

Participatory Design Model for Community-Based Rooftop Urban Farming

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Article Information	ABSTRACT
Article History Received : November 04, 2025 Revised : November 14, 2025 Published : January 02, 2026	Rapid urbanization demands innovative approaches to overcome spatial limitations and enhance urban food security, positioning rooftop urban farming as a strategic and sustainable solution. Yet, the long-term success of such initiatives is frequently constrained by social and managerial challenges. This study proposes an optimized Participatory Design Model to strengthen both technical sustainability and community ownership in rooftop urban farming. Adopting a qualitative approach within a Participatory Action Research (PAR) framework, data were collected through Focus Group Discussions (FGDs). The analysis synthesized user driven priorities into a design model that emphasizes reducing maintenance burdens and enhancing social utility. Key strategies include the selection of planting systems with high operational simplicity specifically a combination of hydroponic and soil based media and the incorporation of design elements that facilitate community engagement and interaction. The findings underscore that co-creation is fundamental to developing resilient, user centered rooftop farming systems that minimize maintenance challenges while reinforcing long-term community commitment.
Keywords: <i>Participatory Design; Rooftop Urban Farming; Urban Design; Green Roof.</i>	

INTRODUCTION

The global trend of rapid urbanization presents significant challenges and opportunities for developing sustainable urban environments, particularly in emerging nations. This fast paced urbanization drives a notable shift in food demand, placing an increasing focus on cities (Dale, 2022). In Indonesia, this process is clearly evident, where the proportion of the population residing in urban areas has escalated sharply from 30% in 1990 to 56% in 2020 (Dinda Fitria Pida et al., 2025). Consequently, there is an escalating need for urban areas to become more sustainable, self sufficient, and environmentally friendly. Despite its crucial role in enhancing food security and overall urban sustainability, urban farming initiatives often grapple with substantial challenges. These difficulties include severe constraints on space, limited access to quality soil and water, complex regulatory frameworks, and insufficient financial support (Tabrez, 2025). Furthermore, urban environments introduce complications such as pollution and climate change vulnerability, which makes crop cultivation more challenging.

To mitigate the spatial challenges associated with high density living, rooftop farming emerges as an attractive and viable solution (Su et al., 2020). Rooftop farming, which forms part of a broader framework of urban agriculture practices (Mensah, 2023), involves the cultivation of food and non food crops on the tops of buildings, carried out either in open air setups or through rooftop greenhouses (Appolloni et al., 2021). More specifically, a rooftop farm refers to a

community oriented, non profit farming initiative established on the roofs of privately or publicly owned buildings in cities (Nasr et al., 2017). This approach differs from typical ground level gardens because it involves unique structural and environmental aspects such as load capacity, access, microclimate control, and water management, all of which influence design and operational choices (Appolloni et al., 2021).

The application of green roof technology a widely documented technical and nature based solution can transform these aesthetically indifferent spaces into multi functional and sustainable areas through the deployment of soil and vegetation. Beyond increasing building energy efficiency, this technology offers extensive environmental, aesthetic, psychological, physiological, and economic benefits (Berardi et al., 2014) (Kolokotsa et al., 2020) For instance, rooftop farming of crops like leafy vegetables can be cost effective because it relies on natural sunlight, thus reducing the need for electrical indoor lighting. As a multifunctional green intervention, rooftop farming not only produces food but also enhances environmental quality, social inclusion, and economic resilience, positioning it as a significant component of sustainable urban development (Ampha & Wongbumru, 2025).

The benefits of urban farming extend beyond mere food production; performance in this area is also linked to increasing community well being and generating social benefits (Dieleman, 2017). This practice serves as an effective mechanism to support local community resilience and empowerment (Atmaja et al., 2021). Moreover, rooftop farms encourage social exchange of harvested produce, knowledge, and experience among urban residents, fostering stronger community interaction and collaboration in system management (Banda et al., 2024).

