Nature-based Solutions for urban forestry

Lorenzo Nofroni

Abstract: The chapter concerns the NbS grouped within the urban forestry (UF) approach defined as a strategic and flexible concept aimed at enhancing vegetation in open spaces within urban, suburban, and peri-urban areas. UF is not limited to woodlands but includes the entire vegetation network (street trees, parks, private gardens, infrastructure corridors) as an integrated system. The chapter analyzes six specific NbS that contribute to this strategy: afforestation, tree rows, vegetation cluster, tree plantation on paved surface, hedgerows and shrub strips, flower meadows. Each solution presents a brief description that concisely defines its characteristics and functionalities, a list of the most recurrent synonyms used in scientific and technical literature, a description of technical details with particular reference to Conditions (requirements, loads), specifications for Construction (built-up, layers, performance), and maintenance, and a section dedicated to Societal Challenges, organized into three categories: Biodiversity enhancement, Climate Resilience and Health, Well-being and Air Quality.

Keywords: Urban Forestry, Climate Change Adaptation, Open spaces, Climate Resilience, Green Infrastructure.

The contribution of urban forestry to urban biodiversity

Nature-based Solutions based on the establishment of vegetation in open spaces within urban, suburban, and peri-urban areas can be grouped inside an interpretive category for strategic and design actions referable to the concept of urban forestry. Indeed, the solutions presented in the remainder of the chapter contribute to the implementation of an urban strategy that, through the progressive enhancement of spaces hosting plant populations, aims to protect and strengthen the urban forest, understood as a peculiar wooded system integrated within the city. The result of a long definitional process, the urban forest is frequently considered a «flexible concept that includes tree-lined streets and groups of trees in urban parks, green belts between cities, and even woodlands far from the urban center [...] it occupies that part of the urban ecosystem constituted by vegetation and its natural resources» (Moeller 1977). In this sense, it can be imagined as the totality of plant species within and around urban settlements and includes, for example, vegetation present in both public and private areas; vegetation in parks and gardens, as well as that existing in infrastructural corridors (Miller et al. 2015). Internationally, it is common to refer to urban forests as a network or system that includes woodlands, tree groups, street trees, and individual trees found in urban and peri-urban areas, in parks and gardens, and also in abandoned zones (Salbitano 2016). In the national context, the term appeared since the early 2000s to define «the entirety of vegetation within urban, suburban, and the city-country fringe» (Sanesi 2002), which includes «residual agricultural land, natural spaces, tree-lined areas, avenues, gardens and parks of historic villas, municipal villas, allotments, riparian areas, groves, forest areas, road and railway buffer zones, uncultivated lands, etc.» (Agrimi 2013).

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Urban forests are conceived as multifunctional systems that play an important role in the ecology of human habitats, as they cause variations in climate and economy, are recreational places for city dwellers, and simultaneously represent refuge areas for wild fauna (Jiri Lev 2017). In this sense, it is common to assign a structural role to the concept of urban forest within the context of green infrastructure (Tzoulas et al. 2007). Linked to the broad concept of urban forest is a process-oriented dimension due to the effects on urban environmental factors attributed to the presence of vegetation; this dimension particularly refers to the field of studies on ecosystem services, which investigate vegetation structures with the aim of estimating the value of this component in the production of services within the urban ecosystem (Taylor et al. 2013). In this sense, urban forests «provide a conceptual framework to organize a research program to maximize the benefits that forests can bring to the improvement of urban environments» (Moeller 1977); this objective is at the heart of a strategic approach, usually called urban forestry, aimed at the creation, care, and management of the vegetative component of urban systems. Actions related to urban forestry are considered NbS as they contribute to the pursuit of an adaptive and dynamic urban strategy intentionally inspired by the processes and functions of forest ecosystems to address the social, economic, and environmental challenges of cities in an integrated manner (Sanders and Mc Curdy 2021; Castellar et al. 2021). Furthermore, urban forestry actions entail multiple simultaneous benefits, for example, an urban woodland or a tree-lined avenue can simultaneously regulate the microclimate, contribute to stormwater management, improve air quality, provide wildlife habitats, and offer recreational opportunities. In the international NbS catalogs, actions related to urban forestry are part of numerous documents and data collections, including Unlab, Nature4Cities, ThinkNature, Urbangreenup, and NWRM. Urban forestry and related actions are crucial for biodiversity conservation in highly anthropized contexts (Hutt Taylor et al. 2024) due to three main key factors:

- Urban forestry actions constitute habitats for wild flora and fauna, offer refuge, food, and nesting sites for numerous species, particularly for avifauna, supporting rich and diversified communities.
- Urban forestry actions contribute to ecological connectivity, connect isolated habitat fragments, facilitating species movement, maintaining genetic diversity, and strengthening the resilience of the entire urban ecosystem
- Urban forestry actions makes the living community itself more resilient; for example, a system of open spaces in an urban context rich in arboreal and shrub species more easily overcomes stresses derived from diseases, pests, climate change, and pressures from human presence.

Within the context of the Italian National Recovery and Resilience Plan (PNRR), among the interventions related to safeguarding air quality and territorial biodiversity (Intervention Line 3), specifically Investment 3.1 for the «Protection and Valorization of Urban and Extra-urban Green Spaces», the objective has been set to create urban, peri-urban, and extra-urban woodlands in the broad areas of the 14 Metropolitan Cities. Consequently, the Urban and Extra-urban Forestry Plan has been drafted to strengthen and systematize indications, criteria, and requirements, in order to provide a unified and coherent national reference framework for designing forestry interventions. Other important reference documents for urban forestry actions include:

- the National Biodiversity Strategy 2030 (Mi.T.E. 2023), within which a section of strategic objectives is dedicated to urban biodiversity, with particular reference to Action B10.1 Promoting Urban Greening.

- The National Urban Green Strategy (M.A.T.T.M., Comitato del Verde Urbano 2018), which includes three chapters of the strategic framework dedicated to urban and peri-urban forests, and particularly in the transversal lines of intervention, mentions: «increasing tree and green area cover moving from m2 to ha»; «increasing the plant diversity of urban forests in line with the territorial potential»; «Incentivizing Green Infrastructure projects to reconnect urban and peri-urban green spaces»; «connecting green areas into integrated systems based on the 'demand' for ecosystem services»; «considering tree-lined avenues and tree rows as 'linear parks' useful for the ecological connection of urban and peri-urban forests»; «promoting a more equitable distribution of green areas among different parts of the city».
- The Guidelines for Urban Green Management and initial indications for sustainable planning (M.A.T.T.M., Comitato del Verde Urbano 2018), containing criteria for green space design.
- Ministerial Decree No. 63 of March 10, 2020, for the Minimum Environmental Criteria (CAM) for public green space management and the supply of green care product.

Afforestation

Section A - General description

Fig. 1 – Urban woodland in Natur-Park Südgelände, Berlin (Source: Wiki Common, Autor: Jacobo.ka, 2015 CC By 4.0).

Description

Afforestation is an extensive areal intervention aim to the creation of areas covered with trees, associated with shrub and herbaceous vegetation, with an extension of no less than 5,000 square metres, with a prevalence of tree species that at maturity exceed 5 m in height and with a forest tree cover at maturity greater than 10% (FAO 2020). This action contributes to the creation of multifunctional systems that play an important role in the ecology of human habitats because they determine changes in the climate and the economy, are recreational places for city dwellers and at the same time represent refuge areas for wildlife (Salbitano et al. 2016). In this sense, it is recurrent to assign this action a structural role in the context of green infrastructure (Tzoulas et al. 2007). The intervention may include the maintenance and preservation of existing vegetation, with particular attention to spontaneous trees and shrubs and/or those resulting from the recolonization of abandoned or underutilized areas. The action may include interventions aimed at the creation of surface water regimentation, drainage and retention systems, carried out with low-energy input materials and technologies; paths made with natural filtering materials; elements for geomorphological management derived from local culture and tradition – e.g. dry stone walls – or made with naturalistic engineering techniques. Such forest transformations of the territory can benefit from landscape and forest protection conforming to property rights that prevent or in any case minimise the possibility of building, also prevailing over town planning instruments at municipal level. Given the same area availability, it is preferable to implement the solution in a geometrically regular plot, whose perimeter to area ratio is no greater than 1/8 and average width no less than 20 metres. In relation to the open space system in which it is inserted, this solution can play different roles, e.g. it can take on a protective function – for other habitats –, a connective function – between habitats –, or a generative function – as a habitat.

