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Integrated Rooftop Livestock–Urban Farming: A Conceptual Model for Residential Settings

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Abstract

Background: Urban residential areas face limited productive land, while demand for local food production and resource efficiency continues to increase. Rooftop spaces offer opportunities for integrated food production; however, existing approaches are often developed as individual or partially integrated systems.
Objective: This study aims to develop a conceptual Integrated Rooftop Livestock–Urban Farming System for residential rooftop applications by integrating hydroponic Nutrient Film Technique (NFT), a Recirculating Aquaculture System (RAS), laying hens, and a solar energy support subsystem.
Method: The study employs a systems approach supported by a structured literature review, conceptual system formulation, technical parameterization, resource flow modeling, and conceptual assessment based on the judgments of five multidisciplinary experts.
Results: Five experts assessed the system architecture, resource controls, technical requirements, hygiene considerations, and rooftop constraints. The system was refined to distinguish the transfer of treated water from the RAS from the separately controlled supply of hydroponic nutrients. The resulting conceptual model integrates four subsystems through controlled relationships involving water, nutrients, energy, organic resources, and food products.
Conclusion: The model provides a conceptual basis for further technical parameterization, quantitative modeling, prototype development, performance testing, and residential pilot implementation. Its novelty lies in integrating four food and energy subsystems through controlled resource relationships within a residential rooftop context.

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INTRODUCTION

Urban agriculture has expanded as a response to constraints on productive land and the need to strengthen localized food production, sustainability, and urban resilience. Agricultural land conversion associated with urban and regional development can reduce the availability of productive land and place additional pressure on agricultural production and food security (Syakirotin et al., 2025). Research on urban food production addresses crop, aquaculture, and livestock functions, whereas renewable energy and Food–Energy–Water (FEW) Nexus studies address operational support and resource-flow relationships (Guzman-Molina et al., 2026; Sonnino, 2023a; Wadumestrige Dona et al., 2021; Yuan et al., 2022). These studies indicate that

urban agriculture can support food security and localized food systems, while its development remains influenced by spatial, technological, institutional, and sustainability-related conditions (Hardman et al., 2022; Pickles et al., 2026; Tabrez, 2025).

Rooftops provide an alternative production space where land availability is limited. Studies have examined rooftop farming, rooftop greenhouses, and residential rooftop applications, including their potential contributions to food production and urban sustainability (Akbar et al., 2025; Drottberger et al., 2023a; Gammal et al., 2024a; Harada & Whitlow, 2020a). Rooftop agriculture, however, requires consideration of structural capacity, spatial configuration, access, environmental conditions, management, and implementation support. Urban agriculture and rooftop planning research further emphasises the importance of policy, spatial assessment, governance, and contextual barriers (Nikolaidou et al., 2023; Raja et al., 2024; Yuan et al., 2022). Thus, a rooftop should be considered not merely as a location for production components but also as a system boundary.

Within limited spaces, hydroponic and vertical farming provide controlled approaches to crop production and spatial efficiency, while also requiring careful management of water, nutrients, energy, and environmental conditions (Gammal et al., 2024a; Mir et al., 2022a; Zaręba et al., 2025a). Recirculating aquaculture systems (RAS) and aquaponic systems similarly provide controlled fish production through water circulation, filtration, and nutrient-related processes (Behera et al., 2024a; Ekawati et al., 2021a). Research on integrated aquaculture and circular systems has further explored nutrient cycling, water reuse, and resource recovery (Grozeva et al., 2026a; Zimmermann et al., 2023a). Small-scale poultry and crop–livestock studies demonstrate the potential contribution of animal production to household food access while also highlighting management and sustainability considerations (Braamhaar et al., 2025; Kanosvamhira, 2024; Quaye et al., 2025a). Renewable energy can provide supporting infrastructure for energy-intensive production components, including aquaculture and controlled farming systems (Lee et al., 2025a; Zhang et al., 2024).

Previous urban farming practices have also demonstrated the potential to combine different food-production activities within limited urban spaces. Evidence from Surakarta indicates that household-scale urban farming can contribute to household food provision and food expenditure savings through activities including the production of vegetables, fruits, and freshwater fish (Barokah et al., 2023). In Semarang, integrated urban farming practices have incorporated hydroponic production, aquaculture, livestock-related activities, and renewable energy support (Natama et al., 2024a). These findings indicate that partial forms of integration have already been explored, while also highlighting the need to examine how multiple subsystems can be structured within a coherent system architecture.

