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Enhancing domestic food supply in the UAE: A framework for technology-driven urban farming systems

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ABSTRACT

It is estimated that the recent ongoing supply chain disruptions have forced a transition in the traditional food supply chain business models. Organizations across all sectors are now adopting digital transformation strategies for embracing the new normal. Food security in the United Arab Emirates (UAE) is threatened by country's heavy reliance on food imports. Innovative urban farming systems are anticipated to improve the food security and sustainability to a great extent. Using a survey-based methodology, the present study aims to develop, validate, and apply a multi-dimensional innovative urban food production system framework for UAEs agricultural sector. Based on the data collected from 299 stakeholders across the whole agri-food supply chains in the UAE, the study determines ways of reducing dependency on food imports by scaling up technology-driven and resource-efficient innovative urban farming systems. Data were analysed and the model were moderated using Analysis of MOment Structures (AMOS) and Partial Least Squares- Structural Equation Modelling (PLS-SEM). The findings from the study highlight that digital technology moderates the relationship between innovative urban farming systems and sustainable urban farming. Resource efficiency and conservation practices were positively associated with sustainable urban farming. The study offers several managerial and theoretical insights.

1. Introduction

Global supply chains were severely disrupted by the COVID-19 pandemic and are currently in a state of turbulence due to post COVID-19 recovery and the ongoing geopolitical tensions between Russia and Ukraine (Ivanov and Dolgui, 2021; Nagurney, 2021; Queiroz et al., 2022; Scarpin et al., 2022; Gupta et al., 2023). The nature of global supply chains i.e., being geographically dispersed and fragmented, makes them highly vulnerable to disruptions, particularly the agri-food supply chains (AFSCs) (Ibn-Mohammed et al., 2021; Ardekani et al., 2023). The aftereffects of disruption in the AFSCs are supply-demand imbalances, price rise of essential food commodities, and severe food shortages in net food import nations (Ardekani et al., 2023). Food security, as defined by the Food and Agriculture Organization (FAO) is "*constant physical, social, and economic access for all people to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life*" (FAO, 2002). One of the main obstacles of the 21st century is the generation of an adequate supply of food for the increasing population while reducing the emissions generated from the agricultural sector (McDougall et al., 2019). The current global population is expected to grow from 7.95 billion people in 2022 to 9.7 billion in 2050 and 11 billion in 2100 (Tortajada and Biswas, 2022). In 2020, 56.15% of the global population lived in cities, which is expected to rise to 68% by 2050 and 85% by 2100. This implies that much of the world's population will be consolidated mostly around urban areas, which will undoubtedly increase and intensify stress on food, energy, and water

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among other natural resources, as well as the environment. Although urban food production may help address this issue, research on the productivity of urban farming systems, particularly in the United Arab Emirates (UAE), is scarce.[1] Being a net food importer, the UAE imports approximately 80–90% of its food requirements (Bailey and Willoughby, 2013). The country needs to develop resilience against climate change and growing global food demand. As per the Vision 2021[2] policy goals, UAE is making great efforts in diversifying its income resources by moving away from oil and adopting new green economy models in the agriculture, energy, and the sustainable transport sectors (for supporting long-term economic growth and while protecting the environment).[3] Through sustainable agriculture practices, the UAE aims to establish sustainable food production systems and implement resilient agricultural practices that increase productivity and production to contribute to the maintenance of ecosystems. The UAE aims to develop a sustainable, technology enabled domestic AFSC system through urban farming techniques. Urban farming (various innovative techniques include rooftop farming, hydroponics, aquaponics, and aeroponics) refers to the cultivation of food and agricultural commodities in urban and peri-urban areas using various technologies for increasing yield, productivity, and efficiency (Li et al., 2020). In UAE, there are mostly vertical farms as the electricity costs are low. It is anticipated that the vertical farming in the Middle East and Africa will reach USD 6.22 billion by 2030, owing to socio-demographic factors and growing food security concerns.[4] Urban farming is viewed as a promising approach to climate change adaptation because it has the potential to make cities environmentally sustainable and significantly improve urban climate while enhancing the effective reuse of urban organic waste and lowering urban carbon footprints. The productivity of urban farming exceeds that of conventional agriculture (McDougall et al., 2019). The crop yield from urban farming is twice that of conventional agriculture. However, despite the government's efforts, public involvement, the interest in urban farming operations is limited (Othman et al., 2017). Although urban production systems use land efficiently, their material and labour resources are inefficient. Urban farming is based on a business model and can be highly productive; however, this productivity necessitates numerous trade-offs, and measures to ensure sustainability must be established. Urban farming practices vary across different countries and can be majorly segregated into two types viz., controlled environment farming (refers to the usage of controlled and optimized environmental conditions such as humidity, temperature, nutrients, and light) and uncontrolled environment farming (refers to open agricultural spaces in urban and peri-urban areas). Controlled environment farming examples include aquaponics, vertical farms, hydroponics, and aeroponics and are mostly prevalent in countries such as United States, Singapore, and the Netherlands to name a few. Uncontrolled environment farming examples include community gardening and rooftop gardening and are mostly prevalent in countries such as Malaysia, India, China, to name a few. Apart from the differences in terms of differing environment conditions, adoption of urban farming is also dependent upon the need in a particular country i.e., for enhancing food security, enhancing local job creation, better utilization of urban and peri-urban spaces, strengthening local communities, and promoting local inclusion. Table 1 highlights the previous studies on urban farming systems and compares it with the objectives of the present study.