Synonyms

Forest planting, Forest creation, Woodlands creation

Section B - Technical details

The integration of design solutions into specifically urban contexts requires meticulous planning and design, aimed at identifying specific site characteristics and intervention objectives. It is fundamental to analyze the climatic and edaphic – soil – context, water resource availability, the eco-region, and the – potential and present – vegetation series. Objectives must assess ecological criticalities and potentialities, defining co-benefits and environmental quality standards. The prevailing objective is proper environmental integration within the urban ecosystem, aiming for de-fragmentation and the enhancement of ecological infrastructures. The solution must be coherent with general – Landscape Plans, Hydro-geological Asset Plans, General Regulatory Plans – and specialized – Green Plans, PAESCs – territorial governance instruments.

Conditions: requirements and loads

In medium-density urban environments, the availability of open spaces may be limited, and the integration of the afforestation areas must be adapted to spatial and geometric conditions made complex by the presence of buildings, roads, utilities, and subsurface services. These elements, in addition to constituting physical constraints and stressors on the new environments, necessitate compliance with regulations and codes – e.g., maintaining required distances from roads or private properties –. For sourcing plant material, it is advisable and preferable to use species native to, or compatible with, the environmental context; alien species should be avoided, while the use of invasive exotic species is strictly prohibited. In the design – new development and/or redevelopment – of areas accessible to the public for recreational, play, and social activities, and particularly those used by children, consideration must be given to the allergenic potential of the species to be introduced.

Construction: built-up, layers and performance

Based on implementation experience and the technical and scientific literature, six guiding principles can be identified.

- Minimization of energy and material inputs: achieved by using available resources and observing the site's vocations. This requires a detailed site survey: microclimate – considering the urban 'heat island' effect –, morphology, water runoff, infiltration, soil quality – pH, permeability –, pollutants, existing structures, and a botanical and phytosociological analysis of the vegetation – considering urban alterations and potential vegetation –.
- Correct site configuration: aimed at the effective management of water – surface, infiltration, groundwater – and soil fertility. Traditional methods – e.g., dry-stone walls – or naturalistic engineering techniques can be employed, favoring a minimal intervention approach. Infrastructures – roads, paths – must reduce or eliminate impermeability and integrate hydraulic solutions.
- Principles of systemic forestry 'Silvosystemics': to maximize biodiversity conservation and restoration. The intervention is aimed at constructing a complex biological

system capable of initiating autopoietic – self-regulating – processes and achieving dynamic stability, fostering the free evolution of the plant formation.

- Design of the cultivation unit: the initial vegetation cluster – arboreal, shrubby, herbaceous – must be low-impact, increasing biodiversity and structural diversification. Cultivation operations follow the population's needs rather than rigid schemes. The system must promote continuous natural regeneration. Techniques are suggested for a naturalistic, heterogeneous, and unstructured woodland, where the objective is to trigger the biological process rather than define a static form.
- Choice of the phytocoenosis – plant Community –: a crucial aspect based on studying potential and present vegetation. An incorrect choice leads to high maintenance costs and failure. Considerations must include: eco-compatibility – climate, soil, water –; characteristics of the floristic alliance; growth times and longevity – especially under urban stress –; light tolerance – heliophilous, sciophilous species –; adult habit – aiming for multi-level structures –; foliage persistence, flowering, and fruiting; resistance to pollutants and pathogens; and support for symbiotic mycoflora.
- Support for wildlife: fostered through multi-level, heterogeneous vegetation structures with variable densities to create diverse habitats. A rich floristic composition supports entomofauna – a trophic resource for insectivores – and avifauna – flowers, fruits –. Toxic species must be avoided, and variable terrain morphology – e.g., depressions for water stagnation – should be planned to create further habitats – e.g., for amphibians –.

Maintenance

A correct design approach enables the establishment of a complex vegetation formation capable of rapidly achieving a dynamic equilibrium with the environment, facilitated by its structure being open to self-variations. The management of such areas must aim to support the self-organization of the afforestation area, without directing it towards a predetermined structure. Monitoring and control constitute the essential elements for assessing the evolutionary processes. Silvicultural and utilization interventions are cautious, continuous, and localized, based on the needs of the various stands. At planting and for the subsequent years – a minimum of five –, particular attention must be paid to the water requirements of the newly established vegetation. Silvicultural care must be guaranteed to ensure the proper development of the flora, along with targeted interventions to reduce the impact of pathogens and phytoparasites. The management model can also be based on differentiation criteria for distinct zones and/or by levels of functionality/pressure related to anthropogenic use, applying more extensive and experimental maintenance in areas with low anthropogenic pressure. Experimental maintenance approaches can also be implemented to pursue objectives of public awareness and participation in the care and management of these places.

Section C - Societal challenges

Biodiversity enhancement

Afforestation is a crucial strategy for the restoration of forest ecosystem functions. Plant species diversity in afforested sites is dependent on previous land use, the proximity of natural vegetation, soil properties – e.g., texture, pH, and total nitrogen –, and plantation age. Afforested soils showed higher plant diversity and an improvement in edaphic parameters – soil organic carbon, nitrogen, and potassium – than arable cropped soils. Nevertheless, the conversion from treeless landscapes to forests can have negative impacts on organisms adapted to open habitats (Elmarsdóttir et al. 2008), in particular vascular plant diversity decreases – e.g., shade tolerant plant are favoured – but other functional groups are favoured – e.g., fungi and soil invertebrates –. Finally, considering that forest management and tree species affect all functional groups, it is crucial when planning afforestation to include strategies for biodiversity conservation by preserving endangered habitat and species. To that, urban and metropolitan afforestation projects showed the importance to work in multidisciplinary teams to ensure ecological, historical, spatial quality as well as social goals (Resemini et al. 2025).

Climate Resilience

Forests store and sequester carbon in the above ground vegetation and in the soil, providing climate change mitigation benefits (World Bank 2021; Doelman et al. 2020). Forests have a great potential to mitigate the urban heat island effect by shading building surfaces, deflecting radiation from the sun, and releasing moisture into the atmosphere. Shaded surfaces may be 11-25°C cooler than peak temperatures of unshaded materials. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 1–5°C (EPA n.d). Forests provide large carbon stocks owing to the high carbon content of the above and below ground biomass. Among terrestrial ecosystems and their habitats, forests have the highest carbon sequestration rates, reaching up to three times that of wetlands and agroecosystems (EEA 2026). Forests absorb and retain stormwater. Trees and soils of forested areas intercept precipitation and recycle the water through evapotranspiration, root water uptake, and infiltration (Gehrels et al. 2016). Mountain forests with deep soils can intercept and infiltrate rainwater, reducing flood hazards along canals and rivers downstream (Ozment et al. 2019). Forest soils have an ability to reduce atmospheric and aquatic pollutant sources. The beneficial effects of forests on air quality are well established (Beckett et al. 1998) and forests can also facilitate improvements in surface water and groundwater quality (NRMW). Forests play an important role in the hydrological cycle and its components, having a major influence on the amount of water flowing to groundwater, streams and other water bodies. Forests have a crucial impact on the amount of surface water as well as soil and groundwater (EEA 2015).

