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Designing multifunctional urban agroforestry with people in mind

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Abstract

Urban landscapes combining trees and crops—urban agroforestry (UAF) systems—may offer greater ecological and cultural benefits than annual cropping systems. Interest in UAF is growing, as evidenced by an increasing number of built projects and articles in the popular press and the academic literature on the subject. However, the practice of UAF appears to far outpace research on its scientific underpinnings or its design. Developing sustainable, resilient UAF sites can be challenging because of biophysical and sociocultural conditions unique to the city; however, cities offer opportunities not found in rural environments including the potential to close open nutrient loops between consumers and sites of food production. We argue that these biophysical and sociocultural challenges and opportunities can be best addressed through an evidence-based approach to the design of UAF systems and a complex ecological aesthetic design language integrating theory, principles, and practices from urban agroecology and allied fields, environmental psychology, and landscape architecture. The resulting multifunctional UAF systems would be socially sustainable and equitable and promote the circular metabolism of the city. Drawing on a purposive review of literature from these disciplines, we propose a preliminary framework consisting of 14 guidelines and complementary principles and strategies for the design of multifunctional, culturally preferred UAF and offer recommendations for future research.

1 | INTRODUCTION

Multifunctional green infrastructure (GI) can play a key role in promoting circular urban metabolism (CUM), reducing the ecological footprint of cities and providing a wide range of services including biodiversity conservation (Van Broekhoven & Vernay, 2018). Academics—if not policymakers—increasingly recognize the potential contributions of nontraditional forms of GI such as wastelands (Bonthoux et al., 2014) and informal green spaces (Rupprecht et al., 2015) to CUM and to urban social–ecological systems in general. Productive urban spaces, such as home and community gardens and urban farms, can also be considered to be a nontraditional, multifunctional form of GI. In addition to their productive and diverse cultural functions, these spaces have the potential to infiltrate stormwater, mitigate urban heat island effects, conserve biodiversity, sequester carbon, contribute to soil formation, and recycle urban wastes (Lin et al., 2015; Lovell, 2010; Wielemaker et al., 2018; Wortman & Lovell, 2013).

The research literature documenting the plant diversity of urban home gardens (e.g., Taylor et al., 2017) and

Abbreviations: CT, constructed technosol; CUM, circular urban metabolism; GI, green infrastructure; UA, urban agriculture; UAF, urban agroforestry.

community gardens (e.g., Clarke & Jenerette, 2015) in the United States indicates annual vegetable and herb crops and, to a lesser degree, small fruits are the primary focus of urban agricultural practice rather than perennial crops, possibly due in part to insecure land tenure, a frequent limiting factor in urban agriculture (UA) (Lovell, 2010). However, systems combining trees with other crops, or with the trees themselves as crops (e.g., fruit and nut trees), may offer greater cultural and ecological benefits and sustainability (Lovell, 2020; Lovell & Taylor, 2021), though potentially at some cost to yield from understory species—but not necessarily the system as a whole—in northern climates because of shading (Björklund et al., 2019). We refer to these systems collectively as urban agroforestry (UAF). They potentially include diverse system types including alley cropping, multifunctional woody polycultures (Lovell et al., 2018), underplanted orchards, food forests, forest farming, and urban forests managed for foraging.

Public and academic interest in UAF appears to be growing, with an increasing number of built UAF projects and articles in the popular press and the academic literature on the subject including this special issue and the recently published book, *The Community Food Forest Handbook* (Bukowski & Munsell, 2018). However, the practice of UAF appears to outstrip academic research on the design and dynamics of these systems, particularly for diverse, multistory systems such as the food forest, arguably the mostly popular form of UAF in the United States. In a recent scoping review, Park et al. (2019) identified only eight English-language, peer-reviewed articles addressing, even obliquely, multistory urban food systems with trees in North America and Europe. All were literature reviews or articles reporting the results of observational rather than experimental studies. While a considerable grey literature exists on the design of food forests, it is primarily driven by permaculture theory, including the work of Jacke and Toensmeier (2005), and is based on tropical home garden models. Permaculture theory is largely untested under experimental conditions (Ferguson & Lovell, 2014) and remains, from a scientific standpoint, a set of hypotheses for UAF development.

The developing peer-reviewed literature on UAF recognizes the key role design can play in maximizing the contributions of multifunctional UAF to the urban environment. Clark and Nicholas (2013) see design as the medium or 'common ground' through which the rift between landscape practice and ecological science can be repaired in UAF. They propose "integrating elements of UA, urban forestry, and agroforestry to develop a novel, multifunctional approach to improve urban landscape sustainability, which we term urban food forestry" (p. 1652). Clark and Nicholas's (2013) work is part of a larger conversation about the potential contributions of transdisciplinary approaches to the design of multifunctional agroecosystems. Lovell et al. (2010) define design as the "spatial arrangement of landscape features resulting from the design… process" (p. 328) and agroecosystems as complex systems of interacting social and ecological elements with the production of food, fuel, fiber, medicinals, or ornamentals as one of their functions. Human-imposed design drives the selection of elements and the articulation of those elements at multiple scales—from the components of the soil system to the composition of plant assemblages to the arrangement of systems and spaces at the site level—to achieve a desired set of functions (Lovell et al., 2010). Design can adjudicate tradeoffs between different system and site functions and align functions with community needs and desires (Lovell et al., 2010; Lovell & Taylor, 2021). In the case of urban environments, design can also drive integration of urban agroecosystems with larger-scale urban systems and grey infrastructure to create a more circular urban metabolism (Wielemaker et al., 2018).

Core Ideas

- The practice of urban agroforestry (UAF) outpaces research on system science and design.
- A system-specific complex ecological aesthetic design language could enhance multifunctionality.
- Evidence-based design guidelines, principles, and strategies can inform UAF practice.
- Additional research is needed to bridge the gap between practice and theory.

We build on these ideas in this paper. Recognizing the equal importance of productive, ecological, and cultural functions in UAF, we argue for an even more expansive approach than Clark and Nicholas (2013). We propose integrating theory, principles, and practices from urban agroecology and allied fields, environmental psychology, and landscape architecture to create an evidence-based approach to UAF design and a "complex ecological aesthetic design language" (Egoz & Bowring, 2004) for UAF that recognizes its productive, ecological, and cultural functions and creatively explores the tensions and synergies between these functions in an urban environment. Such a design language—and design guidelines translating theory into practicable form—is necessary to create multifunctional UAF sites that are culturally sustainable and socially equitable, are sources of pleasure and beauty in the urban landscape, and promote the circular metabolism of the city (Figure 1).

The goal of this article is to lay the foundation for this conceptual and practical framework through a narrative review (a) discussing the unique biophysical and sociocultural challenges and opportunities the urban environment poses for UAF design and (b) highlighting the potential

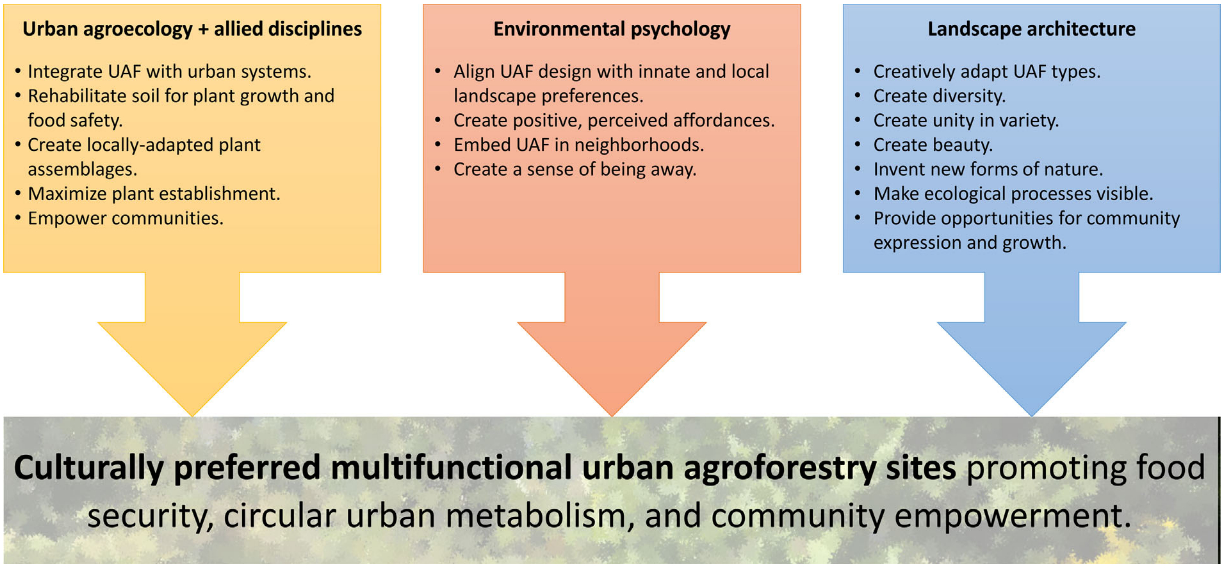

FIGURE 1 Multidisciplinary design principles for multifunctional urban agroforestry

contributions of each discipline to addressing those challenges and opportunities. Based on our selective review of the literature, we articulate a set of provisional design principles for UAF. We do not intend our work to be comprehensive or exhaustive. Instead, we hope it engages members of relevant disciplines in an ongoing dialog on this emerging topic and stimulates future conceptual and empirical research.