[1] The UAE is in an agriculturally constrained geographical area, with dominant and harsh summer atmospheric conditions, a severe lack of freshwater resources, and a scarcity of agricultural land. Agriculture in the UAE is also limited by a lack of technological and managerial expertise required for modern agricultural production (Degefa, 2022).

[2] https://www.vision2021.ae/en/national-agenda-2021

[3] *https://u.ae/en/about-the-uae/economy/green-economy-for-sustainable-development*.

[4] *https://ifarm.fi/blog/vertical-farming-in-the-uae-drives-and-opportunities*.

Table 1
Previous studies on urban farming and their comparison to present study.

Reference (s)	Type of study	Type of urban farming	Country	Rationale
Armanda et al. (2019)	Literature Review	Uncontrolled environment; Controlled environment		Highlights the emerging innovative urban agriculture practices and assess their impact in addressing food security and environmental sustainability.
Hatab et al. (2019)	Literature Review	Uncontrolled environment	Developing economies	Examines the nexus between food security and agricultural systems in developing economies by depicting rurban divide for achieving resilient food systems.
Gumisiriza et al. (2022)	Case Study	Controlled environment	Tanzania and Uganda	Investigates the benefits and drawbacks related to hydroponics in Tanzania and Uganda.
Murdad et al. (2022)	Literature Review	Uncontrolled environment; Controlled environment	Malaysia	Highlights the impact of COVID-19 on acceptance of urban farming practices in Malaysia for ensuring food security.
Wittenberg et al. (2022)	Case Study	Uncontrolled environment; Controlled environment	Germany	Examines various grassroot initiatives and their crucial role in transition towards sustainable urban food systems.
Campbell et al. (2023)	Case Study	Uncontrolled environment; Controlled environment	United States	Characterizes commercial urban farms and identifies their primary barriers in business development and expansion. It also highlights their perceptions related to future opportunities and specific informational needs.
Dorr et al. (2023)	Case Study	Uncontrolled environment	France, Germany, Poland, United Kingdom, and United States	Investigates the resources on data used and the food produced in urban farms using data collected from 72 sites across five countries.

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Table 1 (*continued*)

Reference (s)	Type of study	Type of urban farming	Country	Rationale
Present Study	Empirical	Uncontrolled environment; Controlled environment	UAE	The present study was inspired by the limited efforts to address the country's high dependence on food imports. This study aims to develop, validate, and apply a multi-dimensional innovative urban food production system framework for AFSCs.

Efforts by researchers, governments, and practitioners to address the negative impacts of this sector have been fragmented and disjointed. This lack of holistic understanding could cause practitioners and policymakers to address the wrong issues and neglect significant aspects. Based on the extant review of literature, there are limited studies on technology-based, resource-efficient urban farming approaches in the UAE that can provide sufficient food to meet the demand of the population.