Health, Well-being and Air Quality

Urban forests make a positive contribution to the physical, mental, social, and economic wellbeing of societies (World Bank 2021; Bratman et al. 2019). Forests, rich in photosynthesising biomass, improve air quality by removing tropospheric ozone, a pollutant harmful to human and plant health (Calfapietra et al. 2016). Urban and peri-urban forests are able to absorb ozone through their leaf stomata, thus contributing to the improvement of air quality. Differences between tree species and environmental conditions influence the effectiveness of this process. It is important to promote the selection of species with high ozone uptake capacity to maximise the ecosystem benefits of green areas (Calfapietra et al. 2016). A nationwide assessment estimated that, in 2010, trees and forests in the US removed approximately 17.4 million tonnes of air pollutants, with human health benefits estimated at $6.8 billion. Although most of the pollution removal occurred in rural areas, the health effects were more significant in urban areas (Nowak et al. 2014).

Tree rows

Section A - General Description

Fig. 2 – A tree row with shrubs and herbaceous plants at Queen Elizabeth Olympic Park (London, UK), Piet Oudolf and Nigel Dunant, 2010 (Source: Wiki Common, Autor: DarkestElephant, 2014 CC By 3.0).

Description

Tree Rows are linear interventions aimed at establishing vegetated open space bands, incorporating trees, associated shrubs, and herbaceous vegetation. These rows must have a minimum length of 50 m and a minimum width of 1.5 m, with planting arranged in rows. They can be situated in either mostly unpaved areas like parks and gardens, or predominantly paved areas such as infrastructure surrounds, traffic islands, squares, and parking lots. This solution can be integrated with surface rainwater management and sustainable urban drainage systems. Depending on their context within the open space system, tree rows can serve a role in de-fragmentation and connection.

Synonyms

Street trees; Tree-lined Streets, Green Corridors, Boulevard

Section B - Technical details

The integration of design solutions into the context requires a meticulous planning and design phase. This phase is aimed at identifying the characteristics of the site –climatic, edaphic, water availability, eco-region, potential and present vegetation series – and the project objectives – assessment of ecological criticalities and potentialities, co-benefits, environmental and landscape quality goals –. The prevailing objective for designers is the correct environmental integration into the urban ecosystem, aiming for maximum effectiveness in terms of de-fragmentation, improvement, and enhancement of ecological infrastructures. The solution must be considered part of a broader strategy, requiring adequate planning of open spaces and coherence with general and specialized territorial governance instruments.

Conditions: requirements and loads

In high and medium-density urban environments, the availability of open spaces may be residual, and the integration of the tree row must be adapted to spatial and geometric conditions rendered complex by the presence of building structures, road configurations, and the presence of utilities and subsurface services. These elements, in addition to constituting physical constraints and pressure factors – stressors – on the new environments, necessitate compliance with regulations and codes, for example, maintaining required distances from roads or private properties. For the sourcing of plant material, it is advisable and preferable to use species native to, or compatible with, the environmental context; alien species are to be avoided, while the use of invasive exotic species is strictly prohibited.

Construction: built-up, layers and performance

Based on implementation experience and the technical and scientific literature, six guiding principles can be identified.

- Minimization of energy and material inputs: achievable through the careful use of available resources and observation of the site's vocations. This requires a detailed survey of the area, analyzing microclimatic conditions – including the urban 'heat island' effect –, morphology, slopes, water runoff, infiltration rates, soil quality – e.g., pH, permeability –, pollutants, built elements, and infrastructure. A botanical and phytosociological analysis of the vegetation is also fundamental, considering urban alterations and potential vegetation.
- Correct configurational setup: aimed at the effective management of water – surface runoff, infiltration – and the preservation or improvement of soil fertility. Sustainable Urban Drainage Systems (SUDS) and water-sensitive urban design methods can be used. A minimal approach, with low or zero matter and energy inputs, is preferable. It is also necessary to manage critical nodes related to utilities and subsurface services.
- Maximizing biodiversity: the design approach must be oriented towards ecologically effective choices. The planting – e.g., tree-shrub row – is framed as a solution for linear connection between habitats, strengthening the network of ecological infrastructures. It must possess sufficient complexity to foster autopoietic – self-regulating – processes and dynamic stability.
- Design of the cultivation unit: the plant population must be low-impact, conserving and increasing biodiversity. It must support heterogeneity and compositional diversification. The goal is an indefinite cultivation cycle open to self-variations, based on biological and ecological evaluations – longevity, evolutionary trends –. The choice of structure – even-aged, uneven-aged, hybrid – depends on the initial conditions and the plant alliances.
- Choice of the phytocoenosis – plant Community –: must be executed with care, studying potential and present vegetation. The project's success, functional effectiveness, and dynamic stability depend on this choice. An incorrect choice leads to failure and high maintenance costs. Aspects to consider include: eco-compatibility – climate, microclimate, soil acidity, moisture, porosity and water requirements –; floristic composition of the alliance, growth rates and longevity (considering urban stress); temperament regarding light (heliophilous, sciophilous); adult habit and dimensions – favoring multi-level structures –; leaf persistence, flowering, and fruiting characteristics; urban context – historical-cultural, landscape aspects

–; resistance to pollutants, pathogens, and synergies between species; support for symbiotic and saprophytic mycoflora.
- Protection of wildlife: the project must adopt solutions to protect fauna. Favorable aspects include: favoring multi-level vegetation structures; rich floristic composition – for co-benefits to soil organisms: bacteria, fungi, invertebrates –; species with flowers and fruits to create habitats rich in food and shelter for entomofauna; entomofauna serves as a trophic resource for insectivores – birds, mammals, reptiles –; fruits serve as a trophic resource – especially for birds –; avoiding species toxic to fauna.

Maintenance

A correct design approach allows the establishment of a complex vegetation formation capable of rapidly achieving a dynamic equilibrium with the environment, facilitated also by its structure being open to self-variations. The management of such areas must tend to support the self-organization of the tree-shrub row, without directing it toward a predetermined structure. Monitoring and control constitute the essential elements for the verification of evolutionary processes. Silvicultural and utilization interventions are cautious, continuous, and localized capillary, according to the needs of the various stands. At planting and for the subsequent years – a minimum of five –, particular attention must be paid to the water requirements of the newly established vegetation. Silvicultural care must be guaranteed to ensure the proper development of the flora, along with targeted interventions to reduce the impact of pathogens and phytoparasites. The management model can also be based on differentiation criteria for distinct zones and/or by levels of functionality/pressure related to anthropogenic use, applying more extensive and experimental maintenance in areas with low anthropogenic pressure.

Section C - Societal Challenges

Biodiversity enhancement

Tree rows can play a role in defragmentation and connection, and can also become an integral part of the habitat for birds and invertebrates. Tree rows soils showed higher plant diversity and an improvement in edaphic parameters –soil organic carbon, nitrogen, and potassium – than other types of soils.

Climate Resilience

Tree rows sequester carbon in aboveground vegetation and soil, providing climate change mitigation (World Bank 2021; Doelman et al. 2020) and microclimate regulation benefits by shading surfaces, diverting solar radiation, and releasing moisture into the atmosphere. Shaded surfaces can be 11-25 °C cooler than the peak temperature of unshaded materials. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 1-5 °C (EPA n.d.). Trees and soils intercept precipitation and recycle the water through evapotranspiration, root water uptake, and infiltration (Gehrels et al. 2016). Trees play an important role in the hydrological cycle and its components, having a major influence on the amount of water flowing to groundwater, streams and other water bodies (EEA 2015).

Health, Well-being and Air Quality

Tree rows as an urban forestry intervention make a positive contribution to the physical, mental, social, and economic wellbeing of societies (World Bank 2021; Bratman et al. 2019). Trees, rich in photosynthesising biomass, improve air quality by removing tropospheric ozone, a pollutant harmful to human and plants health (Calfapietra et al. 2016). Tree rows are able to absorb ozone through their leaf stomata, thus contributing to the improvement of air quality.

