Built Environments
16. Urban Greening

DEFINITION

Urban greening is a general term used to describe efforts to renature urban areas by installing various types of green infrastructure. These revegetation strategies are often implemented with climate resilience goals in mind, but are also often cited as a way to increase local residents' mental and physical health (García-Lamarca et al. 2022). This strategy focuses on three different forms of urban greening: urban forestry, green roofs, and pollinator gardens.

Urban forestry is an "integrated concept defined as the art, science, and technology of managing trees and forest resources in and around community ecosystems for the psychological, sociological, aesthetic, economic, and environmental benefits trees provide society" (Konijnendjik and Randrup 2004). *Reforestation* refers to reestablishing trees on lands that were recently covered by forest but experienced a disturbance, such as wildfire, timber harvest, or wind effects. *Afforestation* refers to the establishment of trees in areas that have not recently been covered in forests. Since there is no agreed-upon timeline when referring to reforestation versus afforestation and they are often used interchangeably, the term *urban reforestation* is used here to refer to both reforestation and afforestation, (IPCC 1998). Urban reforestation is a nature-based solution in which trees are planted in urban areas to subdue the effects of climate change and provide cobenefits to the environment and people (Ogunbode and Asifat 2021).

Green roofs, also known as *vegetated roofs* or *living roofs*, are defined by the vegetated layer growing on top of a rooftop (Figure 1; GSA 2021; EPA 2014). There are two different types of green roofs: *extensive*, in which lighter plants are planted and little maintenance is required; and *intensive*, which are similar to traditional gardens or parks and can handle most plant types, but need more structural support, higher initial investment, irrigation, and continued maintenance compared to extensive green roofs (EPA 2008). *Semi-intensive* green roofs represent a hybrid of both types (EPA 2021). Green roofs have layers that each perform different purposes, including plant growth, waterproofing, and structural support (EPA 2014).

Pollinator gardens are efforts to create green spaces filled with native plants that are attractive to pollinators. These gardens are typically installed to help support local pollinators, which globally have been declining due to pesticides, disease, and habitat loss. These gardens are designed to provide resources that pollinators need, including food sources (nectar and pollen), nesting sites, and larval host plants (Majewska and Altizer 2018).

TECHNICAL APPROACH

Technical approaches differ for the three urban greening strategies included in this strategy:

- **Urban forestry:** The Vibrant Cities Lab, a partnership between the US Department of Agriculture Forest Service (USFS), American Forests, and National Association of

Figure 16.1 Green roof in Ohio

Photo courtesy Dan Keck

Regional Council, outlines a seven-step approach to setting up urban forestry projects and programs (Vibrant Cities Lab 2017b).

1. **Assess:** The first step is to assess what the tree canopy looks like within the project area, including street trees outside of established parks. This can be achieved using the i-Tree Canopy application or with other available lidar or remote sensing data (i-Tree n.d.). The USFS has put together a five-step Urban Tree Canopy Assessment that will aid in the process of assessing and monitoring the tree canopy to ensure the proper management decisions are being made (Hermansen-Baez 2019).
2. **Prioritize:** It is important to consider "human health, economic development, water quality, air quality, public safety, equity, transportation, education, and city planning" when deciding which urban public lands should be invested in. A geographic information system is an important tool in this process because multiple different layers of geospatial data can be overlaid to see areas that could benefit most from urban reforestation intervention.

Figure 16.2 Tree planting in South Los Angeles, CA

Photo courtesy Santa Monica Mountains National Recreation Area

3. **Organize:** The next step is engaging the local community, municipalities, parks, and other agencies. Engaging the public can also aid in equity goals. Within the organization phase, it is important to make the case and communicate the goals for the project in a way that brings people into the conversation (TNC 2015; Vibrant Cities Lab 2017).
4. **Plan:** There are comprehensive guides that illustrate the necessary steps that go into an urban forestry plan (Vibrant Cities Lab 2017). It is important to remember what goals the project seeks to achieve with its implementation. These goals can include climate, community, and infrastructure aims dependent on the needs of the region (Kimball et al. 2014).
5. **Build:** This step refers to implementing the plan, specifically tree planting (reforestation) (Figure 2). At this stage, it is a good idea to contact local or state foresters to understand what species will be best for the site, community, and ecology (Vibrant Cities Lab 2017b). Invasive trees are commonly used as street trees and, in some cases, can negatively impact the local ecosystem (Dickie et al. 2013).

