Hort4EUGreen

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URBAN HORTICULTURE

Urban flora diversity

Volume 4

University of Agronomic Sciences and Veterinary Medicine of Bucharest

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"Enhancing practical skills of horticulture specialists to better address the demands of the European Green Deal"

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Milena Yordanova, Mihaela Georgescu,
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Introduction

Urban ecosystems, once considered concrete jungles devoid of biodiversity, have become focal points of interest for master's students in the field of ecology and environmental science. This essay explores the dynamic and often surprising world of urban flora diversity, shedding light on the intricate relationships between plants and the urban environment. By delving into the unique challenges and opportunities presented by urban landscapes, master's students can gain valuable insights into the conservation and sustainable management of urban flora.

Urbanization has transformed landscapes worldwide, creating expansive cities with towering structures and sprawling infrastructure. However, within the concrete confines of urban environments lies a rich tapestry of plant life that has adapted to and sometimes thrived in unexpected niches. Master's students delving into the study of urban flora diversity embark on a journey to uncover the secrets of resilient plant species, intricate ecological networks, and the implications of urbanization on biodiversity conservation.

Understanding the ecological strategies employed by urban flora is a cornerstone of master's research in this field. Investigating traits such as seed dispersal mechanisms, physiological adaptations to urban pollutants, and symbiotic relationships with other organisms provides crucial insights into the resilience and survival strategies of urban plant communities. Students explore how these strategies influence the composition and dynamics of urban flora over time.

One of the central themes of master's research on urban flora diversity is the development of effective conservation strategies. This involves identifying priority areas for conservation, evaluating the efficacy of green infrastructure projects, and proposing measures to enhance urban biodiversity. The goal is to strike a balance between urban development and the preservation of native plant species, fostering sustainable coexistence between nature and the built environment.

Exploring urban flora diversity are poised to unravel the mysteries of life within the concrete jungle. By embracing the interdisciplinary nature of this field, students contribute not only to the advancement of scientific knowledge but also to the development of strategies that foster harmony between urban development and the conservation of diverse and resilient urban flora.

Urban flora diversity

Summary

The manual examines urban flora diversity as an integrated component of urban ecosystems, focusing on plant species selection, functional typologies, and cultivation systems adapted to contemporary urban conditions. It explores ornamental, productive, and multifunctional plants in relation to climate constraints, spatial limitations, pollution exposure, and management intensity. Urban agriculture, agroforestry, rooftop gardening, vertical systems, and mushroom cultivation are analysed through ecological, technical, and food-safety perspectives. Emphasis is placed on biodiversity support, ecosystem services, pollinator interactions, and circular resource use, alongside practical considerations regarding species requirements, maintenance, and productivity. Drawing on empirical studies and applied European examples, the manual provides a structured framework for understanding how plant diversity can enhance resilience, functionality, and sustainability within urban landscapes.

Learning outcome descriptors

By the end of the module, the readers should be able to demonstrate taxonomic proficiency, knowledge to the ecological roles of different plant species and their contributions to urban biodiversity, apply scientific methodologies for urban plant surveys.

General and transferable skills

1	Develop the ability to keenly observe and identify various plant species in urban environments
2	Cultivate skills in documenting and recording plant observations.
3	Hone your skills in effectively communicating information about urban flora.
4	Extends to written, verbal, and visual communication, facilitating the dissemination of knowledge to diverse audiences.

Knowledge, understanding and professional skills

1	Acquire fundamental knowledge of common plant species and their characteristics in urban settings.
2	Understand the ecological roles of urban flora and their contributions to local biodiversity.
3	Develop the ability to engage with the community and communicate urban flora insights effectively.

Unit 4.1 Plants species suitable for growing in an urban environment

4.1.1 Conceptual framework for plant selection in urban environments

Oana Venat, Milena Yordanova,
Mihaela Georgescu, Liliana Bădulescu

The choice of plant species for their cultivation in an urban environment depends on several factors, with the purpose of cultivation, the type of gardens, and climatic factors being some of the leading ones for their selection. When designing mainly ornamental gardens or planning the greening of free urban areas, different types are selected, mainly perennial woody or shrubby species, including annuals for greening.

To transform the landscape in urban spaces into an edible landscape, agricultural species are utilized. This transformation can take the form of the so-called urban agroforestry. In this case, woody shrub-like fruit species, berry-bearing plants, essential-oil-bearing plants, herbs, etc., are selected, and local wild plants are preserved. According

to Romanova & Lovell (2021), there is a wide variety of edible woody species that can be used in this type of urban greening. In their selection, preference may be given to established local varieties or rare, non-traditional ones. Their cold and drought resistance, biological requirements, as well as their morphological features (size of the root system, crown, plant height, shaping potential), etc., are taken into account. A variety of berry crops can also be used, and in their selection, the same factors are considered once again.

In their study, Lee et al., (2017) demonstrate that the selection of edible crops for urban greening is associated with the form of the urban space and its activities. They have found that edible plants are present in 77.9% of green alleys, and alleys with parking are more likely to have edible plants than those without. They add that when using pots placed on the ground, it is more likely for them to cultivate edible plants compared to other types. According to them, in the selection of species, considerations include not only their size and form (i.e., tree, small tree, shrub, ground cover) but also the characteristics of their fruits (e.g., thorns, weight, aroma), which can influence their choice.

It is established that the urban environment has elevated levels of pollution (soil, air, and water) due to intense traffic in cities, as well as various types of industrial production or other sources. Pollutants often move and accumulate in specific areas, most commonly in the soil. Therefore, when using edible plants for designing an edible landscape in cities, it is crucial to be aware of another characteristic: their tendency to accumulate pollutants in their edible parts. This is significant from the perspective of their suitability for consumption. In this regard, preference should be given to plant species with a low risk of pollutant accumulation. They are suitable for cultivation in areas with proven soil and/or air pollution (Romanova & Lovell, 2021).

The planning of an edible landscape in the form of urban agroforestry contributes to the conservation and enhancement of biodiversity. Perennial flowers are included alongside edible woody and shrubby fruit species. This creates conditions for bird habitats and attracts beneficial insects and pollinators. With proper planning, these systems can also provide additional ecological benefits in urban environments and serve purposes such as education, recreation, and hosting various events (Romanova & Lovell, 2021).

When planning different types of urban gardens, the selection of species also takes into account their morphology and biological requirements, as well as the size of the gardens, their goals, and production methods. The range of potential species that can be used is extensive. All types of vegetable crops, essential-oil-bearing, culinary, medicinal, wild species, fruits and berries, flowers, etc., can be utilized. Both annual and perennial species are chosen.

In outdoor cultivation, in soil, climatic factors are crucial, as well as the size and shape of the garden area. When growing them in various containers and pots, plants with more restricted root systems and habitus are selected. When employing soilless cultivation methods (hydroponics, aeroponics, and aquaponics), smaller plants are chosen, primarily leafy vegetables and culinary herbs.

Functional plant traits and ecosystem services

Urban green infrastructure is shifting from aesthetic and taxonomic perspectives toward trait-based design. Functional traits - morphological, physiological, and phenological attributes that determine plant responses to the environment - govern how species deliver ecosystem services such as cooling, air filtration, carbon storage, and habitat support.

Aerial view of lush urban garden

Trait-based ecology enables planners to predict performance under stress and service delivery, even in highly artificial environments. For example, leaf area index (LAI) correlates strongly with canopy cooling capacity, while stomatal conductance controls evapotranspiration efficiency and pollution uptake.

Studies across 14 European cities confirm that functional diversity, not species richness alone, predicts resilience to climate extremes

Functional trait	Ecological function	Ecosystem service	Example urban species
High leaf area and dense canopy	Interception of solar radiation and pollutants	Urban cooling, shading, air filtration	*Platanus × hispanica*, *Tilia cordata*
Deep and extensive roots	Soil anchoring, hydraulic lift	Stormwater regulation, soil stability	*Quercus robur*, *Gleditsia triacanthos*
High stomatal conductance & transpiration rate	Evapotranspirative cooling	Temperature moderation, comfort regulation	*Betula pendula*, *Acer platanoides*
Long flowering period / high nectar production	Resource continuity for pollinators	Pollination services, biodiversity support	*Lavandula angustifolia*, *Salvia nemorosa*
High leaf pubescence / waxy cuticle	Particle and heavy metal capture	Air quality improvement	*Hedera helix*, *Buxus sempervirens*
Rapid phenological response / deciduous habit	Seasonal radiation balance	Urban energy saving, visual comfort	*Ginkgo biloba*, *Ulmus minor*

(adapted from Kattwinkel et al., 2023; Calfapietra et al., 2020)

Trait diversity and multifunctionality

Single traits rarely provide multiple benefits; instead, combinations of traits enable cities to balance cooling, biodiversity, and structural resilience. For instance, *Platanus × hispanica* provides high shading and pollution removal but limited trophic value, while *Tilia cordata* supports pollinators yet is drought-sensitive. Integrating such complementary species enhances multifunctionality - the capacity of green infrastructure to deliver several ecosystem services simultaneously.

Trait-based frameworks are therefore replacing origin-based selection, aligning with sustainable urban design standards and nature-based solutions promoted by the EU Biodiversity Strategy and the Horizon Europe “Green Cities” program.

Applied framework for urban design

Trait-based mapping helps planners match ecological functions with urban contexts:

- Tree traits → shading, microclimate regulation, carbon storage.
- Shrub and herb traits → pollutant interception, pollinator support, aesthetic softening.
- Root and leaf traits → infiltration and soil retention in permeable landscapes.

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Decision matrix for species selection in urban contexts

From ecological data to design decisions

Selecting plant species for urban greening requires balancing ecological, physiological, and regulatory dimensions. Trait-based evidence previousdeveloped provides the foundation for a decision-support framework that prioritizes measurable performance rather than aesthetic or ideological criteria. Each site type - street corridors, pocket parks, courtyards, rooftops, edible gardens - has its own combination of stress factors and ecosystem service priorities.

The following matrix links functional traits to service delivery and risk, helping designers select species that align with local environmental goals and management capacity

Decision matrix: functional traits, services, and risk levels

Urban condition	Key stress factors	Recommended traits	Targeted ecosystem services	Example species	Risk / Notes
Street corridors & traffic islands	Heat, soil sealing, air pollution	High transpiration	Cooling, air filtration, shading	*Platanus × hispanica,*	Low trophic support; monitor
Urban parks & green corridors	Moderate stress, high biodiversity	Flowering continuity, broad	Pollination, biodiversity,	*Tilia cordata, Acer campestre,*	Sensitive to heat; watering needed
Rooftop gardens & engineered	Drought, wind, limited rooting	Shallow roots, succulence,	Cooling, dust capture,	*Sedum album, Lavandula*	Soil depth limits biomass;
Edible gardens & community plots	Soil contamination,	Low metal uptake, compact	Food provision, education, social	*Solanum lycopersicum,*	Regular soil testing; avoid leaf
Riparian or low-lying areas	Flooding, variable moisture	Adventitious rooting,	Stormwater retention, habitat	*Salix viminalis, Iris pseudacorus,*	Monitor spread; exclude invasive
Compact urban plazas /	High temperature, low	Reflective leaf surfaces, deep	Microclimate regulation,	*Ginkgo biloba, Zelkova serrata,*	Non-native; verify compliance with

(WUE = Water-Use Efficiency)

Using the matrix

1. Identify local constraints
2. → Map soil sealing, drought intensity, air quality, and heat-island gradients.
3. Define primary service goals
4. → e.g., cooling, biodiversity, food production, stormwater control.
5. Select trait profiles that match both
6. → Functional compatibility ensures long-term performance.
7. Verify ecological and legal limits
8. → Exclude species on the EU invasive list and those with low trophic or safety value.

The decision matrix encourages a multi-criteria perspective, integrating ecology, design, and policy. It can be expanded into digital GIS-based tools for adaptive urban greening planning.

Representative spatial typologies of urban agriculture: ground-based cultivation, rooftop food production systems, and indoor or vertical growing environments, illustrating distinct spatial constraints and management conditions.

4.1.2 Physiological background of urban plant performance

Liliana Bădulescu, Oana Venat, Milena Yordanova

Urban environments do not merely impose harsher conditions; they impose different physiological regimes. The defining feature of urban plant life is not the intensity of a single stress factor, but the chronic coexistence of thermal load, atmospheric pollutants, irregular water availability, and physical soil constraints. As a result, plant success in cities is primarily a question of physiological regulation and plasticity rather than maximal growth potential.

One of the earliest physiological interfaces affected by urban conditions is gas exchange. Elevated concentrations of ozone (O_3) and nitrogen oxides (NO_x), typical of traffic-dominated environments, enter the leaf predominantly through stomata. Species characterized by strict stomatal control, such as *Tilia cordata* or *Acer campestre*, often exhibit reduced instantaneous photosynthetic rates under polluted conditions, yet show greater long-term persistence due to limited pollutant uptake.

In contrast, species with high stomatal conductance may achieve rapid growth under favorable conditions but suffer cumulative oxidative damage in chronically polluted sites.

Photosynthetic performance in urban plants is further modulated by heat stress and oxidative pressure. Elevated temperatures associated with the urban heat island destabilize photosystem II and increase photorespiration, while particulate matter induces oxidative stress at the chloroplast level. **Urban-tolerant species** frequently compensate through enhanced antioxidant systems and adjustments in chlorophyll concentration. For example, *Platanus × acerifolia* maintains functional photosynthesis under elevated pollution loads partly through robust antioxidative capacity, which explains its widespread use in European cities despite suboptimal growth conditions.

Urban hydrology introduces a distinct physiological challenge: water availability becomes episodic rather than seasonal. Impervious surfaces limit i nfiltration, while shallow soils dry rapidly after precipitation events. Under these conditions, drought tolerance is less a function of deep rooting and more a function of hydraulic regulation. Species with **high intrinsic water-use efficiency** (iWUE), such as *Quercus ilex* or *Robinia pseudacacia*, can sustain metabolic activity during short but intense drought periods by maintaining favorable carbon - water trade-offs. **Osmotic adjustment** at the cellular level allows these species to preserve turgor even as soil water potential declines abruptly.

Belowground physiology plays an equally decisive role. Urban soils are typically compacted, heterogeneous, and periodically hypoxic, severely constraining root respiration and nutrient uptake. In this context, root-system plasticity outweighs absolute rooting depth. Species capable of proliferating fine roots in microsites with improved aeration and nutrient availability demonstrate superior establishment success. For instance, *Acer platanoides* exhibits considerable flexibility in root architecture, enabling survival in highly compacted roadside soils, whereas species with rigid root systems often fail despite adequate aboveground tolerance.

Urban stressors do not operate independently. Heat stress amplifies drought effects; pollutant exposure interacts with stomatal regulation; soil compaction exacerbates water stress by limiting root exploration. Successful urban plants integrate these pressures through coordinated physiological responses across organs and seasons. **Phenological plasticity,** including flexible timing of leaf emergence and senescence, allows plants to exploit short windows of favorable conditions. Early leafing in species such as Betula pendula may confer a temporary photosynthetic advantage in spring, while accelerated senescence later in the season reduces cumulative stress exposure.

