Designing Integrated Urban Agriculture Systems for Spatial Efficiency and Environmental Sustainability in Dense Urban Neighborhoods

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Abstract.

Rapid urban densification in cities of the Global South has intensified land scarcity and constrained the provision of green open spaces, particularly in compact residential neighborhoods. In such contexts, community-based urban agriculture has emerged as an adaptive response to environmental, social, and spatial challenges. While existing studies widely acknowledge the multifunctional benefits of urban agriculture, empirical investigations that systematically examine its spatial logic and integration within dense built environments remain limited, especially in Southeast Asian cities. This study aims to reframe community-based urban agriculture as an integrated socio-spatial and environmental infrastructure embedded within compact urban fabrics. Using a case study approach, the research investigates urban agriculture practices in Kemantren Gondokusuman, Yogyakarta, Indonesia. Data were collected through field mapping, spatial documentation, and descriptive–quantitative analysis focusing on spatial typologies, distribution patterns, green open space ratios, and system integration. The results identify 22 spatially distributed urban agriculture sites operating across private yards, residual spaces, and communal facilities, with a density of approximately 0.055 sites/ha in an area characterized by a green open space provision of only 14.5%. Findings reveal that urban agriculture functions as a micro-scale environmental infrastructure through the integration of spatial efficiency, production systems, environmental functions, and community-based operational mechanisms. Rather than compensating for green space deficits through land expansion, environmental performance is achieved through functional intensification of fragmented spaces. The study proposes an integrated urban agriculture model that synthesizes these interdependent systems, contributing a design-oriented framework for sustainable built environments in dense urban neighborhoods. This research advances built environment sustainability discourse by demonstrating how urban agriculture can operate as a scalable, spatially integrated strategy for enhancing environmental and socio-spatial performance in compact cities.

Keywords: *Urban agriculture ; Built environment sustainability ; Compact urban design; Environmental infrastructure and Community-based system.*

I. INTRODUCTION

State the objectives of the work and provide an adequate background from literature. Rapid urban densification has become a defining characteristic of cities in the Global South, intensifying competition for land and placing significant pressure on urban environmental systems [1]. In compact urban neighborhoods, limited availability of open space often results in the marginalization of productive landscapes, including spaces for food production, environmental management, and social interaction. This condition challenges the implementation of sustainable urban development, particularly in medium-density cities where informal spatial adaptations play a critical role in shaping the built environment.Within the discourse of built environment and sustainability, urban agriculture has been widely recognized for its multifunctional benefits, including contributions to food security, social cohesion, and environmental awareness [2][3]. Studies have positioned urban agriculture as part of green infrastructure systems, climate adaptation strategies, and socio-ecological resilience frameworks [4][5]. Recent studies highlight the transformative potential of urban agriculture modalities such as vertical farming as part of integrated planning processes, demonstrating how multifunctional food production can be reconciled with dense urban spatial structures [6]. Recent expert-based assessments further emphasize the growing strategic importance of urban agriculture in advancing multiple Sustainable Development Goals, particularly those related to sustainable cities, food systems, and environmental resilience [7]. However, these studies also highlight persistent challenges in translating urban agriculture's potential into spatially integrated and scalable systems, especially in land-constrained urban environments.

However, many of these studies emphasize outcomes and benefits, while providing limited analysis of the spatial logic and system configuration through which urban agriculture operates within dense built environments.Recent scholarship on compact city development and sustainable urban design emphasizes the importance of multifunctional and hybrid spaces capable of integrating ecological, productive, and social functions within limited land areas [8][9]. Concepts such as productive urban landscapes and urban green infrastructure further suggest that small-scale and decentralized systems can contribute meaningfully to urban sustainability when strategically embedded within the built environment [10]. In this context, urban agriculture has increasingly been recognized as a potential pathway toward urban resilience and sustainability, particularly through its capacity to enhance land-use multifunctionality and support integrated planning frameworks [11].However, recent critical reviews caution that the contribution of urban agriculture to urban resilience remains uncertain when initiatives are implemented as isolated or socially driven activities without systemic spatial and environmental integration [11]. While systematic reviews indicate that urban agriculture can support local food systems and contribute to urban sustainability by mitigating urban heat islands, reducing emissions, and enhancing biodiversity [12], these benefits are often discussed at a conceptual or outcome-oriented level. Empirical studies that examine how community-based urban agriculture operates as a spatially efficient and environmentally integrated system within high-density neighborhoods remain limited, particularly in Southeast Asian urban contexts.

