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# An exploration of the drivers and barriers to smart urban agriculture implementation for enhancing food security and urban resilience

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## Abstract

Rapid urbanization, increasing pressure on water and land resources, and growing vulnerability of food systems have highlighted the need for innovative food production approaches in urban environments. In this context, smart urban agriculture has emerged as a promising strategy for enhancing food security and urban resilience. This study aims to identify the main drivers and barriers to the implementation of smart urban agriculture and to clarify the requirements for its sustainable development. The study adopted a qualitative review approach using directed content analysis. Data were collected through a review of scientific literature published between 2010 and 2025. Out of selected eligible sources for analysis, a total of 610 initial codes were extracted and categorized using MAXQDA 2022 software. The findings revealed that economic and financial constraints (24.85%) constitute the most significant barriers to the adoption of smart urban agriculture, followed by cybersecurity and data privacy concerns (18.56%). In contrast, technological advancement and innovation (27.54%) and environmental sustainability (23.91%) were identified as the most influential drivers. The results indicate that the development of smart urban agriculture is not merely a technological issue but a multidimensional process shaped by the interaction of technological and institutional infrastructures, human and social capacities, and food security and urban resilience goals. Accordingly, this study proposes a conceptual framework for smart urban agriculture implementation that can support sustainable urban planning and policymaking, particularly in Iran.

## Keywords

Digital technologies
food security
smart city
smart urban agriculture
urban resilience

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## 1. Introduction

Rapid population growth, industrial expansion, and increasing pressure on natural resources have made the provision of basic human needs, including food, water, energy, and housing, one of the most critical global challenges. According to projections by the Food and Agriculture Organization of the United Nations (FAO), the world population is expected to increase significantly by 2050, resulting in an approximately 70% increase in agricultural production (FAO, 2009). These conditions have intensified the need for intelligent, efficient, and sustainable solutions for resource management and productivity enhancement. Within this context, the concept of the smart city emerged as an innovative approach to urban management. Originating in the late 1990s and becoming widely integrated into scientific and urban planning literature from the mid-2010s onward, the smart city concept seeks to optimize urban services, promote sustainable resource management, and improve citizens' quality of life through the use of information and communication technologies. A review of previous studies indicates that smart cities encompass multiple dimensions, including smart economy, smart governance, smart citizens, smart environment, smart infrastructure and technology, smart transportation, smart water and wastewater management, smart security, and smart agriculture. Each of these dimensions plays a distinct role in enhancing urban efficiency and sustainability.

Among the various dimensions of smart cities, smart agriculture occupies a particularly important position, as reducing agricultural land, limited water and energy resources, and growing food demand have substantially reduced the effectiveness of traditional production methods. By utilizing technologies such as smart sensors, advanced monitoring systems, and data analytics, smart agriculture enables precise management of temperature, humidity, crop requirements, and nutritional conditions, thereby reducing resource consumption and increasing production efficiency (Farrokhi & Gapeleh, 2019; Nasiri Zare et al., 2025). However, smart urban agriculture represents a broader approach than conventional smart agriculture because it applies digital technologies within the spatially constrained, densely populated, and complex urban environment. Through the use of the Internet of Things (IoT), artificial intelligence (AI), remote sensing, big data, and automated systems, this approach enables sustainable food production in limited urban spaces such as rooftops, vertical farms, controlled environments, and smart greenhouses (Bagheri, 2021; Jamshidi et al., 2023). In addition to improving productivity and reducing resource consumption, smart urban agriculture reduces environmental impacts, strengthens local economies, shortens food supply chains, and increases urban resilience, making it a key strategy for managing future cities (Gunapala et al., 2025).

Despite global advancements, the implementation of smart urban agriculture in Iran remains in its early stages. Weak technological infrastructure, shortages of specialized skills, spatial constraints, lack of coherent policies, and institutional challenges constitute some of the major barriers to its development (Arabzadeh et al., 2023; Jozay & Tehranifar, 2026; Mirzaeipour et al., 2025). At the same time, Iran's climatic conditions, resource limitations, and the growing need to strengthen food security in urban areas have increased the urgency of adopting this approach and leveraging its potential to enhance urban resilience.

Accordingly, the present study aims to explore the drivers and barriers of smart urban agriculture implementation and to analyze its role in strengthening food security and urban resilience. The study first clarifies the concept and components of smart urban agriculture and then focuses on identifying existing capacities, opportunities, and challenges. It examines the factors that may facilitate the development of this approach as drivers or hinder its implementation in Iranian cities as barriers. This analysis identifies which obstacles exert the greatest influence in slowing the implementation process and which capacities have the greatest potential to accelerate the transition of Iranian cities toward smart urban agriculture development.

## 2. Theoretical and empirical background

This section establishes the theoretical framework and reviews the empirical evidence relevant to the study. It first addresses the concept and dimensions of the smart city, then examines the evolution and enabling technologies of smart agriculture. Subsequently, the necessity, development patterns, and evolution of urban agriculture are discussed, and the role of smart urban agriculture as a key component of food security, urban resilience, and sustainable urban development is clarified. Finally, previous empirical studies are reviewed to identify existing knowledge gaps and to position the present research within the current body of literature.

## 2.1. Concept and dimensions of the smart city

The smart city has emerged as a strategic response to the increasing complexity of urbanization, aiming to improve quality of life, enhance the efficiency of urban services, and promote economic, social, and environmental sustainability. This approach is based on the systematic use of information and communication technologies (ICT) and other digital tools for the efficient management of urban resources, infrastructure, and services (Balouchi et al., 2021; Hatami et al., 2021). In the scientific literature, a smart city is commonly defined as an integrated and multidimensional system in which physical infrastructure, digital technologies, human capital, and social capital interact in a coordinated manner to foster sustainable economic growth, improve urban governance, and strengthen resilience against complex challenges (Caragliu et al., 2011; Gholami Nourabad et al., 2023; Parvin et al., 2025). From this perspective, urban smartification extends beyond the mere application of technology; rather, it represents a knowledge-based and participatory process that promotes learning, innovation, and data-driven decision-making at the urban scale. By providing the conceptual and infrastructural foundation for digital systems, data-oriented management, and technological innovation, the smart city approach creates the necessary conditions for the development of fields such as smart urban agriculture.

