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Container gardens: Possibilities and challenges for environmental and social benefits in cities

Ayako Nagase[1*], Jeremy Lundholm[2]

[1] *Graduate school of global and transdisciplinary studies, Chiba University, Japan*
[2] *Department of Biology, Saint Mary's University, Canada*
**corresponding author: anagase@chiba-u.jp*

ABSTRACT

Container gardens are used in cities around the world where access to soil at ground level is limited. They represent artificial ecosystems but often provide the only vegetation in some highly urbanized locations, and have been used in vertical and horizontal forms of living architecture. Although there are many container gardens in urban areas, container gardening as a component of more broadly considered green infrastructure seems to be unappreciated. The aim of this review is to elucidate potential ecosystem services provided by container gardening. The ultimate goal of this review is to recognize the value of container gardens in order to promote them as part of green infrastructure in urban areas. The ecosystem services which container gardens provide were sorted into the following categories (1) Provisioning (food production and security); (2) Regulating (stormwater management, improvement of air quality, energy savings and thermal comfort); (3) Habitat/Supporting (plant biodiversity and creation of animal habitats); (4) Cultural (aesthetic and improvement of visible green ratio, communication and environmental education, material reuse). Container gardens deserve serious attention as a form of urban greening that can provide many direct and indirect benefits to people living in cities. Moreover, it is important for citizens, local authorities and academics to be aware of the ecosystem services associated with container gardening to promote further development of its potential.

Key words: *Green infrastructure, biodiversity, communication*

INTRODUCTION

Currently, the human population is rapidly concentrating in urban areas and green infrastructure is becoming important for societal sustainability (Brzuszek et al., 2007; Davies and Lafortezza, 2017). Green infrastructure can be defined as "natural, semi-natural, and artificial networks of multifunctional ecological systems within urban areas" (Tzoulas et al., 2007). Green infrastructure comprises open areas such as urban forests, large public parks, gardens, playing fields, rights-of-way along streams and roads, and constructed features such as green roofs, permeable vegetated surfaces, swales, rain gardens and green streets (Mell et al., 2013; Tzoulas et al., 2007). Container gardens are an important component of green infrastructure in many cities.

Container gardens have been used for thousands of years. Carved scenes on limestone walls of an Egyptian temple, dating back 3,500 years, depict frankincense trees growing in pots (Manso and Castro-Gomes, 2015). Container gardening is well established in history as a practical way to replace lost ground space in urban environments (Welch, 2013). They can be easy to move, allowing seasonal transport of plants indoors to avoid winter or dry-season conditions. In addition, they are easy to arrange and decorate in three dimensions. Urban container gardening is often promoted as a solution to lack of space at ground level for gardens (Bailey, 1993; Choonsingh et al., 2010). Container-based systems are also sometimes the only form of gardening available in dense cities where soils are largely covered with hard surfaces, resulting in strong competition for space.

In both private spaces (e.g. around houses, roofs, balconies) and public spaces (e.g. open spaces and roadsides), container gardens are frequently seen. In heavily built-up areas, both formal and informal container gardens can be seen. Formal versions of container gardens are often placed in public lands such as city squares, managed by municipal staff and consist mainly of ornamental landscape plantings similar to those used in in-ground (growing directly in the ground) landscaping in public parks (Figure 1d). These can also be found in corporate and institutional settings, such as courtyards in the urban core, but are similar to other formal container plantings in that paid staff manage the vegetation according to organizational standards. In contrast, informal container gardens tend to be more diverse, driven by the needs and preferences of individual gardeners. They are also generally created and maintained on an unpaid basis (Figure 1a-Figure 1c).

In general, container gardening can be considered as small mobile versions of living architecture. Container gardens are frequently used informally at private dwellings whereas many other kinds of living architecture may be more common in public spaces. While green roofs and living walls may involve containers for plants and growing media, container gardening, especially when done by private citizens, often uses much smaller container formats. This results in high maintenance requirements (e.g. irrigation) but also allows for high plant diversity within small areas due to owner preference.

