of thinner GRs compared to those endowed with thicker soils and/or water storage systems.

Water emerges as a pivotal factor influencing GR performance (Pelorosso et al., 2021). Its indispensability for plant survival, coupled with evaporation occurrences on vegetated roofs during hot, dry weather, renders vegetation presence more efficacious in cooling relative to other roof types. Notably, latent heat and sensible heat fluxes intertwine with evaporation phenomena, with heightened evaporation attenuating the UHI impact. Moreover, as substrate depth and plant cover amplify, a GR's capacity to intercept water escalates. Furthermore, shorter durations of water scarcity foster the growth of diverse plant types, culminating in increasingly varied and aesthetically pleasing eco-urban landscapes. A well-structured GR system harbors thriving and stable vegetation capable of regenerating underutilised and degraded spaces, thereby fostering sociability and regulating air particulates. However, water poses its challenges: unmanaged stormwater contributes to pluvial flooding and drainage system overflow, underscoring the imperative of optimising infiltration and storage of hydrological processes in GRs to mitigate such issues.

The hydrological performance of GRs encompasses both retention and detention. Retention signifies a GR's ability to retain rainwater, typically lost through evapotranspiration processes. Although the retained water can be stored for extended periods, user control over its release and reuse is limited. On the flip side, detention refers to a GR's capability to temporarily hold rainwater with the intent of reducing or delaying peak runoff. Detained water can be stored and subsequently released at opportune times by users, thereby facilitating effective water management and runoff control (Li and Liu 2023; Stovin et al. 2017). Stored water may then be harnessed by GR vegetation or for other water reuse purposes within the building (e.g., domestic sanitary system or irrigation).

The water-regulating prowess of GRs is influenced by diverse design factors (e.g., substrate type, depth, plant species), with meteorological elements such as precipitation and evaporation playing pivotal roles in defining the soil moisture/water content conditions of the roof system preceding meteorological events (Cook et al. 2021). Consequently, GR water retention rates are markedly influenced by the specificities of local climatic conditions (Cuthbert et al. 2022; Wong and Jim 2015; Yan et al. 2022). In this vein, a resilience strategy grounded on continuous data simulation assumes paramount importance, as opposed to an event-based design method reliant on selected return period assumptions (Pons et al. 2022; Pumo et al. 2023a,b). Nonetheless, concerted efforts are indispensable to advance towards performance-based planning of GRs, necessitating the holistic examination of design properties vis-à-vis various performance objectives (Pelorosso 2020). Given the intricacies of evaluations, optimising essential GR features emerges as a priority for cost-effective deployments, particularly in light of evolving stormwater runoff regimes attributed to urbanisation. Furthermore, considerations for resource circularity and hydrological resilience underscore the significance of water reuse and estimation of storable stormwater volume in strategic planning and design of GR interventions and broader NBS development.

Considering the exorbitant costs entailed in gathering empirical data to evaluate specific solutions, modelling often serves as a viable alternative for simulating GR hydrological and hydraulic performances (Jeffers et al. 2022; Liu et al. 2021; Pelorosso et al. 2021). Models leverage analytical relationships among GR components and urban systems, thereby enabling predictions through manipulation of input factors. An array of modelling approaches and tools exists for simulating GR hydrological and hydraulic performance. While empirical models based on curve number and runoff coefficient prove relatively straightforward, numerical hydrological models such as HYDRUS-1D, MIKE URBAN, SWMM, and SWAP find frequent application in simulating single events or long-term rainfall (Jeffers et al. 2022; Liu et al. 2021; Pelorosso et al. 2021). Parameter variability facilitates simulation of scenarios useful for evaluating system performances and supporting design and planning decisions (Pelorosso 2020). Nevertheless, models harbor certain drawbacks, particularly concerning their complexity and calibration. Many model parameters prove challenging to assign or necessitate in situ measurements, thereby complicating calibration efforts. Conversely, empirical data can be instrumental in establishing relationships between hydrological performances and specific indicators linked to design and climatic factors (Li and Liu 2023; Pumo et al. 2023a,b). Nonetheless, experimental studies remain indispensable for comprehensively dissecting GR behaviour in site-specific hydrometeorological conditions.

2.1 Overcoming barriers to Green Roof realisation: strategies and Solutions

The main barriers to implementing green roof solutions include high initial costs for design and installation, as well as potential ongoing operational costs. However, some innovative solutions, such as extensive green roofs that use native and drought-resistant plants, require minimal maintenance. Other technologies, like aeroponics, which allows plants to grow with roots suspended in the air and periodically misted with nutrients, can further reduce maintenance requirements and improve water efficiency. The lack of technical expertise among professionals and inadequate training are additional obstacles, along with building regulations that are not always updated to facilitate such solutions. Limited awareness of the long-term benefits of green roofs among property owners and developers reduces demand, compounded by extreme climatic conditions in some regions that complicate plant cultivation. Furthermore, not all existing buildings can support the additional weight without costly structural modifications. Although green roofs offer long-term economic and environmental benefits, such as energy savings and stormwater management, these benefits are not immediately apparent, discouraging initial investments. Overcoming these barriers requires financial incentives, regulatory updates, training and awareness programs, and the promotion of research on the benefits of green roofs.

To overcome barriers in green roof realisation, a multifaceted approach is required. Financial incentives, such as grants, tax breaks, and subsidies, can help offset the high initial costs of installation and design. Updating building regulations to include green roof guidelines and standards will facilitate their implementation and encourage adoption. Investing in education and training programs for architects, engineers, and builders will enhance the technical expertise needed to design and maintain green roofs effectively. Raising public awareness about the long-term economic and environmental benefits of green roofs through campaigns and information sessions can increase demand and support. Additionally, promoting research and innovation in low-maintenance technologies, such as aeroponics and the use of drought-resistant plants, can further reduce maintenance costs and improve the viability of green roofs in various climatic conditions. Collaboration between government bodies, industry stakeholders, and academic institutions is essential to drive these initiatives and create a supportive ecosystem for green roof projects.

3. Environmental advantages

Green roofs, also known as living roofs or vegetated roofs, present a revolutionary approach to urban infrastructure that offers a plethora of environmental advantages over traditional roofs. At the forefront of these benefits is the mitigation of the urban heat island effect (UHI). Traditional roofs, often composed of materials like asphalt or tar, absorb and retain heat, contributing to elevated temperatures in urban areas. In contrast, green roofs serve as natural insulators, absorbing solar radiation and utilising it for photosynthesis, thus reducing surface temperatures and lowering ambient air temperatures through evapotranspiration. This cooling effect not only creates more comfortable and livable urban environments but also reduces the reliance on energy-intensive air conditioning during hot summer months, consequently lowering energy consumption and greenhouse gas emissions associated with cooling systems. By mitigating the UHI effect, green roofs also contribute to mitigating climate change impacts, as higher temperatures exacerbate the frequency and intensity of heatwaves, which can have dire consequences for human health and well-being.

Moreover, green roofs play a pivotal role in improving air quality by capturing airborne pollutants and particulate matter. The layers of vegetation and soil act as natural filters, trapping pollutants and absorbing carbon dioxide through photosynthesis. This natural filtration process helps to purify the air, reducing the concentration of harmful pollutants and improving overall air quality. In urban areas, where air pollution levels are often elevated due to traffic emissions and industrial activities, green roofs offer a sustainable solution for mitigating air pollution and protecting public health. By creating cleaner and healthier urban environments, green roofs contribute to reducing the prevalence of respiratory illnesses and other health problems associated with exposure to air pollution.

Additionally, green roofs provide valuable habitat and forage opportunities for pollinators such as bees, butterflies, and birds. The diverse array of plant species and vegetation on green roofs support biodiversity and promote ecological connectivity in urban areas, helping to conserve native plant and animal species and mitigate the loss of habitat due to urbanisation. In densely populated urban environments, where green spaces are limited, green roofs serve as important refuges for wildlife and contribute to the preservation of urban biodiversity. By supporting pollinators and other beneficial insects, green roofs also play a crucial role in supporting ecosystem services such as pollination and natural pest control, which are essential for maintaining healthy ecosystems and agricultural productivity.

Furthermore, green roofs act as a buffer against noise pollution, particularly in densely populated urban areas where noise levels can be a significant source of stress and discomfort for residents. The layers of soil, vegetation, and other greenery on green roofs absorb and deflect sound waves, reducing the transmission of noise from outside sources into buildings and creating quieter and more peaceful indoor environments. This acoustic insulation not only improves the quality of life for residents and workers in urban settings but also contributes to better mental health and well-being by reducing the negative impacts of noise pollution on sleep, concentration, and overall comfort.

In addition to their benefits for air quality, biodiversity, and noise reduction, green roofs also play a crucial role in managing stormwater runoff, which is a major challenge in urban areas. The layers of vegetation and soil on green roofs absorb rainwater and slow its release into the drainage system, thereby reducing the volume and velocity of stormwater runoff. This natural water retention and filtration process help to alleviate pressure on stormwater infrastructure, reduce the risk of flooding and erosion, and protect water quality by reducing the amount of pollutants and contaminants entering water bodies. Moreover, by capturing and storing rainwater, green roofs help to recharge groundwater reserves and reduce the risk of drought and water scarcity in urban areas, particularly in regions prone to water shortages and droughts.

The realisation of carbon-neutral communities can be achieved through the adoption of green roofs and Nature-Based Solutions (NBS) in general. Green roofs prove effective in reducing building energy consumption and sequestering carbon from the atmosphere. While supportive guidelines and policies for NBS implementation at the city scale are in development, quantitatively assessing the specific contribution of green roofs to citywide carbon neutrality poses challenges. These challenges stem from uncertainties in input data, quantification methods, and discrepancies in study conclusions arising from different temporal and spatial scales (Xiao et al., 2023). Overall, green roofs offer a holistic and sustainable approach to urban roofing that provides numerous environmental benefits, from mitigating the urban heat island effect and improving air quality to supporting biodiversity, managing stormwater runoff, and reducing noise pollution. As cities continue to grapple with the challenges of urbanisation, climate change, and environmental degradation, green roofs represent a promising solution for creating healthier, more resilient, and sustainable urban environments for current and future generations.

4. Classification of green roofs

Green roofs represent a versatile and dynamic category of roofing systems, offering a plethora of benefits to urban environments. These roofs can be classified in numerous ways based on various criteria such as design, vegetation type, or function. One common classification method divides green roofs into three main types: extensive, semi-intensive, and intensive (Tab. 2).

Extensive green roofs are characterised by their lightweight construction and shallow soil depth, typically ranging from 2 to 6 inches (5 to 15 centimetres). These roofs are specifically designed to support low-growing, drought-tolerant vegetation like sedum, mosses, and grasses. Due to their minimal soil depth and low maintenance requirements, extensive green roofs are often favoured for their cost-effectiveness and ease of installation. Despite their simplicity, they offer several environmental benefits, including stormwater management, thermal insulation, and biodiversity enhancement, albeit to a lesser extent compared to semi-intensive and intensive green roofs.

Semi-intensive green roofs occupy a middle ground between extensive and intensive green roofs in terms of soil depth, vegetation diversity, and maintenance needs. With soil depths ranging from 6 to 12 inches (15 to 30 centimetres), semi-intensive green roofs can support a wider variety of plant species, including small shrubs, perennials, and herbs. These roofs offer enhanced ecological and aesthetic benefits compared to extensive green roofs, such as increased biodiversity, improved air quality, and enhanced visual appeal. However, they require more maintenance and irrigation than extensive green roofs due to their deeper soil profiles and diverse plant communities.

Intensive green roofs represent the most complex and resource-intensive category of green roofs. Characterised by their deep soil profiles, diverse vegetation, and high maintenance requirements, these roofs typically have soil depths exceeding 12 inches (30 centimetres). Intensive green roofs can support a wide range of plant types, including trees, large shrubs, and ornamental plants, offering the greatest potential for biodiversity enhancement, habitat creation, and recreational use. These roofs are well-suited for urban parks, gardens, and public spaces where they can provide valuable green space for residents and visitors alike. However, intensive green roofs require significant structural support, irrigation, and maintenance to sustain the diverse plant communities and ensure long-term viability.

In summary, the classification of green roofs into extensive, semi-intensive, and intensive categories provides a useful framework for understanding their design, vegetation, and maintenance requirements. Each type of green roof offers unique benefits and challenges, and the choice of roof type should be based on factors such as project goals, budget, site conditions, and maintenance capabilities. By selecting the appropriate green roof type and design, urban planners, architects, and building owners can maximise the environmental, social, and economic benefits of green roofs in their communities.

Table 2. Type of GR and main characteristics (Source: Calheiros and Stefanakis, 2021)

Criteria	*Types of green roofs*		
	Intensive green roof	Semi-intensive green roof	Extensive green roof
Maintenance	High	Periodic/moderate	Low
Substrate layer	>25 cm	15-25 cm	8-15 cm
Vegetation	Trees, shrubs, lawn	Grass-herbs, shrubs	Succulent (sedum), mosses, grass
Weight of the system	>350 kg/m^2 ($3.43\ kN/m^2$)	150-350 kg/m^2 ($1,47\text{-}3,43\ kN/m^2$)	80-180 kg/m^2
Accessibility	In general, without limitation	Limited stepping	No stepping, unless for maintenance

An alternative classification system for green roofs involves categorising them as retention roofs and detention roofs. Detention roofs set themselves apart from retention roofs due to the additional layers beneath the soil, capable of temporarily collecting infiltrated water. The primary objective is to reduce or delay the peak runoff. An intelligent weir system can efficiently manage water levels based on user needs and objectives, such as domestic sanitation systems or irrigation. Detention roofs are also referred to as multilayer blue-green roofs (Pelorosso et al., 2024) or purple roofs (Alim et al., 2023). The latter facilitates stormwater detention through specific detention and buffer layers (Figure 1).