## 2.2. Smart agriculture: Concept, evolution, and technologies

In many countries, agriculture continues to account for a significant share of gross domestic product and employment; however, it faces major challenges, including climate change, the reduction of arable land, water scarcity, the spread of pests and diseases, and labor shortages. In response to these challenges, the adoption of digital technologies has led to the emergence of the smart agriculture approach (Hesabi et al., 2023). This approach is considered an extension and evolution of precision agriculture, with the objectives of increasing productivity, reducing dependence on human labor, and enhancing the resilience of food production systems. Although there is no universally accepted definition of smart agriculture, most studies describe it as a set of ICT-based methods and technologies that optimize agricultural production management using environmental and biological data (Sabet & Mohammadpour, 2022; Suma et al., 2017; Virk et al., 2020). By employing sensor networks, data processing systems, and analytical platforms, smart agriculture enables continuous monitoring of climatic conditions, crop growth status, and production inputs. This process generally involves three stages: Data collection, data analysis and pattern extraction, and the application of the results in farm management (Sørensen et al., 2019). The data used in smart agriculture include large-scale climatic data, local environmental data, growing medium information, external data, and biosecurity data. These data are collected through sensors, satellite imagery, and monitoring systems and provide the foundation for data-driven decision-making (De Alwis et al., 2022; Ghasemloo et al., 2024; Mohammadpour, 2024; Tosan et al., 2024).

## 2.3. Urban agriculture: Necessities, evolution, and development models

Necessities and driving forces behind the emergence of urban agriculture

In recent decades, challenges of food provision in urban areas, combined with the impacts of climate change such as recurrent droughts, floods, and declining quality of natural resources, have constrained agricultural production capacity and placed urban food security at risk. At the same time, cities' dependence on long supply chains and food imports has increased the vulnerability of food systems to crises including market fluctuations, pandemics, and geopolitical tensions (Shon et al., 2023). Under such conditions, the development of local, sustainable, and innovation-driven approaches for producing fresh and healthy food within urban areas has become a strategic necessity.

*Historical and conceptual evolution of urban agriculture*

Urban agriculture, as part of the transformation of food production patterns in human-made environments, has deep historical roots. Early ideas for cultivating crops in limited urban spaces emerged in the early twentieth century and later evolved into soilless cultivation methods, green walls, and vertical farming systems. During the late twentieth and early twenty-first centuries, alongside advances in precision agriculture and data-driven technologies, urban agriculture gradually evolved from a small-scale experimental activity into a structured, technology-oriented production system. This transformation paved the way for a new generation of urban food production models aimed at optimizing space utilization, reducing resource consumption, and enhancing the resilience of food systems (Senthamizh, 2025; Shon et al., 2023; Zadouli Khajeh & Asadi, 2024).

*Urban agriculture development models and policies*

Urban agriculture has developed through various models, including community-based agriculture, rooftop farming, indoor farming, and vertical farming. These models often rely on advanced cultivation technologies, such as hydroponics, aeroponics, and aquaponics, which enable intensive and controlled production in limited urban spaces (Chowdhury et al., 2023; Hakimi, 2023; Verma et al., 2024). Globally, the expansion of the urban agriculture market and the increasing adoption of supportive governmental policies reflect the strategic importance of this sector. Many countries, including the United States, India, and several European nations, have promoted urban agriculture through financial incentives, technical support, and policy programs, recognizing it as a component of sustainable development, food security, and urban resilience strategies (Halvey et al., 2021).

## 2.4. Smart urban agriculture

*Concept and rationale for the development of smart urban agriculture*

Smart urban agriculture is regarded as the most advanced form of urban agriculture, relying on digital technologies, data-driven management, and controlled environment systems to enhance the productivity, sustainability, and resilience of urban food systems (Ferreira et al., 2022; Malekinejad et al., 2020). This approach responds to constraints such as limited space, the heterogeneity of urban environments, and the need for continuous, predictable food production. It has emerged from the convergence of urban agriculture, precision agriculture, and controlled environment agriculture (CEA) (Christmann et al., 2025; Marvin et al., 2024).

*Key technologies and infrastructure*

Smart urban agriculture is based on the integration of technologies such as the Internet of Things (IoT), artificial intelligence (AI), smart sensors, drones, and cloud-based processing systems, which enable real-time monitoring, advanced data analysis, and the automation of planting, cultivation, and harvesting processes (Miller et al., 2025). In recent years, the adoption of Edge AI, the fusion of proximal and remote sensing data, and the use of intelligent drones have significantly improved the responsiveness and autonomy of urban agricultural systems. Nevertheless, the absence of integrated data standards and economic challenges remains among the principal barriers to the large-scale deployment of these technologies in urban settings (Avasthi et al., 2025).

*Functions, food security, and urban resilience*

Smart urban agriculture performs multiple environmental, economic, and social functions. By reducing water consumption and chemical inputs, shortening supply chains, and lowering greenhouse gas emissions, these systems help improve urban environmental quality. From an economic perspective, increased productivity per unit area, reduced production costs, and the creation of technology-oriented employment opportunities are among their major benefits. Socially, they promote citizen participation, enhance food security and food justice, and improve environmental literacy (Table 1). In terms of food security, continuous and controlled food production within urban areas reduces dependence on external sources; it strengthens the stability of the food supply in the face of climatic, economic, and geopolitical crises. In this study, urban resilience is defined as the capacity of urban systems to maintain, adapt, and recover their critical functions in response to crises, disruptions, and stresses, including climate change, resource constraints, and interruptions in food supply chains. From this perspective, smart urban agriculture, as a key component of urban resilience, plays a significant role in safeguarding essential urban functions by reducing the fragility of supply chains, enhancing the capacity to respond during emergencies, and strengthening urban ecosystem services (Gunapala et al., 2025; Steenkamp et al., 2021; Tabrez, 2025).

