



GREEN ROOFS AND VERTICAL GARDENS USING ORNAMENTAL PLANTS: A REVIEW OF DESIGN, PLANT SELECTION AND ENVIRONMENTAL BENEFITS

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Abstract:

Rapid urbanization has intensified the demand for sustainable green infrastructure capable of mitigating heat island effects, managing storm water, improving air quality and enhancing urban aesthetics. Green roofs and vertical gardens (also known as living walls or green façades) represent two of the most promising forms of urban greening, particularly when designed with ornamental plant species that combine ecological performance with visual appeal. This article reviews the ecological, architectural and horticultural dimensions of green roofs and vertical garden with particular emphasis on the criteria for selecting ornamental plants suited to these systems. It examines system typologies, substrate and irrigation requirements, plant physiological adaptations to vertical and rooftop microclimates and the environmental, social and economic benefits associated with these installations. The article also discusses design challenges, maintenance considerations, and future research directions, concluding that the integration of ornamental species into green roofs and vertical gardens offers a viable pathway toward more resilient, biodiverse and aesthetically enriched urban environments.

Keywords: Green Roofs, Vertical Gardens, Ornamental Plants, Urban Greening, Sustainable Landscapes, Green Infrastructure.

1. Introduction

The expansion of impervious surfaces in cities has been consistently linked to elevated ambient temperatures, degraded air and water quality, reduced biodiversity, and diminished psychological well-being among urban residents (1,2). In response, planners, architects and horticulturists have increasingly turned to building-integrated vegetation systems, principally green roofs and vertical gardens as tools for reconciling dense urban development with ecological function (3,4). Unlike traditional ground-level parks, these systems exploit otherwise

underused vertical and horizontal building surfaces, allowing greenery to be introduced without competing for scarce urban land (5).

While early applications of green roofs and living walls prioritized functional, low-maintenance groundcovers and sedums, contemporary design increasingly incorporates ornamental plant species selected for their color, texture, seasonal interest and habitat value (4,6). This shift reflects a broader recognition that green infrastructure must serve social and aesthetic functions alongside its ecological roles if it is to be embraced by building owners, occupants and municipal authorities (2,7). This article synthesizes current knowledge on the design and plant selection principles underlying ornamental green roofs and vertical gardens and evaluates their contribution to sustainable urban development.

2. Evolution and global development of green roofs and vertical gardens

The concept of integrating vegetation into buildings dates back to ancient civilizations. One of the earliest examples is the Hanging Gardens of Babylon (ca. 600 BCE), which demonstrated the aesthetic and functional use of rooftop vegetation. During the Middle Ages, Scandinavian countries adopted turf roofs for thermal insulation and weather protection. However, modern green roof technology emerged in Germany during the 1960s and 1970s with the development of engineered waterproofing systems, lightweight substrates and drainage layers, enabling safe and large-scale rooftop greening (8).

Vertical gardening has similarly evolved from traditional climbing plants grown on walls to sophisticated living wall systems (5). A major advancement came through the work of Patrick Blanc, who developed hydroponic living walls capable of supporting diverse ornamental plant species without conventional soil. Today, vertical gardens include green façades, modular panels, felt systems and hydroponic installations used in residential, commercial and public buildings (5).

Green roofs and vertical gardens are now widely adopted across Europe, North America, Australia and Asia as effective nature-based solutions for mitigating urban heat islands, improving storm water management, enhancing biodiversity and reducing building energy consumption (1,3,9). Countries such as Germany, Switzerland, Canada and Singapore have introduced supportive policies and incentives that have accelerated their implementation (8).

In India, the adoption of green roofs and vertical gardens is steadily increasing, particularly in metropolitan cities under the Smart Cities Mission and green building initiatives such as GRIHA and the Indian Green Building Council (IGBC). Ornamental species including *Bougainvillea*, *Portulaca*, *Alternanthera*, *Chlorophytum* and *Philodendron* are increasingly used due to their adaptability and aesthetic value. Continued advances in lightweight substrates, automated irrigation and IoT-based monitoring are expected to further promote vegetated building systems as integral components of sustainable urban development (10,11).

