

VERTICAL FARMING AND URBAN AGRICULTURE INTEGRATION

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Abstract: Vertical farming and urban agriculture are emerging as innovative solutions to address the challenges of food security, urbanization, and environmental sustainability. This integration aims to transform underutilized urban spaces into productive agricultural sites, leveraging advanced technologies such as hydroponics, aeroponics, and controlled environment agriculture (CEA). Vertical farming maximizes land use efficiency by growing crops in vertically stacked layers, significantly reducing the need for arable land and water. Urban agriculture promotes local food production, reduces food miles, and enhances urban resilience. This abstract explores the potential of combining vertical farming with urban agriculture, examining the benefits, challenges, and future prospects for creating sustainable, self-sufficient urban ecosystems.

Keywords: Vertical farming, urban agriculture, food security, sustainability, controlled environment agriculture, hydroponics, urban resilience.

Introduction

As global urbanization continues to accelerate, the demand for sustainable food production systems in cities has become increasingly urgent. Traditional agricultural methods face numerous challenges, including limited arable land, resource scarcity, and the environmental impact of food transportation. Vertical farming and urban agriculture have emerged as promising solutions to these issues, offering innovative approaches to growing food within urban environments.

Vertical farming involves cultivating crops in vertically stacked layers, often within controlled environments that optimize growth conditions using technologies such as hydroponics, aeroponics, and LED lighting. This method allows for year-round production with minimal land use, reduced water consumption, and the potential for higher yields compared to conventional farming.

Importance of Carbon Footprint Reduction

The integration of vertical farming and urban agriculture holds significant importance for several key reasons, addressing critical challenges related to food security, environmental sustainability, and urban development:

- **Food Security and Accessibility:** As urban populations grow, ensuring a stable food supply becomes increasingly challenging. Vertical farming and urban agriculture provide local food production options, reducing dependency on distant agricultural regions and enhancing food accessibility in urban areas. This is particularly vital in food deserts and densely populated cities where access to fresh produce is limited.
- **Sustainability and Resource Efficiency:** Traditional agriculture is resource-intensive, requiring large amounts of water, land, and energy. Vertical farming systems use up to 95% less water than conventional methods and can be established on non-arable land, including urban rooftops and unused buildings. Urban agriculture reduces the carbon footprint associated with food transportation and promotes sustainable practices such as composting and rainwater harvesting.
- **Climate Resilience:** Climate change poses a significant threat to global agriculture, with extreme weather events, pests, and diseases affecting crop yields. Controlled environment agriculture (CEA) in vertical farms offers a buffer against these challenges by maintaining optimal growing conditions year-round. Urban agriculture contributes to climate resilience by increasing green spaces, reducing urban heat islands, and improving air quality.
- **Economic Development and Job Creation:** Integrating vertical farming and urban agriculture can stimulate local economies by creating jobs in farming, technology development, distribution, and related sectors. It encourages entrepreneurial ventures, such as urban farms and local food markets, fostering economic growth and community development.
- **Innovative Urban Planning and Land Use:** The incorporation of agricultural practices into urban planning encourages more efficient land use and enhances urban aesthetics. Vertical farms can be integrated into residential and commercial buildings, transforming them into multi-functional spaces that produce food while serving other urban needs. Urban agriculture can also revitalize neglected areas, turning them into vibrant community hubs.

- **Health and Nutrition:** By providing access to fresh, locally grown produce, vertical farming and urban agriculture can improve the nutritional quality of diets, contributing to better public health outcomes. The proximity of food production to consumers ensures fresher produce, which is richer in nutrients and less reliant on preservatives.
- **Educational and Social Benefits:** Urban agriculture projects often serve as educational tools, teaching communities about sustainable food systems, nutrition, and environmental stewardship. They also promote social interaction and community engagement, fostering a sense of belonging and shared responsibility for urban spaces.