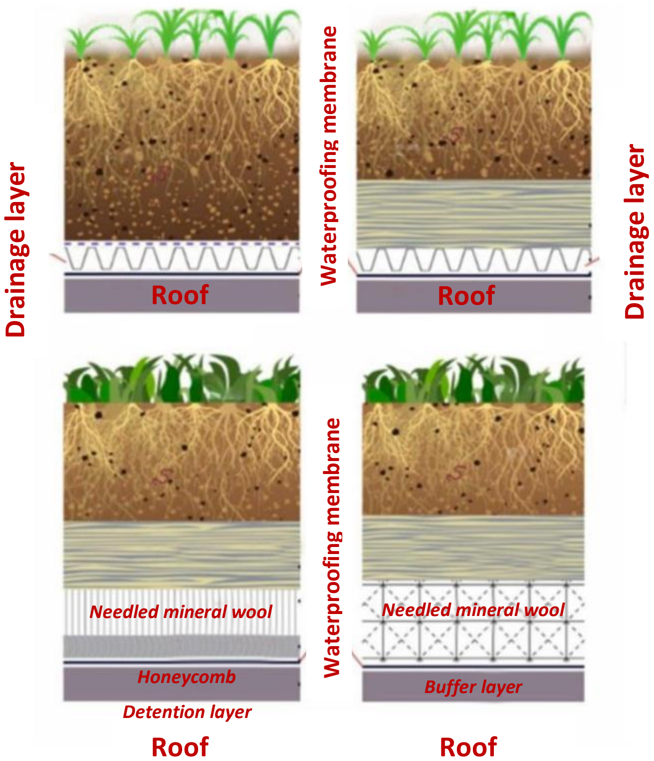

Figure 1. The difference in the design of a retention roof (traditional green roof and sponge roof) and detention roofs (Purple and Blue-green roofs) (Source: Alim et al., 2023 text readability enhanced).

Finally, an additional classification is related to sloped or pitched green roofs. In this exploration, we delve into the classification of green roofs based on roof slope, analyzing the unique characteristics and considerations associated with each type.

I. Flat or Low-Slope Green Roofs:

Flat or low-slope roofs, typically with slopes ranging from 0 to 10 degrees, represent the most common type of green roof installation. These roofs are often found in urban environments where architectural constraints limit the use of steeper slopes. The classification of green roofs on flat or low-slope surfaces includes extensive and intensive systems.

II. Moderate-Slope Green Roofs:

Moderate-slope green roofs, with inclinations ranging from 10 to 45 degrees, bridge the gap between flat and steep-slope roofs. These roofs offer a balance between aesthetic appeal and practicality, allowing for a variety of green roof designs based on the specific slope characteristics.

a) Tray or Modular Green Roofs

On moderate-slope roofs, tray or modular green roofs present a viable option. These systems utilize pre-planted trays or containers that can be easily installed and removed, simplifying maintenance and plant selection. The modular approach also facilitates water management and reduces the risk of erosion on slopes.

b) Sloped-Edge Green Roofs

Sloped-edge green roofs are designed to adapt to the changing inclinations of a roof. Using a tiered approach, these roofs accommodate different plant species at various slope levels. This design not only enhances visual appeal but also optimises stormwater retention and provides a natural habitat for diverse flora and fauna.

III. Steep-Slope Green Roofs:

Green roofs on steep-slope surfaces, characterised by inclinations greater than 45 degrees, pose unique challenges and opportunities. While steep slopes limit direct human interaction and increase the risk of erosion, these roofs offer aesthetic advantages and can contribute to biodiversity in unexpected ways.

a) Blanket or Mat Green Roofs:

Blanket or mat green roofs are designed for steep-slope applications, featuring a layer of pre-planted vegetation blankets or mats that provide immediate coverage. These systems are effective in preventing soil erosion, promoting water retention, and enhancing the overall aesthetic appeal of steep-slope buildings.

b) Reinforced Slope Green Roofs:

Reinforced slope green roofs utilise engineering solutions to create a stable environment on steep roofs. Terracing, retaining walls, and specialised reinforcement materials help mitigate erosion risks and provide a stable foundation for a diverse range of plantings. These systems require careful planning to ensure the safety and longevity of the green roof on steep surfaces.

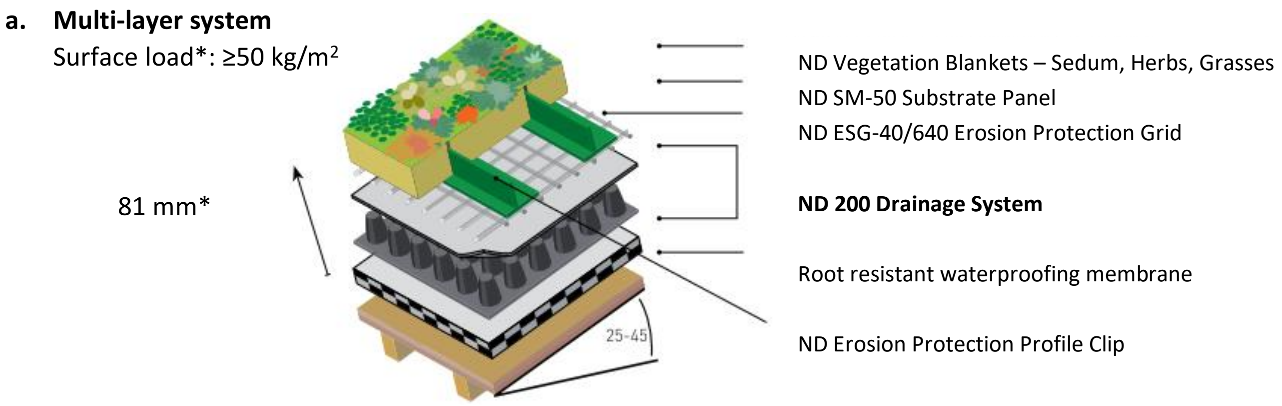

Figure 2. Example of steep-slope green roof (Source: Nophdrain, 2010)

The classification of green roofs based on roof slope offers a comprehensive understanding of how these innovative systems can be tailored to diverse architectural and environmental conditions. Whether on flat, moderate, or steep-slope surfaces, green roofs contribute significantly to sustainable urban development by mitigating the urban heat island effect, reducing stormwater runoff, and enhancing biodiversity. As the demand for green building solutions continues to grow, the exploration of green roof classifications based on roof slope provides valuable insights for architects, engineers, and urban planners seeking to integrate environmentally friendly practices into the built environment.

5. Structure of green roofs

Green roofs consist of several layers that work together to support vegetation and provide numerous environmental benefits. The structure of a green roof can vary depending on factors such as climate, building design, and intended use, but generally, it includes several key components: the roof deck, waterproofing membrane, drainage layer, growing medium, vegetation, and optional additional layers for insulation, root barrier, and irrigation systems.

The first layer of a green roof is the roof deck, which serves as the structural foundation for the entire system. This can be made of various materials such as wood, concrete, or metal, depending on the building's design and load-bearing capacity. The roof deck provides the necessary support for the additional layers of the green roof and ensures the structural integrity of the building.

Next is the waterproofing membrane, which is essential for protecting the roof deck and building structure from water infiltration. This membrane is typically made of synthetic materials such as PVC (polyvinyl chloride) or EPDM (ethylene propylene diene monomer) rubber and is installed over the roof deck to create a watertight barrier. The waterproofing membrane prevents water from seeping into the building and causing damage to the interior spaces.

The drainage layer is designed to facilitate the movement of water off the roof surface and away from the building. This layer typically consists of a lightweight, porous material such as gravel, expanded clay aggregate, or specially designed drainage mats. The drainage layer allows excess water to drain freely from the roof, preventing water buildup and reducing the risk of leaks or structural damage.

Above the drainage layer is the growing medium, also known as substrate or soil, which provides a medium for plant growth. The growing medium is specially formulated to be lightweight, well-draining, and nutrient-rich, allowing plants to establish and thrive on the roof surface. It typically consists of a blend of organic materials such as compost, peat moss, and lightweight aggregates, with the exact composition tailored to the specific needs of the vegetation and climate.

The vegetation layer is the most visible and recognizable component of a green roof, consisting of the plants and vegetation that cover the roof surface. Green roofs can support a wide variety of plant species, including grasses, sedums, wildflowers, herbs, shrubs, and even small trees, depending on factors such as climate, sunlight exposure, and maintenance requirements. The vegetation layer not only enhances the aesthetic appeal of the roof but also provides numerous environmental benefits, including improved air quality, habitat for wildlife, and reduced urban heat island effect.

In addition to these primary components, green roofs may also include optional additional layers for insulation, root barrier, and irrigation systems. Insulation layers, such as rigid foam or lightweight concrete, can be installed beneath the waterproofing membrane to improve energy efficiency and thermal performance. Root barrier membranes are sometimes used to prevent plant roots from penetrating and damaging the waterproofing membrane, while irrigation systems may be installed to provide supplemental water to the vegetation during dry periods.

Overall, the structure of a green roof is carefully designed to create a supportive environment for plant growth while protecting the building structure from water damage and ensuring long-term durability and performance. By incorporating multiple layers of materials and components, green roofs provide a sustainable and environmentally friendly solution for reducing stormwater runoff, improving air quality, and enhancing urban biodiversity.

6. Structural elements in detail

As aforementioned, a green roof, also known as a vegetated roof or eco-roof, is a complex system consisting of several structural elements working together to support vegetation and provide environmental benefits. Understanding the individual components of a green roof is essential for designing, installing, and maintaining a successful green roof system. Each structural element is listed below in detail:

1. Roof Deck

The roof deck serves as the foundation for the entire green roof system. It is the structural surface upon which all other components are installed. Roof decks can be made of various materials, including wood, concrete, metal, or composite materials. The choice of material depends on factors such as the building's design, load-bearing capacity, and environmental conditions. Wood decks are commonly used in residential buildings due to their affordability and ease of installation, while concrete decks are more suitable for commercial or industrial structures requiring greater load-bearing capacity. Metal decks are lightweight and durable, making them suitable for a wide range of applications. Composite decks, made of materials like fiberglass or reinforced plastic, offer a combination of strength, durability, and resistance to moisture and corrosion. Proper preparation and maintenance of the roof deck are essential to ensure the long-term performance and integrity of the green roof system.

2. Waterproofing Membrane

The waterproofing membrane is a crucial component of the green roof system, providing a protective barrier against water infiltration and moisture damage. It is installed directly over the roof deck to create a watertight seal and prevent water from penetrating into the building structure. Waterproofing membranes are typically made of synthetic materials such as PVC (polyvinyl chloride), TPO (thermoplastic polyolefin), EPDM (ethylene propylene diene monomer), or bitumen (asphalt). These materials offer excellent resistance to water, UV radiation, and temperature fluctuations, ensuring the long-term durability and performance of the green roof system. Proper installation and maintenance of the waterproofing membrane are essential to prevent leaks, water damage, and premature deterioration of the roof structure.

3. Drainage Layer

The drainage layer is designed to facilitate the movement of water off the roof surface and away from the building. It is installed above the waterproofing membrane and serves several important functions, including preventing water buildup, reducing hydrostatic pressure, and promoting drainage efficiency. Drainage layers are typically made of lightweight, porous materials such as gravel, expanded clay aggregate, or specially designed drainage mats. These materials allow excess water to drain freely from the roof, preventing water buildup and reducing the risk of leaks or structural damage. Proper design and installation of the drainage layer are essential to ensure optimal drainage performance and prevent water infiltration into the building structure.

4. Growing Medium (Substrate)

The growing medium, also known as substrate or soil, provides a medium for plant growth on the green roof. It is installed above the drainage layer and serves as the root zone for vegetation. The growing medium is specially formulated to be lightweight, well-draining, and nutrient-rich, allowing plants to establish and thrive in the harsh rooftop environment. The composition of the growing medium can vary depending on factors such as climate, vegetation type, and maintenance requirements. Common components of growing mediums include organic materials such as compost, peat moss, and lightweight aggregates. The growing medium provides essential nutrients, moisture, and support for plant roots, allowing vegetation to flourish on the green roof surface. Proper selection and installation of the growing medium are critical to ensure the long-term health and vitality of the vegetation and prevent erosion, compaction, and nutrient depletion.

5. Vegetation

The vegetation layer is the most visible and recognizable component of the green roof system, consisting of the plants and vegetation that cover the roof surface. Green roofs can support a wide variety of plant species, including grasses, sedums, wildflowers, herbs, shrubs, and even small trees, depending on factors such as climate, sunlight exposure, and maintenance requirements. The vegetation layer not only enhances the aesthetic appeal of the roof but also provides numerous environmental benefits, including improved air quality, habitat for wildlife, and reduced urban heat island effect. Proper selection and installation of vegetation are essential to ensure compatibility with the growing medium, climate, and intended use of the green roof. Maintenance of the vegetation layer is also important to prevent weed growth, maintain plant health, and ensure the long-term viability of the green roof system.

6. Additional Layers (Optional)

In addition to the primary structural elements, green roofs may include optional additional layers to enhance performance and functionality. These additional layers may include insulation, root barrier membranes, and irrigation systems. Insulation layers, such as rigid foam or lightweight concrete, can be installed beneath the waterproofing membrane to improve energy efficiency and thermal performance. Root barrier membranes are sometimes used to prevent plant roots from penetrating and damaging the waterproofing membrane, while irrigation systems may be installed to provide supplemental water to the vegetation during dry periods. The inclusion of these additional layers depends on factors such as project goals, budget, site conditions, and maintenance capabilities.