These research gaps have led us to investigate the following research questions (RQs) in this present study.

RQ1. To what extent do urban farming practices impact resource efficiency and sustainability in the UAE?

RQ2. How does resource efficiency mediate the relationships between predictor variables and sustainability performance (environmental, economic, and social) in the UAE?

RQ3. What is the moderating impact of digital technology on the relationship between the innovative urban farming system and resource efficiency, and sustainable urban farming performance in the UAE?

For addressing these RQs, a research framework is developed based on the resource-based view and innovation-diffusion theory. We then analysed this framework using AMOS and PLS-SEM on the data collected from a sample of 299 farming industry professionals from the UAE. The development of a comprehensive and systematic investigation covering various stakeholders (from production to consumption) would address the relevant issues. Sustainable agriculture practices have the potential to minimize the negative impacts on the environment while optimizing production through the efficient use, protection, conservation, and enhancement of natural resources. It must also strike a balance between protecting agri-ecosystems and meeting society's growing needs. This study aims to provide insight into the opportunities and challenges of urban food production systems in the UAE and determine ways of reducing the country's dependence on food imports by scaling up technology-driven, resource-efficient urban farming and enhancing sustainable technology-enabled domestic food supply across the value chain.

2. Theoretical underpinnings and hypothetical model

2.1. Resource based view

Drawing upon from the resource-based view (RBV) perspective, organizations make use of their tangible resources (for e.g., technology, capital) and intangible resources (for e.g., human assets, management skills) for sustainable competitive advantage (Barney, 1991). Based on these resources, certain urban farming organizations with valuable and inimitable resources can build and sustain a competitive position in the market. Technology can be thought as one of the strategies for building and sustaining that competitive advantage. Also, based on the digital orientation dimensions provided by Kindermann et al. (2021), we argue that digital technology capabilities of an organization improve the products, internal, and external processes which leads to a sustainable impact.

Bharadwaj (2000) highlights that an organization gains sustainable competitive advantage by technology adoption and the synergistic benefit achieved through real-time integration. In agricultural food supply chains (AFSCs), many organizations have leveraged their competitive performance and have created a niche in the agricultural marketspace by usage of various technologies such as precision agriculture, internet of things, blockchain, and artificial intelligence. Rejeb et al. (2022) claim that the interaction between these technologies and AFSCs is dependent on interrelationships between resources such as soil, water, and humans. In another study by Lakshmi and Corbett (2020), they highlighted those technological resources have the potential to unlock food insecurity and climate change related challenges in the AFSCs. Epelbaum and Martinez (2014) highlighted that upskilling of human resources through innovation and technologies can lead to a sustainable performance in the AFSCs. Sharma et al. (2022) argues that digital technologies (as organizational resources) can improve the forecasting capabilities in the AFSCs and thereby lead to an improved sustainable performance.

Along with the implementation of technological resources in urban farming, there are beliefs that an organization has for accepting or rejecting this innovation. This is discussed in the following subsection as innovation diffusion theory.

2.2. Innovation diffusion theory

Technology innovation diffusion in agriculture typically refers to the process wherein newer agricultural technologies and inventions start to spread from the source of innovation and are adopted and used by most stakeholders in the agricultural value chain. In order to reap the benefits of an innovation, it must be incorporated into the organization. Various diffusion activities then serve as facilitators for incorporating the innovation (Rogers, 2003). Hazen et al. (2012) highlight that Rogers (2003) offers a generalized view of the innovation diffusion process in organizations and the study by Cooper and Zmud (1990) describe the information technology diffusion model based on the change model by Lewin (1951). The adoption and incorporation processes of a technology in an organization are highlighted by the post-adoption process viz., acceptance, routinization, and assimilation (Hazen et al., 2012). Rogers (2003) also highlighted five critical characteristics of innovations viz., a) relative advantage of the innovation in comparison to existing processes or technologies in an organization; b) compatibility of the innovation with the prior processes or technologies; c) complexity of the innovation in terms of usage; d) trialability of the innovation in terms of its testing and experimentation before adoption and implementation; and e) observability in terms of the tangible results the process or technology produces. Table 2 highlights the five characteristics of urban food production systems as an innovation.

