

Urban Resilience Improvement Strategy: A Multi-dimensional Efficiency Study of Roof Greening and Vertical Greening

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Abstract As complex and diverse ecosystems, cities encounter numerous challenges posed by both nature and humanity. Architecture, serving as the framework and texture of the city, has undoubtedly emerged as a crucial guide in addressing urban resilience issues. Roof greening and vertical greening of buildings, as eco-friendly urban green infrastructures, hold significant potential for mitigating these challenges. This paper explores the methods and strategies for implementing roof greening and vertical greening as solutions to enhance urban resilience. The objective is to offer valuable insights for sustainable urban development, encourage the widespread adoption of these greening techniques in urban construction, and ultimately strengthen urban resilience.

Keywords Urban resilience, Roof greening, Vertical greening, Disaster response, Sustainability

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Urban resilience refers to the capacity of cities to swiftly recover and continue to thrive in the face of various natural disasters and man-made crises. Cities are susceptible to an array of risks, encompassing both natural disasters, such as earthquakes and floods, and social crises, including public health emergencies and economic crises. The importance of urban resilience is evident at multiple levels. Firstly, from the perspective of disaster response, cities with high resilience can mitigate the adverse effects of disasters, thereby protecting the lives and property of their residents. In earthquake-prone areas, buildings designed for optimal seismic performance, along with well-equipped emergency shelters, can effectively safeguard residents during an earthquake. Secondly, from the standpoint of sustainable

urban development, resilient cities are better equipped to respond to changes in the economy, the environment, and various other sectors. For instance, in the case of certain resource-based cities, resilient cities can sustain their development momentum through industrial transformation and alternative strategies when resources are gradually depleted. Furthermore, urban resilience strengthens a city's capacity to withstand risks and its ability to absorb, adapt to, and transform in response to a variety of challenges.

This study examines the significant role that roof greening and vertical greening of buildings play in addressing urban resilience challenges. It also investigates the associated mechanisms and explores the innovative concepts and directions these practices offer for sustainable urban

development.

1 Importance of roof greening and vertical greening on buildings in solving urban resilience issues

Roof greening and vertical greening of buildings, characterized by their distinctive plant transpiration and shading efficiency, have emerged as significant strategies for regulating the urban microclimate, mitigating the heat island effect, lowering urban temperatures, and decreasing energy consumption. Relevant studies have demonstrated that the implementation of roof greening can lead to a significant reduction in the surface temperature of buildings, ranging from 3 °C to 10 °C^[1]. This reduction effectively mitigates the challenges associated with the urban heat island phenomenon. In terms

Column introduction

The City Observer column, initiated by Yang Xin and Zhang Qi, the hosts of the RLncut research station, seeks to observe the cities in which we live.

The current column emphasizes the enhancement of urban resilience. By conducting a comprehensive investigation of the functions and roles of roof greening and vertical greening in the construction of urban resilience, this paper offers guidance for cities in the strategic organization of green spaces. Such initiatives aim to improve the ecological carrying capacity and risk resistance of cities, while also facilitating the thorough implementation of sustainable urban development concepts.

Yang Xin, Zhang Qi, the hosts of RLncut research station

of flood control and disaster risk reduction, these greening measures significantly alleviate the pressure on urban drainage systems by facilitating rainwater retention, minimizing surface runoff, and prolonging the infiltration duration of rainwater. In addition, roof greening and vertical greening function as air purifiers by absorbing harmful gases and particulate matter, thereby significantly enhancing urban air quality and fostering a healthier living environment for residents. At the same time, these greening strategies offer essential habitats for urban wildlife, promote biodiversity conservation, and contribute to the overall stability of urban ecosystems.

Simultaneously, the implementation of roof greening and vertical greening initiatives not only expands public spaces and recreational areas for urban residents but also significantly enhances the urban landscape. These initiatives contribute to the aesthetic value of the city and improve the quality of life for its inhabitants, thereby increasing the city's attractiveness and competitiveness. Through the establishment of green roof gardens, residents can engage in recreational activities, alleviate stress, and foster emotional interactions among neighbors, thereby contributing to the enhancement of community cohesion.

It is of significant practical importance to thoroughly explore the functions and roles of roof greening and vertical greening in the construction of urban resilience. This approach not only provides a solid scientific foundation for urban planning and design but also guides cities in the rational layout of green spaces, enhances the ecological carrying capacity, and improves resilience against risks. Additionally, it promotes the comprehensive implementation of urban sustainable development concepts. The promotion of roof greening and vertical greening can significantly contribute to the development of related industries, create additional employment opportunities, and infuse new vitality into the urban economy (Fig.1).