At the system level, Food–Energy–Water (FEW) Nexus and circular-resource perspectives emphasize the interdependence of food production, water, energy, nutrients, and organic resources (Caputo et al., 2021a; Huang & Chang, 2021a). Urban food-system research further highlights localization, resilience, and the relationship between agricultural production and household food needs (Zeeuw & Drechsel, 2015; Zhong et al., 2023; Zhu & Tsoulfas, 2024). The literature examined in this study addresses rooftop agriculture, aquaculture, livestock production, and renewable energy integration through individual technologies or partial system combinations. However, the synthesis identifies a need for a conceptual architecture that explicitly coordinates these subsystems and their controlled resource-flow relationships within a residential rooftop boundary. In particular, the integration of livestock production with rooftop food–energy–water systems requires further conceptual development, considering the operational, spatial, and resource-management requirements of residential (Braamhaar et al., 2025; Huang & Chang, 2021b; Quaye et al., 2025b).

This study addresses this gap by developing a Rooftop Livestock–Urban Farming Integrated System that integrates hydroponic Nutrient Film Technique (NFT), recirculating aquaculture systems (RAS), laying hens, and solar energy within a residential rooftop boundary. The model represents water, nutrients, energy, organic resources, and food products through controlled resource-flow relationships rather than assuming unrestricted circularity. The study therefore positions its contribution at the level of integration architecture, resource-flow relationships, and residential system boundaries, rather than technological novelty in the individual subsystems.

Accordingly, three research questions guide the study: (RQ1) How can hydroponic NFT, RAS aquaculture, laying hens, and solar energy be integrated within a residential rooftop architecture? (RQ2) How can their water, nutrient, energy, organic-resource, and food-product relationships be controlled? (RQ3) How can expert judgment be used to assess and refine the conceptual model? The objectives are to develop the four-subsystem architecture, formulate the controlled resource-flow framework, and refine the conceptual model based on expert judgment.

METHOD

This study adopted a system-oriented conceptual research approach to develop a Rooftop Livestock–Urban Farming Integrated System for residential rooftop applications. The research focused on developing an integrated conceptual model rather than experimentally testing a physical prototype. The research process comprised a literature review and state-of-the-art analysis, research gap identification, conceptual model development, technical parameterization, resource-flow modeling, expert judgment, and model assessment and refinement.

The system is structured around four primary subsystems: hydroponic Nutrient Film Technique (NFT), Recirculating Aquaculture System (RAS)-based aquaculture, laying hens, and solar energy. Each subsystem was examined in terms of its function, resource requirements, outputs, inter-subsystem relationships, technical requirements, hygiene considerations, and applicability within a residential rooftop boundary.

The study used secondary and primary qualitative data. Secondary data were obtained from scientific articles, literature reviews, technical references, and supporting documents to establish the state of the art, research gap, and supporting technical information. Primary data were obtained through direct field observations and technical discussions or interviews with practitioners involved in laying-hen farming, hydroponic systems, aquaculture, and solar-energy systems. These activities included site observations, discussions, question-and-answer sessions, and technical consultations regarding operational conditions, resource requirements, equipment configurations, production capacities, and energy requirements.

Additional primary qualitative data were obtained through expert judgment to assess the conceptual model, resource relationships, technical feasibility, hygiene, residential rooftop applicability, implementation considerations, and research boundaries.

The conceptual model was developed by synthesizing the literature evidence, identified research gap, field observations, practitioner consultations, subsystem functions, and residential rooftop constraints. The four subsystems were subsequently structured within a common system boundary and connected through relationships involving water, nutrients, energy, organic resources, and food products.

Technical parameterization was applied to establish a practical operating basis for the conceptual relationships. Technical parameters were derived from a combination of field observations, practitioner consultations, supporting literature, and author calculations. Field observations and technical discussions were used to identify practical operating conditions, subsystem configurations, capacity considerations, resource requirements, equipment characteristics, and energy requirements. Parameters obtained from field observations or practitioner consultations were treated as field-informed technical parameters, while values derived through calculations were treated as calculated parameters. Design values introduced for the proposed integrated configuration were treated as initial design parameters.

The parameters included water and nutrient requirements, pH, electrical conductivity (EC), total dissolved solids (TDS) or parts per million (PPM), temperature, and production capacity for hydroponic NFT; water volume, fish stocking capacity, circulation, dissolved oxygen, and ammonia and nitrite concentrations for RAS-based aquaculture; the number of chickens, space requirements, ventilation, feed, egg production, and manure generation for laying hens; and energy demand, installed capacity, daily energy production, and operating load for solar energy.

These parameters provide a field-informed technical basis for the conceptual configuration but do not constitute empirical performance validation of the integrated system. The integrated configuration has not yet been physically operated or tested under residential rooftop conditions. Therefore, subsystem performance, energy sufficiency, resource efficiency, production capacity, structural feasibility, and overall system performance require further validation through quantitative modeling, prototyping, and controlled testing.