6. **Protect:** Possible risks that may need to be mitigated include flooding, fire, pests, disease, invasive species, and climate change. Ensure that the budget will allow for risk mitigation efforts. (Vibrant Cities Lab 2017b).

- **Green Roofs:** There are three primary steps for a green roof installation project.

  1. **Green roof type:** After determining the site for the green roof, the next step is to decide on installing an extensive or intensive green roof. This will depend on the initial investment, maintenance capacities, and the project's goals as a result of the installation (EPA 2008).

  2. **Vegetation:** Once the green roof type is selected, it is essential to decide on the vegetation, which will depend on the roof type, building design, climate, sunlight, irrigation ability, and expected use of the green roof (EPA 2008). For extensive green roofs, the report *Selecting Plants for Extensive Green Roofs in the United States* is a helpful resource for selecting vegetation types; for intensive green roofs, there are many more options (Getter and Rowe 2008, EPA 2008).

  3. **Installation:** Multiple layers are included in green roofs underneath the vegetative layer. These layers include, from the top down, a growing medium, filter membrane, drainage layer, root barrier, thermal insulation, vapor barrier, and structural support (EPA 2014). The growing medium is typically 3 to 6 in. deep for extensive and 6 to 48 in. deep for intensive green roofs. It provides space for the plant's roots and is typically a combination of organic and inorganic materials. The filter membrane prevents the growing media from clogging the drainage layer. The drainage layer removes excess moisture and water from the root zone and can be a variety of thicknesses depending on the vegetation type. The root barrier is meant to protect the water-tight barrier from being infiltrated by the roots. The thermal or insulation layer is used to keep mildew out of the building. The vapor barrier (waterproofing layer) is designed to prevent water damage through the structural building layer; some green roofs will have an additional leak detection system. Lastly, the structural layer is the foundation of the green roof (DOEE n.d., EPA 2014).

     It is possible to intentionally install green roofs with plants that attract and support pollinators, creating a combination green roof and pollinator garden (Howell et al. 2017). For more information on pollinator gardens, see the following section.

- **Pollinator gardens**: Installing pollinator gardens does not take a lot of technical expertise, and the major technical decision required is deciding which plants to include. There are numerous regional native plant guides available that help gardeners select appropriate plants for their geographic region (e.g., the National Park Service (NPS) Ecoregional Planting Guide Cards). Existing guides help gardeners select plants that offer a diverse array of pollen and nectar as well as reproductive resources for pollinators (Majewska and Altizer 2018). The intended garden site must also be appropriately prepared before planting occurs. This includes eliminating existing vegetation, suppressing competition from seeds in the soil, sod removal, smothering, tilling, and appropriate herbicide application. Additional tips for making the garden most productive for pollinators include clustering plants of the same species for

efficient foraging and leaving some bare soil available for ground-nesting insect pollinators (USDA 2017).

OPERATIONS AND MAINTENANCE

Operations and maintenance differ for the three urban greening strategies included.

- **Urban forestry**: Monitoring an urban forestry project is crucial to ensure that trees grow properly, risks are being appropriately managed, and the community is engaged. Ensure there is staff dedicated to the maintenance and monitoring of the trees and that they are equipped with the proper tools. Tree maintenance can cost $15-–$81 per tree per year (NOAA 2020). Community volunteers and stewardship organizations can be engaged to aid in monitoring and maintenance efforts (Vibrant Cities Lab 2017b).
- **Green roofs:** Maintenance requirements vary based on the roof type; extensive roofs require much less maintenance than intensive roofs. In general, using low-maintenance vegetation is typically best. Roof inspections should be done twice per year to ensure there are no leakage, structural issues, or drainage problems. During this inspection, it is also essential to check for invasive species and overgrowth. More regularly, the roof may need to be watered and inspected for dead or dying vegetation (DOEE n.d.).
- **Pollinator gardens:** Maintaining a pollinator garden is no different than maintaining any other garden. Maintenance efforts are typically relatively little, including weed removal, pest control, pruning, fertilizing, and watering (Majewska and Altizer 2018). It is important to avoid using pesticides and insecticides for pest control, as even sublethal doses can affect insect pollinator foraging and nesting behavior (USDA 2017).