**Table 1. Functions and benefits of smart urban agriculture**

| Dimension | Main functions and benefits |
|---|---|
| Environmental | - Reduction in water consumption through precision irrigation<br>- Reduced dependence on chemical pesticides and fertilizers<br>- Lower greenhouse gas emissions through shortened supply chains<br>- Contribution to mitigating the urban heat island effect and improving air quality |
| Economic | - Increased productivity per unit area<br>- Reduced production costs through automation and intelligent management<br>- Creation of new jobs in agricultural and data-driven technology sectors<br>- Strengthening of local markets and shortening of supply chains |
| Social | - Greater participation of local communities in food production<br>- Strengthening of social capital and neighborhood relationships<br>- Enhancement of food security and food justice<br>- Improvement of environmental literacy and public awareness |

## 2.5. Review of empirical studies

A review of the existing literature indicates that studies on smart urban agriculture can be classified into three main categories. The first category includes studies focusing on urban agriculture, examining its capacities, spatial limitations, social implications, and its role in urban sustainability and food security. The second category comprises research on smart agriculture technologies and systems, including the Internet of Things (IoT), artificial intelligence (AI), environmental control technologies, and precision farming systems, which evaluate the capabilities and technical challenges of these technologies. The third category encompasses more recent investigations that directly address smart urban agriculture and vertical farming, emphasizing the integration of technology, urban design, energy management, and data management within urban environments. Taken together, these studies provide a comprehensive understanding of both the opportunities and the limitations associated with implementing smart agriculture in urban areas. They collectively demonstrate that the successful development of this approach requires the simultaneous advancement of technological innovations, effective institutional frameworks, and integrated urban planning strategies. Table 2 presents a structured summary of some of the most significant studies conducted in this field.

**Table 2. Key studies, methods and findings, and their relevance to the present research**

| Author/study title | Method/ study type | Key findings | Relevance to the present study |
|---|---|---|---|
| Zaręba et al., 2021 (Urban vertical farming as an example of nature-based solutions supporting a healthy society living in the urban environment) | Review/case study | Social, economic, and climatic benefits of vertical farming; practical examples | Highlights opportunities and advantages (drivers: Productivity, space efficiency, and quality) |
| Huang & Chang, 2021 (Prospects for rooftop farming system dynamics: An action to stimulate water-energy-food nexus synergies toward green cities of tomorrow) | Modeling/ feasibility analysis | Predictive production model with minimal water consumption for rooftop farming | Water optimization technologies (technological drivers) |
| Ivascu et al., 2021 (The perception and degree of adoption by urbanites towards urban farming) | Survey | Citizen participation indicators: Trust, sense of community, and enjoyment | Social dimensions (social drivers and barriers) |
| Arabzadeh et al., 2023 (Planning and designing smart plant platforms in the form of home vertical farming in residential and urban spaces of Iran) | Applied/ design analysis | Development of smart vertical farming platforms in residential spaces; enhancement of spatial efficiency and food security | Design and spatial drivers of smart urban agriculture implementation and its role in food security |
| Hardman et al., 2022 (Mainstreaming urban agriculture: Opportunities and barriers to upscaling city farming) | Review and analysis | Economic challenges, soil quality issues, infrastructure maintenance, and practical solutions | Financial and technical barriers |

| Author/study title | Method/ study type | Key findings | Relevance to the present study |
|---|---|---|---|
| Van Gerrewey et al., 2022 (Vertical farming: The only way is up?) | Systematic review/ analytical study | Commercial assessment, technological issues, and sustainability challenges of vertical farming | Capital and energy costs (economic and technical barriers) |
| Shon et al., 2023 (Characteristics of smart farms for architectural planning and design) | Design and architectural feasibility | Design requirements for greenhouses and urban spaces integrating smart technologies | Spatial and structural design requirements as both drivers and barriers |
| Oh & Lu, 2023 (Vertical farming – smart urban agriculture for enhancing resilience and sustainability in food security) | Literature review | Vertical farming as a strategy for strengthening food security; need for improved energy efficiency | Benefits and challenges of vertical farming (drivers and barriers) |
| Dibbern et al., 2024 (Main drivers and barriers to the adoption of digital agriculture technologies) | Review/ meta-analysis | Cost, infrastructure, training, data concerns, and regional differences | A set of drivers and barriers that are also applicable in urban environments |
| Sowmya et al., 2024 (Recent developments and inventive approaches in vertical farming) | Review | Emerging techniques and the role of vertical farming in dense urban food production | Technical innovations and cost-reduction pathways (drivers) |
| Teoh et al., 2024 (A review on urban farming: potential, challenges and opportunities) | Review | Assessment of the potential, drivers, and barriers of urban farming | Synthesis of opportunities and risks at the urban scale |
| Zikri, 2024 (Smart urban farming 5.0: Integration of vertical farming automation and solar panels for maximum energy efficiency and productivity) | Technical analysis | Integration of automation and solar energy to increase efficiency | Innovation and resource-optimization drivers |
| Aborujilah, 2025 (Towards sustainable vertical farming: A systematic review of energy return on investment efficiency and optimization strategies) | Systematic review | Energy consumption challenges in vertical farming and optimization strategies | Economic and technical barriers and energy-management drivers |
| Jozay & Tehranifar, 2026 (Vertical green systems in smart cities: A comprehensive review of design, functionality and environmental impacts) | Review/ comprehensive analysis | Environmental benefits, spatial efficiency, and the role of vertical green systems in smart city development | The role of green infrastructure and urban design in supporting smart urban agriculture implementation and enhancing resilience |

## 2.6. Research gap and positioning of the present study

Although the existing literature demonstrates that smart urban and vertical agriculture possesses significant potential for enhancing food security and urban resilience, a review of previous studies indicates that comprehensive investigations into the drivers and barriers of implementing this approach remain limited. A considerable proportion of earlier research has focused primarily on technical dimensions and technologies such as vertical farming, the Internet of Things (IoT), and automated systems; this is while comparatively less attention has been paid to institutional factors, policy frameworks, social acceptance, compatibility with urban structures, and the implications for resilience and food security. Furthermore, the empirical literature, including case-based evidence, economic evaluations under different climatic conditions, and field-based studies in developing countries, remains relatively scarce, creating an important gap in evidence-informed decision-making. This gap is particularly pronounced in countries with arid and semi-arid climates, such as Iran, where only a limited number of studies have explicitly examined the implementation of smart urban agriculture. Accordingly, there is a clear need for research that systematically explores the drivers and barriers to implementing smart urban agriculture. The present study seeks to address this need by providing a comprehensive understanding of the factors influencing the realization of this approach and by contributing to the existing knowledge base on enhancing food security and urban resilience in urban environments.

## 3. Methodology

This review-analytical research was conducted using a qualitative-descriptive approach, based on document analysis and qualitative content analysis. Given the emerging and interdisciplinary nature of the concept of smart urban agriculture and its close relationship with smart cities, food security, and urban resilience, this approach was considered appropriate for examining key concepts, comparing different perspectives, analyzing global trends, and identifying existing knowledge gaps. Research data were collected through library research and a systematic review of the literature. The processes of searching, selecting, and analyzing sources were conducted according to the search strategy presented in Table 3. The selected sources included studies related to smart urban agriculture, smart cities, food security, and urban resilience, which were screened and scientifically evaluated before being incorporated into the qualitative content analysis process.