Resource relationships were mapped across water, nutrients, energy, organic resources, and food products. Water was represented as RAS → filtration/treatment → controlled reuse, while nutrient management remained controlled within the hydroponic subsystem. Energy was represented as solar energy → electrical demand → hydroponic NFT, RAS, and supporting loads. Organic resources were represented as chicken manure/organic waste → management/treatment → potential reuse. Food products, including eggs, fish, and vegetables, were treated as outputs directed toward consumers within the system boundary.

These relationships were formulated as controlled resource flows rather than unrestricted circular flows because outputs from one subsystem cannot automatically be transferred as inputs to another subsystem without considering operational, quality, treatment, and safety requirements.

Expert judgment was conducted to assess the conceptual relevance, technical feasibility, resource relationships, residential rooftop applicability, hygiene, and implementation aspects of the proposed integrated system. Five multidisciplinary experts contributed complementary assessments. Expert 1, specializing in government food policy, evaluated system relevance. Expert 2, with expertise in economics, assessed implementation considerations. Expert 3, representing BRIN research, examined technical integration. Expert 4, specializing in residential architecture, assessed residential rooftop constraints. Expert 5, with expertise in food technology, evaluated food production and hygiene requirements.

The experts were selected purposively based on the relevance of their professional or academic backgrounds to the multidisciplinary dimensions of the proposed model. The assessment involved model presentation, discussion, structured questioning, and the collection of expert perspectives and recommendations. The experts assessed the four-subsystem architecture hydroponic NFT, RAS-based aquaculture, laying hens, and solar energy with particular attention to system structure, inter-subsystem relationships, controlled resource flows, technical and operational considerations, residential rooftop conditions, hygiene and safety, and model boundaries.

Expert statements and recommendations were organized into recurring themes covering system architecture, resource-flow relationships, technical feasibility, residential rooftop conditions, hygiene and safety, economic and implementation considerations, and research limitations. Areas of agreement were identified when expert perspectives supported the same conceptual principle, while differing perspectives were retained as complementary considerations. The resulting findings were used to identify elements that should be retained, clarified, or refined in the conceptual model.

Literature data were analyzed through thematic synthesis to establish the state of the art and research gap. Technical and design data were analyzed through system parameterization, while resource-flow data were analyzed by mapping water, nutrient, energy, organic-resource, and food-product relationships. Expert statements and recommendations were analyzed qualitatively through thematic synthesis to identify assessment findings and model-refinement requirements.

The analytical structure was aligned with the research questions: system analysis addressed RQ1, resource-flow analysis addressed RQ2, and thematic analysis of expert judgment addressed RQ3. The resulting outputs were an integrated four-subsystem architecture, a controlled resource-relationship framework, and an expert-refined conceptual model. The research stages, from the literature review and problem formulation through model development, expert assessment, and refinement, are presented in Figure 1.