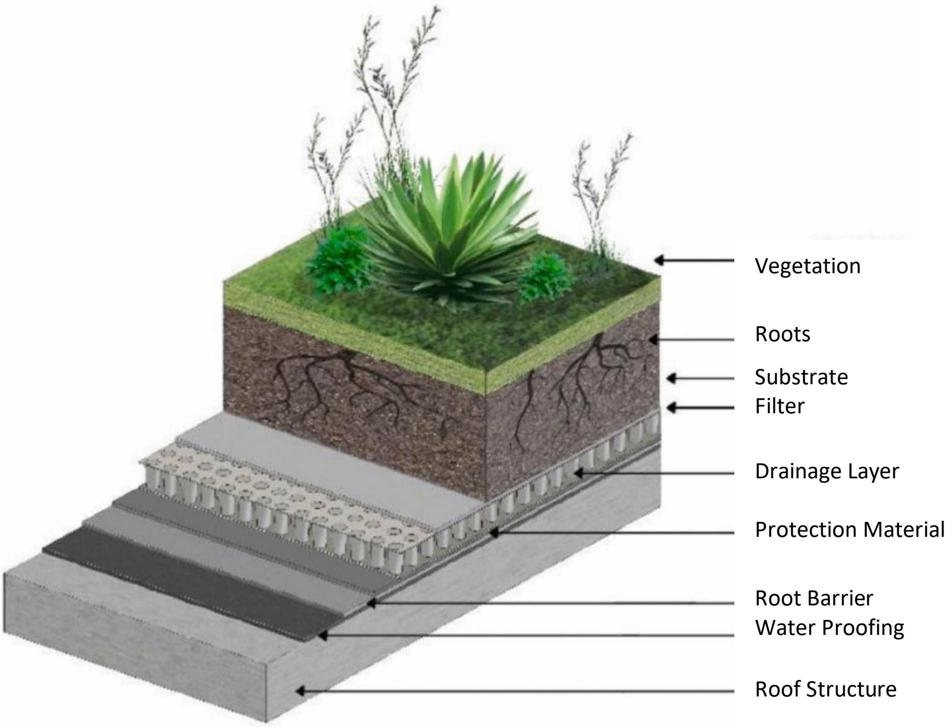

Figure 3. Typical green roof layers (Source: Mihalakakou et al 2023).

In summary, the structural elements of a green roof work together to create a sustainable and environmentally friendly roofing system that provides numerous benefits, including stormwater management, thermal insulation, biodiversity enhancement, and improved air quality. Proper design, installation, and maintenance of each component are essential to ensure the long-term performance and viability of the green roof system. By incorporating these structural elements into their building projects, architects, engineers, and building owners can create green roofs that contribute to a healthier, more sustainable built environment.

7. The legislation on green roofs

There isn't a specific European Union (EU) legislation exclusively dedicated to green roofs. However, several EU directives and regulations indirectly influence the promotion and implementation of green roofs across member states. The EU emphasises sustainability, biodiversity conservation, climate change mitigation, and adaptation in various policy areas, which can impact the development and adoption of green roofs. One such policy is the European Green Deal, a comprehensive roadmap introduced by the European Commission in 2019, aiming to make the EU's economy sustainable and achieve carbon neutrality by 2050. The Green Deal includes initiatives such as the EU Biodiversity Strategy for 2030, which seeks to restore degraded ecosystems, halt biodiversity loss, and integrate nature-based solutions into urban planning. Green roofs are recognized as one of these nature-based solutions that contribute to biodiversity conservation, climate resilience, and sustainable urban development. Additionally, the EU's Circular Economy Action Plan promotes resource efficiency and waste reduction, encouraging the reuse of materials and the adoption of sustainable construction practices, which could indirectly support the use of green roofs. Furthermore, EU directives related to water management, air quality, and energy efficiency, such as the Water Framework Directive, the Ambient Air Quality Directive, and the Energy Performance of Buildings Directive, may influence member states to adopt green roofs as a means to address these environmental challenges. Despite the absence of specific legislation, various EU-funded research projects, initiatives, and best practice guidelines exist to support the implementation of green roofs across Europe. These efforts contribute to raising awareness, building capacity, and providing technical assistance to policymakers, urban planners, architects, and building owners interested in integrating green roofs into their projects. Overall, while there isn't dedicated EU legislation on green roofs, the broader policy framework and initiatives at the European level play a significant role in promoting their adoption and integration into urban landscapes to achieve sustainability goals.

Moreover, several European countries have varied approaches to green roof legislation, with some nations having specific regulations or incentives, while others rely on broader environmental policies to promote green roof adoption. In the following the national legislation on green roofs in several European countries are listed:

a. In Italy, the promotion of green roofs is supported at both national and local levels through a combination of regulations, tax incentives, and urban initiatives. Nationally, Legislative Decree 192/2005, amended by Legislative Decree 311/2006, sets measures to improve the energy performance of buildings, indirectly encouraging the adoption of green roofs. At regional and municipal levels, cities like Milan, Bologna, Turin, Florence, and Rome have implemented specific regulations and sustainable development plans that encourage green roof installation, offering tax incentives and public funding. Best practices include the adoption of extensive and intensive green roofs, integration into urban development plans to mitigate urban heat islands and manage stormwater, and public-private collaborations to develop innovative technologies. Notable examples are found in universities, such as the University of Milan Bicocca, which integrate green roofs into their campuses as part of sustainability strategies. These combined efforts aim to make the implementation of green roofs in public and private buildings both economically advantageous and environmentally sustainable.

b. In Greece the promotion of green roofs is supported through national energy efficiency policies and local initiatives aimed at urban sustainability. Nationally, Greece has integrated green roofing into its National Energy Efficiency Action Plan, which encourages sustainable building practices to improve energy performance and reduce environmental impact. At the municipal level, cities such as Athens have introduced specific incentives for green roof installations to combat urban heat islands and improve urban living conditions. Best practices in Greece involve using native and drought-resistant plants suited to the Mediterranean climate, ensuring that green roofs require minimal maintenance and water. Public-private partnerships are also encouraged to facilitate the development and implementation of green roofing projects. Additionally, universities and research institutions in Greece play a crucial role in advancing green roof technologies and integrating them into urban planning and development strategies. These efforts aim to enhance energy efficiency, promote biodiversity, and improve the quality of life in urban areas while making green roofs a viable and attractive option for buildings across Greece.

c. In Spain, the promotion of green roofs is supported by national regulations and regional initiatives aimed at enhancing sustainability and energy efficiency. Nationally, the Spanish Technical Building Code includes provisions that encourage sustainable building practices, including green roofs. At the regional level, areas such as Catalonia and Madrid have implemented additional regulations and incentives to promote the adoption of green roofs. Best practices in Spain focus on water conservation through the integration of rainwater harvesting systems and the use of drought-resistant plants suitable for the Mediterranean climate. Public-private collaborations are common, facilitating the development of innovative green roofing solutions and their integration into urban planning. Universities and research institutions are actively involved in advancing green roof technologies and incorporating them into sustainability curricula and research programs. These combined efforts aim to improve urban biodiversity, manage stormwater, and reduce the urban heat island effect, making green roofs a practical and environmentally beneficial choice for buildings across Spain.

d. Germany has been a pioneer in promoting green roofs for several decades. In 2016, Germany passed the Green Roofing Guideline, which outlines technical requirements and best practices for green roof installation. Many German cities offer financial incentives and subsidies to encourage green roof construction, with Berlin being a notable example. Additionally, the German Sustainable Building Council (DGNB) has developed certification standards for sustainable buildings, including criteria for green roofs. These initiatives reflect Germany's commitment to sustainable urban development and climate resilience.

e. France has also embraced green roofs as part of its efforts to promote sustainable urban development. In 2015, France passed legislation requiring all new buildings in commercial zones to include green roofs or solar panels. This law aims to enhance biodiversity, reduce urban heat island effects, and promote renewable energy generation. Additionally, several French cities, including Paris, have implemented green roof programs and incentives to encourage building owners to install green roofs voluntarily.

f. Switzerland has a long history of green roof adoption, dating back to the 1970s. In recent years, the Swiss government has introduced financial incentives and tax breaks to encourage green roof construction. Additionally, many Swiss cantons and municipalities have implemented regulations requiring green roofs on new buildings or offering subsidies for retrofitting existing structures. Switzerland's strong tradition of environmental stewardship and sustainable development has contributed to the widespread acceptance and adoption of green roofs across the country.

e. Netherlands:

The Netherlands has emerged as a global leader in green roof innovation and implementation. Dutch cities face challenges such as flooding and urban heat islands, making green roofs an attractive solution. The Dutch government has introduced various policies and incentives to promote green roofs, including subsidies, tax incentives, and technical support programs. Additionally, the Netherlands Green Roof Association (NGB) provides guidance and resources to building owners, architects, and policymakers interested in implementing green roofs.

f. Sweden:

Sweden has prioritized green roofs as part of its broader efforts to combat climate change and promote sustainable urban development. The Swedish government offers financial incentives and grants for green roof construction, particularly in areas prone to flooding or urban heat islands. Many Swedish municipalities have also implemented green roof requirements or incentives as part of their urban planning and building regulations. Sweden's commitment to environmental sustainability and innovation has led to significant growth in green roof adoption across the country.

g. United Kingdom:

The United Kingdom has seen increasing interest in green roofs in recent years, driven by a growing awareness of their environmental benefits. While there is no national legislation specifically targeting green roofs, several cities, including London and Manchester, have developed green roof policies and incentives to encourage their adoption. Additionally, the UK Green Building Council (UKGBC) has developed best practice guidelines and certification standards for green roofs, providing guidance to building owners and developers.

h. In **Ukraine**, the promotion of green roofs is gaining momentum, although it's still emerging compared to other European countries. Nationally, Ukraine is in the process of updating its building codes to include provisions for green infrastructure as part of its commitment to sustainability. While specific national regulations supporting green roofs are still developing, there is growing interest and local initiatives in cities like Kyiv and Lviv.

At the local level, some Ukrainian cities are independently promoting green roofs as part of their urban development plans. These initiatives often aim to mitigate urban heat islands, improve air quality, and manage stormwater runoff. Best practices in Ukraine typically involve the use of cost-effective green roof solutions due to budget constraints, including the incorporation of local materials and native plants that can thrive in the region's climate conditions.

Public-private partnerships play a significant role in advancing green roof technologies in Ukraine, facilitating knowledge sharing and innovation in sustainable building practices. Universities and research institutions are increasingly involved in conducting studies on the benefits of green roofs and exploring ways to integrate them into urban planning and development strategies.
Overall, while Ukraine is in the early stages of adopting green roofs on a broader scale, there is a growing recognition of their potential environmental and social benefits, paving the way for further development and implementation in the future.

i. In **Poland**, the promotion of green roofs is supported through a combination of national regulations, regional initiatives, and local incentives aimed at enhancing sustainability and environmental resilience. Green roof regulations in Poland are mainly governed by construction law and local zoning plans. In Poland, there are programs and funds that support the establishment of green roofs, especially in the context of environmental activities and improving the quality of the urban environment. Nationally, Poland incorporates green roofing into its environmental policies, supported by the National Fund for Environmental Protection and Water Management, which provides funding for green infrastructure projects including green roofs.
At the municipal level, cities like Warsaw have specific guidelines and subsidies for green roof installations, encouraging their adoption as part of urban development strategies. These initiatives aim to mitigate urban heat islands, improve air quality, and manage stormwater runoff effectively.
Best practices in Poland often include the integration of green roofs with renewable energy systems such as solar panels, enhancing energy efficiency and sustainability benefits. There is also a focus on promoting biodiversity through the selection of plant species that are native to the region and resilient to local climatic conditions.

Public-private partnerships play a crucial role in advancing green roof technologies in Poland, fostering collaboration between municipalities, businesses, and research institutions to develop innovative solutions and promote knowledge sharing.
Universities and research centers actively contribute to the advancement of green roof technologies through research and educational programs, integrating them into architectural and environmental studies. These efforts contribute to making green roofs a viable and attractive option for sustainable building practices across Poland, aligning with broader European Union directives and initiatives promoting green infrastructure and urban sustainability.

Overall, European countries have taken various approaches to promote green roofs, reflecting their unique environmental challenges, policy priorities, and cultural contexts. While some nations have enacted specific legislation or incentives to support green roof adoption, others rely on broader environmental policies and initiatives to encourage their implementation. Despite these differences, the common goal across Europe is to create sustainable, resilient, and environmentally friendly cities through the widespread adoption of green roofs.

Moreover, at a **global level,** green roofs are increasingly recognized as a sustainable urban development strategy, with initiatives spanning various regions including Europe and countries such as Ukraine. In Europe, directives like the Energy Performance of Buildings Directive (EPBD) and initiatives such as the Urban Agenda for the EU promote the integration of green roofs to enhance energy efficiency and urban resilience. EU funding programs like Horizon 2020 and the LIFE Program support research and innovation in green roof technologies, reflecting global trends towards sustainable building practices. Worldwide, cities in diverse regions are adopting green roofs to mitigate urban heat island effects, improve air quality, and manage stormwater runoff. Universities and research institutions globally contribute to advancing green roof technologies, ensuring alignment with global goals of sustainable urban development and environmental stewardship.

