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Wilde, Professor of Energy and Building Design at Lund University (Sweden), recognized internationally for his expertise in building performance modelling and simulation.

This Proceedings Book compiles the written contributions presented at the conference, including both peer-reviewed papers and keynote addresses. All authors submitted papers (ranging between 1500 and 3000 words), which were blind peer-reviewed by the Scientific Committee to ensure academic rigor and quality. The accepted papers published herein represent a diverse and inspiring collection of ideas that reflect the conference's central aim to go *beyond all limits* in reimagining sustainability for the built environment.

On behalf of the Conference Organization Committee, we would like to express our deepest gratitude to all members of Çankaya University, Università degli Studi della Campania "Luigi Vanvitelli", Lund University, and Azerbaycan Technical University for their invaluable contributions, dedication, and collaborative spirit in organizing this international event.

We would also like to extend our sincere appreciation to all authors, speakers, reviewers, and participants for sharing their research, insights, and visions. Your active participation and commitment to advancing sustainable design and planning make this conference a vibrant and meaningful academic platform.

We wish you all a productive and inspiring conference experience, filled with fruitful discussions, new collaborations, and lasting connections.

Conference Organization Committee

BEYOND ALL LIMITS 2025 – 3rd International Conference on Sustainability in Architecture, Planning, and Design

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FROM GREY TO GREEN: RETHINKING URBAN IN-BETWEEN SPACES THROUGH ROOFTOP AGRICULTURE AND CLIMATE DESIGN

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From Grey to Green: Rethinking Urban In-Between Spaces through Rooftop Agriculture and Climate Design

Abstract: Urban in-between spaces, often overlooked in conventional planning, present untapped opportunities to address climate change through spatial reactivation. This paper explores the potential of rooftop agriculture as a climate-responsive strategy to convert residual urban surfaces into productive green infrastructures. Grounded in the concepts of climate-sensitive design and nature-based solutions, the study discusses how rooftops can contribute to urban decarbonization. By examining the ecological, social, and spatial dimensions of rooftop agriculture, the research proposes a reconfiguration of urban metabolism based on multi-functional land use. The aim is to offer a contribution that integrates architecture, agriculture, and climate resilience, transforming the urban fabric from grey to green. The paper contributes to the discussion on climate-neutral cities by highlighting the strategic role of in-between spaces in sustainable urban transformation.

Keywords: rooftop agriculture; climate design; urban farming; in-between spaces; decarbonization

Introduction

Cities must adopt a holistic perspective to strengthen resilience against future climate and health-related crises, fostering greener, smarter, more equitable, and efficient urban environments (WEF, 2021). Prioritizing human well-being in this process is essential for mobilizing collective support for climate mitigation (UNEP, 2020). The primary challenge lies in enhancing urban adaptive capacities while advancing a circular and green economy in the built environment—shifting from reactive responses to proactive strategies that address the causes of climate risks (WEF, 2021).

In this context, green infrastructure has increasingly been recognized as a pivotal strategy for embedding ecological functionality into urban environments. Defined as a coherent system of natural and semi-natural spaces designed and managed to deliver a wide range of ecosystem services, it contributes to improving air quality, reducing the urban heat island effect, managing stormwater, and enhancing urban biodiversity (Kabisch et al., 2016).

Within the urban system, in-between spaces are increasingly recognized as potential connective elements and microclimatic regulators. Historically marginalized as “leftovers” of urban morphology, their inherent spatial ambiguity positions them as transitional environments that mediate between built form and social use, embodying flexibility and temporality (Carmona, 2010). They could be pertinent to buildings, indoor or outdoor, between buildings or a network of different spaces. If strategically designed, in-between spaces can be repurposed as multifunctional ecological platforms that contribute to both environmental performance and urban liveability, as a strategic design tool to reframe the relationship between architecture and ecological systems, contributing to decarbonization and climate neutrality.

Rooftops, given their prevalence in dense urban contexts, represent a critical resource for climate-sensitive retrofitting (Shahmohammad et al., 2022). Rooftop greening enhances passive energy performance by improving building insulation and regulating microclimatic conditions, including the reduction of urban heat islands and mitigation of stormwater runoff (Berardi, 2016). Beyond these technical benefits, rooftop green spaces can foster social inclusion and cohesion by creating opportunities for community interaction, collective urban gardening, and environmental education.