3. Types of green roofs and vertical gardens

3.1 Green roofs

Green roofs are typically classified into three categories based on substrate depth and maintenance intensity (4,6):

- **Extensive green roofs** feature shallow substrates (typically 5–15 cm), low weight loads and minimal irrigation. These systems favor drought-tolerant, low-growing ornamental species such as *Sedum* spp., *Sempervivum* spp. and select ornamental grasses (6,12).
- **Intensive green roofs** resemble rooftop gardens, with deeper substrates (20 cm or more) capable of

supporting shrubs, small trees and a wider palette of ornamental perennials, but requiring greater structural capacity, irrigation and maintenance (4).

- **Semi-intensive green roofs** occupy a middle ground, supporting a broader range of ornamental groundcovers and perennials than extensive systems while remaining less resource-intensive than intensive designs (4).

3.2 Vertical gardens

Vertical gardens are generally divided into two main types (5):

- **Green façades**, in which climbing or trailing plants are trained to grow up or across a support structure (trellis, mesh or cable system) directly from ground-level or planter-based root zones. Ornamental climbers such as *Trachelospermum jasminoides*, *Clematis* spp. and *Parthenocissus* spp. are commonly used (5).
- **Living walls (bio-walls)** employ modular panels, felt pockets or hydroponic troughs to support a dense matrix of plants rooted directly within the vertical structure itself, independent of soil-level planting (5). Living walls permit far greater species diversity and are frequently used to create intricate, tapestry-like ornamental displays combining ferns, bromeliads, flowering perennials and foliage plants (5).

3.3 Emerging green roof systems

Recent advancements have led to the development of innovative green roof technologies:

- **Biodiverse roofs** are designed using native vegetation to enhance urban biodiversity and provide habitats for insects and birds (13).
- **Blue-green roofs** combine vegetation with storm water storage systems to improve rainwater retention and reduce urban flooding.
- **Biosolar roofs** integrate photovoltaic panels with vegetation, where plant cooling improves solar panel efficiency while maximizing rooftop land use.

4. Criteria for ornamental plant selection

Selecting ornamental plants for green roofs and vertical gardens requires balancing horticultural performance with aesthetic and ecological objectives (6,12). Key selection criteria include:

- **Drought and heat tolerance:** Particularly for extensive green roofs and sun-exposed façades, where substrate volumes are limited and evapo-transpiration rates are high (6,14).
- **Root system characteristics:** Favoring shallow, fibrous or adventitious root structures that avoid damaging waterproofing membranes while stabilizing substrate (12).
- **Wind and structural resilience:** Especially for rooftop and high-rise installations subject to elevated wind loads (4).
- **Seasonal and visual interest:** Incorporating variation in foliage color, flowering periods and texture to maintain year-round aesthetic value (4).
- **Habitat and pollinator value:** Favoring nectar- and pollen-rich ornamental species (e.g., *Lavandula* spp., *Echinacea* spp., *Salvia* spp.) that support urban biodiversity (9,13).
- **Compatibility with substrate depth and irrigation regime:** Ensuring that root depth and water demand align with the specific system typology (4,6).
- **Regional climatic suitability:** Prioritizing native or climate-adapted ornamental species to reduce

maintenance inputs and improve long-term survivability (13).

Commonly cited ornamental genera across the literature include *Sedum*, *Delosperma*, *Festuca*, *Heuchera*, *Salvia*, *Nepeta*, *Hedera* and various ferns and bromeliads for shaded living wall applications (6,12).

Components and design principles of green roofs and vertical gardens

The performance and longevity of green roofs and vertical gardens depend on proper system design and the integration of suitable structural and horticultural components (4,5). Each layer performs a specific function, ensuring plant growth while protecting the building from water infiltration, excessive loading and structural damage (4).

5. Components of gardens

5.1 Components of green roofs

A typical green roof consists of the following layers (4,9):

- **Vegetation layer:** Comprises ornamental plants selected according to climatic conditions, substrate depth, and maintenance requirements.
- **Growing medium (substrate):** A lightweight engineered medium that provides anchorage, nutrients, water retention and aeration for plant growth.
- **Filter layer:** Prevents fine substrate particles from clogging the drainage system while allowing water to pass through.
- **Drainage layer:** Removes excess water, preventing water logging and maintaining adequate root aeration.
- **Root barrier:** Protects the waterproof membrane from root penetration and damage.
- **Waterproof membrane:** Prevents water leakage into the building structure.
- **Roof deck:** The structural base that supports the entire green roof system.