8. Vegetation for green roofs

Vegetation selection is a critical aspect of green roof design, as it determines the overall performance, aesthetics, and ecological benefits of the system. Green roofs can support a wide variety of plant species, ranging from low-maintenance sedums to native grasses, wildflowers, herbs, shrubs, and even small trees. The choice of vegetation depends on factors such as climate, sunlight exposure, soil depth, irrigation availability, and maintenance requirements. In the following, the characteristics, benefits, and considerations for various plant types commonly employed in green roof systems are explored.

a. Sedums (Sedum spp.):

Sedums are one of the most popular and widely used plant species in green roofs due to their adaptability, drought tolerance, and low maintenance requirements. These succulent plants are well-suited to the harsh rooftop environment, with shallow root systems and water-storing leaves that enable them to thrive in dry, sunny conditions. Sedums come in a variety of colors, textures, and growth habits, making them versatile for creating visually appealing green roof landscapes. Common sedum species used in green roofs include Sedum acre, Sedum album, Sedum spurium, and Sedum reflexum. Sedums are typically planted in extensive green roofs with shallow soil depths, where they can form dense mats of foliage that provide habitat for insects and wildlife, reduce stormwater runoff, and enhance thermal insulation.

b. Grasses (Festuca spp., Carex spp., Poa spp.):

Grasses are another popular choice for green roofs, offering a naturalistic aesthetic, soil stabilisation, and habitat for wildlife. Native grass species such as Festuca rubra (red fescue), Carex flacca (blue sedge), and Poa pratensis (Kentucky bluegrass) are commonly used in green roof installations, as they are well-adapted to local climate conditions and require minimal maintenance. Grasses have fibrous root systems that help prevent soil erosion and promote water infiltration, making them ideal for extensive green roofs with shallow soil depths. Additionally, grasses provide habitat and food for birds, insects, and other wildlife, contributing to biodiversity conservation in urban environments.

c. Wildflowers (Achillea spp., Centaurea spp., Geranium spp.):

Wildflowers are valued for their beauty, biodiversity, and ecological benefits in green roofs. These native or adapted flowering plants provide food and habitat for pollinators such as bees, butterflies, and hummingbirds, enhancing urban biodiversity and ecosystem resilience. Common wildflower species used in green roofs include Achillea millefolium (yarrow), Centaurea cyanus (cornflower), and Geranium sanguineum (bloody cranesbill). Wildflowers are typically planted in semi-intensive or intensive green roofs with deeper soil profiles, where they can establish robust root systems and produce colorful blooms throughout the growing season. Incorporating a diverse mix of wildflowers in green roofs promotes pollinator health, enhances aesthetic appeal, and contributes to overall ecological function.

d. Herbs (Thymus spp., Rosmarinus officinalis, Lavandula spp.):
Herbs are prized for their culinary, medicinal, and aromatic properties, as well as their ornamental value in green roofs. Species such as Thymus serpyllum (creeping thyme), Rosmarinus officinalis (rosemary), and Lavandula angustifolia (English lavender) are well-suited to the dry, sunny conditions of green roofs, requiring minimal water and maintenance. Herbs have shallow root systems and compact growth habits that allow them to thrive in containers or shallow soil depths, making them suitable for extensive green roofs. In addition to their culinary and aromatic uses, herbs attract beneficial insects such as bees and butterflies, support local biodiversity, and provide seasonal interest with their fragrant foliage and flowers.
e. Shrubs (Arctostaphylos uva-ursi, Juniperus spp., Cotoneaster spp.):
Shrubs are larger, woody plants that add structure, height, and habitat diversity to green roof landscapes. Species such as Arctostaphylos uva-ursi (bearberry), Juniperus communis (common juniper), and Cotoneaster horizontalis (rock cotoneaster) are commonly used in green roof installations for their low-maintenance requirements, drought tolerance, and year-round interest. Shrubs are typically planted in semi-intensive or intensive green roofs with deeper soil profiles, where they can establish extensive root systems and provide habitat for birds and small mammals. Incorporating shrubs in green roofs enhances biodiversity, improves aesthetic appeal, and contributes to ecosystem services such as air purification, stormwater management, and climate regulation.

f. Trees (Acer spp., Betula spp., Malus spp.):
Trees are the largest and most impactful vegetation type in green roofs, providing shade, habitat, and ecosystem services on a larger scale. Species such as Acer palmatum (Japanese maple), Betula

pendula (silver birch), and Malus domestica (apple tree) are sometimes used in intensive green roofs or rooftop gardens, where soil depths and structural support allow for tree growth. Trees offer numerous benefits in green roofs, including carbon sequestration, air purification, temperature regulation, and aesthetic enhancement. However, their large size, deep root systems, and maintenance requirements make them challenging to incorporate into green roof designs, requiring careful consideration of structural integrity, weight load, and long-term management.

In conclusion, green roofs can support a diverse array of vegetation types, each with its own unique characteristics, benefits, and considerations. From low-maintenance sedums to towering trees, the selection of vegetation in green roofs depends on factors such as climate, site conditions, maintenance requirements, and project goals. By carefully choosing and integrating a diverse mix of plant species, green roofs can maximise their ecological, aesthetic, and functional potential, contributing to urban biodiversity, climate resilience, and sustainability.

9. Green roofs and thermal insulation of buildings

Green roofs play a significant role in thermal insulation, offering numerous benefits that contribute to energy efficiency, comfort, and sustainability in buildings. The thermal insulation properties of green roofs are attributed to several factors, including the layers of vegetation, soil, and drainage materials that form the roof assembly, as well as the vegetation's ability to regulate heat transfer through evapotranspiration, shading, and thermal mass. In the following, the mechanisms by which green roofs provide thermal insulation and their impact on building energy performance are listed.

1. Green Roof Layers:

Green roofs typically consist of multiple layers, including a waterproofing membrane, drainage layer, growing medium (soil or substrate), and vegetation. Each layer contributes to the thermal performance of the roof assembly by adding insulation, regulating moisture levels, and reducing heat transfer. The waterproofing membrane prevents water infiltration into the building, protecting the structure from moisture damage and heat loss. The drainage layer facilitates water runoff and prevents waterlogging, ensuring proper drainage and preventing heat loss through water accumulation. The growing medium acts as a thermal barrier, providing additional insulation and thermal mass to regulate temperature fluctuations. Finally, the vegetation layer shades the roof surface, absorbs solar radiation, and releases moisture through evapotranspiration, further reducing heat gain and enhancing thermal comfort indoors.

2. Insulation Properties of Growing Medium:

The growing medium or soil substrate used in green roofs plays a crucial role in providing thermal insulation. Green roof substrates are typically lightweight and porous, with high air content and low thermal conductivity, which helps trap heat and minimise heat transfer through the roof assembly. The insulation properties of the growing medium depend on factors such as particle size, moisture content, and organic matter content. Lightweight aggregates such as expanded clay, perlite, or pumice are commonly used in green roof substrates to enhance insulation while reducing weight load on the building structure. Additionally, the composition and depth of the growing medium influence its thermal resistance and capacity to retain heat, with deeper substrates providing greater insulation and thermal mass.

3. Evapotranspiration and Cooling Effect:

One of the key mechanisms by which green roofs provide thermal insulation is through evapotranspiration, the combined process of water evaporation from the soil and transpiration from plant leaves. Evapotranspiration cools the green roof surface by absorbing heat energy from the surrounding environment and converting it into latent heat, thereby reducing roof temperatures and mitigating heat transfer into the building. The cooling effect of evapotranspiration is particularly pronounced during hot, sunny days when green roofs can significantly lower surface temperatures compared to conventional roofing materials. This cooling effect not only reduces the need for air conditioning and mechanical cooling systems but also improves thermal comfort indoors, creating a more pleasant and habitable living environment for building occupants.

4. Shading and Solar Reflectance:

The vegetation layer of green roofs provides shading and reduces solar radiation absorption, thereby minimising heat gain through the roof surface. Green roof vegetation absorbs and reflects a portion of incoming solar radiation, particularly in the visible and near-infrared spectrum, which helps lower roof temperatures and reduce thermal stress on the building envelope. The shading effect of green roofs is especially beneficial in urban areas with high levels of solar exposure and heat island effects, where conventional roofing materials can absorb and retain heat, leading to increased energy consumption and indoor temperatures. By shading the roof surface, green roofs reduce solar heat gain, improve energy efficiency, and prolong the lifespan of roofing materials by minimising thermal expansion and contraction.

5. Thermal Mass and Heat Storage:

Green roofs act as thermal masses, absorbing and storing heat energy during the day and releasing it slowly at night, thereby moderating temperature fluctuations and reducing thermal lag in buildings. The soil substrate and vegetation of green roofs have a high heat capacity, allowing them to absorb excess heat during peak solar exposure and release it gradually over time, which helps stabilise indoor temperatures and reduce heating and cooling loads. This thermal buffering effect is particularly beneficial in climates with large diurnal temperature variations, where green roofs can help maintain a comfortable and stable indoor environment year-round. Additionally, the thermal mass of green roofs can reduce temperature extremes in urban areas, mitigating heat island effects and improving overall urban microclimate conditions.

6. Energy Savings and Building Performance:

The thermal insulation properties of green roofs result in significant energy savings for buildings by reducing heating and cooling loads, improving indoor comfort, and enhancing overall building performance. Studies have shown that green roofs can reduce building energy consumption for heating and cooling by up to 30%, depending on factors such as climate, building design, and vegetation density. By insulating the roof assembly, green roofs help regulate indoor temperatures, minimise heat loss in winter, and prevent heat gain in summer, resulting in lower energy bills, reduced carbon emissions, and improved indoor air quality. Additionally, green roofs contribute to building certification programs such as LEED (Leadership in Energy and Environmental Design) by enhancing energy efficiency and sustainability metrics, making them a valuable investment for both new construction and retrofit projects.

In conclusion, green roofs offer effective thermal insulation by incorporating layers of vegetation, soil substrate, and drainage materials that regulate heat transfer, reduce solar heat gain, and enhance thermal comfort indoors. Through mechanisms such as evapotranspiration, shading, and thermal mass, green roofs provide significant energy savings, improve building performance, and contribute to sustainable urban development. As cities continue to grapple with climate change, urban heat island effects, and rising energy demand, green roofs offer a sustainable solution to mitigate heat stress, reduce energy consumption, and create healthier, more resilient built environments for current and future generations.

9.1. Assessment of green roofs impact on building energy consumption and indoor thermal comfort (To be done by Enrique UCA, on progress)

1. About "EnergyPlus"[1]

A physically based model of the energy balance of a vegetated rooftop has been developed and integrated into the EnergyPlus building energy simulation program. This green roof module allows the energy modeller to explore green roof design options including growing media (soil), thermal properties and depth, and vegetation characteristics such as plant type, height and leaf area index (vegetation density). The model has been tested successfully using observations from a monitored green roof in Florida. Hence, it is evident that the green roof model can serve a valuable role in informing green roof design decisions.

The green roof model accounts for long-wave and short-wave radiative exchange within the plant canopy; plant canopy effects on convective heat transfer; evapotranspiration from the soil and plants; heat conduction (and storage) in the soil layer; and moisture-dependent thermal properties. It simultaneously solves for soil surface and foliage temperature each time step.

The user then can either accept default values or specify various parameters of the green roof construction including growing media depth, thermal properties, plant canopy density, plant height, stomatal conductance (ability to transpire moisture), and soil moisture conditions (including irrigation and precipitation). At the present time, the effects of the drainage layer and protection membranes are not taken into account explicitly within the green roof module, and must be modelled separately.

The most important characteristics of the growing media are its thermal conductivity, specific heat capacity, and density. The characteristics of the vegetation that are most important from the standpoint of impacts on the heat transfer through the roof are height, leaf area index (LAI), fractional coverage, albedo, and stomatal resistance. The LAI is a representation of the plan-form area coverage of the leaves. If the average parcel of roof surface is beneath two leaves the corresponding LAI is 2. The fractional vegetative cover represents the fraction of the roof surface that is directly covered by one or more leaves. The albedo is the reflectivity of the surface to the solar energy incident on the

[1] https://energyplus.net/

surface. Lastly, the stomatal resistance is a biophysical parameter that governs the rate at which the plant can transpire moisture through its leaf stomata for a given environmental condition.

The energy budget analysis follows the fast all season soil strength (FASST) model developed by Frankenstein and Koenig [6,7] for the US Army Corps of Engineers. FASST was developed, in part, to determine the ability of soils to support manned and unmanned vehicles and personnel movement. In order to accomplish this, however, FASST tracks the energy and moisture balance (including ice and snow) within a vegetated soil. It is a one-dimensional model that draws heavily from other plant canopy models including BATS [8] and SiB [9]. The EnergyPlus model is based on FASST with only a few modifications to adapt it for use with a relatively thin soil layer.

2. About "TRNSYS"[2]

Recently, TESS has included into its library for TRNSYS program a green roof model (Type number 785), which is available on order. This component models a green roof that can be implemented with Type56 (TRNBuild). Energy balances for vegetated and unvegetated portions of the roof are computed simultaneously so that the vegetation level may be varied throughout the year.

[2] https://www.trnsys.com/

10. Green roofs 5.0: against climate change

In the face of climate change, modern and recent advancements in green roof technology have emerged as crucial tools for mitigating its effects. Green roofs have evolved from simple vegetated coverings to sophisticated systems designed to combat the environmental challenges posed by global warming. With their multifaceted benefits ranging from carbon sequestration to urban heat island reduction, contemporary green roofs, often referred to as Green Roofs 5.0, are at the forefront of sustainable urban development strategies. In the following, the innovative features, scientific principles, and real-world applications of Green Roofs 5.0, elucidating how they can effectively counteract climate change and foster resilient, livable cities, are explored.

1. Advanced Insulation Techniques:

Green Roofs 5.0 integrate cutting-edge insulation technologies to enhance their thermal performance and energy efficiency. Innovative materials such as aerogels, phase change materials (PCMs), and vacuum insulation panels (VIPs) are incorporated into green roof assemblies to minimise heat transfer through the building envelope. Aerogels, known for their ultra-low thermal conductivity, offer superior insulation properties while maintaining lightweight and flexibility, making them ideal for green roof applications. PCMs, which absorb and release thermal energy during phase transitions, stabilise indoor temperatures by regulating heat flow through the roof structure. VIPs, consisting of evacuated panels with extremely low gas pressure, provide high levels of insulation with minimal thickness, maximising space utilisation and reducing construction costs. By integrating these advanced insulation techniques, Green Roofs 5.0 effectively reduce heating and cooling loads, resulting in energy savings and reduced carbon emissions.