Transforming unused roof surfaces into productive landscapes by introducing vegetated surfaces in dense urban contexts, contributes to climate resilience strategies, strengthening the adaptive capacity of cities in the face of increasing climate variability and extreme weather events (Zölch et al., 2017).

Ranging from intensive greenhouses to extensive green roofs for vegetables or herbs and implemented through climate design principles, rooftop green infrastructure can serve as an enabling infrastructure for low-carbon, adaptive, and inclusive cities, boosting the socio-ecological integration within the built environment, enhancing environmental performance, such as stormwater retention and CO_2 sequestration, and contributing to food security, community engagement, and local economic development (Specht et al., 2014).

This paper explores the intersection of rooftop agriculture and climate-sensitive urban design within the framework of in-between spaces. Its objective is to examine how architectural interventions on rooftops can contribute to the broader agenda of urban decarbonization. By analyzing both theoretical and applied perspectives, the study aims to offer a design-oriented contribution to the discourse on sustainable urban transformation.

Methodology

This research adopts a multi-step methodological approach that combines theoretical inquiry with empirical analysis.

First, a comprehensive literature review was conducted, examining the state of the art at both national and international levels. Academic sources, scientific reports, and institutional documents were analyzed to trace the evolution of discourses on urban resilience, climate-sensitive design, and building-integrated agriculture. This phase provided the conceptual and theoretical foundations for framing the role of in-between spaces, and specifically rooftops, as enabling infrastructures for sustainable urban transformation.

Second, the study engaged in a systematic review of policy frameworks and sectoral reports. By integrating global, European, and local-scale documentation, this stage assessed how policy directives, regulatory instruments, and institutional agendas are currently addressing rooftop greening, urban agriculture, and climate-adaptive infrastructures. This step allowed for identifying both enabling conditions and governance gaps in the implementation of rooftop farming practices.

Third, an analytical investigation of selected case studies was undertaken. International best practices of rooftop agriculture and green infrastructure were examined, with particular attention to their design strategies, technical feasibility, and socio-ecological impacts. Cases were chosen to reflect a diversity of scales, typologies, and contexts, ranging from experimental research centers to large-scale commercial farms and community-based initiatives. Comparative analysis enabled the identification of transferable design principles and context-dependent variables.

Finally, the insights from the literature, policy review, and case study analysis were synthesized into a design-oriented framework. This interpretive step aimed to articulate how rooftop farming and climate-sensitive strategies for in-between spaces can contribute to urban decarbonization and resilience. The resulting framework underpins the discussion and conclusions of the paper, offering a structured contribution to the ongoing discourse on sustainable architectural and urban design.