In compact neighborhoods where green open space provision frequently falls below regulatory standards, the central challenge is therefore not merely to increase the quantity of green areas, but to intensify environmental functions within existing spatial constraints. Nevertheless, few studies operate spatial efficiency and environmental contribution through measurable indicators, such as site density, land-use typologies, or green open space ratios, within dense urban fabrics. This gap highlights the need for design-oriented and empirically grounded investigations that situate urban agriculture explicitly within the discourse of built environment sustainability.In cities characterized by high residential density and fragmented land ownership, such as Yogyakarta, Indonesia, community-driven urban agriculture has emerged as an adaptive response to land scarcity, environmental challenges, and food access concerns. In Kemantren Gondokusuman, urban farming initiatives utilize narrow yards, residual plots, and communal facilities through modular and flexible spatial arrangements. These practices indicate the potential of urban agriculture to function as micro-scale environmental infrastructure, integrating food production with waste reuse, water management, and microclimate regulation. Nevertheless, despite the proliferation of such initiatives in dense urban neighborhoods, existing studies rarely examine community-based urban agriculture through the lens of architectural design and environmental engineering, nor frame these practices as integrated spatial and environmental systems, particularly in Southeast Asian cities where land fragmentation and compactness are structural conditions.

This study addresses this gap by reframing community-based urban agriculture in Kemantren Gondokusuman as an integrated socio-spatial and environmental infrastructure within a compact urban setting. The objectives of this research are to (1) identify spatial typologies and system components of community-based urban agriculture in dense neighborhoods, (2) analyze their contribution to spatial efficiency and environmental sustainability, and (3) develop an integrated urban agriculture model from a built environment and environmental design perspective to inform architectural and environmental design strategies for compact cities. By situating urban agriculture within the framework of built environment sustainability, this study advances the state of the art beyond social program narratives and contributes an empirically grounded, design-oriented perspective relevant to high-density urban contexts.Figure 1 illustrates the conceptual positioning of this study by situating community-based urban agriculture within the broader context of compact urban fabrics characterized by high density, fragmented land parcels, and limited green open space. The diagram highlights the structural constraints commonly faced in dense neighborhoods and visualizes how urban agriculture operates as an integrated system composed of spatial, production, environmental, and operational components. Rather than functioning as isolated activities or social programs, these components interact to form a micro-scale environmental infrastructure capable of enhancing spatial efficiency and environmental performance within existing urban constraints. This conceptual framework clarifies the research gap addressed by the study and provides a foundation for the analytical approach adopted in the Results and Discussion sections.

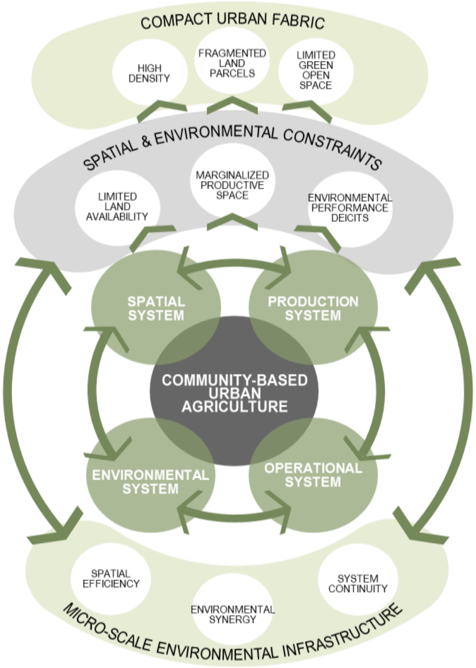

Fig 1. Conceptual positioning of community-based urban agriculture within compact built environments.