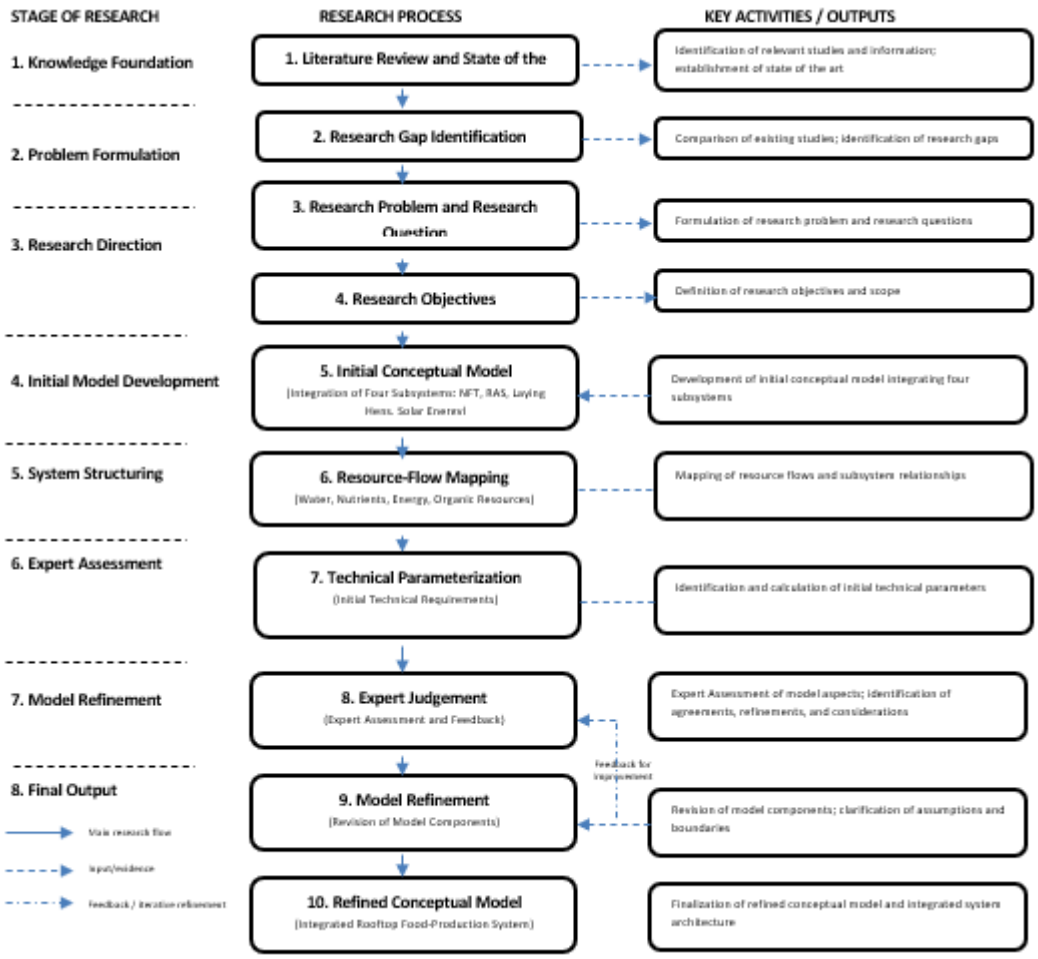

Figure 1. Research framework for the development and refinement of the integrated residential rooftop food-production conceptual model

RESULTS AND DISCUSSION

Results

Integrated Rooftop System Architecture and Technical Configuration

The first result is an integrated rooftop livestock–urban farming conceptual architecture that combines four primary subsystems within a residential rooftop boundary: hydroponic Nutrient Film Technique (NFT), a Recirculating Aquaculture System (RAS), laying hens, and solar energy. These subsystems provide complementary functions, including vegetable production, fish production, egg production, and supporting energy provision. The architecture considers the four subsystems as components of a common system rather than as independent production units, with their relationships defined through water, nutrients, energy, organic resources, and food products.

Previous studies demonstrate the applicability of rooftop farming, hydroponics, vertical farming, aquaculture/RAS, integrated farming, and renewable energy under spatial and resource constraints (Behera et al., 2024b; Drottberger et al., 2023b; Lee et al., 2025b; Mir et al., 2022b; Zaręba et al., 2025b). However, these approaches generally address individual technologies or partial combinations. This observation is consistent with previous urban farming studies showing that integrated practices have been developed through combinations of hydroponics, aquaculture, livestock, and renewable energy support, but within particular program or community contexts (Natama et al., 2024a). This study therefore proposes a four-subsystem residential rooftop architecture that retains subsystem-specific requirements while defining their relationships within a single system boundary.