Vegetation clusters

Section A - General Description

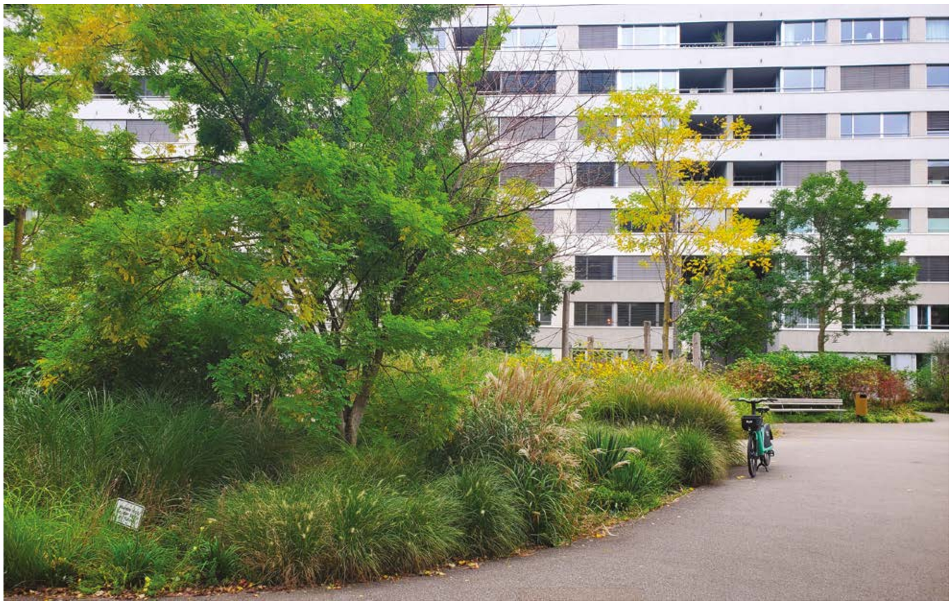

Fig. 3 – One of the vegetation clusters designed by Vulkan Landschaftsarchitektur for the Maaghof-Park in Zurich, 1999 (Source: Lorenzo Nofroni).

Description

Vegetation clusters are small-scale, localized interventions aimed at promoting the spread of complex vegetation structures, including tree, shrub, and herbaceous layers. These interventions can be implemented in urban green spaces such as gardens, parks, building grounds, and areas surrounding squares and infrastructure. They can be used to replicate mini and micro forests in urban settings (Eisenberg et al. 2022). In some urban contexts, like abandoned areas undergoing natural rewilding, vegetation clusters can be formed around spontaneously established groups of trees and shrubs, often made up of pioneer and ruderal species undergoing free, dynamic evolution (Eisenberg et al. 2022). This solution can also be combined with surface stormwater management and sustainable urban drainage systems. Depending on the open space system in which it is integrated, it can play a supporting role in strengthening ecological networks, helping to reduce habitat fragmentation and promote habitat reconnection.

Synonyms

Group of trees; Micro forest, Vegetation Patch, Plant Clump

Section B - Technical details

The incorporation of design interventions into the surrounding context mandates a meticulous planning and design phase. This foundational stage is focused on identifying the site's specific characteristics, including climatic, edaphic, and hydrological conditions, as well as the eco-region and both potential and extant vegetation series. Concurrently, this phase defines the project objectives, encompassing the evaluation of ecological criticalities and potentialities, the assessment of co-benefits, and the establishment of environmental and landscape quality goals. The objective for practitioners is achieving correct environmental assimilation into the urban ecosystem. This integration strives for maximum effectiveness in terms of ecological de-fragmentation, and the improvement and enhancement of green infrastructures. Any solution must be viewed as an integral part of a broader strategic framework, necessitating suitable planning of open spaces and ensuring coherence with general and specialized territorial governance instruments.

Conditions: requirements and loads

The integration of vegetation cluster must be adapted to complex spatial and geometric constraints imposed by built structures, road configurations, and the presence of subterranean utilities and services. These factors not only constitute physical limitations and exert stress on the new environments but also mandate strict adherence to regulations and codes, such as maintaining prescribed distances from roadways or private property. Regarding the procurement of plant material, the use of species that are native to, or at least compatible with, the local environmental context is strongly advisable and preferred. Alien species should be avoided, and the use of invasive exotic species is strictly forbidden.

Construction: built-up, layers and performance

Based on practical implementation experience and the techno-scientific literature, six guiding principles can be delineated:

- Minimization of energy and material inputs: this is achievable through the judicious use of available resources and by observing the site's natural vocations. This necessitates a detailed survey of the area, analyzing microclimatic conditions – including the urban 'heat island' phenomenon –, morphology, slopes, water runoff patterns, infiltration rates, soil quality – e.g., pH, permeability –, existing pollutants, built elements, and infrastructure. A thorough botanical and phytosociological analysis of the vegetation, considering urban alterations and potential vegetation dynamics, is also fundamental.
- Correct configurational setup: This principle aims for the effective management of water – both surface runoff and infiltration– and the preservation or enhancement of soil fertility. Methodologies such as Sustainable Urban Drainage Systems (SUDS) and water-sensitive urban design may be employed. A minimal-impact approach, characterized by low or zero inputs of matter and energy, is preferred. It is also imperative to manage critical junctures related to utilities and subterranean services.
- Maximizing biodiversity: the design methodology must be oriented toward choices that are ecologically effective. The planting is conceived as a solution for linear connectivity between habitats, thereby reinforcing the network of ecological infrastructures. It must possess adequate complexity to foster autopoietic – self-regulating – processes and achieve dynamic stability.
- Design of the cultivation unit: the plant population selected must have a low environmental impact, while conserving and augmenting biodiversity. It must support heterogeneity and diversification in both structure and composition. The objective is an indefinite cultivation cycle that remains open to self-variation, predicated on biological and ecological assessments – e.g., longevity, evolutionary trends –. The selection of the structure – e.g., even-aged, uneven-aged, hybrid– is contingent upon the initial site conditions and the identified plant alliances.

- Choice of the phytocoenosis – plant community –: this selection must be executed with extreme care, involving the study of both potential and extant vegetation. The project's ultimate success, functional effectiveness, and dynamic stability are dependent on this choice. An erroneous selection will invariably lead to failure and substantial long-term maintenance costs. Factors requiring consideration include: eco-compatibility – relative to climate, microclimate, soil acidity, moisture, porosity, and hydrological requirements –; the floristic composition of the alliance, growth rates, and longevity – especially considering urban stressors –; temperament concerning light exposure – heliophilous vs. sciophilous –; adult habit and dimensions – favoring multi-level structures –; characteristics of leaf persistence, flowering, and fruiting; the specific urban context – including historical-cultural and landscape aspects –; resistance to pollutants and pathogens, and inter-species synergies; and support for symbiotic and saprophytic mycoflora.
- Protection of wildlife: the project must incorporate solutions designed to protect fauna. Favorable aspects include: favoring multi-level vegetation structures; implementing a rich floristic composition – which provides co-benefits to soil organisms like bacteria, fungi, and invertebrates –; selecting species with flowers and fruits to create habitats rich in food and shelter for entomofauna. This entomofauna, in turn, serves as a trophic resource for insectivores – e.g., birds, mammals, reptiles –. The fruits also serve as a crucial trophic resource, especially for avifauna. Finally, species known to be toxic to wildlife must be avoided.

Maintenance

A correct design approach facilitates the establishment of a complex vegetation formation. This formation is capable of rapidly achieving a dynamic equilibrium with the environment, a process aided by its structure being open to self-variation. The management of such areas must be oriented toward supporting the self-organization of the vegetation clusters, rather than directing it toward a predetermined structure. Monitoring and control represent the essential elements for verifying evolutionary processes. Silvicultural and utilization interventions should be cautious, continuous, and highly localized capillary, tailored to the specific needs of various stands. Both at planting and during the subsequent years – a minimum of five –, particular attention must be devoted to the water requirements of the newly established vegetation. Continuous silvicultural care must be guaranteed to ensure the proper development of the flora, alongside targeted interventions to mitigate the impact of pathogens and phytoparasites. The management model can also be predicated on differentiation criteria, distinguishing between distinct zones and/or by levels of functionality and anthropogenic pressure. This allows for the application of more extensive and experimental maintenance strategies in areas subject to low anthropogenic pressure.

