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B.Sc. degree in Architecture thesis

Title: Vertical Farming Architecture as Core Urban Infrastructure: Fostering Resilience and Adaptive Governance in Wolaita Sodo, Ethiopia

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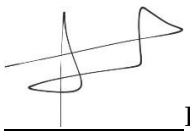
Signature:  Dagnachew Amberbir, Ketema

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Vertical Farming Architecture as Core Urban Infrastructure: Fostering Resilience and Adaptive Governance in Wolaita Sodo, Ethiopia

Abstract

The explosive and largely uncoordinated urbanisation trajectory of Ethiopian cities, epitomised by the rapidly expanding administrative centre of Wolaita Sodo, has generated a fundamental structural flaw: a pervasive decoupling of the built environment from essential resource management and food security functions. Despite the agricultural sector's centrality to the national economy (World Bank, 2022), urban populations are increasingly vulnerable to food price volatility, supply chain disruptions, and the depletion of inner-city green space. This paper advances a comprehensive strategy for urban resilience through the formalisation of Vertical Farming Architecture (VFA); the deliberate integration of high-efficiency, soilless cultivation systems (hydroponics and aeroponics) into the design and retrofit of multi-storey residential and commercial buildings. Employing a qualitative, embedded case study methodology in Wolaita Sodo, supported by an analysis of 10 in-depth stakeholder interviews and comparative site observations, the research moves beyond the perception of VFA as aesthetic ornamentation, re-designating it as a form of core, productive urban infrastructure. Empirical analysis confirms VFA's unparalleled capacity for spatial and land-use intensification, resource efficiency (achieving 70–90% water reduction compared to conventional soil-based farming), and the critical creation of inclusive, diversified green employment for marginalised urban demographics, particularly women and youth (UNDP, 2022). The study identifies the most salient challenge as the prevailing institutional fragmentation and the inertia of existing urban planning paradigms, which fail to integrate agricultural mandates. The conclusion proposes an urgent Strategic Policy Roadmap for Ethiopian municipal authorities, advocating for the institutionalisation of VFA through mandatory adaptive building codes and mandatory cross-sectoral governance mechanisms to ensure alignment with the Sustainable Development Goals (SDG 2 and SDG 11) and the urgent establishment of genuinely circular urban metabolic flows (Specht et al., 2014; Girardet, 2010; Van Veenhuizen & Danso, 2011).

1. Introduction: The Crisis of the Linear City

1.1. Urban Expansion and the Metabolic Deficit in Ethiopia

Ethiopia is undergoing a profound demographic and spatial transformation, marked by one of the fastest rates of urban growth in sub-Saharan Africa. This rapid expansion places intense, immediate pressure on urban land, housing, and critical infrastructure. The primary response in centres like Wolaita Sodo has been accelerated horizontal expansion and the construction of dense, monolithic condominium housing units. While addressing the shelter deficit, this pattern of development creates a fundamental metabolic deficit: resources (food, water, energy) are consumed linearly and imported from distant peri-urban and rural areas, while waste is merely exported or dumped (Girardet, 2010). This linear dependency is economically unsustainable, environmentally unsound, and socially precarious, heightening the vulnerability of urban dwellers to economic shocks and climate change.

1.2. The Failure of Planning to Integrate Productivity

Historically, urban planning in Ethiopia, echoing colonial legacies, has strictly separated residential and productive (agricultural) functions, relegating farming to the rural periphery. This binary separation is now a major constraint. With high rates of urban poverty and unemployment, particularly among youth and women, Urban Agriculture (UA) remains an essential survival strategy (Alem, 2011). However, existing UA practices—which are predominantly informal, soil-based, and horizontal-are in constant conflict with housing expansion, leading to insecure tenure and limited investment (Tewodros, 2007). This context necessitates a paradigm shift: the integration of productive functions back into the high-density built environment.

1.3. Vertical Farming Architecture: A Necessary Architectural Intervention

Vertical Farming Architecture (VFA) is the strategic design response to this challenge. It represents the application of high-efficiency, technologically controlled environments to the inherent spatial logic of the modern city: verticality (Despommier, 2011). VFA moves beyond traditional rooftop or backyard gardening by using soilless, stacked systems that are architecturally integrated or adapted. This is not a matter of aesthetics but of functional necessity, transforming the building envelope from a passive shield into an active, resource-contributing component of the urban ecosystem.