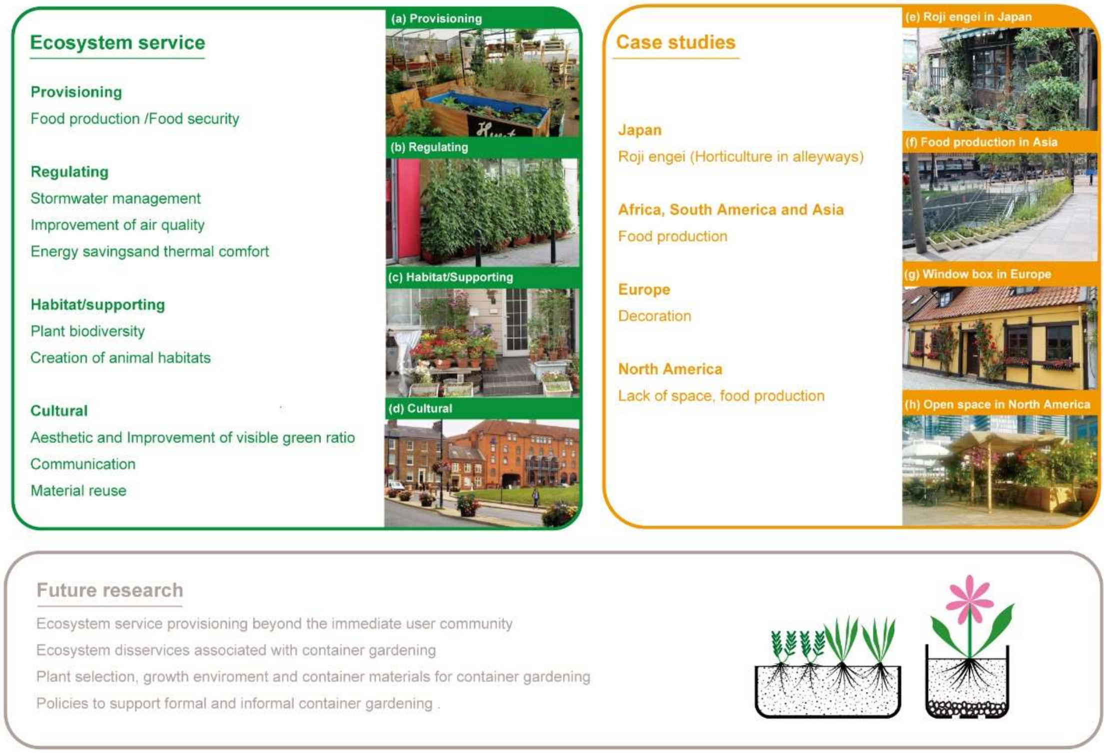

Figure 1 Summary of review. Ecosystem services, case studies and future research are shown. The pictures are examples of container gardening from different countries (a) Mexico (b) Japan (c) Japan (d) UK (e) Japan (f) Korea (g) Sweden (h) Canada. All photographs were taken by Ayako Nagase.

Although there are many container gardens in urban areas, container gardening as a component of more broadly considered green infrastructure seems to be unappreciated. One of the reasons might be that individual containers are too small to be commonly recognized as a component of green infrastructure. While individual containers are small, a large amount of containers may be able to complement other greening initiatives in high density areas. Container gardens, whether developed by individual citizens as home gardens or municipalities or corporations as formal urban landscaping, are often part of in-ground gardens as well. Hence much of the urban gardening literature may include but not mention specifically the containers that can be a key component of all urban gardens in some regions (Buchmann 2009). For home gardens, another reason for the lack of attention to container gardens might be that much of this gardening can be perceived as a recreational activity for people and is largely unmanaged by local governments, in contrast to other types of green infrastructure, therefore, in general, they are not treated as seriously. Most of the urban ecology literature ignores container gardens or lumps them in with conventional ground-level gardens.

Ecosystem services, conceptualized as benefits from ecosystems to human well-being (TEEB, 2011) are increasingly acknowledged to ameliorate urban living conditions (Elmqvist 2013; Tzoulas et al., 2007). There has been recent attention to urban gardens from the perspective of ecosystem services (e.g. Borysiak et al., 2017; Cameron et al., 2012; Goddard et al., 2010; Jim and Zhang 2015). Home gardens, community gardens and informal container gardens represent a "bottom-up" activity and they may contribute to the same ecosystem services. However, it is necessary to review ecosystem services separately for container gardening because the uniqueness of container gardening has not been discussed and they differ from other kinds of gardens in growth conditions, plant selection and mobility. There has been little review of research on ecosystem services derived from container gardening. This is the research gap. The aim of this review is to elucidate potential ecosystem services provided by container gardening. In this paper, containers are defined as vessels for growing plants with surface areas of substrate generally less than 1 m × 1 m, which may or may not be fixed in place. They consist of plants, substrate (substrate), the container itself and occasionally gravel or rocks at the base as a drainage layer. They are maintained and irrigated regularly and sometimes fertilizer is applied. From previous studies, we classified ecosystem services which container gardening may provide into these four common ecosystem services (TEEB, 2011): (1) Provisioning (food production and security); (2) Regulating (stormwater management, improvement of air quality, energy savings and thermal comfort); (3) Habitat/Supporting (plant biodiversity and creation of animal habitats); (4) Cultural (aesthetic and improvement of visible green ratio, communication and environmental education, material reuse). After summarizing the ecosystem services, we describe international case studies to address the regional differences in drivers of container gardening adoption. We then discuss future directions for research in container gardening. The ultimate goal of this review is to recognize the value of container gardens in order to promote them as part of green infrastructure in urban areas.