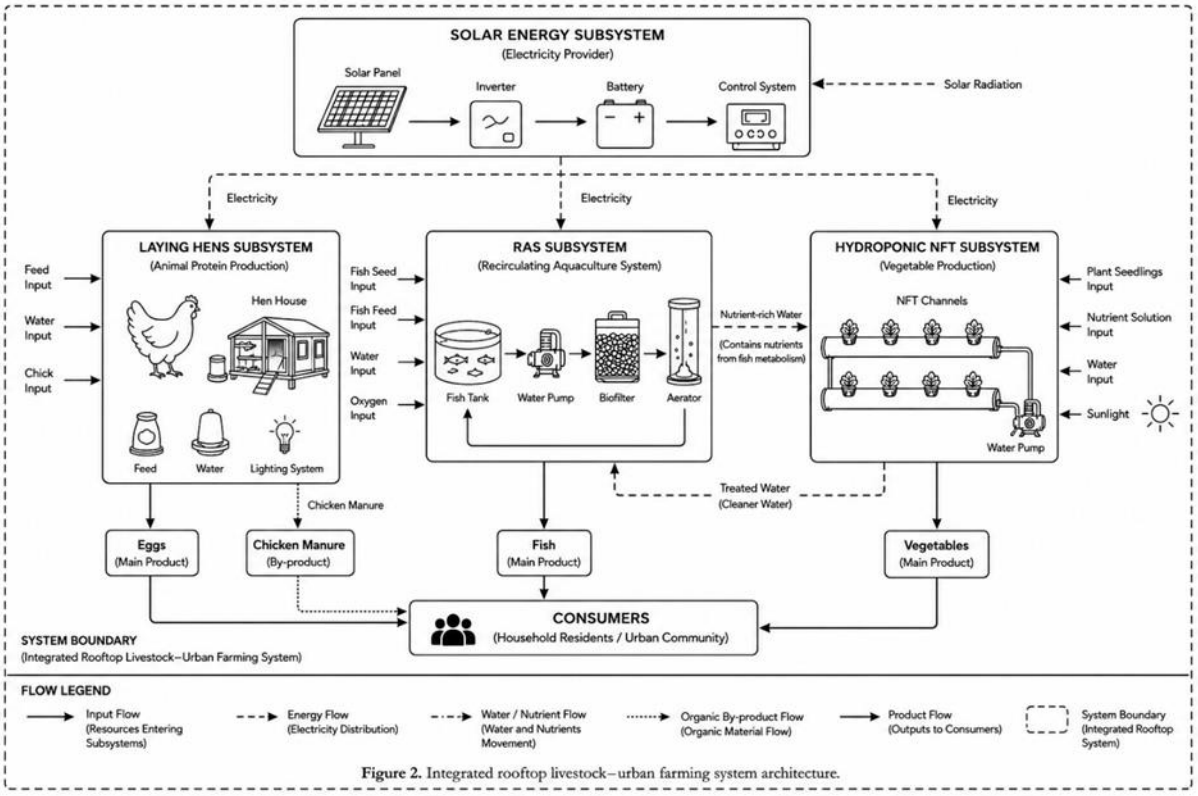

Figure 2. Integrated rooftop livestock–urban farming system architecture.

Figure 2. Integrated rooftop livestock–urban farming system architecture

These technical values are retained as preliminary design parameters and reported calculations derived from the available research materials. Because the supporting records do not consistently identify the individual sources or calculation procedures for each parameter, the values should not be interpreted as experimentally verified operating measurements. Further technical documentation and empirical validation are required before their applicability to the proposed integrated residential rooftop system can be established.

These values provide a research-informed technical basis for the conceptual configuration rather than empirical performance validation. In particular, the 400 Wp capacity does not demonstrate energy sufficiency because actual performance depends on solar irradiance, photovoltaic yield, battery and inverter losses, and operating conditions. Subsystem capacities and overall system performance therefore require further validation.

The architecture establishes the basis for resource-flow analysis and model refinement. By defining subsystem functions, preliminary parameters, resource requirements, and residential constraints, it moves beyond simple co-location toward an integrated food–energy–resource system and provides a basis for assessing its potential contribution to household food availability.

Controlled Resource-Flow Framework

The second result is the development of a controlled resource-flow framework connecting the four subsystems through water, nutrients, energy, and organic resources. The framework does not assume unrestricted circulation of all subsystem outputs. Instead, each resource relationship is defined according to the technical, operational, quality, treatment, and hygiene requirements of the receiving subsystem. This approach extends Food–Energy–Water Nexus and circular-resource perspectives by incorporating livestock within a residential rooftop system boundary.

The water relationship is established between RAS aquaculture and hydroponic NFT. Water from the RAS may support water use within the hydroponic subsystem, but it is not considered a replacement for hydroponic nutrient inputs. The hydroponic NFT subsystem therefore retains separately controlled AB Mix management according to pH, EC, and nutrient requirements. This distinction is consistent with integrated aquaponic and RAS research emphasizing controlled water and nutrient interactions (Ahmed et al., 2026; Ekawati et al., 2021a).

The energy relationship is represented by solar energy supporting the electrical requirements of RAS, hydroponic NFT, laying hens, and associated system loads. Solar energy therefore functions as a supporting subsystem within the integrated architecture rather than as an independent food-production component. Previous research supports the integration of renewable energy with aquaculture and controlled food-production systems (Lee et al., 2025a; Zhang et al., 2024).

The organic-resource relationship originates primarily from the laying-hen subsystem through manure and litter. These materials are treated as potential resources requiring collection, storage, treatment, and hygiene control, rather than as direct inputs to other food-production subsystems. Circular aquaculture and bioeconomy research demonstrates the potential for resource recovery while emphasizing appropriate processing and management before reuse (Grozeva et al., 2026b; Zimmermann et al., 2023b). Thus, untreated livestock waste is not assumed to enter food-production processes directly.

Table 1

Controlled resource flows in the integrated rooftop system

Resource	Source	Destination	Relationship Type	Control / Requirement	Purpose / Function
Water	RAS aquaculture	Hydroponic NFT (vegetables)	Controlled	Water quality control (e.g., filtration, dissolved oxygen, solids removal)	Water supply and circulation for the hydroponic system
Nutrients	Nutrient Input (AB Mix)	Hydroponic NFT (vegetables)	Directly controlled	pH, EC, and nutrient concentration control	Support plant growth in the hydroponic system
Energy	Solar Energy Subsystem (PV panels)	RAS aquaculture, Hydroponic NFT, Laying hens subsystem	Supporting	Energy management and load allocation	Support system operation (pumps, aeration, lighting, monitoring, etc.)
Organic Resources	Laying hens (manure, litter)	Organic resource management	Treatment-dependent	Collection, storage, and treatment (e.g., composting) and hygiene requirements	Enable controlled management and potential reuse

Note. Relationship type indicates: (i) Directly controlled = resource utilized under specified operational controls; (ii) Controlled = resource flow requiring quality or process control before utilization; (iii) Treatment-dependent = resource requiring appropriate treatment before potential reuse; (iv) Supporting = resource that supports system operation rather than serving as direct food-production input

Table 1 summarizes four resource-flow categories (water, nutrients, energy, and organic resources); vegetables, fish, and eggs are distinct food outputs, not additional resource-transfer categories. The table is an authors' synthesis, not a reproduction from a single previous study. It makes explicit the relationships among water, nutrients, energy, and organic resources while retaining the control requirements of each subsystem. The resulting structure is a key research finding: system integration is achieved through controlled resource relationships rather than unrestricted circulation of all subsystem outputs.