2. Climate-Responsive Irrigation Systems:

Green Roofs 5.0 employ sophisticated irrigation systems equipped with climate-responsive sensors and controllers to optimise water usage and enhance vegetation resilience in changing environmental conditions. These smart irrigation technologies utilise weather forecasts, soil moisture sensors, and evapotranspiration models to adjust watering schedules and irrigation volumes dynamically. By synchronising irrigation with prevailing weather patterns and plant water requirements, Green Roofs 5.0 minimise water waste, prevent overwatering or underwatering, and promote healthy plant growth.

Additionally, drip irrigation, capillary mats, and subsurface irrigation systems deliver water directly to the root zone, minimising surface runoff and evaporation losses. Rainwater harvesting and greywater recycling systems further supplement irrigation water supply, reducing dependence on potable water sources and enhancing overall water efficiency. Through intelligent irrigation management, Green Roofs 5.0 ensures the long-term viability and ecological functionality of green roof ecosystems, even in the face of climate variability and water scarcity.

3. Dynamic Vegetation Selection:

Green Roofs 5.0 incorporates dynamic vegetation selection strategies to optimise biodiversity, ecosystem services, and climate resilience. Utilising ecological principles such as plant community composition, functional diversity, and adaptive capacity, these green roofs are designed to support diverse assemblages of native and adapted plant species capable of thriving in a changing climate. Species selection considers factors such as drought tolerance, heat resistance, pollutant tolerance, and seasonal variability, ensuring year-round vegetation cover and ecological functionality. Furthermore, Green Roofs 5.0 employ modular planting systems and pre-vegetated mats to facilitate rapid installation, minimise transplant shock, and promote vegetative establishment. By fostering diverse and resilient plant communities, Green Roofs 5.0 enhances carbon sequestration, air quality improvement, stormwater management, and habitat provision, thereby contributing to climate change mitigation and adaptation efforts in urban environments.

4. Solar Photovoltaic Integration:

Green Roofs 5.0 embrace the integration of solar photovoltaic (PV) panels to enhance energy generation, carbon neutrality, and climate resilience. Combining green roofs with solar PV arrays maximises the productive use of rooftop space, harnessing both solar energy and vegetative cover to offset building energy consumption and reduce greenhouse gas emissions. Building-integrated PV (BIPV) systems are seamlessly integrated into green roof assemblies, providing dual benefits of renewable energy generation and thermal insulation. Moreover, agrivoltaic systems, which combine agriculture with solar energy production, leverage the shading and cooling effects of green roofs to enhance crop yields and mitigate heat stress in plants. Through innovative PV integration, Green Roofs 5.0 exemplify the synergy between renewable energy technologies and green infrastructure, advancing the transition to carbon-neutral, climate-resilient cities.

5. Data-Driven Monitoring and Optimization:

Green Roofs 5.0 leverage data-driven monitoring and optimization techniques to continuously assess performance, identify opportunities for improvement, and adapt to evolving climate conditions. Utilising sensor networks, remote sensing technologies, and building management systems, these green roofs collect real-time data on environmental parameters such as temperature, humidity, solar radiation, and plant health. Machine learning algorithms and predictive analytics analyse this data to optimise green roof operation, maintenance, and performance. Automated systems adjust irrigation, ventilation, shading, and insulation parameters in response to weather forecasts, energy demand, and vegetation dynamics, ensuring optimal functioning under diverse climatic scenarios. Furthermore, digital twin simulations and scenario modelling enable planners, designers, and building managers to explore the potential impacts of climate change and evaluate adaptation strategies proactively. By harnessing the power of data and analytics, Green Roofs 5.0 empower stakeholders to make informed decisions, optimise resource allocation, and enhance climate resilience in the built environment.

In conclusion, Green Roofs 5.0 represent a paradigm shift in sustainable building design and urban resilience, harnessing innovation, technology, and ecological principles to combat climate change. Through advanced insulation techniques, climate-responsive irrigation systems, dynamic vegetation selection, solar PV integration, and data-driven monitoring, these green roofs exemplify the next frontier in green infrastructure. By integrating these innovative features, Green Roofs 5.0 have the potential to mitigate urban heat island effects, reduce energy consumption, enhance biodiversity, and promote climate adaptation in cities worldwide. As climate change continues to pose significant challenges to urban environments, Green Roofs 5.0 offer a multifaceted solution that combines ecological functionality with technological innovation, paving the way for a more sustainable and resilient future.

10.1. Assessment of green roofs impact on urban micro-climate

1. ENVI-met:

Available on www.envi-met.com. Developed by Prof. Dr. Michael Bruse & Team, Environmental Modeling Group, Inst. of Geography, University of Mainz (Germany).

This is a three-dimensional microclimate model designed to simulate surface-plant-air interactions in urban environments with a typical resolution of 0.5 to 10 meters in distance and 10 seconds in time.

Typical areas of application, to name a few, are Urban Climatology, Architecture, Building Design and Environmental Planning.

It enables to analyse small-scale interactions between urban design and microclimate. The model combines the calculation of fluid dynamics parameters, such as wind flow or turbulence, with the thermodynamic processes that take place on the ground surface, on walls and roofs or in plants. The model can simulate complicated geometries such as terraces, balconies or complex quarters.

The model includes the simulation of: Flow around and between buildings, heat and vapor exchange processes with the surface of the ground (land) and with walls, turbulence, exchange with vegetation and vegetation parameters, bioclimatology and dispersion of contaminants.

- The calculation model includes: Short-wave and long-wave radiation fluxes with respect to shading, reflection and re-radiation from building systems and the vegetation, transpiration, evaporation and sensible heat fluxes from vegetation to air including complete simulation of all plant physical parameters (for example, photosynthesis rate, surface and wall temperature for each grid point and wall, exchange of heat and mass (water) within the soil, calculation of biometeorological parameters such as Mean Radiant Temperature or Fanger's Predicted Mean Vote (PMV)-value, dispersion of inert gases and particles including sedimentation of particles on leaves and surfaces, buildings, vegetation, soil/surfaces and contaminant sources can be introduced within the model area. In addition to natural and artificial sources, the model is also capable of treating water bodies.

ENVI-met is a high-resolution urban microclimate modelling software that allows you to simulate urban environments and analyse the impact that a certain urban and architectural design has on the urban microclimate or outdoor environment, allowing the design of efficient buildings urban areas.

To simulate the dynamic behaviour of the complex microclimatic system, this tool uses a holistic approach in which all interacting phenomena or processes are integrated, interconnected and simulated together in a single detailed 3D model. This 3D microclimatic model allows us to simulate small-scale surface-plant-air interactions that take place in an urban environment for microscale with a typical horizontal resolution from 0.5 to 10 m, a typical time frame of 24 to 48 hours and a time step from 1 to 5 seconds.

The simulation model includes: atmospheric dynamics, flow around and between buildings through the use of CFD, exchange processes at the ground surface and at building walls (including soil hydrology), building physics (building energy simulation, building indoor climate), impact of vegetation of the local microclimate, bioclimatology and pollutant dispersion.

The model is in continuous development, and the user can find a summary description of the different versions and latest updates on its website. In addition to the free version (ENVI-met Standard), there is a Professional Version with additional analysis modules and an Expert Version with advanced modelling features, although this last version is only available within ENVI-met`s team consulting work. Additionally, developers can offer a wide range of customized and specialized simulation modules according to particular design requirements, even offering support on the best strategies to optimize a given design. On the website, the user can find a wide collection of tutorials, FAQs and useful information about the program and its use, as well as articles and research publications related to the program. The program is NOT Open Source.

2. SOLENE-microclimate:

SOLENE is a 3D numerical simulation tool that was initially developed by the CERMA laboratory to evaluate the radiation processes that take place in urban environments. Subsequently, additional models were added that expanded the scope of the tool, so that currently the SOLENE-microclimate tool [15] has the purpose of allowing the evaluation and quantification of the direct and indirect impact that the microclimate originating in an urban environment has on:

- Thermal comfort in outdoor environments.
- The thermal loads of a certain building in the environment.

By using this tool, it is then possible to evaluate and quantify the impact that different urban climate mitigation solutions have on the comfort and thermal loads of the building.

The models developed and implemented in SOLENE-microclimate that allow this evaluation are the following:

- Models for determining microclimatic conditions in the environment:
- Solar radiation
- Exchanges of long wave radiation with the environment
- Heat transfer through the building envelope
- Transmission through the terrain
- Convection between surfaces and air
- Evapotranspiration on natural surfaces (vegetation)
- Evaporation in masses or sheets of water
- Anthropogenic heat (only sources due to conditioning systems)

- Air movement (air velocity field)
- Thermal comfort model
- Building thermal behaviour model (calculation of thermal loads and temperature in free oscillation for a building in the domain under study)

Several vegetation models have been implemented, such as models for high-rise vegetation, such as trees, and low- and medium-rise vegetation, such as facades or green roofs [6]. The integration of these models in the tool allows evaluating the interaction of vegetation with the environment, and studying, for example, the influence of some specific parameters on the energy consumption of buildings. A comparison of the results obtained for green facades with experimental data was carried out by [15].

The impact of vegetation on the environment is taken into account through:

- Projected shadows (in the case of tall vegetation)
- Long wave radiant exchange with the rest of the surrounding surfaces
- Convection with the surrounding air
- Evapotranspiration
- Pressure loss in air movement (high altitude vegetation is considered a porous medium)

High-altitude vegetation is considered in the model as a volumetric cell. Therefore, it is not only taken into account in the SOLENE-microclimate thermal model, but also in the CFD model, in order to evaluate its effect on air movement. On the contrary, low and medium height vegetation is considered a surface cell and, consequently, is only taken into account in the thermal model (surface thermal balance). Obviously, in both cases, there is a coupling between the SOLENE-microclimate thermal model and the CFD model.

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11. GREENO2 Case studies

11.1. Case study in Italy

The illustrative case study featured here focuses on the Polder Roof, a Blue-Green Roof (BGR) created by the MetroPolder Company based in the Netherlands. This experimental BGR pilot is situated at the hydrological research site of the University ofTuscia in Central Italy, accessible at www.mechydrolab.org and depicted in Figure 4. Elevated 90 cm above the ground on a wooden structure, the roof covers a total area of 16 m2 (4 m × 4 m). It consists of an 8-cm storage layer and 10 cm of soil. The smart valve, positioned at a fixed height of 7 cm, represents the maximum retention capacity for the specific BGR under observation.

This predetermined retention capacity enables the assessment of the BGR's performance in a Mediterranean climate, characterised by high water demand during dry periods. The vegetation on the roof includes Sedum album and Sedum acre. The dataset utilised in this study spans a period of from October 30, 2020, to December 31, 2022. The primary objectives of this section are as follows:

• To present the hydrological performance of the examined BGR, considering the entire rainfall time series and at the scale of individual rainfall events.

• To present the thermal performance of the BGR, considering a 5 minute resolution data for the year 2021 compared to a benchmark roof.

Figure 4. The BGR case study in Viterbo (Central Italy)

The hydrological performance of the BGR is intricately tied to the operational management of the smart valve, which has been consistently set at a height of 7 cm throughout the observation period. This height corresponds to the maximum water storage capacity for the specified BGR. During the period from August 30, 2020, to December 31, 2022, the cumulative rainfall recorded was 1779 mm, with a cumulative runoff of 585 mm. No instances of snowfall were noted during this investigative timeframe.

Breaking down the cumulative rainfall amounts, from August 30, 2020, to December 31, 2020, the observed cumulative rainfall was 527.3 mm. The annual cumulative rainfall increased to 706 mm in 2021 but decreased to 546 mm in 2022. These values notably fall below the average cumulative rainfall recorded in Viterbo since 1916, which stands at 810 mm. The year 2022, in particular, witnessed severe drought conditions.

Turning attention to BGR runoff, cumulative values were 198 mm from August 30, 2020, to December 31, 2020, followed by 283 mm in 2021 and 103.5 mm in 2022. The Stormwater Retention Rate (SRR) calculated for the entire period was 67.1%, with specific rates of 62.3% from August 30, 2020, to December 31, 2020, 59.8% in 2021, and a notable increase to 81% in 2022. The considerable variation in SRR between 2021 and 2022 can be attributed to the reduced annual rainfall depth in 2022 (-22%), leading to drier conditions in the BGR. Consequently, there is an increased void volume capable of retaining stormwater. Refer to Figure 5 for a visual representation of the observed rainfall and BGR runoff time series.