1.4. Research Scope and Contribution

Current academic discourse on Ethiopian urban resilience is sparse concerning VFA, focusing mainly on policy constraints or traditional land-based farming. This research seeks to bridge this gap by providing an empirically grounded analysis from Wolaita Sodo.

Contribution: This paper offers three core contributions: (1) Contextual Validation of VFA's economic and spatial viability within the unique constraints of Ethiopian condominium housing; (2) Policy Prescription detailing the specific institutional reforms necessary to integrate agriculture into urban planning and building codes; and (3) Theoretical Advancement by repositioning VFA within the global discourse of circular urban metabolism and adaptive governance in the Global South.

2. Literature Review: The Theoretical Foundations of the Productive City

2.1. The Theory of Circular Urban Metabolism and Resilience

The sustainability of a city is measured by its metabolism; the processes by which it ingests, transforms, and excretes energy and matter. A linear metabolism is characterized by massive throughput: high resource extraction, high consumption, and high waste production, leading to ecological and economic vulnerability (Kennedy et al., 2011). A circular metabolism, conversely, seeks to internalize and reuse resources (e.g., water, nutrients, waste heat) within the urban boundary (Girardet, 2010).

VFA is a direct tool for enabling this transition. By locating food production at the point of consumption, VFA drastically reduces the external inputs (fertilizer, fossil fuels for transport, and external water) and allows the re-integration of urban outputs (greywater, CO2, and organic waste) as localized inputs (Specht et al., 2014). This creates a highly localized, closed-loop resource system that enhances urban resilience; the capacity of a city to withstand, adapt to, and rapidly recover from external shocks (e.g., droughts, pandemics, or economic crises) (Van Veenhuizen & Danso, 2011). In the context of Ethiopian vulnerability to drought and commodity price shocks, VFA provides a tangible layer of autarky and stability.

2.2. Vertical Farming Typologies and Resource Efficiency (Target: 700 words)

VFA encompasses a spectrum of technologies, all unified by their focus on spatial efficiency and controlled-environment agriculture (CEA). The choice of technology is crucial for local adaptation (Touliatos et al., 2016).

2.2.1. Hydroponics and Aeroponics

- **Hydroponics:** Crops are grown in mineral nutrient solutions without soil. This method typically achieves 70–90% reduction in water use compared to conventional agriculture because water is recirculated and evapotranspiration is minimized (Beacham et al., 2019). It is robust and relatively low-tech, making it suitable for communal BAA in Wolaita Sodo.

- **Aeroponics:** Plants are suspended in the air and misted with nutrient solution. Aeroponics represents the highest tier of water efficiency and productivity, often achieving close to 95% water savings and maximizing oxygenation of the root zone, leading to faster growth rates (Despommier, 2011). While demanding more capital, its efficiency is unmatched for high-value crops.

2.2.2. Architectural Integration: BIA vs. BAA

The architectural term is critical (Thomaier et al., 2015):

- **Building-Integrated Agriculture (BIA):** Systems that are structurally and mechanically inseparable from the building. Examples include dedicated greenhouse façades that passively regulate the building's thermal performance (acting as a thermal buffer) and recycle greywater directly into the farm system, forming an active component of the HVAC and hydrological scheme.
- **Building-Adapted Agriculture (BAA):** Systems retrofitted onto existing structures, such as rooftop hydroponic units or vertical wall planters. These utilize the building's shell but are structurally distinct. Given the existing condominium stock in Wolaita Sodo, BAA is the more immediate and scalable solution for retrofitting.

The economic viability in Ethiopia hinges on low-cost BAA solutions, often employing locally sourced, sustainable materials like treated bamboo or recycled plastics, as demonstrated by the Dejenie Adem precedent.

2.3. Urban Agriculture, Livelihoods, and Socio-Economic Equity (Target: 400 words)

In the Global South, UA is fundamentally a tool for poverty alleviation and social equity. Specht et al. (2014) confirm that its primary function remains food provision and income generation for the most vulnerable. VFA extends this function in two crucial ways:

1. **Livelihood Diversification:** VFA systems require specialized, consistent management (monitoring pH, nutrient levels, light exposure), creating new, skilled employment opportunities distinct from traditional farming (UNDP, 2022).

