KAPITEL 11 / *CHAPTER 11* [11]
INTEGRATING GREEN ROOFS INTO URBAN ENVIRONMENTS: PRESENT CHALLENGES AND PERSPECTIVES

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Introduction

Green roofs (GRs) represent a sustainable alternative to conventional roofing systems, offering a wide array of ecosystem services. Their integration into urban landscapes is particularly pertinent given the rapid expansion of built environments in cities. This paper provides a systematic and comprehensive review of literature on GRs from 2011 to 2019, aiming to elucidate the challenges and perspectives related to their urban integration.

The review indicates that the effectiveness of GRs in delivering ecosystem services is highly contingent upon context-specific factors such as climatic conditions and existing construction or design parameters. The integration of GRs into urban areas poses challenges due to the diverse range of stakeholders, functions, and conditions that characterize these environments. Although substantial research has been conducted on GRs, there is a pressing need for studies that cover a broader range of geographical locations and contexts.

The review underscores the importance of incorporating future urbanization scenarios, including the prevalence of tall buildings, when assessing the impact of GRs on ecological networks. It also highlights the necessity of considering urban morphological parameters and analyzing the effects of GRs on microclimate regulation and air quality. From a social perspective, the review notes the significance of understanding the temporal cycles of vegetation to accurately capture user perceptions and suggests that further research is needed to explore the social impact of GRs, particularly their influence on property values.

Finally, the review calls for more comprehensive city-scale studies to better understand the impact of GRs on ecosystem services, emphasizing the need for an interdisciplinary approach that integrates ecological, social, and urban planning

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perspectives to optimize the benefits of GRs in urban environments.

11.1. Overview

Unprecedented urbanization worldwide has led to significant challenges, including increased energy consumption, social inequality, air and water pollution, and resource depletion, which collectively strain urban systems. The United Nations estimates that by 2050, about one-third of the global population will reside in cities. Therefore, it is crucial to transform how urban spaces are constructed and managed to ensure sustainable urban development.

Currently, urban ecosystems comprise a high proportion of built infrastructure and dense populations. These ecosystems face issues such as the urban heat island (UHI) effect, pollution, and frequent flooding due to the lack of green spaces. Impervious surfaces, like building roofs, make up approximately 20-25% of urban areas. These roofs are situated on buildings that consume substantial energy and contribute significantly to greenhouse gas (GHG) emissions. In this context, nature-based solutions like green roofs (GRs) are gaining popularity for their positive impact on urban ecosystems.

Green roofs, defined as living vegetation planted on building roofs, improve the energy efficiency of buildings and help mitigate the UHI effect by lowering atmospheric temperatures and enhancing human thermal comfort. They also play a crucial role in stormwater management due to their high-water retention capacity. Beyond environmental benefits, GRs enhance the quality of life for urban residents.

GRs are generally categorized into intensive and extensive types (IGRs and EGRs, respectively), based on differences in substrate thickness, benefits, costs, maintenance, and vegetation types. IGRs feature a thick substrate layer, supporting diverse plant varieties but requiring additional structural support due to their weight. Examples include urban rooftop agriculture and gardening. In contrast, EGRs have a thin, lightweight substrate that needs minimal additional support and maintenance, making them more widely applicable and cost-effective. Recently, a hybrid type, semi-intensive GRs, has been developed to combine the benefits of both IGRs and EGRs.

Due to their sustainability and environmental benefits, both private and public sectors promote GR installations. Many municipalities in North America, Europe, and Asia encourage GR adoption through policies and economic incentives. Academic research on GRs has also surged in recent years.

Rapid urbanization has pushed urban planners to address the challenge of sustainable city planning. Sustainable urban forms, such as dense and compact cities, are often favored over urban sprawl. However, densification often reduces green spaces, which are essential for providing ecosystem services and maintaining wildlife habitats. Thus, finding feasible and socially acceptable solutions to increase urban green spaces is vital.

Integrating GRs into urban areas is highly relevant due to the rise in built-up areas, necessitating an understanding of their urban integration. This paper aims to identify the challenges and perspectives related to integrating GRs into urban environments by reviewing current literature on their provision of ecosystem services, including biodiversity enhancement, climate regulation, water management, and air quality improvement, along with their social acceptability and feasibility. The paper discusses the challenges in delivering these ecosystem services and perceiving the benefits and feasibility of GRs, providing a perspective for future studies.