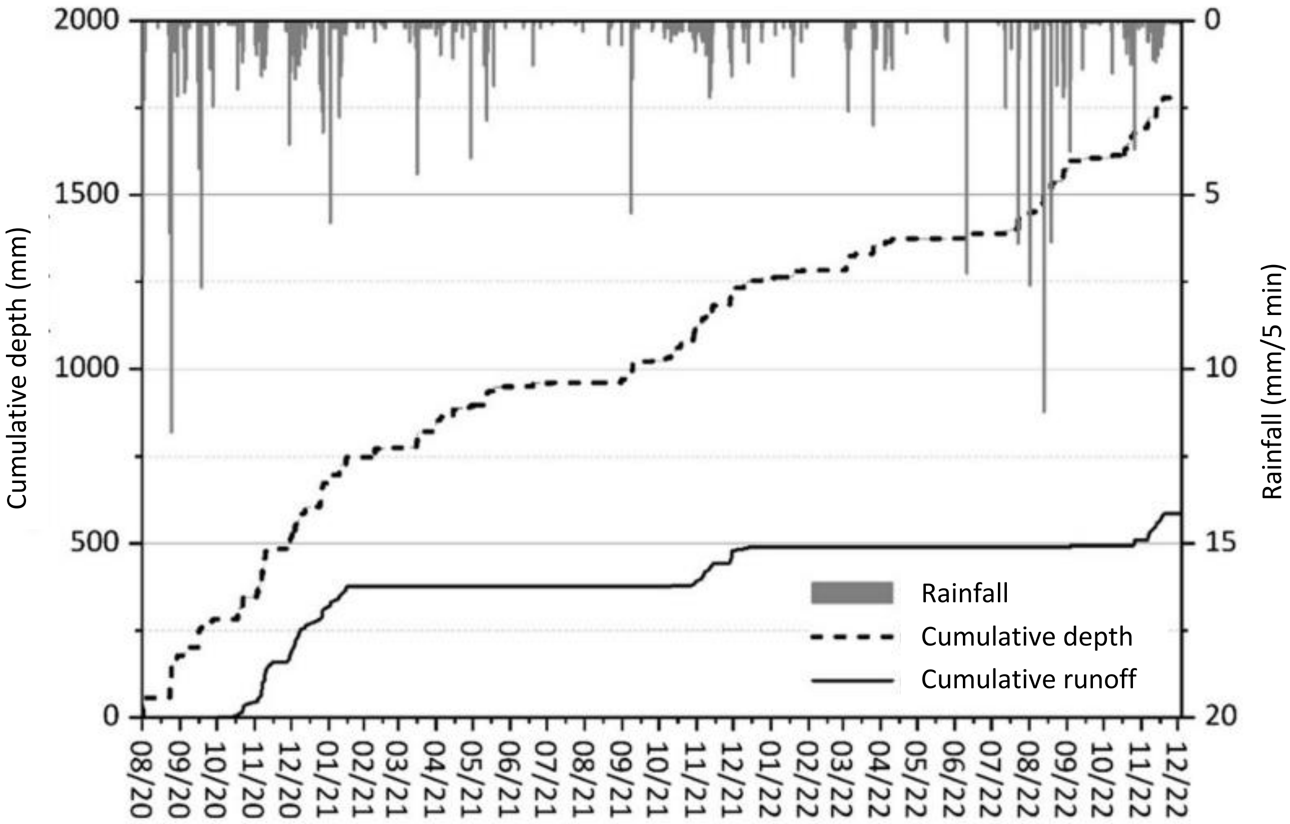

Figure 5. Rainfall time series, cumulative rainfall depth, and cumulative BGR runoff depth time series at 5 min of time resolution for the entire observation period.

Figure 6 presents a comprehensive overview of the 79 events recorded in the investigated time period, distinguishing those with and without BGR runoff, as well as events occurring during both dry and wet periods. As previously mentioned, no runoff events were observed during the dry period. Additionally, the figure provides a reference by illustrating the intensity–duration–frequency curves (IDF) for return periods (Tr) of 2 and 5 years. These curves were estimated by applying the generalised extreme value distribution to the annual maxima time series of the Viterbo rain gauge station, available since 1916, for durations of 1, 3, 6, 12, and 24 hours. It becomes apparent that the majority of events were ordinary, with only three having a return period of approximately 2 years. When focusing on events during the wet period, there is no clear distinction between events with and without runoff, represented by blue squares and red circles, respectively. This lack of differentiation could be attributed to the antecedent rainfall depth, which evidently plays a significant role in determining the BGR response.

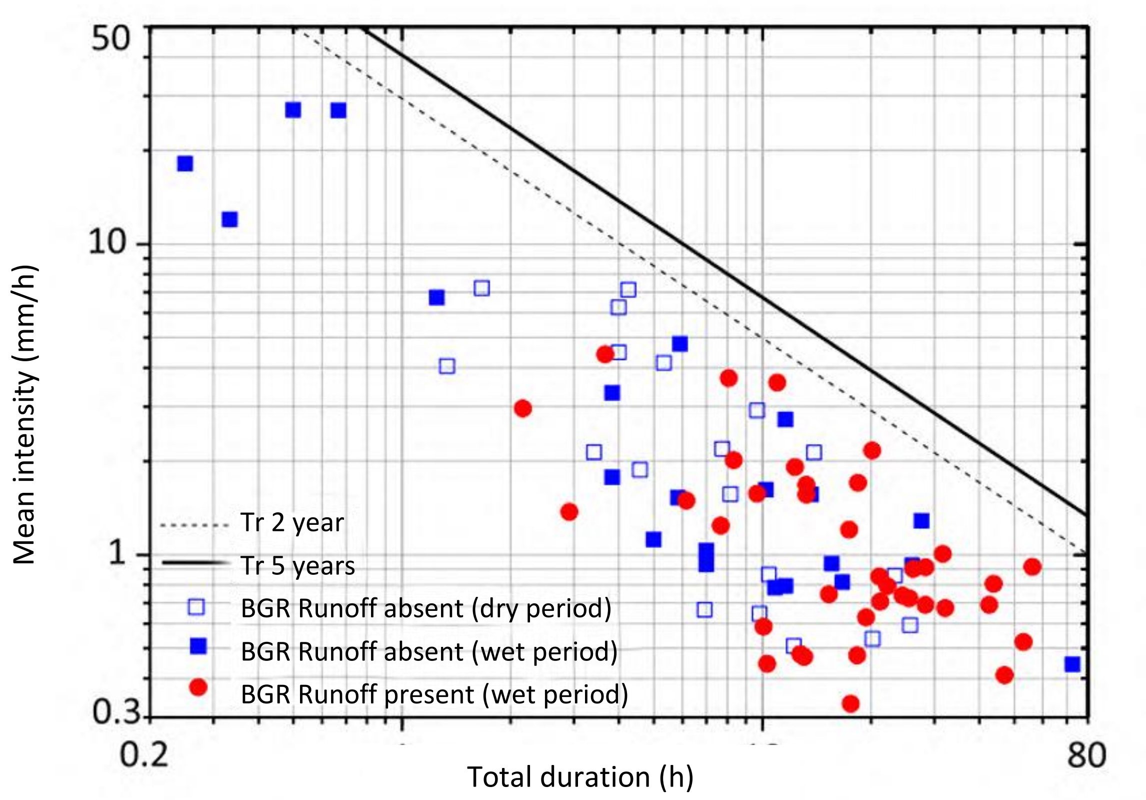

Figure 6. The 79 observed rainfall events. The visual representation includes blue empty squares, denoting events without BGR runoff during the dry period (spring and summer), and blue squares, representing events without BGR runoff during the wet period (autumn and winter). Furthermore, red circles indicate events with BGR runoff during the wet period (autumn and winter). Notably, no events with BGR runoff were observed in the dry period. The figure also incorporates Intensity–Duration–Frequency (IDF) curves for various return periods. The dotted line corresponds to a return period of 2 years (Tr 2 years), while the thick line represents a return period of 5 years (Tr 5 years).

For the analysis of the thermal efficiency of the BGR, the air temperature just above the green roof has been examined and compared with that recorded on a steel roof (Benchmark) located a few meters from the BGR (Figure 7).

Figure 7. The steel roof (benchmark).

Figure 8 depicts the trend of the average temperature difference between the BGR and the Benchmark per quarter. It is evident that the temperatures on the benchmark roof are higher compared to those recorded on the BGR, especially during the hottest hours of the day.

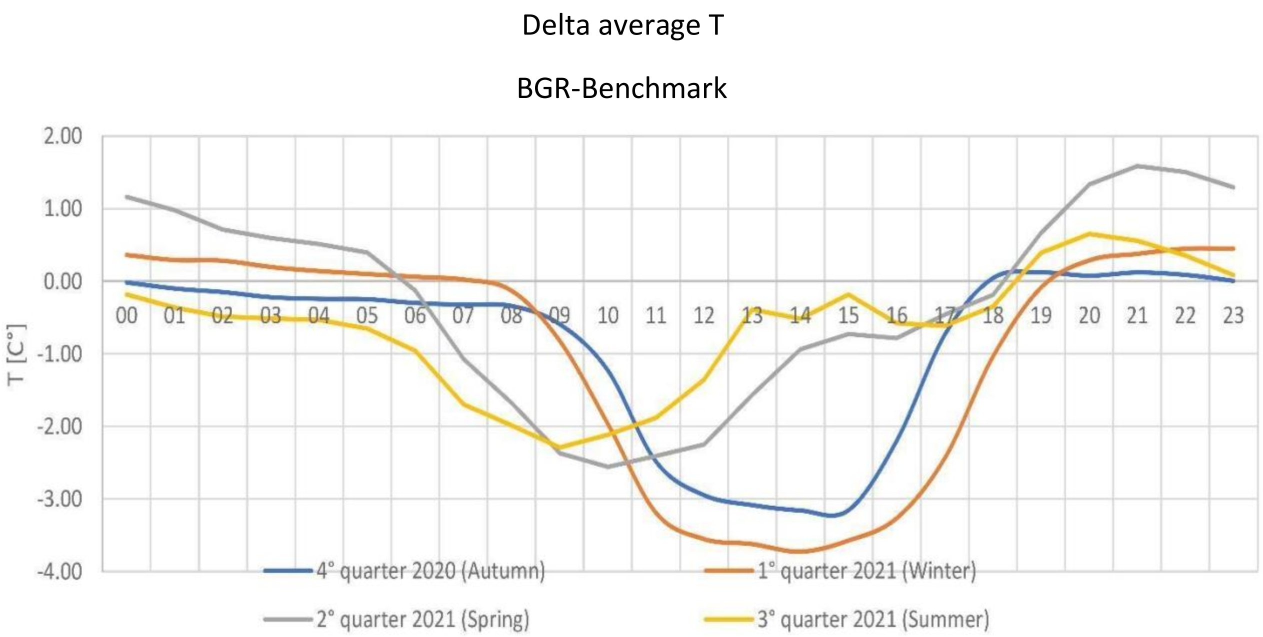

Fig. 8. Delta mean Temperature (T) BGR(Polder)-Benchmark for quarter (year 2021).

However, analysing individual months and hours reveals divergent dynamics. For instance, in the month of February (Figure 9), when the BGR exhibits lush vegetation and the soil is saturated with rain, the thermal effect is significant, with max air temperatures even up to 11 degrees lower than the benchmark. However, during the summer period, especially in times of intense aridity with dry or absent vegetation, the scenario changes. In August 2021 (Figure 10), the max hourly temperatures recorded on the Polder Roof are equal or slightly higher (up to a maximum of 5.5°), particularly during the hottest hours of the day (after 11 am).

Figure 9. Trend of max hourly temperatures for the Polder Roof (BGR) and Benchmark, February 2021.

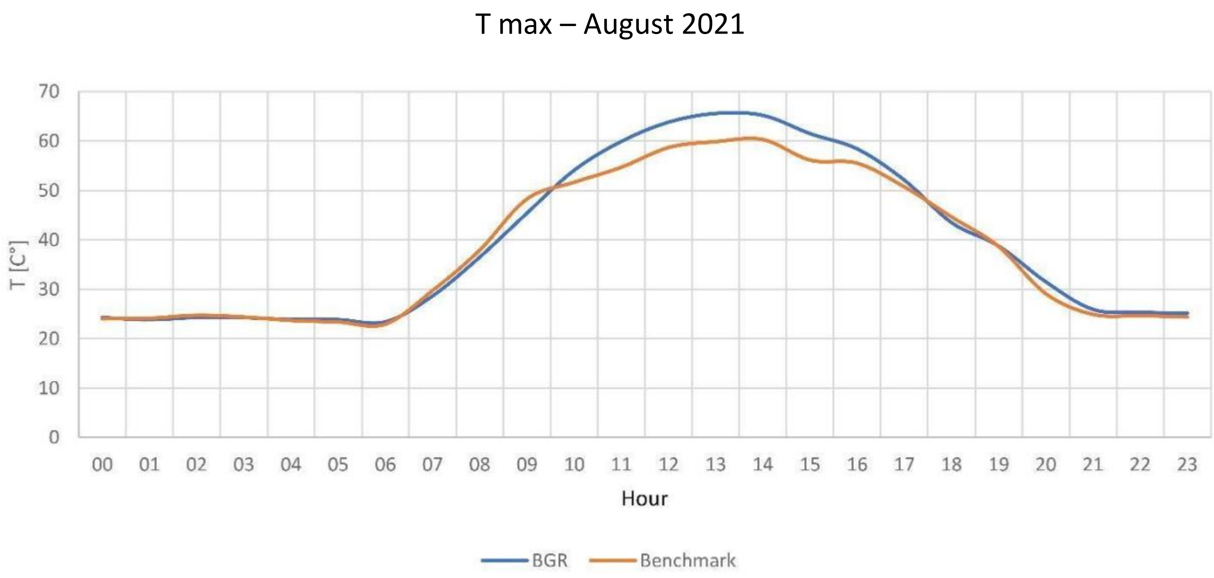

Figure 10. Trend of max hourly temperatures for the Polder Roof (BGR) and Benchmark, August 2021.

In conclusion, from a hydrological perspective, a significant portion of meteorological events is retained by the BGR, even though extreme events have not been measured in the considered two-year period. The efficiency of the BGR diminishes during wet periods when the green roof becomes saturated, and antecedent conditions are crucial in determining its performance. In this case, it is essential to assess the hydrological performance of green roofs, taking into account the annual and interannual climatic variability specific to the investigated location, especially the antecedent rainfall depth.

From a thermal standpoint, seasonal variability is a fundamental factor influencing the thermal performance of the green roof, albeit in an inverse manner. While lower air temperatures on the BGR, even up to 11 degrees, are recorded during wet periods compared to metal sheet roofs, performance reduces in the summer, becoming, in some cases, worse due to the reflectance and thermal capacity of the soil in the absence of vegetation and moisture. Hence, the need for supplemental irrigation during summer periods is evident to maintain thermal efficiency and vegetation.

Conversely, in the summer, the green roof exhibits its maximum capacity to retain rainwater, thus limiting urban runoff due to voids in the BGR structure. However, it is during winter that this regulatory capacity for rainwater becomes most crucial, necessitating the emptying of the BGR before critical meteorological events. Like all nature-based solutions, maintaining the multifunctionality of ecosystem services provided by the BGR throughout the year requires consideration of site specificity, local climate variability, and the maintenance and management of irrigation and drainage systems.

