A Scenario-based Exploration Framework and Design

Support System for Building-Integrated Agriculture

Zohreh Hassanpour Kahnamouei[1], Halil Erhan[2], Alesandros Glaros[3], Esmaeil Mottaghi[4] and Mohamed Imam[5]
[1,2,4]Simon Fraser University, [3]University of the Fraser Valley, Canada.
[5]Perkins&Will Canada Architects.
[1]zha87@sfu.ca, 0009-0009-8032-6951
[2]herhan@sfu.ca, 0000-0002-7630-6351
[3]alesandros.glaros@ufv.ca, 0000-0001-8461-2634
[4]ema63@sfu.ca, 0009-0005-6082-9966
[5]mohamed.Imam@perkinswill.com, 0000-0001-6977-2840

Abstract. In building design phases, considering food production and resource circularity has been a common practice to increase urban resilience. However, tools for designing Building-Integrated Agriculture (BIA) are fragmented, limited to single-scenario assessments, and hinder understanding of how to effectively combine building spaces, resource flows, and agricultural needs within a coherent decision-making process. This paper introduces a scenario-based BIA exploration framework grounded in the literature and a design-support concept modelling BIA as a multi-layered scenario space. We seek answers to what tools currently support BIA decisions and how scenarios can fit into the design workflow. The proposed modular framework structures the generation and recombination of scenarios derived from building data, resource retrieval, spatial opportunities, BIA systems, and crops. The outcome is a structured logic for exploring multiple "what-if" pathways rather than single solutions. The main outcome is a structured logic for exploring multiple “what-if” pathways rather than focusing on a single solution in BIA design. We argue that scenario-based modelling can enable more holistic, data-informed, and flexible integration of BIA into architectural design, supporting sustainable and resource-efficient urban development.

Keywords. Scenario-based design, building-integrated agriculture, resource circularity, sustainable design, design analytics

1. Introduction

There is an increasing need for innovative solutions leading to greater food security, resource efficiency, and climate resilience in cities, such as Built-Environment

© 2026 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

Integrated Agriculture (BIA). While urban agriculture is gaining popularity, many existing design decision-making tools lack predictive and recommendation features that help architects, planners, and designers to identify opportunities to incorporate food production into built spaces and recyclable resources into their workflows. Most current tools do not adopt a comprehensive system-level approach; instead, they tend to be context-specific, focusing on limited inputs within narrow built-environment scopes. To overcome this, we propose a framework that models a holistic process, allowing exploration of BIA opportunities within the design process and across a broader tool ecosystem.

This paper introduces a scenario-driven resource-circularity framework for evaluating the potential and application of BIA during architectural design. The framework is built on an approach that considers built-environment functions and occupancy-driven resource circularity as potential inputs. We aim to present the framework and demonstrate how it can be realized in a computational BIA design decision-support system to assess the potential of integrated agriculture in existing and new environments. The framework formalizes the following high-level functions: 1) resource and waste-to-resource cycling assessment; 2) scenario generation and exploration of BIA integration; and 3) data-informed assessment of scenarios.

The framework aims to guide future implementation efforts by demonstrating how scenario-based exploration, computational assessments, and cross-domain data integration can be incorporated into design modelling systems to enable interactive exploration of "what-if" scenarios and improve data-informed sustainable strategies. Building on this motivation, we argue that effective BIA integration requires computational approaches capable of generating, comparing, and evaluating multiple scenarios rather than operating on a single scenario at a time. Therefore, our research is guided by two questions:

> *What current technologies and approaches are used in computational systems that support design decision-making for incorporating BIA?*
>
> *How can a computational approach be integrated into existing design workflows to support BIA-related decision-making?*

We explore the first question through a literature review that examines software tools and domain-specific applications in agriculture, resource circularity, and building design. Existing tools in the literature operate within a single scenario, rely on limited datasets, and remain isolated from design platforms. They tend to focus on one analytical pathway at a time—such as weather analysis, plant-growth modelling, building design workflows, or resource-cycling spreadsheets—without integrating these domains into a unified design process. Building on this literature review, and to address the second question, we introduce a scenario-based framework capable of representing and combining various decision components and analytical pathways. After our motivation, we detail both the literature review and the framework below.