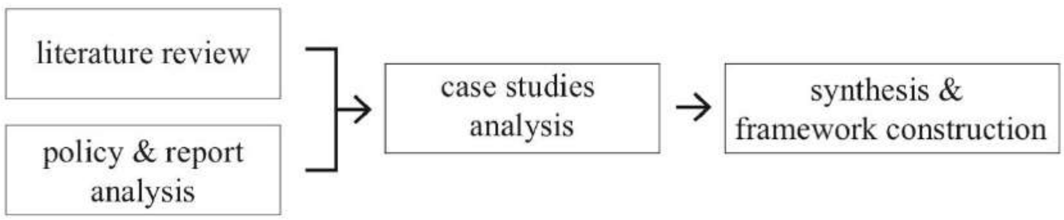

Figure 1 – Four steps of the methodological framework

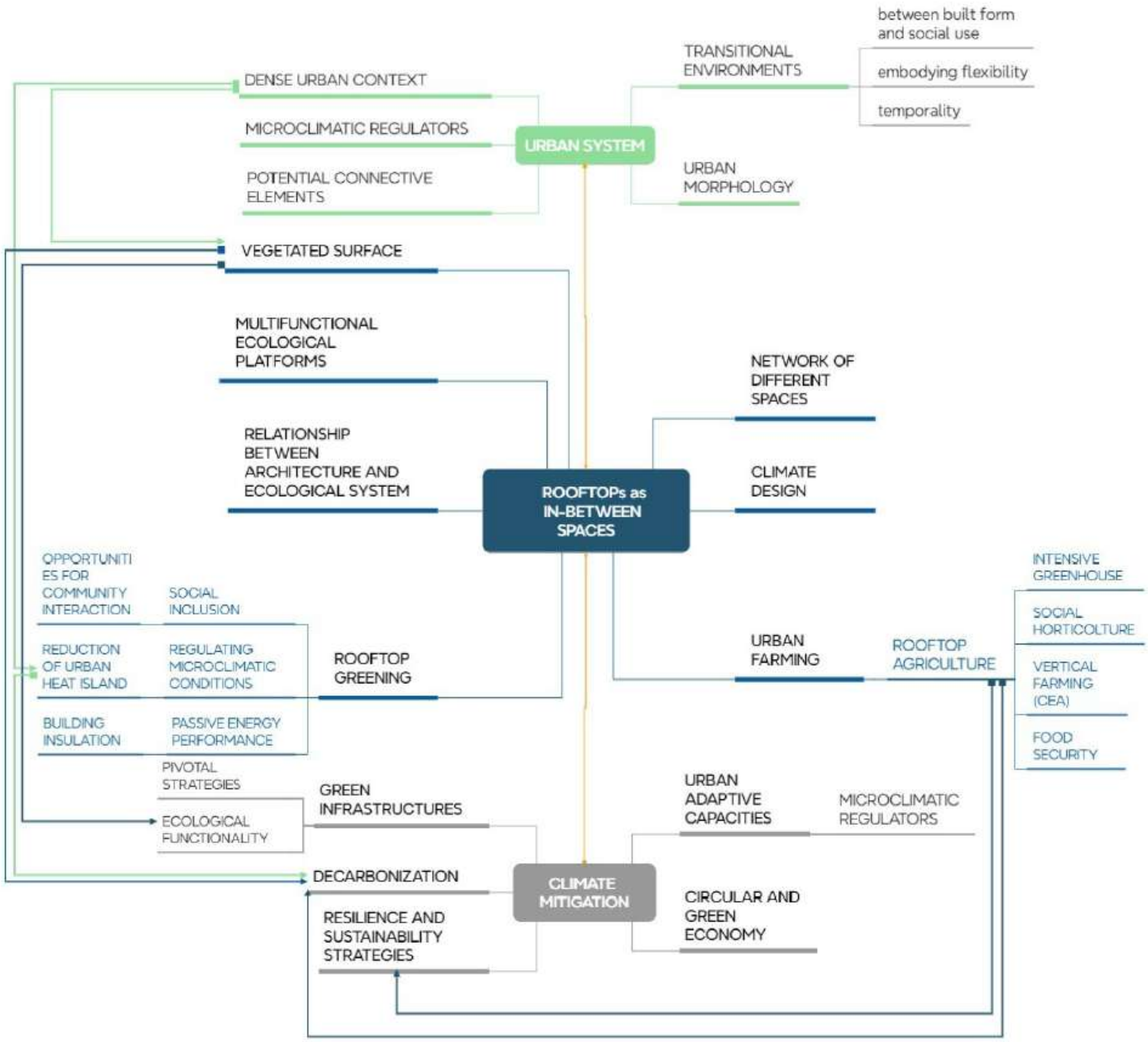

Figure 2 – Scheme of the methodological process to describe the connection between rooftop topics, urban system and climate mitigation.

Food production and building-integrated agriculture

With the high growth rates of urbanized areas, food systems can play an important role in increasing their resilience and sustainability, taking on a role in shaping land use patterns, consumption, and waste disposal, as well as their substantial contribution to climate change, fostering food production, social inclusiveness and new spatial realities within urban fabrics.

The urban demand for food coverage is met at the local level by Local Food Policies, in opposition to the global process of production-distribution-consumption system deterritorialization, to which both social and environmental needs are linked (Di Iacovo, 2008).

The spatial relationship between the built environment and food production occurs through urban and peri urban agriculture and the implications related to land consumption and the reuse of brownfield sites (Resilience Alliance, 2007). Urban agriculture, in all its forms and variations, promotes encounters, the creation of social mixite and relationships, and therefore a sense of community, becoming a resilient tool for social inclusion and rehabilitation within communities, whether neighborhood, local, or condominium based.

Cities must consider a holistic territorial approach to food systems that involve both the region and cities, connects urban and peri-urban areas to rural areas, thereby recognizing that urban agriculture and soilless systems, such as hi-tech farms and vertical farming, are not sufficient to meet food demand (ICLEI, 2019).

The spatial scale of implementation also affects impact. Beyond the building scale, green rooftops influence broader urban systems, as an integral part of the urban socio-economic and ecological system (Mougeot, 2000) and varies from city to city, depending on size, actors involved, intra-urban or peri-urban location, private or public, types of products, types of economic activities, and markets.