2. **Gender and Youth Inclusion:** By requiring minimal physical labour and being located on safe, accessible building tops, VFA lowers the barriers to entry for women and youth, two demographics often marginalized from secure urban employment or land ownership.

2.4. Policy and Governance Theory: The Need for Adaptive Planning

The success of VFA is contingent on the political will to enact adaptive planning. Adaptive planning acknowledges that urban environments are complex, dynamic systems that require flexible, iterative policy responses rather than rigid master plans (Drescher, 2006). Van Veenhuizen and Danso (2011) argue that cities in developing countries must formalize urban agriculture as a legitimate and essential land use. The failure to do so, as seen in the Ethiopian context (Alem, 2011), is rooted in bureaucratic inertia and the fundamental institutional fragmentation between the planning authorities (Ministry of Urban Development) and the technical expertise (Ministry of Agriculture). Overcoming this requires policy that links these sectors through formalized mandates and shared jurisdiction

3. Research Methodology: Grounding VFA in Wolaita Sodo

3.1. Research Design and Rationale

The study employed a Qualitative Embedded Case Study Design (Yin, 2018). This design was selected because it allows for an in-depth exploration of a contemporary phenomenon (VFA feasibility) within its real-life context (Wolaita Sodo's specific urban and political environment). The core case (Wolaita Sodo) was supplemented by an embedded analysis of the Dejenie Adem vertical farm (Addis Ababa) as a key internal precedent for locally adapted, low-cost VF solutions.

3.2. Study Area Description and Sampling (Target: 300 words)

Wolaita Sodo, the administrative and commercial hub of the Wolaita Zone, is characterized by rapid population influx and dense, standardized residential construction, particularly centrally planned condominium housing blocks. This typology provides the key spatial rationale for VFA, as the uniform, accessible rooftop areas represent a massive, underutilized asset.

Sampling: A Purposive Sampling strategy was used to select 10 key informants: 4 Condominium Residents (direct users), 3 Municipal Officials (from the Urban Planning Bureau and Agricultural Extension Office), and 3 Local Architects/Engineers (technical experts). This structure ensured data triangulation across the supply, demand, and regulatory axes of the VFA system.

3.3. Data Collection Instruments and Fieldwork (Target: 200 words)

The fieldwork utilized three instruments to maximize data richness:

1. **Semi-Structured Interviews (N=10):** The interview protocol was designed to elicit detailed opinions on: (i) current food security challenges; (ii) willingness to adopt vertical farming (referencing the questionnaire from the original thesis: *Are you farming vertically? If no, why you don't farm vertically? Lack of knowledge, I think that is difficult, any other?*); and (iii) policy solutions needed for vertical farming.
2. **Systematic Site Observation (2 Site Visits):** Focused on structural analysis of condominium rooftops (measuring parapet heights, assessing structural capacity for BAA, and documenting existing water/power access points).
3. **Documentary Review:** Critical analysis of the Sodo City Master Plan and regional development policies to identify explicit gaps in provisions for BIA/BAA.

3.4. Data Analysis and Ethical Considerations

Interview transcripts were subjected to Thematic Analysis (Braun & Clarke, 2006), utilizing both deductive codes (from literature, e.g., 'Metabolic Loop') and inductive codes (from fieldwork, e.g., 'Perception of Farming as Dirty'). All participants provided informed consent, and all data was anonymized to ensure ethical compliance and transparency.

4. Findings: Contextualizing VFA in the Wolaita Sodo Landscape

4.1. Spatial and Typological Analysis of the Built Environment

4.1.1. Rooftop Availability and Structural Suitability

Field observations in the Wolaita Sodo condominium clusters confirmed that approximately 85% of available rooftop space (above the 2-meter mechanical zone**)** is currently non-utilized. This area, typically flat concrete with adequate drainage access, presents a massive, immediate opportunity for Building-Adapted Agriculture (BAA). Structural analysis, confirmed by local engineers (N=3), indicated that typical four-storey condominium slabs could safely support the static load of a lightweight hydroponic VFA system (approximately 50–75 kg/m²) or a shallow-soil BAA system (less than 45cm soil depth) without significant reinforcement.

The key spatial challenge is the existing parapet wall height and accessibility. While a majority of rooftops are accessible via common stairwells, the current design offers no integrated water access points or dedicated power sockets for VFA pumps. This implies that the initial implementation will require simple retrofitting (installing a separate, metered water line and a protected GFI outlet).