ECOSYSTEM SERVICES

Provisioning Services

Food Production

Currently, interest in urban agriculture is increasing rapidly and people are motivated to grow vegetables and fruits for food (Figure 1a and Figure 1f). Home gardens can produce a substantial amount of food in urban areas (CoDyre et al., 2015). Many participants are activists who wish to promote social change, ensure affordable access to vegetables or improve health (Kirkpatrick and Davison, 2018). In urban areas, planting in containers or raised beds on apartment building balconies or roof tops is common in many countries (Dunnett and Clayden 2007; Nasr et al., 2017; Oh et al., 2018; Vazhacharickal, 2014). Vegetables are most commonly grown in container food gardens, but many small fruit trees are also common, especially in the tropics. In some places, apple and pear, and shrubs with pliant branches are used as espaliers (pruned trees or shrubs trained flat against a wall) in container gardening (Cantor 2008).

According to studies of container gardens in Singapore, provision of food and medicinal resources (77.5%), and aesthetic benefits (72.3%) were the key ecosystem services provided by the plant species present (Oh et al., 2018). Container gardening is used for supplemental food production in home gardens, but new initiatives are using containers in public or corporate spaces to host community gardens. One study estimates that 77% of the vegetable requirements in Bologna, Italy, could be met if all available rooftops were gardened using container plantings (Orsini et al., 2014) and food security concerns are driving an expansion in container gardening globally (Bailey 1993; Buchmann 2009; Gopal and Nagendra 2014). Preparing for uncertain factors such as natural disasters and climate change is also becoming important. However, very little published research is available on growing vegetables and fruits in containers beyond production aspects. There are many popular books for gardeners that introduce methods for growing vegetables and fruits in containers but scientific studies are lacking on the effects of growing media composition and depth, cultural practices, potential water-quality issues of effluent and how food production could influence the other known benefits attributed to container gardening (Whittinghill and Rowe 2011).

Regulating Services

Stormwater Management

Storm water management is one of the important environmental benefits of green infrastructure. Traditional urban runoff management strategies rely on channeling rainwater into city sewer systems, but peak storm events can overwhelm system capacity (Newell et al., 2013). Since space tends to be limited in urban areas, planters are appropriate for storm water management. Specifically designed storm water planters are above-ground planting containers that intercept water. They reduce water runoff through infiltration, evaporation, transpiration and storage (Dunnett and Clayden 2007). In terms of design, the ability of a container planting to retain stormwater depends on substrate properties such as porosity, organic matter content, and antecedent moisture conditions. Some studies on growing media used in containers show up to two times the variability in soil moisture contents under the same moisture regimes depending on the kind of media used (Fonteno 1988). The surface area available and the depth of the substrate are also crucial in determining overall runoff retention ability.

Although container plantings have been introduced in rain gardens (Ellis 2013; Kuller et al., 2018), little research documents the benefits of container planting to reduce water runoff and to improve water quality. While larger catchment areas reduce peak runoff by a greater amount than smaller areas, with the same substrate depth, studies on small green roof trays or experimental systems show similar runoff reduction to larger scale green roofs (e.g. Nagase and Dunnett 2012) so the small area of individual containers should still allow substantial stormwater retention in urban areas dominated by hard surfaces. Capture and storage of rainwater in barrels or cisterns is also used to irrigate container gardens in some places, and this represents a positive benefit that also reduces runoff into urban systems.

Improvement of Air Quality

Container gardens can contribute to improving outdoor air quality. Urban vegetation is known to trap airborne particles and to take up other contaminants such as nitrogen oxides (Oberndorfer et al., 2007). Once inside the leaf, gases diffuse into intercellular spaces and may be absorbed by water films to form acids or react with inner-leaf surfaces (Smith, 2012). Many studies have shown that trees can contribute to improvement of outdoor air quality, however, while trees and shrubs are sometimes used in container gardening, studies of the impact of herbaceous plants, which are more commonly used in containers, on air quality are limited. Herbaceous plants can also improve urban air quality (Currie and Bass 2008). Analysis of leaves harvested from roadside herbaceous vegetation in Berlin showed that species with the highest particulate matter accumulation rates were ones with hairy or rough leaves and that leaves 15 cm or higher from the ground collected more particulate matter (Weber et al., 2014). Herbs with smooth leaves and grasses were found to accumulate less particulate matter than other plants with hairy leaves. Although herbaceous plants were not very effective in removing particulates from the air, different herbaceous plant species captured different sizes and types of particulate matter (Weber et al., 2014). Further research is necessary to document how plants which are commonly used for container plants can contribute to the improvement of air quality.

