



## SMART URBAN AND PERI-URBAN GARDENING: INTEGRATING PROTECTED CULTIVATION, IOT AND AI FOR SUSTAINABLE CITIES

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### Introduction

Rapid urbanization is steadily reducing agricultural land, creating a gap between cities and their traditional food production systems. At the same time, the demand for fresh, safe, and locally grown produce is increasing, especially among urban populations. To address this challenge, urban and peri-urban agriculture (UPA) has emerged as a promising solution, utilizing available spaces such as rooftops, balconies, backyards and city outskirts for cultivation.

However, growing crops in limited spaces with changing climatic conditions requires more efficient and modern approaches than conventional farming. In this context, protected cultivation, along with advanced technologies like the Internet of Things (IoT) and Artificial Intelligence (AI), is playing a transformative role. Protected structures help create a controlled environment for crop growth, while IoT enables real-time monitoring of key parameters such as temperature, humidity and soil moisture. Further, AI supports data-driven decision-making, improving crop management and productivity.

Together these technologies are converting urban spaces into smart, efficient

and sustainable production systems, paving the way for resilient and self-sufficient cities.

### Linking Cities with Sustainable Gardening

Before understanding the role of smart technologies like IoT and AI, it is important to first look at the spaces where this new form of agriculture is developing. With rapid urban expansion in cities such as Mumbai and Delhi, agricultural land is continuously being converted into residential and commercial areas. As a result, traditional farming is declining within city limits.

However, urban and peri-urban gardening is emerging as an effective solution, making use of available spaces and adapting to the challenges of modern cities.

### Urban vs Peri-Urban Gardening

Although often discussed together, urban and peri-urban gardening differ in their location and scale, while still being closely connected.

**Urban Gardening:** This type of cultivation takes place within the city itself, including rooftops, balconies, kitchen gardens, terraces and even indoor spaces. Due to limited space, it mainly focuses on high-density cultivation using containers, vertical systems and protected structures.

**Peri-Urban Gardening:** This is practiced on the outskirts of cities where relatively more land is available. These areas are ideal for commercial-scale cultivation, especially of high-value crops like vegetables, flowers and nursery plants under protected structures such as polyhouses and greenhouses. Together, these systems create a continuous supply chain, linking production areas near cities directly with urban consumers.

### **The Growing Importance of Urban and Peri-Urban Farming**

Urban and peri-urban gardening is not just a trend but a necessity for sustainable city living. Its importance can be understood through the following points:

**Food and Nutritional Security:** With increasing population, the demand for fresh and safe food is rising. Urban farming ensures year-round availability of vegetables, fruits and flowers close to consumers, improving food quality and nutrition.

**Employment Generation:** These systems provide new opportunities for income generation, especially for youth and entrepreneurs. Protected cultivation and smart farming technologies have high commercial potential, creating jobs in both urban and peri-urban areas.

**Waste Recycling and Sustainability:** Urban gardening promotes efficient use of resources like water, fertilizers and space. Organic waste from households can be recycled into compost, reducing environmental pollution and supporting sustainable production.

**Reduced Food Miles and Carbon Footprint:** Producing food near consumption areas reduces transportation needs, lowering fuel use and carbon emissions. This contributes to a cleaner and greener urban environment.

### **Protected Cultivation in Urban and Peri-Urban Areas**

As cities expand and weather becomes more unpredictable, growing food in the open is increasingly risky. Protected cultivation offers a practical solution by creating a controlled environment for crops. Farmers grow plants inside specially designed structures where temperature, light, humidity and other factors can be managed. This helps crops grow efficiently throughout the year, regardless of external climatic conditions or pollution.

#### **Types of Protected Structures**

Protected cultivation can be adapted to different spaces, from large farms to small urban areas.

**Greenhouses and Polyhouses:** These are the heavyweights of protected farming, ranging from naturally ventilated structures (which use zero energy) to fully climate-controlled systems equipped with exhaust fans, cooling pads and foggers. They are constructed using steel or aluminum frames and covered with glass, polycarbonate or specialized plastic films.



**Shade Net Houses:** A highly cost-effective solution, these structures use specialized nets to filter out intense solar radiation and provide protection against wind and large insects. They are particularly useful in warmer peri-urban climates for growing leafy greens and ornamentals.

**Terrace Gardens and Vertical Farming:**

Designed specifically to combat the urban "space crunch", these systems utilize the Z-axis. Vertical farming stacks growing channels in multiple layers (often 5 to 7 layers deep), maximizing production output by taking advantage of 3-dimensional space. Rooftop gardens turn unused, sun-drenched concrete expanses into productive green zones.