FACTORS INFLUENCING SITE SUITABILITY

Urban Forestry

- ✓ **Hardiness zone:** Growers can use the hardiness zone of an area to determine which plants or trees would have success (USDA 2012).
- ✓ **Soil volume, composition, and depth:** Adequate soil structure is critical for site suitability for urban trees. Each tree will have different soil requirements, but in general degraded and compact soil will likely not be the best conditions for adequate tree growth (Arango 2015).
- × **Wind:** It is important to ensure that the trees are adapted to the wind in the area, so they will not be blown over. If trees are adapted to a specific site, they are more resistant to winds (Ogunbode and Asifat 2021).
- × **Salt:** In urban areas where salt is either used for deicing, there is sea spray, or there are generally salty soils, it is important to plant saline-tolerant trees. Trees that are not saline-tolerant can have adverse reactions to high salinity in soils, such as diminished growth and appearance or death (Fox and Koci 2022).

- ✗ **Other trees:** Too many trees in one area will lead to disrupted tree growth (Price 2003).
- ✗ **Overhead wires, lights, and signs:** The distance to powerlines and other overhead obstructions is critical when planting urban trees, specifically street trees. Knowing the tree's height at its tallest is essential to ensure it will not impede on or damage any infrastructure. For powerlines specifically, "within 6 feet the tree should be less than 25 feet tall, but planting isn't recommended; from 6-40 feet the tree should be 10 feet shorter than the wire or the canopy should be less than twice the distance to the wire; and over 40 feet any tree can be planted (Vibrant Cities Lab 2017b)."
- ✗ **Underground utilities:** Trees need room to ensure their roots can grow properly, so it is essential to know where underground utilities such as electric, gas, water, and sewers are located before planting (International Society of Arboriculture 2021).
- ✗ **Adjacent buildings:** Each tree will have a different canopy structure, and based on the canopy structure, one can determine how close the tree can be to a nearby building (i-Trees 2021).
- ✗ **Rooting space:** Because of the spatial limitations of cities and urban areas, finding sites that accommodate tree rooting space can be challenging (Pataki et al. 2021).

Green Roofs:

- ✓ **Built-up urban centers:** Areas in cities that are especially dense with buildings are good sites for green roofs because of the limited space for vegetation elsewhere and the extensive impervious surface coverage (EPA 2008).
- ✓ **Roof size:** Stakeholders will often want green roofs to be implemented on larger roofs to get the most benefits; larger roofs are typically found on low- to midrise buildings (EPA 2008).
- ✓ **Roof type—concrete:** It is easier to add a green roof to roofs that already have a concrete structure (EPA 2008).
- ✓ **New building:** Green roofs are usually easier to install in new buildings because they can be designed as part of the architecture (EPA 2008).
- ✗ **Roof type—steel:** Steel roofs require more intervention and cost to install a green roof (EPA 2008).
- ✗ **Slope:** Sloped roofs are more challenging to install green roofs on, but they can typically be done with extensive green roofs (EPA 2008). Slopes for green roofs can be up to 30%; beyond that, they are typically defined as *green walls* (DOEE n.d.)
- ✗ **Climate:** It is important to consider the local climate when considering vegetation types (EPA 2008).

Pollinator Gardens:

- ✓ **Location:** As long as soil and water are available, pollinator gardens can be planted almost anywhere. However, appropriate plants should be selected based on geographic region and desired pollinators.

TOOLS, TRAINING, AND RESOURCES FOR PLANNING AND IMPLEMENTATION

Urban Forestry

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Urban Forestry Toolkit	Toolkit/ website	Not provided	Vibrant Cities Lab (USFS, American Forests, and the National Association of Regional Councils)	National	Provides a more user-friendly adaptation of The Sustainable Urban Forest: A Step-by-Step Approach (Leff 2016). This is a full-service resource for all the guides, case studies, and research needed for an urban forestry project.	✓	✓	✓	✓
The Sustainable Urban Forest: A Step-by-Step Approach	Guidebook	2016	USFS and Davey Institute	National	Provides a detailed approach to managing forests in the urban setting.	✓	✓	✓	✓
i-Trees	Software	2006	USFS	National	Software that provides tree benefit estimation science through various tools and support.	✓	—	✓	—
Urban Tree Canopy Assessment	Report	2019	USFS	National	Overview of the process of urban tree canopy assessment, including best practices and additional resources.	✓	✓	✓	✓
Tree Planting Campaign Guide	Guidebook	2022	Green Infrastructure Center and USFS	National	Provides guidance on implementing urban tree planting projects from start to finish.	✓	✓	✓	✓
Forests in Cities	Resource library	2019	Natural Areas Conservancy	National	Resource library that provides managers with best practices for managing forests within urban areas as opposed to street trees or landscaped parks.	✓	—	✓	✓