**Table 3. Conceptual design and search strategy for the review of smart urban agriculture studies**

| Component | Description |
|---|---|
| Research design | Review–analytical (qualitative–descriptive), based on document analysis and qualitative content analysis |
| Time span of sources | 2010–2025 |
| Source languages | Persian and English |
| Databases used | Scopus, Web of Science, ScienceDirect, Springer, Taylor & Francis, IEEE Xplore, Google Scholar, SID, and Civilica |
| Types of sources | Journal articles, review articles, international reports, and authoritative policy documents |
| Main keywords | Smart urban agriculture, urban farming, smart city, food security, urban resilience, precision agriculture, IoT-based agriculture, controlled environment agriculture (CEA) |
| Search strategy | Combined searches using the AND and OR operators in titles, abstracts, and keywords |
| Inclusion criteria | Direct relevance to smart urban agriculture, smart cities, food security, and urban resilience; presence of a valid theoretical framework and methodology; publication between 2010 and 2025 |
| Exclusion criteria | Duplicate sources, undocumented reports, articles lacking scientific structure, and studies without explicit relevance to the urban context and smart components |
| Initially identified sources | 942 records |
| Final selected sources | 51 sources (22 review articles, 24 journal articles, and five international reports) |
| Data analysis software | MaxQDA 2022 |
| Analytical method | Directed qualitative content analysis, open coding, axial coding, and selective coding |
| Validation procedures | Source triangulation, peer review, analytical inference, and double recoding (agreement coefficient = 0.82) |

In this study, gray literature consisted of reports and policy documents published by reputable international organizations, including the FAO, OECD, the World Bank, and UN-Habitat, which were included in the analysis process after evaluating source credibility and thematic relevance. Accordingly, during the identification stage, 942 records were identified from international and domestic scientific databases. After removing 271 duplicate records, 671 records entered the title and abstract screening stage. At this stage, 580 records were excluded due to the lack of direct relevance to smart urban agriculture, an exclusive focus on non-urban topics, or the lack of connection to food security and urban resilience. Subsequently, 91 studies were assessed through full-text review, and 40 additional studies were excluded because of unavailable full texts, weak conceptual relevance, or insufficient focus on the opportunities and barriers associated with smart urban agriculture. Ultimately, 51 studies were selected for qualitative content analysis and coding and were included in the final analysis process (Figure 1).

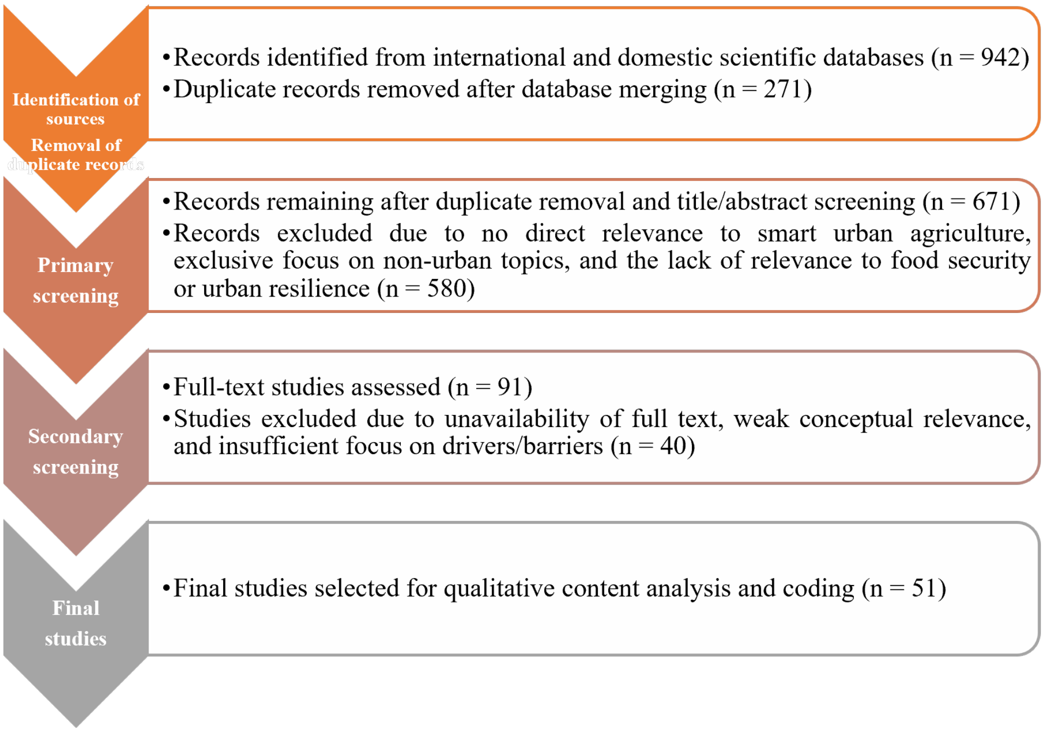


**Figure 1. The process of study identification, screening, and selection**

After selecting the sources, the data were analyzed in three stages (Table 4). In the first stage, all texts were imported into MaxQDA 2022, and the basic concepts, definitions, technologies, and key variables were extracted. In the second stage, axial and thematic coding was conducted using a directed qualitative content analysis approach, guided by relevant theoretical frameworks. The coding process was organized around two principal dimensions: Challenges/barriers to smart urban agriculture and opportunities/drivers of smart urban agriculture. The extracted codes were subsequently structured into sub-codes, intermediate themes, and overarching themes. In the third stage, the conceptual relationships among smart technologies, smart city development, food security, and urban resilience were analyzed, and the study's final conceptual framework was developed.

**Table 4. Data analysis process and code organization in the study**

| Analysis stage | Activity description | Result obtained |
|---|---|---|
| Stage 1: Concept extraction | Importing the 51 selected sources into MaxQDA 2022 and extracting concepts, definitions, technologies, and key variables | Extraction of 610 initial codes |
| Stage 2: Open coding | Identifying similar concepts and conducting the initial categorization of data based on directed qualitative content analysis | Formation of sub-codes |
| Stage 3: Axial coding | Aggregating sub-codes and organizing them into intermediate themes | Extraction of relevant intermediate themes |
| Stage 4: Selective coding | Final classification of themes according to the two main dimensions of the study | Identification of the two principal categories: "Drivers" and "barriers" |
| Stage 5: Conceptual analysis | Examining the relationships among smart technologies, smart cities, food security, and urban resilience | Development of the conceptual framework of the study |

To enhance the scientific credibility of the findings, source triangulation, peer review, analytical inference, and comparative analysis with global models were employed. The reliability of the coding process was confirmed through double recoding, resulting in an inter-coder agreement coefficient of 0.82. Given the review–analytical nature of the study and its focus on conceptual exploration, analysis of global trends, and the development of a theoretical framework for smart urban agriculture, the use of field data was not considered necessary. Accordingly, the study was classified as an exploratory–analytical investigation.