2.3. The relationship between innovative urban farming systems, resource efficiency, and sustainable urban farming performance

Globally, the conventional food production systems and the processes will find it difficult to sustain the ever-growing rurban population in the coming years (Alfiero et al., 2021). Therefore, in order to overcome the challenges (such as lack of land resources, mass urbanization, and climate change) new and innovative solutions must be found out. Solutions that are scalable, deploy less labour, can work in varying geographies, and do not compromise environmental sustainability (Sisodia

Table 2
Characteristics of urban food production systems as an innovation.

Innovation Characteristics	Context with respect to urban farming systems	Reference(s)
Relative advantage	Contribution towards food resilience, reduces food miles, and certain social and economic advantages such as local job creation.	Armanda et al. (2019); Andronie et al. (2021)
Compatibility	Compatible with the existing technologies such as precision agriculture and the internet of things platform.	Tan et al. (2020); Arabzadeh et al. (2023)
Complexity	Technological complexity in terms of sophisticated construction, equipment, and automation levels.	Song et al. (2022); Chen et al. (2022)
Trialability	Many institutions have tried and tested urban farming systems, and these have shown remarkable results in comparison to traditional farming systems.	Armanda et al. (2019); Van Gerrewey et al. (2022)
Observability	Urban farming systems are known to have high yield for certain crops such as lettuce, tomatoes, strawberries, and other leafy vegetables.	Lal (2020); Armanda et al. (2019)

et al., 2021). Majority of the organizations and individuals (entrepreneurs) are shifting their focus towards disruptive technologies in agriculture (see vertical farming, hydroponics, aeroponics, rooftop farms, greenhouse farms), giving rise to the phenomena of urban agri-food cultivation or innovative urban farming systems (IUFS) (Sridhar et al., 2022; Biancone et al., 2022; Bresciani et al., 2018). IUFS falls under the aegis of urban agriculture and pertain to the growing horticultural crops in urban and peri-urban areas. Many studies in the past (see Poulsen et al., 2017; Ilieva et al., 2022; Murdad et al., 2022) have highlighted the economic benefits of IUFSs such as significant contribution towards food security (Murdad et al., 2022), local job creation (Poulsen et al., 2017), and creation of rural entrepreneurship opportunities (Lohrberg et al., 2016). IUFSs can help in achieving self-sufficiency in terms of crop production, mitigate climate change effects, and help in increasing resource efficiency and circularity (Weidner et al., 2019). IUFS are a critical component in the context of smart cities and are anticipated to support sustainable agricultural practices through innovation and collaboration (Secinaro et al., 2021). Sridhar et al. (2022) report that IUFS helps in developing and sustaining a stable agro-food economy for ensuring food security. Azunre et al. (2019) highlighted that IUFS emphasises on generation of local employment, social safety, and leads to promotion of environmental sustainability. Various studies (Qureshi et al., 2022; Khan et al., 2020a) have also depicted IUFS as a highly resilient farming technology for ensuring food security as it overcomes diversified farming methods and short food supply chains.