We begin with urban agroecology, which is foundational to UAF, and allied fields such as UA and urban forestry. These fields can inform the design of UAF as ecological engineering and, in the case of agroecology—which is a political movement in addition to a science and a practice (Wezel et al., 2009)—as a tool for empowering communities. Environmental psychology provides guidance in aligning the design of UAF systems with the preferences of and affordances perceived by community stakeholders, as suggested by the inspiration for this article—*With People in Mind: Design and Management of Everyday Nature* (Kaplan et al., 1998)—and its title. Finally, landscape architecture provides a unifying theoretical and applied framework for UAF design. We summarize our discussion with a set of preliminary design guidelines and recommendations for future research related to the design of UAF systems.

2 | UNIQUE CHALLENGES OF THE URBAN ENVIRONMENT

The literature on UA, urban ecology, and UAF indicates the design of multifunctional UAF faces a number of biophysical and sociocultural challenges.

2.1 | Biophysical challenges

Cities are warmer than their hinterlands—particularly at night—because of a wide range of anthropogenic factors (Oke, 1982), with increased potential evapotranspiration (Zipper et al., 2017). Buildings may provide shelter from prevailing winds and sun but may also, in combination with urban morphology, increase wind speed and turbulence (Eliasson et al., 2006). The heat island effect may increase plant growth and productivity and extend the growing season in cities. However, in combination with higher evapotranspirative demand and increased wind speed it may increase the risk of heat and drought stress in urban plantings.

Poor soil quality potentially constrains plant growth, particularly the growth of woody species with extensive root systems. Because of infilling with foreign soils, construction debris, and other materials, the soil on an individual site may bear little resemblance to the soils on adjoining lots or to the original, native soil, creating a highly heterogeneous patchwork of soils across the landscape and even within sites (Effland & Pouyat, 1997). Soils may be compacted as a result of their history of use, and they may be high in pH and calcium because of the weathering of liming materials in infill and adjacent paving and building materials and the deposition of calcium carbonate as calcite (Pouyat et al., 2007; Washbourne et al., 2015). Organic matter may be low—or very high on some sites—compared with native, undeveloped soils because of histories of use or neglect (Taylor & Lovell, 2015; Ugarte & Taylor, 2020). In the absence of additions of organic matter, elevated soil temperatures resulting from the urban heat island effect and changes in above- and belowground biota may accelerate the decomposition of organic matter, resulting in loss of the O horizon in urban forests, the rapid release and potential leaching of nitrogen and other nutrients throughout the soil profile, and reduced sequestration of carbon in the soil (Pavao-Zuckerman & Coleman, 2005; Pouyat et al., 1997). Contamination by heavy metals and toxic organic compounds, such as polychlorinated biphenyls (PCBs), may pose risks to human health (Ferreira et al., 2018).

2.2 | Sociocultural challenges

In cities, UAF may be expected to perform at higher levels of landscape multifunctionality than in periurban or rural areas—where marginal lands may be used for agroforestry—in order to justify the use of valuable urban real estate for agricultural production. Urban agroforestry sites may need to be not only productive and economically sustainable but also beautiful, psychologically restorative, and culturally acceptable—if not desirable—while providing recreational and educational opportunities (Park et al., 2018, 2019). Public UAF can also be expected to have a broader, much more culturally diverse base of stakeholders than rural agroforestry sites, which, unless communally managed, may have just a single user (Lovell & Taylor, 2021). Urban agroforestry stakeholders may have different perceptions of landscape affordances and diverse and sometimes conflicting expectations for landscape aesthetics and performance, placing greater demand on landscape functionality and complicating the adjudication of trade-offs between ecosystem services (Lovell & Taylor, 2021).

Furthermore, in the absence of empirical research on perceptions of UAF, we hypothesize the public may perceive more ecologically complex UAF sites to be socially transgressive because they deviate from conventional public landscape types such as the pastoral landscape park with widely scattered groupings of trees on lawn. While research on perceptions of urban greenspace with trees is plentiful and can offer some design guidance, UAF projects are unique in appearance, purpose, and composition. With their high levels of plant diversity, wildness, and use of productive plants without conventional aesthetic attributes, multistory UAF, in particular, may be perceived to be unkempt, unmanaged, neglected, and weedy, particularly in contrast to the manicured landscapes dominating cities (Riolo, 2019) or more natural urban forests. For UAF practitioners, the seeming messiness of plantings may represent ecosystem health and symbolize practitioners' rejection of conventional landscape norms. Other members of the community, however, may find these unconventional landscapes to be objectionable or unsafe. Even private UAF in backyards or front yards, we hypothesize, may be a source of conflict between neighbors because of their visibility from adjacent residences, streets, sidewalks, and alleys.

Access, governance, and tenure can also be significant obstacles to the successful implementation of UAF systems because of their permanence and may explain the apparent focus of existing UA on annual vegetable crops or relatively fast-yielding small fruits. Even dwarf fruit trees require ≥3 yr to begin to bear in northern climates, while strawberry (*Fragaria* ×*ananassa* Duchesne ex Rozier) plants can be grown as annuals and raspberry (*Rubus idaeus* L.) and blackberry (*Rubus* spp) plants require only 2 yr to bear (Eames-Sheavly et al., 2003). The latter three crops are also more easily moved to a new garden than trees. Urban agroforestry is thus not amenable to the conditions of short-term land tenure that some community gardening organizations, such as the Peterson Garden Project in Chicago, have successfully negotiated by securing leases on borrowed land for pop-up gardens (Peterson Garden Project, 2021). Furthermore, UAF projects demand long-term management and continuous care. Research on community gardens suggests that mixed forms of governance—described by Fox-Kämper et al. (2018) as "bottom-up with political and/or administrator support (PAS)" (p. 63)—may be particularly effective in ensuring the success and persistence of UAF sites.

2.3 | Opportunities

Despite these challenges, the urban environment also offers a number of design opportunities for UAF. Urban agroforestry systems can be woven into the urban fabric, providing opportunities for residents to experience the psychologically restorative properties of encounters with everyday nature. Community members can serve as advocates and caretakers for UAF sites, providing a source of labor for site management, which can be limiting in more rural and private forms of UAF (Björklund et al., 2019). If designed properly, these sites can be an antidote to urban "blandscaping," the aesthetic, ecological, and biotic homogenization endemic to cities in developed countries (Connop & Nash, 2018), strengthening place attachment among community members while conserving biodiversity. Urban agroforestry sites can, like other forms of UA, also serve as nucleation points within the community for a political agroecology or liberation permaculture seeking to empower marginalized groups and to transform the dominant industrial food regime (Massicotte & Kelly-Bisson, 2019). Finally, because of their close proximity to where urban wastes, such as stormwater, greywater, and organic solid wastes, are produced, UAF sites can—like GI in general—enhance the circular metabolism of the city if connected appropriately to grey infrastructure (Artmann et al., 2019).

3 | DESIGN CONTRIBUTIONS OF EXISTING DISCIPLINES

In the following sections, we discuss the potential contributions of each selected discipline—urban agroecology and allied fields, environmental psychology, and landscape architecture—to overcoming the challenges and leveraging the opportunities of agroforestry in an urban environment through design as ecological or social engineering or creative endeavor. General design principles and specific design strategies are summarized in Table 1.

3.1 | Urban agroecology and allied fields

Agroecology as a science and a practice is foundational for the design of any agroforestry system. Principles of complementarity and facilitation, for example, guide plant selection and vegetation layering in UAF just as they do in nonurban systems. However, agroecological principles and practices and those from allied fields, including UA, horticulture, and forestry, need to be adapted to the scale, constraints, and opportunities of the urban environment and to the particular requirements of cropping systems with trees.