Urban Forestry

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Trees and Health App	Website		Portland State University, Sustaining Urban Places Research Lab, USFS, PlanIT GEO	Albuquerque, NM; Atlanta, GA; Baltimore, MD; Cincinnati, OH; Denver, CO; Houston, TX; Minneapolis, MN; Orlando, FL; Phoenix, AZ; Pittsburgh, PA; Portland, OR; Sacramento, CA; Tampa, FL; Treasure Valley, ID	For 13 cities, this web-based app provides information to allow managers to assess, prioritize, and plan urban forestry projects.	✓	✓	✓	✓
Urban Forest Assessment Resource Guide	Guidebook	2013	American Forests	National	A guide to help assess the urban canopy/street trees within a project area. Provides external sources to help with assessment, management, and modeling.	✓	—	✓	—
Urban Forest Management Plan Toolkit	Website	2016	California Urban Forest Council, USFS, California Department of Forestry and Fire Protection	Designed for California but most of the information is more broadly applicable	This tool kit provides information on developing an urban forest management plan.	✓	✓	✓	✓
Choosing Suitable Trees for Urban and Suburban Sites	Book Chapter	2007	The University of Florida University of Florida's Institute of Food and Agricultural Sciences Extension	Designed for Florida, but most of the information is more broadly applicable	This chapter provides in-depth specifications for deciding what tree species to plant. It does not include a species list but explains what to look for at the site to determine what species to consider.	✓	—	—	—

Urban Forestry

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Resource Includes: Site Selection?	Resource Includes: Monitoring Guidance?	Resource Includes: Example Projects?
USDA Plant Hardiness Zone Map	Map	2012	USDA	National	This interactive map provides information on plant hardiness zone, informing managers about what species to plant.	✓	—	—	—
Urban Watershed: Urban Tree Planting Guide	Guidebook	2016	Center for Watershed Protection	National	This manual helps managers determine the tree planting specifications for an urban reforestation project.	✓	—	✓	✓

Green Roofs

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Green Roof Toolkit	Guidebook	2018	Government of the District of Columbia, Department of Energy and Environment	National	This toolkit provides basic information about green roofs, their benefits, installation considerations, and maintenance needs.	✓	—	✓	—
Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West	Guidebook	2010	Green Roofs for Healthy Cities, City and County of Denver, Environmental Protection Agency Region 8, Urban Drainage and Flood Control District, Colorado State University	Arid Western US states	This guide provides information on designing and maintaining green roofs in arid western states. It provides information on when certain types of green roofs are most appropriate and their different benefits	✓	—	✓	✓
A Designer's Guide to Small-Scale Retro-fit Green Roof Planning, Design, and Implementation	Guidebook	2013	Kansas State University	National	This guide provides information on how to implement smaller green roofs.	✓	—	✓	—
Green Roofs on Historic Buildings	Website	Not provided	NPS	National	This webpage provides information on how to implement green roofs on historic buildings, specifically within the NPS.	✓	—	✓	✓
Selecting Plants for Extensive Green Roofs in the United States	Guidebook	2015	Michigan State University	National	This guide provides information on what plants have been tested for extensive green roofs in different states.	✓	—	✓	—

Pollinator Gardens

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Resource Includes: Site Selection?	Resource Includes: Monitoring Guidance?	Resource Includes: Example Projects?
Pollinator Gardens Design Guide	Guidebook	2017	USDA Natural Resources Conservation Service	National	Tips for how to plant a successful pollinator garden. Includes pollinator garden designs for various site conditions.	✓	—	—	✓
Ecoregional Planting Guides	Guidebook	n.d.	Pollinator Partnership: NAPPC, US Forest Service, Bureau of Land Management, Plant Conservation Alliance, Natural Resources Conservation Service, US Geological Survey, National Association of Conservation Districts	National (individualized guides for each ecoregion of the United States)	Individualized guidebooks for each US ecoregion detailing the pollinators and plants appropriate for pollinator gardens in that region.	✓	—	—	—
Ecoregional Planting Guide Cards	Guidebook	n.d.	NPS	National (individualized factsheets for each ecoregion of the United States)	Individualized guidance for each US ecoregion detailing the plants appropriate for pollinator gardens in that region.	✓	—	—	—
Pollinator-Friendly Best Management Practices for Federal Lands	Guidebook	2015	Pollinator Health Task Force	National	This guidebook is an overview of best practices to promote healthy pollinator populations on federal lands. It is not specific to pollinator garden creation, but includes information that is helpful to those creating pollinator-friendly habitat.	✓	✓	—	—