II. METHODS

This study adopts a case-study applied research approach focusing on Kemantren Gondokusuman, Yogyakarta, Indonesia. The case-study strategy is employed to enable an in-depth investigation of community-based urban agriculture within a specific spatial, environmental, and socio-institutional context, where urban density and land fragmentation constitute structural conditions of the built environment [13]. The research is grounded in a built environment and environmental systems perspective, emphasizing spatial configuration, functional integration, and micro-scale environmental performance.

Research Design

The research is designed as an applied case study integrating three complementary analytical dimensions:

1. Spatial analysis, aimed at mapping the distribution, typologies, and spatial configuration of urban agriculture sites within dense residential neighborhoods;
2. Environmental analysis, focusing on the role of urban agriculture in supporting micro-scale environmental functions, including waste reuse, water efficiency, and microclimate regulation;
3. System analysis, examining the interrelationships between spatial arrangements, production practices, environmental functions, and community-based management mechanisms.

This integrative design enables the examination of urban agriculture not as isolated activities, but as a multifunctional system embedded within the urban fabric, aligning with contemporary approaches to green infrastructure and sustainable urban systems [4][14]. By combining these analytical dimensions, the study addresses both the physical and operational aspects of urban agriculture as part of the built environment.

Data Collection and Analytical Procedures

Data were collected through field mapping, direct observation, and documentation of community-based urban agriculture practices across Kemantren Gondokusuman. Spatial data collection involved identifying the location, typology, and physical characteristics of urban agriculture sites, including the use of narrow residential yards, residual spaces, and communal facilities. These data were used to analyze spatial distribution patterns and typological variations within a compact urban setting.A descriptive–quantitative spatial analysis was employed to assess key indicators, including the number of urban agriculture sites (22 locations), site density (0.055 sites/ha), land-use typologies, and the proportion of green open space within the study area (14.5% of total land area).

These indicators provide an empirical basis for evaluating spatial efficiency and the activation of underutilized urban spaces.Environmental analysis focused on qualitative and semi-quantitative assessment of system functions, including organic waste reuse, water use efficiency, and contributions to local microclimate conditions. System continuity and operational characteristics were analyzed by examining management structures, role distribution, and maintenance practices within community groups. Community participation was treated as an operational mechanism for system functionality, rather than as a primary research objective.This methodological approach is consistent with built environmental research that conceptualizes small-scale, decentralized systems as integral components of urban environmental infrastructure networks, particularly in compact and land-constrained urban contexts [4][14][15]. These quantitative indicators are not intended for statistical generalization, but to support system-based interpretation of spatial efficiency and environmental integration within compact urban fabrics.

III. RESULT AND DISCUSSION

Spatial Typologies and Distribution of Urban Agriculture

The study area of Kemantren Gondokusuman covers approximately 398.7 ha and is characterized by a high residential density of 18,442 inhabitants/km², reflecting a compact urban structure with limited availability of formal green open space. The proportion of existing green open space accounts for only 14.5% of the total area, indicating a substantial deficit when compared to the national regulatory standard of 30%. Within this spatially constrained context, community-based urban agriculture has emerged as an adaptive spatial practice distributed across the neighborhood.Field mapping identified a total of 22 urban agriculture sites, resulting in a spatial density of approximately 0.055 sites per hectare. Rather than forming contiguous productive landscapes, these sites are spatially dispersed and embedded within the existing urban fabric.

Three dominant spatial typologies were identified based on land-use characteristics and physical configuration:

1. Private residential yards, consisting of narrow plots adjacent to housing units, typically utilizing container-based and vertical planting systems;
2. Residual and leftover spaces, including alley edges, building setbacks, and marginal parcels with irregular geometries and limited prior use;
3. Communal facilities, such as neighborhood-scale public spaces and shared facilities adapted for collective food production.

