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INTEGRATION OF URBAN AGRICULTURE SYSTEMS INTO INTERIOR ARCHITECTURE: CASE EXAMPLES AND A MODULAR DESIGN PROPOSAL

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Abstract: Rapid urbanization, environmental disruption, and recurring disasters have intensified the need for resilient food strategies that can operate within constrained urban interiors. Although indoor urban agriculture and controlled-environment systems are increasingly discussed, their integration as an interior architecture problem especially for compact and post-disaster living contexts remains insufficiently articulated. This study investigates how interior architecture can support food resilience by embedding modular indoor agriculture into everyday environments. The research adopts a qualitative, literature-based analytical framework and a comparative case evaluation of two precedents that Pasona Urban Farm (Tokyo) and InFarm modular systems (Berlin). Case documentation and published sources were analyzed to extract spatial-technical requirements and user-facing design strategies. Findings are synthesized into a set of transferable principles: resilient modularity for diverse interior typologies, water circularity through closed-loop/low-loss systems, human-plant cohabitation via lighting and access ergonomics, and operational simplicity through legible maintenance and digital feedback. Building on these principles, the paper proposes the Adaptive Hydro-Cell (AHC) as a conceptual prototype: a portable hydroponic unit designed for compact urban dwellings and post-disaster interiors, integrating stackable growth trays, filtration, and mobile monitoring. The contribution lies in positioning interior architecture as a mediating discipline that translates agricultural infrastructure into human-centered, deployable interior systems, and in articulating a resilience-oriented design framework to guide future prototyping and validation.

Keywords: Interior architecture, Hydroponics, Modularity, Urban agriculture, Sustainability, Adaptive design

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1. Introduction

Rapid urbanization, climate change, and the increasing strain on global food systems have intensified the search for sustainable and resilient food production strategies within urban environments. More than half of the global population now resides in cities, a proportion expected to rise substantially in the coming decades. As urban areas expand and arable land diminishes, urban agriculture has gained renewed importance as a strategy to enhance food security, environmental sustainability, and urban resilience (Zaręba et al., 2021). As urban areas expand and arable land becomes increasingly limited, urban agriculture has emerged as a critical approach to enhancing food security, environmental sustainability, and urban resilience (Mougeot, 2006; Al-Kodmany, 2018).

Traditionally, urban agriculture has been associated with outdoor environments such as community gardens, rooftops, and vacant lots. However, recent technological advancements in controlled environment agriculture (CEA) have enabled a major transition toward indoor and vertical farming. Hydroponic, aeroponic, and modular vertical farming systems now make it possible to cultivate crops year-round within enclosed spaces, optimizing water, energy, and spatial efficiency (Daneshyar, 2024; Ghazal et al., 2023; Zhang et al., 2025). These innovations position indoor urban agriculture as a viable and sustainable solution for dense metropolitan contexts where outdoor growing space is limited or inaccessible (Nicola et al., 2021; Akintuyi, 2024).

Beyond agricultural production, indoor urban agriculture introduces new design challenges and opportunities for interior environments. Interior spaces are increasingly expected to contribute to sustainability, occupant well-being, and multifunctional living. The integration of productive systems within interiors thus represents a paradigm shift in spatial design-transforming interiors from passive environments into active ecological systems that participate in food production and environmental regeneration (Pakravan et al., 2022; Ordia, 2023).

From an interior architecture perspective, this integration requires careful consideration of both spatial and technical parameters, including lighting, air circulation, irrigation, modularity, and user interaction. While recent studies have optimized system performance, energy use, and crop yield, they often overlook the spatial and experiential dimensions of such integrations (Wallis and Petrović, 2022; Kuo et al., 2025). Without a design-oriented framework, urban agriculture risks being treated as a purely technical infrastructure rather than a human-centered and spatially integrated system.

The current research addresses this gap by exploring interdisciplinary approaches that merge interior architecture, environmental engineering, and sustainable agriculture. It examines how modular hydroponic and vertical farming systems can be integrated into interior spaces in adaptable, scalable ways that support both productivity and aesthetic quality. Through a qualitative and case-based methodology, this study aims to contribute to the emerging discourse on productive interior environments, providing practical insights for designers, architects, and researchers seeking to bridge the boundaries between design and food production (Zhang et al., 2025; Ghazal et al., 2023).

In recent years, the increasing frequency of environmental disasters, supply chain disruptions, and infrastructure breakdowns has further underscored the necessity of developing resilient and self-sufficient food systems. Following large-scale crises such as earthquakes or pandemics, the urban population often faces not only shelter shortages but also limited access to fresh food and clean air. In this context, indoor agriculture especially modular and low-resource systems emerges as a critical design strategy to enhance both food resilience and environmental health in emergency and post-disaster housing scenarios (Griebel et al., 2022; Grochulska-Salak et al., 2021). Therefore, this study approaches indoor urban agriculture not solely as a sustainability measure but also as a resilience-based interior architecture solution, adaptable to temporary and resource-constrained environments.

1.1. Literature Review

Urban agriculture has evolved from a peripheral urban practice into a key component of sustainable city-making, driven by global challenges such as population growth, land scarcity, and environmental degradation. While early models focused on open-air community gardens and rooftop farming, the recent emergence of indoor and vertical agriculture marks a paradigm shift in the spatial logic of food production (Abbasi, 2020; Zhang et al., 2025). This shift reflects not only technological progress in controlled environment agriculture (CEA) but also a growing awareness of the built environment's potential to serve as an active ecological system.

Recent studies have expanded the scope of urban agriculture to include post-crisis and transitional environments, emphasizing its role in rebuilding local food networks and improving psychological recovery in displaced populations (D'Ostuni et al., 2024; Ghazal et al., 2023). Within this framework, interior spaces often the first rebuilt environments after disasters offer protected and controllable conditions ideal for establishing small-scale, modular cultivation systems. The integration of productive agricultural modules into interior architecture thus extends beyond sustainability or aesthetics. It becomes a means of restoring ecological and social continuity in times of disruption.