Energy Savings and Thermal Comfort

Container gardens installed adjacent to buildings can contribute to improved energy savings and thermal comfort in the urban environment. Container plants directly exposed to the sun intercept solar radiation, cooling local microclimates via reflection and transpiration. However, in urban areas, the placement of container gardens relative to shade from adjacent buildings or trees will have a large influence on the degree to which container plants can influence urban climates. In terms of plant selection, species that tend to be taller and have greater leaf areas and stomatal conductance rates have higher overall evapotranspiration (ET) (Fynn et al., 1993; Stanley and Harbaugh 1992), so these should increase microclimatic cooling but such species may have greater irrigation requirements. Growing media properties can also influence the thermal performance of container plantings. Soil moisture holding capacity can result in higher ET (Valdés et al., 2008), and soil amendments including mycorrhizal inoculation can result in larger plants with greater horizontal cover (Srinath et al., 2003), leading to greater cooling potential.

The deployment of containers on vertical surfaces may increase the utility of container gardening for ameliorating climate in hot conditions. Simple green facades using containers, the so-called "green curtains", are very popular in Japan, particularly after the Great East Japan Earthquake in 2011 since awareness of power savings has increased (Okushima et al., 2014; Suzuki 2012) (Figure 1b). Some local authorities provide plants for green curtains without charge to promote energy savings. They also organize workshops on how to grow these plants. Plants which are commonly used for green curtains at home are annuals such as *Momordica charantia* var. *pavel*, *Luffa cylindrica* and *Ipomoea* sp. over summer. They usually expect to reduce building cooling costs over summer, and then they remove them in the autumn and set up again in the spring. A few studies have been carried out to show how green curtains reduce summer wall temperatures. One study compared outside surface temperatures of windows behind different screens of green curtains; the temperature behind a cheesecloth screen was highest, that behind a reed screen was second, and that behind the *Momordica charantia* L. was the lowest (Okushima et al., 2014). However, the plant growth of green facades using containers may be less than those of which are planted on the ground because of limited soil volume. Further studies are required to elucidate the relationship between soil volume and thermal performance.

Habitat/Supporting Services

Plant Biodiversity and Creation of Animal Habitats

Although there are long lists of recommended plants for container gardens internationally in books (e.g. Kasahara 2005; Peters et al., 2007; Titchmarsh 2009), little empirical research has documented what kinds of plants are actually used or preferred for container gardens in different regions. Some studies provided detailed plant lists for container gardening. Shinozuka et al. (2002) studied container gardening in Sumida city in Tokyo and they showed that the plant list can be divided into five broad types of plants: ornamental flower plants, ornamental leaf plants, ornamental fruit plants, food plants and plants grown for good luck or other cultural significance ("lucky charm" plants). Many people prefer to keep lucky charm plants in front of their houses and some of them were originally housewarming gifts when they moved in (Figure 1e). In another study, Oh et al. (2018) studied the (outdoor) corridors of apartment buildings in Singapore, and showed that across 1.86 ha of surveyed corridors a total of 265 plant species and cultivars were present in the containers, with an average richness of 124 species per hectare. They also showed that 10.4% of plants were natives, including some rare native species, and 82.2% were exotics. Jonas (2007) studied container gardening in Tsukishima in Tokyo and showed that most of the plants are around 20-100 cm tall, and the usual diversity combines 3-10 species such as *Azalea* spp., *Amaryllis* spp., *Camelia* spp., *Cyclamen* spp., *Fuchsia* spp., *Hibiscus* spp., *Hydrangea* spp., *Mimosa* spp., *Nerium oleander*, *Schefflera* spp., *Viola* spp., *Yucca* spp. Matsuo (1977) studied container gardens in Kagoshima city, Japan and found that about 260 plant species were observed and 70 % of them were ornamental plants. Container gardens can contain a high number of plant species within a small area.

Many studies have been carried out to show that domestic gardens can contribute biodiversity benefits (Goddard et al., 2010). There are limitations, however, to the ability of constructed ecosystems to supply biodiversity benefits in urban areas: relative isolation from green spaces, the presence of non-native species, novel ecological conditions and stressful environments (Williams et al., 2014) may reduce the ability of container gardens to support biodiversity conservation aims. Given the small relative area of container gardens, it is likely that they may provide habitat primarily for generalist species that are already successful in urban environments (Cameron et al., 2012; Williams et al., 2014). Birds have also been reported to use container gardens (Oh et al., 2018).

Cultural Services

Aesthetics and Improvement of Visible Green Ratio

In Japan, container gardening was frequently seen in the immediate surroundings of buildings preferably close to or even on private property and only slightly extending beyond this 'territory' (Jonas 2007; Shinozuka 2002; Takahashi and Shimomura 2005). When possible, the gardens are adjacent to the building, with the exception of large arrangements which usually spread onto the street or sidewalk. Takahashi and Shimomura (2005) showed that many put containers on hard surfaces directly (69.3 %) but use of hangers (12.3 %) and stands (10.5 %) was also observed. Oh et al. (2018) showed that corridor designs with a larger area and simpler geometry significantly increase the abundance of pots in Singapore.

