Nature-Based Solutions as a Strategy for Adaptation to Climate Change

NEW ENERGIES FOR THE CITIES

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Alessandro Rogora and Paolo Carli

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PART II

SYSTEMS AND TOOLS FOR ENVIRONMENTAL EVALUATION, AND MODELLING

Nature-Based Solutions as a Strategy for Adaptation to Climate Change

Roberto Giordano

Nature-based solutions (NBS) are 'solutions' for urban infrastructures that use greenery to address complex challenges related to the effects of climate change at the urban scale. From forests to Living Wall Systems (LWS), NBS integrate vegetation and urban materials.
In addition, within several frameworks, including urban planning and building detailing, NBS offers multiple environmental, social and economic benefits. With a focus on climate change adaptation, NBSs mitigate the urban heat island effect and improve stormwater management.
The chapter describes the results of a research study on the design and construction of an LWS. Some of its physical, technological and agronomic performances were monitored over about two years.
Based on the achievements, the chapter, finally, highlights some critical issues that must be addressed to promote and disseminate NBSs, particularly LWSs in the future.

The Nature-Based Solutions

A Nature-Based Solution can be defined as urban infrastructure based on greenery to simultaneously tackle sustainability challenges by maximising the benefits of nature (Sowińska-Świerkosz et al., 2022; European Commission, 2015; European Commission, 2022).
Nature-Based Solution encompasses many possibilities, ranging from urban and peri-urban forests to Living Wall Systems (to be understood as vertical enclosures or partitions that allow the rooting and growth of one or more plant species on its surface) (Dorst, H., 2019).
This means some Nature-Based Solutions are wholly and entirely made up of plant elements. In contrast, others require the integration of vegetation and materials, which, once fully integrated, make up a technology (i.e., a green roof solution). The materials perform several functions, such as filtration, control of root growth, drainage, and waterproofing. (Figure 1).

A Nature-Based Solution is used in several fields: i.e. urban planning, agriculture, water management, and infrastructure development.
The scientific literature provides an articulate picture of Nature-Based Solutions' features and properties.
First, Nature-Based solutions aim to provide many benefits concurrently, addressing multiple environmental, social and economic issues. For example, wetland renewal improves water quality and provides a habitat for wildlife and recreational opportunities for people (Sowińska-Świerkosz et al., 2022; Jessup, K. et al., 2021).

Figure 1. Examples of Nature-Based Solutions' integration in urban settlements. Author's source.

Besides, Nature-Based Solutions recognise the importance of local knowledge and empower communities to participate actively in decision-making processes. In other words, it emphasises community engagement and cooperation among several stakeholders (Adams et al., 2023; Wickenberg et al., 2022).
Finally, Nature-Based Solutions enhance the resilience of the natural and built environment to some climate change effects (Xi, 2022), as is also better described in the next paragraph.

Nature Based-Solutions as a strategy for climate change adaptation

Adapting cities to climate change means implementing a certain number of strategies to maintain a comfort and safety threshold in terms of temperature, rainfall, humidity, etc., that will no longer be the same in 20-30 years.

Looking at a City such as Milan in 2050 that will have a similar climate pattern to the City of Denver (Figure 2), there is no doubt that a gradual renovation of both outdoor and indoor environments will be necessary to maintain acceptable ecological and social standards (Bastin, 2019).

By reinventing or renovating the urban environment with Nature-Based Solutions, it is possible to turn cities and neighbourhoods into "urban ecosystems" that contribute