In this study, biophilic design is referenced not as a stylistic preference but as an evidence-informed approach linking interior greenery to occupant well-being and environmental comfort. Within productive interiors, cultivation systems can function as biophilic interfaces by making living processes visible and accessible, thereby supporting psychological restoration alongside performance goals (Zhong et al., 2021).

1.2. Urban Agriculture and the Indoor Shift

Urban agriculture has long been perceived as a spatial and social practice rooted in outdoor environments such as community gardens, green roofs, and peri-urban farms. However, in the context of rapid urbanization and climate instability, the discipline has undergone a notable shift from exterior to interior environments. This evolution has been shaped by the dual pressures of land scarcity and sustainability imperatives, leading cities to explore ways of embedding productive ecosystems within the built fabric (Abbasi, 2020; Zaręba et al., 2021). Rather than existing as peripheral or temporary interventions, urban agriculture increasingly forms part of long-term urban strategies addressing food resilience, energy management, and well-being.

Recent scholarship conceptualizes this "indoor turn" in urban agriculture as both a technological and spatial transformation. Controlled Environment Agriculture (CEA) enables urban production to occur irrespective of climate or soil conditions by employing fully enclosed systems with artificial lighting, hydroponic growth media, and environmental controls (Ghazal et al., 2023). The integration of such systems within existing architectural structures-from repurposed warehouses to high-rise façades-reflects a broader cultural rethinking of the relationship between nature and the built environment (Tablada and Kosorić, 2024; Zhang et al., 2025).

Simultaneously, the movement toward interiorized agriculture challenges conventional boundaries between architecture, landscape, and interior architecture. The distinction between productive and inhabitable space becomes blurred: offices, schools, and homes now act as sites of cultivation as well as occupation (Pakravan et al., 2022). This redefinition positions the interior not merely as a backdrop to daily life but as a dynamic medium for environmental performance and community engagement.

From a design theory perspective, this indoor shift signals a post-disciplinary convergence where environmental technology, spatial design, and social systems overlap (Ordia, 2023). It emphasizes human-centered sustainability, focusing on experiential and participatory dimensions of urban agriculture within interior contexts. While early urban farming studies addressed yield and resource optimization, emerging research argues that the spatial integration and aesthetic mediation of productive systems are equally critical for achieving long-term adoption and social acceptance (Wallis and Petrović, 2022).

1.3. Hydroponic and Vertical Farming Systems

Hydroponic and vertical farming systems represent the technological core of contemporary indoor urban agriculture. They redefine the act of cultivation by removing soil as a growth medium and replacing it with nutrient-enriched aqueous or aerated substrates, allowing plants to thrive in tightly controlled environments. This method not only optimizes water and nutrient efficiency but also reduces land dependency-making it ideal for compact urban interiors (Nicola et al., 2021; Akpenpuun et al., 2025). Recent experiments demonstrate that hydroponic setups can use up to 90% less water compared to traditional agriculture, while LED lighting and automated climate control enable 24-hour growth cycles regardless of seasonal conditions (Shi et al., 2025).

The integration of hydroponic modules and vertical farming towers into architectural and interior systems has been widely explored as a means to achieve sustainable, high-density food production (Ghazal et al., 2023; Zhang et al., 2025). Unlike horizontal layouts typical of greenhouses, vertical configurations capitalize on the vertical dimension of space, allowing for layered cultivation that maximizes yield per square meter. This makes them particularly relevant for interior applications, such as corporate atria, educational institutions, and repurposed urban basements (Martí Torra and Garcia-Alminana, 2023; Zhou, 2024). The flexibility and modularity of vertical farming structures make them adaptable to various scales-from single-room systems to large adaptive reuse projects.

From an engineering standpoint, vertical farming integrates advanced HVAC (Heating, Ventilation, and Air Conditioning) and LED lighting systems that simulate natural conditions while maintaining consistent temperature and humidity. Studies have emphasized the role of AI-assisted environmental control in optimizing plant growth cycles, predicting nutrient requirements, and reducing energy consumption (Akpenpuun et al., 2025; Grasso et al., 2024). The integration of photovoltaic panels and rainwater recovery systems further strengthens their alignment with circular economy models (Zhang et al., 2025).

Despite these technological advances, design challenges persist in aligning functional efficiency with spatial and aesthetic integration. Many prototypes remain confined to research laboratories or isolated pilot projects due to acoustic interference, visual clutter, or spatial rigidity (Kalantari and Mohd Tahir, 2017; Awal, 2023). A key opportunity, therefore, lies in developing modular systems that seamlessly blend environmental control components-such as lighting arrays, air ducts, and nutrient reservoirs-within the spatial logic of interior architecture. This convergence between biotechnical performance and spatial expression defines the next frontier of indoor agriculture.

1.4. Spatial and Technical Requirements in Interior Environments

The successful integration of urban agriculture within interior environments depends on balancing technical efficiency with spatial and experiential quality. Indoor agricultural systems such as hydroponic or aeroponic installations require carefully regulated environmental conditions for optimal growth, yet their implementation must coexist harmoniously with the thermal, acoustic, and ergonomic dynamics of interior spaces. Therefore, the design process operates at the convergence of environmental engineering, architecture, and interior architecture, requiring both systemic precision and spatial sensitivity (Pakravan et al., 2022).

Among the primary determinants of plant and human performance within interior agriculture, lighting plays a crucial dual role. Artificial illumination must not only provide the spectral composition necessary for photosynthesis but also support human visual comfort and circadian rhythm. According to Burattini, Palladino, and Fiorito (2015), lighting design for plant growth and human comfort must simultaneously meet biological efficiency and perceptual quality. Contemporary approaches emphasize tunable LED systems capable of dynamically adjusting color temperature and intensity, thus serving both productive and aesthetic objectives. This dual optimization allows interior spaces to merge horticultural utility with architectural atmosphere, reinforcing the concept of productive aesthetics.