Overall, the framework shifts the interpretation of circularity from simple material circulation toward controlled resource integration, in which transfers between subsystems depend on technical suitability, water and nutrient quality, treatment requirements, hygiene, and operational boundaries. This framework provides the basis for the subsequent expert assessment and refinement of the conceptual model.

Expert Judgement and Model Refinement

Expert judgment was conducted to assess the conceptual relevance, logical consistency, technical considerations, resource relationships, hygiene requirements, and residential rooftop applicability of the proposed integrated system. The assessment involved five experts with professional and academic backgrounds relevant to the dimensions examined. Overall, the assessment supported the four-subsystem architecture comprising hydroponic NFT, RAS aquaculture, laying hens, and solar energy, while identifying several areas requiring clarification and refinement.

The experts generally considered the identified research gap relevant, particularly the limited integration of multiple food-production and supporting subsystems within a residential rooftop context. The proposed novelty was also considered relevant, but the assessment emphasized that novelty should not be claimed simply from combining four existing technologies. Instead, the contribution lies in the integration logic, controlled resource relationships, and application of the architecture within a residential rooftop food–energy–resource system.

A major technical refinement concerned the relationship between RAS water and hydroponic nutrients. The expert assessment indicated that RAS water cannot automatically be treated as the primary nutrient source for hydroponic NFT. Hydroponic nutrient requirements therefore remain separately controlled, including measured parameters such as pH and EC. This refinement is consistent with integrated aquaponic and RAS research emphasizing controlled water and nutrient interactions (Ekawati et al., 2021a).

The assessment also identified the need for treatment and management of organic waste. Chicken manure and litter were not considered suitable for direct transfer into food-production processes because treatment and hygiene controls are required before potential reuse. This approach is consistent with circular aquaculture and bioeconomy research emphasizing resource recovery together with appropriate processing and management (Grozeva et al., 2026a; Zimmermann et al., 2023b). Accordingly, the model was refined from a direct waste-to-input relationship toward Organic Waste → Treatment/Management → Potential Resource.

Residential rooftop conditions were also identified as important boundary conditions. The assessment emphasized structural feasibility, spatial configuration, accessibility, lighting, ventilation, and hygiene. These considerations are consistent with previous research identifying spatial, environmental, and management constraints in rooftop and residential urban agriculture (Drottberger et al., 2023b; Gammal et al., 2024b; Harada & Whitlow, 2020b). The rooftop was therefore incorporated into the model not merely as a production location but as a system boundary that constrains the configuration and operation of the four subsystems.

The expert assessment further supported the positioning of solar energy as a supporting or energy-enabling subsystem. Solar energy was retained within the four-subsystem architecture because it supports system loads such as pumps, lighting, ventilation, and other electrical requirements. However, energy sufficiency, battery requirements, cost, and system scale remain subject to further technical assessment, consistent with the need to consider renewable-energy integration together with system operating requirements (Lee et al., 2025a; Zhang et al., 2024).

Technical parameters, including livestock and fish capacity, water requirements, electrical demand, and production potential, were considered preliminary design or calculated parameters requiring further validation. The assessment therefore reinforced the distinction between conceptual parameterization and empirical performance validation.

Finally, the assessment recommended that the potential contribution of the system to household food availability be made more explicit. Vegetables, fish, and eggs were identified as potential food outputs, while food availability was retained as a potential system-level outcome rather than a demonstrated measure of household food sufficiency. This positioning is consistent with research emphasizing localized urban food production and the potential role of urban agriculture in strengthening household and urban food systems (Zhong et al., 2023; Zhu & Tsoulfas, 2024).

As summarized in Figure 3, refinement addressed three dimensions: (i) controlled resource flows, distinguishing RAS water from hydroponic nutrients and requiring treatment of organic waste; (ii) rooftop conditions, incorporating structural, spatial, environmental, and hygiene constraints; and (iii) applicability limits, treating solar support and technical estimates as

design assumptions while retaining diversified food outputs as a potential contribution to household food availability.