## 4. Findings

The findings of this study are derived from an analysis of the existing literature on smart urban agriculture, indicating that implementing this approach in urban areas is impacted by a combination of drivers and barriers. The qualitative analysis revealed that a substantial portion of the specialized literature focuses on the constraints and barriers to implementing and expanding smart urban agricultural systems, while another group of studies emphasizes the existing capacities and enabling drivers. Through the extraction and aggregation of these themes, a dual framework of barriers and drivers was identified, each exerting a direct influence on the feasibility, efficiency, and sustainability of implementing smart urban agriculture. The following sections present the most significant barriers and drivers identified in the literature, providing a comprehensive picture of the current situation and this approach's future development prospects.

The analysis of the 51 selected sources yielded 610 initial codes, of which 334 (54.7%) were related to barriers and 276 (45.3%) were associated with drivers of smart urban agriculture implementation. To illustrate the relative share of these two main categories, the frequency distribution of the extracted codes is presented in Figure 2. As shown in Figure 2, the proportion of barriers exceeds that of drivers, indicating that challenges and constraints predominate over available opportunities in the implementation of smart urban agriculture. This suggests that, although advanced technologies and smart approaches possess considerable potential for enhancing food security and urban resilience, the realization of this potential depends on overcoming economic, technological, institutional, and social barriers.

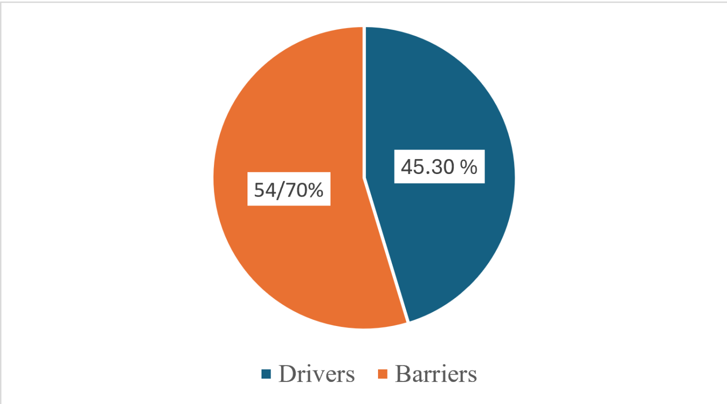


**Figure 2. Relative share of drivers and barriers to smart urban agriculture implementation based on the frequency of extracted codes**

### 4.1. Barriers

The frequency analysis of barriers revealed that economic and financial barriers, with 83 occurrences (24.85%), constituted the largest share and were identified as the most significant obstacle to the development of smart urban agriculture. They were followed by cybersecurity and data privacy concerns, with 62 occurrences (18.56%), ranking second. Technological limitations accounted for 44 codes (13.17%), while lack of knowledge and technical skills represented 43 codes (12.87%), indicating that insufficient technical and human capacity remains a major constraint on the realization of this approach. Other barriers, including climatic and environmental constraints (35 occurrences), insufficient technical and communication infrastructure (27 occurrences), legal and policy-related barriers (21 occurrences), cultural barriers and low social acceptance (14 occurrences), and mistrust of data and concerns regarding data accuracy (five occurrences), had smaller but still noteworthy shares. Table 5 presents the distribution of the identified barriers.

Table 5. Frequency distribution of smart urban agriculture barriers

| No. | Barrier category | Frequency | Percentage of total barriers |
|---|---|---|---|
| 1 | Economic and financial | 83 | 24.85 |
| 2 | Cybersecurity and data privacy | 62 | 18.56 |
| 3 | Technological | 44 | 13.17 |
| 4 | Lack of knowledge and skills | 43 | 12.87 |
| 5 | Climatic and environmental | 35 | 10.48 |
| 6 | Inadequate infrastructure | 27 | 8.08 |
| 7 | Legal and policy-related | 21 | 6.29 |
| 8 | Cultural and social acceptance | 14 | 4.19 |
| 9 | Data trust and data accuracy | 5 | 1.50 |

## 4.2. Drivers

Among the identified drivers, technological advancement and innovation had the largest share, with 76 occurrences (27.54%), indicating that the development of digital technologies, the Internet of Things (IoT), artificial intelligence (AI), drones, and data-driven analytics represents the most influential force driving the implementation of smart urban agriculture. Environmental sustainability ranked second, with 66 occurrences (23.91%), highlighting the important role of smart agriculture in reducing resource consumption, optimizing energy use, and lowering greenhouse gas emissions. Other drivers included improved precision and productivity (41 occurrences), economic benefits (35 occurrences), efficient management of natural resources (24 occurrences), enhanced food security (23 occurrences), reduced labor requirements (four occurrences), social advantages (three occurrences), and improved infrastructure and resources (two occurrences). Table 6 presents the distribution of the identified drivers.

Table 6. Frequency distribution of smart urban agriculture drivers

| No. | Driver category | Frequency | Percentage of total drivers |
|---|---|---|---|
| 1 | Technological advancement and innovation | 76 | 27.54 |
| 2 | Environmental sustainability | 66 | 23.91 |
| 3 | Increased precision and productivity | 41 | 14.86 |
| 4 | Economic benefits | 35 | 12.68 |
| 5 | Natural resource management | 24 | 8.70 |
| 6 | Enhanced food security | 23 | 8.33 |
| 7 | Reduced labor requirements | 4 | 1.45 |
| 8 | Social advantages | 3 | 1.09 |
| 9 | Infrastructure and resource advantages | 2 | 0.72 |
| 10 | Resource optimization and waste reduction | 2 | 0.72 |

These results are also illustrated as bar charts in Figures 3 and 4 to facilitate a visual comparison of frequency distributions. As shown in the charts, a substantial gap exists between economic barriers and the other identified barriers. Similarly, within the driver category, technological advancement/innovation and environmental sustainability account for the largest shares. Furthermore, the analysis of the extracted codes indicated that a considerable proportion of the identified drivers, particularly technological advancement, environmental sustainability, efficient natural resource management, and enhanced food security, contribute directly or indirectly to strengthening urban resilience. By reducing dependence on long supply chains, increasing the stability of food production, improving resource management, and enhancing cities' adaptive capacity in the face of climatic and economic crises, these factors create favorable conditions for improving the resilience of urban systems.