Section C - Societal Challenges

Biodiversity enhancement

Vegetation clusters can be used to replicate mini and micro forests in urban settings (Eisenberg et al. 2022), play a role in defragmentation and connection, and can also become an integral part of the habitat for birds and invertebrates.

Climate Resilience

Vegetation clusters sequester carbon in aboveground vegetation and soil, providing climate change mitigation (World Bank 2021; Doelman et al. 2020) and microclimate regulation benefits by shading surfaces, diverting solar radiation, and releasing moisture into the atmosphere. Shaded surfaces can be 11-25 °C cooler than the peak temperature of unshaded materials. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 1-5 °C (EPA n.d.). Thanks to their permanent vegetation intercept precipitation and recycle the water through evapotranspiration, root water uptake, and infiltration (Gehrels et al. 2016). Trees play an important role in the hydrological cycle and its components, having a major influence on the amount of water flowing to groundwater, streams and other water bodies (EEA 2015).

Health, Well-being and Air Quality

Vegetation clusters are tree planting interventions with an important role in covering, shading, and protecting underlying surfaces. They contribute to making a positive effect on the physical, mental, social, and economic wellbeing of societies (World Bank 2021; Bratman et al. 2019).

Tree plantations on paved surfaces

Section A - General Description

Fig. 4 – The tree-lined urban staircase designed by Kiefer and Koster with Freiraum Landschaftsarchitekten for Pfingstweid Park in Zurich, 2015 (Source: Lorenzo Nofroni).

Description

Tree plantations on paved surfaces are tree planting interventions to be implemented in predominantly paved areas with intense anthropogenic use such as squares, playgrounds, outdoor sports areas, picnic areas, and seating areas. Tree plantations can have an important role in covering, shading, and protecting underlying surfaces. This is an option for designing shaded paved urban areas that can offer advantages in terms of rainwater management and sustainable urban drainage, climate resilience, and mitigation of urban heat stress (Eisenberg et al. 2022). Tree plantations on paved surfaces represent a solution for introducing arboreal vegetation in spaces where, due to surface functionality and accessibility, it is not possible to introduce linear tree rows and vegetation clusters. Their use can perform a subsidiary function and enhance the ecological network, contributing to the de-fragmentation and reconnection of the system. Planting density, species, and diversification of forms and behaviors are to be established according to environmental conditions – phyto- and pedo-climatic – and human presence and related usage and management methods. Preference should be given to trees with expanded canopies, plantations diverse in species and varieties, and with adaptability to critical soil, water, and pollutant conditions.

Synonyms

Mixed plantations for recreation; Regular plantations; Tree canopy for shaded pavement surfaces

Section B - Technical details

The integration of solutions within the context requires a meticulous planning and design phase to identify site-specific characteristics – climatic, edaphic, water availability, eco-region, potential and present vegetation series–. Project objectives must be defined, including ecological assessments – criticalities, potentialities, opportunities, threats –, co-benefits, environmental and landscape quality goals. The prevailing objective is the correct environmental integration into the urban ecosystem, maximizing efficiency in de-fragmentation, improvement, and enhancement of ecological infrastructures. The solution must be considered part of a broader strategy, requiring adequate planning of open spaces and coherence with general – e.g., Territorial Address Plans, Landscape Plans, Hydro-geological Plans, General Regulatory Plans – and specialized – e.g., Green Plans, PAESC – territorial governance instruments.

Conditions: requirements and loads

In high and medium-density urban areas, residual open space availability complicates the integration of tree-shrub elements due to spatial constraints from buildings, road configurations, and sub-services. These factors impose physical limits and stressors, requiring adherence to regulations – e.g., distances from roads/property –. For plant material sourcing, native or compatible species are preferable; alien species are to be avoided, and invasive exotics are prohibited. In public recreational areas, especially those used by children, the allergenic potential of species must be considered to avoid exacerbating allergies and asthma.

Construction: built-up, layers and performance

Based on implementation experience and the technical and scientific literature, six guiding principles can be identified.

- Minimization of energy and material inputs: achieved through judicious use of available resources and observation of site vocations. This requires a detailed site survey, noting microclimatic conditions – including the 'heat island' effect –, morphology, slopes, depressed areas, surface water runoff, infiltration rates, soil typology and quality – e.g., depth to rock, porosity, permeability, pH –, pollutants, built elements, infrastructure, and existing flora – analyzed botanically and phytosociologically – and fauna. Urban contexts necessitate analyzing potential vegetation due to significant alterations.
- Correct configurational setup: the design must ensure effective management of surface runoff and infiltration, alongside the preservation or improvement of soil fertility. Sustainable Urban Drainage (SUDS) and Water-Sensitive Urban Design (WSUD) methods are applicable, though a minimal intervention approach with low or zero inputs is preferable. Critical nodes involving utilities and sub-services must be correctly addressed.
- Maximizing biodiversity: the design approach must prioritize ecologically effective choices to conserve, restore, and enhance biodiversity. Small-area tree-shrub plantings can function as an "archipelago" of vegetated spaces, aiding habitat defragmentation and re-connection within the urban ecosystem. This reinforces the primary and subsidiary ecological infrastructure network, designed with sufficient complexity to trigger autopoietic – self-regulating – processes toward dynamic stability.
- Design of the cultivation unit: the initial planting must be low-impact, conserving and increasing biodiversity. It should favor heterogeneity and structural/compositional diversification for an indefinite cultivation cycle open to self-variation, based on biological and ecological evaluations – species longevity, system evolutionary

trends –. The structure – e.g., even-aged, uneven-aged, hybrid – depends on initial conditions and chosen plant alliances.
- Choice of the phytocoenosis – plant community –: this selection must be executed with extreme care, involving the study of both potential and extant vegetation. The project's ultimate success, functional effectiveness, and dynamic stability are depends on this choice. An erroneous selection will invariably lead to failure and substantial long-term maintenance costs. Factors requiring consideration include: eco-compatibility – relative to climate, microclimate, soil acidity, moisture, porosity, and hydrological requirements –; the floristic composition of the alliance, growth rates, and longevity – especially considering urban stressors –; temperament concerning light exposure – heliophilous vs. sciophilous –; adult habit and dimensions – favoring multi-level structures –; characteristics of leaf persistence, flowering, and fruiting; the specific urban context – including historical-cultural and landscape aspects –; resistance to pollutants and pathogens, and inter-species synergies; and support for symbiotic and saprophytic mycoflora.
- Protection of wildlife: the project must incorporate solutions designed to protect fauna. Favorable aspects include: favoring multi-level vegetation structures; implementing a rich floristic composition – which provides co-benefits to soil organisms like bacteria, fungi, and invertebrates –; selecting species with flowers and fruits to create habitats rich in food and shelter for entomofauna. This entomofauna, in turn, serves as a trophic resource for insectivores – e.g., birds, mammals, reptiles –. The fruits also serve as a crucial trophic resource, especially for avifauna. Finally, species known to be toxic to wildlife must be avoided.

Maintenance

A correct design initiates a complex vegetation formation capable of rapidly achieving dynamic equilibrium, aided by a structure open to self-variation. Management should support the system's self-organization rather than imposing a prefixed structure. Monitoring and control are essential to verify evolutionary processes. Silvicultural interventions must be cautious, continuous, and capillary, responding to stand needs. Post-planting (minimum five years), critical attention must be paid to the water needs of new vegetation. Cultural care is necessary for proper flora development and to mitigate pathogens/phytoparasites. Management models can be differentiated by zones or levels of anthropogenic pressure, applying more extensive/experimental maintenance in low-pressure areas. Experimental approaches can also foster public awareness and participation.