2. Background and Motivation

The integration of agriculture into urban environments has received attention as cities seek sustainable solutions to food security, climate resilience, and resource efficiency

(Despommier, 2010; Specht et al., 2014). Conventional food production systems drive environmental degradation, accounting for nearly one-third of global greenhouse gas (GHG) emissions through deforestation, intensive land use, and long-distance food transportation (Crippa et al., 2021). As urbanization accelerates and these issues become more pressing, cities need to adopt innovative strategies that lower their ecological footprint and enhance local food system resilience.

Built-environment-integrated agriculture (BIA) is an emerging approach to sustainability that integrates food production directly into urban settings (Benis et al., 2017). Unlike traditional urban farming, which is typically limited to land and soil-based forms, BIA integrates food production into a variety of built spaces, creating a seamless integration of architecture and agriculture. Emerging research is exploring the synergies between building waste (e.g., heat, organics, greywater) and agricultural systems to improve resource efficiency (D'Ostuni et al., 2022; Benis et al., 2017; Sanjuan-Delmás et al., 2018). Through these processes, BIA can reduce water consumption, improve energy efficiency, and close resource loops in urban environments (Callahan, 2023).

Another key aspect of BIA development is its practical complexity. Various factors limit which system types are feasible in different settings. Structural elements—including roof shape, load-bearing capacity, glazing, orientation, and architectural details—significantly influence the available design alternatives. Local climate and access to water collection or recycling systems further influence feasibility. Designers and architects often favour certain BIA forms over others based on operational complexity, maintenance needs, or their integration with building energy, water, and waste flows. Additional factors, such as crop choices, business models, management expertise, and regulations, influence the desirability and sustainability of BIA systems.

Overall, these factors underscore that BIA system design is diverse and influenced by complex, context-dependent factors. This complexity is both a challenge and an opportunity. It can hinder designers and planners from creating systems that effectively balance aesthetics, scale, environmental impact, and resource use. At the same time, it offers the chance to develop unique, highly tailored BIA configurations that address local needs, spatial limitations, and sustainability goals and priorities.

The field of BIA is relatively new, and existing tool support for its design and application is limited. This paper aims to advance this field by reviewing existing decision-support tools documented in the scientific literature, highlighting gaps and opportunities for further development. In doing so, it aims to advance broad-based knowledge of decision-support tools in the BIA field, while proposing a novel practical framework to address those gaps.

3. Framework and Design Tool Considerations

Given the complexities of BIA, design tools are a critical factor in supporting effective decision-making. Scenario-based tools such as architectural simulations, energy modelling platforms, and resource-flow optimizers allow designers to assess multiple alternatives, test assumptions, and identify resource-circularity opportunities based on empirical data; however, digital tools supporting decision-making for BIA system implementation face several challenges. A primary obstacle is the absence of predictive, recommendation-based decision-support, grounded in realistic scenarios, at every level, that may help designers explore, compare, and refine BIA strategies using building (design) data, functional needs, and sustainability goals (Kozai, 2018).

The initial phase involved analyzing the literature on BIA operations and the decision-support tools employed to guide their development and implementation. Our primary research question was: What opportunities are available for scenario-based decision-support tools to enhance BIA implementation? Specifically, we examined the types of input data these tools consider (e.g., climate, structural constraints, crop requirements, energy and water flows) and the outputs they produce (e.g., performance indicators, resource-use efficiencies). Additionally, we aimed to determine whether and how these decision-support tools incorporate principles of resource circularity, such as heat recovery, water reuse, nutrient cycling, and energy recapture.

Additionally, building on this case study analysis, we propose a novel framework to support decision-makers in designing and implementing BIA systems in practice. We suggest a scenario-focused framework (rather than a data-focused one) that allows designers to explore ideas within scenarios rather than limited parameters. Scenarios are essentially instances of what could happen. The proposed framework computationally identifies relationships between discrete datasets (e.g., building information, plant growth parameters) to provide designers with a series of logical possibilities as they consider the appropriate design for any BIA system.