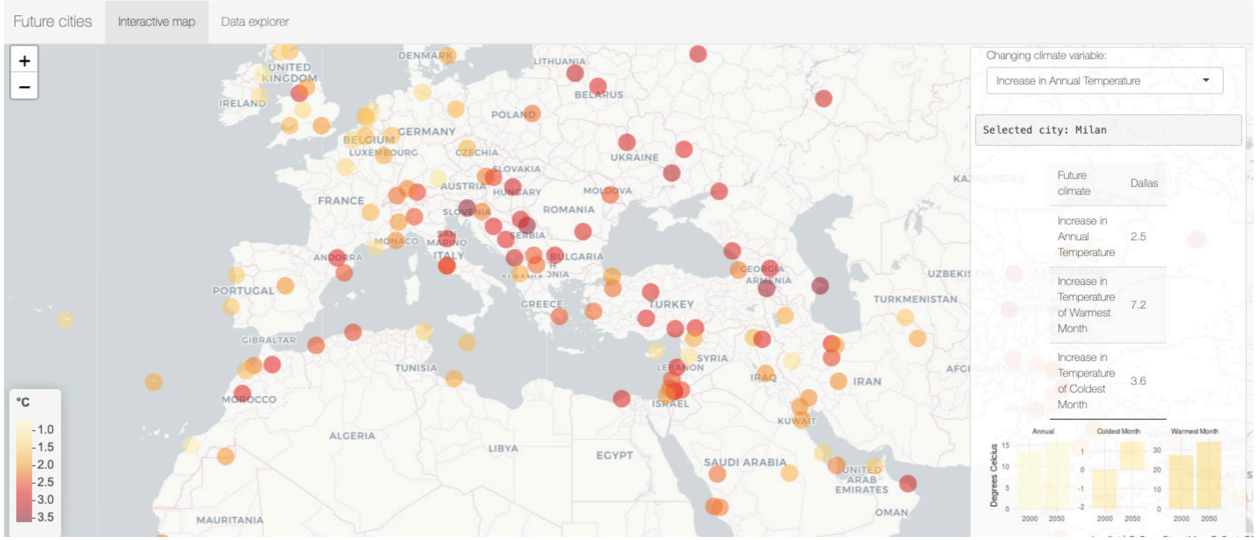

Figure 2. The City of Milan is changing in climate projection by 2050. The expected increase in temperature is about 7.2 °C more than in 2019. (source: https://hooge104.shinyapps.io/future_cities_app/)

to climate change mitigation and adaptation. Nature-Based Solutions' role in climate change mitigation is mainly due to carbon sequestration. Particularly grasslands, wetlands, and forests (including urban forests) can capture and store atmospheric carbon dioxide through photosynthesis. Trees, in particular, are highly effective at carbon sequestration (FAO, 2016; FAO, 2020).

Nature-Based Solutions are a particularly effective climate adaptation strategy, as they can extend shaded surfaces and the evapotranspiration processes in the urban landscape. Simultaneously, they are suitable for reducing building enclosures' surface temperature and helping the rainwater drainage of collection systems. (FAO, 2016).

The effectiveness of Nature-Based Solutions (Figure 3) for climate change adaptation can be approached from several perspectives (IUCN, 2021). Particularly in the urban landscape, Nature-Based Solutions can be used for the following goals:

- **Urban resilience fostering.** By restoring, maintaining and planting forests, wetlands, and greenery, cities increase their ability to resist some climate-related events like heavy rains, floods, and droughts.
- **Urban Heat Island (UHI) mitigation.** Urban areas are particularly exposed to heat waves and increased temperatures due to the UHI effect (Xi, C. et al., 2022; Candelari E. et al., 2014). Nature-Based Solutions can mitigate the UHI by reducing the temperature locally and providing cooling benefits for citizens.
- **Rain Water management.** Nature-Based Solutions can contribute to effective rainwater management, regulating