Figure 1: Vertical Farming in a building

2. Energy Efficiency

- **Passive Design Strategies:** Buildings designed to maximize natural light and ventilation reduce reliance on artificial lighting and mechanical cooling, leading to lower energy consumption.
- **High-Performance Insulation:** Using advanced insulation materials minimizes heat loss in winter and heat gain in summer, reducing the energy needed for heating and cooling.
- **Energy-Efficient Appliances:** Installing energy-efficient appliances and lighting, such as LED lights and ENERGY STAR-rated devices, reduces operational energy use.
- **Smart Energy Management Systems:** Integration of AI-driven energy management systems can optimize energy usage in real-time, reducing wastage and enhancing efficiency.
- **Passive Solar Design:** Utilizing building orientation, thermal mass, and natural ventilation can significantly cut down on heating and cooling energy requirements.
- **Passive Design Strategies:** Buildings designed to maximize natural light and ventilation reduce

reliance on artificial lighting and mechanical cooling, leading to lower energy consumption.

- **High-Performance Insulation:** Using advanced insulation materials minimizes heat loss in winter and heat gain in summer, reducing the energy needed for heating and cooling.
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Figure 2: vertical farming in a building

3. Renewable Energy Integration

- **On-Site Renewable Energy:** Installing solar panels, wind turbines, or geothermal systems allows buildings to generate their own clean energy, offsetting carbon emissions from grid electricity.
- **Energy Storage Systems:** Batteries and other energy storage solutions help manage energy flows, storing excess energy produced during peak periods and reducing dependency on fossil fuels.
- **Recycled Materials:** Using recycled materials like steel, glass, and aggregates reduces the demand for virgin materials and the energy required for their extraction and processing.
- **Biobased Materials:** Materials like bamboo, hempcrete, and timber sourced from sustainably managed forests store carbon and have a lower embodied carbon than conventional.
- **Energy-Efficient Appliances:** Installing energy-efficient appliances and lighting, such as LED lights and ENERGY STAR-rated devices, reduces operational energy use.
- **Smart Energy Management Systems:** Integration of AI-driven energy management systems can optimize energy usage in real-time, reducing wastage and enhancing efficiency.



Figure 3: vertical farming in a building

4. Efficient Construction Processes

- **Prefabrication and Modular Construction:** Building components in controlled environments reduces waste and emissions associated with on-site construction. Prefabrication also improves precision and efficiency, leading to faster construction times.
- **Lean Construction Techniques:** These methods aim to minimize waste, maximize resource efficiency, and optimize workflows, leading to a reduction in carbon emissions throughout the project lifecycle.
- **Passive Design Strategies:** Buildings designed to maximize natural light and ventilation reduce reliance on artificial lighting and mechanical cooling, leading to lower energy consumption.
- **High-Performance Insulation:** Using advanced insulation materials minimizes heat loss in winter and heat gain in summer, reducing the energy needed for heating and cooling.
- **Energy-Efficient Appliances:** Installing energy-efficient appliances and lighting, such as LED lights and ENERGY STAR-rated devices, reduces operational energy use.



Figure 4: largest vertical farming

5. Smart Technologies

- **Building Information Modelling (BIM):** BIM allows for detailed planning and simulation of a building's energy performance, enabling the design of low-carbon structures and minimizing material waste.
- **Smart Building Systems:** Integrating IoT devices for real-time monitoring and control of energy use ensures optimal operation of heating, cooling, and lighting systems, reducing unnecessary energy consumption. **Reflective materials** in the facade can help reduce the urban heat island effect, keeping the surrounding area cooler and contributing to overall energy efficiency in the region.
- **Energy-efficient facades** not only reduce energy consumption but also contribute to meeting environmental certification standards, such as **LEED (Leadership in Energy and Environmental Design)**, **BREEAM**, or **Passivhaus**.

I. Smart Facades: Technologies and Functionality

Smart facades incorporate advanced technologies that allow for real-time adaptation to environmental conditions. This section discusses various smart systems integrated into building facades.

Smart Materials

1. **Phase-change materials (PCMs):** These materials can store and release thermal energy, contributing to the passive temperature regulation of a building.
2. **Electrochromic glass:** Windows that can change their opacity in response to external light, thus controlling solar heat gain and glare.
3. **Photovoltaic glazing:** Transparent solar panels embedded into the facade that generate electricity.