2 Overview of roof greening and vertical greening on buildings

2.1 Types and characteristics of roof greening

2.1.1 Extensive green roofs. Extensive green roofs, recognized as a fundamental and prevalent form of roof greening, play a significant role in the roof greening of urban buildings due to their simplicity and practicality. The depth of the substrate in green roofs typically ranges from 5 to 15 cm. This type of roof greening

often employs a relatively straightforward selection of plant species that are adaptable and require minimal maintenance. Commonly utilized species include *Sedum lineare*, *Sedum sarmentosum*, *Hylotelephium erythrostictum*, and other members of the Crassulaceae family. These plants exhibit resilience to drought, cold temperatures, and barren conditions, enabling them to thrive in the challenging environment presented by roofs.

The primary advantage of extensive roof greening is the reduction in maintenance costs, as it does not necessitate frequent activities such as pruning, watering, and fertilization. The presence of a single plant species facilitates similar growth habits, thereby simplifying maintenance and management processes. This simplification contributes to a reduction in the costs associated with human and material resources. Additionally, single plant species has the capacity to absorb a portion of stormwater runoff, which alleviates the burden on urban drainage systems. Extensive roof greening is characterized by its lightweight nature and relatively low load-bearing requirements, making it suitable for a variety of building types, including both new constructions and the renovation of existing roofs.

In practical applications, extensive roof greening is implemented in various urban residential areas, commercial buildings, and public facilities. In the roof renovation projects of certain older districts, the installation of basic roof greening contributes to an increase in the green space within the area, thereby enhancing the ecological environment of the district. Extensive roof greening has been shown to effectively lower roof temperatures, thereby mitigating deterioration and damage to the waterproofing layer of the roof and prolonging its lifespan.

Nevertheless, owing to its single plant species and limited coverage area, it is incapable of offering adequate recreational space for users, and it may not sufficiently cover the roof of a building with a substantial area^[2].

2.1.2 Intensive green roofs. Dense green roofs contribute significantly to urban landscapes by enhancing landscape effect and providing a range of ecological functions. These roofs typically feature a substrate depth ranging from 15 to 60 cm, allowing for the cultivation of various plant species, including trees, shrubs, and herbs. This particular type of green roof offers enhanced ecological services, including the improvement of air quality, the promotion of biodiversity, the absorption of increased rainwater runoff, and the provision of recrea-

tional space. Nevertheless, it is important to note that the associated construction and maintenance costs are also elevated.

Intensive roof greening fulfills multiple functions, including providing spaces for recreation and relaxation, serving as habitats for urban organisms, and promoting the conservation of biodiversity.

Intensive roof greening necessitates the installation of a thicker layer of planting soil, thereby imposing greater load-bearing requirements on the roof structure. Additionally, the implementation of intensive roof greening often involves the integration of design elements such as sketches, water bodies, and other facilities. This not only contributes to an increased load on the roof but also incurs relatively high maintenance costs. To ensure the healthy growth of the plants and the sustainability of the landscaping effect, regular maintenance activities, including pruning, watering, fertilization, pest control, and other related tasks, are essential.

2.1.3 Semi-intensive green roofs. Semi-intensive green roofs represent an intermediary category between extensive and intensive green roofs, characterized by a substrate depth of approximately 15 cm. This type of green roof is suitable for the cultivation of shrubs and herbs, thereby offering ecological benefits that lie between those provided by extensive and intensive green roofs. These benefits include the mitigation of the urban heat island effect, the absorption of a portion of rainwater runoff, enhancements in the energy efficiency of buildings, and the promotion of biodiversity. Additionally, the construction and maintenance costs associated with semi-intensive green roofs are positioned between those of the extensive and intensive green roofs.

Semi-intensive green roofs integrate the benefits of both extensive and intensive green roofs, facilitating the cultivation of shrubs and herbs while maintaining cost efficiency. Additionally, they offer a broader spectrum of ecological services. However, it is important to note that this type of green roof has certain limitations and necessitates adequate structural support^[2].