Given these multidimensional benefits, the successful and sustainable implementation of rooftop urban farming is not merely a technical issue but fundamentally a social one, requiring deep involvement from the end-users. Community participation has been widely acknowledged as a crucial factor for the long-term sustainability of these projects. Participatory frameworks empower residents to take part in decision-making processes concerning the design, use, and maintenance of the shared rooftop space (Fitriana & Mulyono, 2019). The necessity of early community involvement is paramount to ensure the adoption, operationalization, and sustainability of the rooftop farming system. Pro-social behaviors such as promoting healthy lifestyles and organizing community events are linked to collective well-being (Das & Ramaswami, 2022) (DeMarsh, 2022). Furthermore, active public involvement enhances resilience and risk reduction in urban systems (Haynes et al., 2020). The sustainability of community-based rooftop farms is assessed through indicators of collective sense of ownership and consistent maintenance practices (Fitriana & Mulyono, 2019) (DeMarsh, 2022). Studies show that well-kept spaces receive higher approval (Kordon et al., 2022), and participation enhances psychological well-being, sustaining motivation for continued operational maintenance (Suto et al., 2021). While the literature extensively validates the technical viability of green roofs and affirms the critical importance of community participation for project longevity, it currently lacks a systematic, transferable model that bridges these two domains. Specifically, a clear and validated methodology for socially embedding these technically sound projects integrating community input directly into the design process to maximize long-term social and production benefits remains undefined in the context of urban centers.

Therefore, this article addresses this crucial implementation gap by proposing a Participatory Design Model for Community-Based Rooftop Urban Farming. The primary objective is to integrate the technical potential of green roof systems with a democratic and user-driven approach, ensuring that the resulting urban farming system is robust, socially cohesive, and maximizes production and environmental sustainability. The findings of this research offer significant practical implications in the design of urban green infrastructure provision to ensure

meaningful community involvement in the design process. This model serves as a blueprint for transforming often-underutilized roof spaces into sustainable, resilient, and socially cohesive collective assets, fundamentally enhancing the long-term viability of community-based urban farming projects.

RESEARCH METHODS

This study uses a qualitative participatory design approach to develop a community-based rooftop urban farming model, specifically chosen to ensure the design framework directly reflects the needs, values, and lived experiences of the local community. The population for this study represents the community, taking into consideration potential users' perspectives and experiences in urban farming. Sampling was conducted using a purposive sampling technique. Participants were divided into two separate Focus Group Discussions (FGDs). These groups included 22 members of the Santri Peduli Lingkungan Community (focusing on ecological aspects) and 11 members of the Family Welfare Movement Community (focusing on social and emotional dimensions).

Data were collected using semi-structured questions and collaborative session vignettes, which constituted the specific phase of the data collection. The research procedure proceeded sequentially, following several data collection phases, inputs were analyzed to formulate initial design criteria, leading to a synthesis phase where these criteria were compiled into a final participatory design model. Data were analyzed using thematic analysis following an inductive process. The resulting patterns and ideas were specifically organized based on three main thematic parameters, functional design preferences, social participation and ownership, and sustainability and maintenance strategies. Synthesizing insights from all these parameters ultimately resulted in the final participatory design model. Throughout the study, all ethical procedures were strictly adhered to, including obtaining informed consent and maintaining confidentiality.

RESULTS AND DISCUSSION

A comprehensive thematic analysis derived from the data has yielded a significantly optimized design model. This optimization is instrumental in determining the sustainability level of the proposed Rooftop Urban Farming system, addressing both its technical feasibility and long-term social adoption.

Maintenance Ease and Operational Ergonomics

The initial phase was centered on a critical evaluation of conventional planting media models that are commercially available. The objective of this phase was to identify the most optimal system for the rooftop context and to assess its potential for adoption and scalability. Four primary media types were introduced and analyzed based on their operational sustainability, Hydroponics, Vertical Gardens, Soil Media, and Aeroponics. Following this foundational comparative analysis, the discussion proceeded to focus on the identified shortcomings and required design adjustments, directly leading to the articulation of principles for Prioritizing Maintenance Ease and Operational Ergonomics.

1. Considerations of Planting Media Options and Determination of Optimal Planting Media for Sustainability

The choice of four growing media yields several points. Hydroponic systems offer strong adoption potential through centralized nutrient control, but are constrained by limited structural space, which hinders long-term access and sanitation. Vertical gardens face similar access and maintenance challenges due to their excessive height, in addition to psychosocial issues such as acrophobia near roof edges. Conventional soil media remains very familiar to users, but persistent sanitation issues arise due to the buildup of debris in the narrow gaps beneath the pots. Aeroponic systems pose the highest operational risk, as intense heat and wind on rooftops accelerate water evaporation and disrupt consistent nutrient distribution.