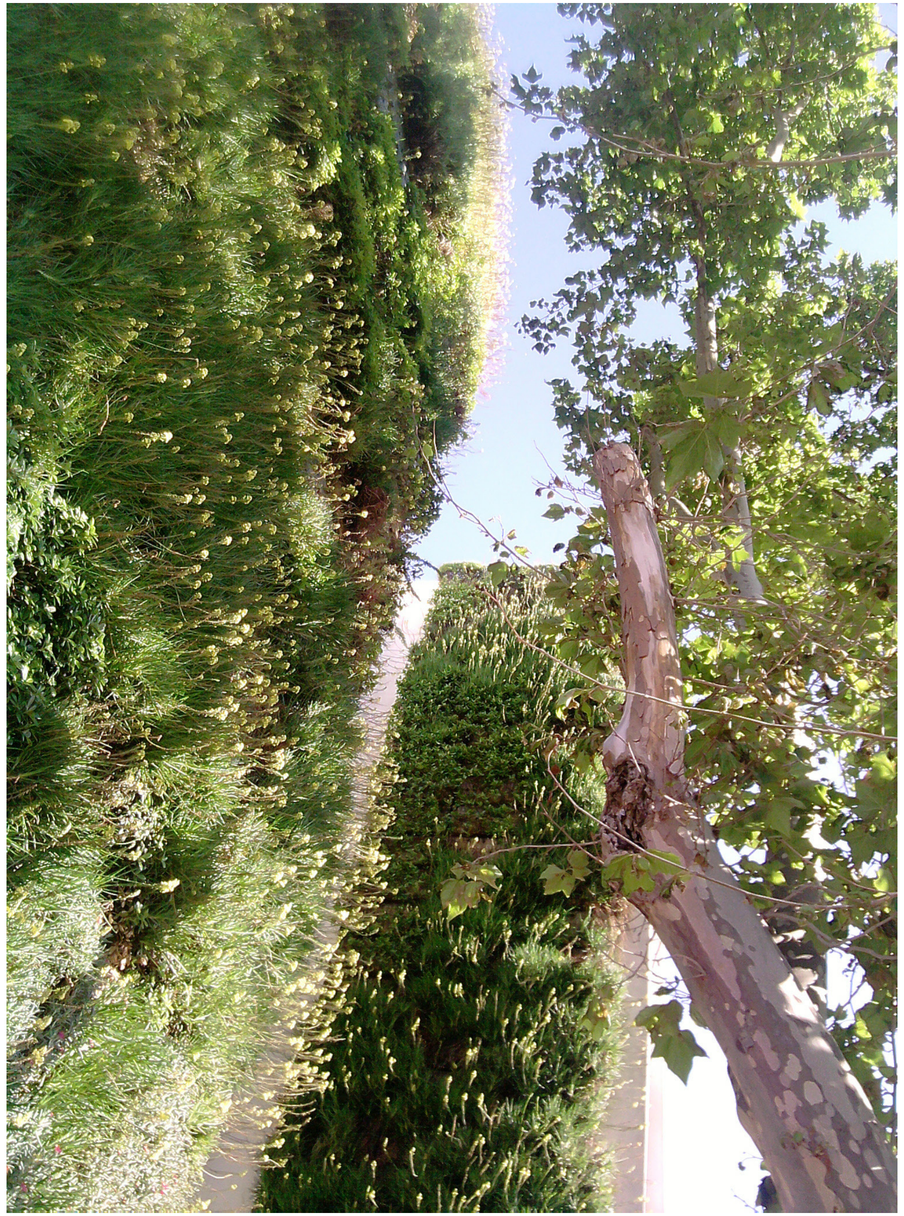

Figure 3. City of Valencia. Example of an integration of Nature-Based Solutions in the urban habitat.
Author's source.

water flows, filtering water, and reducing the risk of floods. They can also enhance water availability during dry periods and recharge groundwater reserves.

Table 1 summarises the significance of trees and greenery for climate change mitigation and adaptation in the urban landscape.

As shown in Table 1, vegetation - regardless of its design - is a compelling adaptation solution to climate change.

Table 1. Significance of urban forest type for climate change. Author's elaboration from the book Guidelines on Urban and peri-urban forestry.

Nature-Based Solutions	Significance on a scale of 1 to 5 (1 = very low significance; 5 = very high significance)	
	Climate change mitigation	Climate change adaptation
Peri-urban forest and woodlands	●●●●●	●●●●●
City parks and urban forest (> 0.5 ha)	●●●	●●●●●
Pocket parks and gardens with trees (< 0.5 ha)	●	●●●●
Trees on streets or in public squares	●●	●●●●
Other green spaces with trees and greenery (i.e. green roofs, green walls)	●●	●●●●

Living Wall Systems and climate change adaptation

The Technology and Environment research team of the Politecnico di Torino carried out some research projects in Nature-Based Solutions. One focuses on Living Wall Systems and some related environmental performances that were investigated and monitored.