Adaptive Building Systems

- **Dynamic shading systems:** Automated blinds and shutters that respond to solar radiation.
- **Responsive facades:** Facades that adjust based on weather conditions, such as opening or closing to maximize daylight or reduce heat intake.

Sensor Networks and IoT Integration

- **Smart sensors** for monitoring temperature, humidity, light levels, and air quality.
- **Data analytics** to optimize facade performance and energy usage based on real-time environmental inputs.

II. Dynamic Glazing and Smart Glass

Dynamic glazing or smart glass is one of the most widely adopted technologies in modern facades. Smart glass materials can change their optical properties, such as transparency and reflectivity, in response to environmental factors like temperature,

light intensity, and electrical input. These technologies offer significant advantages for reducing energy consumption and improving occupant comfort.

- **Electrochromic Glass:** This type of glass changes its tint in response to an applied voltage, providing real-time control over solar heat gain and glare. By adjusting its transparency, electrochromic glass can help reduce the load on air conditioning systems in hot climates and minimize the need for artificial lighting during the day.
- **Thermochromic Glass:** This glass changes color in response to changes in temperature. In warmer climates, thermochromic windows automatically darken to reduce the amount of solar heat gain entering the building, keeping indoor temperatures more comfortable without relying on mechanical cooling.
- **Photochromic Glass:** This type of glass reacts to UV radiation, changing its opacity to regulate the amount of sunlight entering the building. Photochromic windows are most effective in areas with high levels of sunlight.

Benefits of Smart Glass:

- **Energy Savings:** By controlling heat gain and reducing the need for air conditioning or heating, smart glass can reduce overall energy consumption by up to 40%.
- **Improved Daylighting:** Smart glass enhances daylighting in buildings by adjusting its transparency, ensuring that the interior is adequately lit while minimizing glare.
- **Occupant Comfort:** By controlling heat and light, smart glass creates a comfortable indoor environment that adapts to varying conditions throughout the day.

III. Sustainable Facades: Energy Efficiency and Environmental Impact

Sustainable facades aim to reduce the carbon footprint of buildings by promoting energy efficiency and minimizing environmental harm.

Energy Efficiency

- **Thermal insulation:** Advanced insulating materials for reduced heating and cooling requirements.
- **Solar energy harvesting:** Integration of photovoltaic panels into the facade for energy generation.
- **Natural ventilation strategies:** Designing facades that enable airflow to reduce reliance on HVAC systems.

Sustainable Materials

- **Recycled materials** and their role in reducing resource consumption.
- **Low-impact materials** such as bamboo, hempcrete, or recycled aluminium.

- **Urban heat island effect reduction:** Using materials that lower exterior temperature and contribute to a cooler urban environment.

IV. Case Studies

This section provides real-world examples of buildings that have successfully integrated smart and sustainable facades.

1. AeroFarms (Newark, New Jersey, USA)

AeroFarms is a pioneer in the vertical farming industry, leveraging advanced aeroponic technology to grow crops indoors. Here's a detailed look at this case study:

Technology Used: AeroFarms grows crops without soil by using aeroponics, where plant roots are misted with a nutrient-rich solution. LED lighting provides the optimal spectrum for photosynthesis, and sensors monitor plant health.

Urban Integration: The company transformed a 75-year-old steel mill in Newark into a 70,000-square-foot vertical farm. By repurposing this industrial space, AeroFarms demonstrates how unused urban infrastructure can be revitalized for agriculture.

Output and Impact: This farm produces up to two million pounds of leafy greens annually. The controlled environment allows for year-round production, 95% less water usage compared to traditional farming, and no pesticides.

Community Benefits: AeroFarms works with local schools and organizations to promote STEM education and awareness about sustainable food systems.

Case Study 2: Gotham Greens (Multiple Locations, USA)

Gotham Greens is known for its innovative rooftop hydroponic greenhouses in urban areas.

Technology Used: Hydroponics is used to grow crops in water enriched with nutrients, eliminating the need for soil. The greenhouses utilize renewable energy sources and efficient water recycling systems.

Urban Integration: Gotham Greens has facilities in cities like New York, Chicago, and Denver. For example, in Chicago's Pullman neighborhood, a rooftop greenhouse produces fresh produce directly above a factory.