Air circulation and humidity management represent equally vital components of indoor agricultural environments. High plant density increases evapotranspiration and heat loads, making ventilation strategies essential for energy balance and microclimate stability. Studies such as Ahmed, Abdelkader, and Soliman (2024) have shown that leveraging natural convection and passive airflow within controlled environments can significantly reduce HVAC dependency while maintaining stable temperature gradients. Similarly, the integration of hybrid mechanical systems coupled with passive convection principles can further minimize energy demand without compromising plant health or occupant comfort. When these environmental systems are spatially integrated through concealed ducting, acoustic insulation, and modular ceiling design, they reinforce architectural coherence rather than disrupting it.

Beyond technical functionality, spatial design also mediates the sensory and psychological dimensions of productive interiors. The arrangement of planting modules, light fixtures, and irrigation components affects both usability and emotional engagement. By adopting biophilic design principles, designers can transform these environments into restorative, human-centered spaces that foster well-being and social interaction. As Zhong et al., (2021) argue, biophilic design establishes an evidence-based framework connecting sustainability with psychological health. In the context of indoor agriculture, this approach reinforces the visual and material integration of natural elements, providing multisensory experiences that encourage mindfulness, productivity, and ecological awareness.

Collectively, these findings underscore that the interiorization of urban agriculture is not a mere technical challenge but a design opportunity. It is a synthesis of systems thinking, environmental psychology, and spatial creativity. The success of productive interiors depends on how effectively design translates environmental technology into meaningful human experience.

1.5. The Mediating Role of İnterior architecture

The integration of urban agriculture into interior spaces necessitates a design framework that mediates between technological systems, environmental sustainability, and human experience. As productive systems migrate from industrial or outdoor contexts into everyday environments such as offices, schools, and residences, interior architecture becomes the translational layer that interprets these technical infrastructures into spatial, sensory, and cultural experiences. In this sense, the designer's task extends beyond functionality - it encompasses creating atmospheres where living systems and human activity coexist symbiotically (Ordia, 2023; Pakravan et al., 2022). Interior environments thus evolve from passive containers into active ecological agents, shaping user behavior and environmental performance simultaneously.

A growing body of research emphasizes that design decisions - from material selection to lighting modulation - directly affect how users perceive and engage with indoor agricultural systems. The biophilic design approach, as discussed by Zhong et al., (2021), provides an evidence-based foundation for integrating living systems within interior contexts to enhance mental health and well-being. Similarly, Ordia (2023) argues that interior architecture can act as a restorative interface between nature and the built environment by incorporating multisensory and aesthetic elements that evoke emotional attachment and ecological awareness. Within productive interiors, this implies that design choices-color temperature, sound absorption, plant visibility, and modular composition-play psychological and social roles equal to technical efficiency.

Moreover, interior architecture serves as a strategic mediator between engineering optimization and spatial quality. Engineering disciplines tend to prioritize system performance - energy, water, yield - while design disciplines foreground usability, comfort, and meaning. Bridging these orientations requires an integrated process where aesthetic and technical systems evolve together. Case studies such as Ghazal et al., (2023) AGRI|gen modular system demonstrate that the architectural expression of hydroponic systems can reinforce not only function but also identity, transforming infrastructure into design language. Likewise, Zhang et al. (2025) propose a modular agrivoltaic envelope that combines photovoltaic and hydroponic systems through a circular design framework - an approach in which form and function are mutually generative.

Finally, the mediating role of interior architecture extends into cultural and pedagogical dimensions. Productive interiors act as visible demonstrations of sustainability principles, making environmental processes tangible in daily life. As noted by Pakravan et al. (2022), the design studio can become a pedagogical laboratory where urban agriculture fosters interdisciplinary learning and environmental empathy. In this sense, the integration of agriculture into interiors is not only an ecological intervention but also a didactic and symbolic practice, cultivating awareness of interdependence between humans and ecosystems. By positioning design as a medium of translation - between technology, culture, and ecology - the interior discipline assumes a central role in shaping resilient, regenerative urban futures.

2. Materials and Methods

2.1. Research Design

This research employs a qualitative, literature-based, and case-oriented design framework to investigate how urban agriculture systems can be spatially and aesthetically integrated into interior environments. The purpose is to identify the design principles that enable interior spaces to function simultaneously as productive and habitable environments.

The study builds on a three-stage process:

1. Theoretical and Contextual Review – examining interdisciplinary literature in the domains of interior architecture, urban agriculture, and sustainable system design to establish conceptual grounding (Zhong et al., 2021; Pakravan et al., 2022).
2. Case-Based Analytical Evaluation – selecting two distinct yet complementary cases that demonstrate interior-agriculture integration in different spatial and systemic typologies.
3. Comparative Synthesis – extracting cross-case insights to propose a modular interior architecture approach suitable for residential and compact urban contexts.

The research follows a qualitative–interpretive method rather than a quantitative or experimental model. It prioritizes spatial observation, interpretive reading, and comparative logic over statistical measurement. Since the analysis is entirely based on secondary sources and case documentation, no human subjects or ethical approval are required.

2.1.1. Literature search strategy

A structured literature search was conducted to ensure procedural transparency. Searches were performed in Scopus, Web of Science, and Google Scholar between 2010-2025, with an emphasis on 2015-2025 to capture recent indoor farming and modular design developments. Key strings included combinations of: "indoor urban agriculture", "vertical farming", "hydroponic module", "interior architecture", "productive interiors", "post-disaster housing", and "resilience design". Inclusion criteria were: peer-reviewed journal articles, conference papers, and authoritative institutional reports; explicit relevance to indoor cultivation systems and/or interior spatial integration; and sufficient methodological or design detail to support extraction of spatial and technical requirements. Exclusion criteria were: purely outdoor urban agriculture without interior implications; papers lacking system or spatial descriptors; and non-archival media content used only for contextual precedent illustration. The search and screening logic follows established guidance for transparent literature reviews (Elshater and Abusaada, 2022; García-Peñalvo, 2022; Shaffril and Samsuddin, 2021).