Section C - Societal challenges

Biodiversity enhancement

Tree plantations on paved surfaces is an option for designing shaded paved urban areas that can offer advantages in terms of rainwater management and sustainable urban drainage, climate resilience, and mitigation of urban heat stress (Eisenberg et al. 2022). They represent a solution for introducing arboreal vegetation in spaces where, due to surface functionality and accessibility, it is not possible to introduce linear tree rows and vegetation clusters. Their use can perform a subsidiary function and enhance the ecological network, contributing to the de-fragmentation and reconnection of the system.

Climate Resilience

Tree plantations on paved surfaces store and sequester carbon in the above ground vegetation and in the soil, providing climate change mitigation benefits (World Bank 2021; Doelman et al. 2020). Tree plantations can have an important role in covering, shading, and protecting underlying surfaces. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 1–5°C (EPA n.d). Among terrestrial ecosystems and their habitats, Paved Surfaces can contribute to the carbon sequestration rates (EEA 2022). Thanks to their permanent vegetation, tree plantations on paved surfaces offer favorable conditions for effective water infiltration and slowing surface flow. They thus promote natural water retention. Along slopes, they can reduce soil erosion by intercepting and slowing surface water runoff (Catalogue of NWRM 2013).

Health, Well-being and Air Quality

Tree plantations on paved surfaces are tree planting interventions to be implemented in predominantly paved areas with intense anthropogenic use such as squares, playgrounds, outdoor sports areas, picnic areas, and seating areas. Tree plantations can have an important role in covering, shading, and protecting underlying surfaces. They contribute to make positive effect on the physical, mental, social, and economic well-being of societies (World Bank 2021; Bratman et al. 2019).

Hedgerows and shrubs strips

Section A - General Description

Fig. 5 – A flowering and shrubby strip designed by Michel Desvigne for the Parc de Saône within Lyon Confluence, 2010 (Source: Wiki Common, Autor: Guilhem Vellut, 2017 CC By 2.0).

Description

Hedgerows and shrubs strips are predominantly linear areas characterized by vegetation cover. Their specific vegetation configuration is determined by environmental conditions – phyto and pedo-climatic –, competitive or cooperative interactions with other plant and animal species, human presence, and associated usage and management methods. These strips can range from alliances consisting solely of herbaceous species to highly structured associations of herbaceous, shrubby, and arboreal species. Hedgerows and shrubs strips are typically located at the margins of watercourses – known as riparian strips –, woodlands – clearing shrublands –, grasslands, and cultivated areas – field hedges –. They are also found in parks, public gardens, and adjacent to transport infrastructure – hedges and shrub strips –. They differ from tree lines primarily because they are composed mainly of herbaceous and shrubby species, with arboreal species being more sporadic. Beyond serving as habitats for various species, including plants, animals – vertebrates and invertebrates –, fungi, and bacteria hedgerows and shrubs strips can play a significant connectivity role. Where they form linear systems and nearly continuous networks, they are utilized by certain species for movement between different areas. Strips featuring species that produce berries, fruits, and nectar are important foraging sites, particularly for insects and birds. In rural contexts, hedgerows and shrubs strips are typically used for controlling livestock, delimiting boundaries, or providing shelter. In urban areas, they can constitute boundary hedges or function as separation and protection strips for other vegetation structures. Thanks to their permanent vegetation, hedgerows and shrubs strips offer favorable conditions for effective water infiltration and slowing surface flow. They thus promote natural water retention. Along slopes, they can reduce soil erosion by intercepting and slowing surface water runoff (Catalogue of NWRM 2013).

Synonyms

Street hedgerows, buffer shrubs strips, green fences, roads verges.

Section B - Technical details

The integration of solutions within the context requires a meticulous planning and design phase to identify site-specific characteristics – climatic, edaphic, water availability, eco-region, potential and present vegetation series –. Project objectives must be defined, including ecological assessments – criticalities, potentialities, opportunities, threats –, co-benefits, environmental and landscape quality goals. The prevailing objective is the correct environmental integration into the urban ecosystem, maximizing efficiency in de-fragmentation, improvement, and enhancement of ecological infrastructures. The solution must be considered part of a broader strategy, requiring adequate planning of open spaces and coherence with general – e.g., Territorial Address Plans, Landscape Plans, Hydro-geological Plans, General Regulatory Plans – and specialized – e.g., Green Plans, PAESC – territorial governance instruments.

Conditions: requirements and loads

In high and medium-density urban areas, residual open space availability complicates the integration of tree-shrub elements due to spatial constraints from buildings, road configurations, and sub-services. These factors impose physical limits and stressors, requiring adherence to regulations – e.g., distances from roads or property –. For plant material sourcing, native or compatible species are preferable; alien species are to be avoided, and invasive exotics are prohibited. In public recreational areas, especially those used by children, the allergenic potential of species must be considered to avoid exacerbating allergies and asthma.

Construction: built-up, layers and performance

Based on implementation experience and the technical and scientific literature, six guiding principles can be identified.

- Minimization of energy and material Inputs: this principle is achievable through the prudent utilization of available resources and a sensitive observation of the site's natural vocations. It mandates a detailed survey of the intervention area. This analysis must encompass microclimatic conditions – including the urban 'heat island' phenomenon –, morphology, slope gradients, water runoff patterns, and infiltration rates. Furthermore, a thorough assessment of soil quality – e.g., pH, permeability, porosity –, the presence of pollutants, and existing built elements or infrastructure is required. A foundational component is the botanical and phytosociological analysis of extant vegetation, considering potential vegetation series and an understanding of urban alterations.
- Correct configurational setup: the design must establish a configuration aimed at the effective management of water dynamics, including both surface runoff and infiltration, while simultaneously preserving or enhancing soil fertility. Methodologies such as Sustainable Urban Drainage Systems (SUDS) and water-sensitive urban design (WSUD) can be employed. However, a minimal intervention approach, characterized by low or zero inputs of matter and energy, is preferable. It is

also imperative to correctly manage critical nodes and potential conflicts related to the presence of utilities and subsurface services.

- Maximizing biodiversity: the design methodology must be oriented toward ecologically effective choices to conserve, restore, and enhance biodiversity. The planting – e.g., a tree-shrub row or patch – should be framed as a solution for linear connectivity or as part of a 'vegetated archipelago'. This strengthens the network of ecological infrastructures by fostering habitat de-fragmentation and re-connection within the urban ecosystem. The system must possess sufficient complexity to foster autopoietic – self-regulating – processes, thereby achieving long-term dynamic stability.
- Design of the cultivation unit: the initial plant population, or cultivation unit, must be designed for low environmental impact, focusing on conserving and increasing systemic biodiversity. It must support heterogeneity and diversification in both structure and composition. The objective is an indefinite cultivation cycle that remains open to self-variations, predicated on biological and ecological evaluations such as species longevity and the system's evolutionary trends. The choice of structure – e.g., even-aged, uneven-aged, regular, or hybrid – is contingent upon the initial site conditions and the selected plant alliances.
- Choice of the phytocoenosis – plant community –: this selection must be executed with extreme care, involving the study of both potential and extant vegetation. The project's ultimate success, functional effectiveness, and dynamic stability are dependent on this choice. An erroneous selection will invariably lead to failure and substantial long-term maintenance costs. Key aspects to consider include: eco-compatibility with climatic, microclimatic, and edaphic conditions – acidity, moisture, porosity – and water requirements; the specific floristic composition of the alliance; growth rates and longevity, especially considering urban stressors; species' light temperament – heliophilous vs. sciophilous –; adult habit and dimensions, favoring multi-level structures; phenological characteristics – leaf persistence, flowering, fruiting –; the urban context – historical-cultural, landscape –; resistance to pollutants and pathogens; inter-species synergies; and support for symbiotic and/or saprophytic mycoflora.
- Protection of wildlife: the project must adopt solutions specifically designed to protect and support fauna. Favorable aspects include: implementing a rich floristic composition, which provides co-benefits to soil organisms – bacteria, fungi, invertebrates –; and selecting species with flowers and fruits to create habitats rich in food and shelter for entomofauna. This entomofauna, in turn, serves as a critical trophic resource for insectivores – e.g., birds, mammals, reptiles –. Furthermore, fruits – berries, drupes, etc.– provide a trophic resource for numerous species, especially avifauna. Species known to be toxic to wildlife must be avoided.