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Plant species with high physiological plasticity in urban environments (physiological mechanisms enabling adaptation and urban benefits)

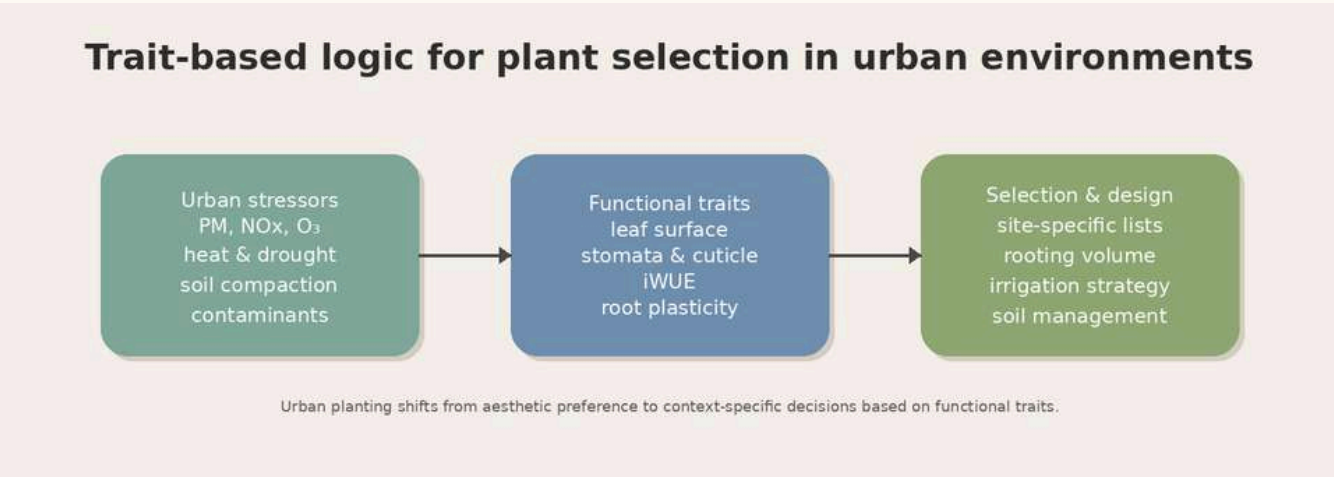
Species (Latin name)	Key physiological mechanism	Physiological basis	Functional benefit in urban environments
Acer campestre	Conservative stomatal regulation	Limits ozone uptake and transpirational water loss	High persistence along polluted streets
Platanus × acerifolia	Strong antioxidant capacity	Mitigates oxidative stress induced by PM and NO_x	High tolerance to atmospheric pollution
Tilia cordata	Phenological plasticity	Adjusts growth period to urban microclimates	Long lifespan and effective shading
Quercus robur	Hydraulic regulation	Maintains xylem conductivity under moderate drought	Structural stability in urban soils
Quercus ilex	High intrinsic water-use efficiency (iWUE)	Optimized carbon–water trade-off	Suitable for heat- and drought-prone areas
Robinia pseudacacia	Nitrogen fixation + high iWUE	Compensates nutrient-poor, dry soils	Rapid establishment and soil stabilization
Gleditsia triacanthos	Fine, compound leaves	Reduces leaf overheating and transpiration	Improved urban thermal comfort
Fraxinus excelsior	Root-system plasticity	Exploits aerated microsites in compacted soils	Survival in heterogeneous substrates
Ulmus minor (tolerant clones)	Integrated stomatal control	Balances gas exchange under stress	Controlled reintroduction in cities
Celtis australis	Heat tolerance	Maintains metabolic stability at high temperatures	High performance in southern urban climates
Betula pendula	Early phenology	Exploits short favorable spring windows	Fast early establishment
Elaeagnus angustifolia	Osmotic adjustment	Tolerance to salinity and drought	Reclamation of degraded urban sites

Plant species physiologically mismatched with urban environments
(physiological constraints and negative outcomes)

Species (Latin name)	Main physiological limitation	Typical urban manifestation	Practical consequence
Catalpa bignonioides	High susceptibility to powdery mildew	Chronic physiological stress in temperate continental climates	Persistent disease pressure
Aesculus hippocastanum	Low oxidative stress tolerance	Leaf necrosis, miner infestation	Rapid functional decline
Picea abies	Rigid hydraulic strategy	Severe drought stress	High mortality in cities
Abies alba	Sensitivity to air pollution	Chlorosis, reduced growth	Unsuitable for urban planting
Betula pubescens	High moisture demand	Chronic water stress	Poor urban survival
Fagus sylvatica	Low phenotypic plasticity	Heat and drought sensitivity	Failure in street environments
Acer saccharinum	Weak wood + poor stress regulation	Breakage and water stress	High maintenance costs
Prunus cerasifera	Permissive stomatal behavior	Pollutant-induced stress	Short urban lifespan
Magnolia × soulangeana	Sensitive root physiology	Stress under soil compaction	Poor performance outside parks
Thuja occidentalis	High transpiration rates	Rapid desiccation	Frequent losses in urban plantings
Pseudotsuga menziesii	Sensitivity to particulate matter	Photosynthetic imbalance	Inefficient in polluted areas
Larix decidua	Rigid phenology	Poor synchronization with urban climate	Low functional value
Populus alba	Excessive vegetative growth, allergies	Mechanical instability	Increased urban risk

Urban stressors and plant selection

Urban environments impose interacting abiotic constraints that differ in intensity and simultaneity from non-urban habitats. The most recurrent stressors are: atmospheric pollution (particulate matter, nitrogen oxides, ozone), increased thermal load via the urban heat island, altered water regimes (episodic drought, reduced infiltration), soil compaction with restricted rooting volume, and soil contamination with metals and persistent organic pollutants. Species performance is therefore not explained by a single “tolerance trait”, but by trait syndromes and by the timing/recurrence of stress exposure.



Urban plant performance is governed by the interaction of multiple stressors rather than by isolated tolerance traits; successful species selection requires an integrated, context-specific assessment of pollution, heat, water availability, and soil conditions.

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Edible plant cultivation in urban settings must explicitly consider organ-specific pollutant accumulation; fruiting species generally present lower food safety risks than leafy vegetables in contaminated contexts.

Native species offer ecological integration benefits, but urban resilience is not guaranteed by origin alone; functional compatibility with urban stress regimes is a more reliable criterion than nativeness *per se*.

A trait-based selection logic is increasingly recommended over generic planting lists. For example, leaf surface and cuticular features, together with stomatal behaviour, influence both pollutant injury and pollutant capture; meanwhile, water-use strategies (intrinsic water-use efficiency and drought strategy) and root-system plasticity become decisive under heat - drought - compaction combinations. Urban planting, when grounded in functional traits, supports both **survivorship** and **ecosystem services**, but requires site-specific matching rather than one-size-fits-all recommendations.

Leaf-level traits (cuticle properties, stomatal behaviour, surface roughness) and root-system plasticity are central determinants of plant resilience under chronic urban stress, particularly in compacted and contaminated soils.

Urban plants should be regarded as components of green infrastructure delivering ecosystem services (thermal regulation, air quality improvement, habitat provision), not merely as decorative elements.

Pollutant accumulation in edible urban plants

Urban agriculture provides valuable local food sources but operates under complex exposure to atmospheric and soil pollutants. The accumulation of contaminants in edible tissues depends strongly on both pollutant type (metals, organic compounds, airborne particles) and plant organ. Understanding these pathways is essential to ensure food safety and optimize species selection for urban growing systems.

Organ-specific accumulation patterns

1. Leaves. Foliar surfaces act as primary receptors for airborne pollutants. Fine particulate matter ($PM_{2.5}$–PM_{10}), soot, and metal-rich dust (e.g., Pb, Cd, Zn, Cu) can deposit on or penetrate the leaf cuticle, especially in plants with high surface roughness or pubescence. Leafy vegetables such as *Lactuca sativa* (lettuce) and *Spinacia oleracea* (spinach) often show the highest accumulation levels, particularly when grown near traffic corridors or industrial zones. Washing and peeling reduce but do not eliminate this risk
2. Roots and tubers. In contaminated soils, roots accumulate heavy metals and metalloids through uptake and adsorption processes. Root crops such as *Daucus carota* (carrot) and *Raphanus sativus* (radish) exhibit strong correlations between soil and tissue metal concentrations, with cadmium and lead as major concerns. Root morphology, soil pH, and organic matter content critically modulate bioavailability.
3. Fruits and seeds. Pollutant translocation to reproductive organs is generally limited. Fruit-bearing species such as *Solanum lycopersicum* (tomato), *Capsicum annuum* (pepper), and *Fragaria × ananassa* (strawberry) show significantly lower contaminant levels compared with leafy or root vegetables, as metals and organic pollutants rarely cross the phloem barrier efficiently

Comparative pollutant accumulation in edible plant organs

Plant organ	Dominant exposure route	Typical pollutants	Relative accumulation risk	Representative species
Leaves	Atmospheric deposition	Pb, Cd, Zn, PAHs, PM	High	*Lactuca sativa, Spinacia oleracea, Ocimum basilicum*
Roots / Tubers	Soil absorption	Pb, Cd, As, Cu	Medium–High	*Raphanus sativus, Beta vulgaris, Daucus carota*
Fruits / Seeds	Translocation via xylem	Minimal metal uptake	Low	*Solanum lycopersicum, Fragaria × ananassa,Prunus cerasus*

Beyond individual plant responses, pollutant accumulation has ecosystem-wide implications. In highly sealed or industrialized areas, airborne deposition contributes to soil contamination over time, creating feedback loops that affect microbial communities, soil fertility, and urban biodiversity. Integrating pollution-tolerant yet non-edible plant species in buffer zones - such as *Festuca arundinacea, Miscanthus sinensis,* or *Salix viminalis* - can help intercept contaminants and limit their transfer to food crops.

4.1.3 Food safety implications

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Urban-grown produce is not inherently unsafe, but risk depends on site history and pollution load. Raised beds with clean substrates, barrier layers, and atmospheric buffers (e.g., green walls, hedges) can significantly reduce contaminant exposure. Guidelines increasingly recommend prioritizing fruiting species for direct human consumption, while leafy vegetables are better suited to educational or decorative gardens unless soil quality is certified. Regular soil and tissue testing remains essential to comply with EU food safety standards (Regulation (EC) No. 1881/2006).

Edible urban plants vary widely in their pollutant accumulation capacity. Fruiting species are generally safer, while leafy and root crops require careful site management and monitoring to ensure food safety without compromising the ecological value of urban agriculture.

Urban design measures like vegetative barriers, vertical greening, and strategic crop zoning are now recognized as critical tools for maintaining food safety while preserving the ecological functions of urban green spaces. These solutions align with the “safe-to-grow” principle, emphasizing that urban agriculture should coexist with environmental restoration rather than compete with it (Guerrieri et al., 2024).

Food Safety, urban food movements and risk reduction

1. Urban food ideals meet environmental reality

Movements such as *Slow Food* (https://www.slowfood.com/), *short food supply chains (SFSCs)* - https://www.fao.org/family-farming/detail/en/c/415240/, and the *Edible Cities Network* (https://ediblecitiesnetwork.com/) emerged as responses to the industrialization of food systems. They promote proximity between producer and consumer, seasonality, and transparency - yet urban soils and air pollution introduce a paradox: the closer food is grown to consumers, the greater the potential exposure to contaminants.

Short supply chains are designed to ensure freshness and social equity, but urban environmental quality often determines food safety more than distance does (https://www.nss-journal.org/articles/nss/pdf/2017/01/nss170018.pdf?utm_source=consensus).

In cities like Hanoi, Dakar, and São Paulo, short-chain vegetable markets have improved local diets while facing challenges from irrigation water contamination and heavy metal residues.

2. Edible cities as laboratories of resilience

Urban projects across Europe, Asia, and Australia demonstrate that edible landscaping can coexist with food safety when science-based risk management is applied.

In **Málaga and Granada (Spain)**, peri-urban organic systems linked to local markets have shown how slow-food principles and safety monitoring can sustain trust between producers and citizens.

In **Melbourne (Australia)**, the "Edible Cities and Towns" initiative mapped over 100 urban farms and rooftop gardens; results showed food grown in raised beds and controlled media had contaminant levels well below regulatory limits.

In **Bangalore (India)**, local markets revealed high heavy-metal loads in fruits grown within the metropolitan area, underlining the need for source testing and consumer awareness.

Málaga and Granada
(Spain)

Melbourne (Australia)

Bangalore (India)

3. Balancing localism with precaution

Urban and peri-urban farms often occupy brownfields, road verges, or reclaimed industrial lands. Without remediation, such sites can accumulate Pb, Cd, and PAHs (polycyclic aromatic hydrocarbons) in edible tissues. A balance must therefore be maintained between the values of localism (freshness, community, reduced food miles) and the principles of toxicological precaution.

Contemporary "edible city" models - from Berlin to Oslo, Rotterdam, and Singapore - illustrate how controlled-environment systems (hydroponics, aquaponics, rooftop farms) can decouple production from soil contamination while still supporting short food chains.

Prinzessinnengarten community garden in St. Jacobi cemetery

Edible Cities Network (EdiCitNet) - Oslo

Rotterdam - DakAkker rooftopfarm

4. Towards risk-aware local food systems

Food safety in urban contexts depends on integrating citizen movements, municipal policies, and scientific risk assessment.

A sustainable short food chain must:

- Implement soil and water testing protocols for all edible gardens;
- Prioritize fruiting crops and raised-bed production in high-density areas;
- Foster urban circularity by reusing clean organic residues while excluding contaminated composts.

The synergy between slow food culture and urban resilience planning can thus produce edible cities that are both nutritionally meaningful and toxicologically safe - transforming urban food from a risk into a regenerative ecosystem function.

4.1.4 From aesthetics to functional resilience

Milena Yordanova, Mihaela Georgescu, Oana Venat, Sorina Petra

Urban-grown produce is not inherently unsafe, but risk depends on site history and pollution load. Raised beds with clean substrates, barrier layers, and atmospheric buffers (e.g., green walls, hedges) can significantly reduce contaminant exposure. Guidelines increasingly recommend prioritizing fruiting species for direct human consumption, while leafy vegetables are better suited to educational or decorative gardens unless soil quality is certified. Regular soil and tissue testing remains essential to comply with EU food safety standards (Regulation (EC) No. 1881/2006).

Edible urban plants vary widely in their pollutant accumulation capacity. Fruiting species are generally safer, while leafy and root crops require careful site management and monitoring to ensure food safety without compromising the ecological value of urban agriculture.

For much of the twentieth century, ornamental planting in cities was guided primarily by visual criteria: floral display, crown symmetry, seasonal color, and immediate aesthetic impact. Species selection was often driven by fashion, nursery availability, or symbolic value, with limited consideration for long-term performance under urban stress. As a result, many urban landscapes achieved short-term visual success at the expense of durability, ecological function, and maintenance efficiency.

Contemporary urban horticulture increasingly recognizes that ornamental plants must be evaluated not only as **decorative elements** but as components of **urban green infrastructure**. This shift does not reject aesthetics; rather, it reframes ornamental value within a functional context. A visually appealing species that fails physiologically under **pollution, heat, or soil compaction** rapidly loses both aesthetic and ecological relevance. In contrast, species with moderate ornamental traits but high resilience often provide sustained visual structure, seasonal continuity, and ecosystem services over decades.

Urban ornamental planting operates under conditions fundamentally different from those of parks, gardens, or peri-urban landscapes.

Street canyons, paved squares, traffic corridors, and residential courtyards impose spatial confinement, altered light regimes, reflected heat, and chronic atmospheric pollution. Under such conditions, ornamental performance depends less on maximal growth or floral abundance and more on stability of form, foliage persistence, and resistance to cumulative stress. This explains the continued prevalence of certain genera in urban settings, even when their ornamental expression is relatively restrained.

Woody ornamentals illustrate this functional transition particularly clearly. Species such as *Platanus, Tilia*, *Acer*, or *Gleditsia* are not selected solely for crown architecture or leaf shape, but for their capacity to maintain structural integrity and foliar function under repeated stress cycles. In contrast, species with spectacular flowering but narrow ecological amplitudes often perform well only in protected urban niches, such as inner courtyards or large parks with buffered microclimates.




Herbaceous ornamentals follow a similar logic. Annual species with high decorative impact may dominate seasonal displays, yet they require intensive inputs and frequent replacement. Perennial ornamentals, although often less visually striking at peak bloom, contribute to continuity, soil protection, and reduced maintenance over time. In urban contexts, ornamental perennials that combine extended phenology with physiological tolerance offer a more sustainable alternative to purely seasonal planting schemes.