5.2 Components of vertical gardens

Vertical gardens generally include (5):

- **Support framework:** Metal or plastic structures that securely hold the planting system against the building.
- **Planting modules or panels:** Containers, felt pockets or hydroponic units that support plant growth.
- **Growing medium:** Lightweight substrates or soilless media that provide root support and moisture.
- **Irrigation system:** Usually drip or automated fertigation systems that ensure uniform water and nutrient supply.
- **Drainage system:** Collects and removes excess irrigation water to prevent water accumulation and structural damage.

5.3 Design considerations

Successful installation requires careful planning of structural and environmental factors, including (4,5):

- Building load-bearing capacity.
- Climate and microclimatic conditions (temperature, sunlight, wind and rainfall).
- Selection of suitable ornamental plant species.
- Efficient irrigation and drainage systems.

- Ease of maintenance and accessibility.
- Long-term durability of waterproofing and root barrier materials.

Proper integration of these components enhances plant survival, reduces maintenance requirements and maximizes the environmental benefits of vegetated building systems (4,9).

6. Environmental and social benefits

6.1 Thermal regulation and energy performance

Vegetated roofs and walls reduce surface and ambient temperatures through evapo-transpiration and shading, thereby mitigating the urban heat island effect and reducing building cooling loads (3,15,16). Ornamental species with dense canopy structures or high leaf area indices tend to provide superior insulating benefits compared to sparse or leafless winter-dormant plantings (14,16).

6.2 Storm water management

Green roofs retain a substantial proportion of incident rainfall within their substrate and vegetative layers, reducing peak runoff volumes and easing pressure on urban drainage infrastructure (6,9). Retention capacity varies with substrate depth, plant root density and antecedent moisture conditions (6).

6.3 Air quality and carbon sequestration

Foliage on green roofs and vertical gardens intercepts particulate matter and absorbs gaseous pollutants, while contributing modestly to carbon sequestration through biomass accumulation (2,9). Living walls with dense, multi-layered ornamental plantings have demonstrated measurable improvements in localized air quality (2,5).

6.4 Biodiversity enhancement

Ornamental plantings selected for flowering diversity and structural complexity can support pollinators, birds and beneficial insects, contributing to urban ecological networks even within highly built environments (9,13).

6.5 Psychological and social well-being

Exposure to vegetated surfaces has been associated with reduced stress, improved cognitive function and increased occupant satisfaction (2,7). Ornamental plantings, by virtue of their visual richness, are particularly effective in generating these restorative psychological effects compared to purely functional, monochromatic plant palettes (7).

7. Design and engineering considerations

Successful integration of ornamental plants into green roofs and vertical gardens requires careful coordination between horticultural and structural design (4,5). Key considerations include:

- Structural load capacity, particularly for intensive green roofs and living walls with saturated substrate weight (3,4).
- Waterproofing and root barrier systems, to prevent membrane penetration and water infiltration into building structures (4).
- Irrigation and drainage design, including drip irrigation, capillary mats, or automated re-circulating systems for living walls (5).
- Substrate composition typically engineered lightweight mixes combining mineral aggregates, organic matter, and water-retention additives (6,12).
- Micro-climatic variation, accounting for differential sun exposure, wind speed, and humidity across building orientations, which necessitates zone-specific plant selection even within a single installation

(15).

8. Irrigation and nutrient management

Efficient irrigation and nutrient management are essential for maintaining healthy plant growth in green roofs and vertical gardens. Due to the limited substrate volume and rapid moisture loss, these systems require carefully planned water and nutrient supply to ensure long-term performance while minimizing resource use (5,6).

8.1 Irrigation systems

The choice of irrigation system depends on the type of green roof or vertical garden, climatic conditions and plant requirements (4,5):

- **Drip irrigation:** The most widely used system, delivering water directly to the root zone with minimal losses.
- **Capillary irrigation:** Uses capillary mats to distribute water uniformly, reducing evaporation.
- **Hydroponic irrigation:** Common in living walls, where nutrient-rich water continuously circulates through the root zone.
- **Rainwater harvesting:** Collected rainwater can be reused for irrigation, reducing dependence on potable water.
- **Automated irrigation:** Soil moisture sensors and timers regulate water application based on plant requirements, improving water-use efficiency (10).