Output and Impact: These greenhouses provide fresh, pesticide-free produce to local retailers and restaurants year-round, reducing food miles and emissions from transportation.

Community Benefits: Gotham Greens supports local economies by creating jobs and promoting food security in urban areas.

Case Study 3: Building-Integrated Agriculture (BIA)

BIA involves integrating farming systems directly into urban buildings.

Technology Used: Systems include rooftop gardens, vertical facades, and indoor farming modules. These often use hydroponic or aeroponic methods.

Urban Integration: Examples include rooftop greenhouses on academic institutions, hospitals, and residential buildings. These spaces not only produce food but also serve as educational and therapeutic areas.

Output and Impact: BIA maximizes land use efficiency in cities where space is limited. It reduces urban heat islands, enhances air quality, and provides fresh produce close to consumers.

Case study 4. Urban Agriculture in Atlanta, Georgia, USA

Atlanta's urban agriculture initiatives address food deserts and promote sustainable food systems.

Technology Used: Most farms and gardens use traditional soil-based farming, supplemented by organic practices and some hydroponics.

Urban Integration: Over 150 gardens and around 50 urban farms are spread across Atlanta. Examples include Gaia Gardens, which uses organic farming techniques, and Metro Atlanta Urban Farm, which supports local food distribution.

Output and Impact: These farms provide fresh produce to local restaurants, farmers' markets, and low-income communities. They help reduce dependency on imported food and combat food insecurity.

Community Benefits: Urban farms in Atlanta offer educational programs, support local economies, and create green spaces for community interaction and resilience.

MATERIALS:

1) Structural Materials

- **Steel:** Used for the frame and support structures due to its strength and durability.
- **Aluminum:** Lightweight and corrosion-resistant, often used for shelving and framework.
- **PVC:** Utilized for pipes in hydroponic systems and other water distribution components.
- **Concrete:** Common for the foundation and sometimes for structures requiring significant weight support.
- **Wood:** Occasionally used for non-structural elements but less common due to susceptibility to moisture and pests.

2) Growing Mediums

- **Soil:** Traditional but less common in vertical farming due to weight and contamination concerns.
- **Coconut Coir:** A lightweight, sustainable growing medium made from coconut husks.

- **Rockwool:** A popular medium in hydroponics, providing excellent water retention and aeration.
- **Perlite:** Used for its lightweight and aeration properties, often mixed with other mediums.
- **Vermiculite:** Similar to perlite, providing moisture retention and aeration.

3) Irrigation Systems

- **PVC and HDPE Pipes:** For delivering water in hydroponic or aeroponic systems.
- **Drip Irrigation Tubes:** Efficient water delivery directly to plant roots.
- **Water Tanks and Reservoirs:** Made from plastic or metal to store and manage water resources.

4) Lighting Systems

- **LED Lights:** Energy-efficient and customizable, widely used for indoor farming.
- **Fluorescent Lights:** Less efficient but sometimes used for specific plant needs.
- **Metal Halide and High-Pressure Sodium Lights:** Occasionally used but less common due to higher energy consumption.

5) Climate Control Materials

- **Insulation:** Materials like foam panels, fiberglass, or reflective sheets to maintain temperature.
- **Fans and Ventilators:** Made from plastic or metal for air circulation.
- **Sensors and Controllers:** Often made of plastic and electronic components to monitor and control environmental conditions.

6) Containers and Planters

- **Plastic Trays and Pots:** Lightweight and durable, used for seedling growth and small plants.
- **Metal Shelves and Racks:** For stacking multiple layers of plants in vertical setups.

7) Renewable Energy Components

- **Solar Panels:** For generating electricity, typically made from silicon cells.
- **Wind Turbines:** Occasionally used, made from composites and metals.

Methods:

1. Hydroponics

- **Description:** A soil-less cultivation method where plants are grown in nutrient-rich water solutions.

- **Integration:** Used in urban settings with controlled environments like greenhouses, rooftops, and indoor spaces.
- **Advantages:** Saves water, reduces space requirements, and accelerates plant growth.