2.2 Methods and characteristics of vertical greening

2.2.1 Direct attachment of climbing plants. The vertical greening of buildings can be accomplished through the cultivation of climbing plants, such as *Hedera nepalensis* and *Parthenocissus tricuspidata*, to achieve the desired vertical greening effects. The direct attachment of these climbing plants offers several advantages,

including ease of implementation and low cost. However, the effectiveness of this beautification method is limited during the growth phase of the plant, as it is contingent upon the plant's development. Additionally, the roots of the plant may infiltrate the building's surface, potentially resulting in structural damage. Furthermore, this vertical greening technique requires regular maintenance through pruning.

2.2.2 Modular green wall system. The modular green wall system consists of pre-planted plant modules and presents several advantages. Firstly, the installation process is notably rapid, eliminating prolonged waiting time and enabling the swift incorporation of greenery into a given space. Secondly, these plant modules reach maturity prior to their integration into a green wall. Following transplantation, they exhibit a rapid adaptation to their new environment and demonstrate favorable landscape effects. Thirdly, regarding maintenance and management, the modular green wall system is relatively straightforward. Each module has comparable plant growth requirements, which facilitates centralized maintenance and allows for the easy replacement of individual modules when issues occur. Nevertheless, the modular green wall system presents several limitations. Firstly, the initial investment is substantial, encompassing various expenses such as the cultivation of plant modules, production, and the professional design and installation processes, which contribute to increased financial pressure. Secondly, the implementation of this system necessitates specialized design and installation, requiring a high level of professional knowledge and skills from the team, thereby posing challenges for individuals lacking expertise in this area. Lastly, if the appearance of the modular green wall system does not align with the architectural style of the building, it may detract from the original appearance of the structure and compromise the overall aesthetic coherence.

2.2.3 Suspended greening system. Suspended greening system, a distinctive form of urban greening, contributes to the enhancement of green landscapes in urban environments by incorporating plants on the facades of buildings (Fig.2).

The advantages of this greening system are substantial. Firstly, it optimizes space utilization; as the plants are suspended on the external walls, they do not occupy significant interior space within the building. This characteristic renders it an exceptionally appealing greening option for structures with spatial constraints. Secondly, the aesthetic enhancement provided by vertical

greening is remarkable, as it creates a distinctive visual effect that transforms monotonous building facades into vibrant structures, significantly increasing the landscape value of the buildings and allowing them to stand out within the urban environment. Thirdly, this method facilitates rapid greening without the necessity for complex construction processes. It merely requires for the installation of previously prepared hanging plants on the exterior walls, enabling the swift completion of environmental greening in a short timeframe.

Nevertheless, the suspended greening sys-

tem presents several limitations. Primarily, it necessitates a high level of professional design and installation expertise. The design of the hanging system must thoroughly account for various factors, including the weight and distribution of the plants as well as the load-bearing capacity of the building's external walls. Additionally, the installation process requires the involvement of skilled professionals, rendering it challenging for typical homeowners to undertake independently. Secondly, the management of maintenance for suspended plants is inherently more complex, necessitating regular tasks such as

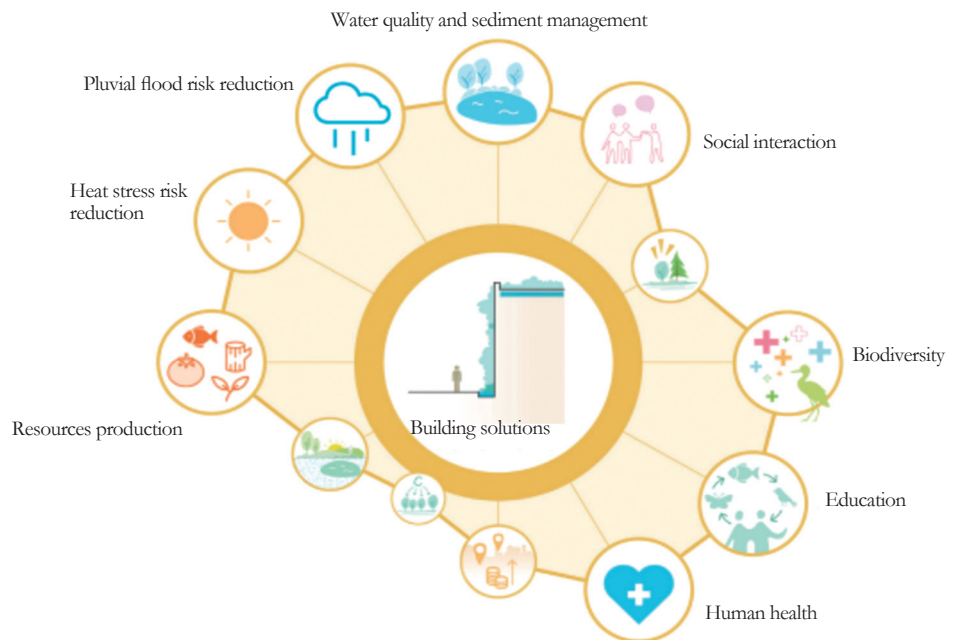


Fig.1 Importance of roof greening and vertical greening in solving urban resilience issues^[2]