Similar findings were demonstrated in a study of container gardening in Tokyo (Shinozuka, 2002). Yamamoto (2017) showed that containers tend to be placed in different configurations depending on the width of the alley in Nagono area, Nagoya city in Japan. People tended to put the containers either inside or outside of their property when alleys were less than 4 m width. In alleys between 4 m and 10 m width, people put containers both inside and outside of their private property. Over 10 m width of alleys, there was a tendency that containers were mainly placed outside of their private property.

Street-level greenery has long played a critical role in the visual quality of the urban landscape. Visible green ratio can be defined as the amount of greenery in the field of vision (Ding et al., 2016). Mizukami (2013) studied 126 alleys in Kyoto, Japan and found 3.6 containers per linear meter. Although each container was small, they contributed to an increase in visible green ratio: the visible green ratio increased linearly with the number of containers ($Y = 0.2818X + 1.7082$ ($R^2 = 0.479$)). According to this formula, a single container could contribute to increase the visible green ratio by approximately 2%. Shinozuka et al., (2002) studied 40 alleys (width 1.7 m – 6.9 m) in downtown Sumida-ku, Tokyo, Japan and analyzed the relationship between width of the alley and the proportion of different vegetation types (container plants vs. trees). They showed that the number of containers increased as the width of the alley increased. Alleys less than 2 m wide had greater than 80% of the vegetation provided by containers.

Communication/Social Interaction

The main requirements for maintenance of container gardens are watering, transplanting, applying fertilizer and moving containers. An interview study showed that container gardening was maintained by private citizens without professional help and maintenance was a part of daily life for many people (Yamamoto 2017). In another study, most people (20 out of 24 households), spend less than 15 minutes for daily maintenance of plant containers (Narukawa et al., 2003). Over 90% of container garden maintenance was conducted by housewives in a survey in Tokyo (Noguchi et al., 1999). Mason et al. (2008) studied the consumer preference of container plants and showed that the level of maintenance information provided were the most important attributes in the decision to purchase a container garden.

Container gardening can contribute to enhanced communication among residents in the neighborhood. People have been exchanging growing plants for a long time because potted plants and their parts are suitable gifts due to their longevity and evocation of social memories (Ellen and Komaromi 2013). People tend to propagate plants themselves and exchange plants with neighbors. The number of containers tends to increase over time because of this exchange. People also enjoy exchanging information on horticulture.

Container gardening is also appropriate for guided programs such as education and horticultural therapy. Container gardens are frequently used for environmental education because they are appropriate for observation; to get to know plants better by seeing them close-up, by looking at them from different angles, studying their structure, texture, colour and seasonal change (Brandt 1977). It is relatively easy to manipulate growth conditions for container plants, for example, it is possible to change the amount of fertilizer applied to plants and observe their growth. Container gardens are used as horticultural therapy because of the intimate quality and personal ownership they evoke in the garden. Container gardens often provide a high degree of accessibility because containers can easily be raised, lowered, or sized to meet specific access needs (Simson and Straus 1997).

Material Reuse

Plastic, terracotta and pottery are frequently used for containers. Takahashi and Shimomura (2005) studied 115 container gardens including a total of 665 containers in front of houses in Kyoto, Japan and showed that plastic is the most frequently used (52.8 %), followed by terracotta (26.3 %) and pottery (6.1 %). Plastic has been used for a long time as container materials because it is cheap and lightweight, facilitating handling. Recycled materials are frequently used for container gardening. Many daily materials can be recycled for use in container gardening. For example, tires, jute bags, used tins, PET bottles and even cars have been used for plant containers (De Zeeuw et al., 2017), and the idea is virtually unlimited. Gopal and Nagendra (2014) also showed that the types of pots used in container gardens in Bangalore slums included earthen pots, plastic pots, cemented structures, plastic bags, discarded paint containers, earthen water pots, plastic buckets, metallic cans, hindalium pots (an alloy of aluminum), battery cans and aluminum buckets. Although there are many suggestions for container materials on websites and in books, there is little quantitative research about the materials used in container gardens. Matsuo (1977) studied 4,200 buildings in Kagoshima city, Kyushu in Japan and found that 30 % of buildings use recycled materials for container gardening. The most commonly used were wooden boxes (31.6 %), followed by sinks and/or washbasins (21.3 %), and polyethylene buckets (16.8 %). The wooden boxes were originally used to transport fishes or apples. They have good aeration and filtration and are appropriate for growing plants. The author pointed out that many kitchen items have been converted into containers for plants. This study was carried out more than 40 years ago and current-day materials may be different, but this study demonstrates shows that recycled materials have been used as containers for a long time.