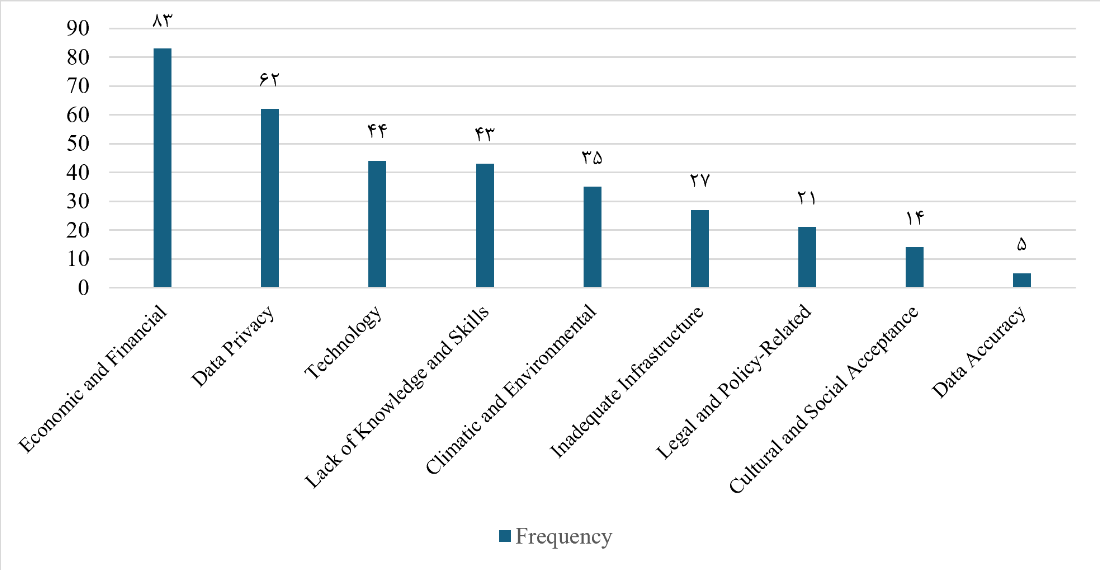


**Figure 3. Frequency distribution of barriers to smart urban agriculture implementation**

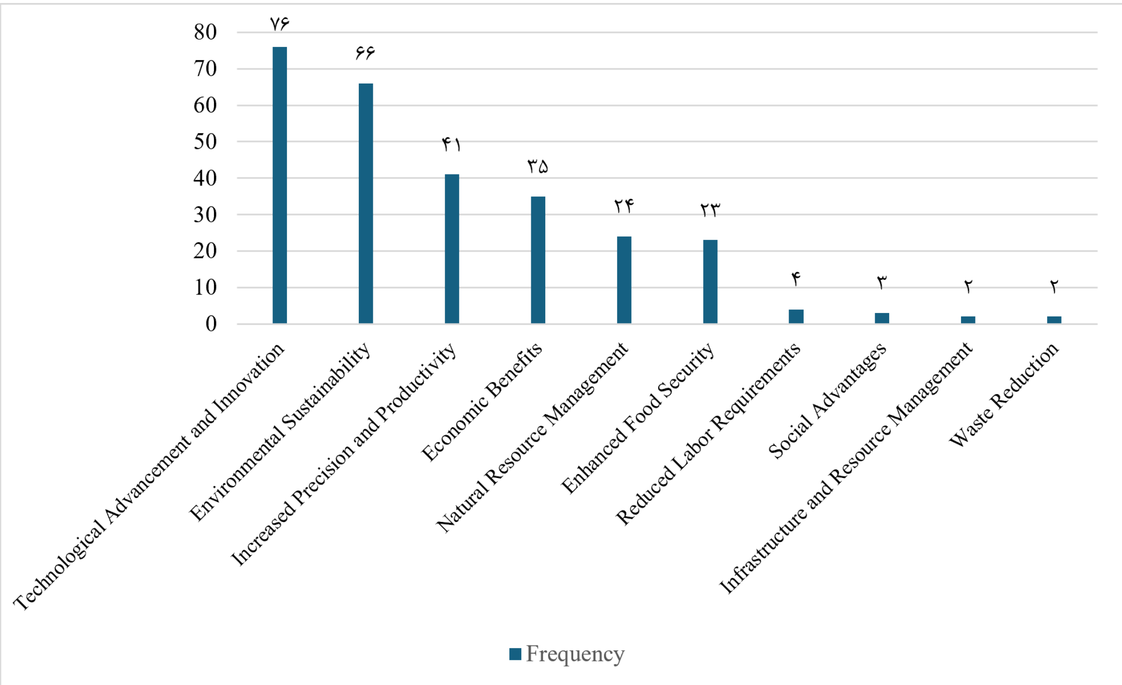


**Figure 4. Frequency distribution of drivers of smart urban agriculture implementation**

## 5. Discussion and interpretation of findings

The discussion and interpretation of this study's findings are based on the analysis of barriers and drivers influencing the implementation of smart urban agriculture to enhance food security and urban resilience. The findings indicate that implementing this approach is not merely a technological process but rather a multidimensional phenomenon intertwined with the city's economic, institutional, social, and environmental structures. Examining barriers and drivers simultaneously reveals that the development pathway of smart agriculture in urban contexts is shaped by the dynamic interaction between structural constraints and technological opportunities, and effective policymaking and evidence-based planning cannot be achieved without understanding this interaction. The results further demonstrate that the identified barriers and drivers extend beyond their influence on the implementation of smart urban agriculture and play a decisive role in strengthening urban resilience. On the one hand, economic and financial barriers, technological limitations, and inadequate technical and communication infrastructure limit the capacity to adopt and expand advanced food production systems, thereby increasing urban vulnerability to supply chain disruptions, climate-related crises, and resource constraints. On the other hand, technological advancement and innovation, environmental sustainability, efficient natural resource management, and enhanced food security improve urban resilience by increasing productivity, reducing dependence on external resources, and enhancing the stability of food production and distribution systems. From this perspective, the development of smart urban agriculture should be regarded not only as a means of increasing food production, but also as a strategic approach for enhancing the resilience and sustainability of urban systems. The most significant barriers and drivers affecting the adoption and expansion of smart urban agriculture, based on the findings of the present study and the existing theoretical literature, are presented in Tables 7 and 8, providing a comprehensive picture of the existing constraints, available capacities, and potential future pathways for the development of this approach.