Living Wall Systems is a specific vegetated façade solution for a building. The Living Wall Systems' features can be summarised as follows (Giordano et alt., 2017; Riley, 2017):

1. They generally include a modular or container system containing the plants and growing medium. Living Wall Systems are often fastened directly to walls and require a specific frame or vertical and horizontal mullions to support the plant and growing medium's weight.
2. They usually incorporate irrigation to water and provide plant nutrients.
3. They commonly have a higher planting density compared to green walls. The species are carefully planted, making dense vegetation on the wall.

GRE_EN_S (GREen ENvelope System) is the acronym of an EU-funded research project that was aimed at designing, prototyping and monitoring an advanced Living Wall System designed with modular container covered with vegetation, made of recycled and natural materials and characterised by a high-energy/environmental performance (Serra et al., 2018). Among other specific objectives, the research project aimed to assess the potential of the Living Wall System as an adaptation solution to climate change-related environmental effects, namely the UHI.

GRE_EN_S was divided into phases that dealt with the following tasks:

- the survey of existing Living Wall Systems solutions;
- the material sorting for the modular system (container) and the growing medium;
- the design and construction of prototypes;
- the assessment of technological, agronomic, and thermal and acoustic performance on a test cell and a sample building in Turin. (Figure 5).

Three Living Wall System prototypes were designed and built. The third and last prototype was a 50 by 50 cm module, about 6 cm thick (without vegetation). Each module had six pockets arranged in two lines to contain the plants. The module also had a few holes to allow the watering system to pass through. Once the prototype was verified to operate correctly on the test cell, the research team built around 90 modules, 80 of which were installed onto the sample building.
The sample building was aligned along the east-west axis, allowing it to have a south and a north façade. The absence of obstructions around the building permits, especially on the south façade total exposure to the sun in both the summer and winter seasons.

Figure 5. The GRE_EN_S sample building is located in Turin (I). Latitude: 45°04'13". The picture shows the building's surface temperature sensors.

Figure 5 shows a building divided into two independent portions. The first (left) is the Living Wall System developed within the GRE_EN_S project. The second (right) is an insulated wood-clad façade. Both facades have the same theoretical U-value. The two sample building portions were equipped with radiant heating panels with temperature sensors for the winter period.

The monitoring was carried out for 18 months (2013-2015), covering two summers and one winter season. It has been handled by an interdisciplinary team organised as follows:

- The building technology researchers have investigated the water needs during the summer months (L/m² per day of water) and have checked, through regular inspections, for possible failures of materials and components.
- The agronomists have analysed the leaf apparatus of the plant species selected for the sample building (Leaf Area Index - LAI).
- The energy department researchers have monitored the surface temperature of south and north-facing façades (T °C).

The monitoring reports the following findings. It was checked that the water requirement in the hottest period (June to September) is at most 2 L/m² per day. Such value is less than that of an extensive green roof in a Mediterranean climate, for which an average daily water requirement is ranged between 2.6 and 9.0 L/m² per day (Pirouz, 2021).
Although the Living Wall System cross-section is only a few centimetres, thus enabling a small growing medium, the plant species tested (Bergenia crassifolia, Heuchera and Lonicera nitida) did not show any stress, keeping the LAI comparable to an analogue species, planted in soil, under the same climate (Serra et al., 2018).

The measurements in the summer season were carried out in free-floating conditions.

Free-floating conditions helped assess the surface temperature of the sample building walls in the absence of summer air-conditioning services. The outdoor surface temperature was measured on the south and north façades (Living Wall System vs wood cladding).
Particularly the peak temperature difference between the Living Wall System (covered with Lonicera nitida) and the wood cladding wall was found to be 23°C on the average sunny summer day, i.e. the daily hourly average temperature (24h) calculated in July. Such temperature variation is mainly due to the vegetation's evapotranspiration processes. Relative temperature differences were also found with the other plant species tested.