3.1.1 | Integrate UAF sites with urban systems including grey infrastructure

Urban agroforestry sites—and urban metabolism in general—can benefit biophysically from their close proximity to the built, inhabited environment. Organic wastes, including food, yard, and even human waste, can be cycled through urban production sites, including UAF sites, offsetting nutrient losses from harvest and leaching and reducing or even eliminating the need for allochthonous inputs (Wielemaker et al., 2018). Wastes (excluding, of course, human waste) could be brought to the UAF site and composted ex situ or, alternatively, they could be composted by stakeholder households in situ and the finished compost brought to the site. Both conventional composting and vermicomposting are sustainable alternatives for management of household wastes (Lleó et al., 2013), and home composting can be more sustainable than industrial composting from a lifecycle assessment perspective (Martínez-Blanco et al., 2010). Integration of UAF with recovery of nutrients and organic matter from human waste would require substantial public investment in recovery technologies where exceptional quality biosolids are not already available and also shifts in legislation and public attitudes toward their use in urban areas (Harder et al., 2019; Wielemaker et al., 2018). Regardless of waste source, the small size of urban sites and the concentration of wastes on those sites can rapidly increase soil organic matter and soil quality (Beniston et al., 2016). Given the potential for accelerated loss of organic matter from urban forest soils as a result of the heat island effect, continued carbon additions from waste sources may be key to maintaining UAF health and carbon sequestration services over the long term without a reliance on inputs from distant sources.

Access to water can be a production constraint in urban environments (Wortman & Lovell, 2013). Newly planted trees and shrubs require irrigation, as may established plants during drought, particularly under urban conditions of elevated temperature and vapor pressure deficits. Irrigation—in concert with improved soil quality from amendment with organic wastes—can dramatically increase yields and precocity in urban agroecosystems in general (Amos et al., 2020) and, potentially, the ability of UAF to address food insecurity and low access to nutritious foods in urban neighborhoods. However, municipal sources of water may not be accessible, and, even if they are, the use of treated, potable water for irrigation is neither sustainable nor cost effective (Lovell, 2010). Urban stormwater, particularly the relatively clean water collected from rooftops, can be redirected to UAF for irrigation and also infiltration (Amos et al., 2018). Diversion of rainwater has the additional benefit of reducing the volume of water flowing into storm drains and local waterways. Rainwater harvesting systems can be as simple as rain barrels, but storage in large above- or belowground tanks during periods of water stress potentially increases system resilience and plant productivity (Amos et al., 2018). Distribution systems can be as simple as buckets and watering cans or as sophisticated as subsurface irrigation (Amos et al., 2018). Low-pressure drip irrigation is easily installed, sustainable, and water wise (Woltering et al., 2011). On small sites, traditional pitcher irrigation with unglazed clay pots or a modern adaptation, "bottle feeding," may also be appropriate and particularly beneficial for tree crops (Merrey & Langan, 2014). Rooftop rainwater can meet a substantial amount of the water requirements of UA; a study in Rome found that 41% of the needs of horticultural crops could be met through water harvested from roofs within the study area (Lupia & Pulighe, 2015).

Rainwater for irrigation could be augmented with greywater diverted from adjacent buildings, as it is in developing countries for use in UA (Faruqui & Al-Jayyousi, 2002). From a safety perspective, greywater collected through a decentralized system does not need to be treated if it is applied immediately to biologically active soil (Al-Jayyousi, 2003). However, if it is to be stored, greywater must be treated through one of several technologies (Al-Jayyousi, 2003) including biological treatment techniques, which are more efficient than physical or chemical treatment (Yoonus & Al-Ghamdi, 2020). Treatment may also be required by municipal regulations and may be desirable for irrigation of food crops if the water will come into contact with edible plant parts.

TABLE 1 Multidisciplinary design principles and design strategies for multifunctional urban agroforestry (UAF)

Design principles by discipline		Design strategies
Urban agroecology + allied fields	Integrate UAF with urban systems.	Recover nutrients and carbon from organic waste including food, yard, and human waste.
		Harvest rainwater from rooftops.
		Harvest greywater from building systems.
		Integrate UAF with building structure and systems.
	Rehabilitate urban soils for UAF.	Add organic matter recovered from urban waste as compost.
		Fertilize with phosphorus from urban waste sources (compost or struvite extraction from human urine) to immobilize lead.
		Cover crop to reduce compaction and add organic matter.
		Create application-specific constructed technosols.
	Create plant assemblages for urban environments and populations.	Match food plants to preferences of local community.
		Reproduce traditional production practices to reify local agroecological knowledge.
		Use indigenous plants—local ecotypes if available—as resource plants, e.g., as nitrogen fixers.
		Adapt polycultures to local flora and food plant preferences.
		Layer vegetation but omit layer of large canopy trees if shading will reduce production (recognizing tradeoffs with biodiversity conservation).
	Maximize woody plant establishment in a challenging environment.	Enrich soil with compost from urban waste and irrigate with harvested rainwater or greywater.
		Apply a modified Miyawaki method of high-density plantings to increase rates of establishment and growth and to reduce colonization of invasives.
	Empower communities.	Draw on foodways of the local community to create a site-specific design language reifying local agroecological knowledge and fostering place attachment.
Environmental psychology	Align design with innate and local landscape preferences.	Plant trees but recognize that preference may decline at highest densities and with increasing canopy closure.
		Delineate open spaces with masses of vegetation
		Preserve sightlines by avoiding tall, dense understory vegetation.
		Use “cues-to-care” to make “messy” but ecologically healthy plantings socially acceptable.
	Create positive affordances perceived by local stakeholders.	Engage stakeholders in program development
		Layer vegetation to conserve biodiversity and to create opportunities for mindless fascination.
		Combine productive and social spaces, to support engagement with plants and people.
	Embed UAF in residential neighborhoods.	Insert small-scale UAF into the neighborhoods where people live so they can take advantage of affordances, including psychological restoration, and benefit from ecological functions.
		Connect UAF to grey infrastructure in residential neighborhoods to promote circular urban metabolism.

(Continues)

TABLE 1 (Continued)

Design principles by discipline		Design strategies
		Arrange and connect small-scale UAF to create corridors and stepping-stones for the movement of wildlife across the urban landscape.
		Create spaces for children in UAF to provide safe environments promoting socialization and physical activity.
	Create a sense of being away.	Screen the site periphery with structure or vegetation, though be mindful of the need to preserve sightlines.
		Use gateways and transition spaces to differentiate the UAF site from its context.
		The entire site should not be visible from a single viewpoint. Instead, choreograph movement and spaces so that the site is slowly revealed to the visitor. Use strategically placed masses of vegetation and curved paths to conceal what lies ahead
		Create a sense of uniqueness through a distinctive palette of plants, materials, and site details aligned with local culture.
Landscape architecture	Creatively adapt UAF types to the local social and biophysical environment.	Rescale, distort, meld. and transform the conventional UAF types.
		Challenge visitors' expectations for UAF.
		Draw on traditional, vernacular forms to create local, culturally appropriate variations on UAF types in collaboration with community stakeholders.
	Create diversity.	Integrate UAF types and other spaces, including social spaces, to provide a wide range of affordances for communities with varied preferences and needs.
		Match UAF types and spaces to stakeholder needs and preferences and environmental limitations.
		Layer vegetation
		Manipulate plant color, texture, size, and scale and site materials and furnishings to create complexity and interest.
	Create unity in variety.	Apply classic ordering principles to create unity in variety and enhance aesthetic appreciation.
		Use frames or datums to simultaneously organize disparate parts—including "messy" ecosystems—and signal human intention and management in the landscape.
		Develop a unifying theme or narrative structure across the site to which all elements—plants, materials, furnishings, spaces, spatial organization—are subordinated.
	Create beauty and opportunities for pleasure.	Fuse UAF types with iconic or vernacular landscape types.
		Invent new forms of nature rather than reproducing natural systems.
		Make ecological functions visible, in expressive ways.
	Invent new forms of nature.	Mimic, don't reproduce, natural ecosystems.
		Reinterpret natural ecosystems in new, context-sensitive ways.
		Heighten or blur the contrast between the UAF site and its context
	Make ecological functions and processes visible in expressive ways.	Vivify, or heighten, natural processes to make them visible to stakeholders.