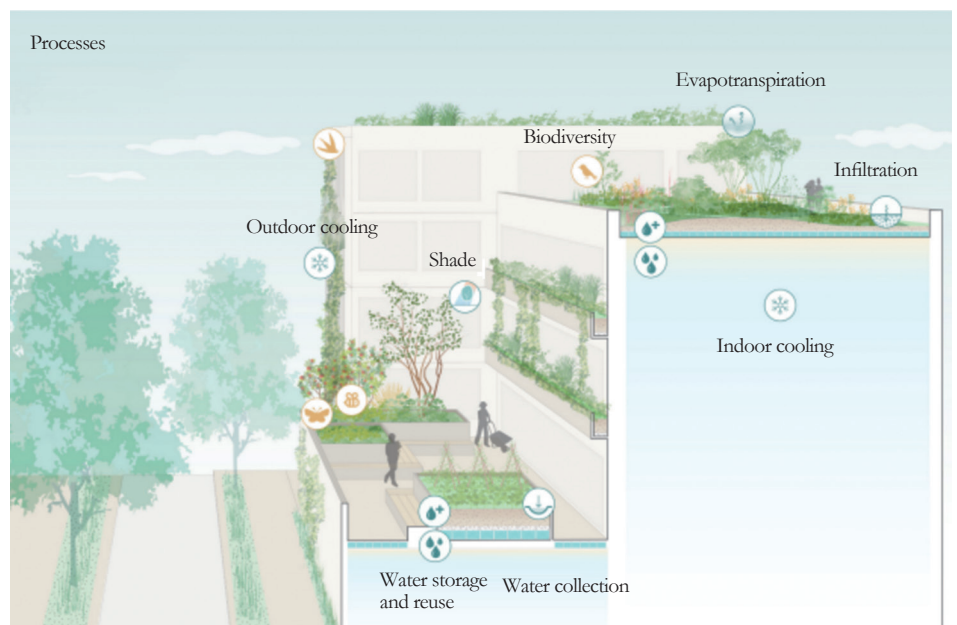


Fig.2 Application of roof greening and vertical greening in building^[2]

watering and pruning. If these activities are not conducted properly, the aesthetic appearance of the building may be adversely affected. Thirdly, the weight of both the suspension system and the plants may impose a significant load on the building's structure. Consequently, it is imperative to ensure the safety and integrity of the suspension system, as failure to do so could result in potential safety hazards^[2].

3 Mechanisms for addressing urban resilience with roof greening and vertical greening

3.1 Rainwater retention by roof greening

Roof greening is instrumental in urban rainwater management and flood mitigation, with its rainwater retention capabilities primarily achieved through the synergistic interaction between vegetation and substrate materials. Within a roof greening system, the leaves and branches of plants serve as natural barriers that initially intercept rainwater. When precipitation occurs, a portion of it adheres to the surfaces of leaves and branches, subsequently returning to the atmosphere through the process of evapotranspiration. Relevant studies indicate that the retention capacity of plants is closely associated with various factors, including the species of the plant, the morphological structure of the leaves, and the volume of rainfall. For instance, plants characterized by broader leaves and rougher surfaces exhibit a comparatively higher capacity for rainwater retention.

The substrate layer of roof greening is composed of various materials that exhibit favorable water absorption and retention characteristics. When rainwater permeates the substrate layer via the plant layer, the substrate is capable of rapidly absorbing and retaining significant quantities of rainwater. A portion of stored rainwater is utilized by the plant root system for growth and transpiration, while the remaining water is gradually released into the atmosphere over time. This process effectively regulates the rate of rainwater discharge and mitigates the peak of rainwater runoff.