In Japan, water left over from washing rice is commonly used for irrigation in container gardens. Ohta and Iijima (1994) studied the awareness of water-related environmental issues in residents in Tokyo and they showed that many people have a custom to use rice water for plants to save resources and be more environmentally friendly. Eggshells and sea shells are commonly put on the soil of containers or mixed with soil. It is believed that they would release nutrients for the plants, although there is little research to show how the application of eggshells or sea shells improves plant growth. Other studies indicate that recycled products such as sugarcane residue and compost are commonly included in container gardens (Vazhacharickal 2014). The use of recycled materials can make a positive contribution to the overall sustainability of urban environments where container gardens are prevalent.

CASE STUDIES

Container gardening is common internationally and various drivers of deployment of container gardening have been identified. There appear to be regional differences in the drivers and motivations for people to engage in container gardening. However, we were not able to find papers documenting the role of culture in shaping regional practices of container gardening. Here, we discuss further the culture of container gardening in different countries.

Roji Engei (Horticulture in Alleyways) -Japan

Domestic container gardens are commonly seen in traditional downtowns in high density areas of Japan. This tradition of container gardening is called *Roji engei* (horticulture in alleyways) (Figure 1e). While urban alleyways have long been associated with blight and crime in some countries (Seymour et al., 2010), alleyways in Japan have a reputation as peaceful places. These gardens consist of countless flowerpots and boxes, some are carefully arranged and others are more chaotic (Jonas, 2007). Buildings take up most of the space in such areas; each house is built to maximize the space occupied and container gardening plays a role as a buffer between buildings and roads. The value of *Roji engei* as a community landscape has been recognized and some studies of *Roji engei* have been carried out since 1990s in Japan. *Roji engei* as practiced in Japan, aside from reasons derived from culture, tradition or the present cityscape, the main reason for keeping a flowerpot garden is simply personal fulfillment in caring for plants, working with one's own hands and creating living, thriving, blossoming compositions of plants to enjoy, show and share (Yamamoto, 2017). *Roji engei* is important as a kind of community landscape and exemplifies the value of informal container gardening (Jonas 2007; Aoki et al., 1994). Container gardens can facilitate conversations between residents and passers-by. Sometimes, there is no direct communication, but people start container gardens due to the influence of their neighbor's containers (Manabe 1998; Yamamoto 2017).

Food Production -Africa, South America and Asia

In Africa, South America, and Asia, especially in warmer climates, domestic, informal container gardening is a ubiquitous feature of high density urban areas. Food production is a major goal of these container gardens (Barau 2015; Buchmann 2009; Gopal and Nagendra 2014), but across continents, these gardens also usually include a high proportion of medicinal and ornamental plants, as well as species with spiritual importance (Nemudzudzanyi et al., 2010) and they often feature high plant species diversity. Terrace gardens are promoted by various government agencies in India to promote food security among the urban poor (Nasr et al., 2017). In central America, container gardening is common on patios, especially where paved corridors are common (González-García and Sal 2008). Given that initiatives to promote food security in these regions aim at accessibility, low cost systems, including creative re-use of locally availability materials, composted growing media and water recovery for irrigation are key features of container gardens throughout the Global South (De Zeeuw et al., 2017).

Decoration - Europe
In Europe, container gardening tends to be used for decoration purposes. For example, window boxes, outdoor window boxes placed under the window, are commonly seen in Europe (Figure. 1g). Some window boxes are arranged using various kinds of flowers and forbs, and some window boxes use a single flowering species, such as Geranium (Hiller, 1991). Hanging baskets are also commonly seen in Europe and they can support small groups of plants in positions that would be otherwise impossible to consider: hanging on the side of a house or on garden walls, below the branches of a tree, or suspended from the beams of a porch, pergola, arch, or arbor (Hiller 1991).

Lack of Space, Food Production - North America
In North America, urban container gardening is often promoted as a solution to lack of space at ground level for gardens (Bailey 1993, Choonsingh et al., 2010) (Figure 1h). The emphasis is generally on food production. Another factor is the widespread perception that urban soils contain contaminants, so it is believed that using soil-less media may result in less contaminated vegetable production. Some government initiatives target not just food security but promote container gardening in high density areas with high-rise apartment buildings as a way to increase social interaction (Choonsingh et al., 2010).

DISCUSSION

From the above review, it is clear that published research on container gardening in urban areas is limited. Further research on container gardening is necessary, therefore, we recommend the following research directions to develop container gardening as green infrastructure. Summary of this review is shown in Figure 1.