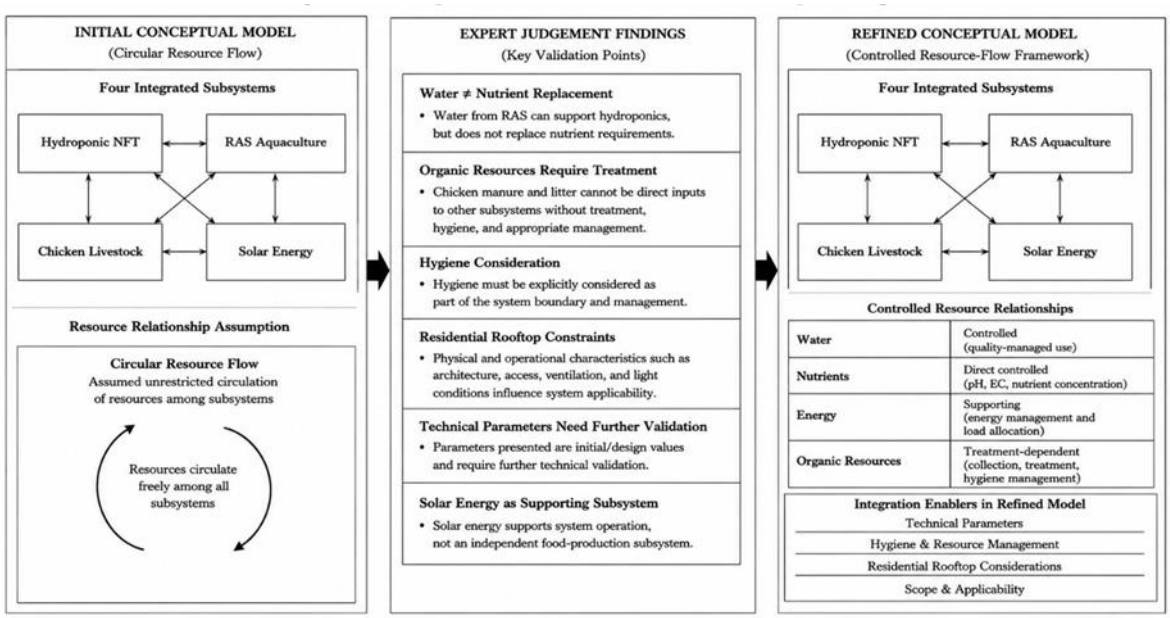

Figure 3. Conceptual model refinement based on expert judgement

Figure 3 represents the refined conceptual model developed in this study, rather than a model reproduced from a single previous study. The refinement demonstrates how literature-based subsystem configurations and technical parameters were integrated with expert assessment to establish a residential rooftop architecture based on controlled resource relationships.

Discussion

Potential Contribution to Household Food Availability

The integrated model indicates a potential pathway through which residential rooftop spaces may contribute to household food availability by combining several complementary food-producing functions. Hydroponic NFT provides a vegetable-production component, RAS provides fish production, and laying hens provide eggs, while solar energy supports system operation. Coordinating these functions within a shared rooftop boundary creates a multi-source food-production configuration rather than a single-production unit. This configuration is consistent with research emphasizing the potential of urban agriculture, rooftop production, and small-scale food-production systems to contribute to localized food provision and urban food-system resilience (Akbar et al., 2025; Kanosvamhira, 2024; Payen et al., 2022; Quaye et al., 2025a).

The potential household food-provision role of the proposed model is also consistent with evidence from Surakarta, where household-scale urban farming contributed to food provision and food expenditure savings through the production of vegetables, fruits, and freshwater fish (Barokah et al., 2023). The present model extends this perspective by combining vegetable, fish, and egg production within a single residential rooftop boundary.

The conceptual contribution lies in coordinating vegetable, fish, and egg production within a shared residential rooftop boundary rather than demonstrating a specific production capacity. This positioning is consistent with urban food-system research that emphasizes the potential contribution of localized production to household food availability (Sonnino, 2023b; Zhong et al., 2023; Zhu & Tsoulfas, 2024). Because household production volumes were not measured in this study, the proposed contribution to food availability remains a conceptual pathway requiring further quantitative assessment.

The potential contribution should nevertheless be interpreted cautiously. The present study establishes a conceptual architecture and controlled resource relationships but does not empirically demonstrate production capacity, resource efficiency, or the ability of the system to

satisfy household food requirements. Actual contribution would depend on subsystem capacity, rooftop conditions, resource availability, operating efficiency, hygiene, and validated production performance. Research on urban agriculture productivity and rooftop farming also indicates that actual outcomes depend on site-specific production conditions, spatial characteristics, and management practices (Akbar et al., 2025; Payen et al., 2022). Thus, household food availability is positioned as a potential system-level outcome and future performance variable, rather than as an established empirical finding.