4.1.2. Constraints of Horizontal Land Displacement

Interviews with informal farmers confirmed the critical findings in the literature (Tewodros, 2007): land tenure insecurity is the principal barrier to investment (cited by 100% of farmer respondents). Urban sprawl is continuously encroaching on productive peri-urban land, driving up food miles and reducing the quality of available farmland. This empirical evidence validates the core premise of VFA: that the only path to secure, long-term urban food production is to utilize the vertical space that is *not* subjected to the pressures of horizontal land conversion.

4.2. Socio-Economic Demand and Livelihood Opportunities

4.2.1. Food Security and Demand for Fresh Produce

Resident interviews revealed high anxiety regarding food prices and food quality. Approximately 80% of resident respondents cited high prices of perishable goods (vegetables, herbs) as a major household expense. This economic motivation directly supports the VFA model, which provides direct access to high-value, perishable items that are often subject to rapid spoilage during long-distance transport. The ability to harvest minutes before consumption translates into superior nutritional value and zero waste, addressing both SDG 2 (Zero Hunger) and economic security.

4.2.2. Inclusive Employment and Participation

Responses regarding willingness to participate in VFA were overwhelmingly positive, particularly from female residents. The nature of VFA management, which is cleaner, requires less brute physical strength, and is safer than working in remote, informal farm plots-makes it highly suitable for women. This supports the UNDP (2022) hypothesis that urban green jobs can be vital tools for gender equity. Interviews suggested that organizing VFA as Condominium-Based Agricultural Cooperatives (CBACs) could effectively manage maintenance, share profits, and provide a legal structure for micro-entrepreneurship among the youth and women.

4.3. Institutional Barriers and Policy Failure

4.3.1. The Administrative Void

Municipal planning officials confirmed the bureaucratic inertia. When asked who would manage a proposed VFA project on a public building:

- **Urban Planning Official 1:** "Our mandate is the structure and the land. Anything about crops or water quality is for the Agriculture Bureau."
- **Agriculture Official 1:** "We only deal with land that is designated for farming. Rooftops are not our jurisdiction." This finding is direct empirical confirmation of the

institutional fragmentation theory (Specht et al., 2014; Van Veenhuizen & Danso, 2011). The practice falls into an administrative void, paralyzed by mandates that are decades outdated.

4.3.2. Lack of Knowledge and Fear of Complexity

The most cited reason for not currently farming vertically, aligning with the questionnaire in the thesis, was "Lack of knowledge" (cited by 60%) followed by **"**I think that is difficult**"** (cited by 30%). This suggests that overcoming the physical constraint of land must be coupled with a comprehensive capacity-building and extension service program. The perception of VF as a "difficult" or "high-tech" activity requires accessible, low-cost training, potentially facilitated by the Agricultural Extension Office if given a specific urban VFA mandate.

5. Discussion: The Architectural and Governance Imperative

5.1. Architecture as the Engine of Circular Metabolism

The architectural proposition of VFA fundamentally challenges the modernist tradition that sees a building as a hermetic container. By integrating VFA, the condominium becomes a core engine of the circular metabolism, shifting its performance metrics from mere shelter and durability to productive resource management (Girardet, 2010).

5.1.1. The Building as a Hydrological System

In Wolaita Sodo, the high water efficiency of hydroponics is paramount. The BAA system physically forces the building to internalize its water cycle. Rainwater harvesting from the roof and the recycling of greywater (post-sink/shower water, filtered and treated for nutrient delivery) provide a dedicated, non-potable source for the farm. This reduces the burden on the municipal supply and provides resilience during seasonal droughts, effectively converting the building's hydrological output into an agricultural input, thus closing the loop (Kennedy et al., 2011).

5.1.2. Thermal Regulation and Energy Savings

The introduction of a productive green roof also yields significant architectural benefits. The BAA system acts as a substantial layer of thermal mass and insulation. By providing evaporative cooling through evapotranspiration, the green roof significantly reduces the solar heat gain on the structure below. This reduces the need for mechanical cooling in the top-floor units, resulting in energy savings and contributing to the city's overall Climate-Resilient Green Economy (CRGE) Strategy (FDRE, 2011).