**Low Tunnels and Walk-in Tunnels:** For smaller peri-urban plots or community gardens, these affordable, quasi-permanent plastic structures provide an excellent entry point. They are easy to construct and highly effective at shielding young crops from heavy rains and sudden temperature drops.

**Advantages of Protected Cultivation**

Protected cultivation provides several important benefits for urban and peri-urban farming.

**Year-Round Production:** Crops can be grown in any season, ensuring a steady supply and better market prices during off-season periods.

**Protection from Climate and Pests:** These structures act like a shield against extreme weather and insects, reducing the need for chemical pesticides and producing safer food.

**Efficient Use of Water and Land:** When combined with drip irrigation, water is

delivered directly to plant roots, saving up to 80% compared to traditional methods. Space is also used more efficiently, especially in vertical systems.

**Higher Yield and Better Quality:** Plants grow in stress-free conditions, leading to healthier crops, reduced losses and significantly higher profits often 4 to 8 times more than open-field farming.

**Internet of Things (IoT) in Urban and Peri-Urban Areas**

The Internet of Things (IoT) is defined as a technology that enables connections between people and objects at any time and location, utilizing varied networks and services. In the context of urban protected cultivation, IoT facilitates the transition of environmental monitoring from traditional offline systems to wireless and cloud-based platforms. This framework allows electrical devices, sensors and actuators to exchange information with centralized servers without the need for human intervention.

**Components of the IoT Architecture**

A comprehensive IoT system for greenhouse monitoring and control relies on several interconnected layers, primarily consisting of data acquisition (sensors), processing (microcontrollers) and cloud analytics.

**Data Acquisition: Sensor Technologies**

Sensors are electronic instruments that measure environmental characteristics and transmit data as electrical signals to the main automation computer for interpretation.

**Soil Moisture Sensors:** Common variants include capacitive and resistive sensors. Capacitive soil moisture sensors measure the dielectric constant of the media to calculate

Volumetric Water Content (VWC), offering low salt sensitivity and low power consumption.



**Temperature and Humidity Sensors:** Air and root zone (substrate) temperatures are critical for controlling plant development and are typically monitored using thermostats and thermocouples. Humidity is measured using capacitive, resistive or thermal conductive sensors, with thermal conductive variants performing exceptionally well in high-temperature environments.

**Radiation and Light Sensors:** Light intensity and spectrum are monitored using Pyrometers (measuring global radiation in  $W.m^{-2}$ ), PAR (Photosynthetically Active Radiation) sensors (measuring the 400 to 700 nm waveband), and Light Dependent Resistors (LDR).

**Carbon Dioxide (CO<sub>2</sub>) Sensors:** Monitoring CO<sub>2</sub> is critical as concentrations can drop significantly in tightly enclosed greenhouses during winter mornings due to plant photosynthesis. A standard instrument is the InfraRed Gas Analyzer (IRGA), which detects CO<sub>2</sub> using the Non-Dispersive InfraRed (NDIR) principle.

**Chemical and Nutritional Sensors:** For precision fertigation and hydroponics, pH sensors determine the acidity or alkalinity of the solution, while Electrical Conductivity (EC) sensors indicate overall nutrient concentration. NPK sensors collect real-time data on Nitrogen, Phosphorus and Potassium

composition to facilitate targeted precision fertilization strategies. Advanced vertical farming operations also utilize Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) sensors.

**Controllers and Automation Systems:** The microcontroller (e.g., Raspberry Pi, Arduino, ESP32) functions as the core processing unit of the IoT system. It continuously monitors the digitized parameters from each sensor and verifies them against predefined threshold values. If a parameter deviates from the threshold, the microcontroller activates output controlling devices such as solenoid valves, foggers and exhaust fans through relays to perform corrective operations.

**Cloud Platforms and Data Analytics:** Data transmitted from the IoT system is managed by high-performance cloud servers that provide tools for collecting, processing and storing large datasets. IoT analytics transform this raw data into meaningful information for real-time analysis, which is then presented through a user interface to allow growers to observe trends, set up alarms or automate crop management protocols.

### Artificial Intelligence in Smart Gardening

Artificial Intelligence (AI) in smart gardening refers to the use of advanced algorithms and machine learning techniques to analyze data collected from sensors and other sources. It helps convert raw environmental data into meaningful insights, enabling better decision-making in urban and protected cultivation systems. AI enhances precision, reduces human effort and improves overall efficiency in crop production.