2.1.2. Case documentation sources

Case documentation relied on triangulated secondary sources. For Pasona Urban Farm, documentation included published architectural descriptions, academic discussions of building-integrated agriculture, and publicly available project documentation (e.g., photographs and reported system descriptions). For InFarm, documentation included scholarly discussions of modular vertical farming and controlled-environment systems, complemented by publicly available technical descriptions of modular operation and monitoring features. No interviews or on-site measurements were conducted, therefore, the analysis is explicitly framed as qualitative and interpretive, focusing on design-system relationships evidenced in available documentation.

2.2. Case Selection Criteria

The case selection was guided by three principal criteria reflecting the research's interdisciplinary scope:

1. Indoor Applicability – Each system must operate wholly or partially within an enclosed built environment.
2. System Integration – The agricultural component must interact directly with architectural systems (lighting, HVAC, or structure).
3. Design Relevance – The project must exhibit design intent beyond technical efficiency, engaging user experience, aesthetic composition, and social meaning.

Based on these conditions, two case studies were selected to represent distinct approaches to interior agricultural integration:

Case 1 – Pasona Urban Farm (Tokyo, Japan): A large-scale corporate office environment fully integrating hydroponic systems into its architectural and interior architecture.

Case 2 – InFarm Modular Urban Farming System (Berlin, Germany): A distributed modular farming platform integrated into retail and semi-public interiors. The system illustrates a new model of urban food production embedded within existing building infrastructures, reducing transportation and storage impacts while enhancing local food accessibility (Benis and Ferrão, 2017).

Together, these cases exemplify both the holistic integration of agriculture within designed environments and the scalable modular adaptation of food production systems within urban interiors.

Table 1. Comparative overview of selected cases

Aspect	Case 1: Pasona Urban Farm (Tokyo, Japan)	Case 2: InFarm Modular System (Berlin, Germany)
Type	Realized interior office environment	Real-world modular urban farming system
System	Hydroponic + LED lighting: human participation	IoT-based hydroponic modular vertical farms
Scale	4,000 m^2 integrated workspace	Compact, distributed modules (supermarkets, restaurants, universities)
Design Intent	Integrate food production within corporate architecture	Embed food cultivation in everyday public interiors
User Interaction	Employees as co-producers	Shoppers and visitors as participants
Architectural Strategy	Farming integrated into ceilings, partitions, and meeting spaces	Transparent plug-and-play vertical units
Relevance to Study	Demonstrates interior-scale social and environmental integration	Demonstrates modularity and technological adaptability

The two selected case studies that Pasona Urban Farm in Tokyo and InFarm Modular Urban Farming System in Berlin represent distinct yet complementary models of integrating food production into interior environments. While Pasona Urban Farm exemplifies a holistic architectural transformation, where hydroponic systems are fully embedded into the spatial and social fabric of a corporate office, InFarm demonstrates a distributed modular approach, embedding compact, IoT-controlled farming units within retail and semi-public interiors. Together, these cases illustrate the dual spectrum of interior urban agriculture: from large-scale, human-centered ecological design to scalable, technology-driven modularity. Their combined analysis enables a comprehensive understanding of how productive systems can operate across different interior typologies, offering both experiential and systemic insights for future residential applications (Table 1).

The selection of Pasona Urban Farm and InFarm Modular System was also guided by their potential relevance to resilience design principles. Pasona exemplifies how agricultural systems can be architecturally integrated into existing structures, creating self-sustaining interiors that support human well-being and productivity. InFarm, on the other hand, represents the distributed and adaptive logic necessary for crisis-responsive urban systems. Together, these cases provide a dual framework for developing a modular, low-resource, and relocatable interior agriculture model applicable to post-disaster living conditions.

2.3. Evaluation Criteria and Analytical Framework

The two cases are evaluated through dual lenses which are design-oriented and system-oriented to identify converging principles of functionality, spatial experience, and sustainability. This analytical framework supports a cross-disciplinary understanding of productive interior environments and informs the modular design proposal in later sections (Table 2).

Table 2. Design-system evaluation framework

Criteria Type	Design-Oriented Indicators	System-Oriented Indicators
Spatial Integration	Visual openness, ergonomic access, lighting composition	Vertical layering, structural adaptability, compact layout
Environmental Performance	Air quality, biophilic comfort, material expression	Energy efficiency, water recycling, LED optimization
User Interaction	Participation, sensorial immersion, accessibility	Automation, IoT monitoring, maintenance cycles
Scalability and Modularity	Flexibility, compositional reconfiguration	Stackability, distributed deployment, interoperability
Urban Relevance	Health and well-being benefits, urban lifestyle enhancement	Resource efficiency, local food systems, resilience potential

Table 2 presents the Design-System Evaluation Framework used to assess interior urban agriculture integrations. The framework was developed through a deductive process based on recurring categories in the literature on controlled-environment agriculture and interior spatial integration. Core dimensions (e.g., spatial integration, environmental performance, user interaction, scalability/modularity, and urban relevance) were consolidated because they repeatedly appeared as design-relevant variables across indoor farming studies and productive interior discussions. These criteria were then operationalized as paired indicators which is design-oriented and system-oriented to support consistent cross-case comparison. The resulting matrix functions as an analytical rubric that structures the case reading and ensures that evaluations are traceable to predefined criteria rather than ad hoc interpretation.

2.4. Thematic Intersection and Residential Relevance

The comparative analysis identifies synergistic themes between the two systems that can inform a residential application model, particularly in dense, polluted urban environments where access to greenery and food security is limited (Table 3).

Table 3 synthesizes the comparative case analysis by mapping “thematic intersections” between Pasona Urban Farm and InFarm. Intersections were identified through an iterative coding process applied to case documentation (published descriptions, visuals, and reported system characteristics). First, evidence relevant to the Table 2 criteria was extracted for each case (e.g., visibility of cultivation, maintenance legibility, modular connectivity, and user engagement). Second, themes were marked as “intersections” when both cases demonstrated convergent patterns, even if realized at different scales or through different technologies. Finally, each intersection was translated into a residential relevance statement, clarifying how the shared theme informs the proposed Adaptive Hydro-Cell’s application in compact or post-disaster interiors. In this way, Table 3 functions as a bridge from case evaluation to design synthesis.