GRAY INFRASTRUCTURE ALTERNATIVES

- **Urban forestry:** Urban forestry can be an alternative to gray infrastructure approaches that reduce the effects of urban runoff (stormwater drainage system) and urban heat (shade structures). The ability of an urban forestry project to replace or supplement one of these gray infrastructure types depends strongly on the project's location and whether it is designed to create the necessary outcomes. Certain environmental conditions may require gray infrastructure rather than urban forestry. See the gray infrastructure alternative tables in Section 1 for a comparison of urban forestry to these alternatives.
- **Green roofs:** Green roofs can be an alternative to cool roof coatings, which are also designed to reduce urban heat and energy use. The ability of a green roof project to replace or supplement this gray infrastructure approach depends strongly on the project's location and whether it is designed to create the necessary outcomes. Certain environmental conditions may require gray infrastructure rather than a green roof. See the gray infrastructure alternative tables in Section 1 for a comparison of green roofs to this alternative.

LIKELY BENEFITS AND OUTCOMES

Primary objectives for each strategy are highlighted.

Climate Threat Reduction

- **Heat mitigation:**
  - **Urban forestry:** Trees reduce heat islands as a result of shading and the evapotranspiration of water from their leaves (Ennos 2012). *Heat islands* are areas with structures such as buildings and roads that absorb and reemit the sun's heat. Heat islands lead to an increase in energy consumption, emissions of air pollutants and greenhouse gases, compromised human health, and poorer water quality. Adding greenery, specifically trees, can significantly decrease the impacts of urban heat islands (EPA 2014).
  - **Green Roofs:** Green roofs can reduce urban heat through shading and evapotranspiration (EPA 2008, GSA 2021). Green roofs can stay 40°F to 50°F cooler than conventional roofs (DOEE 2018)
- **Improved air quality:**
  - **Urban forestry:** Trees can reduce pollution because of their cooling effects and removing pollutants from the air. Trees' stomata (leaf pores) can directly remove gaseous pollutants from the air. Trees can also temporarily contain particulates on the surfaces of leaves and bark, but they will reenter the environment either in the air or soil (NPS 2022). In the Northeast and Midwest regions of the United States, the removal of air pollutants was valued at an estimated $1.36 billion (NMSFA 2022).

    - **Green roofs:** Green roofs create more vegetation in the urban environment, which removes pollution and greenhouse gases (GHGs) as a result of carbon sequestration and storage. The reduction in energy use also leads to reduced GHG emissions. Another GHG reduction is provided from the cooling effect, which helps reduce ground-level ozone caused by increased urban temperatures (EPA 2008).

- **Carbon storage and sequestration:**
    - **Urban forestry:** One benefit of trees is their ability to absorb and store carbon dioxide. Though urban forests in the United States account for only 3% of the country's forests, their carbon storage can help cities reach their emission reduction goals (Pregitzer et al. 2021). In the Northeast and Midwest regions of the United States, the sequestration of carbon in urban forests was valued at $1.06 billion (NMSFA 2022).
- **Reduced flooding:**
    - **Urban forestry:** The installation of urban trees reduces flood risk (Leff 2016). Trees distribute water due to the canopy cover, which decreases rapid water rise. Trees also provide porous soils, so water can more easily infiltrate (Trees Energy Conservation 2019).
    - **Green roofs:** Green roofs can reduce and slow stormwater runoff because of the vegetation's ability to use and retain water (GSA 2021). A study of an agricultural green roof in New York City found that the green roof retained 2.3 times more stormwater when compared to urban forests (Harada and Whitlow 2020).
    - **Pollinator gardens:** Pollinator gardens can allow for increased infiltration of stormwater for localized flood reduction benefits (APA 2021)

Social and Economic

- **Jobs:**
    - **Urban forestry:** Urban reforestation provides local jobs (Vibrant Cities Lab 2017b). In the Northeast and Midwest regions of the United States, urban forestry employed more than 357,200 people with a payroll of ~$16.05 billion (NMSFA 2022).
    - **Green roofs:** The green roofing industry continues to provide stable employment for both installation and maintenance (DOEE 2018).
- **Mental health and well-being:**
    - **Urban forestry:** Numerous studies correlate physical and mental health with green spaces. However, there is still a need for studies to quantify the influence of urban trees on human health (Pataki et al. 2021). There are also correlations between natural areas and stress reduction, which leads to a more positive emotional state (Ulrich et al. 1991).