11.2. Case study in Greece

Another interesting case of a green roof comes from Greece, which is also part of the project consortium. The **extensive biodiversity green roof**[3] is located at l'Oréal's premises in Athens, Greece. It is located in an urban zone surrounded by public and private gardens, archaeological sites, sports stadiums and small hills. The main objectives of the action plan were to recognise nature as an integral part of innovative urban development and to explore the potential in terms of climate change mitigation. The landscape design proposed a green roof in two distinct zones, which would stimulate the small habitats in the surrounding area and provide a biodiversity hub for education and awareness raising for staff and visitors. The information and awareness zone emphasized on demonstrating the value of biodiversity through demonstration interventions. The wildlife zone emphasized hosting flora and fauna species with minimal human intervention.

[3] https://iflaeurope.eu/

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It consists of areas for fauna to winter, rest, nest, breed and feed. Trees, shrubs and perennials, fostering a biodiversity that gives the roof both ecological, visual and social values.

Figure 11. The green roof design

Figure 12: The extensive biodiversity green roof

11.3. Case study in Poland

Another example of a green roof from a consortium country, Poland, is the green roof of the University of Warsaw[4]. The green roof of the University of Warsaw Library (BUW) is one of the most beautiful and expansive rooftop gardens in Europe. The green roof spans over 1 hectare (10,000 square meters) and is divided into two main sections: the upper and lower gardens. The upper garden

[4] https://inplacescityguide.com/green-roofs-in-warsaw/

includes viewing terraces with scenic views of the Vistula River and Warsaw's skyline. The roof is covered with a wide variety of plants, including perennials, shrubs, and trees, carefully selected to thrive in rooftop conditions. There are water features and small ponds that attract birds and insects, contributing to biodiversity.

Figure 13: Green roof in Warsaw, Poland

11.4. Case study in Ukraine

Green roof of the Tetris-Hall residential complex is an innovative space for recreation and leisure in the capital of Ukraine, Kyiv. The roof of this in the heart of the city has become a unique space for its residents and guests. Thanks to the expertise of professionals from the landscape architecture studio "KOTSIUBA", a park was created featuring mature trees, forested areas, open relaxation zones, a summer cinema, a BBQ area, and a glass bridge connecting the towers of the complex.

The Importance of Green Roofs

Green roofs are a crucial element of modern urban planning, contributing to environmental sustainability, improving building energy efficiency, and creating a comfortable living environment. Tetris-Hall serves as an excellent example of how a well-implemented green roof concept can seamlessly blend natural and urban elements, offering residents a high-quality living space.

Challenge and Solution

The main objective was to create functional zones that cater to the needs of all resident groups on the building's roof. This required a re-evaluation of the space's scale and functionality, leading to the development of a multifunctional area suitable for various activities throughout the year.

Location and Panoramic Views

Tetris-Hall is situated in the very center of Kyiv, providing easy access to the city's major cultural and entertainment venues. Before the design process began, a study was conducted to identify the key viewpoints, ensuring maximum utilization of the roof's panoramic city views.

Master Plan and Zoning

The rooftop serves as a social hub for residents and their guests, featuring:

- Swimming pool – for relaxation during the warm season.
- Summer cinema – for open-air movie screenings.
- Café and BBQ area – offering stunning city views.
- Green park – a space for walks and leisure.

The initial zoning primarily included large spaces for groups gathering at the pool, bar, or BBQ area. The new concept introduced additional functional elements, enabling year-round rooftop use. The variety of spaces, differing in scale and purpose, meets the diverse needs of all residents.

Key Functional Zones

- Open plaza – The bench arrangement allows for flexible use of the space.
- BBQ area – Designed with separate sections for four groups and a shared common zone.
- Children's playgrounds – A Lego zone and a web structure create an engaging play environment.
- Café – An enclosed space that enables comfortable rooftop use regardless of weather conditions.
- Park – A green area with flowing, curved shapes that enriches the leisure experience of residents.

Thus, the Tetris-Hall roof has become more than just a technical structure – it is a comfortable space for relaxation, work, and socialization, harmoniously integrated into the city's dynamic rhythm. Its implementation showcases the effectiveness of green roof concepts in modern urban development, creating an environmentally sustainable and attractive living environment.

Figure 14: Green roof in Kyiv, Ukraine

11.5. Case study in Spain

This section presents a curated list of real-world examples of buildings with green roofs from various parts of the world. Each example highlights the unique design, implementation, and benefits realised, demonstrating how green roofs contribute to energy efficiency, urban cooling, environmental improvement, and biodiversity enhancement. Through these case studies, we aim to illustrate the transformative potential of green roofs in creating more sustainable, resilient, and livable cities.

Isla Cristina City Hall

Location: Isla Cristina, Spain

Area: approx. 200 m²

Construction year: 2020

Architect/Planning: impermeabilizaciones Sinhume.

Applied system: Sedum-mix blanket

To improve interior thermal comfort and reduce energy consumption, a 200 m² green roof has been installed on the new town hall building in Isla Cristina.

Isla Cristina is located in the province of Huelva, in the south of Spain. It has a climate characterised by a high number of sunny hours per year and is one of the warmest areas in Spain. This makes it very important to reduce solar gains through the roof. Vegetative covers are highly effective in reducing solar gains. In particular, Sedum plants absorb up to 50% of solar radiation and reflect 30%, maintaining their temperature close to that of the surrounding air. Many species of Sedum originate from the Mediterranean region, making them well-adapted to the conditions of this locality. Due to their natural properties, they require little maintenance, water, and nutrients, making these plants ideal for dry and/or cold areas where water may be scarce.

This ecological solution helps create a cooler and more pleasant indoor climate, thanks to its high thermal insulation capacity. Consequently, the air conditioning system can operate with less intensity, resulting in energy savings.

11.6. Other case studies

Harbour building

Location: Roscoff, France

Area: approx. 1300 m²

Construction year: 2014

Architect/Planning: designed by Archus and built by Serneke.

Applied system: Sedum-mix blanket

A multifunctional building was constructed in the port of Roscoff, France, housing a restaurant and a fishing club, among other things. In 2014, a green roof was installed, featuring Sedum-type vegetation known for its ability to adapt to the variable conditions of the oceanic climate. This green cover is easy to maintain and protects the roof material from adverse weather, extending the roof's lifespan for many years.

The building also features a wooden bridge that runs over the green roof, offering beautiful views of the port, the sea, and the deck itself.

LIDL Headquarters, Sweden

Location: Stockholm, Sweden

Area: approx. 4000 m²

Construction year: 2021

Architect/Planning: designed by Archus and built by Serneke.

Applied system: Sedum-mix blanket

In recent years, Lidl has upgraded several of its stores with green roofs as part of its ongoing sustainability and environmental protection strategy. The new headquarters office building in the Stockholm region, which will initially house more than 400 employees, as well as the adjoining store, have been designed to meet the wishes and needs of the German supermarket chain. The roof is covered with greenery that enhances comfort conditions and reduces the building's energy consumption, while also serving as a habitat for insects and small birds. This new headquarters has received the BREEAM Excellent environmental certification.

AMPO Headquarters

Location: Idiazabal, Spain

Area: approx. 6000 m²

Construction year: 2018

Architect/Planning: LKS KREAN.

Applied system: Urbanscape Green Roof System

The AMPO Group, an international leader in stainless steel and high alloy foundries, inaugurated its new facilities in Idiazabal on October 17, 2018. The project, which was completed in 24 months, was designed and built by LKS KREAN.

The building merges the concepts of industry and nature, envisioning it as a forest capable of hosting different inhabitants, uses, and scenarios, all contributing to a living and sustainable ecosystem. The envelope of the building incorporates natural concepts, with the roof materializing in a green roof that enhances energy efficiency and interior thermal comfort.

The green roof covers an area of more than 6,000 m² with Sempergreen Sedum-mix blankets. It is equipped with an Urbanscape green roof system, a lightweight green roof system with high water retention capacity. This green roof system weighs only 65 kg/m² when fully saturated, making it an ideal lightweight solution for any type of roof. It is capable of reducing stormwater pressure on the local sewer system by almost 60%, depending on annual rainfall.

Lagoh Shopping Centre

Location: Seville, Spain

Area: approx. 10,000 m²

Construction year: 2019

Architect/Planning: L35 Arquitectos, S.A.P., Madrid

Client: Grupo Lar, Madrid

Realisation: Viveros Olimpia S.L, Sevilla and Ancoma S.L., Sevilla

Applied system: ZinCo® Pitched roof with Floraset® FS 75

The green roof of approximately 10,000 m² of the Lagoh shopping centre provides climatic, visual and environmental benefits, by increasing biodiversity and reducing the carbon footprint in addition to increasing the feeling of comfort and well-being.

Because the roof is inclined, commercial elements appropriate for this type of roof were used, such as the Floraset® FS 75 drainage element, which was used on the entire surface, being ideal for stabilising the substrate in the areas of inclined roofs, preventing its erosion. The TRP 140 profile was used to create retention barriers by distributing the thrust forces.

Al Shaheed Park, Kuwait

Location: Kuwait, Kuwait

Area: approx. 19.500 m²

Construction year: 2014

Architect/Planning: TAEP, The Associated Engineering Partnership, Kuwait

Applied system: Stabillodrain Stabilodrain® SD 30

"Al Shaheed Park" is located on the country's oldest ring road on the periphery of Kuwait City. It is the largest city park in the country. It was primarily built to protect the city from sandstorms and to reduce air pollution. Additionally, the park is meant to commemorate the victims of the first Gulf War, as "Al Shaheed" means "Park of the Martyrs."

As part of the redesign, an artificial lake was situated in the center of the park. This feature is not only a landscape element but also serves as a water reservoir during the hot season. The park accommodates two museums, a visitor's center, an underground garage with 800 parking spaces, restaurants, and shops. To maintain the continuous park character, most of the buildings were equipped with accessible green roofs. Despite the well-chosen vegetation, these still need to be irrigated.

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12. Communication dimensions of the green roof concept in social discourse: a view from Ukraine

The acceptance of any idea in society begins with a social dialogue. The key actors in this dialogue are those who have a sufficient level of social significance for the audience, and their success depends on the extent to which the arguments for a new idea or process meet social needs and reflect general humanistic trends. The concept of green roofs has become the occasion for a broad social discussion, the participants (actors) of which were representatives of the scientific community (from ecologists, biologists and chemists to specialists in administration and social dimensions of community activities), business representatives, NGOs, social activists, etc. The level of discussion about the appropriateness of introducing the idea of green roofs has become so strong that separate programmes and projects have emerged to promote and implement various components of the concept, from the emergence of new specific objects to the formation of a communication field in the social discourse on the need to develop and support urban greening based on this concept.

The study of the key areas of social debate on the implementation of the green roof concept has two key objectives: the first is to identify how often new ideas, theories, conceptual solutions and processes for implementing the concept appear and articulate the processes of implementing the concept; the second is to identify which information or technological categories are less articulated in social discourse and require rethinking and greater communication activity to implement the idea of green roofs in Europe and the world as a whole.

To solve these problems, we will provide a brief overview of approaches to covering the issue of green roofs in the field of science, business and NGOs. Our study is based on the material of Ukrainian sources, but the analysis of these sources suggests that the communication model of popularising the concept is more or less universal and can reflect the state of communication articulation of the problem of green roofs in general.

The scientific understanding of the problem is mostly presented in the works of natural scientists, which focus on the typology of green roofs and the formation of approaches to creating real projects, taking into account modern scientific achievements and purely technological approaches. It is worth noting that natural scientists also focus on business and economic categories, projecting the possibilities of social change and transformation if the concept is implemented, so we will mention some studies in the part of the paper that deals with these aspects.

The approach to the selection of scientific papers used in this material is not so much intended to absolutise and reflect all Ukrainian research on green roofs, but rather to reflect the directions and aspects of social discussion, to reveal certain areas that are indicative of the implementation of the green roof concept in society. Therefore, the materials mentioned here will reflect the scientific diversity of approaches and views to a greater extent, which will make it possible to fulfil the second objective of this work - to reflect the information niche and form promising trends in the communication development of the green roof concept in social discourse.

The first study worth mentioning was published in Ukraine more than 10 years ago (Bogun K., 2013) and aims to scientifically qualify the benefits of roof greening. The researcher consistently and fully lists technical, social, economic and environmental benefits with reference to previous sources and studies where these aspects are presented more fully. From the point of view of the communication value of this material, we will define two aspects: the formation of a generalised picture of the feasibility of implementing the green roof concept and the structuring of the benefits of implementing the concept in real projects in the sequence indicated above. It is important to note that the technical benefits, including solving the problem of cooling (air conditioning) of premises, noise reduction, heat island effect, and protection from ultraviolet rays, succinctly express the scientific discourse of the problem within a brief statement that reflects and summarises scientific research from previous years. The researcher puts social benefits in second place, although she only touches upon the problem of creating “additional space that can be used as a place for recreation” and creating “a positive effect from people’s contact with nature”. This level of understanding of the problem indicates that in 2013 and in previous years, at least in Ukraine, the issue of green roofs as a platform for social activity and community unity in environmental issues and the creation of a comfortable living space was not properly actualised and presented. However, later this problem became more clearly articulated. The economic and environmental benefits of green roofs actually repeat the approaches of previous natural science studies and reflect a global trend.