2.5. Methodological Contribution

The dual-case methodology establishes an analytical bridge between design-centered integration (Pasona Urban Farm) and system-centered modularity (InFarm). By comparing these typologies, the study identifies transferable principles applicable to residential interiors, particularly in high-density, pollution-prone, and green-space-deficient cities. This methodological structure also provides the foundation for the design proposal developed in Section 5. In this section a modular, scalable, human-centered interior agriculture system that merges environmental technology with interior architecture strategies. The integration of these cases ensures that both spatial experience and technological adaptability are represented as co-dependent pillars of sustainable urban living.

Table 3. Thematic intersection matrix

Design–System Axis	Pasona Urban Farm	InFarm Modular System	Potential for Residential Application
Spatial Integration	Entire office converted into agricultural interior	Modular vertical units adaptable to confined interiors	Small-scale, modular systems for apartments and communal housing
User Experience	Employees interact with plant systems daily	Consumers harvest and observe in real time	Residents engage in food-growing and sensory interaction
System Complexity	Multi-zone hydroponic infrastructure	Compact IoT-controlled farming units	Smart home-compatible vertical modules
Aesthetic Role	Greenery as spatial and symbolic feature	Transparent design highlights production process	Biophilic modules as part of interior décor
Sustainability Focus	Social sustainability and workplace well-being	Localized food loops and circularity	Food resilience and improved indoor air quality

3. Results

3.1. Case Studies

3.1.1. Pasona urban farm

The Pasona Urban Farm, designed by Kono Designs and completed in 2010 in Tokyo, is one of the most cited examples of integrating hydroponic agriculture within a corporate office interior. The nine-story headquarters of the Pasona Group transformed approximately 4,000 square meters of workspace into a productive biophilic environment that houses rice paddies, tomato vines, and salad greens grown under LED and natural light systems. The design integrates hydroponic installations into ceilings, walls, and meeting rooms, merging the concepts of workspace, nature, and agriculture in a continuous spatial experience (Al-Kodmany, 2024; Hoang, 2021). This integration redefines how interiors can simultaneously function as both productive systems and occupant-centered environments, reflecting a new paradigm of urban agriculture as architectural infrastructure rather than an external supplement.

A key architectural challenge in Pasona's design was to balance technological precision required for plant cultivation with human comfort parameters such as light quality, humidity, and airflow. Hydroponic systems are distributed through transparent partitions, suspended planters, and ceiling-integrated channels, with automated nutrient cycles and climate control mechanisms (D'Ostuni et al., 2024). The resulting environment demonstrates a symbiotic exchange between building and biology. Plants contribute to improved indoor air quality, acoustic dampening, and psychological well-being, while the building provides the necessary structural and environmental support for sustained cultivation. This configuration exemplifies a circular environmental model, where the workspace itself becomes a living system contributing to ecological performance and employee engagement (Figure 1).

From a design perspective, Pasona Urban Farm embodies the concept of biophilic productivity, where contact with living systems enhances both cognitive and emotional well-being. Recent analyses highlight how employees' exposure to cultivated greenery leads to measurable reductions in stress and increases in perceived creativity and workplace satisfaction (Ugai, 2012; Markerink, 2020). Unlike conventional green offices that use static plants for visual comfort, Pasona's approach introduces dynamic growth cycles. It includes employees witness planting, harvesting, and seasonal change, thereby transforming everyday routines into participatory environmental experiences. The presence of hydroponic cultivation units inside meeting rooms and hallways reinforces the notion of agriculture as interaction, making sustainability an embodied part of workplace culture rather than a background feature (Cam-Ly, 2025). In environmental terms, Pasona's integrated hydroponic model also achieves substantial resource efficiency compared to traditional office greening strategies. Studies on hybrid building-greenhouse typologies have shown that such integrated systems can reduce CO_2 emissions and cooling loads by 20–30%, while supporting local food production cycles (Negrello, 2019; D'Ostuni et al., 2024). The case thus presents a prototype for future interior agriculture typologies, buildings designed as metabolic systems that circulate air, light, and nutrients through productive networks. Pasona Urban Farm's success lies in its holistic fusion of architecture, agriculture, and corporate identity, offering a blueprint for how interior environments can cultivate resilience, productivity, and environmental literacy simultaneously (Mulugu et al., 2019). This case corresponds to the first example presented in Table 1 (Comparative Overview of Selected Cases), where Pasona Urban Farm represents the design-integrated, holistic model of indoor urban agriculture, contrasting with InFarm's modular, distributed approach.

The Pasona Urban Farm case exemplifies the architectural and experiential potential of integrating food production systems within interior environments. Its success lies in translating hydroponic technology into a multisensory workplace experience that redefines the relationship between design, productivity, and well-being. Table 4 summarizes the key intersections between interior architecture and hydroponic system integration, highlighting how spatial, aesthetic, and environmental decisions shape the project's contribution to productive interior research.

Table 4. Design–system relationship in case 1: Pasona urban farm (Tokyo, Japan). Source: Kono designs (2010); D'Ostuni et al. (2024); Ugai (2012); Hoang (2021); Markerink (2020)

Design Aspects	System Aspects (Farming Components)	Interior-Farming Intersection / Rationale for Selection
Biophilic integration – greenery as part of workspace aesthetics and psychological comfort	Hydroponic rice and vegetable systems integrated into ceilings and glass partitions	Demonstrates how agricultural systems can *coexist with office functions* without compromising spatial quality, aligns with biophilic and wellness-driven design.
Spatial transparency – open-plan offices merged with planting areas	Climate-controlled irrigation and LED lighting embedded in interior structures	Illustrates integration of *building services* with productive systems, turning the building into a living environmental interface.
Multi-functionality – meeting rooms as cultivation zones	Automated nutrient circulation ensuring year-round growth	Shows how productive activities enhance human experience. It represents a design typology where *interior use and agriculture overlap physically*.
Aesthetic identity and brand narrative – corporate image built around sustainability	Hybrid lighting design balancing human comfort and plant requirements	Chosen for its demonstration of *architecture-agriculture symbiosis* and strong relevance to *productive interior architecture research*.

