Sustaining Green: Quality Improvement of Green Infrastructure in Residential Facilities through Effective Maintenance and Resident Participation

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Abstract

The integration of green infrastructure (GI), such as green roofs, green facades, and tree plantings, is increasingly recognized as an effective approach to mitigate the negative effects of climate change, particularly the urban heat island effect. However, in addition to initial investment costs, ongoing maintenance efforts are imperative to ensure the vitality of GI, necessitating continuous expenditures. While these costs are often viewed negatively, they are essential to maintaining the multifunctionality of GI. In response to this challenge, we piloted a resident participation project and offered comprehensive maintenance instructions addressing various GI types and different maintenance levels, in order to involve resident laymen. Additionally, we differentiated between professional green space management and amateur practices, to foster a bottom-up approach that actively engages residents. Lastly, we evaluated different incentives such as financial and social aspects, knowledge acquisition, nature experience, aesthetical improvement and private gardening. By prioritizing the integration, maintenance, and development of green spaces through effective guidelines and measures, urban areas can create sustainable and vibrant environments that mitigate climate change impacts and enhance the well-being of residents.

Keywords:

Green Infrastructure, Maintenance, Urban Heat Island Mitigation, Urban green spaces, Sustainability

1. Introduction

GI provide a wide range of ecosystem services, from mitigating the urban heat island effect and flooding's to food production, and are therefore seen as a valuable tool for creating resilient cities. According to Gaffin et al. (2012) GI in urban settings comprise a wide range of components and typologies. These include planar areas like urban forests and parks, linear features such as street trees or seepage basins, and stepping stone corridors that consist of gardens, terraces, balconies, green roofs, and green façades. Public GI commonly manifests in various forms, including roadside verges and trees, public parks and commonages, greenbelts, as well as gardens linked to public institutions such as hospitals, police stations, museums, schools, and other local and provincial departments (Gwedla and Shackleton 2015). Vegetation serves as the core component of GI, offering a diverse range of services such as air filtering, noise reduction, light diffusion, shade, cooling, balanced energy and water cycles, and wildlife habitats (Pitman et al. 2015). Moreover, GI in proximity to buildings fulfils various functions, providing recreational spaces like lawns and playgrounds, serving technical purposes such as shade provision, wind protection, and erosion control, contributing to aesthetics, supporting ecological well-being, and even yielding economic benefits such as increased property value (Angelo 2019). In order to maximize the benefits provided by GI, it is imperative to ensure their functionality and maintain high standards of quality (Fongar et al. 2019). Consequently, sustaining the multifaceted functions of GI after installation necessitates the implementation of appropriate maintenance measures (Immitzer et al. 2020). These measures not only ensure the continued provision of numerous ecosystem services but also safeguard the inherent monetary value associated with GI. Inadequate resource allocation for maintenance compounds the challenges posed by the increasing urban density and incorporation of green spaces in building projects (Lindholst et al. 2018).

The primary obstacle to maintaining the quality of green spaces is consistently reported to be inadequate budgets (King and Shackleton 2020). Even with the addition of new GI, there is typically no proportional increase in budget allocation, and the potential consequences of neglecting open space maintenance remain uncertain. It is expected that maintaining quality in green spaces will progressively become more difficult (Fongar et al. 2019). The maintenance of GI is often overlooked in many cities due to the urgent requirements for grey infrastructure development and services resulting

from rapid urbanization and financial constraints (Xu et al. 2011; Lindley et al. 2018; King and Shackleton 2020). Nevertheless, a mounting body of evidence suggests that ample and well-maintained GI can substantially aid in mitigating and alleviating the sustainability challenges confronted by urban planners and authorities (Jennings et al. 2016; Zhou et al. 2017).

Several cost-benefit studies have shown that the advantages derived from urban trees as part of urban GI surpass the associated costs by a factor of 2 to 5 (Song et al. 2018). However, many of these benefits do not translate into direct financial returns for the property owners, while the costs incurred represent tangible monetary expenditures. Allocating adequate budgets is essential to cover expenses such as employee wages, vehicle and equipment costs, and ongoing operational expenses required for establishing and maintaining public GI. Unfortunately, these costs are often perceived as a drawback (Qiao and Randrup 2022). Despite their fundamental role in creating attractive, valued, sustainable, and economically viable environments, GI suffer from compromised quality due to insufficient management (Dempsey and Smith 2014).