**Table 7. Barriers to smart urban agriculture implementation: Relative share, analytical dimensions, and research evidence**

| Barrier | Relative share (%) | Key analytical dimensions | Supporting studies (selected examples) | Implications for policy and planning |
|---|---|---|---|---|
| Economic and financial | 24.85 | High urban land costs; initial technology investment; operational expenses; uncertain returns; long payback period | Teoh et al., 2024; Whittinghill & Sarr, 2021; Pickles et al., 2025 | Financial incentives; microcredit schemes; public–private partnerships; allocation of underutilized urban spaces |
| Cybersecurity and data privacy | 18.56 | Risk of cyberattacks; unclear data ownership; concentration of data in cloud platforms; ethical concerns | Campoverde-Molina & Luján-Mora, 2025; Miller et al., 2025 | Data governance policies; encryption; decentralized AI; improvement of data literacy |
| Technological | 13.17 | Limited sensor accuracy; calibration fluctuations; platform incompatibility; difficulty in integrating data | Rajak et al., 2023; Ahoa et al., 2025; Miller et al., 2025 | Equipment standardization; digital infrastructure develop-ment; investment in fault-toler-ant AI |
| Lack of knowledge and skills | 12.87 | Weak practical skills; system complexity; shortage of specialized human resources | Amarasinghe et al., 2024; Kumar et al., 2025; Teoh et al., 2024 | Specialized training; modern extension services; university–government–industry learning networks |
| Climatic and environmental | 10.48 | Water stress; high temperatures; equipment deterioration; energy consumption; electronic waste | Miller et al., 2025; Dzvene et al., 2025 | Development of climate-adap-tive technologies; energy-effi-cient and resilient equipment |
| Inadequate infrastructure | 8.08 | Weak internet and electricity networks; insufficient water and wastewater infrastructure; unstable grids | Dibbern et al., 2024; Olatinwo et al., 2025 | Strengthening energy and communication infrastructure; integration with urban planning |
| Legal and policy-related | 6.29 | Lack of data ownership frame-works; AI liability issues; weak zoning and urban regulations | Zampati, 2023; Yuan et al., 2022; Gavai et al., 2025 | Data regulations; algorithmic transparency; support for small-scale farmers |
| Cultural and social acceptance | 4.19 | Mental resistance; fear of technology; traditional percep-tions of urban agriculture | Ivascu et al., 2021; Ilieva et al., 2022 | Public education; participatory projects; social trust-building |
| Data trust and accuracy | 1.50 | Sensor errors; data noise; communication interruptions; heterogeneous datasets | Fizza et al., 2021; Miller et al., 2025 | Standardization; data validation; data cleansing and blockchain applications |

**Table 8. Drivers of smart urban agriculture implementation: Relative share, analytical dimensions, and research evidence**

| Driver | Relative share (%) | Key analytical dimensions | Supporting studies (selected examples) | Implications for policy and planning |
|---|---|---|---|---|
| Technological advancement and innovation | 27.54 | Internet of Things (IoT); artificial intelligence (AI); vertical farming; real-time monitoring; data-driven management; automation | Singh & Singh, 2024; Gupta et al., 2025 | Investment in digital infrastructure; support for innovation; development of technology ecosystems |
| Environmental sustainability | 23.91 | Reduced water and energy consumption; input control; pollution reduction; mitigation of urban heat island effects | Singh & Singh, 2024; Gupta et al., 2025; Padhiary et al., 2025 | Integration of smart agriculture into climate and sustainable development policies |
| Increased precision and productivity | 14.86 | Precise control of growing conditions; reduced input losses; stable product quality | Kumar et al., 2025; Padhiary et al., 2025; Singh & Singh, 2024 | Improved productivity per unit area; reduced production costs; enhanced competitiveness |
| Economic benefits | 12.68 | Lower input costs; higher yields; creation of new jobs; long-term profitability | Bilal et al., 2023; Moghayedi et al., 2022 | Economic incentives; attraction of private investment; development of local markets |
| Natural resource management | 8.70 | Efficient use of water, energy, and fertilizers; soilless systems; data-driven decision-making | Liu et al., 2025; Gupta et al., 2025 | Integration of smart agriculture with resource management policies |
| Enhanced food security | 8.33 | Sustainable urban food production; reduced dependence on imports; reduced supply chain losses | Gunapala et al., 2025; Zivhave & Kornienko, 2025 | Strengthening food resilience; promoting local production; urban food planning |
| Reduced labor requirements | 1.45 | Automation; robotics; reduced human error; lower labor costs | Bazargani & Deemyad, 2024; Widianto & Juarto, 2023 | Support for automation; development of new workforce skills |
| Social advantages | 1.09 | Community participation; social capital; improved food literacy; enhanced quality of life | Ilieva et al., 2022; Zhou et al., 2023; Tabrez, 2025 | Participatory programs; urban extension initiatives; increased social acceptance |
| Infrastructure and resource advantages | 0.72 | Digital infrastructure; sustainable energy; underutilized urban spaces | Christmann et al., 2025; Fei et al., 2025 | Urban infrastructure development; regeneration of urban spaces |
| Resource optimization and waste reduction | 0.72 | Reduced water and input losses; lower post-harvest waste; shorter supply chains | Dongyu, 2019; Sowmya et al., 2024 | Circular economy strategies; reduction of food waste; smart supply chain management |

## 6. Conceptual model and theoretical contribution of the study

The analysis of evidence derived from the selected sources demonstrates that the development of smart urban agriculture is simultaneously influenced by technological, environmental, economic, and managerial drivers, as well as by economic, infrastructural, skill-related, institutional, and social barriers (Figure 5). The conceptual framework proposed in this study suggests that food security and urban resilience are not merely outcomes of technological advancement; rather, they emerge from the synergy among innovation, policymaking, human capacity, appropriate infrastructure, and social acceptance. Accordingly, the successful implementation of smart urban agriculture requires a systematic, multidimensional approach that simultaneously addresses technical, economic, social, and governance dimensions.