Most of the IUFSs optimize resource usage (such as irrigation, soil, fertilization, application of pesticides) through novel methods like internet-of-things based irrigation systems (Halgamuge et al., 2021), soil moisture-based irrigation systems (Singh and Sobti, 2022), nutrient management (Mulier et al., 2022), and internet-of-things based fertigation systems (Cui et al., 2022) that are comparatively less prevalent in present farming systems. Various studies (Sridhar et al., 2022; Pal et al., 2022) have highlighted that in certain IUFSs the plant growth is up to 50% faster in comparison with regular soil media. Other advantages include minimal pesticide usage, efficient water usage, and higher yields. Mulier et al. (2022) report that food produced by IUFSs can help in reducing the food miles which results in energy and cost savings for transportation, storage, and handling operations. Cifuentes-Torres et al. (2021) and Lopez-Galvez et al. (2016a,b) illustrate that wastewater or treated wastewater can be used in case of hydroponic systems before discharging thereby reducing the potential environmental damage. Aquaponics systems have been known to effectively transform waste to nutrients and have reduced the environmental pollution to a greater extent. These systems present a circular, sustainable, and a low carbon production solution for urban farming (Wei and Jones, 2022). On the sustainability front, IUFSs are local food production sources and provide employment in the form of urban agricultural jobs (Zezza and Tasciotti, 2010). Several landfill sites and low fertile land in city spaces can be converted into food gardens for improving land use planning, thereby improving urban resiliency and sustainability (Langemeyer et al., 2021). As IUFSs would lead to enhanced local production of horticultural crops and reduce dependency on long haul transportation thereby reducing CO_2 emissions, improving decarbonization measures, and optimizing transportation costs (Gómez et al., 2019). IUFSs would also improve market accessibility and ensure food production throughout the year. It is also anticipated that urban agricultural practices will play a crucial role in creating sustainable agri-food supply chains. Thus, we posit that.

H1. Innovative urban farming system (IUFS) is positively associated with sustainable urban farming performance (SUFP).

H2. Innovative urban farming system (IUFS) is positively associated with resource efficiency (RE).

2.4. The relationship between agrochemical optimization practices, logistics strategies, crop production practices, and resource efficiency

Modern farming practices have resulted in high crop yields owing to extensive farm machinery, chemical fertilizers, and pesticides. However, this practice makes agricultural production more efficient and reduces costs but renders it unsustainable (Trautmann et al., 2020). The extensive usage of chemical fertilizers and pesticides leads to detrimental ecological impacts (soil and water pollution). In addition to this, much of the solid waste (as nutrients in food and materials) generated in the cities is discharged as wastewater streams with little or minimal organic material recovery and reuse. Through modern processes and technologies, converting these nutrients can be converted into bio-fertilizers and composts. Urban farming systems can then use these bio-fertilizers and compost for reintroducing the nutrients into the food system and thereby help in restoring the nutrient cycle (Wielemaker et al., 2019). Such amendments in the form of bio-fertilizers and compost enhance soil quality and improve plant growth. Urban farming systems deploy various state-of-the-art techniques for nutrient recirculation and minimizing the fertilizers usage thereby improving essential nutrient recovery and reuse (Rufí-Salís et al., 2020). Various aquaponic systems have the capability to recycle the nutrients back to the plants resulting in zero wastewater discharge to the external environment (Yang and Kim, 2020). Therefore, most of the urban farming systems optimize the agro-chemical usage and recirculate the nutrients back into the system for efficient plant growth. Hence, we can hypothesize.

H3. Agrochemical optimization practices (AOP) are positively associated with resource efficiency (RE).

Jones (2002) highlighted that urban farming systems enhance food security by improving the resilience of agri-food supply chains. Which is also brought about by minimizing GHG emissions by reducing exorbitant transportation distances (food miles). Studies in the past (Li et al., 2022; O'Sullivan et al., 2020; Avgoustaki and Xydis, 2020; Gentry, 2019) have highlighted that localization of the produce are more carbon-friendly and cause less environmental harms. The growing concerns around sustainability, provenance, safe-handling, and food safety has led to the emergence of short food supply chains (Thomé et al., 2021). Many studies argue that short food supply chains are healthy (Bakalis et al., 2020), natural (Marsden et al., 2000), and more sustainable (Giampietri et al., 2016) in comparison to conventional agri-food supply chains. As the number of intermediaries in the short food supply chains is lesser in comparison with the conventional food supply chains therefore, factors such as trust, transparency, and communication of the urban farming system organization plays a critical role in their business choices (Grando et al., 2017). Adding further, many IUFS organizations are investing in renewable energy sources for upstream and downstream transportation for reducing the carbon footprint (Weidner et al., 2019). Food packaging is another area of focus for reducing the carbon emissions and presents avenues for innovation and resource circularity. Studies in the past (see Sanyé-Mengual et al., 2013; Theurl et al., 2014) have highlighted that IUFS organizations tend to recycle and reuse packaging material which has a positive impact on reducing CO_2 emissions. Therefore, we hypothesize that.