(Continues)

TABLE 1 (Continued)

Design principles by discipline		Design strategies
		Route rooftop stormwater through the site to introduce movement, sound, and visual interest and to provide wildlife habitat in the form of runnels and pools.
		On larger sites, use swales in expressive ways across the site while also creating habitat.
		Develop chronosequences to illustrate natural processes such as succession or soil formation.
	Make ecological processes visible through designed experiments.	Collaborate with ecologists to create designed experiments demonstrating the ecological impacts of different design interventions and mechanisms behind those impacts and yielding new landscape types.
		At the site level, develop side-by-side research plots evaluating different plant assemblages, soil rehabilitation methods, plant establishment methods, etc.
		At the neighborhood level, compare sites with different site designs or plant assemblages, e.g., natives vs. nonnatives.
	Provide opportunities for community creative expression.	Enable stakeholders' visions for the site.
		Encourage bricolage, environmental art, gardening, and other creative activities.
		Allow the site to evolve over time and be shaped by the community.

Building-integrated UAF on rooftops, cantilevered balconies, or elevated terraces or at ground level could be the most efficient approach to integrating UAF with the metabolism of the city in ways that enhance its circularity and sustainability. Extensive and intensive green roofs are increasingly common forms of urban GI, and interest in vertical greenery systems is growing (Wang et al., 2020). Rooftop UA with annual crops provides multiple ecosystem services including stormwater management, thermal regulation of both building and the ambient environment, food production, recreation, biodiversity conservation, and employment (Specht et al., 2014). Building-integrated UAF could be expected to provide similar services plus increased biodiversity conservation. It also obviates the problem of insecure land tenure and a lack of available land, common issues in urban production (Lovell, 2010) and particularly salient for UAF. Retrofitting buildings for rooftop UAF may not be feasible because of the depth of substrate required to support even small fruit and nut trees. The substrate, however, need not be of uniform depth across the entire roof, and with the use of lightweight substrates, some existing commercial and industrial buildings with flat roofs may be able to support the required additional weight. Even if structural or sustainability concerns preclude rooftop or vertical UAF, the landscape surrounding a new building could be designed—or the landscape of an existing building retrofitted—as ground-level UAF integrated with waste management systems.

3.1.2 | Rehabilitate urban soils for UAF

Urban agroforestry sites may require the redesign or re-engineering of the entire soil system. As already discussed, urban soils may be compacted, may be low in organic matter, and may deviate strongly from the chemical composition of native soils because of contamination with heavy metals or organic chemical compounds or because of calcareous materials in the urban environment. Woody fruit and nut tree species, overall, may accumulate heavy metals and polycyclic aromatic hydrocarbons at lower concentrations than vegetable crops, suggesting contamination may be less of a concern for UAF on sites with low levels of contaminants (Romanova & Lovell, 2021). However, accumulation rates vary by species, variety, and soil factors (Romanova & Lovell, 2021), and UAF systems typically mix woody and herbaceous species including vegetable crops.

The physical and chemical properties of urban soils can be quickly improved through the incorporation of organic matter including compost (Beniston et al., 2016) and exceptional quality biosolids suitable for use in urban environments (Alvarez-Campos & Evanylo, 2019). The addition of organic matter directly dilutes contaminant concentrations in soils and reduces concentrations in harvested plant tissues by increasing plant growth and harvested plant biomass (Attanayake et al., 2014). High levels of phosphorus in organic amendments or the addition of phosphorus fertilizers can stabilize soil lead, reducing its bioavailability; however, the benefits of this strategy must be weighed against the environmental threat posed by phosphorus-enriched stormwater runoff (Wortman & Lovell, 2013). Lead could also be immobilized through the application of phosphorus-containing compounds recovered from urban wastes including human urine in the form of struvite (Wielemaker et al., 2018). Phytoremediation of soil lead is not practicable, though phytoremediation of other heavy metals may be (Blaustein, 2017).

On highly contaminated sites, the best mitigation option for UAF may be one of several cap-and-fill techniques in which the entire site is capped with a geotextile, geomembrane, or gravel and then filled to a depth of ≥15–45 cm with a constructed technosol (CT), often a mix of clean topsoil and compost such as that used in UA in Chicago, IL (Ugarte & Taylor, 2020). This can be an expensive alternative even at the shallow substrate depths required for annual production depending on the source of the mineral and organic portions of the CT. However, use of construction debris and subsoil excavated from building sites for CTs could be a more sustainable alternative to conventional methods of waste disposal (Deeb et al., 2020).

Constructed technosol characteristics need to be tailored to their particular application (Deeb et al., 2020); in UAF, this would require calibrating the degree of physical support provided by the CT to tree height. Material inputs for CTs could be reduced by limiting the uppermost tree layer of fruit or nut trees to those grown on rootstock with more limited rooting volume, by varying substrate depth across the site to accommodate groupings of woody plants, or by planting larger trees in in-ground, CT-filled tree pits or aboveground planters with the surrounding area filled to a lesser depth for shallower-rooted shrubs and herbaceous plants. Alternatively, nonfood crops, such as woody floral crops or dyestuffs, could be grown with minimal remediation measures such as mulching with woodchips to reduce human exposure to contaminated soil.

Root-limiting soil compaction on UAF sites can be reduced through tillage alone or through cover cropping. Tap-rooted forage radish (*Raphanus sativus* L. var. *longipinnatus* L. H. Bailey 'Daikon') can penetrate subsurface layers of compaction at a depth of up to 50 cm more effectively than fibrous-rooted cereal rye (*Secale cereale* L.) or tap-rooted rapeseed (*Brassica napus* L. subsp. *napus*), creating deep root channels that can be used by subsequent crops (Chen & Weil, 2010). Forage and other cover crop species also scavenge and conserve nitrogen, suppress weeds, provide resources for beneficial insects, protect soils from erosion, fix nitrogen if leguminous, contribute organic matter to soils, and could be used as an understory crop during the extended establishment period for larger tree species. Stocks of soil organic carbon accumulate much more slowly from cover cropping than from the application of compost in annual systems (White et al., 2020). Repeated applications of compost high in phosphorus, however, may create pollution hotspots and contribute to stormwater pollution (Small et al., 2019). In urban environments, where organic compost stocks are often abundant, the best strategy for initial soil preparation on only mildly degraded UAF sites may be the initial shallow incorporation of compost followed by annual cover cropping. On more severely degraded sites, more aggressive approaches such as profile rebuilding with deep tillage and incorporation of compost may be required to restore soil quality and carbon stocks at lower soil depths (Chen et al., 2013).

3.1.3 | Create UAF plant assemblages for urban environments and local communities

Design goals drive plant selection. Some site designs may prioritize production, others may privilege cultural or ecological functions, while yet others may attempt to achieve a balance between two or all three categories of functions. Production, however, is a defining feature of UAF systems. Other types of urban agroecosystems, such as home gardens and community gardens, have been found to be important sources of culturally important foods, particularly for immigrant communities (Clarke & Jenerette, 2015; Taylor & Lovell, 2015; Taylor et al., 2017). Food plant assemblages for UAF should, first and foremost, reflect the cultural preferences of the local community and, when possible, incorporate traditional production practices to conserve biocultural diversity. Otherwise, food plants and resource plants, such as nitrogen fixers that are indigenous to the area, should be selected. The topic of native vs. nonnative plants in urban systems is a contentious issue (Gaertner et al., 2017), but we argue the potential harm of the latter outweighs their benefits in UAF. Nonnative plants can be invasive—including several species such as autumn olive (*Elaeagnus umbellata* Thunb.) recommended for use in food forests—and a source of ecosystem disservices with economic impacts (Charles & Dukes, 2008). The sheer number of plant taxa used on some UAF sites increases the likelihood of introducing an invasive plant into an urban ecosystem. Native plants in urban gardens, on the other hand, have been shown to support greater native biodiversity at higher levels in the trophic chain than nonnative plants (Burghardt et al., 2009; Lin et al., 2015; Pardee & Philpott, 2014). Gardening for native biodiversity also has a wide range of psychological and social co-benefits, including increased place attachment (Raymond et al., 2019), and use of natives resists the global biotic homogenization of urban flora (McKinney, 2006). Considerable grey and popular literature (e.g., Jacke and Toensmeier 2005) has been devoted to the design of plant assemblages for food forests based on permaculture theory. These assemblages, based on a reading of the ecological literature and on observation, may require local adaptation to reflect indigenous flora and community food preferences.