Ecosystem Service Provisioning beyond the Immediate User Community
Container gardening can contribute to various kinds of social ecosystem services in urban areas. Many ecosystem services provided by container gardens overlap with the ecosystem services which other kinds of green infrastructure may provide, although there are some limitations because of the small size of containers relative to other types of ecosystems. For example, for biodiversity, given the small relative area of container gardens, it is likely that they may provide habitat primarily for generalist species (Cameron et al., 2012; Williams et al., 2014). However, this may depend on the availability of other green spaces within the city; container gardens are likely important for biodiversity in urban core areas since other green space, such as parks, may be largely absent. Diverse plant assemblages are common in domestic container gardens due to gardener preferences for species that perform a range of different functions (Gopal and Nagendra 2014; Oh et al., 2018; Shinozuka et al., 2002), and some rare native species have been observed in container gardens in Singapore (Oh et al., 2018). Michishita et al. (2005) studied home gardens including container gardens and pointed out that they may function as *ex situ* conservation opportunities because red-listed plant species were observed. Therefore, scientific understanding of the growth conditions facing container plants in different regions are essential to explore the potential for plant conservation.

In this review, one highlighted point is that much container gardening represents a community-driven activity. Previous research on container gardening is mainly focused on the current status of container gardening and cultural services, such as communication among local residents. There has been little review of research on ecosystem services derived from container gardening and many people engage in container gardening without noticing their ecosystem services. It is necessary to study ecosystem services separately for container gardening because its uniqueness has not been recognized. The size and diversity of containers and plants is expected to influence the overall provisioning of benefits in urban areas, as will the location of container gardens relative to other features of the urban environment. Further studies are required to quantify the large-scale benefits of container gardens. In addition, studies to show the integrated benefits of ecosystem services are required, including a quantitative account of costs and disservices.

Ecosystem Disservices Associated with Container Gardening.

There are few references to ecosystem disservices associated with container gardening. One important negative impact is nutrient runoff. Compared to in-ground gardening, nutrient leaching from containers deployed on hard surfaces tends to enter urban waterways or stormwater infrastructure where it can contribute to downstream eutrophication or at least impose a cost for its treatment (Majsztrik et al., 2011). Additionally, the soil-less growing media often used in container plantings can be low in cation exchange capacity, meaning less ability to retain nutrients (Majsztrik et al., 2011). Other issues with container gardening include greater levels of irrigation compared with in-ground gardens and green roofs, leading to overall lower sustainability of container-based systems (Lazzerini et al., 2018). Finally, given the popularity of ornamental plants in container gardens worldwide, and the propensity for ornamental species to become invasive in natural ecosystems (Kowarik 2005), container gardens, like other kinds of urban horticulture can increase the risk of invasive plant species introduction.

Plant Selection, Growth Environment and Materials for Container Gardening

Previous plant studies were carried out through observations on plant choices in container gardening and indicated that plant selection for container gardens incorporates high species diversity. Container gardens can contain a high number of plant species within a small area. Private or home container gardens show a range of forms and diversities, from messy to decorative. Conversely, plant selection for container gardens that are installed by companies or governments may be decided by practical reasons of plant availability or ease of maintenance, and tend to show less individual variation due to conventions of public landscaping.

Very little research has been carried out to investigate the unique growth environment faced by plants in container gardens. Maximizing the benefits of container gardening as green infrastructure will require knowledge of growth conditions to aid in the selection of appropriate plants and improve maintenance. Further experimental studies are required in controlled environments to choose appropriate plants for container gardening in urban environments. These could include screening for drought tolerance, water and temperature requirements in small containers for regional climates.

It is important to recognize the differences between in-ground urban gardens and container gardens in terms of the environment for plant growth. From an ecological perspective, the main difference between in-ground urban gardens and container gardens is the isolation of the substrate and plant roots from soil in the ground and from the roots of other plants. Green roofs and walls may incorporate containers as well, but container gardening on the whole tends to employ smaller containers. This can be an advantage to gardeners as the smaller containers are easily moved, but the containers present several challenges to plant survival and growth. Container plants can experience more extreme temperatures than plants growing in the ground (Young and Bachman 1996), therefore, root damage is possible, resulting in reduced capacity for nutrient uptake (Mathers 2003). Root restrictions due to confinement in pots is commonly reported in horticultural research (Di Benedetto et al., 2006), leading to reduced growth rates and water uptake. Container size relative to the plant species grown is an obvious consideration for maximizing plant survival and growth (NeSmith and Duval 1998). Since the growth environment for container gardening can be severe, it is important to choose appropriate container size and materials. Innovations in container design featuring alternatives to traditional smooth-sided containers can reduce circular growth around the pot and root death (Amoroso et al., 2010). Caputo et al. (2017) point out that containers placed on hard surfaces can have drainage issues, e.g. waterlogging of roots, that would not usually occur with in-ground plantings, unless there is some space between the roots and containers, so container design and placement is important.