3.1.2. InFarm modular vertical farming units

The InFarm Modular Urban Farming System, developed in Berlin in 2013, represents one of the most successful applications of modular and scalable vertical farming within retail and public interior environments. Unlike large-scale, building-integrated farms such as Pasona, InFarm's model decentralizes production by installing compact hydroponic units inside supermarkets, restaurants, and educational spaces. Each module functions as a self-contained, climate-controlled micro-farm capable of growing over 350 varieties of herbs, leafy greens, and micro-vegetables (Marius-Catalin, 2023). These plug-and-play systems are IoT-connected, allowing centralized monitoring of nutrient levels, temperature, and humidity through cloud-based management networks. The result is a hybrid system where food production becomes both visible and interactive, bridging agricultural processes and everyday consumption.

From a spatial design perspective, InFarm's units demonstrate how productive systems can be integrated into non-traditional interior typologies from grocery aisles to office lobbies, without major architectural alterations. The modularity of the design allows the units to adapt to different floor plans, ceiling heights, and lighting conditions. Each module consists of a vertical hydroponic column enclosed within transparent glass housing, lit by optimized full-spectrum LEDs to ensure uniform plant growth (Abbasi, 2020; Lam, 2022). The transparent enclosure enables users to observe the cultivation process, creating a performative and educational dimension to interior spaces. As a result, InFarm installations act as micro-landscapes of productivity, where the act of harvesting becomes a social and sensory experience embedded in urban daily life (Anand et al., 2022).

In technological terms, InFarm exemplifies how smart agritech systems can be applied to urban interiors to create energy-efficient and data-driven cultivation networks. The integration of sensors, automation, and machine learning algorithms enables the system to optimize light and nutrient delivery dynamically, leading to water savings of up to 95% and a 90% reduction in food miles compared to conventional supply chains (Kabir et al., 2023; Minaei, 2022). This digitally enhanced farming approach has been characterized as part of the emerging "Agro-IoT paradigm," where food systems and architecture converge through real-time environmental feedback loops (Monteiro et al., 2023). Such adaptability allows InFarm modules to function as scalable building components that can be deployed across different contexts from commercial interiors to high-density housing. It is offering flexible pathways toward resilient urban food infrastructures.

From a design and sustainability standpoint, InFarm's success lies in transforming urban consumption sites into production environments. Studies indicate that the psychological impact of visible plant growth within everyday commercial spaces enhances consumer engagement and fosters environmental awareness (Akintuyi, 2024; Failor, 2023). Moreover, the modularity of the InFarm system supports circular lifecycle strategies, allowing easy maintenance, relocation, and material recycling. This design logic aligns with the broader movement toward distributed, user-centered urban farming systems, which democratize access to fresh food while redefining the spatial and social boundaries of agriculture. The InFarm model, therefore, offers a replicable design prototype for future interior applications, especially in dense metropolitan areas where air quality, limited greenery, and community well-being are key urban design concerns. This example corresponds to Table 1, representing the modular, distributed, and IoT-enabled model of indoor urban agriculture which is complementary to the holistic, spatially integrated model of Pasona Urban Farm (Figure 2).

Figure 1. Pasona urban farm by kono designs (https://static.dezeen.com/uploads/2013/09/dezeen_pasona-urban-farm_ss_12.jpg).

Figure 2. Infarm's urban farming system in Germany (https://nocamels.com/2020/02/infarm-tech-micro-farms-fresh-produce-urban/).

The InFarm Modular Urban Farming System represents a contrasting yet complementary model, emphasizing adaptability, modularity, and user engagement across diverse urban contexts. By merging IoT-enabled agricultural systems with interior architecture principles, InFarm transforms commercial interiors into interactive micro-farming spaces. Table 5 outlines the principal design-system relationships observed in this case, illustrating how digital technology, modular form, and spatial transparency collectively support the emergence of a new typology of smart, biophilic interiors.

Urban food resilience has become an urgent issue in the face of climate crises, natural disasters, and the fragility of global supply chains. Recent research emphasizes the necessity of developing adaptive and low-resource agricultural systems capable of functioning in post-disaster or resource-constrained interiors (Grochulska-Salak et al., 2021; Griebel et al., 2022; D'Ostuni et al., 2024). Within this context, this study introduces the Adaptive Hydro-Cell (AHC). It is a modular, self-sufficient, and air-purifying hydroponic system specifically designed for use in temporary housing, compact urban dwellings, and post-earthquake recovery units. Unlike existing modular systems such as InFarm or IKEA Växer, the AHC prioritizes resilience, autonomy, and health over commercial scalability. Each module functions as both a productive agricultural cell and an environmental device; filtering air, reusing greywater, and regulating humidity (Figure 3).

Figure 3. Adaptive hydro-cell concept renders.

Table 5. Design–system relationship in case 2: InFarm modular urban farming system (Berlin, Germany). Source: Marius-Catalin (2023); Abbasi (2020); Lam (2022); Kabir et al. (2023); Monteiro et al. (2023)

Design Aspects	System Aspects (Farming Components)	Interior-Farming Intersection / Rationale for Selection
Modularity and scalability – adaptable units for various interior typologies	Plug-and-play hydroponic modules with IoT sensors and cloud control	Selected for its *high adaptability* to existing interiors and demonstration of *distributed urban agriculture networks*.
Transparency and visibility – plants as active interior elements	Glass-enclosed growth chambers using full-spectrum LEDs	Represents performative design where farming becomes a *visual and educational experience* in public and retail spaces.
Flexibility and portability – units can be relocated or reconfigured	Lightweight structural design with closed water cycles	Chosen to represent *temporary or adaptive urban systems*, essential for resilient post-disaster or mobile urban contexts.
Digital aesthetics and smart interaction – users engage with data and plant growth	Agro-IoT data feedback and AI optimization	Demonstrates the emerging *"smart biophilic interior"* concept, where design and biology are linked through digital feedback loops.