4. Literature Review on Tools for BIA

We conducted a systematic scoping review using PRISMA search and reporting procedures, mapping the relevant literature that tests or evaluates computational design tools and decision-support systems for building-integrated agriculture (BIA). Our goal was to identify gaps, methodological patterns, and emerging needs within studies that employ digital modelling, simulation, or performance assessment for BIA or closely related urban agriculture systems. We began by identifying peer-reviewed academic literature and conference proceedings that examined simulation platforms, performance-evaluation frameworks, or site-selection tools used to support BIA implementation. The search strategy employed a Boolean string designed to capture a wide range of BIA-related tools:

```
("building integrated agriculture" OR "zero acreage farming" OR "vertical
farm") AND ("simulation" OR "decision support" OR "digital tool")**.
```

The Web of Science search yielded 113 records. We refined this set by applying the following criteria: studies published from 2015 onward, reporting on a digital model, simulation, plugin, or tool evaluating BIA system performance, and analyzing farm-scale systems. This process resulted in 12 papers. Studies focusing solely on individual components, such as lighting, irrigation, or specific horticultural techniques, were excluded because they did not align with our focus on system-level decision support. The curated studies offer an overview of current digital tools used for BIA.

Several tools are available for urban farming assessments, each focusing on specific aspects of integration. Below, we highlight some examples before reviewing the relevant literature. For example, MIT's Harvest plugin evaluates sunlight and shading to determine optimal cultivation zones for crops (Benis et al., 2017). Similarly, Specularia, a Rhino Grasshopper plugin, models spectral daylight in Controlled Environment Agriculture (CEA) to optimize lighting for plants and occupants, emphasizing Photosynthetically Active Radiation (PAR) and Daily Light Integral (DLI) (Callahan, 2023). Other tools like USDA Virtual Grower 3, a decision-support system for greenhouse management (U.S. Department of Agriculture, Agricultural Research Service, 2025), and "Design.agritecture," a platform for planning urban agriculture projects by modelling feasibility, financials, resources, and sustainability (Agritecture, 2025), offer valuable insights into costs, resource use, and environmental impact. Nonetheless, despite their benefits, these tools do not fully address dynamic resource flows or waste-to-resource cycles within building environments, emphasizing the need for holistic decision-support systems tailored for BIA integration.

The reviewed literature on Building-Integrated Agriculture (BIA) modelling and simulation (2017–2024) is beginning to shift from energy-focused assessments to more integrated frameworks that capture broader environmental factors, such as water, organics, carbon dioxide, and circular resource flows. Across eleven studies, two main system types dominate: rooftop greenhouses and indoor vertical farms. Rooftop systems, mainly in Europe (Portugal, the United Kingdom, Spain, Sweden, and Italy), are often modelled as thermal extensions of host buildings using tools like EnergyPlus, BES, or IESve to quantify heat exchange and energy recovery. Rooftop models are predominantly located within the ICTA-ICP Rooftop Greenhouse Lab (RTG-Lab) in Barcelona, Spain. The literature on indoor vertical farms, common in North America and Asia, often uses custom or equation-based simulations (e.g., Python, MATLAB, Vertical Farming Wizard) to optimize yield, lighting, and carbon dioxide management. Only a few studies, notably Chowdhury and Asiabanpour (2024) and Li et al. (2020), go beyond energy modelling to include multi-loop nutrient and waste integration, aligning with circular economy principles.

Energy performance remains the focus of analysis. Research by Benis et al. (2017), Jans-Singh et al. (2021), Muñoz-Liesa et al. (2020), and Hugo et al. (2021) mainly views BIA as a passive or active energy-recovery element within building envelopes. While this approach enhances understanding of thermal interactions and site selection considerations or symbioses, it overlooks biological and hydrological processes crucial for evaluating the overall system metabolism. Crop representation is limited (mostly tomatoes and lettuce), with occasional inclusion of herbs or mixed leafy greens, probably because these crops are common in indoor vertical farming. The few efforts to diversify, such as the halophyte and aquaponic integration modelled by Chowdhury and Asiabanpour (2024), demonstrate agronomic innovation but remain at the proof-of-concept stage rather than being validated through empirical data.