The growth environment may affect plant selection for container gardening. For example, studies in Mediterranean climate cities indicated that the harsher conditions in containers resulted in gardeners choosing more non-native succulents in high density urban habitats compared to lower density areas where containers were less common (Marco et al., 2008). Maximizing the benefits of container gardening as green infrastructure will require knowledge of growth conditions to aid in the selection of appropriate plants and improve maintenance. Further experimental studies are required in controlled environments to choose appropriate plants for container gardening in urban environments. These could include screening for drought tolerance, water and temperature requirements in small containers for regional climates.

From our review, it is apparent that recycled materials were frequently used for container gardening. Recently, research on the life cycle assessment (LCA) of urban greening materials has increased. LCA examines the environmental impact associated with products or systems throughout their life cycles. Considering the whole life cycle of a system, the environmental burden due to the extraction, transportation, production, and construction of raw materials is largely dependent on the type of system and materials involved (Perini and Roccotiello 2018). Recycled materials may be used as for pragmatic reasons, such as their availability to gardeners, but there may also be an awareness of broader environmental concerns driving these practices.

Policies to Support Formal and Informal Container Gardening

Previous studies demonstrated that container gardening provides several benefits such as community development and improvement of visual quality in urban landscapes. In many cities, funding for urban landscaping has decreased, therefore, urban greening by citizens is getting more and more important (Mattijssen et al., 2017). However, currently, city planning and politics have paid little attention the fact that informal gardens shape cities to a large extent. From our review, it was shown that container gardens were often established by private citizens without professional help and maintenance was a part of daily life for many people. Container gardening, even as a voluntary and leisure activity has significant social and ecological implications that cannot be simply ignored. Mattijssen et al. (2017) studied the long-term management or 'place-keeping' of urban green space by citizens and found that the supporting role of authorities was key in legitimizing and supporting place-keeping by citizens. Authorities can support place-keeping by citizens by providing security via stable policies, formally protecting the involved spaces, allowing long-term management contracts and contributing resources. Place-keeping can be defined as 'responsive long-term management which ensures that the social, environmental and economic quality and benefits a place brings can be enjoyed by present and future generations' (Dempsey and Burton 2012).

Although container gardening is popular in Japan, only a few local regulations deal with container gardening directly and no laws apply to them (Jonas 2007). Some local authorities provide funding and materials such as plants and flower pots for container gardens, but most of them target group activities in public areas (e.g. Nagoya city in Japan). In Hong Kong, government initiatives promote container gardening in high density areas with high-rise apartment buildings as a way to increase social interaction (Choonsingh et al., 2010). Similarly, some government initiatives are promoting container-based food production in cities, for example, in Bangalore where over 14,000 people have a terrace container garden. These gardens use a variety of purchased and recycled containers to grow over 50 species of fruits and vegetables (De Zeeuw et al., 2017). It would be valuable for local governments to play a greater role in encouraging container gardening. By using container gardening, households can voluntarily extend urban greening projects into other public spaces within their neighborhoods in a way and manner that local planning authorities could not ordinarily achieve (Barau 2015). It may be important to keep their activities bottom-up (informal) rather than top-down (formal) because much container gardening is spontaneous and results from the expression of individual tastes and preferences.

We were not able to find any papers to describe formal container gardening. Some city councils have policies to encourage formal container gardening. For example, city councils offer sponsorship, such as Aberdeen in the UK, offers sponsorship opportunities for floral displays (e.g. containers and hanging baskets) across the district. The sponsors purchase hanging baskets and containers from Aberdeen City Council, who will install and maintain them throughout the season (Aberdeen City Council 2020). These kinds of activities may encourage container gardening and future academic research of formal container gardening is required.

From this review, it was shown that container gardening can contribute to increase the visible green ratio and the distribution of container gardening was influenced by the design of space. Therefore, space design and city planning that facilitate container gardening are required. For example, window boxes are deeply rooted culture, and they can represent a symbol for particular cities. Currently, it seems that there are no regulations nor obligations to have flowers. The activities of container gardening should be optimized to realize increased greenery in cities.

CONCLUSIONS

This study showed that container gardening has a potential to be an important component of urban green infrastructure. It is clear that container gardening can contribute to various kinds of ecosystem services in urban areas. In this study, only English and Japanese language papers were studied and there may be some literature in other languages on container gardening. Further studies are necessary to understand what the drivers of container gardening in different countries are.

Developing container gardening as green infrastructure or living architecture is challenging because very limited information is available to show the current extent, value and effects of container gardening in urban areas. To develop container gardening, it is important to engage citizens, local authorities and academia. It is important for citizens to be aware that they can contribute to improving the urban environment although much container gardening may be done as a hobby. Local authorities should be aware of the potential to support their activities through policy and inform the value of container gardening in town planning. In academia, further research on container gardening should be undertaken to show its value and effects on the urban landscape. Cooperation among academics, local authorities and citizens is required to further develop container gardening to provide many direct and indirect benefits to people living in cities.

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