  - **Green roofs:** Cooler temperatures benefit human health and comfort. Green roofs also provide spaces for people to connect with nature in urban areas, which has proven health benefits (EPA 2008).
  - **Pollinator gardens:** Pollinator gardens provide access to nature in urban areas, which has been known to be associated with mental health benefits (APA 2021)
- **Recreational opportunities:**
  - **Urban forestry:** Urban greenspace and forests encourage people to recreate and exercise (Lupp et al. 2016).
- **Aesthetics:**
  - **Urban forestry:** The aesthetic value of trees, although difficult to quantify, is a crucial benefit of urban trees (Price 2003).
  - **Green roofs:** Green roofs provide positive aesthetics for those who enjoy them (Skabelund and Brokesh 2013).
  - **Pollinator gardens:** Pollinator gardens are centered on flowering plants, providing aesthetic benefits (APA 2021)
- **Increased property values:**
  - **Urban forestry:** Home prices increase if a tree is on the premises (NC State 2022).
  - **Green roofs:** The addition of a green roof can increase the value of the building (DOEE 2018).
- **Wind and noise reduction:**
  - **Urban forestry:** Urban trees and parks can help reduce wind and noise by acting as barriers (Chiesura 2004).
- **Crime reduction:**
  - **Urban forestry:** Numerous case studies show a correlation between increased canopy cover and reduced crime (Vibrant Cities Lab 2017a, Kuo and Sullivan 2008). However, this relationship has been debated in the academic literature (e.g., Troy et al. 2012; Bogar et al. 2015).
- **Reduced energy use:**
  - **Urban forestry:** Urban trees can help reduce energy use by helping to shade buildings, cooling air temperatures, and altering wind speeds around buildings. In the United States, residential energy savings by trees has been valued at $7.8 billion annually (Nowak et al. 2017).
  - **Green roofs:** Because of the water storage capabilities of green roofs, they can provide insulation in both the summer and winter by reducing temperature fluctuations (EPA 2008). In the summer, green roofs can cool the air through evapotranspiration (EPA 2014). Green roofs can lower the cost of energy by reducing heating and cooling needs for buildings (Tolderlund 2010).

- **Food security:**
  - **Green roofs:** Green roofs can be used to house community gardens, greenhouses, or rooftop farms, which can contribute to increased food security (Harada and Whitlow 2020).
- **Reduced or avoided costs:**
  - **Green roofs:** Green roofs typically last twice as long as conventional roofs (GSA 2021).

Ecological

- **Reduced runoff:**
  - **Urban forestry:** Tree canopies can reduce both the temperature and volume of stormwater runoff because of rainfall interception from leaves, porous soils, and shading over the pavement (Kimball et al. 2014). In the Northeast and Midwest regions of the United States, an estimated $635 million was valued from stormwater reduction (NMSFA 2022).
- **Supports wildlife:**
  - **Urban forestry:** Additional trees within urban areas can produce a more robust pollinator population (species dependent on location). More pollinators can contribute to a healthier ecosystem and increased biodiversity (Baldock et al. 2015).
  - **Pollinator gardens:** Pollinator gardens are created to provide food, habitat, and reproductive resources for pollinator species (APA 2021).
- **Enhanced biodiversity:**
  - **Urban forestry:** Urban trees can create additional habitats and resources for wildlife, positively impacting the ecosystem (Mexia et al. 2018).
  - **Green roofs:** Green roofs can provide habitat for plants, insects, and birds in urban environments (GSA 2021; DOEE 2018). Green roofs can also provide effective corridors for these various species and provide critical habitats for pollinators (Harada and Whitlow 2020).

BARRIERS AND SOLUTIONS FOR PRACTITIONERS

Common Barriers

Several barriers are common across many of the nature-based solutions strategies; these are described in more detail in Section 1 of the Roadmap. Additional notes about the barriers specific to urban greening are included here.