Table 6. Design principles of the adaptive hydro-cell (AHC)

Design Principle	Description	Expected Benefit	Supporting Sources
Resilient Modularity	Stackable and connectable units for flexible interior adaptation.	Rapid deployment in emergency housing and scalable integration in apartments.	Ghazal et al., 2023; Zhou, 2024
Water Circularity	Dual-loop greywater filtration and hydroponic recirculation.	Reduces freshwater dependency and waste.	D'Ostuni et al., 2024; Zhang et al., 2025
Air Purification Layer	Active carbon and root-zone filtration integrated into module base.	Improves indoor air quality in polluted or temporary environments.	Burattini et al., 2015
Solar-Assisted Power	Thin-film PV cells embedded in upper frame with micro-battery storage.	Enables off-grid operation up to 48 hours.	Zhang et al., 2025; Lakhiar et al., 2025
Biophilic Lighting and Recovery	Dynamic spectrum LEDs tuned for both plant growth and human circadian rhythm.	Enhances psychological well-being and trauma recovery.	Zhong et al., 2021; Cam-Ly, 2025

3.2. Modular Design Proposal for Interior Urban Agriculture

3.2.1 Conceptual framework: adaptive hydro-Cell (AHC) and Design Framework

The Adaptive Hydro-Cell is conceived as a plug-in modular system that can be rapidly deployed in temporary or permanent interiors. Each unit measures approximately 1.2m × 0.6m × 2.2m, designed to fit within standard housing modules or converted shelters. The modular geometry allows horizontal and vertical stacking, enabling multiple configurations such as from single-user kitchen walls to collective food "columns" in community shelters.

The AHC combines hydroponic growth layers, a dual-loop water system, and a biophilic lighting system. Its structure uses recycled biocomposite panels (bamboo fiber, hemp, mycelium-based materials) that can be locally produced at low cost. Integrated active carbon filters and root-zone aeration act as a micro air-cleaning system, improving indoor air quality in polluted or enclosed post-disaster shelters.

Each AHC module integrates four main systems (Figure 4):

1. Hydroponic Growth Chamber - three vertically stacked trays for leafy greens, herbs, or micro-vegetables, optimized for 20–25°C.
2. Water and Filtration Loop - passive capillary irrigation system powered by a low-energy pump, recycling greywater through a three-stage carbon–UV filter.
3. Air Filtration Chamber - includes bioactive substrates at the root level, reducing CO_2 and volatile organic compounds (VOCs).
4. Lighting and Power Unit - full-spectrum LEDs with solar microbattery integration and light sensors for adaptive output.

The Adaptive Hydro-Cell is envisioned as a trans-scalar system, functioning across residential, institutional, and emergency contexts (Table 7).

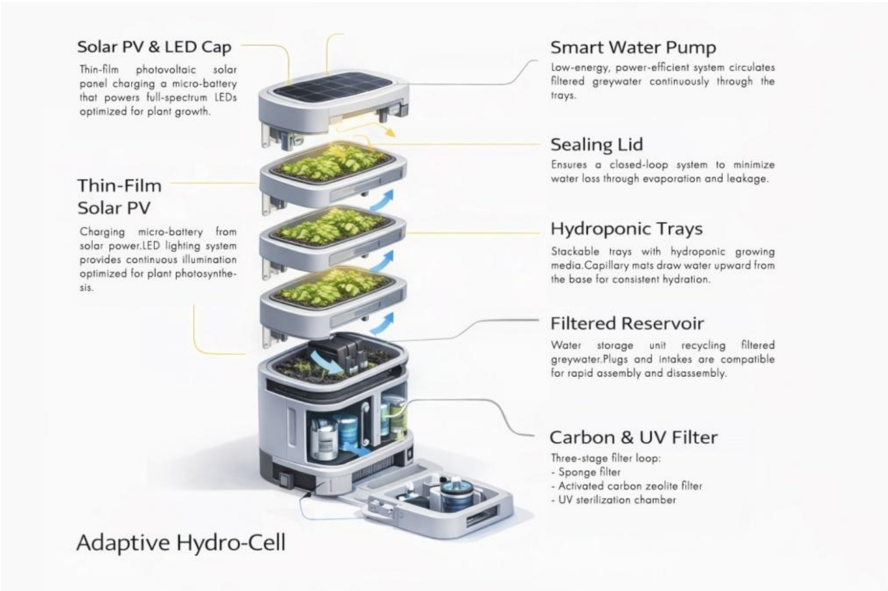

Figure 4. System Diagram of the Adaptive Hydro-Cell**.** Schematic showing airflow, water recirculation, lighting array, and modular connectivity.

Table 7. Potential applications of the AHC system

Context	Mode of Use	Potential Impact
Post-Disaster Housing	Installed within prefabricated shelters or containers as plug-in modules.	Ensures immediate food access and psychological recovery through nature exposure.
Urban Micro-Apartments	Mounted on walls or integrated into kitchen cabinetry.	Enhances air quality and daily nutrition in dense urban dwellings.
Community Centers / Schools	Configured in clusters to serve as micro learning gardens.	Promotes environmental education and communal resilience.
Healthcare / Recovery Spaces	Integrated as therapeutic biophilic elements.	Aids stress reduction and post-trauma mental health.

3.2.2. Original Contribution and Research Value

Beyond functionality, the AHC's biophilic design logic aims to restore emotional balance in uncertain or traumatic environments. Studies have shown that interaction with living systems inside confined spaces supports cognitive recovery, relaxation, and environmental empathy (Zhong et al., 2021; Ugai, 2012). The lighting design uses gradient color temperatures warmer tones for relaxation and cooler spectrums for photosynthesis to ensure both human comfort and plant vitality. Thus, the AHC is not only a survival tool but a living therapeutic element within interior architecture (Figure 5).