Based on the comparative consideration of operational strengths and weaknesses, both Hydroponics and Conventional Soil Media generated the most positive participatory responses and were selected as the primary media types for the rooftop urban farming project. This decision was largely driven by the practical consideration of maintenance uniformity. The strategy of limiting the selection to only two media types with distinct underlying principles (liquid and solid) was intended to restrict complexity, if too many variations of media were used, maintenance behaviors would become highly disparate, which would increase control difficulties and ultimately reduce the community's level of sustainability.

2. Maintenance simplicity and operational ergonomics

Maintenance simplicity and operational ergonomics, identified as a critical factor in ensuring project longevity (Teymourian et al., 2017). The core focus was directed toward access pathways and cleaning processes, which were formalized into three main technical principles:

- Multi Directional Access and Logistics.** The pathways between the planting beds must be designed for accessibility from all sides and dimensioned sufficiently to allow passage for supportive tools, specifically miniature carts. This provision is essential for facilitating efficient maintenance and harvesting activities.
- Hygienic Surface Condition.** The access pathways must utilize non soil surfaces that are solidified and easy to clean. This measure effectively prevents the accumulation of mud and debris tracks, thereby maintaining the area's hygiene and operational efficiency after activities.
- Mitigation of Waste Accumulation.** The planting bed structures must be designed to incorporate an adequate under structure space. This feature serves a strategic function in minimizing the buildup of waste or organic debris in hard to reach areas, significantly simplifying routine cleaning and suppressing the potential propagation of pests.

Formulation and Implications of the Integrated Design Model

1. Innovation in Hydroponic Module Design and Technical Implications

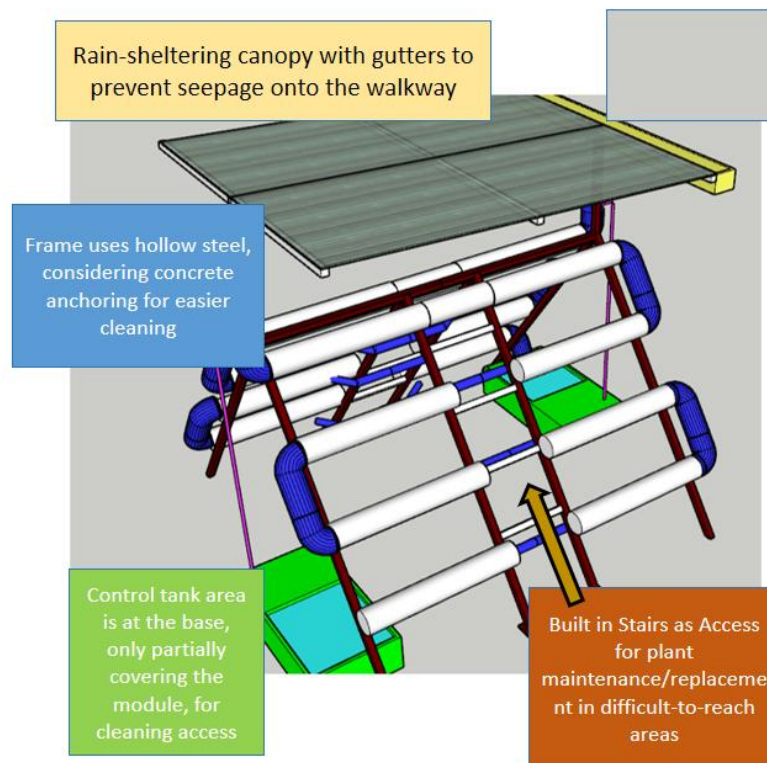


Figure 1. Hydroponic Module Design Result

The developed hydroponic module is a direct adaptation of conventional design, primarily prioritizing accessibility to ensure sustainable adoption and ease of maintenance. Design prioritized user ergonomics, setting a standardized table height that minimizes stooping for comfortable planting and harvesting, further supported by dedicated, integrated stairs for accessing hard to reach areas. Agronomic efficiency required fixing the minimum vertical distance between NFT pipe levels at 40 cm. This critical clearance prevents shading, maximizes light exposure, and ensures optimal yield for wide leaf crops in stacked systems, This spacing is directly supported by literature that emphasizes the need for adequate vertical spacing. (Specht et al., 2014), Table 2 summarizes the design implications derived:

Table 2. Hydroponic Module Design Implications

Input Point	Justification (Academic and Operational Context)	Design Implementation
Ideal Height	The planting table height must be ergonomic neither too low to prevent stooping nor too high to facilitate planting and harvesting.	The planting table height (topmost pipe) is fixed based on stair accessibility.
Clear Stacking	The vertical distance between pipes must be adjusted so that wide leaf plants (such as lettuce and mustard greens) receive sufficient light and do not shade each other during harvest.	The minimum vertical distance between NFT pipe levels is set at 40 cm.
Plant Diversification	The need to grow not only leafy vegetables but also longer lived plants (chili, tomato) for daily kitchen needs.	System integration is implemented.