In general, layering of vegetation in UA is correlated with biodiversity (Lin et al., 2015). Urban agroforestry has, at minimum, two layers of vegetation and food forests up to seven (Jacke & Toensmeier, 2005). Larger canopy trees make a strong contribution to carbon sequestration, thermal regulation, atmospheric particulate reduction, and stormwater management (Carlyle-Moses et al., 2020; Gunawardena et al., 2017; Nowak & Crane, 2002; Solecki et al., 2005). However, at maturity, their canopies may also become so broad and dense that low light levels limit the productivity of plants in lower layers of the UAF system (Björklund et al., 2019). Forms of forest farming, rather than food forestry, may be more appropriate when the services of large trees are desirable, with native food- or non-food-producing canopy trees helping to suppress undesirable understory plant species at canopy maturity and shade-tolerant understory species contributing to system productivity. Alternatively, to maximize productivity on small sites, the canopy layer could even be eliminated, a practice that appears to be common in community food forestry and may be desirable in more light-limited northern latitudes (Björklund et al., 2019). Doing so would eliminate costly long-term maintenance of canopy trees, which can be an obstacle to urban forestry in low-income neighborhoods (Heynen et al., 2006). The resulting semi-open landscape may also be preferred to one with a closed tree canopy according to the savanna hypothesis of landscape preference (Orians, 1980), though preferences for degree of canopy closure may have cultural determinants (Hägerhäll et al., 2018). Clearly, decisions related to vegetation layering will result in tradeoffs between functions and must be based on the project's overall design goals and stakeholder preferences.

3.1.4 | Maximize woody plant establishment in a challenging environment

Urban agroforestry sites, particularly when developed as pocket parks on vacant lots in residential neighborhoods, may be much smaller in size than their rural counterparts. The dimensions of a standard city lot in Chicago, IL, for example, are 7.6 by 38.1 m (302 m^2). Increased edge effects from their large edge-to-area ratio, in combination with elevated temperatures, increased vapor pressure deficits, and low soil organic matter, may reduce rates of establishment and growth of woody species on newly planted sites. Enrichment of soils with locally produced organic wastes and irrigation with rainwater or greywater can enhance establishment success. If the desired endpoint of site development is a food forest with a closed canopy or a restored native forest supporting foraging, the Miyawaki method of microforest reconstruction (Miyawaki & Golley, 1993) may offer more rapid plant growth and canopy coverage and higher rates of tree establishment than the instant succession sometimes used in food forest development (Jacke & Toensmeier, 2005). While in the latter method, canopy and subcanopy trees from the desired end point of succession are planted at their final spacing in beds of woody and herbaceous vegetation from the target end point and earlier stages of succession, in the Miyawaki method, seeds or small seedlings of only canopy trees are planted at high densities in irrigated beds enriched with organic matter. The original Miyawaki method assumes that desirable subcanopy vegetation will eventually invade the plot from the surrounding landscape. In a modified method, the initial planting includes both canopy trees and woody and herbaceous subcanopy species (Ottburg et al., 2017). The original method has been applied in urban and rural contexts in temperate, tropical, and Mediterranean climates (Miyawaki, 2004; Schirone et al., 2011) but not, it appears, to the design of UAF systems. Though the mechanisms responsible for the reported success of the method are underexplored, at close spacings tree seedlings may compete with one another but also act as nurse plants facilitating the growth of their neighbors through environmental modification, an effect that may be more important to target plant survival and performance in challenging environments (Padilla & Pugnaire, 2006). Tree seedling have been shown to share resources through mycorrhizal networks (Simard & Durall, 2004), and we hypothesize that close planting may also encourage the early development of supportive mycorrhizal networks between seedlings. Furthermore, rapid canopy closure with the Miyawaki method may inhibit colonization by invasive species, to which young forests are particularly vulnerable (Trammell et al., 2020). The Miyawaki method has the disadvantage of being material and labor intensive, though community labor could be mobilized for tree planting, and the use of small seedlings is potentially more sustainable than planting more mature bareroot, container, or balled-and-burlapped stock.

3.1.5 | Empower communities through UAF design

Agroecology is not only a science and a practice but also a social and political movement (Wezel et al., 2009). Research on community gardens has repeatedly demonstrated they can be sites for political empowerment and mobilization through which marginalized groups stake their claim to space and "the right to the city" (Aptekar, 2015; Schmelzkopf, 2002). Urban agroforestry sites, like UA sites in general (Galt et al., 2014), are potentially subversive, interstitial spaces, and the design of UAF systems offers the opportunity to empower local communities through participatory design processes, the coproduction of space, and, as with community gardens (Barthel et al., 2010), the reification of local social–ecological knowledge and values in the site itself. United States cities are increasingly diverse, with the foreign-born population making up 22% of the U.S. urban population in 2016 (Parker et al., 2018). Immigrants bring with them diverse foodways and, if they have experience gardening or farming in their country of origin, diverse food crops and agricultural production practices, including traditional agroforestry systems such as the *milpa* (Taylor & Lovell, 2015; Taylor et al., 2017; Taylor & Mione, 2020). These cultural resources could provide a rich vocabulary for the design of UAF sites, creating a sense of place, engendering feelings of ownership, community, and solidarity among stakeholders, and affirming their right to the city.

3.2 | Environmental psychology

Theory and empirical research in environmental psychology can help to align the design of UAF sites with stakeholders' landscape preferences and desired landscape affordances, ensuring sites meet the needs of culturally diverse urban communities. Given the depth and breadth of the literature, in this section, we highlight findings with particular relevance to our topic.

3.2.1 | Align UAF design with innate and local landscape preferences

A number of consistent findings of potential application to UAF emerge from almost half a century of research in environmental psychology on landscape preference. That research indicates that in urban settings, preference increases with increasing tree density (Kuo et al., 1998; Suppakittpaisarn et al., 2019a), though the relationship may be quadratic, with declining preference at the highest density levels, and may vary with participant demographics (Bjerke et al., 2006). Canopy cover may have a negative impact on the perceived uniqueness of urban forests and consequently on the appreciation of forests (Wang et al., 2019), suggesting that UAF without canopy closure, such as an underplanted orchard with semidwarf trees or a food forest without a canopy layer, may be a preferred condition.

The quality and density of understory vegetation also matter. While Suppakittpaisarn et al. (2019a) found that landscape preference was positively correlated with density of understory vegetation in a power curve relationship, the scenes used in that study were almost all of urban and suburban streetscapes with streets and sidewalks signaling easy movement through the landscape. Most landscape studies, in fact, suggest that moderate vegetation density is most preferred for urban parks, with areas of open space delineated by masses of vegetation (Bjerke et al., 2006) and clear accessibility (Hofmann et al., 2012)

These findings are congruent with Kaplan and Kaplan's (1989) environmental preference model, which posits four characteristics of preferred environments: complexity and mystery, which invite exploration and offer opportunities for attention restoration through mindless fascination, and coherence and legibility, which facilitate information processing and movement through the landscape. In urban environments, dense vegetation and obstructed sight lines may also increase safety concerns, though the research is equivocal on this point (Hadavi et al., 2015). Research consistently shows that neatness matters in the design of urban GI. "Neat" bioretention areas with a clear geometry, massing of plants, and restrained plant growth are preferred to "messy" bioretention areas with a less geometric design and more mixed, exuberant plantings (Suppakittpaisarn et al., 2019b). Green infrastructure dominated by masses of flowering plants is also highly preferred (Suppakittpaisarn et al., 2019b). Nassauer (1995) suggests that incorporating such "cues to care"—neat edges, massing of plants, and enrichment with flowering species—can help to align landscape preference with ecological health in GI such as rain gardens and native plant landscaping.

Overall, landscape preference research indicates (a) UAF should be psychologically preferred over other landscape types lacking trees, (b) moderate understory vegetation is preferable to dense or no understory vegetation, and (c) a clear path through the site—though not necessarily a straight path and possibly a curving path suggesting mystery—is desirable.

3.2.2 | Create positive affordances perceived by local stakeholders

Environmental affordance theory complements landscape preference theory. An affordance is "what [the environment] offers the animal, what it provides or furnishes" (p. 127), and landscapes rich in positive affordances with few negative affordances are preferred (Gibson, 1986). The perception of affordances is shaped by biology, personal experience, skills, and culture (Rietveld & Kiverstein, 2014) and so may be expected to vary across UAF users and by user across time.