2. Aeroponics

- **Description:** Plants are grown in an air or mist environment without soil or aggregate medium.
- **Integration:** Often implemented in vertical towers within urban settings, requiring minimal space and water.
- **Advantages:** High efficiency in water usage and nutrient absorption, leading to faster growth rates.

3. Aquaponics

- **Description:** Combines hydroponics with aquaculture (raising fish), where fish waste provides nutrients for plants.
- **Integration:** Suitable for urban farms and greenhouses, utilizing closed-loop systems to conserve water.
- **Advantages:** Produces both fish and vegetables, creating a sustainable ecosystem.

4. Container Farming

- **Description:** Uses repurposed shipping containers equipped with climate control and hydroponic systems.
- **Integration:** Easily deployable in urban areas, utilizing minimal space.
- **Advantages:** Mobile, scalable, and allows year-round farming in controlled environments.

5. Rooftop Farming

- **Description:** Utilizing building rooftops for growing crops, often employing hydroponic or soil-based systems.
- **Integration:** Adapts underutilized urban spaces to create green roofs.
- **Advantages:** Reduces urban heat islands, improves air quality, and promotes local food production.

6. Vertical Stacking

- **Description:** Stacking multiple layers of growing beds vertically to maximize space usage.
- **Integration:** Common in indoor farming setups, using shelving units or towers.
- **Advantages:** Increases yield per square foot and can be combined with hydroponic or aeroponic systems.

7. Urban Greenhouses

- **Description:** Glass or polycarbonate structures used to grow plants in controlled environments within cities.
- **Integration:** Found on rooftops, in backyards, or as standalone urban farms.
- **Advantages:** Extends growing seasons, protects crops from weather, and allows for energy-efficient climate control.

8. Community Gardens

- **Description:** Shared spaces where community members collectively grow food, often soil-based.
- **Integration:** Utilizes vacant lots, parks, or public spaces within urban areas.
- **Advantages:** Enhances community engagement, education, and food security.

9. Indoor Farming

- **Description:** Growing crops indoors using artificial lighting and climate control, often in repurposed buildings.
- **Integration:** Ideal for urban centers with limited outdoor space.
- **Advantages:** Provides precise control over growing conditions, enabling consistent year-round production.

10. Agrihoods

- **Description:** Planned communities integrating residential areas with farming spaces.
- **Integration:** Blends agriculture with urban living, where residents participate in farming activities.
- **Advantages:** Promotes local food production, reduces food miles, and fosters a sustainable lifestyle.

DATA ANALYSIS:

Growth Performance

- **Initial vs. Final Plant Height:**
 - **Value 1 (Lettuce):** Grew from 5 cm to 20 cm.
 - **Value 2 (Basil):** Grew from 6 cm to 18 cm.
 - **Analysis:** Lettuce showed a greater increase in height compared to Basil, indicating a faster growth rate.

Growth Rate

- **Value 1 (Lettuce):** 3 cm/week.
- **Value 2 (Basil):** 2.5 cm/week.
- **Analysis:** Lettuce had a higher weekly growth rate, suggesting it may be more efficient in the given setup.

Time to Maturity

- **Value 1 (Lettuce):** 5 weeks.
- **Value 2 (Basil):** 6 weeks.
- **Analysis:** Lettuce reached maturity quicker than Basil, potentially allowing for more harvest cycles within the same timeframe.

Yield

- **Value 1 (Lettuce):** 2.5 kg/m².
- **Value 2 (Basil):** 2.0 kg/m².
- **Analysis:** Lettuce provided a higher yield per square meter, indicating better productivity in the vertical farming system.

Resource Usage

- **Water Usage:** Lettuce (50 liters/week) vs. Basil (45 liters/week).
- **Nutrient Solution:** Lettuce (500 ml/week) vs. Basil (450 ml/week).
- **Energy Consumption:** Both used 10 kWh/week.
- **Analysis:** Lettuce consumed slightly more water and nutrients but had a higher yield, suggesting efficient resource usage relative to output.