The responsibility for maintenance measures varies depending on the ownership, with either the public or private sector assuming the role (King and Shackleton 2020). Apart from maintaining private gardens and public green structures, there is a diverse array of GI that often rely on the involvement of external companies to carry out the required maintenance tasks. Most commonly, the responsibility and management of GI are integral components of the facility management (FM). Those entail the utilization of legal, technical, economical, and organizational instruments to facilitate dynamic maintenance of the open space and their structures.

Strategic management of GI involves the implementation of a maintenance concept accompanied by continuous adaptations (Jansson and Lindgren 2012). The objective of maintenance management is to cultivate a healthy and resilient plant population, enabling the attainment of predefined greening goals such as desired growth, extent of coverage, shading, cooling effects and aesthetics. At the operational level, it is crucial to professionally execute the required green space management activities through specialized companies or service providers (Randrup et al. 2017). Insufficient funding is a major challenge in maintaining quality green spaces, and this issue is exacerbated by the anticipated increase in tasks due to the growing number of GI to manage, leading to a future dilemma (Fongar et al. 2019). As the number of GI

typologies within an area to be maintained expands, the corresponding maintenance effort increase. Consequently, the maintenance required for a lawn alone would be less demanding compared to the upkeep of additional components like a green roof or a green façade (Langeveld et al. 2022). The maintenance of GI not only plays a role in environmental preservation but also serves as a source of employment for skilled and unskilled workers across the public and private sectors (King and Shackleton 2020).

Based on the aforementioned challenges, this article aims to address the following areas: (1) establishing maintenance levels that align with the required care and desired target state, (2) providing general maintenance instructions for different types of GI, (3) offering customized lawn care strategies based on specific lawn types, (4) differentiating between professional green space maintenance and amateur practices, and (5) exploring incentives for resident participation for the maintenance of GI. The here reported findings were elaborated by the authors in the project Care4GREEN based on an exhaustive literature research on care and maintenance practices. For the literature search, we primarily utilized the databases PubMed and Google Scholar, using a combination of keywords such as 'maintenance of green infrastructures,' 'green infrastructure management,' 'urban green space upkeep,' 'sustainable landscaping,' and 'resident participation in maintenance.' Additionally, a workshop series was developed and carried out to involve and instruct housing residents in GI maintenance. During these joint interactions guided discussions were conducted to gain insights into residents` perceptions and willingness to participate in care activities and to derive guidelines for incentivization. By delving into these key aspects, we aim to contribute to the understanding and implementation of effective maintenance practices in the realm of green spaces and GI.

2. Maintenance measures and categorization

To effectively implement maintenance measures for GI, it is essential to possess the necessary knowledge and effectively organize activities based on seasonal considerations. Ideally, the appropriate maintenance concept is already considered in the planning process. This concerns the accessibility of the greened areas, the consideration of safety aspects during the specific working procedures (equally valid for specialist and laymen personnel) as well as the use of easy to care systems and open communication about the expected works. To evaluate the quality and scope of maintenance measures, it is feasible to establish specific categories for each type of

GI. Maintenance categories for GI were developed based on the works of Niesel (2006) and Knoll and Dopheide (2018), as illustrated in Table 1. Based on specific requirements and needs four maintenance levels, ranging from Level I (maximum) to Level IV (minimum) are differentiated. While Level I necessitate almost daily maintenance measures, Level II requires weekly attention, Level III requires monthly care, and the lowest Level IV, is typically sufficient with maintenance once or twice a year. It is noted that the aesthetic quality of the green space improves with each level ranking higher from minimum to maximum.

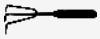
Table 1: Maintenance level ranking with maintenance frequency or intensity of GI (own development 2021, based on Niesel (2006), Knoll and Dopheide (2018).

Intensity	Maintenance level	Frequency	Tasks
Maximum maintenance	Level I: High-quality, diverse, representative green spaces.	Daily tasks	Small-scale maintenance work, tying and directing shoots, removing withered plants, mowing lawn.
High maintenance	Level II: Green areas of higher standard and lower diversity.	Weekly tasks	Fertilizing, mulching, plant protection, transplanting, pruning.
Moderate – maintenance	Level III: Ordinary green area of average standard.	Monthly tasks	Only necessary pruning measures.
Low – minimum maintenance	Level IV: Simple-design, near-natural areas, extensively maintained green areas or near-natural green and biodiversity areas.	1-2 times a year (or case-by-case care assignments as needed)	Rudimentary maintenance measures depending on use and environment such as weeding and mowing.