The paper is structured as follows: Section 2 outlines the methodology, Section 3 provides an in-depth discussion on the contributions of GRs to various aspects, and present the discussion and conclusions, respectively.

11.2. Methodology

There are several review-based studies on green roofs (GRs) that either highlight their benefits or emphasize their role in enhancing ecosystem services. For instance, Berardi et al. [5] offer a comprehensive overview of the benefits of GRs, concluding that their advantages are undeniable. In contrast, a recent review by Francis and Jensen [3], which focuses on three specific ecosystem services provided by GRs—urban heat island (UHI) mitigation, air quality, and energy consumption—suggests that the benefits of GRs are inconclusive and effective only under certain conditions. Another review by Shafique et al. [2] provides a general overview of GR literature but lacks a systematic approach, with no explicit methodology and limited discussion on critical ecosystem services like biodiversity enhancement, water quality management, air quality improvement, and social preferences and acceptance.

Therefore, a systematic and comprehensive review of recent literature on GRs is necessary to cover a broader range of ecosystem services and aspects of social acceptability and feasibility. This review adopts a methodology similar to that of Francis and Jensen [1].

The review includes peer-reviewed journal articles sourced from the SCOPUS database, using relevant synonymous terms to identify literature related to the six aspects mentioned above. The search combined terms like green roofs, city, and specific aspects to ensure relevant publications were selected. To ensure a reasonable number of publications, proxies of the key terms were added to the query. The key terms were searched only in the titles, abstracts, and keywords of papers to obtain literature specific to the subject.

This review focused on research articles to provide an overview of original research in the field of GRs. The search, conducted in April 2020, was limited to articles written in English and published from January 2011 to December 2019. The titles and abstracts of the identified papers were screened to eliminate those not focused on understanding the impact of GRs on the selected aspects. Additionally, to maintain a feasible number of publications for review, only papers comparing GRs with bare, impervious, and conventional roofs were included, while those discussing other types of green urban infrastructure were excluded.

11.3. Green roofs technology

This section critically examines the findings and highlights the challenges associated with integrating green roofs (GRs) into urban areas.

Regarding biodiversity, our review indicates that GRs on lower-height buildings tend to support species more effectively [4]. With urban areas increasingly densifying and growing vertically, building height becomes a crucial factor in assessing GRs' impact on biodiversity. However, the literature lacks sufficient studies examining how building height influences GRs' biodiversity impact. Only two studies, by Braaker et al. [5 ,6] focusing on buildings 15 m or less, and Wang et al. [8, 9, 10] studying a 50 m tall roof garden, were found. Further research is needed to explore the relationship between building height and GR biodiversity.

Similarly, there is a dearth of literature on GRs' role in enhancing ecological connectivity. Only a few studies, such as those by Braaker et al. [5, 6] and Joimel et al. [7], have addressed this aspect to some extent. Given that GRs are meant to act as substitutes for ground-level green spaces, more evidence is necessary to understand their potential to strengthen ecological networks across urban landscapes. Additionally, our review notes concern mosquito abundance on GRs [11, 12, 13], which could impact public health, particularly in densely populated urban areas.

In terms of water management, GRs are recognized for their ability to retain water effectively, particularly during low to moderate rainfall. They can help mitigate flood-like conditions to some extent, although extreme rainfall may necessitate additional solutions. However, runoff from GRs can introduce phosphorus into water resources, especially with commercial substrates, posing a pollution risk. Extensive use of fertilizers in intensive green roofs (IGRs) contributes to higher nutrient concentrations compared to extensive green roofs (EGRs), which typically use alternative substrates and vegetation to reduce nutrient and metal content [14, 15].

Regarding urban heat island (UHI) mitigation, our review suggests that GRs have a limited impact on pedestrian thermal comfort, particularly in high-rise buildings. Building height significantly influences GRs' ability to regulate street-level

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temperatures, and urban morphology plays a crucial role in this regard. Further research should explore how different urban morphologies affect GR performance in UHI mitigation.

Our review highlights that GRs effectively reduce roof surface temperatures compared to bare roofs, leading to significant reductions in energy consumption for cooling, particularly on upper floors. However, maintenance is crucial to sustain these benefits, especially during extreme weather conditions.

In terms of air quality improvement, GRs have been shown to reduce pollutant concentrations near the roof surface and improve air quality in immediate surroundings. However, existing models used to assess air quality improvements often oversimplify urban morphologies, potentially leading to discrepancies between modeled and real-world results [16, 17].