The identification of these spatial typologies was supported by systematic field mapping and visual documentation, which enabled the classification of fragmented and informally adapted spaces. Figure 2 visualizes the spatial distribution and typological configuration of community-based urban agriculture sites in Kemantren Gondokusuman, revealing a dispersed and non-contiguous pattern embedded within a dense residential fabric. The mapping identifies 22 urban agriculture sites distributed across private yards, residual spaces, and communal facilities, indicating spatial logic based on micro-scale insertion rather than land consolidation.

The predominance of residual spaces as host locations highlights the activation of previously underutilized urban fragments, while the presence of private and communal typologies demonstrates adaptive integration within both domestic and collective spatial domains. This distributed configuration supports the interpretation of urban agriculture as a decentralized environmental system, in which environmental functions are generated through functional intensification across fragmented parcels rather than through the expansion of formal green open space. Similar mapping-based approaches have been shown to be effective in capturing the spatial characteristics and operational boundaries of community-based urban agriculture in dense urban contexts [16].

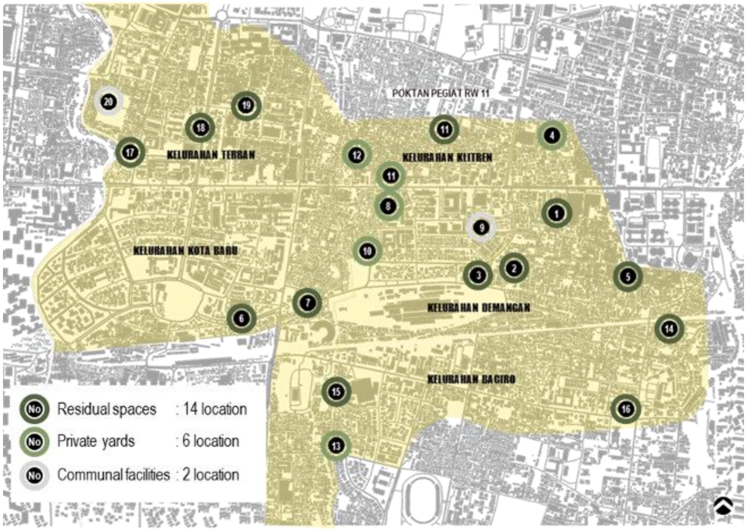

Fig 2. Spatial distribution and typologies of community-based urban agriculture in Kemantren Gondokusuman

Across all typologies, urban agriculture occupies small, fragmented parcels that were not originally designated for productive or ecological functions. The spatial configuration is characterized by compact layouts, vertical stacking, and modular arrangements, enabling the activation of underutilized spaces without altering the primary residential function of the area. This distribution pattern indicates spatial logic based on micro-scale insertion and spatial opportunism, rather than land consolidation or large-scale land conversion. From a spatial performance perspective, the dispersion of urban agriculture sites across multiple typologies contributes to the activation of idle spaces throughout the neighborhood. Although each site operates at a limited physical scale, their cumulative presence introduces productive and environmental functions into areas otherwise devoid of green infrastructure. These findings demonstrate that, within compact neighborhoods, spatial efficiency is achieved not through spatial expansion, but through the intensification of functions within existing spatial constraints.

Integrated Urban Agriculture Systems

Further analysis reveals that urban agriculture in Gondokusuman operates not as isolated planting activities, but as an integrated system composed of multiple interrelated components. Four core system dimensions were consistently observed across the 22 sites: spatial, production, environmental, and operational systems. The spatial system is defined by compact layouts, the extensive use of vertical structures, and adaptation to irregular landforms. Across all sites, spatial arrangements prioritize maximum functional output within minimal land areas, reinforcing principles of compact urban design and spatial efficiency.The production system is predominantly based on short-cycle horticultural crops, selected for their adaptability to limited space and low maintenance requirements. Crop selection and planting methods reflect an orientation toward micro-scale productivity aligned with daily household or community needs, rather than commercial-scale output.The environmental system integrates food production with localized environmental functions. Observations indicate that urban agriculture sites consistently incorporate organic waste reuse through composting practices, contribute to efficient water use, and provide localized vegetation cover that supports microclimate regulation. While these environmental contributions operate at a limited spatial scale, their distribution across the neighborhood enhances environmental functionality beyond formally designated green spaces.The operational system is organized through flexible, community-based management structures.