Maintenance

A correct design approach facilitates the establishment of a complex vegetation formation. This formation is capable of rapidly achieving a dynamic equilibrium with the environment, a process aided by its structure being open to self-variation. The management of such areas must be oriented toward supporting the self-organization of the hedgerows and shrubs strips, rather than directing it toward a predetermined structure. Monitoring and control represent the essential elements for verifying evolutionary processes. Silvicultural and utilization interventions should be cautious, continuous, and highly localized capillary, tailored to the specific needs of various stands. Both at planting and during the subsequent years – a minimum of five –, particular attention must be devoted to the water requirements of the newly established vegetation. The management model can also be predicated on differentiation criteria, distinguishing between distinct zones and/or by levels of functionality and anthropogenic pressure. This allows for the application of more extensive and experimental maintenance strategies in areas subject to low anthropogenic pressure.

Section C - Societal challenges

Biodiversity enhancement

Where hedgerow and shrubs strip form linear systems and nearly continuous networks, they are utilized by certain species for movement between different areas. Strips featuring species that produce berries, fruits, and nectar are important foraging sites, particularly for insects and birds. In rural contexts, hedgerows and shrubs strips are typically used for controlling livestock, delimiting boundaries, or providing shelter. In urban areas, they can constitute boundary hedges or function as separation and protection strips for other vegetation structures. Thanks to their permanent vegetation, hedgerows and shrubs strips offer favorable conditions for effective water infiltration and slowing surface flow. They thus promote natural water retention. Along slopes, they can reduce soil erosion by intercepting and slowing surface water runoff (Catalogue of NWRM 2013).

Climate Resilience

Hedgerow and shrub strip store and sequester carbon in the above ground vegetation and in the soil, providing climate change mitigation benefits (World Bank 2021; Doelman et al. 2020). Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 1-5°C (EPA n.d). Among terrestrial ecosystems and their habitats, Hedgerow and shrub strip can contribute to the carbon sequestration rates (EEA 2022). Thanks to their permanent vegetation, hedgerows and shrubs strips offer favorable conditions for effective water infiltration and slowing surface flow. They thus promote natural water retention. Along slopes, they can reduce soil erosion by intercepting and slowing surface water runoff (Catalogue of NWRM 2013).

Health, Well-being and Air Quality

Hedgerows and shrubs strips as an urban forestry intervention contribute to make positive effect to the physical, mental, social, and economic wellbeing of societies (World Bank 2021; Bratman et al. 2019).

Flower meadows

Section A - General Description

Fig. 6 – One of the flower meadows designed by Nigel Dunnett for the Tower of London superbloom 2022 (Source: Wiki Common, Autor: amandabhslater, 2022 CC By 2.0).

Description

Flower meadows are habitat characterized by the dominance of annual and/or perennial herbaceous species, favored by low-intensity anthropogenic management, related usage patterns, environmental conditions – phyto and pedo-climatic – and the interactions with other plant species – trees and shrubs –, animals, fungi, and bacteria. Flower meadows can take various shapes and sizes: from small patches or strips in areas adjacent to buildings and infrastructure, to large meadow extensions in parks or grazing meadows in urban rural areas. They are distinguished from high-intensity anthropogenically managed grass lawns – seeding, mowing, irrigation, fertilization – by a greater diversity of plant, animal, bacterial, and fungal species and a different human approach to use and management, which allows herbaceous populations to complete their entire life cycle, accommodate other spontaneous herbaceous species, and change over time and with the seasons. Given that flower meadows are characterized by plant species that have evolved zoogamous pollination strategies through co-evolutionary processes with pollinating insects (Adams 2005), this type of habitat, in addition to representing a great opportunity to increase plant diversity in urban areas (Chollet. et. al. 2018), has high potential for the protection of animal biodiversity, as the very survival of a flowering meadow depends on the presence of a wide range of invertebrates – pollinators and their predators – for which it simultaneously represents a habitat and an ecological corridor (Klaus 2013). Two types of urban flowering meadows can be distinguished: those with a prevalence of annual herbaceous plants or those with a prevalence of perennial herbaceous plants. The first type is characterized by the presence of species that complete their life cycle in one year or one season; therefore, they develop and change very rapidly with short cyclical phases. The second type is characterized by the presence of perennial species whose life cycle is multi-year. These meadows take two to three years to establish because perennial grasses have a deep root system and spend much of their energy in the first year on root growth, in the second on root system expansion, and in the third on above-ground establishment. Numerous experiments on the formation and management of urban flowering meadows have shown that the creation and/or maintenance of a mosaic of diversified types of flowering meadows: varying in height – controlled through the number of mows –; in species richness in the initial seed mix; and in the alternation between annual and perennial species, improves biodiversity – plant, animal, fungal, and bacterial – over an annual cycle, to a greater extent than creating habitats with only one type of meadow (Norton et. al. 2019).

Synonyms

Wildflower Meadow, Perennial Meadow, Wildflower Field

Section B - Technical details

The integration of solutions within the context requires a meticulous planning and design phase to identify site-specific characteristics – climatic, edaphic, water availability, eco-region, potential and present vegetation series –. Project objectives must be defined, including ecological assessments – criticalities, potentialities, opportunities, threats –, co-benefits, and environmental/landscape quality goals. The prevailing objective is the correct environmental integration into the urban ecosystem, maximizing efficiency in de-fragmentation, improvement, and enhancement of ecological infrastructures. The solution must be considered part of a broader strategy, requiring adequate planning of open spaces and coherence with general – e.g., Territorial Address Plans, Landscape Plans, Hydro-geological Plans, General Regulatory Plans – and specialized – e.g., Green Plans, PAESC – territorial governance instruments.

Conditions: requirements and loads

In high and medium-density urban areas, residual open space availability complicates the integration of tree-shrub elements due to spatial constraints from buildings, road configurations, and sub-services. These factors impose physical limits and stressors, requiring adherence to regulations. For plant material sourcing, native or compatible species are preferable; alien species are to be avoided, and invasive exotics are prohibited. If a survey determines the site already contains a degree of wildflower diversity and old meadow grasses – and no pernicious weeds –, this diversity should be retained.

Construction: built-up, layers and performance

Based on implementation experience and the technical and scientific literature, six guiding principles can be identified.

- Minimization of energy and material Inputs: this principle is achievable through the prudent utilization of available resources and a sensitive observation of the site's natural vocations. It mandates a detailed survey of the intervention area. The ideal site for a species-rich meadow, which minimizes long-term management inputs, is one with low soil fertility. High nutrient levels, particularly available phosphorus, tend to promote the growth of vigorous grasses and pernicious weeds – like nettles, thistles, and docks –. These undesirable plants outcompete the desired wildflowers for nutrients and water. A preliminary soil test is recommended to establish baseline levels of available Nitrogen (N), Phosphorous (P), Potassium (K), and soil pH. On sites with very high fertility, it may be necessary to remove the topsoil to reduce nutrient loads, though this requires expert assessment to determine the correct depth. In long-term management, it is essential to remove all cut material – cuttings – from the site after mowing. This prevents the cuttings from smothering the sward and, critically, stops nutrients from being returned to the soil, thus maintaining the desired low-fertility state.