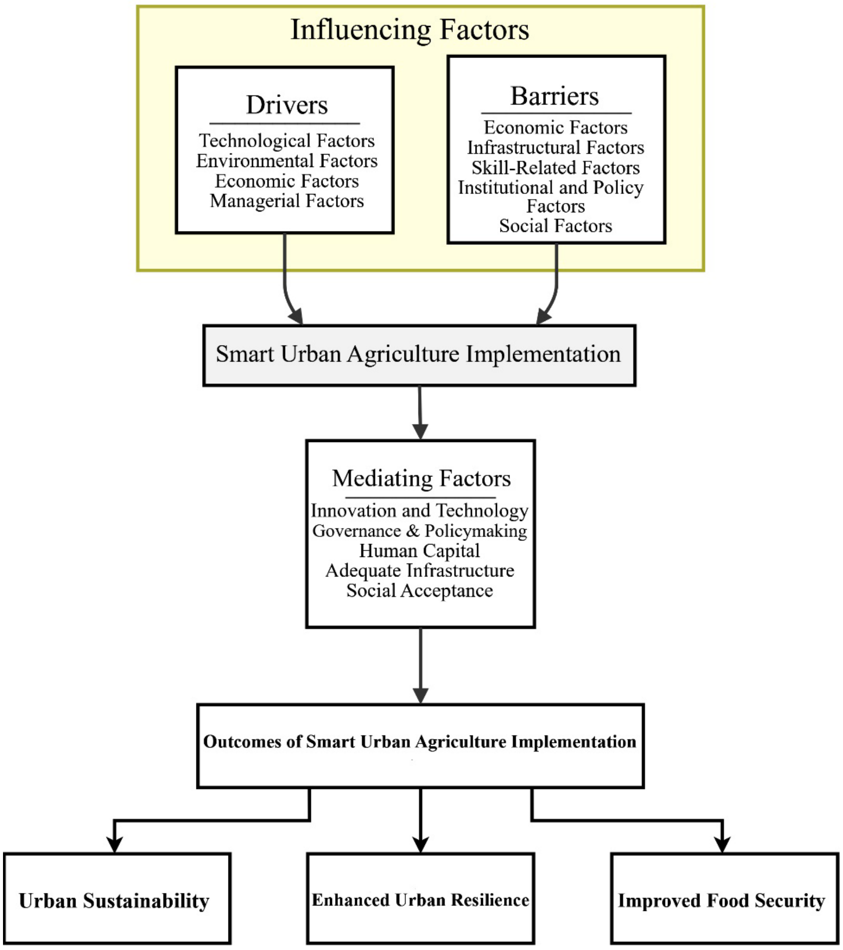


**Figure 5. Conceptual model of the study on the interaction between drivers and barriers of smart urban agriculture implementation**

## 7. Research limitations

The findings of this study are based on document analysis and a review of the global literature on smart urban agriculture. Therefore, the direct generalization of the results to the Iranian context requires field studies, economic evaluations, and contextual adaptation in accordance with the country's climatic, institutional, and infrastructural characteristics. In addition, the limited number of empirical studies and case-based investigations on smart urban agriculture in developing countries constitutes another limitation of the present research. Consequently, future studies are recommended to employ field data, quantitative approaches, and case study methodologies to validate and localize the findings of this research.

## 8. Conclusion

Overall, the findings of this study indicate that the accelerating pace of urbanization, intensifying climate change, declining water resources, and soil degradation in arid and semi-arid regions, particularly in countries such as Iran, have made reconsidering food production models and urban development patterns more urgent than ever. Within this context, smart urban agriculture, as a key component of smart city strategies, represents not only a technological response to food production challenges but also a strategic instrument for enhancing environmental sustainability, urban livability, resilience, and food security. The results demonstrate that integrating advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), remote sensing systems, and drones into urban production systems can significantly improve the management of limited resources, increase operational precision, reduce dependence on traditional agricultural practices, and enhance both spatial and functional efficiency within cities.

Despite these capacities, the analysis of the identified barriers and drivers shows that implementing smart urban agriculture requires an approach sensitive to local conditions, structural constraints, and technological capabilities. Economic and financial barriers, technological challenges, limited knowledge and skills, inadequate infrastructure, data security concerns, and legal and policy shortcomings constitute the main obstacles to the development of this approach. These barriers suggest that even when technological solutions are available, the absence of effective financial mechanisms, technical standards, stable communication infrastructure, and supportive regulations may slow or even hinder implementation.

Conversely, the findings emphasize that drivers such as technological advancement and innovation, environmental sustainability, increased productivity, intelligent resource management, and improved food security provide substantial momentum for the expansion of smart urban agriculture. The use of precision irrigation and smart sensors can significantly reduce water consumption, while digital technologies can decrease labor requirements, production waste, and operational costs. In addition, the production of fresh food near consumption centers, improvements in air quality, mitigation of urban heat island effects, enhancement of spatial equity, and the creation of new employment opportunities are among the notable benefits of this approach. These results indicate that smart urban agriculture is not merely a production technology, but rather a transformative mechanism for improving urban quality of life and strengthening urban resilience.

Beyond identifying barriers and drivers, the principal contribution of this study lies in offering an integrated perspective on smart urban agriculture within the framework of food security and urban resilience. Unlike many previous studies that have primarily focused on individual technologies, vertical farming, or technical aspects, the present research systematically analyzed the existing literature; it synthesized the extracted codes to demonstrate that the successful implementation of smart urban agriculture depends on the simultaneous interaction of technological, economic, institutional, infrastructural, and social factors. Accordingly, smart urban agriculture should not be viewed solely as a food production technology, but as a component of the broader urban resilience and sustainability system whose realization requires synergy among technological innovation, supportive policymaking, infrastructure development, and human capacity building. This integrated perspective constitutes the main theoretical contribution and added value of the present study.

In conclusion, the future of smart urban agriculture depends on the effective integration of three key elements: Smart policymaking, strengthened technological infrastructure, and empowered human capital. Urban planners and policymakers can facilitate the implementation of this approach through supportive regulations, financial incentives, technology standardization, digital infrastructure development, and expanded educational programs. The linkage between advanced technologies, local knowledge, and integrated urban planning can create a context in which cities simultaneously achieve economic dynamism, social equity, and environmental sustainability. From this perspective, smart urban agriculture has the potential to become one of the main drivers of urban transformation in Iran, accelerating the transition toward a resilient, green, and intelligent urban future.

## Authors' Contributions

The authors contributed equally to this article.


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## Conflict of Interest

The authors declare no conflict of interest.

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