- **Expense:**
  - **Green roofs:** Green roofs are more expensive than conventional roofs. Intensive green roofs typically cost around $40 more per square foot, and extensive green

roofs generally cost around $10 to $30 more per square foot than conventional roofs (DOEE 2018). There is also a significant maintenance cost, especially with intensive green roofs (Salter 2021).

- **Capacity**
- **Public opinion**
- **Conflict with other land uses:**
  - **Urban forestry:** Urban areas are limited in their capacity to implement reforestation projects because much of the community space is already allocated toward initiatives like affordable housing (Pataki et al. 2021). Some activist groups are promoting a "Trees and" approach for cities to follow, allowing both initiatives to be achieved through conscious planning (Ionescu 2022).
- **Regulation**
- **Lack of effectiveness data**

Economic

- **Urban forestry:**
  - **Maintenance:** In 2005, the cost of maintaining urban trees was estimated between $12.87 to $65 annually per tree. It is crucial to factor maintenance costs into a project budget to ensure trees are properly maintained. However, though maintenance expenditures can be high, the benefits reported from the same cost-benefit analysis stated that for every dollar spent, the return on investment ranged from $1.37 to $3.09 (McPherson et al. 2005).
  - **Damage to infrastructure:** Tree roots often damage sidewalks, which can lead to liability claims. Falling trees can also damage homes, cars, lighting, sewers, and phone or electrical wires. Damage can be avoided with proper site suitability analyses and site preparation (Trees Energy Conservation 2019).
  - **Cost of improper planting:** If trees are planted or maintained incorrectly and die, they can be an eyesore, imply a lack of investment in the community, and have significant financial costs (Roman et al. 2021).
- **Green roofs:**
  - **Potential leakage:** There is a potential for the roots to penetrate the waterproof layer, which causes leaks, potentially leading to structural and property damage. Finding the leak can also be a challenge because of the complexity of the roof (Salter 2021).

Community

- **Urban forestry:**
  - **Safety concerns of large wooded areas:** Some people may not want a large wooded area close to them because of their associated potential danger (Pataki et

al. 2021). A case study in Washington, DC, showed that automobile-related crimes were more common in areas with trees as a result of more visual ground coverage (Vibrant Cities Lab 2017a).

- **Barriers to access:** Green spaces are less accessible for low-income communities of color as compared to affluent, white neighborhoods. In Los Angeles, this disparity is evident in the tree canopy cover. The tree canopy cover is 55% in an affluent neighborhood, compared to 10% in a low-income neighborhood (Kunsch and Parks 2021). Acknowledging and combating these disparities in urban reforestation projects' development, implementation, and maintenance stages is essential.
- **Lack of community involvement:** In an example in Detroit, the city tried to implement an urban tree project, but many residents did not want trees on their property. The residents felt the city was not involving them in the conversations, and communities of color did not have a seat at the decision-making table. It is important to ensure all stakeholders have a place in the discussion in regard to any environmental justice or community environmental initiative (Mock 2019).

- **Green roofs:**
  - **Fire hazard:** Green roofs can become a fire hazard when dry, so it is essential to use fire-resistant plants, like sedums, and construct a fire break if the vegetation is expected to dry out in the summer (EPA 2008).

Ecological

- **Urban forestry:**
  - **Spread of pests:** Urban trees are often more susceptible to pests because of the proximity to human activities that aid in the spread of forest pests. Pest management can cost agencies and municipalities millions of dollars. It is important not to plant a single species and to diversify urban trees to limit the spread and impact of forest pests (Hudgins et al. 2022).
  - **Nonnative invasive trees:** Often, trees used as street trees or for urban forests are invasive or nonnative, and this can result in disturbance to the ecosystem (Roman et al. 2021).
- **Pollinator gardens:**
  - **Pesticides:** One of the major threats to insect pollinator populations is harmful pesticides. Even if pesticides aren't used within a pollinator garden, their use in nearby areas can negatively affect pollinators that visit the garden (Xerces Society, n.d.).