Roof greening possess a rainwater retention capability that significantly alleviates the burden on urban drainage systems. In conventional urban development, a substantial number of building roofs are constructed using hard materials, such as concrete and asphalt. These materials exhibit minimal capacity for rainwater retention, leading to the rapid generation of surface runoff following precipitation events, which exerts considerable pressure on urban drainage infrastructure. The implementation of

roof greening transforms roofs from a 'source of generation' of rainwater runoff to a 'source of absorption', thereby effectively diminishing the volume of urban rainwater discharge.

3.2 Temperature regulation and mitigation of the heat island effect

3.2.1 Heat insulation and cooling principles of roof greening. The heat insulation and cooling principles of roof greening rely on the transpiration and shading effects provided by vegetation. During the hot summer, plants absorb water through their roots and subsequently convert it into water vapor, which is released into the atmosphere via the process of transpiration. This mechanism requires a significant amount of heat, thereby effectively reducing both the temperature of the roof surface and the surrounding air temperature.

The vegetative layer of green roofs serves as a shading mechanism, effectively obstructing direct solar radiation from impacting the roof surface. The leaves and branches of the plants are capable of absorbing and reflecting a portion of the solar radiation, which in turn diminishes the heat absorption by the roof. Estimates suggest that roof greening can decrease solar radiation absorption on the roof surface by approximately 30%–50%, consequently leading to a reduction in roof temperature.

Roof greening is a significant strategy for mitigating the urban heat island effect. This phenomenon occurs when numerous hard surfaces in urban areas, such as buildings and roads, absorb and retain solar radiation, leading to markedly higher temperatures in the city center compared to the surrounding suburban regions. The extensive implementation of roof greening initiatives can enhance the overall green space within urban environments, lower local temperatures through the transpiration and shading effects of vegetation, and thereby alleviate the urban heat island effect^[3].

3.2.2 Improvement of building microclimate by vertical greening. Vertical greening has a substantial impact on the enhancement of the building microclimate, primarily manifested in the regulation of building wall temperature and the reduction of heat exchange between indoor and outdoor environments. This approach effectively moderates the temperature of building walls through the transpiration processes of plants. During the summer months, the process of evaporation of water from the surfaces of plant leaves facilitates the absorption of heat from the surrounding environment, resulting in a reduction of the temperature of adjacent building walls. This phenomenon

not only contributes to the preservation and longevity of the structural integrity of the walls but also fosters a more comfortable external environment for the building.

The branches and leaves of plants can mitigate the heat absorbed by building walls by obstructing direct solar radiation. There are variations in the shading effectiveness among different plant species, and those with larger leaves and greater density exhibit enhanced shading capabilities. For instance, the vigorous growth of *H. nepalensis*, *P. tricuspidata*, and other similar species can create a dense green barrier that effectively blocks solar radiation, thereby reducing the temperature of the walls.

Vertical greening contributes to the reduction of heat exchange between indoor and outdoor environments. During the summer months, it effectively obstructs the ingress of outdoor heat into indoor spaces, thereby lowering indoor temperatures and decreasing reliance on air conditioning and other refrigeration systems, which ultimately leads to a reduction in energy consumption. Conversely, in winter, vertical greening serves a significant role in insulation, minimizing indoor heat loss and enhancing the overall warmth of indoor environments.

3.3 Biodiversity conservation and ecological restoration

3.3.1 Providing habitat for flora and fauna. Roof greening and vertical greening contribute significantly to urban biodiversity conservation by offering abundant food sources and habitats for avian species, insects, and other organisms within urban environments. In the context of roof greening, the flowers, fruits, and seeds produced by a variety of plant species serve as ample food resources for both birds and insects. Insects, including bees and butterflies, are drawn to the flowering plants on green roofs. While they gather nectar from these flowers, they facilitate the process of plant pollination and contribute to plant reproduction. Additionally, birds may construct nests and roosts among the plants on green roofs, thereby seeking refuge from potential natural predators.

Vertical greening offers a distinctive habitat for various living organisms. Vertical greening walls have emerged as habitats for numerous small animals within urban high-rise environments. Certain insects seek refuge from wind and rain while foraging for food beneath the leaves of vertical greening plants. Additionally, spiders and other small arthropods construct webs to capture prey among the branches and leaves of these plants.

3.3.2 Improving urban ecological environment.

The implementation of roof greening and vertical greening initiatives has significantly expanded the greening area within urban environments, thereby making a substantial contribution to the enhancement of the urban ecological landscape. Given the constraints on land resources in urban areas, large-scale ground-level greening is often impractical. In contrast, roof and vertical greening effectively utilize the available roof and wall spaces of buildings, thereby broadening the extent of urban greening efforts. Empirical studies indicate that for every additional 10,000 m² of roof and vertical greening, the overall greening coverage rate of a city can increase by approximately 0.03%-0.1%^[4].