Roles and responsibilities are distributed among members of local farmer groups, enabling system continuity through shared maintenance and collective decision-making. Importantly, community participation functions as an operational mechanism supporting system performance, rather than as an end in itself. The operational system observed in Gondokusuman is closely linked to collective spatial awareness and shared management practices. Participatory mapping and visual communication tools play a critical role in aligning spatial use, production activities, and maintenance responsibilities among community members. Previous studies demonstrate that such participatory and visual-based approaches enhance system operability and continuity in urban farmer groups, particularly in spatially constrained environments [16].Across the study area, all urban agriculture sites exhibit at least three overlapping system components, with spatial and production systems present in all cases, while environmental and operational components vary in intensity depending on site typology. This integrated configuration enables urban agriculture to function as a micro-scale environmental infrastructure, embedding productive and ecological functions within the dense residential fabric without requiring additional land allocation.

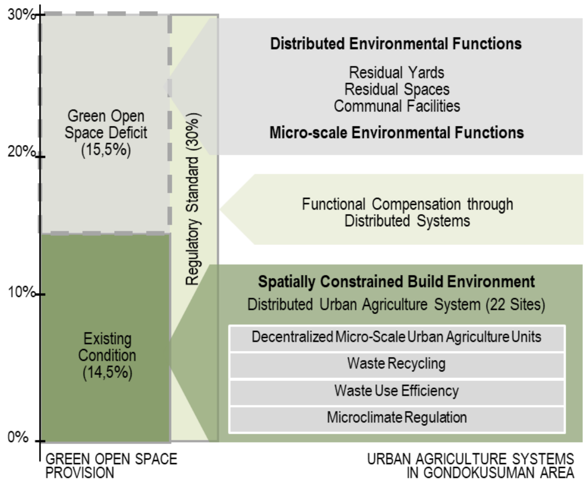

Fig 3. Ratio of Green Open Space Deficit and Distributed Urban Agriculture Systems

Figure 3 quantitatively illustrates the structural mismatch between green open space provision and environmental demand in compact urban neighborhoods. Despite a green open space provision of only 14.5%, environmental functions are partially compensated through the spatial distribution of 22 urban agriculture sites, corresponding to a density of 0.055 sites/ha. This visualization underscores that environmental performance in dense urban fabrics emerges from functional intensification rather than spatial expansion.

Discussion

Urban Agriculture sebagai Infrastruktur Lingkungan Skala Mikro

Existing literature on urban agriculture predominantly situates the practice within the domains of food security, livelihood strategies, or community empowerment [11][16]. Within this framing, urban agriculture is often treated as a socially driven activity operating in parallel to, rather than as part of urban spatial and environmental systems. The contribution of urban agriculture to urban resilience remains uncertain when initiatives are fragmented, socially driven, and weakly connected to broader environmental and spatial systems [11]. The findings of this study respond directly to this critique by demonstrating that, in compact urban neighborhoods, urban agriculture can operate as a form of micro-scale environmental infrastructure when spatial configuration, environmental functions, and operational mechanisms are systematically integrated. Rather than relying on scale or land area, the Gondokusuman case illustrates how resilience-related functions emerge from distributed and functionally intensive systems embedded within the built environment.Within this interpretation, urban agriculture as micro-scale environmental infrastructure is not defined by land extent or spatial continuity, but by the manner in which environmental functions are spatially distributed, functionally intensified, and systemically integrated within the built environment [16]. Its infrastructural character is operationalized through three interrelated dimensions: spatial distribution across fragmented parcels, functional intensity achieved through vertical and compact configurations, and system integration linking production, environmental management, and community-based operation.