Geographically, modelling efforts tend to focus on temperate and subtropical areas, with limited consideration for cold climates or northern urban settings where controlled-environment agriculture could be most effective. African and Asian case studies (Hugo et al., 2021; Shamshiri et al., 2020; Li et al., 2020) demonstrate climatic sensitivity, showing that rooftop systems in hot regions can result in negative energy balances unless combined with active cooling or renewable energy sources. This challenges the idea that rooftop agriculture is suitable everywhere and highlights the importance of analyzing geographic and climatic considerations.

Socio-economic modelling is rare; de Oliveira et al. (2021) is the only example that considers BIA within a business planning and economic optimization framework. Their analysis includes key data such as capital and operational expenditures, cost of goods, and perhaps most uniquely within the dataset, risk curves for the adoption of building-integrated agriculture systems. Most studies use proprietary design software, but there's a trend toward open-source platforms (such as Python, Arena, and Vertical Farming Wizard) that improve accessibility and collaboration.

Overall, the literature reveals a fragmented field, primarily focused on energy, which is now beginning to broaden its scope. Energy simulations with resource circularity have proven the feasibility of BIA. Still, few models currently include water cycling, nutrient recovery, or organic waste valorization—key aspects of circular building-integrated systems. Future research should integrate biophysical resource modelling with economic and spatial data, diversify crops and systems to incorporate emerging options such as algae, aquaponics, and halophytes, and shift from isolated energy metrics to comprehensive system assessments of carbon and nutrients. This can help BIA move beyond building performance to a holistic framework that supports resource circularity and the integration of sustainable food, energy, and water systems.

Most models rely on spreadsheet-based and parametric tools to evaluate BIA model performance, highlighting a gap in decision-support tools. These models depend on detailed user input, which can be challenging for designers less familiar with BIA systems and models. Additionally, reliance on data and single-output solutions or models overlooks the context-specific and varied nature of decision-making in practice. Scenario-based modelling, as proposed in the following section, is often neglected in the reviewed literature.

5. Scenario-Based Framework for BIA Design

We propose a framework that reconceptualizes BIA as a multi-layer scenario space built from existing building information, resource flows, environmental data, and agricultural requirements. Rather than producing a single “optimal” solution, it structures the problem into modular analytical steps that each generate families of alternative scenarios. These scenario sets can then be recombined, filtered, and assessed, supporting designers in exploring multiple pathways for integrating BIA (Fig. 1). It comprises six core modules. Each module takes one or more additional datasets as input, applies domain-specific criteria, and outputs a corresponding set of scenarios. In the detailed schema (Fig. 2), these modules are further specified, along with their associated datasets and scenario outputs, which serve as structured inputs to subsequent modules. This modular scenario-generation logic makes the framework directly translatable into a future design-support system.

Design Data Extraction module structures design data from architectural models. Its output consists of structured datasets describing the building program (spaces, use types, occupancy), building geometry (envelope, floor areas, roof types, façades), and mechanical systems (HVAC systems, waste-heat sources, ventilation strategies). Together, these datasets form the building-context integration layer and are used to generate a set of design scenarios DS_i. Each DS_i represents a distinct configuration of programmatic, geometric, and mechanical attributes, which then serve as inputs for the next modules—Retrieve Resources, Process Resources, and Identify Locations.

Resource Retrieval module identifies resource and waste streams that could be repurposed for BIA. Inputs include waste-related data (greywater, blackwater, organic waste, waste heat), water and energy meter data, and waste-generation factor datasets. The module estimates available quantities, temporal profiles, and quality constraints, producing a set of resource scenarios RS_j. Each RS_j represents a distinct retrieval option—for example, stormwater capture alone, combined greywater and condensate recovery, or retrieval of low-grade waste-heat streams.