- Correct configurational setup: a successful setup begins with a comprehensive site survey that must assess existing vegetation, hydrology, and all site conditions. The primary goal when creating a meadow from scratch is to produce a firm, weed-free tilth through soil cultivation. This setup phase is critical for removing competition. Pernicious weeds must be addressed. A typical ground preparation sequence for fertile sites involves: shallow cultivation – e.g., rotovator – followed by rolling to consolidate the ground, harrowing or treating regrowth, and finally, using a power harrow to create a fine surface tilth. A final spray may be required before sowing.
- Maximizing biodiversity: starts with assessing current assets. A site survey may reveal existing diversity, as wildflowers might be present in the seed bank. If a survey determines the site already contains a degree of wildflower diversity and old meadow grasses – and no pernicious weeds –, this diversity should be retained. Biodiversity can be enhanced by introducing new seeds: this is done by using a harrow or disc to expose at least 30% bare earth and then broadcasting a 100% wildflower seed mix. To ensure the new introductions are appropriate, it is vital to use native provenance seed sourced from reputable suppliers adhering to the Flora Locale Code of Conduct. Furthermore, if the site is in or near an environmentally sensitive area – such as a designated site for nature conservation –, seed must not be introduced from outside the local area. Long-term biodiversity is ensured through monitoring; botanical surveys should be conducted at fixed points for at least the first 5 years to assess vegetation establishment, species abundance, and flowering potential.
- Design of the cultivation unit: the optimal timing for sowing seed is late summer or early autumn. This timing avoids high soil temperatures and exposes the seeds to cold, moist winter temperatures, which can help break the dormancy of some species. Spring sowing – March/April – is also suitable, particularly for areas of land that are prone to winter flooding. During application, the seed must be mixed regularly to ensure even species distribution and surface broadcast. Recommended sowing rates are 5g/m2 for 80:20 grass/wildflower mixes or 1.0 g/m2 for pure wildflower mixes. After sowing, the seed bed must be firmed; this is achieved using a Cambridge Roller or by using cattle to tread the seed in. Alternatively, for small areas – under one hectare – or for specific species, plug plants can be used. Small plugs should be planted at a density of 20 plants per sqm, arranged in clusters of 4 to 5 plants per species.
- Choice of the Phytocoenosis – plant community –: it is important that the correct plant species are selected which are adapted to the local site conditions and resemble the semi-natural plant communities of the local area. Species must be matched to the site's soil type (pH), fertility, hydrology, and topography. A commonly recommended seed mix is an 80:20 grass-to-wildflower ratio. However, this mix must not include vigorous grasses, as these will compete with the wildflowers for resources. If vigorous grasses are identified as a problem on the site, the introduction of the annual plant Yellow Rattle – *Rhinanthus minor* – can be highly effective. This plant is parasitic on the roots of grasses and is effective at reducing their vigour.

- Protection of wildlife: management protocols are essential for protecting the floral community, which in turn supports wildlife. The first year of establishment is critical for controlling weeds and reducing competition from grasses. In Year 1, the sward should be kept short – cut to 5cm –, cutting roughly every two months or when the sward reaches 15cm. Critically, cutting must stop during June, July, and August; this allows any establishing wildflowers to set seed. A final cut is made in September/October. For future maintenance of a summer flowering meadow, the first cut (5cm) should take place in March/April. The main second cut – 5cm – should occur after the flowering season, during September/October. This "hay cut" timing allows plants to complete their life cycle. For cornfield annuals, the management differs: the site must be harrowed – in Autumn or Spring – to regenerate the annuals. Where persistent weeds are a problem, they should be spot-treated with a broad-spectrum herbicide or dug out.

Maintenance

A correct design approach facilitates the establishment of a flower meadow formation capable of rapidly achieving a dynamic equilibrium with the environment, a process aided by its structure being open to self-variation. Monitoring and control represent the essential elements for verifying evolutionary processes. Botanical surveys should be conducted by a suitably qualified person at fixed points within the meadow for at least the first 5 years. These surveys must assess vegetation establishment, species abundance, sward height, vegetation cover, and flowering potential. The management model can also be predicated on differentiation criteria, distinguishing between distinct zones and/or by levels of functionality and anthropogenic pressure.

In the first year of management, particular attention must be paid to control weeds and reduce competition from grasses. For spring-seeded meadows, the first cut – to 5cm – should be in May. For autumn-seeded meadows, the first cut – 5cm – is March/April. The sward should be cut every 2 months, or when it reaches approximately 15 cm. Cutting must cease from June to August to permit wildflowers to set seed. A final cut is required in September/October. It is critical to remove all cuttings to prevent smothering the sward. For future maintenance – perennial meadows – first cut – to 5cm – should be performed in March/April. The second, primary cut – 5cm – must occur at the end of the flowering season, during September/October. All cuttings must be removed. Additional cuts may be necessary in autumn to remove untidy growth if the growing season is extended.

Section C - Societal challenges

Biodiversity enhancement

Flower meadows, spontaneous or sawn-on-purpose provide habitat and connectivity increasing diversity at many levels. Flower meadows create continuity between rural and urban areas, increasing the diversity of plant species and invertebrates (Bretzel et al 2016), represent a fundamental strategy and an often-overlooked opportunity to enhance and sustain biodiversity in urban environments. These spaces, when properly managed, counteract the ecological sterility of traditional short-mown grasslands, which dominate urban greening initiatives but offer scarce ecological value. The primary importance of FM lies in their capacity to transform low-biodiversity green areas into complex and vital habitats. This management shift permits a variety of wildflower species to complete their life cycle -flowering and setting seed- which is impossible in grasslands subjected to continuous cutting. This increase in plant diversity triggers a positive cascading effect on the entire ecosystem. Flower meadows provide essential food resources – nectar, pollen, seeds – and shelter for a wide range of wildlife, particularly pollinators – such as bees and butterflies –, birds, and other small fauna that struggle to survive in the built environment. Finally, this biodiversity is not an end in itself: it contributes to the general stability of the meadow ecosystem and enhances the resilience of the urban environment.

Climate Resilience

Flower meadows contribute to carbon storage through rich herbaceous biomass (Wang et al. 2021), carbon accumulation in topsoil (Kortleve and Mogollón 2023), and higher net primary productivity. Plant diversity and low-intensity management further enhance this effect (Thölix et al. 2025). Flower meadows reduce surface runoff thanks to vegetation cover, which intercepts rainfall, and more porous soil due to root systems. Studies show a 20-50% reduction in runoff compared to conventional lawns (Lin et al. 2020) and better infiltration than cultivated fields (Zimmermann et al. 2006). Root biodiversity improves soil structure (Bardgett et al. 2014), enhancing water retention. Flower meadows improve water quality by reducing erosion, retaining nutrients – e.g., nitrates and phosphates –, and filtering pollutants. Roots stabilize the soil and increase nutrient uptake (Zhang et al. 2010; Tilman et al. 2002). Meadow buffer strips reduce nitrates by up to 80% and phosphates by up to 90% (Hefting et al. 2005). Additionally, requiring fewer fertilizers, they lower contamination risk (Tzoulas et al. 2007).

Health, Well-being and Air Quality

Flower meadows increase physical activity by making green spaces more attractive and inviting (Pretty et al. 2005; Norton et al. 2019). Their biodiversity and aesthetics encourage walking and outdoor recreation, especially in urban areas (Giles-Corti et al. 2005; Hoyle 2016). Exposure to natural settings also improves mood, indirectly boosting motivation to move (Barton et al. 2010). Meadows thus support healthier, more active lifestyles. Flower meadows improve mental health and reduce chronic stress by providing restorative natural environments that lower cortisol and anxiety (Ulrich et al. 1991). Their biodiversity enhances wellbeing through sensory stimulation (Fuller et al. 2007). Urban meadows encourage social interaction and physical activity, benefiting mental health (Hoyle 2016). Reduced mowing increases natural aesthetics, promoting relaxation (Chollet et al. 2018). Natural sounds in meadows further decrease stress responses (Alvarsson et al. 2010).

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