Empirically, these dimensions are reflected in the density of urban agriculture sites (0.055 sites/ha), the diversity of spatial typologies (private yards, residual spaces, and communal facilities), and the consistent overlap of production, environmental, and operational functions observed across sites. Through this configuration, environmental performance is generated not by scale or land accumulation, but by the cumulative effect of distributed, multifunctional, and interdependent systems embedded within dense residential fabrics.The findings of this study indicate a substantive paradigm shift. In Gondokusuman, characterized by a residential density of 18,442 inhabitants/km² and green open space provision of only 14.5%, urban agriculture does not function as a substitute for conventional green open space based on land area. This observation supports [15] critique that land-area–based green metrics are insufficient for compact urban environments with structural land constraints.Unlike dominant green infrastructure models that prioritize linear corridors or large ecological nodes [14], urban agriculture in Gondokusuman operates as a distributed micro-scale environmental infrastructure embedded within the residential fabric.

The presence of 22 spatially dispersed urban agriculture sites, with a density of approximately 0.055 sites/ha, forms a decentralized network of environmental functions integrated into everyday neighborhood spaces. This configuration aligns with broader conceptualizations of green infrastructure as networks of natural, semi-natural, and artificial ecological systems capable of delivering ecosystem services across multiple spatial scales [17]. Rather than relying on spatial continuity or large land parcels, the Gondokusuman case demonstrates how fragmented, yet functionally integrated systems can generate environmental performance within compact urban environments. This configuration extends the green infrastructure discourse by demonstrating that environmental performance can emerge from fragmented yet functionally integrated spatial systems.This study therefore contributes to built environment scholarship by demonstrating that, in high-density Southeast Asian cities, environmental functionality can be achieved through spatial efficiency and functional intensification rather than through spatial expansion of green areas.The findings presented in the Results section demonstrate that urban agriculture in Gondokusuman operates through spatially compact, functionally layered, and environmentally responsive configurations. These characteristics support the interpretation of urban agriculture not merely as a land-use activity, but as a form of micro-scale environmental infrastructure embedded within dense residential fabrics. This infrastructural role extends beyond ecological performance, providing a foundation for socio-spatial interactions discussed in the following section.

Socio-Spatial Integration in Dense Urban Neighborhoods

Socio-spatial integration has been widely discussed within the built environment literature as a critical dimension of sustainable urban development, particularly in compact and high-density cities [18][19]. These studies emphasize that spatial configuration plays a decisive role in shaping social interaction, collective action, and long-term spatial viability. However, much of the existing literature conceptualizes socio-spatial integration through formal public spaces, institutionalized participation mechanisms, or planned community facilities.The findings of this study provide an alternative empirical perspective on socio-spatial integration in dense urban contexts. In Gondokusuman, socio-spatial integration does not primarily emerge through formally designated public spaces, but rather through everyday spatial practices embedded within community-based urban agriculture systems. The distributed utilization of narrow residential yards, residual plots, and shared neighborhood spaces illustrates how informal, small-scale spatial adaptations can sustain collective engagement within compact urban fabrics. This observation is consistent with Healey's argument that social integration and spatial governance are produced through relational practices, rather than through predefined or formally planned spatial forms [18].

Furthermore, the operational continuity of 22 urban farmer groups, maintained through regular collective activities and shared management routines, supports Madanipour's assertion that socially inclusive urban spaces are not defined solely by their degree of openness, but by their capacity to accommodate repeated and meaningful social practices over time [19]. In this context, participation functions not as an abstract social objective, but as an operational requirement that enables the persistence of the spatial system itself.From a green infrastructure perspective, multifunctional green infrastructure should integrate social, ecological, and spatial functions simultaneously, particularly in land-scarce urban environments [4]. The Gondokusuman case empirically substantiates this claim by demonstrating that socio-spatial integration is achieved through the functional overlap of production, environmental management, and collective use within a single spatial system. Rather than competing with residential functions, urban agriculture becomes embedded within daily domestic and neighborhood routines.