2. Innovation in Soil Media Module Design (Planter Box)

The design of the soil media module addresses the core challenge often encountered in conventional container planting, the issue of poor drainage and excessive water retention. The primary objective of this design is to mitigate poor drainage and water retention common in ordinary planting containers while providing controlled water access.

a. Core Design Principles and Weight Sustainability

This Planter Box design fundamentally tackles two key sustainability issues. First, the system is developed to prevent roots from becoming submerged (*waterlogged*) by ensuring that excess water is immediately discharged, thus guaranteeing root health. Second, from a structural perspective, the strategic use of drainage layers and aggregates reduces the required amount of planting media, thereby significantly mitigating the total static load of the installation on the rooftop.

b. Ergonomics and Accessibility

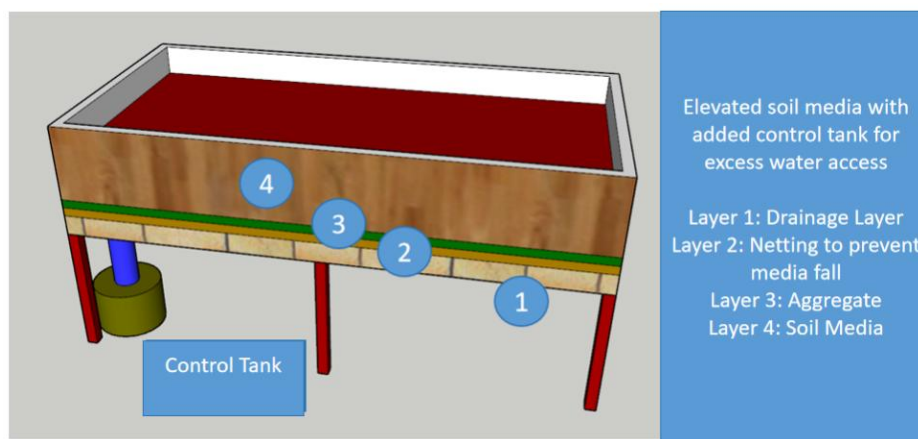
To enhance usability, the soil media module installation is designed to be elevated. Because it is elevated, the installation offers ergonomic comfort during planting and maintenance, reducing the need for bending (user friendly). This accessibility principle is crucial for ensuring active and sustained participation from community members.

c. Component and Layer Analysis

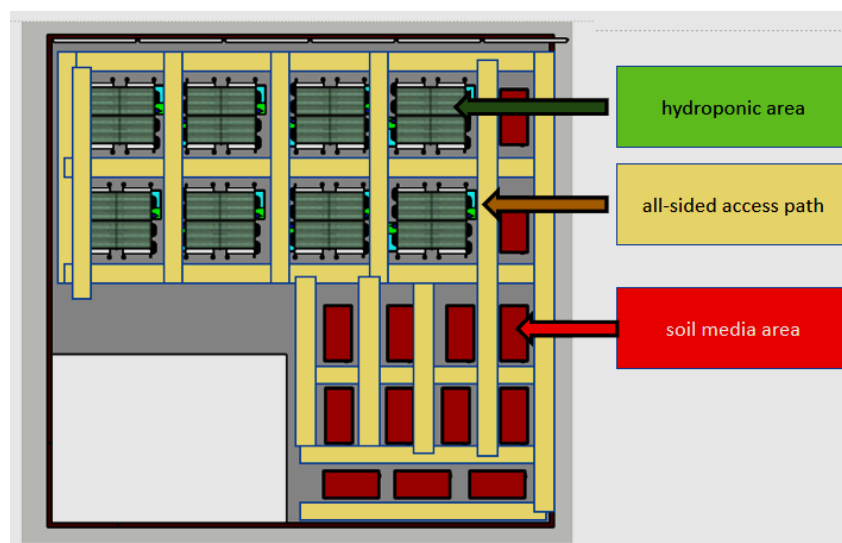
The design consists of four main internal layers and one essential external component, the Control Tank. These components function to reduce the potential for excessive wetness and limit the affected area. Table 3 below details the function of each layer to ensure efficient drainage.