Regarding social acceptance, there is a growing demand for low-cost GRs with high aesthetic value. However, challenges such as high installation and maintenance costs, coupled with limited awareness, can hinder GRs' acceptance in urban areas. Feasibility studies highlight that private sector adoption of GRs is hindered by high costs, suggesting a need for financial incentives. The uneven distribution of UHI benefits across different floors of multi-story buildings also complicates approval from all residents.

Social preference studies typically focus on well-maintained GRs with lush vegetation, which are positively perceived by users. However, vegetation appearance during extreme weather conditions, such as dry and brown foliage in summer or winter, can influence public opinion. Comprehensive studies are required to evaluate GRs' social acceptability throughout the year.

In our review, social benefits in feasibility analyses primarily address public health impacts, with limited consideration for broader social impacts such as community cohesion and inclusivity. Green initiatives have the potential to increase property values, contributing to gentrification and possibly marginalizing lower-income residents. More research is needed to understand the neighborhood-scale social impacts of GRs.

Overall, while GRs offer promising benefits, their integration into urban environments requires addressing multifaceted challenges through comprehensive research and strategic planning.

This section explores future research directions for the urban integration of green roofs (GRs). The suggested areas for further investigation are as follows:

Biodiversity: Future studies should consider the impact of GRs on urban biodiversity in the context of taller buildings. Additionally, research on the role of GRs in ecological connectivity should account for building height. Integrating GRs into city-scale habitat network analyses is essential to connect existing ecological areas.

Water Management: Given concerns about the quality of runoff water from GRs, future research should examine how this runoff affects surface water sources and urban water management systems.

Urban Heat Island (UHI) Mitigation: As urban morphology can influence the impact of GRs on pedestrian thermal comfort, future studies should include urban morphological parameters to better understand how GRs affect thermal comfort at the pedestrian level.

Air Quality: Research should incorporate more realistic urban morphologies when analyzing the impact of GRs on air quality. Additionally, larger-scale studies are needed to provide stronger evidence of GRs' effects on air quality.

Social Acceptability: To facilitate better integration of GRs into urban areas, low-cost solutions are essential. However, the aesthetic value of GRs can also enhance their implementation. Future research should consider the temporal cycles of vegetation when assessing user perspectives on the acceptability of GRs.

Feasibility: The cost of GRs is a significant concern. While subsidies could be a solution, identifying affordable components of GRs through research could promote large-scale adoption.

Social Impact: Further research should investigate the social impact of GRs, particularly their effect on property prices and the potential for gentrification.

These future research directions aim to provide a comprehensive understanding of GRs' impacts, facilitating their effective and widespread integration into urban environments.

Conclusion

This paper systematically and comprehensively reviewed recent literature on green roofs (GRs) to identify the challenges and perspectives related to their urban integration. Our review indicates that GRs have the potential to simultaneously deliver multiple ecosystem services. In light of the rapid increase in built-up areas and the decreasing availability of open spaces for intensive green infrastructure, GRs emerge as a highly effective tool. However, the effectiveness of GRs in delivering these ecosystem services is heavily dependent on context-specific factors, such as weather conditions and existing construction or design parameters.

Integrating GRs into urban environments presents significant challenges due to the diverse range of stakeholders, functions, and conditions that characterize these areas. Despite extensive research on GRs, there is a pressing need for studies that cover a wider range of geographical locations and contexts.

Firstly, our review highlights the necessity of incorporating future urbanization scenarios, such as the prevalence of tall buildings, when analyzing the impact of GRs on ecological networks. Secondly, the quality of runoff from GRs is a concern that requires further investigation to understand how it affects surface water sources and urban water management. Regarding UHI mitigation, the review emphasizes the importance of including urban morphological parameters in future analyses, as urban morphology plays a crucial role in microclimate regulation. Similarly, realistic urban morphologies need to be considered when evaluating the impact of GRs on air quality.

From a social perspective, our review underscores the importance of considering the temporal cycles of vegetation to accurately capture user perceptions. Further research is also needed on the social impact of GRs, particularly their influence on property prices. Finally, the review stresses the need for more city-scale studies on the impact of GRs on ecosystem services, especially in terms of biodiversity and air quality.

In conclusion, while GRs offer significant potential benefits, their successful integration into urban areas requires addressing a variety of challenges through comprehensive and context-specific research. Future studies should aim to provide a holistic understanding of GRs' impacts, considering ecological, social, and urban planning perspectives to optimize their effectiveness and acceptance.

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