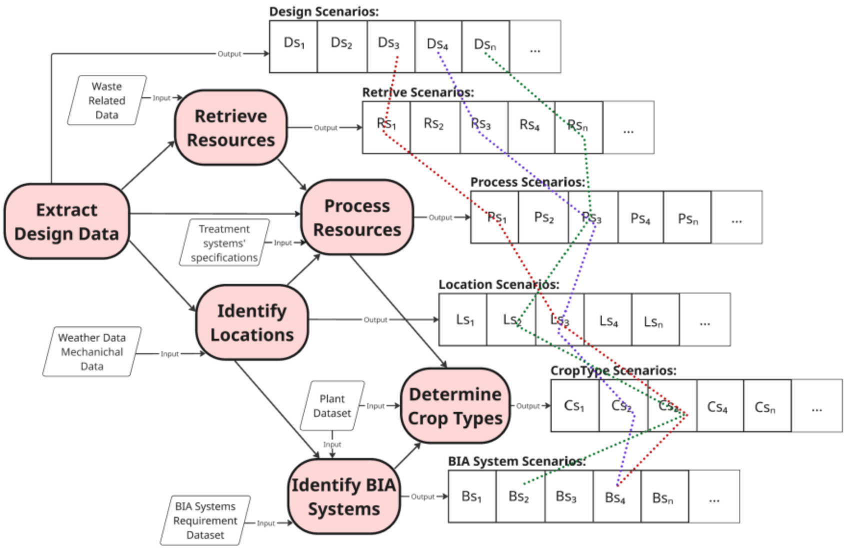

Figure 1. Abstract schema of the scenario-based framework to guide BIA solutions in building design workflow.

Resource Processing module, given the retrieved streams, identifies feasible processing and treatment configurations. It uses treatment-system typology datasets to determine which technologies can upgrade each resource to a quality suitable for BIA use. The output is a set of process scenarios PS_kthat describe alternative treatment systems, their conversion efficiencies, and associated space and energy requirements, as well as the resulting recovered-resource type and quantity datasets and the percentage of usable recovered waste.

Location Identification module determines candidate physical locations for both BIA systems and treatment systems within or around the building. Inputs include weather and climate data, as well as geometric or environmental attributes derived from the design model (orientation, shading, accessibility, structural capacity). The module produces a set of location scenarios LS_l, each representing a potential site — such as roof zones, façades, atria, or interior spaces—and the environmental conditions and constraints that influence suitability for BIA or treatment-system placement.

Crop Types Determination module uses plant datasets (species requirements, yield potentials, light and temperature ranges, water and nutrient needs) to determine crop compatibility scenarios considering the identified resource and location conditions. The output is a set of crop-type scenarios CS_m, each specifying candidate crop types or crop mixes, their associated resource requirements, expected yields, and external resource needs, after accounting for recovered resource availability.

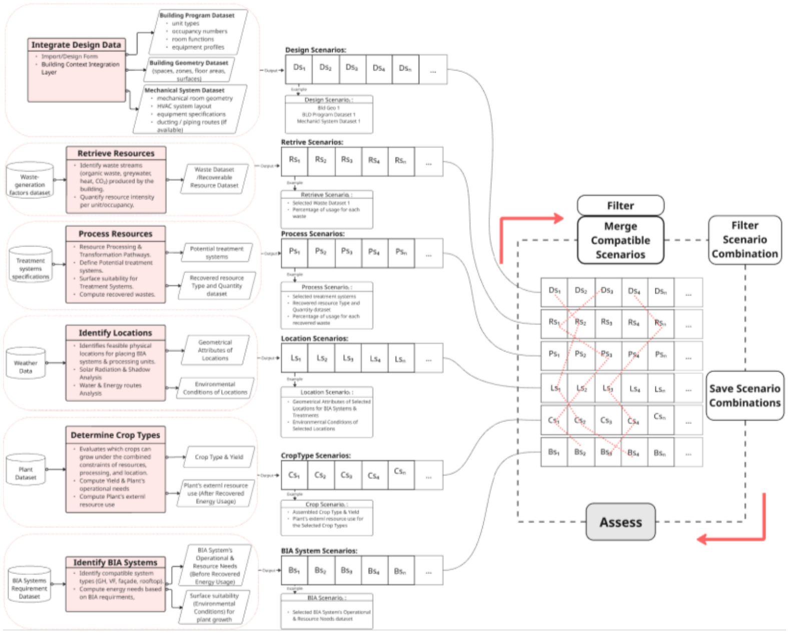

Figure 2. Framework with six modules according to the high-cohesion and low-coupling principle.