Table 3. Soil Media Layers in the Planter Box Module

Component	Design Description	Function and Remarks
Layer 4, Planting Media (Top Layer)	Red media shown above the aggregate.	Root growth area.
Layer 3, Aggregate (Stone/Gravel)	A thick layer above the netting.	Separator and Drainage , Functions as a final filter and helps slow water flow before reaching the drainage layer, maintaining aeration at the lower boundary of the planting media.
Layer 2, Netting	The layer separating the aggregate and the drainage layer.	Filter , Prevents fine media (soil) and aggregate from dropping into or clogging the drainage channel below.
Layer 1, Drainage Area/Layer (Bottom Layer)	The empty space at the bottom of the installation.	Excess Water Collector , Functions as the main cavity or channel that drains excess water from the planting media and aggregate towards the Control Tank.
External, Control Tank	A cylindrical tank connected to Layer 1 via a pipe underneath.	Excess water will be collected here.

**Figure 2.** Soil Media Module Design

3. Principles of Modularity, Standardization, and Layout Accessibility

**Figure 3.** Modulation phase 1

The overall design adheres to principles of repetitive modularity with standardized unit sizes to ensure efficiency in construction, replication, and long-term maintenance. Modularity is key to creating a flexible and scalable system that aligns with the community's functional requirements.

For standardization, the model establishes eight uniform primary planting units as the hydroponic standard, supporting ease of operation and inventory management. These units are positioned within a 2x4 grid layout.

The efficiency of the layout is governed by maintenance accessibility. The modular placement is specifically configured to have access paths that spread throughout the entire area, serving the dual function of creating efficient circulation and preventing the formation of corner paths or dead ends. This configuration ensures that every planting unit can be reached quickly and safely for maintenance.

Utility Needs and Enhancing Sense of Ownership (Social Aspect)

Input on utility aspects, functional relevance, and enhancing the sense of ownership, all of which are critical for ensuring social sustainability and long-term adoption. The FGD analysis indicated that commodity selection and social interactive aspects were key determinants in terms of commodity relevance and visit sustainability. Factors of harvest sustainability and frequency of visits (engagement) were established as the primary parameters for commodity selection. Based on this, a priority was set for plants directly integrated into daily household consumption and life (e.g., vegetables or culinary herbs), which intrinsically increases the motivation of the women to maintain and harvest the produce.

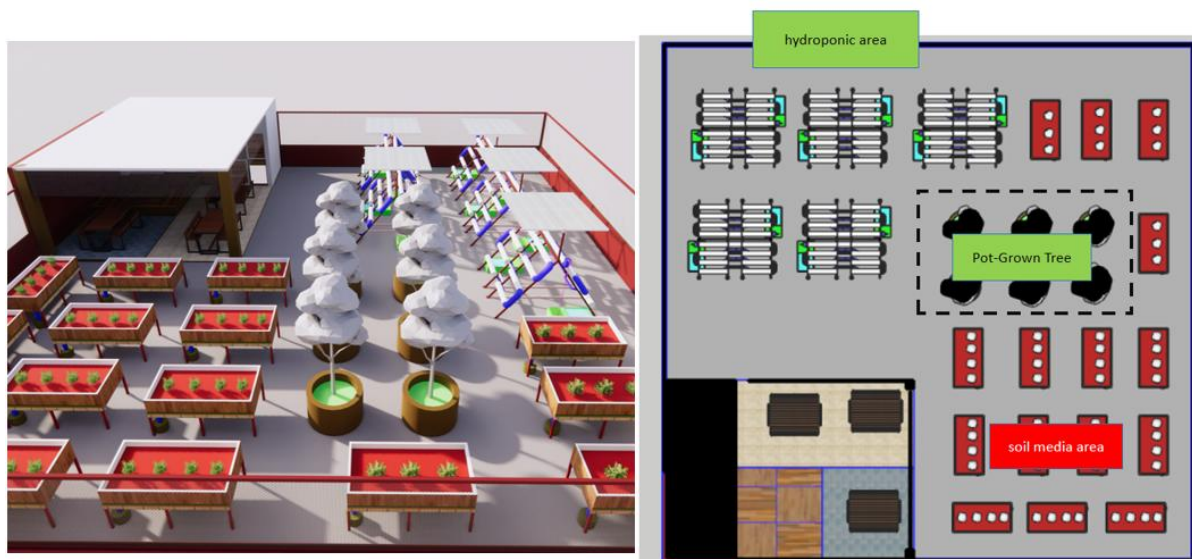


Figure 4.Final design and Modulation

The integration of diverse planting systems within this design model is based on the principle of functional diversification to comprehensively meet the community's food and herbal needs. System selection is primarily driven by specific crop agronomic criteria and growth characteristics. Table 4 summarizes the justification for plant placement based on the most ideal planting system:

Table 3. Planting System

Plant Group	Plant Type	Most Ideal Planting System	Justification for Placement
Hydroponics (NFT/DFT Pipe)	Leafy Vegetables, Mustard greens, Spinach, Lettuce, Water spinach	Hydroponic System	Short lived plants with shallow fibrous roots and low biomass. They are ideal for vertical/stacked pipe systems as this maximizes space and the efficiency of water and nutrients.
Soil Media (Planter Box/Pot)	Fruiting Vegetables, Tomato, Chili	Soil Media	Plants with deeper roots, requiring richer nutrients for fruit formation, and needing support (stakes). More stable when grown in appropriately sized pots.
Soil Media (Root/Shrub Crops)	Herbs & Medicine, Turmeric, Lemongrass, Basil, Turmeric Root, Yodium (Gynura procumbens), Aloe vera, Ginger, Pandan	Soil Media	Root crops (Turmeric, Ginger, Lemongrass) require a stable and wide volume of soil media. Pandan, Aloe vera, and Yodium are perennial/herbal shrubs unsuitable for the fast water flow of pipe hydroponics.
Large Trees & Shrubs (Tabulapot)	Mango, Guava, Key Lime, Starfruit, Longan, Candlenut, Citrus Leaves	<i>Tabulapot</i> (Fruit Trees in Large Pots)	Plants possess strong tap roots, woody stems, and high weight. They must be planted in large pots (special Planter Boxes) to limit size growth (<i>dwarfing</i>) and control the static load on the roof structure.

Overall, the design model resulting from this participatory process integrates various multidimensional considerations. This design adaptation fundamentally prioritizes operational ergonomics and maintenance simplicity, as evidenced by the emphasis on fostering a home garden feel. Home garden is a concept reflects the effective management of limited land resources to function as an independent food safety net (Wahyuningsih et al., 2023). This design synthesis focuses on enhancing a sense of shared ownership through incorporating functional preferences and plant commodity selection, simultaneously optimizing communal spaces. The strategic integration of hydroponic and soil media, evaluated based on maintenance ease, is not merely a matter of preference but also offers distinct advantages in thermal performance. In the garden concept, the presence of water and soil helps distribute temperature and humidity more evenly (Sastrawan & Darmawan, 2025), demonstrating its relevance in the context of rooftop urban farming.

The implications of this participatory approach align with the principles of urban ecological adaptation, where community involvement acts as a key factor in managing urban ecosystems, enabling more effective ecological revitalization (Febrian & Rosita, 2024). The dimension of social sustainability inherent in the design is reflected through parameters of participation and versatility (Audri et al., 2024). The participatory aspect is closely linked to the community's socio-cultural factors, demonstrated by the preference for plant types that meet household needs, which, in turn, strongly fosters a sense of ownership. This collective ownership indicates the long-term sustainability of the rooftop urban farming model. Furthermore, the versatility component transforms the rooftop into a free space with a farming ambiance experience often unseen in the urban context due to limited land. Thus, this design not only fulfills basic food needs but also provides a new cultural nuance and valuable experience for urban communities.

CONCLUSION

This study presents the formulation of an Integrated Participatory Design Model for community-based rooftop urban farming, directly addressing the critical challenges of achieving social and technical sustainability in dense urban environments. The research translates community needs into tangible design solutions that prioritize user engagement and operational

simplicity. The proposed model introduces several key innovations, a modified hydroponic design that fundamentally emphasizes accessibility and ease of maintenance for sustained long-term operation, and an elevated soil media design which includes an essential clearance underneath to facilitate cleaning and maintain operational ergonomics. Both design adaptations feature a high degree of modularity, enabling the system to be readily adjusted and scaled according to the varying dimensions and constraints of individual rooftop spaces. Overall, this design demonstrates that the application of a co-created and community-centered design approach transforms previously underutilized rooftop spaces into resilient multifunctional urban farming systems. a holistic design that provides urban food security, increasing social interaction as social sustainability in an urban context.

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