Roof greening and vertical greening initiatives can significantly contribute to ecological restoration in urban environments. In regions previously affected by industrial pollution, the strategic planting of vegetation with air-purifying properties on building roofs and walls can facilitate the absorption of harmful airborne substances, thereby promoting the gradual restoration of the local ecological environment^[5].

3.4 Air quality improvement and purification

3.4.1 Air purifying functions of plants. Plants contribute to air purification through the process of photosynthesis, thereby enhancing the freshness and cleanliness of urban environments. This process not only serves as a fundamental basis for the growth of the plants themselves but also plays a critical role in maintaining the carbon and oxygen balance within urban areas. The implications of this phenomenon suggest that the widespread implementation of roof and vertical greening can significantly benefit cities by continuously supplying fresh oxygen to residents and effectively mitigating the elevated carbon dioxide concentrations often associated with high population density, frequent industrial activities, and other factors.

Plants also have the ability to adsorb harmful gases and particles in the air. The surface of plant leaves is usually rich in special structures such as villi, stomata and secreted mucus, which can adsorb harmful gases such as sulphur dioxide, nitrogen oxides, formaldehyde, benzene and other particles such as PM_{2.5} and PM₁₀. The adsorption capacity of different plants for pollutants varies, for example, *Chlorophytum comosum* has strong adsorption capacity for formaldehyde, while *H. nepalensis* can effectively remove harmful substances such as benzene.

Plants possess the capability to transform and degrade adsorbed pollutants through their

physiological and metabolic processes. Certain plant species can effectively purify pollutants by converting absorbed harmful gases into innocuous substances via a series of enzymatic reactions occurring within their biological systems.

3.4.2 Effect on urban air circulation. Roof greening and vertical greening can significantly enhance urban air circulation and improve air quality in urban areas. In urban environments, the density of buildings often hinders air circulation, leading to the accumulation of pollutants. However, the implementation of roof greening and vertical greening can establish distinct airflow channels that mitigate this obstruction to air circulation.

The incorporation of plants and planting substrates in green roofs enhances the roughness of the roof surface, which induces turbulence in the airflow as it traverses the roof and facilitates air mixing and diffusion. Conversely, vertical greening walls function as green barriers that direct airflow, thereby altering both the direction and velocity of the air movement. In certain narrow streets situated between high-rise buildings, vertical greening can effectively channel airflow into the street, thereby improving air mobility.

Roof greening and vertical greening contribute to the establishment of temperature differentials in relation to the surrounding environment, thereby generating localized thermal circulations. On hot days, the temperature in the greened areas is comparatively lower, resulting in descending air and the formation of a high-pressure zone. Conversely, the temperature in the adjacent non-greened areas is elevated, leading to rising air and the creation of a low-pressure zone. This dynamic facilitates the movement of air from the high-pressure zone to the low-pressure zone, engendering a natural airflow that aids in the influx of fresh air into urban areas while simultaneously expelling pollutants, thereby enhancing urban air quality.

4 Case study

4.1 Cairo green roof program

Cairo, the capital of Egypt and one of the largest cities in both Africa and the Middle East, is confronting a range of environmental and social challenges attributed to rapid urbanization. These challenges include a deficiency of green spaces, deteriorating air quality, a significant heat island effect, water scarcity, and increased pressure on the food supply. To address this array of challenges, the local government initiated the Project of Green Food from Green

Roofs in Urban and Peri-Urban Environments from 2001 to 2003. This initiative aimed to develop and demonstrate roof microgarden systems at four pilot sites in Cairo, thereby enhancing the availability of high-quality fresh vegetables (Fig.3). The project employed soilless cultivation systems to grow a diverse range of vegetable crops during both winter and summer seasons. Additionally, it organized workshops on roof gardening, provided customized training for 100 families, and produced manuals and videos, along with establishing a dedicated website.

The extensive implementation of this policy not only fosters local agricultural development and provides self-sufficient food sources for low-income families, but also enhances urban green spaces and improves the local environment. Additionally, it mitigates rainwater runoff and alleviates pressure on the city's drainage system through the transpiration of vegetation and soil infiltration. Furthermore, the policy facilitates water conservation by enabling the harvesting and reuse of rainwater.