BIA System Identification module identifies compatible BIA systems (e.g., rooftop greenhouses, vertical farming) for the location scenarios. It uses a BIA system requirements dataset (structural loads, footprint, operational requirements, maintenance needs) to generate BIA scenarios BS_n. Each BS_n scenario specifies the selected system's operational and resource needs (before accounting for recovered resources) and its surface suitability based on environmental conditions relevant to plant growth. The BS_n scenarios serve as inputs to the Determine Crop Types module.

Each module in the framework produces a structured scenario set—*DS, RS, PS, LS, BS, and CS*—which together form layered slices of the overall design space (Fig. 1–2). Rather than prescribing a linear workflow, the framework conceptualizes BIA integration as a process of navigating, comparing, and recombining these scenario layers. Designers may, for example, hold building design scenarios (*DS*) constant while exploring alternative resource-retrieval (*RS*) or resource-processing (*PS*) strategies or begin from a preferred crop scenario (*CS*) to examine how different BIA systems (*BS*) and locations (*LS*) affect feasibility.

In the detailed schema (Fig. 2), scenarios generated by each module populate a scenario-combination matrix. Instances from different layers—for example, $DS_i, RS_j, PS_k, LS_l, BS_n, CS_m$—are cross-referenced to identify potential multi-step integration pathways across the building. The compatibility filtering ensures that only coherent combinations progress forward, evaluating constraints. For example, let $DS = \{d_1, \ldots, d_m\}$ be the extracted design data. Based on DS, the scenario sets

$DS_i, RS_j, PS_k, LS_l, BS_n, CS_m$ generated as outlined above. The modules are connected by compatibility relations *Compat_R, Compat_L, Compat_C*, and *Compat_B*. A scenario ($RS_i, PS_j, LS_k, CS_t, BS_u$) is valid when all compatibility relations hold. The set of valid integrated scenarios is: $\boldsymbol{S}^*=\{(RS_i, PS_j, LS_k, C_tS, BS_u) \mid Compat\_RS(RS_i, PS_j) \wedge Compat\_LS(PS_j, LS_k) \wedge Compat\_C(LS_k, CS_t) \wedge Compat\_B(CS_t, BS_u)\}$. A design is feasible when $\boldsymbol{S}^* \neq \emptyset$.

After incompatible combinations are filtered out, the remaining scenario pathways represent a set of feasible BIA integration strategies. These combinations are then evaluated using performance criteria such as energy use, water and nutrient recovery, GHG emissions, crop yield, and operational considerations. Instead of producing a single optimal solution, the assessment stage generates multiple candidate strategies with clear trade-offs. Within design workflows, this scenario-based structure helps designers incorporate domain-specific analyses, compare different scenario combinations, and align BIA system and crop choices with project goals. It also provides a methodological foundation for future computational tools that support interactive "what-if" exploration within design modelling environments.

6. Conclusion

This paper introduces a scenario-based exploration framework that addresses the limitations of Building-Integrated Agriculture (BIA) design tools, which are often fragmented, focused on single-scenario assessments, and primarily energy-oriented. By redefining BIA as a process of navigating and recombining six modular scenario layers (Design, Resource Retrieval, Processing, Location, BIA System, and Crop Type), we provide a structured, logical method for generating and evaluating multiple feasible "what-if" pathways.

The key contribution is a methodological foundation that supports a holistic, data-informed, and adaptable integration of BIA into architectural design, promoting resource circularity and sustainable growth. The modular design and explicit constraint-filtering logic of the proposed framework lay the groundwork for future computational implementation. By populating a scenario-combination matrix, the framework aims to help designers balance trade-offs across complex criteria, including resource circularity, energy use, nutrient recovery, and crop yield. Moreover, the conceptual model offers a transferable approach for managing complexity beyond BIA. Its main goal is to structure workflows involving diverse data streams and multiple performance objectives—such as circular building retrofits or district-scale resource systems—making it a valuable contribution to the broader field of sustainability, design analytics and decision-making systems.

Acknowledgements

This research was funded by the British Columbia Centre for Agritech Innovation (BC CAI) and Perkins&Will Canada Architects Co. We thank Dr. Laila Benkrima for her advice on biotechnology and agri-food data.