EXAMPLE PROJECTS

Urban Forestry

Name and Link	Location	Leading Organizations	Techniques Used	Size	Cost	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Providence Neighborhood Planting Program	Providence, RI	City of Providence, Rhode Island Parks Department, Providence Neighborhood Planting Program	Community urban tree planting	20.6 mi^2	Not provided	Ongoing (began 1988)	The Providence Neighborhood Planting Program aims to engage the community by planting trees in lower-income areas with less canopy cover. (American Forests 2023.	Store carbon, cool the city	Working with anchor institutions like schools can have a larger impact than working directly with individuals (American Forests 2023).
Million Trees NYC	New York City	City of New York Department of Parks and Recreations	Municipality planted 70% of trees in public spaces and relied on private owners to plant 30% of the trees	~300 mi^2	$400 million	2007–2015	This project was in partnership with New York Restoration Project, and the goal was to plant 1 million trees throughout NYC. This was achieved in 2015.	Carbon sequestration, reducing energy use, reducing CO2 emissions, improving air and water quality, lowering summer air temperature	Developing a program for community members to lead tree stewardship efforts in their area helped with the maintenance and education efforts across such an expansive area (New York City Global Partners 2013).
Madrid Reforesta: Bosque Metropolitano	Madrid, Spain	Área de Gobierno de Desarrollo Urbano	The leading organization split the project into five lots, each with unique forest and land use types.	75 km	€77 million euros(~ $80 million USD)	12 years	This project is multipart, aimed at achieving climate and community goals. It is a forest belt that will surround the city.	Soil restoration, ecosystem restoration, reduce CO2 emissions	Not provided

Urban Forestry

Name and Link	Location	Leading Organizations	Techniques Used	Size	Cost	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
2 Billion Trees Program Canada	Canada	Government of Canada	Canadian citizens and organizations will be able to receive government funding to do tree planting projects throughout the country. There will be resources to address knowledge gaps in tree planting and maintenance processes	Throughout Canada, the total tree area is not known at this point.	$3.2 billion	10 years	This project aims to bring more trees to all parts of Canada, including rural, remote, and urban areas, on private and public lands.	Cool cities, increase biodiversity, clean air and water, reduce disaster risk	The project will not fund projects to plant trees in important ecosystems like grasslands, nor will they fund private projects that are “business as usual.”

Bolding indicates DOI affiliates.

Green Roofs

Name and Link	Location	Leading Organizations	Techniques Used	Size, ft²	Cost	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
NOAA Satellite Operations Center	Suitland, MD	US General Services Administration, National Oceanic and Atmospheric Administration	Green roof	146,000	$81 million	Not provided	This project aimed to create a low-impact building for the satellite operations center.	Stormwater management	Not provided
Chicago City Hall Green Roof	Chicago	US Environmental Protection Agency, City of Chicago	Semi-intensive on a 1.5% slope, irrigation system along with rainwater collection	20,300	$2.5 million	1.5 years	This project was meant as a test to see how well a green roof would operate in Chicago, and it was a success in mitigating urban heat and propagating urban ecology (Dvorak).	Combat urban heat, improve air quality	It is crucial to secure funding for proper maintenance (Dvorak).
Hassalo on Eighth Green Roof	Portland, OR	American Assets Trust	Intensive and extensive on a 1% slope, wastewater treatment using a natural Organic Recycling Machine	38,000	The total price was not provided, but the project was refunded $1.48 million because of innovative stormwater management.	~1 year	This project was a part of multiple green roofs being used for wastewater treatment using the natural organic recycling machine. This project was a cutting-edge stormwater treatment strategy.	Reduce stormwater runoff, relieve stormwater treatment facilities	Because of the welcoming design, this project also achieved community engagement and use.

Bolding indicates DOI affiliates.

Pollinator Gardens

Name and Link	Location	Leading Organizations	Techniques Used	Size	Cost	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Living Roof at 50 UN Plaza	San Francisco, CA	US General Services Administration	The green roof uses 8 in. of growing media to support succulents and native California plant species that provide nectar.	14,000 ft^2	Not provided	Not provided	Combination green roof with a succulent carpet and wildflower mix.	No	No
Smithsonian Urban Garden	Washington, DC	Smithsonian Institute	Installation of plants known to attract and support butterflies	11,000 ft^2	Not provided	Not provided	Butterfly habitat garden supports plants that have specific relationships to life cycles of eastern US butterfly species.	No	No
Jennings County Pollinator Habitat Program	Jennings County, IN	Jennings County Soil and Water Conservation District	Public education to spread word about pollinator declines, working with farmers to create pollinator habitat near farmland, and funded pollinator habitat creation on public and private property within the county	More than 600 habitat patches, ranging from 1 m^2 to >1 acre in size	Not provided	4.5 years	A county-wide pollinator habitat initiative	No	No

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