8.2 Nutrient management

Plants growing in shallow substrates require periodic nutrient supplementation to maintain healthy growth and flowering (6). Slow-release fertilizers are generally preferred because they provide nutrients gradually, minimizing leaching and reducing maintenance. Organic amendments such as compost and biochar can also improve nutrient availability and enhance substrate quality. Regular monitoring of substrate pH and electrical conductivity helps maintain an optimum growing environment.

8.3 Sustainable water management

Sustainable irrigation practices improve the environmental performance of green roofs and vertical gardens (3,5). Rainwater harvesting, greywater reuse and smart irrigation systems can significantly reduce freshwater consumption while ensuring adequate moisture for plant growth (10). These approaches contribute to water conservation and enhance the resilience of urban green infrastructure under changing climatic conditions (3).

9. Challenges and limitations of green roofs and vertical gardens

Despite their numerous environmental and aesthetic benefits, green roofs and vertical gardens face several technical, economic and maintenance challenges that may limit their widespread adoption (3,5). Addressing these constraints is essential for ensuring their long-term performance and sustainability.

9.1 High installation cost

The initial cost of installing green roofs and living walls is generally higher than that of conventional roofing systems due to the need for specialized materials, irrigation systems, waterproofing membranes and skilled labor (3,5). However, long-term savings through reduced energy consumption and maintenance can offset these costs (3).

9.2 Structural constraints

Green roofs, particularly intensive systems, add considerable weight to buildings (3). Existing structures may

require structural assessment and reinforcement before installation to ensure safety and durability (3,4).

9.3 Water and irrigation requirements

Although many ornamental plants are drought tolerant, prolonged dry periods may necessitate supplemental irrigation (14). In regions with limited water availability, efficient irrigation systems and rainwater harvesting become essential.

9.4 Plant survival and maintenance

Plants are exposed to extreme environmental conditions such as high temperatures, strong winds, heavy rainfall and limited rooting space (8,13). Regular maintenance, including irrigation, fertilization, pruning and replacement of dead plants, is necessary to maintain healthy vegetation (4,5).

9.5 Pest and disease management

Green roofs and vertical gardens may be affected by insect pests, fungal diseases and weed invasion (8). Integrated pest management (IPM) practices should be adopted to minimize chemical pesticide use while maintaining plant health.

9.6 Technical and policy barriers

The lack of standardized guidelines, limited awareness among stakeholders and insufficient government incentives can hinder the adoption of vegetated building systems, particularly in developing countries (2,9). Increased research, policy support, and public awareness are needed to encourage large-scale adoption (2).

10. Future perspectives and emerging technologies

Advances in green building technologies and digital agriculture are enhancing the efficiency and sustainability of green roofs and vertical gardens (10,11). The integration of Internet of Things (IoT) sensors, artificial intelligence (AI), automated irrigation systems and remote sensing enables real-time monitoring of soil moisture, temperature and plant health, thereby optimizing water and nutrient use while reducing maintenance costs (10,11). Innovative systems such as biosolar roofs, which combine vegetation with photovoltaic panels, and blue-green roofs, which integrate vegetation with stormwater storage, further improve energy efficiency and urban water management. These technologies are transforming vegetated buildings into multifunctional systems that support climate resilience and sustainable urban development (1,3).

Conclusions

Green roofs and vertical gardens have emerged as effective green infrastructure solutions that enhance urban sustainability by integrating ornamental plants into built environments (3,5). These systems provide multiple environmental, ecological and socio-economic benefits, including mitigation of the urban heat island effect, improved storm water management, enhanced air quality, increased biodiversity, energy conservation and improved human well-being (1,2,9). The success of these systems largely depends on appropriate design, suitable substrate composition, efficient irrigation practices and careful selection of ornamental plant species adapted to local climatic conditions (4,6).

Despite challenges such as high installation costs, structural limitations, and maintenance requirements, continuous advancements in horticulture, engineering, and smart technologies are improving the feasibility and performance of vegetated building systems (5,10). The adoption of innovative approaches such as IoT-based monitoring, AI-assisted irrigation, bio-solar roofs and climate-resilient ornamental plants is expected to further enhance their sustainability and functionality (10,11). Increased research, supportive policies and public

awareness will play a crucial role in promoting the widespread implementation of green roofs and vertical gardens, contributing to the development of resilient, environmentally friendly and aesthetically enriched cities (2,7).

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