An additional challenge in ornamental urban horticulture is taxonomic homogenization. Repeated use of a narrow palette of "safe" species may initially reduce risk, but it increases vulnerability to pests, diseases, and climate anomalies. The widespread decline of once-dominant ornamental taxa illustrates the danger of relying on visual performance without sufficient functional diversity. Diversification of ornamental plantings, guided by functional traits rather than appearance alone, is therefore a central strategy for resilient urban landscapes.

Ultimately, ornamental planting in cities must be understood as a negotiated balance between **visual intention** and **ecological realism**. Successful designs do not maximize ornamental expression under idealized conditions; they optimize visual quality under constraint. This perspective aligns ornamental horticulture with broader goals of urban sustainability, climate adaptation, and long-term landscape stability.

Taxonomic homogenization and ornamental monocultures as a structural risk in urban horticulture

Taxonomic homogenization in urban ornamental plantings represents a well-documented phenomenon in contemporary cities, arising from the repeated use of a limited number of woody and herbaceous taxa perceived as reliable under a wide range of urban conditions. This process is driven by a combination of factors, including nursery production constraints, standardized planting guidelines, ease of maintenance, and the visual preference for uniform streetscapes. While such approaches may simplify design and management in the short term, they generate systemic vulnerability at the scale of the urban landscape.

From a functional and physiological perspective, homogenized ornamental systems concentrate similar trait syndromes across large spatial extents. When a dominant ornamental species exhibits a specific hydraulic strategy, phenological pattern, or defense profile, the entire planting system becomes synchronized in its response to environmental stress. Under conditions of increasing climatic variability, this synchronization amplifies the impact of extreme events such as heat waves, prolonged droughts, or episodic pollution peaks, leading to abrupt and widespread decline rather than gradual, localized damage.

The physiological consequences of taxonomic uniformity are particularly evident in woody ornamentals used along streets and in paved environments. Species selected primarily for crown architecture or rapid establishment often share limited tolerance ranges for **soil compaction**, **root hypoxia**, or **elevated surface temperatures.** Once these thresholds are exceeded, stress responses manifest simultaneously across large plant populations, resulting in **reduced photosynthetic capacity**, **premature senescence**, and increased **susceptibility to secondary biotic agents**. In this context, ornamental monocultures function as amplifiers of stress rather than buffers.

Taxonomically homogenized ornamental systems

- synchronized phenology
- uniform hydraulic strategies
- similar stress tolerance thresholds
- simultaneous photosynthetic decline
- high vulnerability to extreme events
- abrupt canopy loss
- unstable ecosystem service delivery

Functionally diversified ornamental systems

staggered phenology
- contrasting hydraulic behaviour
- differentiated stress responses
- buffered physiological performance
- localized damage instead of system collapse
- stable canopy structure
- resilient ecosystem service provision

Mitigating the risks associated with taxonomic homogenization requires a documented shift from species-based planting schemes to function-based selection frameworks in urban ornamental horticulture. Evidence from large European cities shows that diversification guided by functional traits, rather than by taxonomic identity alone, significantly reduces system-level vulnerability. For example, urban greening programs in cities such as Berlin, Stockholm, and Barcelona have progressively replaced uniform street tree plantings with mixed assemblages combining species with contrasting hydraulic strategies, phenological patterns, and thermal tolerances. These approaches aim to limit synchronous stress responses under heat waves or prolonged drought, which have been identified as major drivers of large-scale ornamental decline in temperate and Mediterranean cities.

Empirical studies consistently indicate that physiologically heterogeneous plantings maintain canopy function and visual continuity more effectively under extreme climatic events than taxonomically uniform systems.

Importantly, resistance to taxonomic homogenization cannot be achieved through design decisions alone, as institutional frameworks strongly shape the composition of urban ornamental vegetation. Municipal procurement rules, standardized planting lists, and maintenance contracts often favor a narrow selection of well-known ornamental taxa, reinforcing uniformity despite growing scientific evidence supporting diversification. Case studies from cities that have revised their planting guidelines - such as the integration of climate-adapted species lists in Northern European municipalities following recent drought episodes - demonstrate that diversification becomes effective only when supported by policy, management protocols, and long-term monitoring. Consequently, addressing taxonomic homogenization must be understood not merely as a horticultural or ecological issue, but as a combined scientific and governance challenge, requiring alignment between urban ecology research, planning regulations, and operational practices.

https://www.researchgate.net/publication/262051792_Global_patterns_of_diversity_in_the_urban_forest_Is_there_evidence_to_support_the_102030_rule
https://www.researchgate.net/publication/355563830_Homogenization_of_tree_species_diversity_in_urban_green_spaces_along_a_temperature_gradient_in_eastern_China
https://www.sciencedirect.com/science/article/pii/S0304423821003551?utm_source=chatgpt.com
https://www.sciencedirect.com/journal/urban-forestry-and-urban-greening/issues
https://www.sciencedirect.com/science/article/pii/S030147972100222X

Native vs. non-native species in urban planting

In urban horticulture, the distinction between native and non-native plant species cannot be reduced to a biogeographical label, as cities function as novel ecosystems characterized by altered thermal regimes, fragmented soils, modified hydrology, and chronic anthropogenic disturbance. Under these conditions, species performance is determined primarily by **functional traits and stress tolerance**, while species origin becomes a secondary, context-dependent factor.

Large-scale comparative analyses demonstrate that urbanization is consistently associated with biotic homogenization, expressed as reduced taxonomic and functional diversity across cities. In a global study covering more than 110 cities, Aronson et al. reported that urban floras retain only a fraction of the native plant species density found in surrounding natural landscapes, while simultaneously increasing similarity among cities worldwide. This convergence is driven by repeated use of a limited pool of ornamental species and by environmental filtering imposed by urban conditions. However, reduced representation of native species in urban cores does not imply ecological irrelevance of native vegetation. On the contrary, multiple empirical studies demonstrate that native plants provide disproportionately higher trophic support to urban fauna. Burghardt et al. quantified insect herbivore abundance on native versus non-native woody plants and showed that native species support significantly higher biomass and diversity of *Lepidoptera* larvae, a key food resource for **insectivorous birds**.

In suburban landscapes dominated by non-native ornamentals, this trophic bottleneck translates into reduced avian reproductive success. Urban planting systems function as novel ecosystems, where plant performance depends on functional traits rather than on strict biogeographic origin. Yet, the balance between native and non-native species remains one of the most debated issues in urban horticulture and restoration ecology.

1. Context and functional perspective

In urban horticulture, the distinction between native and non-native plants cannot be reduced to geography. Cities are novel ecosystems, shaped by altered microclimates, compacted soils, and pollution. Under such pressures, functional traits - drought tolerance, canopy cooling capacity, pest resistance - determine success more than biogeographic origin.

A large-scale meta-analysis by Tartaglia & Aronson (2024) covering 165 studies found that native plants support higher faunal diversity and a broader range of ecosystem services than non-native taxa, especially in pollinator and bird abundance. However, about 25% of non-native species demonstrated strong adaptability and physiological performance in highly disturbed urban microsites.

Urbanization leads to biotic homogenization, reducing both taxonomic and functional diversity across cities. Comparative analyses confirm that native flora supports richer trophic networks - especially insect herbivores and their avian predators—than non-native ornamentals (Litt & Pearson, 2013).

Functional studies show that when native biomass drops below ~60–70% of landscape vegetation, bird reproductive success declines due to reduced insect prey availability - highlighting the ecological role of native vegetation as a food web foundation.

2. Performance under environmental stress

Contrary to trophic trends, non-native species often show higher physiological plasticity. In cities like Madrid and Paris, drought-tolerant exotics such as *Koelreuteria paniculata*, *Gleditsia triacanthos*, and *Sophora japonica* outperform native trees in sealed or compacted soils.

Comparative attributes of native vs. non-native urban plants

Criterion	Native species	Non-native species
Trophic value	High – supports insects & birds	Often low – fewer coevolved fauna
Physiological tolerance	Moderate – stress sensitive	High – adaptable to drought, heat, salinity
Ecosystem services	Enhances biodiversity & nutrient cycling	Provides shade, cooling, pollution buffering
Management needs	May require irrigation or improved soils	Low-maintenance once established
Risk potential	Minimal, but limited adaptability	Invasiveness, ecological displacement

This supports a “trait-based” selection approach, where tolerance to heat, drought, and pollution can justify cautious use of well-behaved exotics in engineered sites. Trait convergence between native and non-native plants has been documented along climatic and urban stress gradients

Functional integration - combining native plants for biodiversity support with non-natives for environmental buffering - has proven more effective than strict nativeness policies.

Urban forest network analyses reveal that mixed stands provide higher resilience to pests and heatwaves, while preventing monocultural collapse.

3. Resilience and regulatory frameworks

Urban biodiversity planning across Europe now emphasizes diversity over purity. Cities like Vienna, Ghent, and Copenhagen apply the “10-20-30 rule”:

no more than 10% of one species, 20% of one genus, or 30% of one family within the total tree population - a policy that minimizes systemic risks and pest outbreaks.

Under EU Regulation No. 1143/2014, urban planners must assess invasion risk before planting or trading non-native species. Lists are regularly updated; for example, *Ailanthus altissima* and *Robinia pseudoacacia* are banned due to aggressive propagation and allelopathic effects.

Marcolin, F., Mammola, S., Alba, R., Segurado, P., Reino, L., & Chamberlain, D. (2025). Socio-Economic Status and Non-Native Species Drive Bird Ecosystem Service Provision in Urban Areas. Global Change Biology, 31. https://doi.org/10.1111/gcb.70311.

4. Applied design synthesis

Modern urban ecology therefore converges toward a hybrid planting philosophy:

- Native species → maximize biodiversity and trophic support in soil-connected parks and corridors.
- Non-native, stress-tolerant taxa → secure resilience in highly engineered sites (paved plazas, street corridors, rooftops).
- Functional trait diversity → reduces vulnerability to climate extremes and pests, fostering long-term ecological stability.

Key takeaway

- Ecological performance outweighs species origin in determining urban plant success.
- Native species are vital for biodiversity and trophic networks.
- Selected non-natives enhance resilience where native options fail.
- Regulation (EU) No. 1143/2014 ensures ecological safety in plant introductions.
- Urban design should integrate functional diversity, not ideological purity.

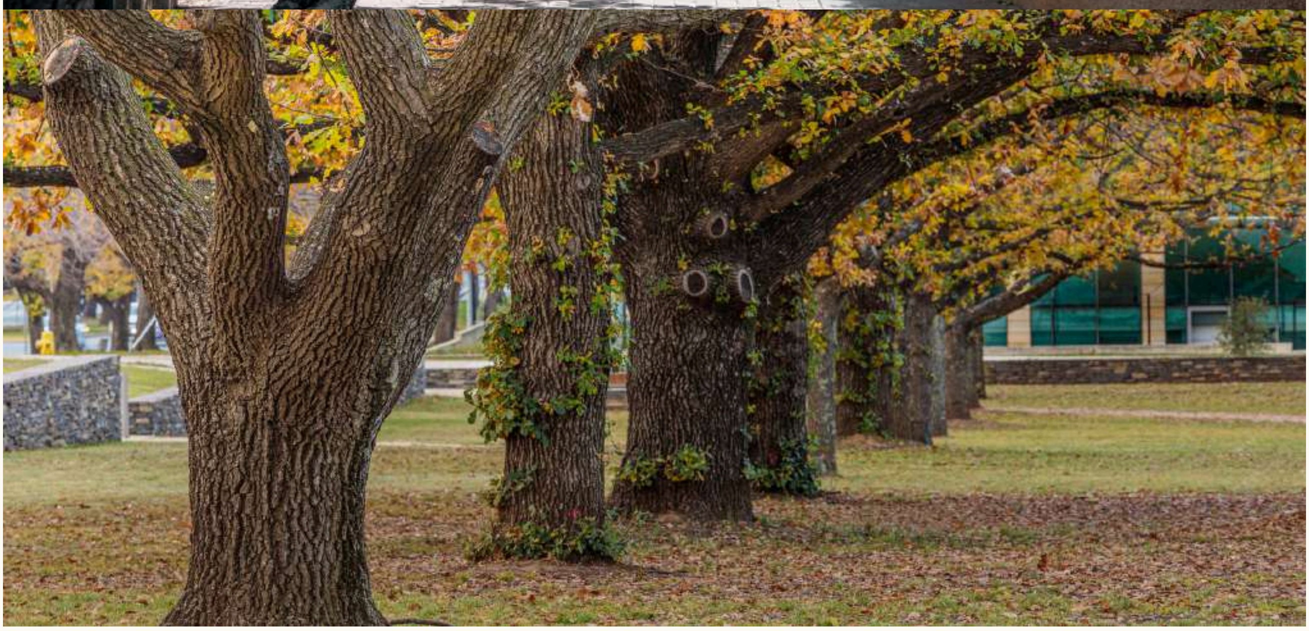
Unit 4.2 Plants suitable for different environments

4.2.1 Plants for ornamental gardening

Milena Yordanova, Vera Petrova,
Mihaela Georgescu, Sorina Petra

The selection of plant species is determined by climatic conditions, primarily low temperatures and the ability of species to withstand winter conditions, as well as summer heat and drought and their resilience. Local, well-known, and adapted species are favored, along with those specifically suited for such types of gardens.

According to a study by Pauleit et al., (2002), even though a variety of species are used in Central and Northwest Europe, only 3-5 genera represent 50-70% of all trees. Among the most commonly used are linden, maple, plane tree, horse chestnut, oak, and ash (*Tilia* sp., *Malus* sp., *Platanus* sp., *Aescules* sp., *Quercus* sp., and *Fraxinus* sp.). They have found that in some cities, only one species may dominate, as exemplified by Reykjavik, where 90% of new street trees represent a single species of poplar (Populus trichocarpa). According to them, cities in Southern Europe and the Mediterranean also use a wide variety of species, with common choices including plane tree (*Platanus x acerifolium*), holm oak (*Quercus ilex*), black locust (*Robinia pseudacacia*), hackberry (*Celtis australis*, *C. occidentalis*), Japanese pagoda tree (*Sophora japonica*), silk tree (*Albizia julibrissin*), mulberry (*Morus* sp.), poplar (*Populus* sp.), and elm (*Ulmus* sp.). They add that parks tend to feature a greater diversity of species compared to street greening.



1. Urban ornamental flora: from aesthetics to resilience

A paradigm shift in urban design. Urban ornamental flora once served primarily as aesthetic components - tools for beautification, order, and visual harmony. From the nineteenth century through the early 2000s, ornamental planting was guided by principles of symmetry, color contrast, and species uniformity, echoing horticultural traditions rather than ecological realities.

However, since 2015, a profound paradigm shift has transformed the discipline: urban planting design is now assessed by its ecological performance and contribution to resilience under climate and environmental stress.

This evolution reflects the growing recognition that beauty alone cannot sustain cities under the pressures of heat, drought, and pollution.

The modern concept of ornamental planting expands beyond visual pleasure to include functional aesthetics — the capacity of designed vegetation to provide ecosystem services such as microclimate regulation, biodiversity support, and psychological restoration. Species traditionally chosen for flower color or leaf texture are now evaluated for drought tolerance, evapotranspiration efficiency, and pollinator support.

Lavandula angustifolia and *Salvia nemorosa* are used for their long flowering periods and resilience in dry, compact soils, offering both visual appeal and ecological value.

Research emphasizes that such multi-functional ornamentals reduce maintenance costs while increasing ecological connectivity and human well-being. (Toscano, 2025; Francini et al., 2022)

2. Design evolution and climate adaptation

Urban horticulture increasingly integrates resilience-based design, where selection criteria include physiological tolerance, rooting depth, and canopy structure. In Mediterranean and continental European cities, planners are shifting from high-input flower beds to perennial and drought-tolerant compositions, creating adaptive plant palettes for changing climates.