H4. Logistics strategies (LS) are positively associated with resource efficiency (RE).

When it comes to the crop range in IUFSs, the choice for growers is very limited (ranging from leafy vegetables to salad leaves) (Beacham et al., 2019). The reason can be attributed to the type of facilities that grow them i.e., horizontal, and vertical growth units and the small size of the crop. The salad leaves and leafy vegetables are generally favoured in IUFSs because they offer high return values in comparison to commodity crops i.e., more crops per unit area (Goldstein et al., 2016). Also, as more plants can be grown in the limited spaces thereby potentially increasing the revenue per unit area. The crops grown in IUFSs have a rapid growth cycle (6–8 weeks) and therefore, more crops can be grown and harvested in a season thereby enhancing the economic performance. This rapid growth cycle of the crops also presents flexibility for the growers in coping with the pests and diseases. Harsh climatic conditions pose minimal threat to certain IUFSs thereby ensuring year-round production of the horticultural crops. Other relative advantages being minimal emissions, efficient water usage, limited chemicals and pesticides usage, and resiliency (Sridhar et al., 2022). Therefore, we hypothesize that.

H5. Crop production practices (CPP) are positively associated with resource efficiency (RE).

2.5. The relationship between resource conservation practices, resource efficiency, and sustainable urban farming performance

Studies in the past have highlighted that IUFSs deploy various practices such as rainwater harvesting (Hume et al., 2022), usage of wastewater and recycled wastewater for irrigation (Cifuentes-Torres et al., 2021), and usage of compost (Wielemaker et al., 2019) which help in conserving precious resources such as soil and water. As sunlight and natural ventilation play a crucial part in the design aspects of an IUFS, rooftop (such as solar panels) and building integrations in IUFSs can also lead to reduced energy usage and CO_2 emissions (Weidner et al., 2019). Touliatos et al. (2016) report that the highest obtainable yields in case of IUFSs is achieved through optimized lighting and growing conditions. Weidner et al. (2019) highlight that IUFSs can improve sustainability by integrating building and household solid waste in the form of essential nutrients thereby closing the nutrient cycle. Various lifecycle assessment (LCA) studies have been performed in the past for assessing the environmental performance and resource efficiency in the case of IUFSs. Nadal et al. (2017) highlighted that usage of an integrated rooftop greenhouse for urban agriculture can improve energy efficiency, optimize costs, and reduce CO_2 emissions (113.8 kg CO_2 (eq)/m^2/yr). Similarly, Sanjuan-Delmás et al. (2018) highlighted how integrated rooftop greenhouses can lead to minimal waste generation and water consumption. Manríquez-Altamirano et al. (2021) report how agro-urban solid waste (biomass) can be reused in urban IUFS for closing the loop from a circular economy perspective. Therefore, we hypothesize that.

H6. Resource conservation practices (RCP) are positively associated with resource efficiency (RE).

Research has suggested that IUFSs contribute immensely towards sustainability (largely from social and environmental point of view) and human health. IUFSs play a crucial role in mitigating challenges brought about by climate change through micro-climate regulation (Sharifi, 2021), achieving self-sufficiency (Weidner et al., 2019), enhance resource circularity and efficiency (Rufí-Salís et al., 2020), enhance community development (Langemeyer et al., 2021), and improve dietary diversity (Weidner et al., 2019). Some other benefits of IUFSs include promotion of social safety, mitigation of food shortages, generation of local employment, and improvement of environmental sustainability. Adding further, research studies have highlighted that IUFSs are more resilient in comparison to diversified farming methods (Sridhar et al., 2022). IUFSs also hold immense potential in tackling high food wastage and disruptions along all phases of the agri-food supply chains (Lal, 2020). Furthermore, IUFSs help in strengthening various ecosystem services such as improving health and wellbeing of individuals, improving food accessibility to the local community, creation of jobs and other economic aspects, education and youth development, cultural integration and preservation, and community resilience (Santo et al., 2017). Therefore, we posit that.