The Adaptive Hydro-Cell fills a distinct gap in the current literature on indoor agriculture and modular design. While existing systems emphasize technological optimization or aesthetic integration, none specifically address post-disaster adaptability, self-sufficiency, and psychological regeneration within interior environments. This proposal introduces a design-driven framework that merges:

- Environmental Engineering (hydroponic efficiency)
- İnterior architecture (spatial and sensory quality)
- Humanitarian Architecture (resilience and adaptability)

By positioning food cultivation as an adaptive survival mechanism, the AHC redefines interior space as a regenerative infrastructure. It capable of sustaining life, health, and hope in the most fragile urban conditions.

Figure 5. Adaptive Hydro-Cell integrated into post-disaster living unit. Schematic rendering of the Adaptive Hydro-Cell (AHC) positioned within a compact living container, illustrating its real-world application in a post-disaster or temporary housing context.

4. Discussion

The Adaptive Hydro-Cell (AHC) presents a new typology in the intersection of interior architecture, environmental design, and controlled agriculture. The system's modularity and autonomous functionality respond not only to the aesthetic and spatial ambitions of urban interior farming but also to the critical need for resilience in post-disaster environments. Through the integration of hydroponic cultivation, air purification, and digital monitoring, the AHC transforms interior spaces from passive enclosures into active ecological infrastructures. From a spatial and experiential standpoint, the AHC redefines the relationship between human comfort, environmental quality, and interior productivity.

Unlike conventional hydroponic systems that prioritize yield and efficiency, this design prioritizes multi-sensory interaction, biophilic presence, and visual integration within domestic and communal environments. Its cylindrical geometry and transparent panels enhance visual permeability, allowing users to perceive plant growth as a living aesthetic component of the interior (Zhong et al., 2021).

In emergency and high-density urban contexts, interior architectureers can employ the AHC as a modular architectural element which is a vertical column of life, capable of adapting to different typologies such as living rooms, dormitories, and prefabricated shelters. Furthermore, its embedded LED spectrum is tuned to both plant growth and human circadian rhythms, promoting psychological stability and routine restoration among displaced or stressed populations (Burattini et al., 2015).

Despite its conceptual and social potential, several engineering challenges must be addressed for large-scale implementation. The energy balance between lighting and water circulation systems remains the most critical technical constraint. While thin-film photovoltaics (Zhang et al., 2025) support partial autonomy, consistent operation in low-light or winter conditions may require hybrid energy solutions.

Additionally, maintaining water quality in closed hydroponic loops poses difficulties under unstable environmental conditions typical of post-disaster shelters. Filters and UV sterilization modules need regular maintenance, which may be challenging without professional supervision. The material sustainability of the modular units is another factor. It though the prototype uses recyclable composites, mass production must ensure low embodied carbon and compatibility with circular construction principles (D'Ostuni et al., 2024). The use of IoT integration provides real-time monitoring advantages but also raises concerns about data reliability, connectivity in remote zones, and the need for simplified user interfaces. Future prototypes should balance technological sophistication with operational simplicity, ensuring usability across diverse socio-economic contexts.

4.1. Design and Research Limitations

This study focuses primarily on the conceptual and spatial aspects of integrating modular hydroponic systems within interior spaces. Although supported by existing literature and precedent cases such as Pasona Urban Farm and InFarm, the Adaptive Hydro-Cell has not yet undergone empirical validation or user testing. Further interdisciplinary research is needed to evaluate long-term performance metrics such as energy consumption, crop yield, user comfort, and indoor air quality improvements in real post-disaster settings.

Moreover, the visual and psychological effects of integrating productive biophilic elements into emergency interiors remain underexplored. Collaboration between interior architectureers, agronomists, and behavioral scientists could extend this research toward a quantitative design-performance framework linking environmental and human health outcomes.

Ultimately, the Adaptive Hydro-Cell suggests a paradigm shift: interiors are no longer static shelters but dynamic, regenerative systems. By aligning spatial design with food and energy cycles, the AHC contributes to a broader discourse on circular design and self-sufficient architecture. In post-disaster housing, this approach not only mitigates supply vulnerabilities but also rebuilds a sense of autonomy, routine, and connection to nature, crucial factors in psychological recovery and social resilience. Thus, this proposal represents more than a design object. It is a prototype for living infrastructure, embodying the convergence of sustainability, adaptability, and care. Its future evolution depends on collective experimentation, bridging the technical precision of engineering with the empathetic intelligence of interior architecture.

5. Conclusion

This study explored the integration of urban agriculture systems into interior environments through a design-oriented approach, culminating in the proposal of the Adaptive Hydro-Cell (AHC). It is a modular, self-sustaining, and resilience-based hydroponic unit. By synthesizing insights from architectural design, controlled-environment agriculture, and post-disaster resilience studies, the AHC redefines the interior as a productive, regenerative, and adaptive system capable of sustaining both ecological and human well-being. The research demonstrates that interior architecture can play a pivotal role in addressing food insecurity, environmental degradation, and psychological recovery in crisis conditions. Although the AHC remains at a conceptual stage, its framework offers a foundation for future empirical testing and interdisciplinary collaboration, particularly in contexts where design innovation meets humanitarian necessity.

This research may contribute to multiple professional domains, including interior architects, architects, urban designers, building-services engineers, and controlled-environment agriculture practitioners, by offering a shared design-system framework for integrating cultivation infrastructures into interiors. It may also inform humanitarian design and disaster-risk reduction efforts by conceptualizing modular food production as an interior resilience strategy suitable for temporary housing and resource-limited urban settings.

In conclusion, the Adaptive Hydro-Cell represents a new paradigm for interior agriculture—one that transcends aesthetics to embody resilience, autonomy, and care. As global urban systems face growing uncertainty, such design-led strategies may hold the key to creating self-sufficient and restorative living environments for the future.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	N.A.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study and the data. The data/information used in this study is publicly available and can be accessed through industry organisations and company websites. Additionally, this study has not been previously published or submitted for publication.

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