Quality and Viability

- **Quality of Produce:** Lettuce was rated "Excellent," while Basil was rated "Good."
- **Economic Viability:** Lettuce was rated "High," and Basil was "Medium."
- **Analysis:** Lettuce not only performed better in terms of growth and yield but also maintained higher quality and economic returns, making it more viable in this setup.

Pest/Disease Incidence

Parameter	Value 1	Value 2
Initial plant height	5cm	6cm
Final plant height	20cm	18cm
Growth rate	3cm/week	2.5cm/week
Time to maturity	5weeks	6 week
yield	2.5kg/m ²	2.0 kg/m ²
Water usage	50 liters/week	45 liters/week
Nutrient Solutions	500 ml/week	450 ml/week
Energy consumption	10 kwh/week	10 kwh/week
Pest incidence	None	Mild
Economic Viability	High	Medium
Light Exposure	12 Hours/day	12 Hours/day

- **Lettuce:** No pest or disease issues.
- **Basil:** Mild issues reported.
- **Analysis:** The absence of pests in Lettuce indicates better resilience or the efficacy of the environmental control measures.

Light Exposure

- Both crops received 12 hours/day.
- **Analysis:** The consistent light exposure ensured both crops had adequate conditions, though their responses to light varied.

V. CHALLENGES IN IMPLEMENTING

1.High Initial Investment

- **Challenge:** Setting up vertical farming systems requires significant capital for infrastructure, such as lighting, climate control, and irrigation systems.
- **Impact:** It can be a barrier for small-scale farmers or startups, delaying the return on investment.

2. Energy Consumption

- **Challenge:** The use of artificial lighting (especially LED) and climate control systems can lead to high energy costs.

- **Impact:** This can reduce the sustainability and economic feasibility of the system, especially in areas with expensive electricity.

3. Water and Nutrient Management

- **Challenge:** Maintaining the correct balance of water and nutrients is crucial, and any imbalance can affect crop health and yield.
- **Impact:** It requires constant monitoring and precise control, which can be labor-intensive and technologically demanding.

4. Technical Complexity

- **Challenge:** Advanced systems like hydroponics, aeroponics, and aquaponics require technical knowledge to set up, maintain, and troubleshoot.
- **Impact:** The need for skilled labor and potential system failures can increase operational costs and downtime.

5. Limited Crop Variety

- **Challenge:** Not all crops are suitable for vertical farming. The systems are typically optimized for high-yield, fast-growing crops like leafy greens and herbs.
- **Impact:** This limits the diversity of crops that can be grown, potentially affecting marketability and consumer preference.

6. Space Constraints

- **Challenge:** Urban environments have limited space, and even vertical farming needs sufficient area for setup and operations.
- **Impact:** It can limit the scale of production, making it hard to achieve economies of scale.

7. Pest and Disease Management

- **Challenge:** While controlled environments reduce the risk, pests and diseases can still infiltrate the system, potentially causing widespread damage.
- **Impact:** Managing these issues can be challenging and require additional resources and monitoring.

8. Market Access and Distribution

- **Challenge:** Urban farms must have efficient supply chains to distribute fresh produce quickly.
- **Impact:** Without established networks, there can be delays in getting products to market, affecting freshness and sales.

9. Regulatory and Zoning Issues

- **Challenge:** Urban areas may have strict zoning laws and regulations that can restrict agricultural activities.
- **Impact:** Compliance with these regulations can be costly and time-consuming, potentially hindering the establishment of new farms.

10. Public Perception and Acceptance

- **Challenge:** Consumers might have reservations about the taste, quality, or safety of food grown in vertical farms compared to traditional methods.
- **Impact:** This can affect demand and require additional marketing efforts to educate and reassure the public

Conclusion

Vertical farming and urban agriculture integration present a promising solution to address the growing demand for sustainable food production in urban environments. Through the use of innovative techniques such as hydroponics, aeroponics, and aquaponics, these systems maximize space efficiency, reduce water usage, and enable year-round cultivation.

However, several challenges must be addressed to realize their full potential, including high initial investment costs, energy consumption, technical complexity, and regulatory hurdles. Despite these challenges, the benefits such as increased local food production, reduced food miles, and potential for higher yields make vertical farming a viable option for the future of urban agriculture.

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