From a broader food-security perspective, household food availability should also be distinguished from food security as a multidimensional outcome. Food security encompasses availability together with access, utilization, and stability; therefore, localized food production represents one component of a broader food-system strategy rather than a direct measure of household food security (Prasetyo et al., 2026). Accordingly, the present model is interpreted as having the potential to contribute to food availability, while evidence of household food security would require further assessment of the other relevant dimensions.

Future testing should assess whether diversified food production and controlled resource management improve household food availability under realistic rooftop operating conditions.

Implications and Limitations

Theoretically, the refined model extends integrated urban agriculture by treating residential rooftop food production as a bounded, multisubsystem system. It combines the Food–Energy–Water perspective with rooftop agriculture, livestock, supporting energy infrastructure, and controlled resource relationships within a defined residential boundary (Braamhaar et al., 2025; Caputo et al., 2021b; Huang & Chang, 2021b). This positioning extends previous approaches that commonly examine individual technologies or partial system combinations.

Practically, the model identifies design requirements for space, energy, water, nutrient management, and hygiene without establishing operational feasibility. The defined subsystem boundaries and resource relationships can guide future assessments of spatial requirements, technical compatibility, water and nutrient management, energy demand, hygiene, and operational feasibility. Rooftop and urban-agriculture studies indicate that these factors are important determinants of implementation, while urban planning and governance research highlights the need to consider regulatory and contextual conditions (Harada & Whitlow, 2020a; Hardman et al., 2022; Nikolaidou et al., 2023; Raja et al., 2024; Wadumestrige Dona et al., 2021; Yuan et al., 2022).

The principal limitation is that the study remains conceptual and does not include physical prototype implementation or empirical performance testing. Consequently, subsystem capacity, water and nutrient requirements, energy demand, efficiency, production performance, structural capacity, spatial configuration, environmental conditions, hygiene, and treatment requirements require validation under actual residential rooftop conditions. Economic feasibility, cost–benefit analysis, return on investment, regulatory compliance, business viability, household acceptance, environmental risks, and implementation risks are also beyond the empirical scope of the present study (Kanosvamhira, 2024; Nikolaidou et al., 2023; Raja et al., 2024; Seong et al., 2026).

Future validation should proceed through sequential stages, beginning with quantitative modeling of resource and energy balances, followed by controlled prototype testing of subsystem interactions and residential rooftop pilot trials. These stages should evaluate structural safety, food production, hygiene, operational costs, and system performance. IoT-based monitoring may subsequently be considered to support operational assessment, drawing on existing research concerning digital monitoring, recirculating aquaculture systems, and controlled-environment agriculture (Ghandar et al., 2021; Kabir et al., 2026).

Additional research should also examine quantitative system optimization, environmental and economic trade-offs, governance, household acceptance, and replication potential. Quantitative urban-agriculture frameworks and smart-farming approaches provide relevant directions for developing measurable performance indicators and monitoring mechanisms (Lin et al., 2025; R et al., 2026; Seong et al., 2026).

Overall, the implications and limitations confirm that the contribution of this study is primarily architectural and conceptual. The research provides a refined framework for coordinating multiple food-producing and supporting subsystems within a residential rooftop

boundary while explicitly recognizing the technical, operational, environmental, and implementation conditions that must be addressed before physical deployment. The model therefore provides a foundation for subsequent empirical validation rather than a claim of demonstrated system performance.

CONCLUSION

This study developed an expert-refined conceptual architecture for integrated residential rooftop food production comprising hydroponic Nutrient Film Technique (NFT), a Recirculating Aquaculture System (RAS), laying hens, and supporting solar energy. The proposed model coordinates water, nutrients, energy, and organic resources through controlled relationships while identifying vegetables, fish, and eggs as potential food outputs. Expert judgment contributed to refining the separation of RAS water and hydroponic nutrient management, the treatment requirements for livestock-derived organic materials, and the consideration of structural, spatial, environmental, and hygiene constraints. The principal contribution lies in establishing a conceptual integration framework that connects four complementary subsystems within a defined residential rooftop boundary.

The study remains limited to conceptual development, preliminary technical parameterization, and qualitative expert assessment without physical prototype implementation or empirical performance validation. Consequently, the feasibility of subsystem interactions, resource efficiency, energy balance, production capacity, structural safety, economic viability, and environmental performance remains undetermined. Further research should prioritize quantitative modeling, controlled prototype testing, and residential rooftop pilot implementation to evaluate the technical and operational applicability of the proposed system. These investigations are necessary to determine whether the conceptual architecture can contribute to household food availability and resource-efficient urban food production under actual operating conditions.

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AUTHOR CONTRIBUTION STATEMENT

Novrizal: Conceptualization, methodology, investigation, formal analysis, writing – original draft, and project administration. Cahyatih Kumandang: Methodology, investigation, and validation. Mia Christy Patricia: Data curation, visualization, and resources. All authors contributed to the research and approved the final version of the manuscript.

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