Achievements
The research shows that a Living Wall System with a module thickness of only a few centimetres (6 cm) can be recognised as a suitable technology to improve the adaptation of buildings to the effects of climate change in cities. The Living Wall System reduces the wall surface temperature, thus mitigating the Urban Heat Island (UHI).
However, the Living Wall System's thickness of a few centimetres (excluding the plant part) has another strength. The extra thickness of a wall does not usually exceed 10 cm (counting the 6 cm of the Living Wall System and the air space between the vegetated side and the wall outer side where the irrigation system is installed); this means that the Living Wall System typology, designed and developed within the GRE_EN_S project, has undoubtedly some potential for installation on new buildings, but above all, it is suitable for being easily integrated on existing buildings.
Based on the findings over the 30 months the sample building was monitored, leaf growth was not reduced by the small amount of growing medium in the modules' pockets. The drip-irrigation system, where nutrients were diluted daily, provided a little vegetative suffering (observed on three modules of 80) and good pest resistance.

During the monitoring, leaks in the irrigation system occurred a pair of times (mainly due to some installation difficulties during the construction of the sample building). However, these leaks did not cause any particular inconvenience to Living Wall System’s functions. This is due to the air gap, which keeps the plants and the module away from the wall part, the reverse assembling modules’ construction techniques, thanks to the bayonet mount to the aluminium frames, and, mainly, the small amount of irrigation used to water the Living Wall System (an annual average of 1.2 L/day/m^2), which avoids any stagnation processes.

No studies on the drainage capacity of the Living Wall System (i.e., its ability to retain rainwater for a prolonged period) were conducted as part of the research. Later studies (Boano et al., 2019; Prodanovic, 2019) conducted on Living Wall Systems with similar features to those described in this chapter have, however, demonstrated the potential capacity of plants and growing medium to remove certain substances, in particular nitrogen, usually contained in grey water and rainwater.

These scientific findings highlight another Living Wall System benefit from being considered once again as a solution to improve the climate resilience of the urban habitat.
In many geographical regions, long-term droughts are frequent, followed by extreme weather events during which many millimetres of water are released onto the ground quickly (from 15 minutes to an hour).
The first flush rainwater usually is rich in pollutants. These leach onto impervious surfaces (e.g. roofs and streets) and are rapidly carried to the sewage system without filtration. In some streets and squares, which are more exposed to certain pollutants, such as nitrogen dioxide (NO_2), green roofs, green walls, and Living Wall Systems could be placed to exploit their filtration and dilution properties.
Milan, for instance, has an interactive map that monitors the air NO_2 concentration, showing 50 by 50-metre pixel images. The map highlights the most high-risk city areas (https://www.cittadiniperlaria.org/dati-inquinamento-milano/) where the Nature-Based Solutions integration programmes could be launched.

Conclusions

Nature-Based Solutions, as pointed out by the European Commission, FAO and scientific literature, are technologies able to provide systemic benefits in the urban habitat. The outcomes described in the GRE_EN_S research also highlight the role of Living Wall Systems as an adaptation solution to tackle climate change. At the same time, it is also worth highlighting the constraints of Nature-Based Solutions

deployment, also reported in some of the mentioned papers. One in particular in these conclusions is appropriate to remark. Nature-Based Solutions are predominantly viewed by various stakeholders (citizens, planners, agronomists, politicians) as solutions intended to make the urban landscape more attractive perceptually. It is a correct aim but must be regarded as something other than the leading urban landscape design and construction standard.
Most cities worldwide have a non-negotiable and delayable need to "put into practice" the climate resilience targets in many domestic and international pledges, particularly the Paris Agreement.
It is necessary to make the stakeholders aware of the changing scenarios ahead and the potential of Nature-Based Solutions.
Widespread dissemination to inform stakeholders, including this book, is a chance to raise awareness. Let us hope it works.

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Urban settlements are constantly increasing, and we are approaching a point where over half the human population will live in cities. This human concentration gives rise to complex problems, ranging from pollution to difficulties providing resources to sustain the inhabitants' lives. This situation results in low resilience of urban settlements to events that may affect the territory and the settled society. The complexity of consumption patterns and the flows of energy and matter in transit (inflows and outflows) require a profound rethinking compared to the past, as these flows differ in magnitude and complexity. This book, New Energies for the City, represents an initial attempt to reflect on the complexity and specificity of urban metabolism, as well as on potential solutions to address and transform the identified critical issues into possible elements for mitigating problems. New Energies for Cities explores the challenges and opportunities related to the transition towards more sustainable and resilient cities, with particular reference to Milan.

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