This novel form of small-scale agriculture experienced a surge in popularity in subsequent years, extending its reach from Cairo to the Delta governorates, Upper Egypt, and the New Valley.

4.2 Community-driven vertical greening systems in Lagos, Nigeria

Lagos is experiencing rapid urbanization, with a significant portion of its population residing in economically disadvantaged areas characterized by inadequate green spaces, insufficient infrastructure, and suboptimal environmental quality. This project seeks to implement a straightforward and cost-effective vertical greening system tailored for these low-income communities, with the objective of enhancing the living conditions of the residents.

The project team engaged in close collaboration with the local community to gain a comprehensive understanding of their needs and challenges. As a result, they developed a straightforward prototype of a vertical greening system suitable for installation within residential spaces (Fig.4). This system is constructed from locally sourced materials, is cost-effective, and requires minimal maintenance. Additionally, technical support is offered to local residents to assist them in the installation and upkeep of the system. Training and public education initiatives have been employed to enhance local residents' awareness and engagement in vertical greening practices. This system has yielded significant outcomes due to the collaborative efforts and strong partnership between the government and the community. It has effectively reduced indoor



Fig.3 Cairo green roof program^[2]

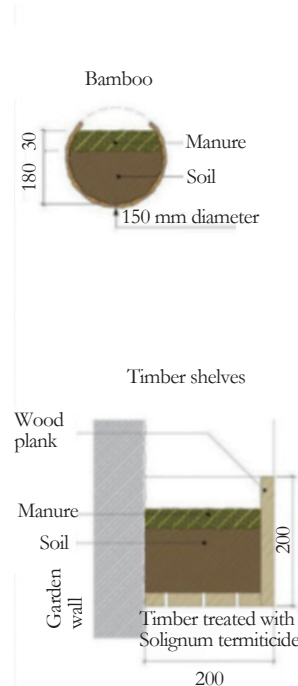


Fig.4 Community-driven vertical greening systems in Lagos, Nigeria^[2]



temperatures and improved the thermal comfort of residents. Additionally, some residents have cultivated medicinal plants to enhance the accessibility of food and medicinal resources.

The project illustrates that, even in resource-constrained settings, the quality of life can be enhanced through community engagement and the implementation of simple technologies. Furthermore, the successful outcomes of this project have the potential to be replicated in underprivileged communities across other developing nations.

5 Conclusions

The ongoing advancements in science and technology are expected to provide new developmental opportunities for roof greening and vertical greening through the application of intelligent and innovative materials. For instance, an intelligent irrigation system is capable of monitoring soil moisture levels and weather conditions in real time through the use of sensors. This system can precisely regulate both the quantity and timing of irrigation water, thereby facilitating the efficient utilization of water resources. Additionally, an intelligent monitoring system can assess the growth status of plants in real time, promptly identify and address pest issues, and enhance the management efficiency of landscaping efforts. Simultaneously, the research and development of novel planting substrates that are characterized by lightweight

properties, high strength, and enhanced water retention and air permeability will contribute to an improved growing environment for both roof greening and vertical greening initiatives. Furthermore, these advancements are expected to alleviate the load-bearing demands on building structures.

In the future, the application of roof greening and vertical greening is expected to broaden significantly. These practices will not only be extensively implemented across various types of urban buildings but will also extend to infrastructure such as bridges, tunnels, and subways, thereby increasing green space within urban environments and improving the overall aesthetic appeal of cities. Furthermore, in response to the growing emphasis on sustainable living, roof greening and vertical greening initiatives will increasingly focus on their integration into the daily lives of individuals. For instance, roof gardens can be developed into multifunctional spaces that incorporate planting, harvesting, leisure, and entertainment, thereby allowing individuals to experience the pleasures of a pastoral lifestyle amidst the hustle and bustle of urban life. Additionally, vertical greening can be integrated with cultural and artistic elements to create urban landscapes that possess distinctive appeal, thereby enhancing the cultural sophistication and artistic ambiance of the city.

In conclusion, both roof greening and vertical greening represent innovative urban

green solutions that significantly contribute to enhancing urban resilience. Furthermore, they offer novel ideas and pathways for sustainable urban development. As technological advancements continue and society increasingly prioritizes green living, the roles of roof greening and vertical greening are expected to become even more pivotal in future urban construction, ultimately fostering an improved living environment for urban residents.

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