Examples include:

London's "pictorial meadows" - low-maintenance, pollinator-rich plantings replacing annual displays.

Milan's Bosco Verticale - ornamental species combined with shrubs and trees for shading, dust capture, and biodiversity refuge.

Copenhagen's Climate-Adapted Parks - resilient ornamental mixes designed for both aesthetics and stormwater retention.

Such projects demonstrate how ornamental flora becomes an infrastructure component, not just a decorative layer.

(Orlóci, 2023)

London’s “pictorial meadows”

Milan’s Bosco Verticale

Copenhagen’s Climate-Adapted Parks

From aesthetic appeal to ecological resilience

Traditional ornamental approach	Resilient ornamental approach
Focus on symmetry, color harmony	Focus on function and adaptability
Exotic species prioritized for novelty	Native or drought-tolerant species prioritized for stability
Frequent maintenance and irrigation	Low-maintenance, water-efficient systems
Short-term visual impact	Long-term ecological and climatic performance
Decorative monocultures	Mixed plantings with layered biodiversity

3. Ecosystem services delivered by ornamental plants

Modern ornamental landscapes provide multiple services beyond aesthetics:

- Climate regulation: through shading, evapotranspiration, and albedo effects.
- Air purification: by particulate capture on leaf surfaces and canopy density.
- Habitat creation: supporting pollinators and small fauna through flowering continuity.
- Human well-being: by fostering restorative environments and green visual access.

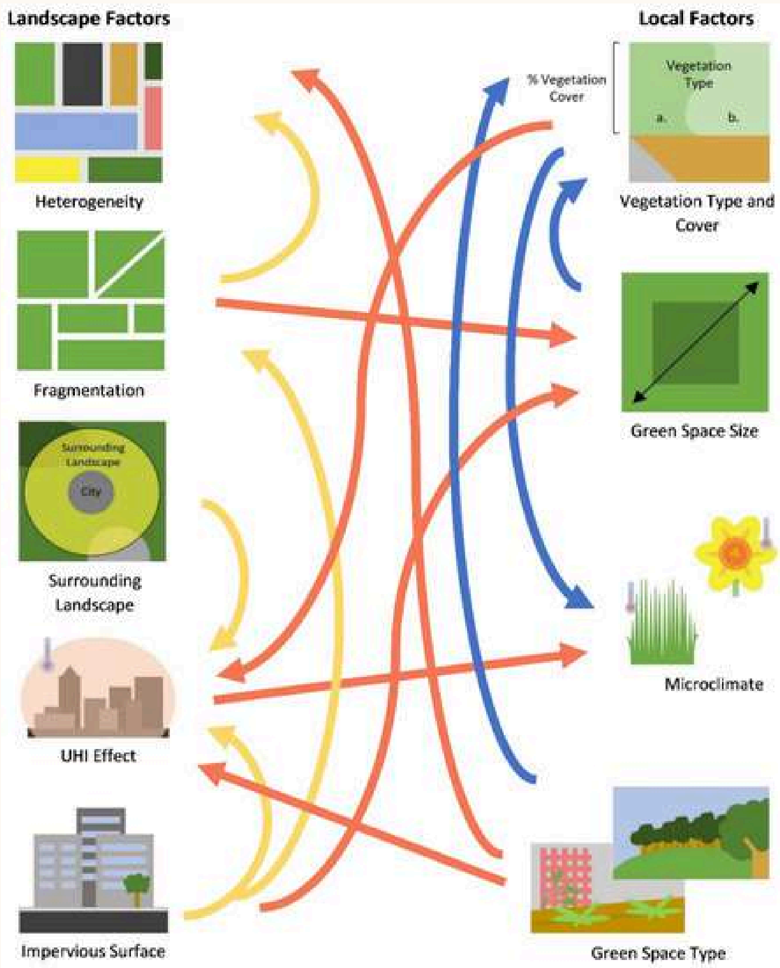
These combined effects reinforce the concept of “ornamental resilience”, where beauty and function co-evolve within the urban fabric (Francini et al., 2022).

From pollinator-supporting plant assemblages to vertical planting systems

Urban studies on plant–pollinator interactions underline the importance of plant composition and floral abundance in sustaining pollinator communities within built environments. Evidence from a survey conducted in urban plots in Zurich illustrates this relationship clearly. A total of eighty-nine plant patches were analysed, recording sixty-seven plant species belonging to nineteen plant families. Among these, *Asteraceae* (17 species), *Fabaceae* (11 species), and Lamiaceae (8 species) emerged as the most species-rich families.

Beyond species richness, floral abundance showed an even stronger concentration within a limited number of plant families. The majority of flowers recorded originated from *Fabaceae* (9,965 flowers), followed by *Asteraceae* (4,180 flowers) and *Lamiaceae* (1,133 flowers), indicating that a small subset of taxa provides a disproportionate share of floral resources for pollinators in urban contexts. These quantitative patterns suggest that ecological functionality in cities depends less on overall plant diversity and more on the targeted inclusion of functionally dominant plant groups.

As ground-level space for planting becomes increasingly constrained in dense urban environments, the implications of these findings extend beyond horizontal garden layouts. The concentration of pollinator resources within specific plant families supports the extension of these functional assemblages into vertical systems. Green walls and bio walls can therefore be designed to replicate the same quantitative logic observed at ground level, integrating flowering species with high pollinator value into façades and rooftop structures. In this way, vertical planting systems move beyond decorative applications and become functional components of urban green infrastructure, capable of supporting biodiversity under severe spatial limitations.



Ayers, A. C., & Rehan, S. M. (2021). Supporting Bees in Cities: How Bees Are Influenced by Local and Landscape Features. Insects, 12(2), 128. https://doi.org/10.3390/insects12020128

4.2.2 Urban vegetation: benefits, risks, and vulnerable populations

Oana Venat

The hidden vulnerability of urban monocultures

Urban landscapes often reveal a deceptive diversity - thousands of trees lining boulevards and parks, yet most belonging to just a handful of species. This phenomenon, known as taxonomic homogenization, results from decades of aesthetic and maintenance-driven planting practices that favored visually uniform, fast-growing ornamentals. However, cities dominated by only a few species or genera face increased biological vulnerability, reduced ecosystem stability, and a higher probability of functional collapse under stress.

Across Europe, a few ornamental trees have long dominated cityscapes:

- *Platanus × hispanica* (London plane),
- *Tilia cordata* (small-leaved lime),
- *Acer platanoides* (Norway maple),
- *Aesculus hippocastanum* (horse chestnut),
- *Robinia pseudoacacia* (black locust).

While each species excels in particular traits - rapid growth, tolerance to pruning, or air pollution - reliance on them has led to recurrent ecological crises.

The *Dutch Elm disease* wiped out *Ulmus minor* populations in nearly every European capital during the 20th century; the ash dieback (*Hymenoscyphus fraxineus*) now threatens *Fraxinus excelsior* in northern cities; and *Cameraria ohridella*, the leaf-miner moth, has devastated *Aesculus hippocastanum* in central and eastern Europe.

(Britt & Johnston, 2020; Pauleit et al., 2022)

Dutch Elm disease

Ulmus minor

Hymenoscyphus fraxineus

Fraxinus excelsior

Cameraria ohridella

Aesculus hippocastanum

Dominant urban species and associated risks

Dominant species	Main use	Common vulnerability	Recent pest/disease threat	Suggested diversification
Platanus × hispanica	Street trees, boulevards	Susceptible to plane wilt (*Ceratocystis platani*)	Plane canker, heat stress	Include *Zelkova serrata, Celtis australis*
Acer platanoides	Parks, avenues	Sensitive to heat, compacted soils	Verticillium wilt	Combine with *Acer campestre, Carpinus betulus*
Tilia cordata	Shade and pollinator tree	Aphids, root compaction	Sooty mold outbreaks	Mix with *Tilia tomentosa, Sophora japonica*
Aesculus hippocastanum	Historic avenues	Leaf miner (*Cameraria ohridella*)	Recurrent defoliation	Replace with *Acer pseudoplatanus, Koelreuteria paniculata*
Robinia pseudoacacia	Rapid colonizer, tolerant	Invasive, allelopathic	Root spread and shading dominance	Limit use; prefer *Gleditsia triacanthos, Albizia julibrissin*

Taxonomic homogenization not only amplifies pest outbreaks but also undermines ecosystem service redundancy - the capacity of multiple species to provide similar ecological functions. When 70% of the urban canopy belongs to one genus, the loss of a single pathogen-sensitive species can cause systemic failures in shade, cooling, or air filtration. To prevent this, arboricultural planning in cities like **Vienna, Copenhagen, and Paris** now follows the **Santamour 10-20-30** rule:

no more than 10% of one species, 20% of one genus, or 30% of one family in the total tree stock.

(Freiburger et al., 2025)

Additionally, the use of “novel natives” - ecotypes and provenances adapted to urban climates - expands resilience without increasing invasion risk.

Projects in **Berlin and Madrid** have shown success using *Quercus cerris, Celtis australis,* and *Sophora japonica* to diversify ornamental canopies under rising heat and drought stress.
(Calfapietra et al., 2020)

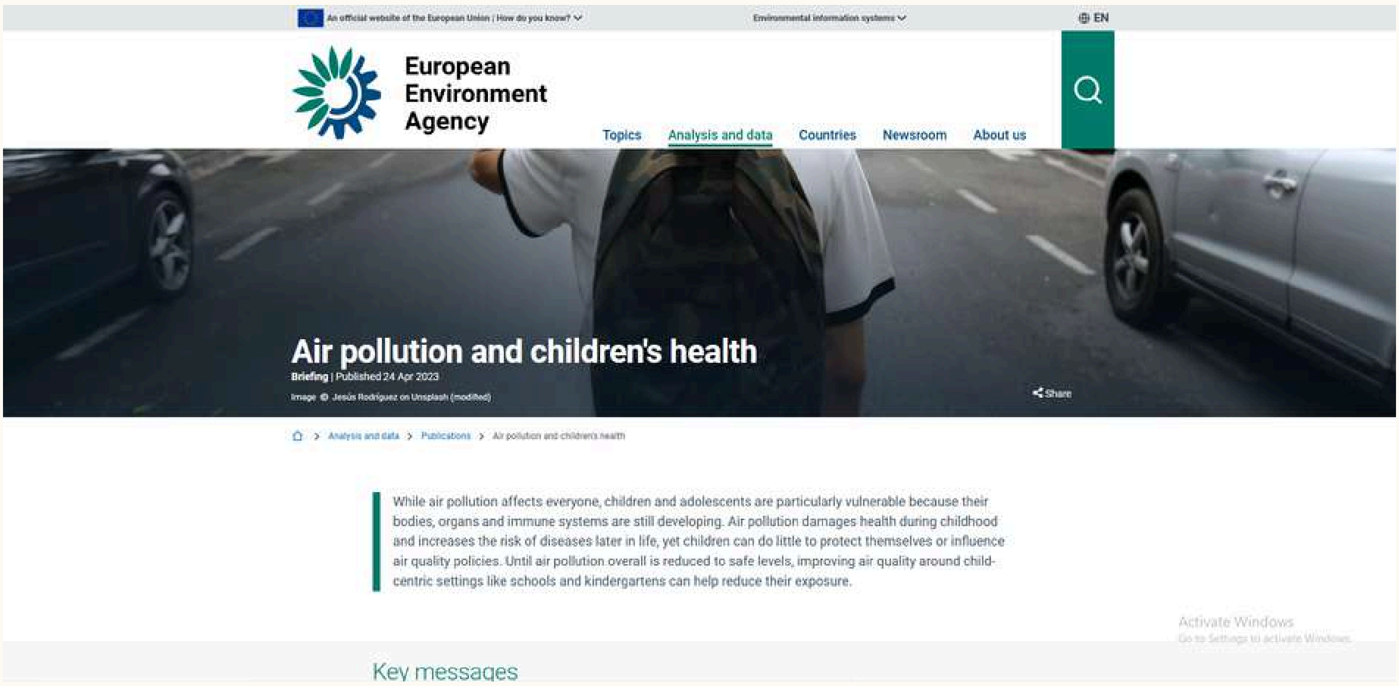
Health risks in children and vulnerable populations linked to urban vegetation and environmental exposures

1. Vulnerability of children and other at-risk groups to urban environmental hazards

Children are among the most vulnerable to environmental exposures because their lungs, immune systems, and neurological systems are still developing, they breathe more air per body weight than adults, and they spend significant time outdoors. Early and sustained exposure to urban air pollution smog, fine particulate matter (PM2.5), nitrogen dioxide (NO_2), ozone (O_3), and volatile organic compounds - has been linked to reduced lung function, increased incidence of asthma and bronchitis, respiratory infections, and allergic diseases. These adverse effects begin even before birth and can persist into adulthood. (Tavares et al, 2025)

Air pollution is a major driver of these outcomes; for example in Europe, air pollution causes an estimated over 1,200 deaths per year in people under 18, along with worsened lung development and allergy risk. Children's elevated breathing rates and proximity to ground-level pollutants further exacerbate exposure.

Older adults, pregnant women, people with pre-existing respiratory or cardiovascular disease, and socio-economically disadvantaged groups are similarly more susceptible to the same urban environmental stressor - especially fine particulate matter and traffic-related emissions - which can worsen chronic conditions and lead to higher hospitalization rates. (Arriazu-Ramos et al., 2025)



2. Urban vegetation: benefits versus pollen-related health risks

Urban greenery and street trees are widely promoted for their beneficial roles: reducing air pollution, lowering local temperatures, supporting mental health, promoting physical activity, and improving well-being. However, when specific plant species produce high quantities of allergenic pollen, they can also trigger or exacerbate allergic diseases - especially in sensitive populations such as children and individuals with asthma or allergic rhinitis.

Allergenic Pollen and Respiratory Health

Many common tree and plant species found in cities produce wind-dispersed pollen that easily enters the respiratory tract:

- Birch (*Betula spp.*), alder (*Alnus spp.*), and hazel (*Corylus spp.*) are major sources of allergenic tree pollen in parts of Europe and are frequently implicated in allergic reactions.
- Grass pollen (e.g., ryegrass) and certain weeds like ragweed (*Ambrosia artemisiifolia*) are significant triggers of hay fever and allergic asthma.
- These pollens are easily inhaled and can provoke immune-mediated responses such as allergic rhinitis, conjunctivitis, and asthma exacerbations in sensitized individuals.

Recent urban studies show that the health risks associated with pollen exposure vary by species composition, abundance, and environmental change: when green spaces are dominated by high-allergen species or have prolonged pollen seasons (due to climate change), respiratory health risks are amplified. (Stevanovic et al., 2025;

The interaction between air pollution and pollen is especially important: pollutants like ozone and NO_2 can modify pollen proteins, increasing their allergenicity and making symptoms worse. This interplay has been linked to higher asthma incidence and severity in polluted urban settings.

Species and urban planning implications

Urban planners and horticulturists must balance beneficial green infrastructure with allergen risk mitigation. Reviews emphasize that:

Reducing the use of wind-pollinated, highly allergenic species (e.g., certain birches, grasses, and ragweed) can help minimize pollen-related health risks in city environments.

Choosing insect-pollinated plants, increasing diversity of species with low allergenic potential, and managing plant gender ratios (to favor less pollen production) are strategies that support both ecosystem services and health protection.

Risk mapping approaches increasingly integrate allergenicity indices and species composition data in urban green space planning to identify areas where pollen risk may be concentrated and to guide planting decisions with public health considerations.

Climate change, health vulnerability, and urban plant risks

Climate-driven intensification of health risks

Climate change acts as a multiplier of existing vulnerabilities in cities.