Affordances may be social or physical; physical affordances are constructed from the physical features of the landscape. The constituent parts of social affordances, in contrast, are the "social knowledge, observed behaviour, expressed attitudes and indigenous culture" of the people inhabiting the space (Clark & Uzzell, 2006, p. 179). Urban gardens offer both kinds of affordances through the reification, enactment, and reproduction of social–ecological knowledge and values in the space of the garden (Barthel et al., 2010). Research specifically on the physical and social affordances of UAF is limited. Stoltz and Schaffer (2018) theorize that the defining features of urban food forests, such as plant and animal diversity and the layering of vegetation, provide affordances with psychological and physical health benefits.

3.2.3 | Embed UAF in residential neighborhoods

The work of Hadavi et al. (2015) on nearby nature suggests small UAF sites embedded within residential neighborhoods may have advantages in terms of affordances over UAF in city and regional parks and other large-scale open spaces. The former offer restorative, daily encounters with nature and simultaneous engagement with plants and people through gardening. They also provide ecological benefits such as stormwater regulation and heat-island mitigation where people live and, when woven into the urban fabric, create stepping-stones and corridors for the movement of wildlife across the landscape. Integration of these sites with grey infrastructure potentially magnifies their impact and is consonant with the principles of smart, compact, green-city design (Artmann et al., 2019). Furthermore, small, distributed sites in residential neighborhoods also promote environmental equity, offering greater accessibility for lower-income households that may not have cars or the time or money to take public transportation to more distant green spaces. In neighborhoods with higher crime rates, they could also contribute to the set of practices parents in such neighborhoods use to keep their children safe while encouraging physical activity (Jarrett et al., 2011).

3.2.4 | Create a sense of "being away"

Creating a sense of "being away" from city life, a desirable affordance for mental restoration according to Attention Restoration Theory (Kaplan, 1995), may be challenging on smaller UAF sites. Stoltz and Schaeffer (2018) suggest food forests need to be large enough to provide a sense of space and to allow visitors to wander around, to engage in soft fascination with nature as a restorative activity. However, by virtue of their material contrast with the built environment, these sites inherently afford a sense of being away, which can be heightened through design strategies including an entry gateway (as suggested by Stoltz and Shaffer [2018]), vegetative screening at the site periphery, and the articulation of internal spaces such that the entire space is never revealed to the visitor at once but instead, through curving paths and massing of vegetation, invites exploration. A distinctive plant and materials palette and site detailing can also create a sense of being away. For a site serving foreign-born stakeholders, a connection to their homeland may be cultivated through the use of traditional plants in ways modeled after traditional agroecosystems or through the use of traditional art and structures, such as the *casita* of Caribbean cultures (Morgan et al., 2005).

3.3 | Landscape architecture

We see landscape architecture theory, principles, and practice as providing a framework for the UAF design process and a means for translating stakeholders' landscape preferences and desired affordances and project design goals and objectives into compelling material form which reflects community values. Landscape architecture is, in essence, the search for spatial form responsive to both site program and site conditions. Form is created through the manipulation of four basic building blocks: landform, plants, water, and structure. By varying scale, proportion, the quality of edges, and materials, designers create spaces with distinct characteristics—intimate spaces, gathering spaces—tailored to the site program. Individual spaces may be organized in different ways, and the designer choreographs the visitor's movement through the site in service to the program and to the overarching design goal developed with the participation of stakeholders.

3.3.1 | Creatively adapt UAF types to the local environment

The arrangement of the basic landscape elements gives rise to repeated patterns, or landscape types. Landscape architects—and designers in general—frequently think in terms of types, and so we begin with the development of a typology for UAF based on general attributes and the existing literature.

Each UAF type offers different spatial opportunities, with functionality varying by type, specific design, and management (Table 2). Though a landscape may be reducible to a type, types are not deployed in rote fashion in landscape design. Instead, Moneo (1978) describes the design process as "a way of bringing the elements of a typology—the idea of a formal structure—into the precise state that characterizes the single work" (p. 23). A type may be formally realized in a project in a very specific—and sometimes unexpected—way but still be recognized as a member of the type. As Moneo (1978) noted with respect to architecture, the "continuous transformation" of types through, for example, the distortion of scale, melding of types, or the invention of new types is "a function of the inventiveness of architects" (p. 27). An underplanted orchard, for example, need not be orthogonal in form; it could have a circular or spiral form. Similarly, a food forest need not have an informal design but could have an orthogonal layout suggesting the form of a traditional orchard or even a French formal or Persian paradise garden. Challenging cultural expectations about form can heighten users' experience of the space. In a diverse urban community, traditional landscape types, such as the *milpa* of Mexico and Central America, can serve as inspiration for local variations on UAF types, developed in collaboration with the community.

TABLE 2 Typology of urban agroecosystems with provisional ratings of functional attributes

Agroecosystem characteristic	Conventional urban agriculture			Urban agroforestry				
System type	Garden or farm with mixed vegetable, herb, herbaceous fruit crops	Orchard, berry patch	Allée, hedge, buffer, street trees	Alley cropping, underplanted orchard	Multifunctional woody polycultures[a]	Food forests (forest gardens)	Forest farming	"Natural" forests supporting foraging
Spatial form	Varied, 1 layer	Massed, 1 layer	Linear, 1 layer	Linear, massed, 2 layers	Varied, 3+ layers	Varied, 3+ layers	Varied, 4+ layers	Varied, 4+ layers
Dominant planned life forms	Herbaceous annuals, perennials	Woody perennials	Woody perennials	Woody perennials + herbaceous annuals, perennials	Woody perennials + herbaceous annuals, perennials	Woody perennials + herbaceous annuals, perennials	Woody perennials + herbaceous perennials+ fungi	Woody perennials + herbaceous perennials + fungi
Rating of functional attributes[b]								
Production								
Productivity or yield	H	H	M	H	H	M	M	L
Efficiency of inputs	M–H	M–H	M–H	M–H	M–H	M–H	M–H	M–H
Diversification of products	L–M	L–M	L–M	M	M–H	H	H	H
Product quality	M–H	M–H	M–H	M–H	M–H	M–H	M–H	M–H
Economic value	M–H	H	M	H	H	M	M	L
Ecological								
Planned biodiversity	L	L	L	M	M	H	H	H
Associated biodiversity	L	M	M	M	M	H	H	H
Carbon sequestration	L	M	M	M	H	H	H	H
Stormwater regulation	M	M	M	M	M	H	H	H
Soil conservation, building	L	L	L	M	M	H	H	H
Heat island mitigation	L	H	M	H	H	H	H	H
Solid waste recycling	M–H	M–H	M–H	M–H	M–H	M–H	M	L
Cultural								
Community empowerment	M–H	M–H	M–H	M–H	M–H	M–H	M–H	M–H
Environmental justice or equity	L–H	M–H	M	M–H	H	H	H	H
Food security	H	H	M–H	H	M	M	M	L
Biocultural diversity	L–H	L–M	L–M	M–H	M–H	M–H	M–H	M–H
Visual quality or art	L	M	M	M	H	H	H	M
Recreation or entertainment	L–M	M	M	M	M	H	H	M
Education or research	L–M	L	L	M	M	H	H	H

[a]Lovell et al. (2018).
[b]L, low; M, medium; H, high. After Lovell et al. (2010).

3.3.2 | Create diversity

A landscape without diversity or complexity fails to hold the attention of the visitor and, according to attention restoration theory, lacks the opportunities for engaging in soft fascination required for psychological restoration (Kaplan, 1995). Urban agroforestry sites are inherently complex because of their plant diversity and layered vegetation. Diversity can be further enhanced through the manipulation of plant color, texture, size, and scale. Diversity may also be created through the inclusion of different agroecosystem types within the site, which form a unique agroecosystem in the aggregate. The Beacon Food Forest in Seattle, WA, for example, has a "giving" garden of annual food crops, the purpose of which is to grow food for donation to food pantries, in addition to extensive food forests (Beacon Food Forest, n.d.). Similarly, the Browns Mill Food Forest in Atlanta, GA, encompasses diverse agroecosystems including community garden plots dedicated to annual crops, a food forest, and a native woodland managed for foraging of edible and medicinal species (Aglanta, n.d.).

Selecting a particular agroecosystem type or set of types for a specific urban site is the first step in the site design process. Site program—reflecting stakeholder preferences and desired affordances—and the assessment of site conditions and context should inform type selection. An annual cropping system, for example, may be preferable when (a) the overarching programmatic goal is to maximize food production to combat community food insecurity, (b) insecure land tenure precludes development of woody plant communities on the site, or (c) highly contaminated soils require use of raised beds precluding deep-rooted woody perennials. In other contexts, a food forest offering a wider range of ecosystem services or an urban forest managed for foraging may be more appropriate for practical, cultural, or ecological reasons.