Importantly, this study extends the compact city discourse articulated by Burton [8] and Newman et al. [9] by illustrating that urban density does not inherently undermine socio-spatial integration. Instead, when spatial systems are designed, or adaptively formed, to support multifunctionality and collective management, high-density environments can foster resilient socio-spatial relationships. In this sense, urban agriculture operates as a mediating spatial infrastructure that reconciles urban density with social sustainability.Consequently, the socio-spatial integration observed in Gondokusuman challenges prevailing assumptions that effective social integration in dense urban neighborhoods requires formal spatial provision or large-scale public investment. Instead, the findings suggest that micro-scale, distributed, and collectively managed spatial systefaoms can generate stable socio-spatial integration, provided they are functionally embedded within the built environment.These socio-spatial dynamics indicate that the effectiveness of urban agriculture systems in dense neighborhoods depends not only on environmental performance, but also on design decisions that enable collective use, adaptability, and operational continuity.

Implications for Built Environment and Sustainability

Building on the interpretation of urban agriculture as micro-scale environmental infrastructure and its role in facilitating socio-spatial integration, this study identifies several implications for built environment and sustainability-oriented design in compact urban contexts. Compact city theory often frames density and green space provision as competing objectives [8]. The empirical evidence from Gondokusuman challenges this dichotomy. Despite a green open space deficit of approximately 61.6 ha relative to national standards, environmental functions are partially compensated through distributed micro-scale urban agriculture systems.The dominance of horticultural crops (±61%) reflects a close alignment between spatial typologies and production strategies, reinforcing arguments that urban agriculture sustainability depends on congruence between spatial design and production systems [15][20]. This finding contrasts with sustainability frameworks that equate environmental performance primarily with land-based green indicators, highlighting instead the importance of function-based spatial efficiency.Land scarcity identity limited spatial integration, and weak alignment between urban agriculture initiatives and urban planning frameworks as key challenges constraining the contribution of urban agriculture to sustainable development goals [7].

The findings of this study directly respond to these challenges by demonstrating how urban agriculture can be spatially embedded within dense urban fabrics through micro-scale, distributed systems that prioritize functional efficiency over land expansion. In this context, the Gondokusuman case provides empirical evidence that urban agriculture's contribution to sustainability is not primarily a matter of production scale, but of spatial configuration and system integration, an aspect highlighted but not empirically resolved in existing expert-driven assessments.In relation to Sustainable Development Goal 11, this study clarifies that the contribution of urban agriculture to sustainable cities lies not in increasing green space quantity, but in optimizing environmental functions under spatial constraints, an aspect underexplored in policy-driven and macro-scale sustainability literature. These implications underscore the need for an integrated design framework that systematically connects spatial configuration, environmental performance, and collective operation, which is synthesized in the proposed model presented in the following section.

Proposed Integrated Urban Agriculture Model (in Relation to Existing Frameworks)

The proposed integrated urban agriculture model consolidates the empirical findings and analytical insights generated in this study into a structured conceptual framework. Rather than introducing additional parameters, the model systematizes the observed interactions among spatial efficiency, environmental functions, and socio-operational mechanisms within the Gondokusuman context. These relationships are articulated as an interdependent system in which spatial configuration governs functional performance, environmental processes are embedded within productive and domestic routines, and socio-operational mechanisms ensure system continuity. By formalizing these empirically grounded linkages, the model provides a technical representation of urban agriculture as a micro-scale environmental infrastructure operating within dense urban fabrics. Existing urban agriculture frameworks tend to segregate production, social, and environmental dimensions [1][2], or position urban agriculture as a supplementary component of green infrastructure without explicit spatial design logic.