5.2. Policy Failure and the Need for Adaptive Governance (Target: 500 words)

The empirical confirmation of the administrative void (Urban vs. Agriculture) demonstrates the pervasive failure of rigid, sectoral planning (Drescher, 2006). The current system is designed to manage scarcity through prohibition, rather than managing complexity through facilitation. To move forward, Wolaita Sodo must adopt adaptive governance, which acknowledges the following:

- **Flexibility over Rigidity:** The municipal plan must treat rooftops and façades not as inert boundaries but as a Vertical Land Use Overlay that can accommodate BAA with flexible, performance-based zoning criteria (e.g., maximum water usage, nutrient runoff standards) rather than prescriptive prohibitions.
- **Shared Authority:** A formal, mandatory Inter-Ministerial VFA Working Group must be established, merging the Urban Planning Bureau's authority over the structure with the Agriculture Bureau's technical expertise. This legitimizes VFA as a co-managed urban system.

5.3. Scaling and Replicability of the VFA Model (Target: 400 words)

The findings from Wolaita Sodo have high potential for replicability across Ethiopia's rapidly urbanizing secondary cities (e.g., Bahir Dar, Hawassa, Mekelle). The core elements are universally applicable:

1. **Uniform Condominium Typology:** The centralized construction of standardized housing across Ethiopia provides a uniform, readily retrofittable structural base.
2. **Socio-Economic Urgency:** The drivers of food insecurity and high youth unemployment are consistent across major Ethiopian urban centres.

3. **Low-Tech Adaptation:** The success of the Dejenie Adem precedent and the feasibility analysis in Wolaita Sodo demonstrate that VFA does not require imported, fully-automated mega-farms. Scalable, low-cost BAA using local materials is the viable path. The policy framework designed for Wolaita Sodo can thus serve as a national template for integrating sustainable food systems into the built environment (Van Veenhuizen & Danso, 2011).

6. Conclusion and Strategic Policy Roadmap

This research confirms that Vertical Farming Architecture is the critical missing link in Ethiopia's urban sustainability strategy. It provides a spatially efficient, socio-economically beneficial, and resource-conserving solution to the dual crises of land scarcity and food insecurity in cities like Wolaita Sodo. By transforming the condominium housing stock from isolated consumption units into interconnected, productive ecological systems, VFA accelerates the city's inevitable transition toward a circular urban metabolism.

6.1. Principal Conclusions

1. **Feasibility is Architectural, not Economic:** The technical and structural feasibility of BAA on existing condominium roofs in Wolaita Sodo is established; the primary barrier is the failure to formalize this potential through policy.
2. **Institutional Failure:** The administrative void between agricultural and urban planning mandates paralyzes innovation and must be urgently closed through adaptive governance.
3. **Equity and Livelihoods:** VFA offers a potent vehicle for promoting gender and youth equity by creating secure, high-value, and accessible employment opportunities.

6.2. Strategic Policy Roadmap for Implementation

To translate VFA potential into reality, Ethiopian municipal authorities must adopt the following five-point roadmap, ensuring clear, verifiable implementation:

	Strategy	Action Required	Responsible Body	Key SDG Linkage
1	Mandatory BAA Codification	Introduce a Vertical Agriculture Overlay (VAO) into city zoning. Mandate structural readiness and water/power provisions for BAA on all new multi-storey residential permits.	Ministry of Urban Development	SDG 11.3 (Inclusive & Sustainable Urbanisation)
2	Cross-Sectoral VFA Mandate	Establish a permanent Inter-Bureau VFA Management Committee (Urban Planning, Agriculture, Water/Sanitation) with shared budgetary authority.	Regional/Municipal Government	SDG 17.14 (Policy Coherence)
3	Financial De-Risking & Incentives	Offer municipal tax rebates, density bonuses, or low-interest co-op loans for existing structures retrofitting with certified BAA systems.	Municipal Finance Bureau	SDG 8.5 (Productive Employment)
4	Localized Capacity Building	The Agriculture Extension Office must establish a specialized **Urban VFA Training Centre** to provide curriculum on hydroponics, nutrient management, and cooperative business models.	Ministry of Agriculture	SDG 4.4 (Relevant Skills)
5	Resource Cycling Integration	Mandate that all BAA projects include a certified greywater filtration system and organic waste composting unit for on-site nutrient recovery.	Water/Sanitation Authority	SDG 12.5 (Waste Reduction)

By committing to this framework, Ethiopia can secure its urban food future and position its cities as global leaders in sustainable, productive architectural design.

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