### **Role of AI in Decision-Making and Prediction**

AI shifts farming from a reactive approach to a predictive one. Instead of responding to problems after they occur, AI can forecast future conditions based on historical and real-time data. For example, it can predict temperature rise, water requirements or potential stress conditions in crops, allowing timely preventive measures. This improves reliability and minimizes risks in urban farming.

### **Applications of AI in Urban and Protected Cultivation**

AI is widely applied in different aspects of urban agriculture, including crop monitoring, resource management and environmental control. By integrating with IoT systems, AI enables automated and intelligent farm operations, making it suitable for both small-scale urban gardens and advanced greenhouse systems.

**Crop Growth Prediction and Yield Estimation:** AI models analyze various factors such as climate, soil conditions, irrigation and crop management practices to predict plant growth and yield. Advanced systems can simulate plant development and estimate productivity before harvest, helping farmers plan marketing and resource allocation efficiently.

**Disease and Pest Detection Using AI:** AI uses image processing and pattern recognition techniques to identify plant diseases and pest infestations at early stages. By comparing images of affected plants with large databases, AI can diagnose issues quickly and accurately, allowing timely intervention and reducing crop losses.

**Smart Irrigation Scheduling:** AI optimizes irrigation by analyzing soil moisture levels, weather data and plant water requirements. It determines the exact timing and quantity of water needed, ensuring efficient water use and preventing over or under-irrigation. This is especially important in water-scarce urban environments.

**Climate Optimization in Protected Structures:** In greenhouses and other protected systems, AI continuously monitors environmental parameters such as temperature, humidity and light. It automatically adjusts conditions using devices like fans, foggers and shading systems to maintain an optimal microclimate for crop growth.



**AI-Based Crop and Nutrient Recommendation Systems:** AI acts as a digital advisor by analyzing soil nutrient levels (NPK), pH and environmental conditions. Based on this data, it recommends suitable crops for cultivation and suggests precise nutrient management practices, improving productivity and soil health.

**Importance of AI in Future Urban Agriculture:** AI plays a crucial role in making urban agriculture more sustainable, efficient and productive. By enabling precision farming, reducing resource wastage and improving crop quality, AI supports the development of resilient food production systems in rapidly growing urban areas.

## The Benefits of Smart Urban and Peri-Urban Gardening

**Efficient Use of Water and Nutrients:** Drip irrigation and fertigation deliver water and nutrients directly to roots, saving 30–80% water and reducing wastage. Advanced systems like aeroponics use even less water.

**Reduced Labor and Input Costs:** Automation through IoT minimizes manual work by handling irrigation, climate and nutrients, reducing labor and operational costs.

**Increased Productivity and Quality:** Controlled conditions boost yields (5-10× higher) and improve quality, while reducing post-harvest losses.

**Climate Resilience and Risk Reduction:** Protected structures shield crops from extreme weather, ensuring stable production with minimal risk.

**Sustainable Urban Ecosystem:** Urban gardening improves air quality, reduces heat and lowers carbon footprint by enabling local food production.

### Challenges and Constraints

**High Initial Investment:** Setting up smart urban farming systems like greenhouses, vertical farms, and IoT devices requires high capital. Advanced sensors and automation technologies further increase costs, making it difficult for small growers to adopt.

**Lack of Technical Knowledge:** Smart farming requires specialized skills in managing sensors, data, and automated systems. Limited technical know-how and lack of user-friendly protocols hinder widespread adoption.

**Maintenance of IoT and AI Systems:** Sensors and electronic devices must operate under harsh conditions like heat, humidity and dust. Regular maintenance and durable protective

systems are needed, increasing complexity and cost.

**Data Management and Connectivity Issues:** IoT systems depend on continuous internet and power supply. Poor connectivity and power interruptions, especially in peri-urban areas, can disrupt monitoring and automation.

**Limited Awareness and Adoption:** Despite its benefits, smart urban farming is still in early stages. Lack of awareness, local adaptation and financial support slows down its adoption among farmers and urban growers.

### Conclusion

Smart urban and peri-urban farming marks a paradigm shift in food production by seamlessly integrating protected cultivation with IoT and Artificial Intelligence to create precise, climate-resilient and data-driven systems. This synergy transforms underutilized urban spaces such as rooftops, vacant plots and peri-urban fringes into highly productive green hubs, bringing fresh, high-quality produce closer to consumers. However, realizing its full potential requires stronger technical awareness, capacity building and continued policy support through initiatives like the National Horticultural Board and National Horticultural Mission. As these technologies scale, they will play a crucial role in building sustainable, self-reliant cities by enhancing food security, optimizing resources and reducing environmental impact.