An interesting conclusion of the study is that, despite its generally naturalistic approach, it appeals to social processes: “Due to the fact that green roofs in Ukraine have not yet gained due popularity among developers and individuals, their promotion, as well as green technologies in general, should be carried out with the participation of local authorities and public organisations. Regulation of this issue should begin with the consolidation of relevant tasks in the Urban Development Strategy, and be detailed in socio-economic development programmes or relevant individual programme documents” (Bogun K., 2013). This statement, as well as the generalised list of green roofs advantages, give grounds to highlight the basic position of the communication model of reflecting the concept of green roofs in scientific discourse: already in 2013, the expediency of creating green roofs was formed and substantiated, their typology was outlined, the requirements and features of implementation were determined, and the complexity of the problem was warned about, which requires not only technical (or technological) solutions, but also correlation with legal and social initiatives that can be implemented at the local authorities level or a higher, national, level.

Next, we will look at a number of studies from the last three years to prove the previous thesis: scholars are more detailed in the key scientific concept of green roofs, studying the features of individual elements or structures of the system, forming the basis for the implementation of specific projects, etc.

An example of such studies is the work of A. Hrechko (Hrechko A., 2022) and O. Rybak, I. Patseva (Rybak O., Patseva I., 2023, Rybak O., Patseva I., 2024). These studies raise the problem of implementing individual green roof projects from the point of view of selecting seed material, although the authors state the problem more broadly and emphasise the advantages and feasibility of introducing green roofs in Ukrainian cities.

At the same time, it should be noted that the opinions of researchers coincide in terms of the implementation of this problem. A. Hrechko writes: "The implementation of green roof technology in different countries has different features, but the common thing is that when choosing plants, it is necessary to use local plants that are adapted to the climatic conditions of a particular area, and a legislative framework is needed to develop this idea. Given all the benefits of using this technology, their implementation is a necessity for adaptation to climate change" (Hrechko, 2022, p. 32). The same thesis is continued by O. Rybak and I. Patseva: "...from an environmental point of view, even for roof gardening, it makes sense to use seeds of wild plants and planting material of local origin" (Rybak O., 2024, p. 170). From the point of view of analysing the communication model, we have to state that ideas and approaches to the implementation of the green roofs concept are repeated in scientific discourse, which, on the one hand, indicates sufficient awareness of the problem, and on the other hand, that the concept has become quite firmly "rooted in the scientific environment". As an illustration, we can cite another thesis by A. Hrechko, which correlates with the above-mentioned study by K. Bogun and previous studies presented in the European academic discourse: "Green roofs as elements of green infrastructure provide certain ecosystem services – the main one is the reduction of the urban heat island" (Hrechko, 2022, p. 39).

Another area of modern scientific research on the green roof concept is the formation of specific conditions for project implementation or the formation of technical approaches in a particular location. For example, consider the article by I. Patseva and her colleagues, which analyses roof greening as a way to adapt to climate change for a specific city in Ukraine that is Zhytomyr (Patseva I. et al., 2023). The study analyses the chemical composition and features of substrates for green roofs, taking into account the climatic characteristics of the city of Zhytomyr, the researchers state that at the time of writing there are no green roofs in the city, but there is a need to implement this concept, given the environmental and economic factors. The researchers experimentally substantiated the need and feasibility of using substrates for planting plants on roofs (including the chemical composition of the substrates) based on the city's climatic conditions. Such studies are interesting because, on the one hand, they offer real tools for implementing the concept, and, on the other hand, they show that there are experts in different locations around the country who can provide a scientifically sound approach to project implementation and thus make these projects successful.

From the standpoint of the communication model, we have to state that such studies form a picture of the future, create the basis for the implementation of green roof projects, and therefore define a clear outline of possible future projects. Another communication conclusion from this text is that the scientific theory of green roofs has been sufficiently developed and accepted both in the scientific community and in society, so much so that further research is focused on specific problems or narrow technological aspects of implementing this concept.

Another example and confirmation are the project by Eliza Repetatska (Repetatska, 2023), a graduation project by a student of a natural science specialised university that raises the issue of green roofs for another Ukrainian city which is Vinnytsia. We have to draw an important conclusion for the formation of a communication model of green roofs in social discourse: the relevance of the green roof concept is determined by the interest of young scholars in the problem, which, by the way, was pointed out in the study by the aforementioned K. Bogun back in 2013, when she identified competitions and projects of young architects, researchers, and public activists as one of the ways to promote the concept. Such studies are not uncommon and convincingly prove that the concept of green roofs is understood and supported by socially active youth.

This short chapter cannot analyse the structure of scientific discourse with a detailed focus on research directions and results, but it is possible to state the individual components of the communication model and the key features of its formation. Several conclusions that are important for the communication model: scientific understanding and research of the conditions for the creation, maintenance and functioning of green roofs as an ecosystem and technological object are fully and thoroughly represented in the scientific discourse, repetitions and references to the research of predecessors show the exhaustiveness of this topic, at least at the current stage of its scientific study.

The attention of researchers is mostly drawn to the partial peculiarities of implementing the concept of green roofs and creating conditions for specific local spaces. These conclusions can be applied not only to natural science research, but we will now turn to works that actualise the problem in the economic and social dimensions, and we will consider media publications alongside scientific research. We can preliminarily state that scientific argumentation, theoretical approaches to justifying business decisions and conceptualising approaches do not go beyond the specified environmental, economic, and technological advantages, which is an example of understanding the current, existing theory in certain economic or social conditions. Understanding the scientific discourse on green roofs as the basis and foundation for further economic and social initiatives, we must state that the scientific argumentation for the need for green roofs is not only clearly formulated, but is also actively articulated in concepts and projects that have clear business or social priorities.

An example of a profound combination of scientific approaches and economic arguments is the article by L. Herasimchuk and her colleagues on the real efficiency of using the green roof concept to generate profit and social and environmental benefits. The authors, based on mathematical analysis and calculation of heat and energy savings, reduction of carbon dioxide emissions, carbon sequestration, nitrogen dioxide absorption and noise absorption, as well as on the analysis of the increase in the average annual rental price of housing under a green roof, concluded: “A green roof provides a number of environmental benefits. The cost of installing a green roof will vary depending on the type of roof, climate, and building regulations. However, the long-term savings and environmental benefits can justify the initial investment. Green roofs provide a variety of financial benefits to the construction industry: increased energy efficiency, longer roof life, effective stormwater management, improved air quality, increased property values, and financial incentives. These benefits, combined with the positive environmental impact, make green roofs an attractive option for environmentally sustainable construction projects” (Herasimchuk L. et al. 2024, p. 48).

Similar ideas and conclusions have been expressed before, however, without a detailed calculation of the effectiveness of the green roof, for example, in the article by D. Nikolchenko and S. Ryndiuk, the environmental, economic benefits of green roofs and the commercial efficiency of their use are analysed, in particular for “...creating various kinds of landscapes and landscapes on the roof; additional space for people to relax (sports ground, café, bureau); increasing the cost of the upper floors, as well as the entire structure, by up to 30%" (Nikolchenko D., Ryniuk S., 2019). The same concepts and understanding of the economic attractiveness of greening technology can be observed in the works of K. Bogun and A. Hrechko: "Green gardens can be both non-commercial and commercial infrastructure facilities, the territory of which can be leased for cafes, restaurants, etc., which is an additional incentive for property owners to implement such projects" (Bogun, 2013); the use of green roofs as a lever of economic nature is also considered by A. Hrechko, pointing to the example of Poland, where the use of green roof technology gives "...grounds for allowing the developer to do larger projects, because green roof technology compensates for environmental damage" (Hrechko, 2022, p. 38).

The concepts outlined above show that over time, researchers are moving from simple statements of economic direction to specific calculations and calculations, thus forming effective tools for designing business solutions and strategies. The scientific discourse on business concepts of green roofs in communication terms already forms practical approaches, ready-made models for implementation, and can offer real tools and arguments that promote the widespread implementation of the green roof concept in industrial and residential construction. It is worth adding here the aspect of optimising building codes and standards, which is mentioned from time to time in the illustrations of scientific understanding of the green roof concept we have provided and in other works.

The category of business arguments for the appropriateness of green roofs also includes publications in the media. Objectively, we can distinguish two types of publications: those initiated by business (or with a focus on business that is interested in making the idea of green roofs attractive) and those aimed at meeting the social need to inform about the issue.

The first type of publications includes those that point out the problems of economic attractiveness and new forms of implementing the green roof concept, for example, the article "Rooftop Garden: How Roofs are Greened in Ukraine and Around the World" raises the issue of using the roofs of industrial buildings, and the arguments provided by the business representatives involved (top employees of the private company "ZinCo", which is directly involved in the creation of green roofs) are mainly aimed at technological and, therefore, economic benefits, for example: "The main problem why industrial roofs are not greened in Ukraine is the lack of understanding that by arranging a green roof using the right technology, you can completely forget about repairing the waterproofing" (Rooftop Garden, 2016). At the same time, the authors also actualise the solution of environmental problems and the creation of new social perspectives using the concept of green roofs.

Another type of articles is informative and aimed at a general readership, while also containing arguments that may be of interest to small businesses. For example, the article "Green Roof – Efficiency + Ecology!" (Green Roof, 2019) points to the possibility of using green roofs for agricultural activities, which is clearly only one narrow area whose effectiveness remains in question, but if we add to this idea the problem of greening industrial areas, where large areas can be used, this area may also have local effectiveness.

The general conclusion about the media articles is that they are aimed at making a business case for green roofs – offering concepts and tools that indicate the economic attractiveness of projects, highlighting the need for investment and cost savings through green roofs in residential and industrial construction. There is also an emphasis on the development of appropriate standards and approaches to construction, taking into account the possibility of creating a green roof.

In media texts, it is worth emphasising another aspect that is aimed at intensifying the activities of NGOs and civic initiatives in general. To illustrate this, let us quote a few words from the aforementioned article "Rooftop Garden: How Roofs are Greened in Ukraine and Around the World", which is quite complete and comprehensive and has absorbed a significant number of components of the communication argumentation of the green roof concept: "Unlike our more successful western neighbours, green roof technology has not yet reached a large scale in Ukraine. While there are more and more customers who want to have a garden on the roof of a private house, such greening of industrial areas or shopping centres is not popular. Nevertheless, art clusters are emerging in Kyiv (PLATFORM art factory, G13), as well as entire shopping centres that could revitalise public spaces with roof gardens"; "...however, the customer's desire is often not enough, unlike in the US or the EU, where city municipalities encourage or even help financially with the creation of green roofs, the Kyiv authorities are currently passive on this issue"; "...there are many areas in Kyiv, including among industrial facilities, where you can create public spaces, make them convenient and comfortable to use. One of the ways is to arrange a "green roof" (Rooftop Garden, 2016).

These theses demonstrate the need for a social articulation of the problem, the creation of movements and initiatives that would contribute to the development of the process of creating green roofs, form new aspects in the understanding of the concept of "comfortable urban life", and become a source of processes that would influence the greening of not only the roofs of residential buildings, but also other locations that create the landscape picture of the city. The material cited was written and published in 2016. Our search for media coverage of social initiatives or civic activities in this area did not yield any encouraging results. This may indicate the passivity of communities (at the level of involvement in the creation of green roofs) or insufficient media activity in reflecting such activities. The Russian war against Ukraine also became a significant obstacle to the development of green roof culture in Ukraine.

At the level of the communication model, we can state that the demand for green roofs has not yet become tangible, not only in terms of evaluating real projects, but also in terms of measuring the possibility of creating such projects. All of this indicates the need for more complete and expressive social communication about the concept of green roofs, the formation of approaches in which communities, community activists would recognise themselves as subjects of initiatives to create green roofs, improve the quality and comfort of life, and create new attractive locations in Ukrainian cities.

Conclusions and Observations. A cursory analysis of publications and articles presenting the concept of green roofs in Ukraine shows a fairly complete picture of how the concept is reflected in social discourse. University scholars, journalists, businesses, and public activists carefully and consistently qualify the environmental, economic, and social benefits, identify the need for specific green roof projects, and highlight the role of these processes in the overall context of the attractiveness of places where people live.

At the same time, as our brief review has shown, there is currently a lack of a communication strategy that would bring together different stakeholders to increase green roofs in the European Union member countries today and in European states that will join the EU tomorrow. Such a strategy should combine different levels of providing opportunities for green roofs: we consider it promising to have activities and their reflection in the media discourse in the areas of community and NGO activity, support for green roof projects by city authorities, up to inclusion in city development programmes (strategies), and the formation of support and benefits at the state level that would make green roofs attractive already at the design stage of new industrial or residential buildings. Once again, these activities will only make sense if they are systematically and consistently reflected in the media discourse, as the scientific and economic feasibility of the green roof concept has long been substantiated and proven, though it has not become the subject of a conscious need for implementation, in our opinion, due to the lack of communication articulation of the concept.

The general model of this strategy may look like this: to bring together stakeholders – city authorities, businesses, communities, and NGOs – through communication within specific projects. It is worth noting that, along with environmental and economic benefits, this will create an effective social background in the city, raise its tourist rating, promote new prospects and opportunities, and, for example, make university infrastructure a more comfortable environment for students and faculty members and administrative staff, for studying and working.

In our opinion, the role of communities and civic activists in the processes of communicating the green roofs concept in each particular city is underestimated; we see the need to actualise their media and socio-political subjectivity in the issue of creating comfortable and environmentally friendly living conditions, one of which is green roofs.

The study of the social effects of implementing the green roof concept is also insufficient today. We do not deny that such research is being conducted, but it has not gained popularity or sufficient social articulation as a model of effective social and environmental solutions, the basis for which may well be the green roof concept, at least these issues are not clearly visible in the media.

A potential source for such studies may be the approaches of a fairly new scientific field – social urbanism, and we see the advantage of this approach in the opposition of contexts: from the "Broken Window Theory" of James Q. Wilson and George L. Kelling to the "Nudge Theory" of Richard H. Thaler and Cass R. Sunstein, especially since awareness of the role of local social groups in creating comfortable and attractive living conditions in Ukraine, as well as in Europe as a whole, is a significant component of social activity. We are convinced that with the right communication articulation of these processes, more and more green roofs will appear in the city after the appearance of one.

13. References

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