Spatial heterogeneity, functional diversity, and the integration of different agrecosystem types with overlapping functions—and other spaces including social spaces—within a single site allow the site to address simultaneously diverse stakeholder needs and desires by providing a wide range of ecosystem services. These characteristics—spatial heterogeneity and functional diversity and redundancy—may also increase the resilience of UAF sites, as has been hypothesized for agroecosystems in general (Cabell & Oelofse, 2012).

3.3.3 | Create unity in variety

Design seeks to create unity in variety. Without order, or without an underlying organizational structure to visual data, for instance, complexity can be psychologically overwhelming, undermining aesthetic appreciation (Van Geert & Wagemans, 2020). We maintain that because UAF sites are potentially highly complex and rich in affordances, applying aesthetic principles, including ordering principles, to these landscapes can simultaneously enhance human experience of the site, the site's ecological, cultural, and productive functions, and visitors' recognition of those functions. Classic ordering principles include axis, symmetry, hierarchy, datum, rhythm, repetition, and transformation plus balance, similarity, contrast, equality, and sequence.

Ordering principles can be applied at several levels in a UAF site to create visual and conceptual coherence. Groupings of plant species, for example, may be repeated across the garden to create visual unity, or spaces may be organized around a central axis or a winding path. A datum such as a mowed border or a low fence can be used to frame "messy" plantings, with the frame also acting as a cultural cue-to-care that makes a potentially transgressive landscape more socially palatable (Nassauer, 1995). Urban food forests, in particular, in juxtaposition with the built form of the city, offer rich opportunities for heightening the contrast between the ecological and the cultural while simultaneously connecting and integrating the two.

Unity may also be created through a unifying theme to which all other elements in the system are subordinated. The designer might, for example, restrict the site's plant palette to only native food and resource plants. Alternatively, the designer can create unity through narrative structure, by telling stories through landscape (Potteiger & Purinton, 1998). They might, for example, organize the site around a narrative focusing on the foodways of local cultural groups or structure the site as a chronosequence representing the stages of food forest succession

3.3.4 | Create beauty and opportunities for pleasure

Landscape theorists, such as Meyer (2008) and Mozingo (1997), argue for (re)integrating aesthetics into sustainable landscape design. This is not aesthetics as surface "beautification or ornamentation" (p. 9) but as a "re-centering [of] human consciousness from an egocentric to a more biocentric perspective" (p. 7) through design as a "cultural act" (p. 15) (Meyer, 2008). Ecological landscapes—which we consider UAF sites to be—can be not only culturally acceptable but "iconic" (p. 46) through, in part, the application of aesthetic principles and traditional landscape types rooted in vernacular responses to the environment (Mozingo, 1997). These landscapes should engage all the senses aesthetically in addition to performing ecologically (Meyer, 2008), and they should afford opportunities for "pleasure, sensuality…and meaning" (Mozingo, 1997, p. 54).

3.3.5 | Invent new forms of nature

Creating landscapes that not only delight and engage the senses but also transorm the subject's perceptions of the relationship between the human and the nonhuman will require not merely reproducing natural forms but inventing new forms of nature (Meyer, 2008). This approach is particularly apt for UAF, especially forest gardens, which already mimic natural models rather than reproducing those models. Further inventive transformation of the type—for example, a geometrically formal site design for a "messy" but biodiverse forest garden—can invigorate the type and draw on local precedent in complex ways. The orthogonal, vernacular form of an underplanted and stylized orchard, for instance, might reproduce the street grid of the American Midwestern city while supporting a productive and ecologically healthy understory and stimulating reflection on the relationship between the social and the natural in an urban context.

3.3.6 | Make ecological functions and processes visible in expressive ways

Ecological landscapes can also make visible their functions in expressive ways. Stormwater has proven to be a particularly expressive element in the work of landscape architects, such as Ramboll Studio Dreiseitl, and could serve a similar role in UAF design. On a smaller site adjacent to buildings, for example, water from rooftops could be diverted to flow through the system in inventive ways that simultaneously vivify the landscape by adding movement, sound, and visual interest, reveal to visitors the role of the the site in infiltrating stormwater, irrigate plantings, and promote biodiversity. On larger sites, swales—a key design strategy for stormwater management in permaculture (Jacke & Toensmeier, 2005)—could be used in similarly expressive and biodiversity-enhancing ways without compromising the permaculture ethics on which they are based.

3.3.7 | Make ecological processes visible through designed experiments

In designed experiments, ecologists and designers collaborate to develop design interventions in the urban landscape that are also ecological experiments (Felson & Pickett, 2005). In the context of UAF, these might include evaluations of the relative performance of polycultures of varying composition (and the processes of facilitation between species within the polycultures) or different methods of soil rehabilitation or woody plant establishment (e.g., the Miyawaki method vs. instant succession) in side-by-side research plots within sites. At the neighborhood level, across sites, designed experiments might evaluate the ecosystem services provided by native vs. nonnative food forests or food forests of formal vs. informal design. Designed experiments can yield both ecological and landscape preference data and can provide designers with new landscape types (Felson & Pickett, 2005).

3.3.8 | Provide opportunities for community creativity

Research on community gardens suggests the role of the professional engaged in the design of a public UAF project should be that of an enabler facilitating the process and giving form to the community's vision for the site rather than imposing their own vision (Fox-Kämper et al., 2018). Within the design framework they establish for a particular site, we suggest UAF designers provide opportunities for ongoing creative expression by the community through bricolage, environmental art, gardening, and other creative outlets to create a sense of place and belonging and to ensure the site reflects and evolves with local community values.

4 | PRELIMINARY DESIGN GUIDELINES

Based on our synthesis of the literature from diverse fields, we have formulated the following overarching guidelines that, with the principles and strategies outlined in Table 1, form a framework for the design of UAF systems. Note that these are provisional and preliminary recommendations in light of the underdevelopment of the science and practice of UAF. They are followed by a discussion of research opportunities in UAF intended to address that state of underdevelopment.

1. ***Co-design through community and expert engagement***. Engage local stakeholders, ecologists and agroecologists, permaculturists, horticulturists, university cooperative extension specialists, and landscape architects in the process of co-design, even for small, neighborhood sites. Each set of actors—but particularly local stakeholders—has a valuable contribution to make to the design of sustainable UAF that is aligned with community food and landscape preferences and contributes to the ecological quality of the urban environment. Engaging diverse actors can help to ensure that no single perspective dominates and that designs reflect both best practices and community needs.
2. ***Form institutional partnerships***. Designing multifunctional UAF that contributes to the circular metabolism of the city requires a wide range of expertise. Reach out to local colleges and universities early in the planning process as potential sources of design and scientific

expertise. Urban agroforestry projects offer opportunities for both faculty and students to work on multidisciplinary, real-world projects. These institutions could be further engaged in UAF research to help guide future projects. Research on interactions between plant species of interest, for example, could help to identify productive combinations marked by facilitation or complementarity.