The most common form is to place a commercial production activity on an urban rooftop farm, where the building must be adaptable to this function, in terms of vertical connections, dimensions and structural characteristics.

Urban building-integrated agriculture (Caplow and Nelkin, 2007) consists of adapting and integrating soilless cultivation techniques such as hydroponics or aquaponics into buildings to exploit synergies between buildings and agricultural activities.

Urban roof farming must contend with automated and digital soil-less systems and sustainable development, in particular with human capital as a productive opportunity and catalyst for economic, environmental, social, and cultural interests, including new forms of governance and farm management, that change systems, zero-kilometer production chain and eating habits towards an ever-increasing consumption of vegetable proteins.

Climate design strategies for green roofs

A climate-sensitive design approach for in-between spaces prioritizes the reduction of greenhouse gas emissions and the enhancement of local environmental quality. Central to this strategy is the concept of decarbonization, which involves minimizing the carbon footprint of buildings and urban systems. The reactivation of underutilized rooftops through green infrastructure contributes to this agenda by enabling passive climate regulation, reducing energy consumption, and promoting carbon sequestration (Getter & Rowe, 2006).

Passive climate-responsive design strategies (such as the use of thermal mass, natural ventilation, strategic shading, and vegetative layering) can be effectively integrated into rooftop configurations to enhance energy efficiency and occupant comfort without relying on mechanical systems. These strategies support a microclimatic balance, reduce cooling loads, and increase surface albedo, thus mitigating the urban heat island effect. In parallel, nature-based solutions (NbS) offer an integrated framework for advancing climate-responsive design by embedding natural processes directly within the built environment. Rather than treating environmental mitigation as an add-on, NbS incorporates ecosystem functions (e.g. shading from vegetation, evapotranspiration, soil-water interactions, and biodiversity corridors) into architectural and urban contexts. This approach facilitates a transition from static, technologically driven systems to adaptive living infrastructures capable of responding dynamically to environmental fluctuations (Frantzeskaki, 2019). When applied to in-between spaces like rooftops, NbS support multiple co-benefits: they regulate thermal performance, improve air and water quality, reduce run-off, and create microhabitats for urban flora and fauna. Moreover, their multifunctional nature makes them suited for dense urban contexts where space is limited but climate adaptation pressure is high. NbS become not merely ecological interventions, but spatial strategies that reconnect built form with environmental processes, while simultaneously enhancing urban resilience and livability.

Roof spaces are technically capable of hosting green and productive functions, due to the presence of water supply and storage rooms. These functions are amplified when vegetation types are selected for evapotranspirative performance, productivity and local adaptability. Vertical farms act as an adaptive and resilient element within urban farms, when installed on urban rooftops, thanks to a subset of integrated or stand-alone green infrastructure systems, indoors and outdoors, whether for self-consumption, commercial purposes, or simply for design.

The widespread adoption of green roofs can lower ambient temperatures at the city level and reduce energy load peaks (Susca et al., 2011). However, it is necessary to understand the scale of the vertical farms, micro or medium, and their location for the extension of cultivation areas: near outdoor spaces, adjacent to buildings, or in interstitial and/or appurtenant or ancillary spaces.

An example of this networked approach is the concept of “green corridors”, which link rooftop and vertical gardens into continuous ecological pathways. These systems promote biodiversity, enable pollination routes, and support peri-urban connectivity. In densely built environments, the use of rooftops for such purposes is often the most viable option for expanding green space.

Design tools such as performance simulation, GIS-based mapping, and participatory co-design methods can guide spatial planning and stakeholder engagement, by combining environmental data with socio-economic indicators. Policies that incentivize green retrofits through subsidies, density bonuses, or regulatory mandates play a crucial role in mainstreaming rooftop agriculture (Oberndorfer et al., 2007).