The Integrated Urban Agriculture Model proposed in this study differs fundamentally by synthesizing four interdependent subsystems, spatial, production, environmental, and operational, within a single design-oriented framework. While conceptually aligned with systems-based approaches in built environment research, this model is explicitly grounded in micro-scale spatial adaptation within compact urban fabrics.Unlike programmatic or policy-driven models, the proposed framework is scalable and design-led, enabling replication at neighborhood and sub-district levels without requiring structural land-use transformation. This contribution bridges the gap between urban agriculture theory and built environment practice, particularly in dense Southeast Asian cities.Figure 4 synthesizes the empirical findings into a design-oriented model that formalizes the interdependencies between spatial efficiency, environmental functions, production strategies, and operational mechanisms. Unlike policy-driven frameworks, the model does not prescribe land-use categories but articulates a relational logic through which urban agriculture operates as micro-scale environmental infrastructure in dense urban neighborhoods.

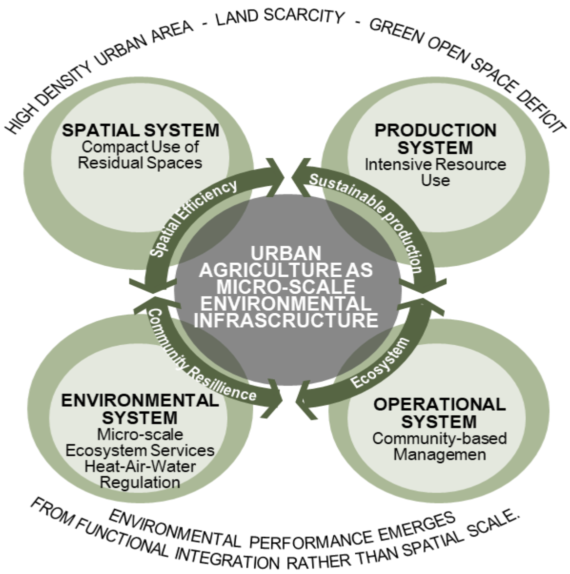

Fig 4. Integrated Argumentative Framework of Urban Agriculture in Dense Neighborhoods

By articulating these interdependencies, the model contributes a transferable design-oriented framework for integrating urban agriculture into dense urban neighborhoods, extending current sustainability and compact city discourses within the built environment field.

IV. CONCLUSION

This study demonstrates that community-based urban agriculture in dense urban neighborhoods can function as micro-scale environmental infrastructure when spatial configuration, production strategies, and operational mechanisms are coherently integrated. Based on the case of Kemantren Gondokusuman, Yogyakarta, the findings show that environmental performance in compact urban settings does not depend primarily on the expansion of green open space, but rather on the functional intensification of fragmented and residual spaces. Despite a green open space provision of only 14.5%, the spatial distribution of 22 urban agriculture sites (0.055 sites/ha) enables localized environmental and productive functions to emerge within the existing urban fabric.The dominance of horticultural crops (±61%) highlights a close alignment between spatial typologies and production strategies, reinforcing the importance of congruence between spatial design and production systems for the sustainability of urban agriculture. This alignment underscores that spatial efficiency and environmental performance are mutually reinforcing, particularly in high-density neighborhoods where land availability is severely constrained.

Rather than operating as isolated green interventions, urban agriculture systems in this context are embedded within everyday residential and communal spaces, enabling adaptive and decentralized environmental functions.The integrated urban agriculture model proposed in this study formalizes these relationships by linking spatial efficiency, environmental performance, and community-based operational mechanisms into a coherent built environment framework. This model advances existing sustainability discourse by shifting the focus from land-based green indicators toward function-based spatial performance, offering a design-oriented perspective that is particularly relevant for compact cities in the Global South.While this research is grounded in a single case study, the proposed framework provides transferable insights for similar dense urban neighborhoods facing green space deficits and environmental pressures. Future research may extend this approach through comparative case studies or by integrating quantitative environmental performance measurements to further strengthen the empirical basis for design and policy applications.

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