- Rising temperatures, prolonged droughts, and increased air stagnation episodes amplify both air pollution exposure and biological stressors such as pollen, molds, and vector-borne diseases.
- Children, older adults, and individuals with pre-existing health conditions experience disproportionate effects because their **thermoregulation, immunity, and respiratory systems are less adaptive**.

Recent assessments from the Lancet Countdown on Health and Climate Change (2024) show that heat-related mortality in European cities has increased by 30–50% in adults over 65 during the last two decades, and asthma hospitalizations in children correlate strongly with warmer, pollen-intensive seasons.

Recent urban studies show that the health risks associated with pollen exposure vary by species composition, abundance, and environmental change: when green spaces are dominated by high-allergen species or have prolonged pollen seasons. (Bignier et al., 2025; Urrutia-Pereira et al., 2025; Esposito et al., 2025)

Pollen, heat, and pollution synergy

Warmer climates extend and intensify pollen seasons, particularly for species such as Betula (birch), Platanus (plane trees), and Ambrosia (ragweed). Rising CO_2 concentrations increase pollen production per plant and elevate allergenic protein content, aggravating allergic diseases. A 2023 multi-city study (Allergy, 2023, 78(5)) showed that in Europe, pollen-related emergency visits for asthma increased by 17% during prolonged heatwaves, compared with cooler years.

Moreover, climate-induced air pollution (ozone, $PM_{2.5}$, NO_2) alters pollen structure, making allergenic proteins more bioavailable and potent.

This triple interaction — **heat + pollution + pollen** — is now recognized as one of the primary urban environmental health risks for children and respiratory patients.

(Chaochen et al., 2023; Peden et al., 2028)

Vector-borne and infectious disease dynamics

Urban heat islands and milder winters allow new vectors and pathogens to persist and expand into previously temperate cities.

Mosquito species such as *Aedes albopictus* (Asian tiger mosquito) - a carrier of dengue, Zika, and chikungunya - have established permanent populations in southern and central Europe.

Tree pits, rooftop gardens, and poorly drained green infrastructures can become vector breeding habitats if not managed with appropriate drainage.

Hort4EUGreen

The European Centre for Disease Prevention and Control (ECDC, 2024) now includes over 350 European municipalities with confirmed *Aedes albopictus* presence.

https://www.ecdc.europa.eu/en/climate-change/climate-sensitive-diseases

Cardiovascular and thermal stress interactions

Elderly and chronically ill populations are particularly vulnerable to heat stress intensified by low-canopy or poorly planned urban vegetation. While green cover generally lowers surface temperatures, certain ornamental designs with high albedo surfaces and limited transpiration (e.g., monocultures of *Tilia cordata* or *Acer platanoides* in paved squares) can create radiant heat traps.

Strategic canopy diversification - mixing shade-tolerant, deep-rooted, and high-transpiration species like *Quercus robur*, *Sophora japonica*, and *Gleditsia triacanthos* - can lower surface temperatures by 2 - 5 °C and reduce cardiovascular event risk during heat waves. (Panno et al., 2017; Lafortezza et al., 2019;).

Compound vulnerability, urban health, and preventive horticulture

Urban environmental inequities generate compound vulnerabilities where climatic, biological, and social stressors interact synergistically to exacerbate health risks among sensitive populations.

https://www.eea.europa.eu/en/analysis/publications/unequal-exposure-and-unequal-impacts
https://environment.ec.europa.eu/topics/urban-environment/urban-nature-platform_en

Communities residing in densely built, low-income districts experience a convergence of multiple exposures - elevated concentrations of airborne pollutants ($PM_{2.5}$, NO_2, and O_3), amplified heat stress due to limited evapotranspiration surfaces, and restricted access to restorative green spaces. Epidemiological evidence demonstrates that these populations also show higher prevalence of asthma, cardiovascular morbidity, and psychosocial strain, creating a feedback loop between environmental degradation and public health. Within this framework, maladapted vegetation design - characterized by the dominance of high-allergen, shallow-canopy, or thermally inefficient species - can unintentionally magnify urban heat and allergenic burden rather than mitigating them.

Contemporary landscape planning therefore promotes a "climate-healthy vegetation design" paradigm, integrating allergenicity indices, leaf-area density parameters, transpiration efficiency, and canopy shading coefficients into urban planting schemes to optimize biophysical regulation and minimize health risks.

From a policy and management standpoint, preventive horticulture constitutes a central mechanism for reducing environmental health disparities under accelerating climate stress. Municipal authorities are encouraged to embed quantitative health-risk assessment and biodiversity metrics into urban forestry and greening frameworks.

Planting strategies should explicitly exclude high-allergen, anemophilous taxa such as *Betula pendula, Populus alba*, and Ambrosia artemisiifolia from sensitive zones including schools, hospitals, and elderly care facilities. Conversely, low-allergen, entomophilous ornamentals such as *Magnolia grandiflora, Cornus kousa,* and *Liquidambar styraciflua* should be prioritized for multifunctional plantings due to their ecological stability and pollinator compatibility. Integrating heat-mapping tools, air-quality sensors, and GIS-based allergenicity modeling into greening plans enables adaptive management aligned with public health goals. These approaches are consistent with the WHO Healthy Cities framework and the EU Urban Greening and Climate Adaptation Strategy (2023), which jointly advocate the fusion of ecological functionality, environmental justice, and population health in vegetation-based urban resilience systems

4.2.3 Good practices across Europe

Oana Venat

Across Europe, urban horticulture good practices illustrate how plant diversity, spatial typologies, and management strategies can be adapted to local environmental, social, and climatic contexts. These practices reflect a shift from ornamental greening towards multifunctional urban systems that integrate biodiversity conservation, food production, ecosystem services, and circular resource use. By combining locally adapted species, appropriate cultivation techniques, and context-specific design, European examples reveal replicable pathways for functional urban green infrastructures.

Vienna, Austria - strategic diversification and institutional frameworks

Vienna's climate adaptation strategy includes explicit selection procedures for tree species in densely built areas, aimed at increasing tolerance to thermal and drought stress by integrating climate resilience criteria into municipal planting processes. Trees are no longer regarded solely as ornamental elements, but as components of broader solutions addressing not only the mitigation of the urban heat island effect, but also the provision of ecosystem services related to temperature regulation and local microclimate control. These plans are developed in accordance with Vienna's Nature Conservation Act and include recommendations for the management of urban forests.

https://www.wien.gv.at/spezial/klimafahrplan-monitoring-en/climate-adaptation/ecosystems-natural-and-recreation-areas/

Recent urban planning strategies combine the reduction of soil sealing with the expansion of "Grün- und Freiraum" (green and open spaces). This approach seeks to balance urban density with ecological connectivity, facilitating the coexistence of built infrastructure and diversified green elements.

Vienna has been recognised through the European City of the Trees award for its systematic efforts to improve the adaptation of urban tree ecosystems, including the use of centrally documented tree cadastres and the selection of root substrates that enhance water retention and soil aeration under shaded urban conditions. European City of the Trees (ECOT) is the title and award given by the European Arboricultural Council (EAC).The award is given annually to a town or city in recognition of efforts to care for trees in its urban area.

https://en.wikipedia.org/wiki/European_City_of_the_Trees

Diversification in this context does not merely imply the introduction of a greater number of species, but the establishment of an adaptive, data-driven municipal framework based on inventories, monitoring tools, and integrated urban planning policies that support long-term stability.
Critical perspective: the absence of comparable frameworks in other Austrian cities (e.g. Graz and Linz) highlights the need for metropolitan-scale planning rather than isolated district-level interventions. (Vuckovic et al., 2023)

Berlin (Germany) - Urban Nature Pact and climate-oriented planning

Berlin has adopted the Urban Nature Pact Guidance, a formal strategic framework through which local and regional authorities commit to biodiversity protection and climate change adaptation. The document provides guidance for integrating nature across urban policies (mobility, health, air quality, climate), including practical measures for the management and diversification of urban trees as a core element of green infrastructure.

(https://citieswithnature.org/wp-content/uploads/2025/02/Berlin-Urban-Nature-Pact_Guidance-v1_EN.pdf)

Local initiatives such as Urban Trees for Berlin focus on the planting of thousands of street trees (approximately 10,000 over five years), reflecting a shift from isolated planting actions to coherent efforts embedded within climate and urban health strategies.

https://una.city/nbs/berlin-fua/urban-trees-berlin

Berlin is updating its strategic instruments (e.g. StEP Klima / Urban Development Plan Climate 2.0) to incorporate long-term urban climate adaptation objectives and the management of structural green assets, including the diversification and enhancement of urban vegetation to counteract climatic stress and reduce urban heat island effects. Berlin provides an example of a holistic urban strategy in which tree diversity is embedded within a broader system of urban nature governance, encompassing connected green ecosystems and climate-oriented spatial planning rather than isolated greening actions. (Mukherjee et al., 2025)

Milan (Italy) - integrated urban projects and diversification

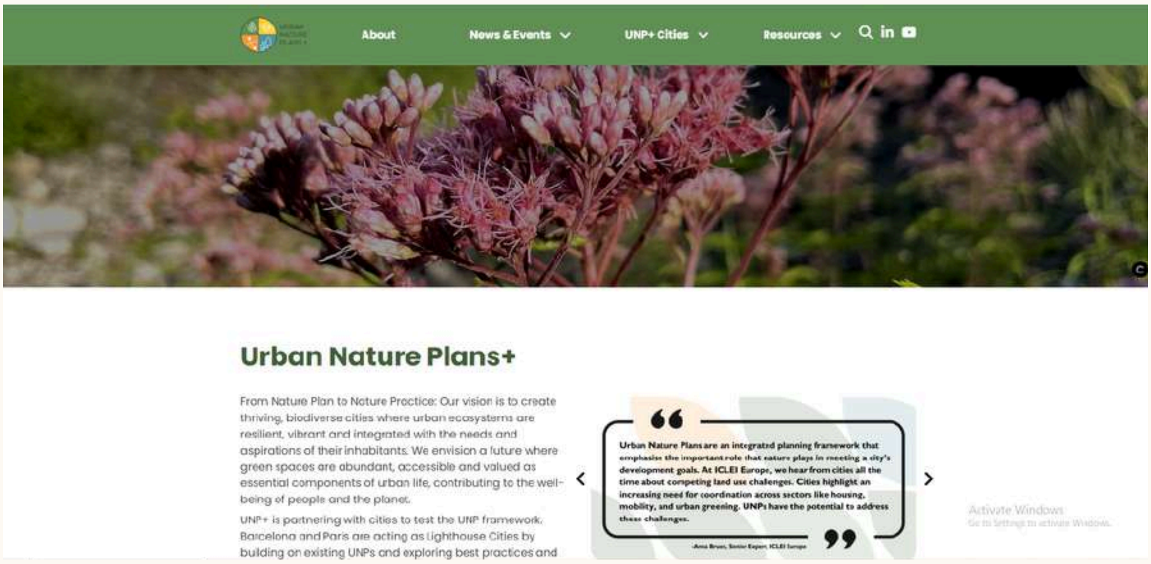
Milan has developed urban regeneration projects that incorporate structured and diversified green elements, a notable example being the Parco Biblioteca degli Alberi (BAM), which includes over 100 plant species and more than 500 trees organised into 22 circular groves within an urban park. This heterogeneous design supports not only species diversity but also differentiated microhabitats for urban fauna and pollinators.

In more recent initiatives, such as “tiny forest” projects inspired by the Miyawaki method in peri-urban areas, high-density planting schemes with diverse species palettes are being tested to accelerate the establishment of urban forest ecosystems and maximise ecosystem services, including microclimatic cooling and trophic support for insects.

https://www.etifor.com/en/updates/urban-forest-week/

Barcelona (Spain) - Urban Nature Plan and climate-resilient solutions

Barcelona was among the first European cities to adopt an **Urban Nature Plan (Pla Natura Barcelona)** as a coherent public strategy to expand and enhance urban green spaces and biodiversity. The plan includes explicit objectives for climate adaptation through the diversification of tree species and other functional green infrastructure elements.



https://oppla.eu/case-study/uforest-case-study-barcelona-nature-plan

Ongoing projects implemented under this plan focus on the creation of climate refugia, combining species selection with functional design and monitoring to increase tolerance to heat waves and reduce thermal stress for both urban populations and vegetation.

https://www.etifor.com/en/updates/urban-forest-week/?

Woody species diversity and climate adaptation

Woody species diversity represents one of the most robust and evidence-based strategies for enhancing urban climate adaptation. In contemporary cities, trees are exposed to cumulative stressors, including prolonged **heat waves**, **irregular precipitation patterns**, **soil compaction, atmospheric pollution**, and **de-icing salts**. Under these conditions, species selection can no longer rely primarily on ornamental value, but must be grounded in physiological tolerance and long-term functional stability. (Alvey, 2026)

Across European cities, several tree species have demonstrated consistent tolerance to urban stress. Among these, *Acer campestre, Tilia tomentosa, Celtis australis*, *Gleditsia triacanthos, Quercus cerris*, selected urban forms of *Quercus robur, Fraxinus angustifolia*, and resilient *Ulmus* cultivars are frequently cited for their adaptive capacity. These taxa combine drought tolerance, thermal resilience, and the ability to persist in compacted or nutrient-limited urban soils.

Urban forestry practice in several European cities illustrates a clear shift from monospecific tree plantings toward diversified species compositions as a climate adaptation measure, demonstrating that long-term canopy resilience relies on taxonomic and genetic diversity rather than on repeated use of a limited set of stress-tolerant species.

https://www.theguardian.com/cities/2023/jan/16/trees-green-vision-europe-cities?

https://environment.ec.europa.eu/news/half-urban-trees-are-outside-their-comfort-zone-future-plantings-must-consider-climate-resilience-2023-03-29_en

https://canopy.org/blog/the-urban-heat-island-effect/

Perennial herbaceous species and urban biodiversity. Role in trophic networks

Perennial herbaceous species play a structurally role in urban biodiversity, acting as a f**unctional interface** between woody vegetation and urban fauna. Unlike annual plantings, perennials provide spatial and temporal continuity, which is essential for pollinators, predatory arthropods, and soil-associated organisms.

From a trophic perspective, genera such as *Achillea spp, Salvia spp., Nepeta spp, Echinacea spp., Geranium spp., Sedum*, and *Rudbeckia* supply nectar, pollen, and shelter over extended periods. Beyond flowering, persistent stems and foliage contribute to decomposition processes, supporting detritivores and soil microfauna - components often overlooked in ornamental urban design.

The temporal distribution of flowering is a functional criterion rather than an aesthetic one. Early-flowering perennials such as *Pulmonaria spp.* and *Helleborus spp.*, mid-season taxa including *Salvia spp.* and *Coreopsis*, and late-flowering species such as *Aster spp.*, *Solidago spp.*, and *Sedum* spectabile ensure trophic continuity from early spring to late autumn. Without this succession, urban biodiversity remains fragmented and ecologically unstable.

Empirical evidence from European cities, including **Copenhagen, Malmö, Utrecht, and Lyon,** shows that perennial meadows managed under low-intensity regimes can support two- to threefold increases in insect diversity compared to intensively mown green spaces.

Functional trophic roles of perennial herbaceous species in urban ecosystems

Trophic function	Mode of action	Ecological consequence in urban systems
Primary resource provisioning	Continuous production of nectar, pollen, foliage, and seeds at low spatial scale	Maintains basal energy input into simplified urban food webs
Support for herbivore guilds	Host plants for larval stages of insects (Lepidoptera, Coleoptera, Hemiptera)	Enables completion of insect life cycles otherwise interrupted in urban matrices
Prey base stabilization	Sustains populations of phytophagous insects with limited dispersal ability	Prevents trophic bottlenecks at lower consumer levels
Detrital input	Annual and perennial biomass senescence at ground level	Fuels detritivore communities and microbial decomposers
Belowground carbon transfer	Root exudates and fine root turnover	Enhances soil microbial food webs and nutrient mineralization
Microhabitat creation	Dense foliage, basal rosettes, persistent stems	Provides refuge for arthropods from temperature extremes and predation

Mechanistic perspective

From a mechanistic standpoint, perennial herbaceous species increase trophic redundancy in cities. When woody plants fail to provide resources due to pruning regimes, drought stress, or phenological mismatches, perennials compensate through rapid regrowth and flexible phenology. This redundancy is essential for preventing collapse of urban trophic interactions during disturbance events. Moreover, perennials reduce trophic decoupling. In highly managed urban landscapes, primary producers and consumers often become temporally or spatially disconnected.