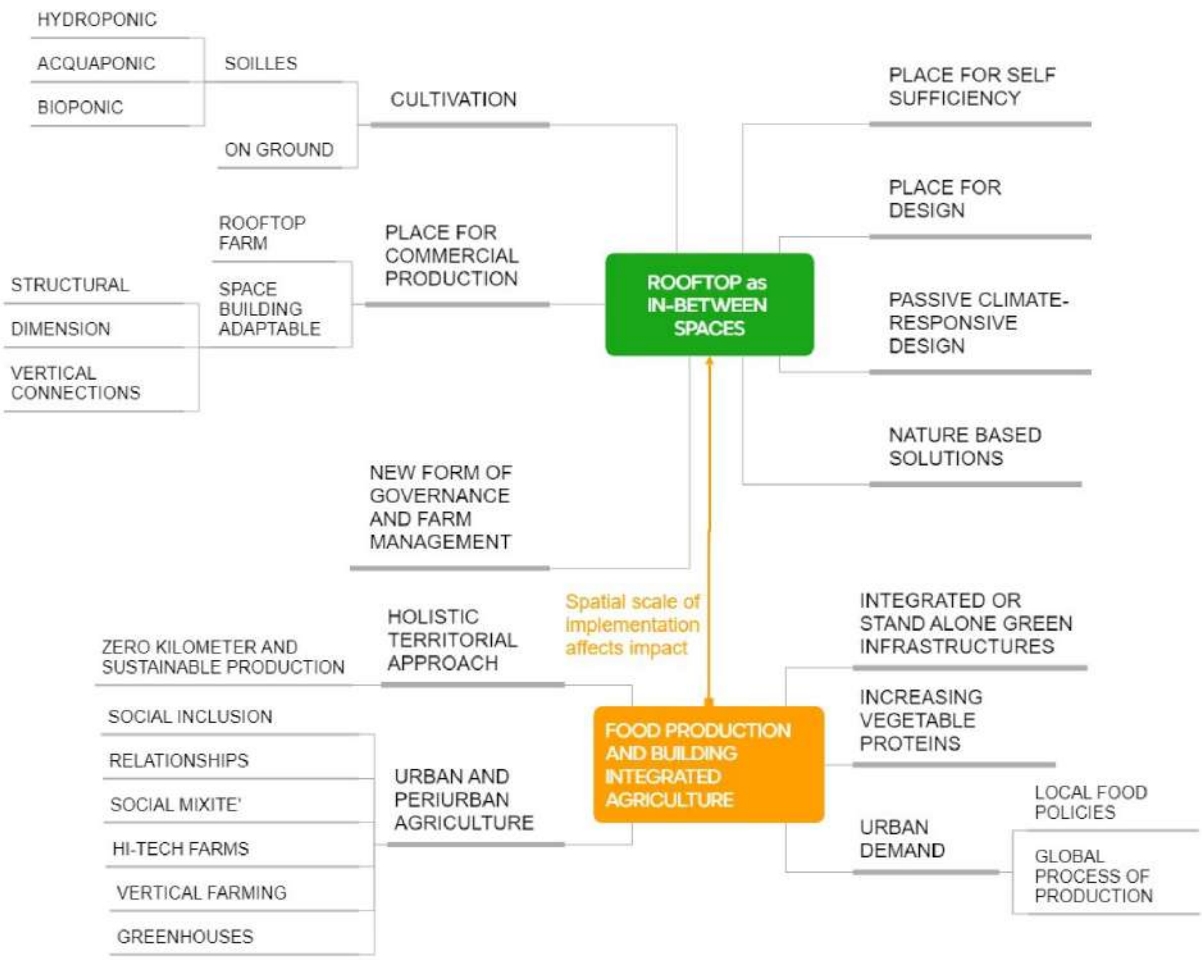

Figure 3 – Scheme of the design-oriented framework to describe building integrated agriculture on rooftops.

From roof to resource: rooftop agriculture as climate infrastructure

Green roofs perform a suite of ecological functions that are pivotal for climate adaptation and mitigation in urban environments, particularly in cities facing intensifying climate-related stressors such as prolonged heatwaves, extreme precipitation events, and drought conditions. As vegetated systems integrated into building envelopes, they intercept and retain precipitation, attenuating peak stormwater flows and reducing the burden on conventional drainage infrastructure (Shafique et al., 2018). Their substrate layers and vegetation act as biofilters, capturing airborne particulate matter and absorbing gaseous pollutants, thereby improving local air quality. Additionally, by providing structurally diverse habitats, green roofs can enhance urban biodiversity, supporting pollinators, birds, and invertebrate species otherwise excluded from densely built environments. In Basel, Switzerland, green roofs are mandatory on new buildings since the early 2000s, while in Paris, rooftop gardens have been incorporated into the city's Plan Biodiversité, illustrating the role of design regulation in promoting ecological integration.