After the greening is installed, the initial focus is on establishment, which aims to achieve the desired condition of the vegetation. These measures, referred to as completion maintenance are crucial for the continuous growth and progress of the greening (ÖNORM L 1120). It is worth noting that during the first year, the (commissioned) landscaper typically assumes responsibility for the maintenance tasks. Subsequently, the maintenance responsibilities may be transferred to other parties depending on the specific arrangements. This phase of development care is crucial in terms of establishing a vital and healthy adult habitus specifically for trees

and woody species, to avoid damage due to catch-up and missing trimming towards target structures (ÖNORM L 1120). Once the target condition of the greening is attained, fulfilling the desired function and (ecosystem) services, long-term maintenance becomes essential. Table 2 provides a list of maintenance tasks that are recommended for regular implementation in both general green spaces and for specific GI. Although there may be additional site-specific maintenance measures based on the GI typology or specific location, Table 2 covers the majority of essential works. With regular maintenance, the green space can develop optimally and the vitality of the plants can be increased. Work routines that usually occur are:

Table 2: General maintenance measures for green spaces, which should be carried out at regular intervals.

Symbol	***Maintenance measure***	***Symbol***	***Maintenance measure***
	Mowing the lawn		Irrigating
	Lawn scarifying and aerifying		Checking functionality of automatic irrigation
	Sowing, reseeding		Adjusting watering schedules
	Fertilizing		Biological plant protection
	Mulching		Removing of unwanted pest plants
	Removing autumn leaves		Winter protection for species sensitive to frost
	Pruning, trimming shoots		Replanting

3. Lawn care strategies based on lawn typologies

This section focuses on the maintenance measures of various lawn typologies based on their unique characteristics and requirements within the field of green space maintenance, according to the maintenance levels described in Sec. 2. Lawns play a crucial role in enhancing the aesthetic appeal and functionality of residential and public areas. Table 3 provides an overview of different lawn types, arranged in the order of maintenance requirements, mowing intervals, and cutting heights. We address

ornamental lawn, known for its meticulous care, and progress to include durable turfs, utility lawns, and near-natural meadows.

Table 3. Maintenance requirements for different types of lawns.

Type of lawn	*Maintenance measure*	*Mowing interval*	*Intensity*
Ornamental lawn	Mowing (cutting height ~3 cm), fertilizing, sprinkling, removing unwanted growth, aerifying, scarifying, removing leaves, reseeding	40-60 times/year with cutting height 6 cm, average growth height.	Maximum maintenance
Hardwearing utility lawn	Mowing (cutting height 3-5 cm), fertilizing, sprinkling, aerifying, scarifying, removing leaves, reseeding	15-25 times/year with cutting height 8 cm, average growth height.	High maintenance
Utility lawn	Mowing (cutting height 3-8 cm), fertilizing, sprinkling, aerifying, scarifying, removing leaves, reseeding	6-20 times/year with cutting height 15 cm, average growth height.	Moderate maintenance
Meadow (landscape lawn, flower meadow)	Mowing (cutting height 5-12 cm), fertilizing if necessary	1-3 times/year.	Low to minimum maintenance

According to the maintenance intensity of lawns, activities such as mowing are required on a regular basis during the vegetation period. In the case of unused open spaces, individual areas should also be managed as low-maintenance, species-rich flower meadows to increase biodiversity, which then only need to be mowed 1-3 times a year. To ensure the long-term vitality of lawns, additional maintenance measures are essential beyond regular mowing. Over time, stressed lawns can become compacted and develop thatch, which can result in water disbalance, in a shift in grass species and an increase in surface weeds. Mechanical techniques like scarifying and aerifying, followed by sanding, help rejuvenate the lawn and are typically performed 1-2 times per year. These measures promote a healthier and more resilient lawn. Stimulating soil life and improving soil structure can be achieved by enriching humus or adding compost. Supplementing nutrients can be done through the application of organic

fertilizers, typically two to three times a year. Nitrogen-emphasized fertilizers are recommended in March/April and June, while potash-emphasized fertilizers are suitable for the fall season. To manage maintenance efforts effectively, selecting the appropriate lawn types and mowing intervals is crucial. A utility lawn with a natural mix of herbs is often the recommended choice for various applications. It is beneficial to tolerate certain herb species such as *Bellis perennis, Achillea millefolium, Ajuga reptans, Glechoma hederacea, Prunella vulgaris, Plantago* sp., and *Trifolium* sp. These herb species are specifically tread-resistant and contribute to the ecological diversity and resilience of the lawn, enhancing its overall health and aesthetic appeal.