Trophic interactions supported by perennial herbaceous species across urban food-web compartments

Food-web compartment	Interaction mediated by perennials	Functional outcome
Primary producers → herbivores	Larval feeding, sap-feeding, leaf mining	Sustains insect biomass essential for higher trophic levels
Herbivores → predators	Concentration of prey near perennial patches	Enhances persistence of predatory insects and spiders
Predators → higher consumers	Increased availability of arthropods for birds and small vertebrates	Supports urban insectivorous fauna
Plant litter → detritivores	Continuous input of fine litter	Maintains decomposer-driven nutrient cycling
Soil microbes → plants	Accelerated nutrient turnover in rhizosphere	Improves plant resilience without external inputs
Trophic network as a whole	Increased interaction density	Greater stability and resistance to disturbance

Ornamental plants as pollinator resources

Ornamental plants can function as effective pollinator resources only when selected according to ecological criteria rather than purely horticultural or visual considerations. Highly bred cultivars with double flowers or sterile traits often provide negligible nectar or pollen, despite their visual appeal. Floral continuity is a prerequisite for functional pollinator support and requires the presence of accessible floral resources throughout the active season of insects.

Ornamental shrubs such as *Cornus mas, Amelanchier lamarckii, Viburnum opulus, Lavandula angustifolia*, and carefully selected Buddleja davidii cultivars extend the trophic window beyond the herbaceous layer. Seasonal selection should explicitly address urban "floral gaps," which frequently occur after spring bulb displays. In many European cities, visually attractive spring plantings are followed by prolonged periods with limited trophic value, negatively affecting local populations of solitary bees and bumblebees.

Urban planting models increasingly operate on the principle of functional layering, in which ornamental structure and trophic function are designed simultaneously rather than sequentially. These systems do not rely on spontaneous biodiversity enhancement, but on controlled spatial, temporal, and phenological planning that allows aesthetic coherence to coexist with measurable ecological output.

1. Structural design principles (technical perspective)

Dual-purpose plantings are typically organised using one of the following design logics:

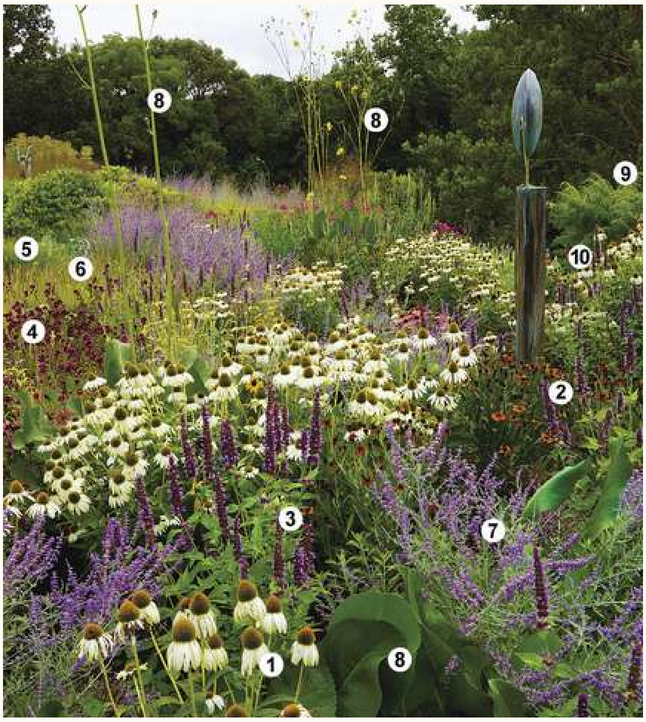
– matrix planting systems, where a dominant ornamental framework species (often structurally stable perennials or grasses) is interspersed with functionally active flowering species;

– layered beds, combining low perennial forbs, mid-height flowering species, and structural accents to create visual order while maximising interaction density;

– managed urban meadows, designed with controlled species composition and mowing regimes to balance appearance and trophic productivity.

In all cases, plant selection prioritises predictable architecture, controlled growth habit, and phenological complementarity, avoiding visual chaos while ensuring ecological continuity.

Source here



Base-level plants

1. 'White Swan' coneflower (Echinacea purpurea 'White Swan', Zones 3–9)
2. 'Mardi Gras' sneezeweed (Helenium 'Mardi Gras', Zones 4–8)
3. 'Black Adder' anise hyssop (Agastache 'Black Adder', Zones 6–9)
4. 'Herrenhausen' oregano (Origanum laevigatum 'Herrenhausen', Zones 7–10)
5. Tufted hair grass (Deschampsia cespitosa, Zones 5–9)
6. Autumn moor grass (Sesleria autumnalis, Zones 5–8)
7. Russian sage (Perovskia atriplicifolia, Zones 6–9)

Punctuation plants

8. Prairie dock (Silphium terebinthinaceum, Zones 3–9)

Focal points

9. Cutleaf staghorn sumac (Rhus typhina 'Laciniata', Zones 3–8)
10. Sculpture

Source here

Ponte de Lima, Portugal
Filipe Mesquita

Source here
USA, Bee City
Ashland, Oregon

2. **Mechanisms ensuring pollinator support within ornamental constraints**

The ecological functionality of these plantings emerges through several technical mechanisms:

– high accessibility floral traits (open corollas, exposed nectaries) are favoured over complex ornamental morphologies;

– staggered flowering phenology is programmed at the design stage, not left to chance;

– repetition of functionally equivalent species ensures redundancy without visual monotony;

– maintenance regimes (selective cutting, delayed mowing, partial biomass retention) are integrated into design specifications.

3. Technical examples of applied models in Europe

https://www.gardensillustrated.com/gardens/town-and-city/grey-to-green-sheffield

https://www.floretflowers.com/attracting-pollinators-into-the-garden/?

In Northern and Western Europe, particularly in the UK, the Netherlands, Germany, and Scandinavia, municipalities increasingly specify pollinator-supportive ornamentals within public planting tenders. These specifications often include functional criteria (flowering duration, nectar accessibility, maintenance tolerance) alongside visual parameters (height uniformity, colour palette, seasonal structure). Long-term monitoring shows that such plantings maintain design integrity while sustaining pollinator visitation rates comparable to semi-natural habitats.

From a systems ecology perspective, dual-purpose plantings increase interaction density without increasing maintenance complexity. By concentrating floral resources within visually ordered structures, they reduce spatial fragmentation of trophic resources and enhance foraging efficiency for insects. Equally important, these systems are socially acceptable. Aesthetic legibility ensures political and public support, which in turn secures continuity of management—an often underestimated prerequisite for ecological success in cities.

Conceptual reframing: ornamental planting as an urban ecosystem unit

In contemporary European practice, diversified ornamental planting is no longer approached as an assemblage of visually compatible species, but as a designed urban ecosystem unit. Such systems are expected to perform multiple, simultaneous functions: ecological regulation, biodiversity support, microclimatic buffering, and social legibility. The ornamental dimension is retained, yet subordinated to systemic performance.

This shift reflects a convergence across European cities toward function-oriented planting frameworks, where aesthetic coherence emerges from structure, phenology, and spatial order rather than from uniformity or repetition. A diversified ornamental planting system can be defined as:

a spatially organised, multi-layered plant assemblage designed to deliver continuous ecological functions (habitat, trophic support, microclimate regulation) while maintaining visual intelligibility and manageable maintenance regimes under urban conditions.

Management as a design variable

Across European urban contexts, management is no longer treated as a post-design constraint, but as a constitutive component of the system. Differential mowing, selective biomass retention, and reduced chemical inputs are predefined within planting concepts. Without such integration, species diversity remains static and fails to translate into functional biodiversity.

Convergent European principles for diversified ornamental planting systems

Principle	System-level meaning	Operational implication in urban planting
Functional primacy	Ecological processes precede visual effect	Species are selected for services provided, not appearance alone
Structural stratification	Vertical and horizontal ecosystem architecture	Integration of tree, shrub, and herbaceous layers; avoidance of monocultures
Temporal continuity	Ecosystem activity across the growing season	Staggered phenology: foliage, flowering, fruiting, biomass persistence
Redundancy without uniformity	Stability through functional overlap	Multiple species performing similar functions without taxonomic repetition
Managed disturbance	Design integrated with maintenance	Mowing, pruning, and biomass retention embedded in planning
Local ecological fit	Adaptation over trend replication	Species chosen based on pedoclimatic performance, not fashion

European guidelines increasingly emphasise structural logic rather than compositional richness per se. Vertical stratification (trees–shrubs - herbaceous layer) increases functional diversity, while horizontal heterogeneity prevents the amplification of biotic and abiotic stress. Importantly, repetition is applied at the level of function, not species identity.

Functional domains and expected ecosystem outputs in urban ornamental plantings

Functional domain	Key processes	Expected ecosystem output
Microclimatic regulation	Shading, evapotranspiration	Reduced surface and air temperatures
Trophic support	Nectar, pollen, herbivore biomass	Stable pollinator and arthropod populations
Habitat provisioning	Structural diversity, refuge	Increased persistence of urban fauna
Nutrient cycling	Litter production, decomposition	Enhanced soil fertility and microbial activity
Social acceptability	Visual order, seasonal structure	Public support and maintenance continuity

A recurring observation from long-term European practices is that locally adapted plant choices perform better than imported design concepts. Cities with stable ornamental plantings tend to rely on species and genotypes suited to local soils, climate, and urban pressures, even when these selections differ from current horticultural fashions.

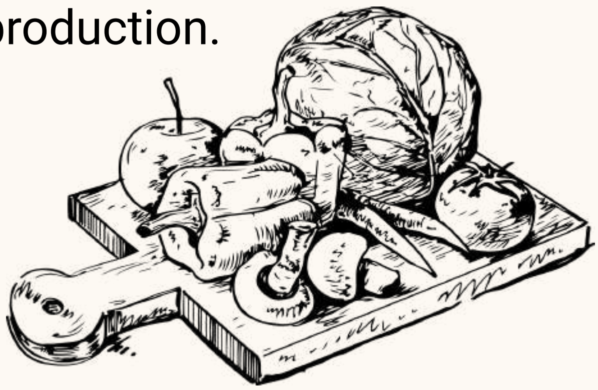
This principle reinforces the idea that resilience in ornamental plantings is not achieved through novelty, but through ecological coherence.

4.2.4 Urban horticulture

Adrian Asănică, Oana Venat,
Roxana Ciceoi, Milena Yordanova

Depending on the type of urban agriculture, a wide range of plants can be used – both annual and perennial; fruit trees, berry bushes, perennial species, as well as annuals. Among fruit trees, apples (*Malus spp*.), pears (*Pyrus* spp.), plums (*Prunus spp*.), cherries, hazelnuts, walnuts, mulberries (*Morus* spp.), and others are commonly used. Various berry bushes from the genera *Rubus, Ribes,* and *Vaccinium* can also be included in urban and fruit gardens (Romanova & Lovell, 2021).

In contemporary urban contexts, plant selection for urban agriculture can no longer be considered a neutral or purely horticultural choice. It is increasingly shaped by interacting constraints, including climatic stress, limited and fragmented space, restricted access to water and other inputs, and the need for stable and predictable production outcomes. Under these conditions, plants are selected not only for their edibility or adaptability, but for their capacity to perform reliably within constrained urban systems. This shift marks a transition from descriptive plant listing toward a system-based understanding of urban food production.



All vegetables can be grown under urban gardening conditions. In order to select the most suitable ones for the specific conditions, a basic knowledge of plants is necessary:

- botanical family and name
- botanical characteristics
- requirements for growth and development factors

In order to assess what types of plants, how many, and how to cultivate them in various types of urban agriculture, de Vries & Fleuren (2015) utilize a calculator for urban food production developed for the Netherlands. They apply it to different types of urban agriculture, considering both vegetarian and flexitarian dietary patterns, basing their testing on an average diet. Their conclusion is that local urban farming systems can provide a small portion of the population's food needs – for example, approximately half of the required quantity of vegetables and fewer potatoes and fish (in the studied Arnhem region). They highlight the absence of space for the production of grain crops, as well as dairy products in the surveyed areas. They suggest that production can be increased by introducing greenhouses, hydroponics, as well as intercropping or polyculture cultivation of plants.

Spatial organisation and production logic in urban agriculture

Urban agriculture is characterised by a high diversity of organisational forms, which differ substantially in scale, spatial distribution, level of professionalisation, and production objectives. Beyond the biological characteristics of cultivated plants, the way urban food production is structured in space plays a decisive role in determining what can be grown, in what quantities, and under which management conditions. For this reason, assessments of urban agriculture increasingly rely on spatial typologies that connect production potential to specific urban settings.

Such typologies are particularly useful for distinguishing between small-scale, household-based systems and larger, collectively or professionally managed forms of production. Productive house gardens, rooftop installations, allotment gardens, community gardens, and professional urban farms operate under markedly different constraints in terms of available area, access to infrastructure, labour input, and regulatory frameworks.

From a planning perspective, spatial typologies provide a common reference framework that allows comparisons across cities and production systems. They help translate abstract calculations of potential production into more tangible categories that reflect real urban land-use patterns. At the same time, they highlight structural limitations inherent to urban environments, such as the scarcity of continuous open land, competition with other urban functions, and the fragmented nature of productive spaces.

The following table summarises common types of urban agriculture, indicating their typical spatial scale, organisational form, and main categories of crops or products, and provides a structured overview of how urban food production is organised in practice.

The spatial typology proposed by **de Vries and Fleuren** provides an overview of how urban agriculture is organised in relation to available space, management structure, and dominant production types. Rather than describing individual projects, the typology groups urban food production systems into recurring categories, such as household-scale gardens, collective initiatives, and professional operations, allowing comparison across systems that differ in scale and organisation.

An important characteristic of this typology is its selective focus on plant-based production systems and closely integrated components. The calculations prioritise vegetables, herbs, fruits, and, in specific configurations, fish or poultry where these are directly linked to crop production systems, such as aquaponics or permaculture-based designs. Livestock systems requiring extensive space, including dairy production and large-scale animal husbandry, are intentionally excluded, reflecting structural constraints typical of urban environments.

From the perspective of plant selection, the typology illustrates that crop choice is closely conditioned by spatial and organisational context. Systems with limited surface area and private management tend to favour fast-growing, high-yield vegetable crops and herbs, while larger collective or professional systems can accommodate a broader range of plant species and cultivation techniques. In this way, spatial typologies provide an interpretative link between production estimates and practical decisions regarding crop selection in urban agriculture.

Among the urban farms analysed, vegetable and legume production is the most common activity, being present in eleven sites. Fruit cultivation is reported in ten farms, while herbs and spices are grown in eight. This pattern indicates that urban farms tend to prioritise crops with high productivity, short growing cycles, and flexible spatial requirements, which are better suited to limited urban spaces.