H7. Resource conservation practices (RCP) are positively associated with sustainable urban farming performance (SUFP).

2.6. The moderating role of digital technology

Technology is considered to have an effective impact in improving the yield and increasing the production capacity of urban farming systems. Of late, recent technological innovations and disruptive technologies are being applied in IUFSs for realizing their full potential and sustainable performance. The review study by Xi et al. (2022) highlights how usage of advanced materials in urban agriculture plays a crucial role in changing the urban farming landscape. It is anticipated that digital technologies such as internet of things (IoT), artificial intelligence, robotics, blockchain, digital twins, and nanotechnology will play a crucial role in improving resource efficiency and sustainability in the case of IUFSs (Singh and Sobti, 2022; Bunge et al., 2022; Purcell and Neubauer, 2022; Xi et al., 2022). IoT applications can be used for remotely controlling various aspects such as integrated nutrient management, irrigation, fertilizer application, and crop monitoring in real-time in the urban farming systems (Singh and Sobti, 2022). IoT applications also help in optimizing water and energy usage for creating a sustainable impact. Automated systems are used in various aeroponic, aquaponic, and hydroponic systems for carrying out day to day activities in an optimized manner such as controlling light intensity, humidity, and temperature. Integrating automated systems with IoT and artificial intelligence helps in optimizing adequate fertilizer and pesticide application in a sustainable way (Sridhar et al., 2022). Usage of artificial intelligence helps in precisely monitoring plant health and reduces carbon footprint based on thorough data-driven decision-making. Other technologies such as blockchain and digital twins help in creating a digital identity of the agricultural produce and enables tracking and traceability in the agri-food supply chain (Bunge et al., 2022). These technologies not only ensure high yield and productivity but also ensure food safety and helps in reducing the inefficiencies faced in conventional food supply chains. Therefore, we hypothesize that.

H8a. Digital technology plays a moderating role between resource conservation practices (RCP) and sustainable urban farming performance (SUFP).

H8b. Digital technology plays a moderating role between innovative urban farming system (IUFS) and sustainable urban farming performance (SUFP).

The present study will also test the relationship of Resource Efficiency with the independent variables and with Sustainable Urban Farming Performance. Therefore, we hypothesize that.

H9. Resource efficiency (RE) is positively associated with sustainable urban farming performance (SUFP).

H10. Resource efficiency (RE) plays a mediating role between independent variables and sustainable urban farming performance (SUFP).

The theoretical model (see Fig. 1) is underpinned by the resource-based view and innovation diffusion theories. In this study, the researchers use the resource-based perspective in explaining how organizations leverage technological tools at their dispense for improving collaboration and attain a sustainable competitive advantage. Digital technologies help in improving collaboration among stakeholders (Sharma et al., 2022) and are thereby anticipated to enhance the sustainable urban farming performance. Following the preceding arguments, the theoretical model is developed which explains how various urban farming practices can improvise resource efficiency for achieving sustainable urban farming performance.

3. Methodology

This section outlines the study's methodology, which consists of the following: research instrument, participants, procedures, and data analysis. Fig. 2 highlights the flowchart of the methodology used in this study.

3.1. Research instrument and participants

This study used extensive literature review was used to develop a comprehensive assessment framework comprising ten constructs and their underlying dimensions. An empirical survey was developed and executed in the spring of 2021 in the UAE. This study used the deductive approach, a quantitative research method, to develop, validate, and apply a multi-dimensional urban food production system framework for the agricultural sector.

A greater part of all the items were adopted from the previous literature. Following the study Majority of the All items were measured on a five-point Likert scale, 1 indicating "strongly disagree" and 5 ″strongly agree." Appendix-A1 presents the specifications and sources of each construct in the measurement scales.

A professional market research company was used to distribute a cross-sectional survey to research participants. A total of 1110 farming industry professionals from the UAE were invited to participate in a quantitative survey. The total number of received responses was 302, 3 of which were incomplete and were eliminated; therefore, a total of 299 participants completed the survey. The response rate was 27%. We thoroughly pre-tested the questionnaire with six academics and thirty-five practitioners before distributing it to the participants. The demographics are highlighted in Table 3.