References

Agritecture. (2025). *Design.agritecture: Urban agriculture project planning tool*. Agritecture. Retrieved March 3, 2025, from https://design.agritecture.com/

Arcasi, A., Mauro, A. W., Napoli, G., Tariello, F., & Vanoli, G. P. (2024). Energy and cost analysis for a crop production in a vertical farm. *Applied Thermal Engineering*, *239*.

Benis, K., Reinhart, C., & Ferrão, P. (2017). Development of a simulation-based decision support workflow for the implementation of Building-Integrated Agriculture (BIA) in urban contexts. *Journal of Cleaner Production*, *147*, 589–602.

Callahan, B. (2023). Specularia: Spectral daylighting simulation in CEA – A Rhino Grasshopper plugin for spectral daylight simulation and analysis in controlled environment agriculture. In ACADIA 2023: Habits of the Anthropocene: Scarcity and abundance in a post-material economy (Vol. 2, pp. 398–407).

Chowdhury, H., & Asiabanpour, B. (2024). A circular economy integration approach into vertical farming with a computer-based simulation model for resource reuse optimization and waste reduction. *Journal of Cleaner Production*, *470*, 143256.

Crippa, M. et al., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. s.l.:Nature Food.

Despommier, D. (2010). The vertical farm: Feeding the world in the 21st century. St. Martin's Press.

De Oliveira, F. J. B., Ferson, S., & Dyer, R. (2021). A Collaborative Decision Support System Framework for Vertical Farming Business Developments.

D'Ostuni, M., Zaffi, L., Appolloni, E. & Orsini, F., 2022. Understanding the complexities of BIA. Can food shape the future built environment? Futures, Vol . 144.

Graamans, L., Baeza, E., van den Dobbelsteen, A., Tsafaras, I., & Stanghellini, C. (2018). Plant factories versus greenhouses: Comparison of resource use efficiency. Agricultural Systems, 160, 31-43.

Hugo, J., du Plessis, C., & Masenge, A. (2021). Retrofitting Southern African cities: A call for appropriate rooftop greenhouse designs as climate adaptation strategy. *Journal of Cleaner Production*, *312*, 127663.

Jans-Singh, M., Ward, R., & Choudhary, R. (2021). Co-simulating a greenhouse in a building to quantify co-benefits of different coupled configurations. *Journal of Building Performance Simulation*, *14*(3), 247–276.

Khan, R., Aziz, Z., & Ahmed, V. (2018). Building integrated agriculture information modelling (BIAIM): An integrated approach towards urban agriculture. *Sustainable Cities and Society*, *37*, 594–607.

Kozai, T. (2018). Smart plant factory: The next generation indoor vertical farms. Springer.

Sanjuan-Delmás, D., Llorach-Massana, P., Nadal, A., Ercilla-Montserrat, M., Muñoz, P., Montero, J. I., ... & Rieradevall, J. (2018). Environmental assessment of an integrated rooftop greenhouse for food production in cities. J. of Cleaner Production, 177, 326-337.

Li, L., Li, X., Chong, C., Wang, C.-H., & Wang, X. (2020). A decision support framework for the design and operation of sustainable urban farming systems. *J. of Cleaner Production*.

Muñoz-Liesa, J., et al. (2020). Quantifying energy symbiosis of building-integrated agriculture in a mediterranean rooftop greenhouse. *Renewable Energy*, *156*, 696–709.

Shamshiri, R. R., Bojic, I., van Henten, E., Balasundram, S. K., Dworak, V., Sultan, M., & Weltzien, C. (2020). Model-based evaluation of greenhouse microclimate using IoT-Sensor data fusion for energy-efficient crop production. *J. of Cleaner Production*, *263*.

Shasteen, K. C., & Kacira, M. (2023). Predictive Modeling and Computer Vision-Based Decision Support to Opt. Resource Use in Vertical Farms. *Sustainability*, *15*(10), 7812.

Specht, K., Siebert, R., Hartmann, I., Freisinger, U. B., Sawicka, M., Werner, A., ... & Dierich, A. (2014). Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. Agriculture and Human Values, 31(1), 33-51.

U.S. Department of Agriculture, Agricultural Research Service. (n.d.). *Virtual Grower 3 model: USDA ARS*. Retrieved March 3, 2025, from https://www.ars.usda.gov/