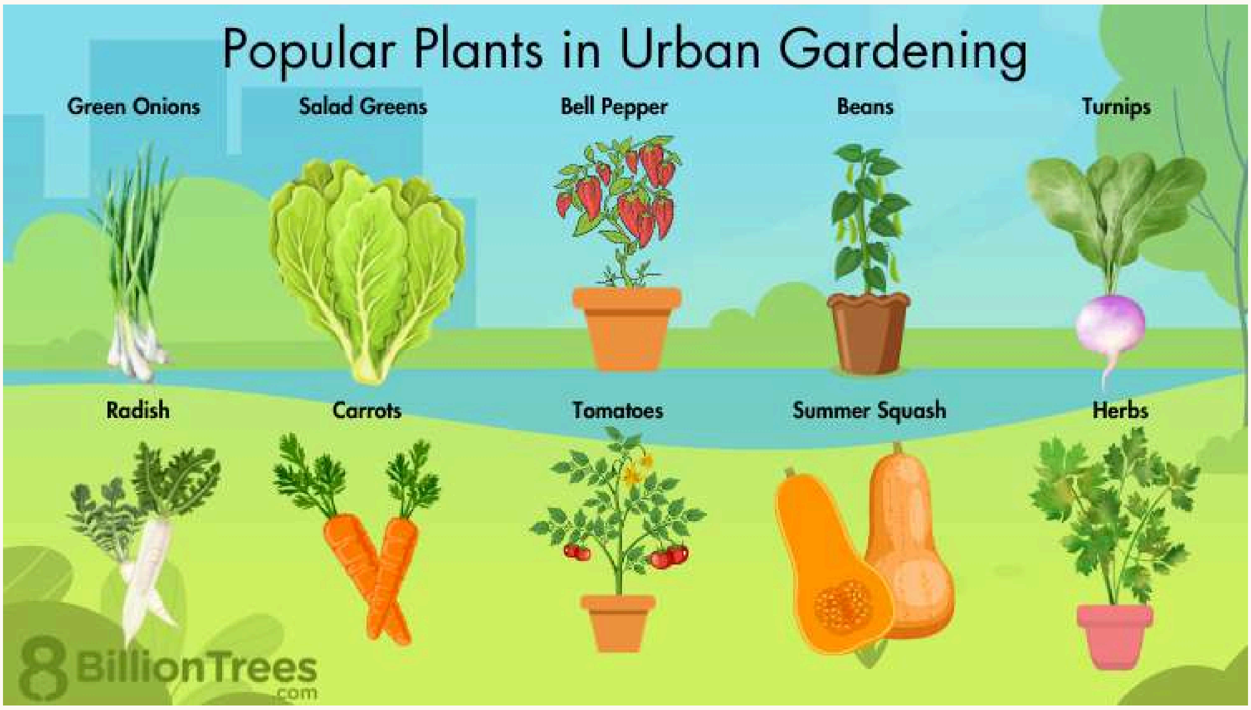
Type of urban agriculture	Organization	Approximate production	Main crops and animal produce
Productive house (indoor) private	Private	2 to 20 m^2 per house	mostly vegetables, herbs, and fruits
Productive roof (flat) private	Private	20 to 50 m^2 per house	mostly vegetables, herbs, and fruits
Productive roof (flat), aquaponics	Private	20 to 50 m^2 per house	vegetables and fish
Kitchen gardens	Private	50 to 300 m^2 per house	potatoes, vegetables, herbs, and fruits
Allotment gardens complex	Private	5,000 to 20,000 m^2	potatoes, vegetables, herbs, and fruits
Community gardens, open field	Collective	400 to 10,000 m^2	potatoes, vegetables, herbs, and fruits
Community gardens, glass house	Collective	200 to 5,000 m^2	vegetables, herbs, and fruits
Edible green amenities	Public	400 to 10,000 m^2	fruits and nuts
Roof gardens aquaponics	Professional	500 to 1,500 m^2	vegetables and fish
Professional horticulture, open field	Professional	5,000 to 40,000 m^2	potatoes, vegetables, herbs, and fruits
Professional horticulture, glass house	Professional	5,000 to 10,000 m^2	vegetables, herbs, and fruits
Professional hydroponics	Professional	1,500 to 10,000 m^2	vegetables, herbs, fruits, and fish
Urban farm	Professional	300,000 to 800,000 m^2	combination of meat, potatoes, vegetables
Green infrastructure farm	Professional	300,000 to 1,200,000 m^2	combination of meat, wheat, vegetables

Source: Spatial Typology of Urban Agriculture with average area and type of production

Crops / Types of urban agriculture	Potatoes	Vegetables (excl legumes)	Legumes	Fruits	Herbs	Grains	Fish	Poultry	Eggs	Access & Facilities
Productive house (indoor) private		70%	10%		20%					0%
Productive roof (flat) private		50%	10%	10%	10%					30%
Productive roof (flat), aquaponics		25%	5%				30%			40%
Kitchen gardens	20%	35%	10%	20%	5%					10%
Allotment gardens complex	20%	35%	10%	20%	5%					10%
Community gardens, open field	20%	40%	5%	15%	5%				5%	10%
Community gardens, glass house		55%	5%	30%						10%
Edible green amenities				30%						70%
Roof gardens aquaponics		27%	3%				30%			40%
Professional horticulture, open field	20%	40%	5%	20%	5%					10%
Professional horticulture, glass house		50%	5%	30%	5%					10%
Professional hydroponics		50%	5%	5%			30%			20%
Urban farm	15%			5%		20%		5%	10%	5%
Green infrastructure farm						10%		10%	5%	5%

Source
http://www.aesoptorino2015.it/content/download/441/2376/version/1/file/25_668_vries+de+spatial+typol+AESOP+2015+update_A.pdf

When discussing the use of species in urban gardening, besides those directly used for food (fruits, vegetables, legumes, and spices), medicinal plants are often utilized, as well as plants with decorative purposes (flowers, shrubs, and trees). Decorative species can be employed solely for ornamental purposes but also as companion plants to enhance biodiversity, attract beneficial insects, or repel pests. Some of the used plant species may serve both decorative and nutritional purposes or as both food and medicinal use. In some gardens, the percentage of these decorative species may dominate. Local wild species, used in gardening practices (e.g., nettles), also fall into these categories, serving as natural fertilizers or for infusions to manage pests (Klepacki & Kujawska, 2018).


Popular Plants in Urban Gardening
Green Onions
Salad Greens
Bell Pepper
Beans
Turnips
Radish
Carrots
Tomatoes
Summer Squash
Herbs
8 BillionTrees .com

Source here

In a study conducted in **Seven Family Allotment Gardens** in three cities in Poland, 46 gardeners of varying ages participated, describing the types of plants grown in their plots. These gardens cultivate various plant species, with grasses being the most numerous, representing 65%, followed by shrubs at 15%, trees at 12%, and others. Concerning their life cycle, perennial plants have the highest percentage at 75%, followed by annuals at 24%, and only 2% representing biennials.

Perennial plants require less maintenance once stabilized, explaining their dominance to some extent. Among all the plants, only 14% have a height exceeding 2 meters. Since these are allotment gardens, with each gardener having plots between 250-500m^2, to cultivate as many plants as possible per unit area, preference is given to grass species with small sizes (Klepacki & Kujawska, 2018).


Decorative species can be present in gardens as complementary elements, but they can also serve as the main focus, considering their preservation and propagation. Most commonly, these include roses (Rosa spp.), peonies (*Paeonia* spp.), phlox (*Phlox paniculata*), boxwood (*Buxus sempervirens*), lily of the valley (*Convallaria majalis*), tulips (Tulipa spp.), dahlias (*Dahlia hybrida*), zinnias (*Zinnia elegans*), asters (Aster spp.), as well as African, French, and other marigolds (Tagetes spp.) (Klepacki & Kujawska, 2018). Marigolds and tagetes are frequently found in various types of urban gardens due to their decorative purposes and their utilization in strategies for pest control.

Among the woody species, the most commonly used ones include apples (*Malus domestica*), pears (*Pyrus communis*), and plums (*Prunus domestica*). Among shrubs, representatives of the genera *Ribes* and *Rubus* are often cultivated, including currants and raspberries. Other tree species, such as apricots, are also included (Klepacki & Kujawska, 2018).

Regarding vegetables, tomatoes (*Lycopersicon esculentum*) are most commonly grown, followed by cucumbers (*Cucumis sativus*) and green beans (*Phaseolus vulgaris*). In terms of herbs, parsley (*Petroselinum crispum*) is frequently cultivated. In allotment gardens, five medicinal plant species have been registered, including mint (*Mentha* sp.), garden sage (*Salvia officinalis*), lemon balm (*Melissa officinal*is), thyme (Thymus sp.), and nettle (*Urtica dioica*) (Klepacki & Kujawska, 2018).

The potential yields from growing vegetables can reach and exceed 50 kg/m^2 per year, making urban gardening one of the most crucial components of urban agriculture. Vegetable crops offer numerous advantages over other types: high nutritional value, suitability for fresh consumption, short vegetative periods, and the ability to harvest multiple times per year from the same area. Some varieties are ready for harvest as early as 40-60-90 days after sowing. The pre-production of seedlings further shortens their stay on the plot (Orsini et al., 2013; Eigenbrod & Gruda, 2015).

One type of gardening, rooftop gardening, has been gaining momentum again and is considered a vital element of urban gardening, especially in central city districts where open land for urban gardening is scarce (Walters & Stoelzle Midden, 2018).

Aerial View Showing Lush Urban Community Garden with Greenhouses and Solar Panels between Brick Buildings. Represents Sustainability and Green City Living Concepts.

Roof terace in Paris

4.2.5 Plants for urban agriculture systems

Oana Venat, Roxana Ciceoi,
Adrian Asănică

1. Plants used for food production in ground-based urban gardens

Ground-based urban gardens represent the most ecologically complete and agronomically flexible form of urban food production. Unlike systems established on anthropogenic structures or in controlled environments, these gardens operate directly on soil, allowing the full expression of plant - soil interactions, perennial growth cycles, and long-term structural complexity. Plant selection in such systems reflects both immediate food production needs and longer-term strategies related to resilience, continuity, and multifunctionality.

The flora cultivated in ground-based urban gardens is highly heterogeneous and typically organised into functional groups according to life cycle, growth habit, and management intensity. Annual vegetable crops form the dynamic component of these systems. Species such as *Solanum lycopersicum, Capsicum annuum, Phaseolus vulgaris, Pisum sativum, Lactuca sativa, Spinacia oleracea, Raphanus sativus,* and *Cucumis sativus* are widely cultivated due to their short growth cycles, high productivity, and adaptability to small-scale cultivation. These species allow rapid crop turnover and seasonal flexibility, but require regular inputs and consistent management.

Perennial herbaceous food plants play an important stabilising role within ground-based gardens. Species such as *Asparagus officinalis*, *Allium schoenoprasum*, *Rumex acetosa*, *Levisticum officinale,* and *Rheum rhabarbarum* provide repeated harvests over multiple seasons while contributing to soil cover and reduced disturbance. Their persistence supports soil structure and nutrient cycling, particularly in gardens where annual replanting is not always feasible.

A defining feature of productive ground-based urban gardens is the extensive use of woody food plants. Fruit-bearing shrubs constitute a core structural and productive element. Commonly cultivated species include *Ribes nigrum*, *Ribes rubrum*, *Ribes uva-crispa*, *Rubus idaeus*, *Rubus fruticosus* agg., *Vaccinium corymbosum*, *Vaccinium myrtillus*, *Aronia melanocarpa*, *Lonicera caerulea*, and *Sambucus nigra*. These shrubs combine high nutritional value with moderate space requirements and long productive lifespans, making them particularly suited to urban plots.

Woody perennial species also include a wide range of fruit trees, often selected in dwarf, semi-dwarf, or trained forms adapted to limited space. Common examples are *Malus domestica, Pyrus communis, Prunus domestica, Prunus avium, Prunus cerasus, Cydonia oblonga*, and *Morus alba* or *Morus nigra*. In many urban gardens, these species are integrated along plot boundaries, in espalier systems, or as central structural elements.

Their role extends beyond fruit production, contributing to microclimatic regulation, shade, and vertical stratification of the garden.

Nut-producing trees and multipurpose woody species are present to a lesser extent but remain characteristic of many long-established urban gardens. Species such as Juglans regia, *Castanea sativa,* and *Corylus avellana* are cultivated where space and soil conditions permit. Although their long juvenile phases and larger size limit their use in small plots, their inclusion reflects long-term food security strategies rather than short-term yield optimisation.

In addition to fruit and nut species, ground-based gardens frequently include woody plants with multiple edible or functional uses. *Morus* spp. provide fruit and shade; *Sambucus nigra* offers flowers and berries; and *Cornus mas* is valued for early fruiting and resilience. These species illustrate the multifunctional logic that distinguishes productive ground-based gardens from ornamental plantings.

Herbaceous aromatic and medicinal plants are commonly intercropped with woody species and annual vegetables. Species such as *Ocimum basilicum, Thymus vulgaris*, *Salvia officinalis*, *Rosmarinus officinalis*, *Mentha spp*., and *Petroselinum crispum* contribute directly to food production while also supporting ecological interactions and pest regulation.

Their integration reflects a polycultural approach rather than strict crop separation.

Plant assemblages in ground-based urban gardens therefore combine annual, perennial, herbaceous, and woody species within a single productive space. This structural diversity distributes risk, buffers against environmental variability, and allows continuous harvests across seasons. Productivity is achieved through cumulative output rather than through maximisation of individual crop yields.

The plant assemblages described here also overlap with small-scale urban agroforestry practices, where perennial food plants, shrubs, and herbaceous crops are combined within ground-based systems. In this module, such configurations are addressed through their plant composition rather than treated as a separate system type.

Ground-based urban gardens rely on a broad spectrum of food plants, with woody species playing a central role in long-term productivity and system stability. These plant assemblages differ fundamentally from ornamental urban plantings in both species composition and functional intent, reflecting the agricultural character of these gardens and their contribution to urban food resilience.

2. **Plants used for food production in rooftop and structure-based urban gardens**

Urban food production systems established on anthropogenic structures - such as rooftops, parking garages, commercial terraces, public transport stations, and other built surfaces - represent a distinct category of urban agriculture. Unlike ground-based gardens, these systems are shaped by structural load limits, reduced substrate depth, increased exposure to wind and solar radiation, and constrained water availability. As a result, plant selection is governed by a combination of horticultural performance, physiological tolerance, and system-level feasibility.

Different types of vegetation are suitable for food production on rooftops and other built structures, depending on substrate depth, system intensity, and maintenance capacity. In this context, it is essential to distinguish between rooftop gardening as a predominantly recreational activity and rooftop food production as a functional agricultural system. While the former prioritises leisure, visual appeal, and individual experimentation, the latter is constrained by structural and environmental limits and requires predictable yields over time. This distinction has direct implications for plant selection, system design, and management intensity.

Vegetable crops form the primary component of food-producing rooftop gardens. Species such as *Solanum lycopersicum* and

Capsicum annuum are frequently cultivated due to their adaptability to container growth and their capacity to tolerate high temperatures typical of exposed urban surfaces. Cucurbits, including *Cucumis sativus* and *Cucurbita* spp., are also suitable, provided that vertical support systems are available. Shallow-rooted vegetables such as *Lactuca sativa, Raphanus sativus*, and *Daucus carota* are particularly well adapted to limited substrate depths and are therefore among the most common crops in extensive rooftop systems.

Rooftop food production systems can range from intensive installations, with substrate depths exceeding 15 cm, to extensive systems with less than 15 cm of growing medium. Intensive rooftop gardens are generally preferred for vegetable cultivation, as they allow a broader range of species and support higher yields. However, even in extensive systems, certain crops - especially leafy greens and compact root vegetables - can be cultivated successfully when management is adapted accordingly. Other vegetables, including tomatoes, may be grown under extensive conditions with careful observation and targeted care.

Aromatic and culinary herbs constitute a second major group of food plants used in rooftop and structure-based gardens. Species such as *Ocimum basilicum, Rosmarinus officinalis, Origanum vulgare, Thymus vulgaris,* and *Allium schoenoprasu*m are widely used due to their compact growth, drought tolerance, and high productivity relative to biomass.