4. Differentiating professional green space maintenance from amateur practice

Section 4 delves into the critical aspect of maintenance, examining the distinction between professional maintenance practices and amateur efforts. It explores the specific tasks that require professional expertise, considering legal, technical, and safety aspects. Notably, activities such as tree safety inspections and subsequent care work aimed at ensuring traffic safety demand the skills and knowledge of professionals. These tasks encompass the removal of dead wood and the establishment of sufficient clearance profiles. However, this section also acknowledges the role of residents in contributing to maintenance efforts, as they can actively engage in activities like watering, fertilizing, and pruning small branches. By elaborating on the distinction between professional and amateur maintenance practices, this section aims to establish effective strategies for sustaining green spaces and GI.

When undertaking work on unsecured areas such as green roofs lacking permanent fall protection, or in elevated and difficult-to-access locations, special precautions and safety techniques must be taken to mitigate the risk of falls. These specific tasks should be assigned to specialized companies capable of implementing the necessary safety measures. The same principle applies to the maintenance of vertical greening structures, whether they consist of climbing plants or advanced green wall systems. Hence, it is essential that these tasks are exclusively performed by trained professionals. In addition to greenery maintenance work, it is crucial to prioritize the cleanliness and safety of paved areas and paths, especially in winter. This includes providing services such as snow removal and gritting to ensure safe and accessible use of these areas. Since these tasks are usually carried out by machines, especially

in the case of larger areas, and liability issues can also arise due to the legal obligations, these activities should be contracted to service providers.

Table 4: Green maintenance tasks requiring professional expertise

Task	*Description*
Pruning above head height	Pruning measures performed at heights that are not accessible by regular means.
Tree appraisals and inspections for safety reasons	Assessing and inspecting woody plants to ensure they do not pose a hazard to people and facilities.
Maintenance of difficult-to-access greenery	Managing greenery in challenging locations using specialized equipment and techniques.
Control and upkeep of technical facilities	Monitoring and maintaining complex technical systems like irrigation and lighting.
Winter maintenance and cleaning of paved areas and paths	Ensuring safe and clean conditions on paved surfaces and pathways during the winter.

5. Maintenance strategies for GI: Incentives for resident participation

Usually, the maintenance of open spaces in multi-story residential buildings is outsourced to external service providers, who then maintain the green spaces according to the agreed scope of services. The apparent control of the vegetation can only take place during the actual maintenance work. Spontaneous action in the event of lack of water, for example, is often not possible. However, residents can act quickly through the use and daily visual inspection of their free space and, with the appropriate knowledge, take over many of the otherwise outsourced maintenance activities. It's worth noting that the motivation for resident involvement in these activities may vary depending on whether they rent or own a condominium or similar housing unit (King and Shackleton 2020). In particular, maintenance work such as lawn care, watering, small-scale pruning measures (from the ground), removal of autumn leaves can be taken over by residents. The prerequisite for this is a well-organized communication between the participants and the building managers, as well as appropriate tools and equipment needed to carry out the work. Understanding the motivation factors related to renting or ownership can help tailor the approach to encourage resident participation effectively. Residents of housing projects should be incentivized to participate in the maintenance of community green spaces. The residential green spaces can be

transformed into high-quality, species-rich, climate-sensitive and socially valuable areas in a cost-efficient way through regular monitoring and constant interventions. Figure 1 illustrates several incentives for the participation of residents in maintenance activities of GI which were identified during the course of the project.