3. ***Develop context-sensitive UAF types***. Develop a set of evidence-based variations on the basic UAF types that are sensitive to the local social and ecological context and that can be applied by experienced community members when engagement of experts in the design process is not possible.
4. ***Create spaces for people***. Use landform, plants, water, and structure to create spaces for people within UAF projects. The design of these spaces should reflect the preferred affordances and values of the local community to ensure these systems are cherished and cared for.
5. ***Promote food security through selection of culturally appropriate food plants***. Access to preferred foods is integral to food security (FAO, 1996). In consultation with stakeholders, select productive plants that meet the cultural preferences of local communities.
6. ***Create sites that are culturally relevant and psychologically preferred***. Make landscapes that are culturally preferred and reify local social–ecological knowledge and values. Draw on traditional agroforestry practices of local communities, where applicable, in the design of UAF sites. Apply principles from environmental psychology to create agroecosystems that appeal to deep-seated psychological preferences.
7. ***Apply universal design principles***. To ensure equitable access, apply universal design principles in the design development process to ensure UAF sites are accessible to all. Recognize this may involve tradeoffs and compromises including the use of sustainable, permeable paving materials for paths instead of lower-cost and potentially more sustainable materials such as wood chips or mowed grass.
8. ***Create unity—and beauty—through aesthetic principles***. Apply ordering and other aesthetic principles plus thematic coherence or narrative structure across scales to create unity in diversity within individual UAF sites and to align site functions with the cultural values of the local community.
9. ***Select ecologically appropriate plants***. Use plants indigenous to the area when possible, and avoid invasive plants, which continue to be recommended in permaculture texts. Invasive species not only impact the site itself, because they are difficult to prevent from dominating the plant community, but are also common sources of seed transferred to off-site areas including forests and fragile wetlands. Planting indigenous plants supports biodiversity at higher trophic levels and helps to ensure that UAF sites do not contribute to the increasing homogenization of the global urban flora (McKinney, 2006).
10. ***Integrate UAF with other urban systems to promote CUM***. Recognize that in a human-dominated environment, UAF sites are not isolated, self-regulating systems but are influenced by the social–ecological and technological systems in which they are embedded. Integrate them with those systems to support the circular metabolism of the city and to increase the sustainability and productivity of the agroecosystems themselves through, for example, nutrient recovery from wastes and the use of stormwater for irrigation. Integration may require rethinking and adapting traditional patterns to meet local needs and environmental conditions.
11. ***Locate UAF where people live***. Site UAF where people live, as pocket parks on vacant land, for example, to increase food and recreational access, to facilitate integration of UAFs with urban systems, and to increase surveillance of the site by neighbors who can help to deter vandalism. Locating UAF in large public parks may buffer them from negative urban environmental conditions but limits their contributions to social-ecological systems by reducing opportunities to integrate them with urban waste streams and by reducing stakeholder access when the intent of site developers is, ostensibly, to address food access and availability issues.
12. ***Adapt UAF types to community foodways***. Select UAF types and modify those types to adapt them to local foodways. In temperate areas, for example, consider alternatives to the paradigmatic seven-layer food forest described in the literature on permaculture and edible forest gardening. The perennial crops that can be grown in this system may not be part of the foodways of immigrants, many of whom have emigrated to temperate climates from tropical and subtropical climates. Many annual crops that are part of their foodways, however, can be grown in temperate climates. Mexican- and Chinese-origin gardeners, for example, can grow a wide range of tropical annual crops throughout the United States, including, for the former group, tomato (*Solanum lycopersicum* L.), tomatillo (*Physalis philadelphica* Lam.), chile (*Capsicum annuum* L. var. *annuum*), epazote [*Dysphania ambrosioides* (L.) Mosyakin & Clemants], and squash (*Cucurbita* spp.), and for the latter group, bitter melon (*Momordica charantia* L.), winter melon [*Benincasa hispida* (Thunb.) Cogn.], and sweet potato [*Ipomoea batatas* (L.) Lam. var. *batatas*] greens (Taylor et al., 2017). A more appropriate agroforestry production system might be one which combines edges of layered woody and herbaceous perennials with open spaces (or garden "rooms") for annual vegetable plants. City Farm in Providence, RI, offers one example of such a

system, with areas of layered vegetation—a minimal canopy layer consisting of a dominant silver maple, edges of woody and herbaceous perennial plants including fruit trees, elderberry (*Sambucus canadensis* L.), gooseberry [*Byrsonima lucida* (Mill.) DC.], raspberry, grapevine (*Vitis* spp.), beach plum (*Prunus maritima* Marshall), hardy kiwi [*Actinidia arguta* (Siebold & Zucc.) Planch. ex Miq.], blackberry, flowering shrubs, and herbs—and open areas dedicated to annual vegetable crops.

13. ***Select appropriate materials***. Pay attention to site detailing and create unity across the site through a coherent materials palette. Incorporate sustainably produced, durable, high-quality site furnishings and materials while avoiding the sterility of some professionally designed community UA projects. High-quality site furnishings, such as benches and signage, connote care and intentionality. Durability is a key concern in urban areas as is universal accessibility. While mowed or mulched paths and benches made from logs or found materials may conform to the do-it-yourself aesthetic of many forest gardens—and the latter can convey a sense of play and inventiveness in the garden—the former are not universally accessible, and the latter may be neither durable nor accessible. Engage local craftsmen in the creation of site furnishings, and use local materials—such as decay-resistant black locust (*Robinia pseudoacacia* L.)—when possible.
14. ***Encourage community artistic expression***. Provide opportunities for bricolage, or the inventive and playful use of cast-off materials, and site-specific art to engage the local community and reify local culture, to create design focal points, to encourage place attachment, and to create a sense of distinctiveness and of "being away."

5 | RESEARCH OPPORTUNITIES

The design framework is necessarily incomplete. To solidify and expand on it, we need additional research on the social and ecological functioning and design of UAF systems, particularly food forests.

1. Published, peer-reviewed research on UAF in North America and Europe appears to lag far behind that on other forms of UA including even home gardens. Observational, multidisciplinary research combining methods from the natural and social sciences and modeled on community and home garden research in developed and developing countries is needed to document existing design, practices, and conditions, including biodiversity and structure.
2. Experimental research is needed on best practices for UAF site development including alternatives for soil remediation and plant establishment. While a body of research exists in horticulture on many of the crop species used, the studies are rarely conducted in urban environments.
3. UAF—particularly urban community food forests—offer opportunities for conducting designed experiments (Felson & Pickett, 2005) in urban ecology and agroecology on a diverse range of topics from the integration of UAF with grey infrastructure to the spatial design of UAF sites. Designed experiments treat creative design interventions as opportunities for experimentation, with the collection of ecological data along with data on stakeholder use, affordance perception, and preference (Felson & Pickett, 2005). Designed experiments can help provide an expanded, evidence-based foundation for the design of UAF sites.
4. A framework for assessing the multifunctionality of UAF modeled after Lovell et al. (2010) and validated by experts would be a valuable tool for evaluating tradeoffs in UAF design and the contributions UAF sites make to the urban environment.
5. We found little to no research on public perceptions of community food forests or other forms of UAF. The methods for conducting landscape preference studies are well established and relatively straightforward to implement. Data on stakeholder preferences—including the preferences of the community beyond those directly involved in site development—and the relationships between landscape attributes and perceptions of affordances could form the basis for the development of evidence-based design principles specific to the diverse forms of UAF. Surveyed community members should reflect the age, socioeconomic, and cultural diversity of the community (Botzat et al., 2016).
6. In agroecology, the productivity of polycultures is traditionally evaluated using the land equivalent ratio, which compares yield in polyculture to yields of the same species in monoculture (Vandermeer, 1992). Its application to UAF sites is limited because they are complex systems with many benefits beyond agricultural production. It would, however, be useful to conduct comprehensive, longitudinal life-cycle assessments of different UAF types—or to model them—to compare the sustainability of these systems with their alternatives: annual UA and restored urban forests.
7. Data on the productivity and labor, nutrient-use, and water-use efficiency of UAF sites could inform their design while providing a strong rationale for their inclusion in urban planning.
8. Similarly, estimates of the nonproductive ecosystem services of UAF types, such as stormwater infiltration, carbon sequestration, nutrient cycling, urban heat island mitigation, and biodiversity conservation, could help to justify the use of valuable urban land for these systems and

secure the kind of top-down support that has been found to be a contributor to the success of community gardens (Fox-Kämper et al., 2018).

9. Community assembly theory is an emerging area of interest within community ecology. Studying interactions between plant species at the scale of UAF sites, particularly food forests, could contribute to both ecological theory and to the design of UAF systems and UAF types.

6 | CONCLUSION

Urban agroforestry—particularly in the form of edible forest gardening—is a powerful concept with popular appeal, inspiring diverse people to imagine urban food systems in new ways. Cities are full of potential for creating UAF at a wide range of scales, from residential lots to vacant lots to ecologically depauperate public green spaces. Harnessing public enthusiasm for food forests and other forms of UAF to evidence-based principles derived from urban agroecology and related fields, environmental psychology, and landscape architecture could create a potent force for social-ecological change and transformation in the urban environment. Broad implementation of UAF following our design recommendations would enhance urban food sovereignty and nutritional security while enriching the social lives of urban residents. Moreover, species-rich, structurally diverse UAF woven into the urban fabric could make a substantial contribution to the GI of the city, reducing its ecological footprint through CUM and enhancing its ecological quality. While the future of UAF is bright, advancing this agenda will require the collaboration of a wide range of stakeholders and experts including community members, social and natural scientists, designers, and university outreach.

AUTHOR CONTRIBUTIONS

John Taylor: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Supervision; Visualization; Writing-original draft; Writing-review & editing. Sarah Taylor Lovell: Conceptualization; Writing-review & editing

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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