Acting as distributed "miniature ecosystems", green roofs buffer thermal fluctuations, increase evapotranspirative cooling, and contribute to carbon sequestration. In doing so, they reduce dependence on resource-intensive grey infrastructure while strengthening the ecological resilience of the urban fabric. The multifunctionality of green roofs positions them as a key component in climate-responsive urban design strategies, where adaptation and mitigation goals intersect within a single architectural intervention (Mihalakakou, et al., 2023).

From a food systems perspective, rooftop agriculture introduces productive capacity into urban cores. It addresses issues of food access and environmental justice by providing locally grown produce, reducing food miles, and supporting circular economy practices. Urban farming initiatives can repurpose organic waste into compost, recover water, and shorten supply chains. Such integration fosters a regenerative metabolism within the urban system.

Considering best practices of greenhouse systems as a roofing plan with food production, on existing or new residential or commercial buildings, the building-integrated agriculture may vary depending on type of productions, indoor spaces organization, presence of controlled environmental agriculture (CEA) environments and the capacity to accumulate and transmit energy to the building

The ICTA-ICP research center in Barcelona, was built with a greenhouse on the rooftop, with horizontal structure for food production (not commercial). Collaborating with the atrium for ventilation, the greenhouse allows the reuse of accumulated heat and CO_2 concentration, improving the energy efficiency of the building itself.

The REWE Green Farm in Wiesbaden, Germany, is a medium farm on a shopping center roof. For its building typology, the vertical farm occupies a large surface, enabling production suitable for zero-kilometer sales. As the greenhouses are not directly connected to the atrium, they are CEA environment spaces that can also accommodate aquaponic systems.

The UF002 DE SCHILDE urban farm in Rotterdam was a rooftop greenhouse, added to the roof of a residential building. It was intended as a medium-sized farm for commercialization acting as a buffer zone on the top of the building, hosting hydroponic and aquaponic systems.

Socially, rooftop farms support community cohesion and education, providing spaces for engagement, learning, and co-creation. Brooklyn Grange in New York and Lufa Farms in Montreal demonstrate how rooftop agriculture can function at a commercial scale while maintaining community-oriented programs, highlighting the scalability of climate-resilient design within the economic and regulatory constraints of cities.

Local implementation strategies depend on climatic, cultural, and infrastructural contexts: in Mediterranean cities water-efficient agriculture and drought-resistant vegetation are prioritized; in East Asian metropolises hydroponic rooftop systems are increasingly adopted due to space constraints. These variations demonstrate the adaptability of rooftop agriculture across global urban conditions. Furthermore, emerging technologies such as smart irrigation, IoT-based soil monitoring, and vertical farming systems can enhance productivity and reduce environmental impacts.

Technical feasibility and social innovation are key to the long-term success of rooftop farming. Cooperatives, non-profits, and social enterprises often lead such projects, bridging gaps in knowledge, funding, and management.

Discussion and Conclusion

The revalorization of in-between spaces—especially rooftops—offers a transformative strategy for climate-responsive urbanism. By shifting their role from marginal voids to productive ecosystems, cities can recover unused surfaces for environmental benefit.

A critical reflection on this transition reveals both opportunities and constraints. On one hand, rooftop agriculture enables decentralized infrastructure that responds to local needs and enhances spatial equity. On the other hand, challenges such as structural load capacity, water availability, maintenance, and social acceptance must be addressed. The successful integration of green roofs and urban farms requires collaborative governance, technical expertise, and financial support mechanisms.

The implications extend beyond architecture and urban planning into public health, climate policy, and food systems. By embedding productive green infrastructure in in-between spaces, cities can foster resilience to environmental stressors, economic and social disruptions. Green rooftops can support physical and mental well-being, reduce food insecurity, and promote sustainable behaviours at the community scale.

Future perspectives should investigate cross-scalar impacts, from building to district to metropolitan levels, integrating design tools such as spatial mapping, performance simulation, and participatory planning, to support the implementation. Moreover, interdisciplinary collaboration between architects, ecologists, policymakers, and citizens is essential to advancing this vision.

In conclusion, shifting from grey to green roof and roof farming exemplifies a design-driven approach to climate neutrality. It challenges conventional zoning and land use paradigms, encourages multifunctional thinking, and reconnects the built environment with ecological processes. As cities strive toward sustainability, the green transformation of grey spaces emerges not only as a necessity, but as a powerful opportunity.

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