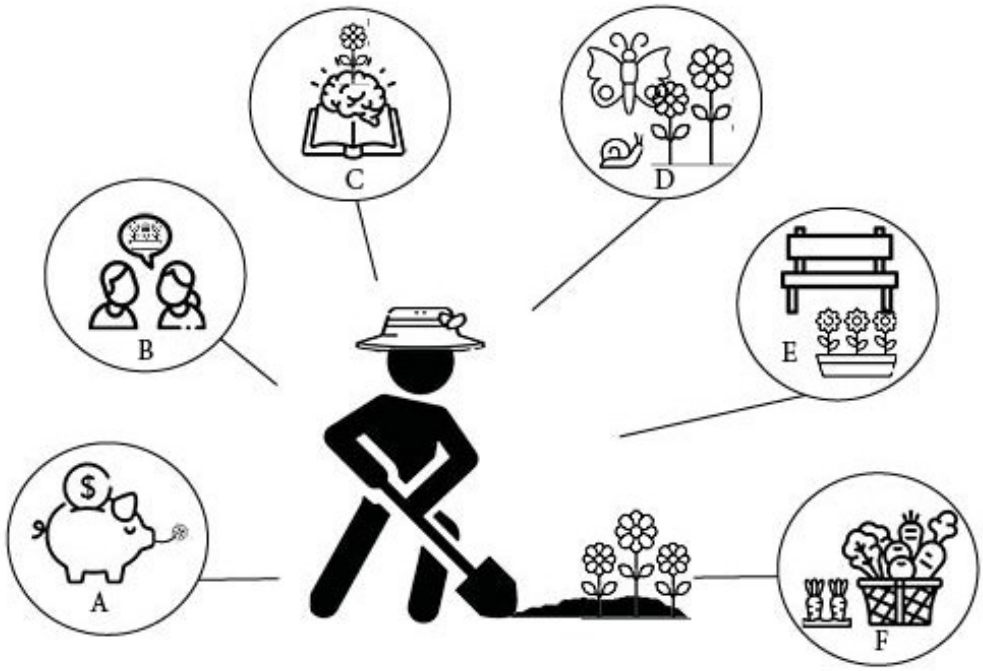


Figure 1. Incentives for the participation of residents in maintenance activities of GI: (A)Financial aspects, (B) Social interaction, (C) Knowledge acquisition, (D) Nature experience, (E) Aesthetical improvements and wellbeing, (F) Private gardening. (Graphic by I. Zluwa and M. Gräf with icons from flaticon.com created by Freepik, Premium, Smashicon, GoodWare, Icongeek26, rismaars, Eucalyp and Arenagraphics).

A: Financial aspects: A reduction in operating costs, which positively impacts all residents, can be achieved when the maintenance activities performed by residents result in actual savings by reducing the services provided by professionals. However, it is not possible to allocate the saved costs to individuals performing the maintenance, as this would require contractual agreements with each person involved. In practice, we observed that the long-term commitment of residents to maintenance activities did not meet our initial expectations. This observation led us to conclude that the likelihood of achieving substantial cost savings through resident participation was less certain than we initially anticipated.

B: Sense of community/social interaction: In housing communities where many individuals have shown interest in gardening within their premises, engaging in gardening activities has been seen as a great motivator for socializing and connecting with neighbors.

C: Knowledge acquisition/guidance: By engaging in maintenance activities and receiving initial guidance from professionals, residents can expand their gardening and botanical knowledge. Additionally, providing specific information about upcoming maintenance tasks in the communal green space throughout the year can further enhance residents' understanding and involvement.

D: Nature experience/enjoyment of gardening: The pleasure derived from gardening activities and spending time in nature is perceived positively by residents involved and serves as a motivator to participate in maintenance tasks.

E: Aesthetical improvement and wellbeing: For many involved, the motivation to participate in maintenance activities results from the desire to improve and beautify one's own living environment. Personal engagement provides opportunities to represent own interests, to participate in decision making and to enforce individual preferences. Additional social value is added by spending time in green spaces and engaging with plants, which has positive effects on well-being, psyche, and health (Houlden et al. 2018; Reinwald et al. 2021).

F: Private gardening: Increasing interest for the cultivation of herbs, vegetables, and ornamental plants in urban settings leads to residents' involvement of maintenance measures.

6. Conclusion

GI play a vital role in creating resilient and sustainable cities by providing a wide range of ecosystem services. Vegetation serves as the core component of GI, offering benefits such as air filtering, noise reduction, and wildlife habitats. However, to ensure the continued provision of these benefits, appropriate ongoing and long-term maintenance measures are crucial (Wang et al. 2020). Inadequate budgets and management challenges often hinder the maintenance of green spaces, posing a significant obstacle to their quality and functionality. Allocating sufficient resources is essential to cover expenses and maintain the inherent value associated with GI. Specific tasks such as tree safety inspections and the maintenance of difficult-to-access greenery require professional expertise, while involving residents in simple, lower level maintenance activities can enhance community engagement and contribute to the upkeep of green spaces. By implementing comprehensive maintenance concepts, accompanied by continuous adaptations, GI can be effectively managed to

create high-quality and socially valuable green spaces. The activation of residents to participate in maintenance activities of GI is likely to have limited effectiveness in reducing maintenance costs; however, it significantly enhances the quality in terms of biodiversity, plant vitality, and aesthetic value. Lastly, residents' involvement in maintenance activities increases their identification with the green space, which, in turn, has positive effects on the overall sense of community within the housing complex.

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