These plants serve both culinary and functional roles, contributing to system resilience and often supporting beneficial insect populations.

Berry-producing plants, including *Fragaria × ananassa*, *Rubus idaeus*, and *Vaccinium spp*., are cultivated to a more limited extent, primarily in intensive rooftop systems where substrate depth and structural load permit. Their inclusion reflects an effort to increase dietary diversity and perennial productivity, although their cultivation requires careful consideration of weight, root space, and long-term maintenance.

Trees and larger woody species are generally restricted to specific contexts and are rarely used for food production on rooftops or other anthropogenic structures. Where present, they are typically confined to engineered planters and selected for reduced size and controlled growth. In most cases, woody species play a secondary or decorative role rather than contributing substantially to food output.

Plant selection in structure-based urban gardens must also account for reproductive requirements and ecological interactions. For crops dependent on insect pollination, such as cucurbits, ensuring access to pollinators is essential. This is commonly achieved through the inclusion of flowering plants that attract and sustain pollinator populations. Aromatic herbs and flowering medicinal plants, including *Monarda didyma* and *Salvia officinalis*, are frequently incorporated for this purpose, serving simultaneously as food plants, companion species, and ecological support elements. The use of species with staggered flowering periods further enhances pollinator presence throughout the growing season.

From a functional perspective, rooftop and structure-based food gardens prioritise reliability and system compatibility over maximum yield. Plant species are selected for tolerance to thermal stress, wind exposure, and intermittent water supply, as well as for their ability to perform under confined rooting conditions. Productivity is achieved through careful matching of species to system constraints rather than through intensification alone.

Food production on anthropogenic urban structures relies on a specific subset of cultivated plants adapted to shallow substrates, high exposure, and structural limitations. Understanding the functional characteristics of these plants is essential for designing viable rooftop and structure-based food systems that balance agricultural output with technical feasibility and long-term sustainability.

3. Plants used for food production in open-air vertical urban gardens

Vertical urban gardens designed for food production in open-air conditions represent a distinct and still relatively experimental category of urban agriculture. Unlike controlled-environment vertical farming systems, these installations are directly exposed to ambient climatic conditions and are therefore subject to fluctuations in temperature, wind, precipitation, and solar radiation. As a result, plant selection is strongly constrained by physiological tolerance, growth form, and the capacity to perform under spatially fragmented and vertically distributed rooting environments.

In non-controlled vertical systems, food production is typically organised along building façades, freestanding vertical frames, pergolas, fences, or modular wall systems attached to existing urban structures. These systems do not aim to replicate industrial vertical farming, but rather adapt traditional horticultural species to a vertical spatial logic, prioritising lightweight structures, low substrate volumes, and simplified maintenance.

Leafy vegetables constitute the most suitable group of food plants for open-air vertical gardens. Species such as *Lactuca sativa*, *Spinacia oleracea*, *Eruca sativa*, *Valerianella locusta*, and *Beta vulgaris* (leaf forms) are widely used due to their shallow root systems, low biomass accumulation, and rapid growth cycles.

Their limited structural demand allows them to be cultivated in vertical modules with restricted rooting depth, while their short production cycles reduce the risk associated with environmental stress events.

Aromatic and culinary herbs represent a second core component of vertical food gardens. Species including *Ocimum basilicum, Thymus vulgaris, Origanum vulgare, Mentha spp*., *Petroselinum crispum*, and *Salvia officinalis* are particularly well suited to vertical arrangements. These plants combine compact growth habits with tolerance to intermittent water availability and high light exposure. In addition to their culinary value, aromatic herbs contribute to system stability by attracting pollinators and beneficial insects, thereby supporting ecological interactions within the vertical garden.

Climbing and trailing edible species are used selectively to exploit vertical space more efficiently. Crops such as *Phaseolus vulgaris*, *Pisum sativum, Cucumis sativus*, and *Vicia faba* can be integrated into vertical systems when adequate support structures are provided. However, their use is generally limited to lower or structurally reinforced sections of vertical gardens, as their biomass and water requirements increase mechanical and management complexity.

Fruit-bearing plants are less frequently used in open-air vertical gardens, but certain compact species and cultivars can be accommodated. *Fragaria × ananassa* is the most common example, benefiting from its shallow root system and suitability for suspended or wall-mounted containers. Other berry species are rarely included due to weight constraints and long-term maintenance demands.

A defining characteristic of plant selection in open-air vertical food gardens is the need to balance vertical positioning with environmental gradients. Plants located at higher levels are typically exposed to increased wind stress, higher irradiance, and greater evapotranspiration rates, while lower sections experience more stable microclimatic conditions. Consequently, species with higher drought tolerance and structural resilience are preferentially placed in upper modules, whereas more sensitive crops are allocated to protected or shaded positions.

From a functional perspective, vertical food gardens do not aim to maximise yield per plant, but rather to increase productive surface area within limited urban footprints. Productivity is therefore achieved through spatial redistribution of crops rather than through intensification. Species are selected for their ability to remain productive under partial shading, irregular watering, and reduced substrate volumes, conditions that are inherent to non-controlled vertical systems.

The successful implementation of open-air vertical urban gardens depends less on technological control and more on careful species selection, spatial arrangement, and alignment between plant traits and structural constraints.

4. **Plants used for food production in controlled-environment vertical urban systems**

Controlled-environment vertical urban systems represent the most technologically intensive form of urban food production. These systems operate independently of ambient climatic conditions and rely on artificial regulation of light, temperature, humidity, nutrient supply, and, in many cases, atmospheric composition. As a consequence, plant selection is driven primarily by physiological efficiency, predictability of growth, and compatibility with highly standardised production protocols rather than by tolerance to environmental stress.

In contrast to open-air vertical gardens, controlled systems are designed to minimise variability and maximise uniformity. Food plants cultivated in these environments are selected for rapid growth, compact morphology, high harvest index, and consistent quality across production cycles. The biological constraints imposed by shallow substrates or spatial fragmentation are largely replaced by engineered growing conditions, allowing a narrower but highly optimised range of species to dominate.

Leafy greens constitute the core crop group in controlled vertical systems. Species such as *Lactuca sativa*, *Spinacia oleracea*, *Eruca sativa*, *Valerianella locusta*, *Brassica rapa* subsp. chinensis, and *Brassica oleracea* (leafy cultivars) are widely used due to their short growth cycles, low structural demand, and efficient conversion of light into edible biomass. Their physiological plasticity allows precise manipulation of growth rates and nutritional profiles through controlled light spectra and nutrient regimes.

Herbaceous culinary plants form a second major category. Species including *Ocimum basilicum*, *Coriandrum sativum, Petroselinum crispum, Allium schoenoprasum,* and *Mentha spp*. are particularly suited to controlled environments due to their predictable architecture and high market value relative to biomass. In these systems, herbs are cultivated not only for yield but also for uniformity of aroma, texture, and visual quality, which can be modulated through environmental parameters.

Microgreens and juvenile plant stages represent a distinct and highly specialised group within controlled vertical agriculture. A wide range of species, including *Raphanus sativus, Brassica spp.*, *Pisum sativum,* and *Beta vulgaris,* are harvested at early developmental stages, when growth is rapid and space efficiency is maximised. The suitability of microgreens for vertical systems lies in their minimal rooting requirements, short production cycles, and high nutritional density per unit area.

Fruit-bearing crops are present only in a limited and carefully selected form. Species such as *Solanum lycopersicum* (dwarf or determinate cultivars), *Capsicum annuum*, and *Fragaria × ananassa* can be cultivated in controlled vertical systems, but their inclusion requires more complex infrastructure and longer production cycles. As a result, these crops are typically confined to systems where economic or research objectives justify increased management intensity.

Root and tuber crops are largely absent from controlled vertical systems due to spatial inefficiency and low compatibility with stacked production formats. Their exclusion reflects a functional prioritisation of crops that maximise edible yield per unit of vertical surface rather than per unit of substrate volume.

A defining feature of plant selection in controlled vertical environments is the decoupling of plant performance from external seasonality. Growth, flowering, and harvest timing are determined by system programming rather than climatic cues. This allows year-round production and precise scheduling but also narrows the range of species that can be efficiently integrated. Plants that require complex developmental signals or extensive root systems are generally excluded.

From a functional perspective, controlled vertical systems prioritise consistency, scalability, and resource efficiency. Plant species are selected for compatibility with automated irrigation, standardised nutrient solutions, and artificial lighting systems. Productivity is achieved through repetition and optimisation rather than diversity, resulting in simplified plant assemblages with high output predictability.

From a functional perspective, controlled vertical systems prioritise consistency, scalability, and resource efficiency. Plant species are selected for compatibility with automated irrigation, standardised nutrient solutions, and artificial lighting systems. Productivity is achieved through repetition and optimisation rather than diversity, resulting in simplified plant assemblages with high output predictability.

4.2.6 Functional constraints and performance in urban food production systems

Oana Venat

Urban agriculture includes a wide range of production systems that differ in space, management intensity, and environmental conditions. Considering all forms of urban food production as a single category overlooks important differences between ground-level cultivation, rooftop gardens, and indoor or vertical systems. Each of these operates under specific constraints and opportunities, which influence plant choice, management practices, and expected yields.

Ground-based urban agriculture benefits from greater rooting volume, higher soil buffering capacity, and more stable thermal and hydrological conditions. These systems are generally less dependent on continuous technical inputs but are constrained by land availability, soil quality, and potential contamination. In contrast, rooftop food production is characterised by structural load limitations, restricted substrate depth, increased exposure to wind and temperature extremes, and higher evapotranspiration rates. As a result, plant performance on rooftops is tightly coupled to substrate properties, irrigation management, and species-specific tolerance to abiotic stress.

Vertical and indoor production systems introduce an additional level of control by decoupling plant growth from natural soil and climatic conditions. In these systems, performance drivers include artificial lighting regimes, nutrient solution composition, and microclimate regulation, while limiting factors are primarily technical and energetic. Although such systems can achieve high productivity per unit area, their functioning depends on sustained input intensity and operational stability.

Recognising these structural differences is essential for interpreting yield data and for defining realistic expectations of urban food production. Plant suitability cannot be assessed independently of the production system, as the same species may exhibit contrasting performance depending on spatial constraints, input availability, and management intensity. This system-specific perspective provides the necessary framework for evaluating empirical yield comparisons across urban agriculture contexts.

Yield variability across urban food production systems: drivers and limitations

Comparative analyses of crop yields in urban agriculture highlight substantial variability across production systems, reflecting differences in resource availability and environmental control. Meta-analytical evidence synthesising more than 200 studies and over 2.000 individual observations indicates that vegetable crops are the most frequently assessed group, followed by cereals, fruits, oilseeds, and root crops. Yield comparisons are typically conducted both at the crop group level and for individual species, allowing system-specific performance patterns to be identified (studies in Reference section).

When urban agriculture is compared with conventional agriculture as a whole, yields of vegetable crops in urban systems are frequently reported to be **more than twice as high**. The most pronounced differences are observed in cucumbers and pickles, where yields in urban production reach up to **4.4** times those recorded in conventional systems. Similarly, tomatoes, hot peppers, and bell peppers show approximately 2.3-fold higher yields under urban cultivation conditions. These increases are largely attributable to intensified management, reduced plant spacing, and optimized water and nutrient delivery.

(Dorr et al., 2021; Payen et al., 2022; McDougall et al., 2019; Dian et al., 2019; Benis et al., 2017)

However, yield responses are not uniform across crops or production systems. Beans and cabbage crops often exhibit yields comparable to those obtained under conventional cultivation, particularly in ground-based urban systems where growing conditions resemble those of small-scale rural agriculture. In vertical farming contexts, yield advantages of approximately 2.4 times have been reported for **leafy vegetables** such as **lettuce** and **chicory** when compared to horizontal cultivation. For **tomatoes**, yields increase by more than 2.5 times in hydroponic systems, while **hot peppers** and **bell peppers** may reach yield increases exceeding sixfold. **Cucumbers** and **pickles** also show higher yields in vertical systems, although their relative gains are generally lower than those observed for tomatoes.

These yield differentials reflect the interaction between crop biological traits and system architecture. Crops with rapid growth cycles, shallow root systems, and high responsiveness to controlled inputs benefit most from vertical and hydroponic environments. Conversely, crops with higher structural biomass requirements or longer development periods do not consistently display amplified yields under intensified urban systems. Consequently, yield comparisons must be interpreted with caution, as they reflect system optimisation rather than intrinsic crop superiority.

Implications for plant selection in urban agriculture

The comparative evidence presented in this chapter indicates that plant performance in urban agriculture is strongly system-dependent. Differences in yield between ground-level cultivation, rooftop systems, and vertical or hydroponic production are not solely attributable to plant species, but arise from interactions between rooting volume, microclimate control, nutrient delivery, and management intensity. Consequently, plant selection for urban food production cannot rely on generalized crop suitability lists, but must be aligned with the specific constraints and operational logic of each production system.

Crops exhibiting rapid growth, shallow root systems, and high responsiveness to controlled inputs tend to perform best in vertical and hydroponic environments, where water and nutrients are continuously available. In contrast, crops with higher biomass requirements or longer growth cycles often show more stable performance in ground-based urban systems, where rooting depth and buffering capacity are greater. These patterns highlight the necessity of distinguishing between potential productivity and achievable productivity under realistic urban conditions. Urban agriculture functions as a distinct set of production systems shaped by specific spatial and technical constraints, rather than as a simplified version of conventional farming. Consequently, plant selection must be aligned with system design and management conditions to avoid misleading yield comparisons.

Unit 4.3 Mushroom growing in urban conditions

Milena Yordanova,
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The cultivation of mushrooms in urban conditions is mainly carried out in buildings, making them highly suitable for inclusion in urban gardening as they can be grown year-round.
The most commonly cultivated mushroom is the oyster mushroom. The reason for its cultivation lies in the use of waste products, which are thus recycled in the process.

The oyster mushroom has the ability to be cultivated on various cellulose substrates, providing an opportunity for the reuse of already generated waste, such as used coffee grounds. It has been estimated that a high-traffic coffee shop can end its day with over 20 kg of used coffee grounds, and instead of being discarded, it can be used as a substrate for cultivating oyster mushrooms (Glück-Thaler & Begg, 2012).

The impact of mushroom production and their integration into the circular economy, using waste substrates like used coffee grounds and wood chips, has been established. It has been confirmed that closing the production cycle by growing mushrooms on waste substrates has a positive effect on climate change.

There are numerous positive outcomes from already implemented projects for establishing mushroom production in urban environments. Some of them are outlined below:

GroCycle urban mushroom farm
is the first of its kind, located on the 3rd floor of an unused office building in the heart of Exeter, England. The space has been transformed into different rooms for each stage of the growing process. As a substrate for mushroom cultivation, coffee waste collected from urban cafes has been utilized. The produced mushroom compost is delivered to restaurants, and the waste from mushroom production is used as compost for gardens. For more information, you can visit their website: GroCycle Urban Mushroom Farm

Natan Jacquemin from Portugal believes that waste is also a possibility. In 2018, he established **Nam Mushroom**, an urban farming project focused on cultivating edible fungus. He formed a partnership with Portugal's largest coffee distributor, Delta Cafés. He cleans their vending machines, collects this waste, and creates a nutrient-rich environment for his mushrooms. For more information, you can visit their website: Nam Mushroom

Another interesting example of closed-loop production is Rotterzwam, a mushroom producer and coffee bar located in a former swimming pool in Rotterdam. The company was founded in 2013 in the old Tropicana swimming pool (now BlueCity) on the Maas River in Rotterdam. Their goal is to close the production cycle. They utilize coffee waste by turning it into a substrate for mushroom cultivation. Gradually expanding, they have earned several awards for being an eco-friendly company. In 2020, they began growing mushrooms year-round instead of seasonally. For more information, you can visit their website: Rotterzwam

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