3.2. Data analysis and results

3.2.1. Exploratory factor analysis

Exploratory factor analysis was used to check the latent factor structure of all the included items using SPSS-IBM, V-26. The scales' dimensions were determined using principal component analysis and the Varimax rotation method (Field, 2013). The test of normality was performed to determine whether the variables were normally distributed. The study results show that p was <0.001: less than 0.05 in both the Kolmogorov–Smirnov and Shapiro–Wilk tests, indicating that the sample was not normally distributed. Furthermore, the histograms of each variable were examined, and all variables were found to be not normally distributed (Field, 2013). However, the sample size (299) was found to be sufficient to represent the 67 included items. Hair et al. (2019) found that a large sample size improves statistical power by reducing sampling error. Hair et al. (2017, 2019) reported that the lack of normality is one of the factors that necessitate the use of Smart-PLS instead of IBM-SPSS-Amos for the structural equation modelling (SEM).

Initially, the conceptual framework included 11 constructs. Furthermore, 6 manifest items were under IUFS, 6 under AOP, 4 under LS, 5 under CPP, 9 under RCP, 8 under RE, 7 under TECH, 7 under ENV, 8 under SOC, and 7 under ECON. However, SUFP was a second-order construct composed of three first-order constructs (ECON, ENV, and SOC). In total, 67 manifest indicators were included in the initial EFA analysis using SPSS-IBM, V-26. The principal component analysis extraction method and Varimax with Kaiser normalization rotation were utilized to conduct the EFA. The Kaiser–Meyer–Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity were examined to determine whether the sample size and correlation matrix were satisfactory and appropriate for factor analysis. The KMO value was 0.951, and the approximate chi-square of Bartlett's measure test was 14,303.770 (df. 2211; p-value <0.0001), indicating that it was statistically significant (Yong and Pearce, 2013). The variables' communality was then checked by assessing the variables' shared, or common, variance among the variables offered by the extracted factors (Hair et al., 2019). All communality values were above 0.35. Any item with cross-loading was removed. However, elimination was performed by removing variables individually and observing the improvement in item performance. The convergent validity values are highlighted in Table 4.

In summary, 19 manifest indicators were removed for their cross-loading problem, leaving only 48 manifest indicators for the subsequent structural equation modelling. Because all four items in the LS construct were eliminated owing to cross-loading issues, this construct was removed from the conceptual framework, and H4 was not included in the subsequent analysis. There were three items (RE6, AOP2, CPP2) in

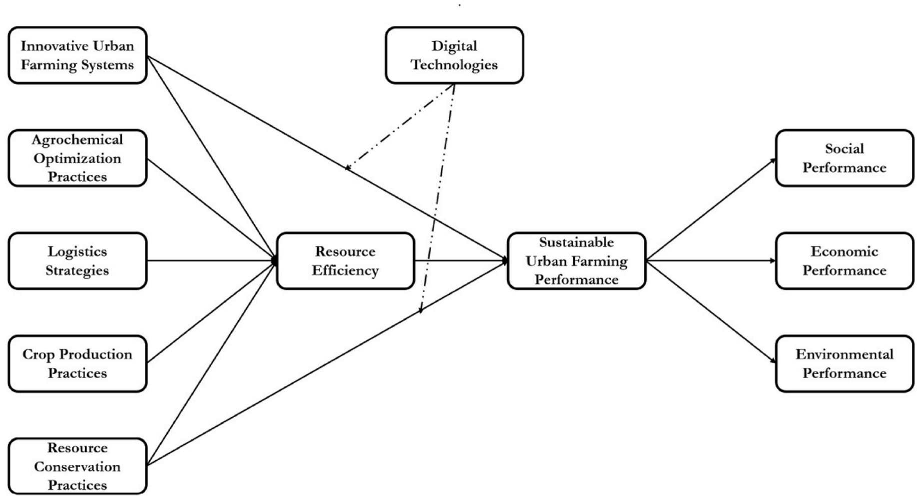

Fig. 1. Theoretical framework.

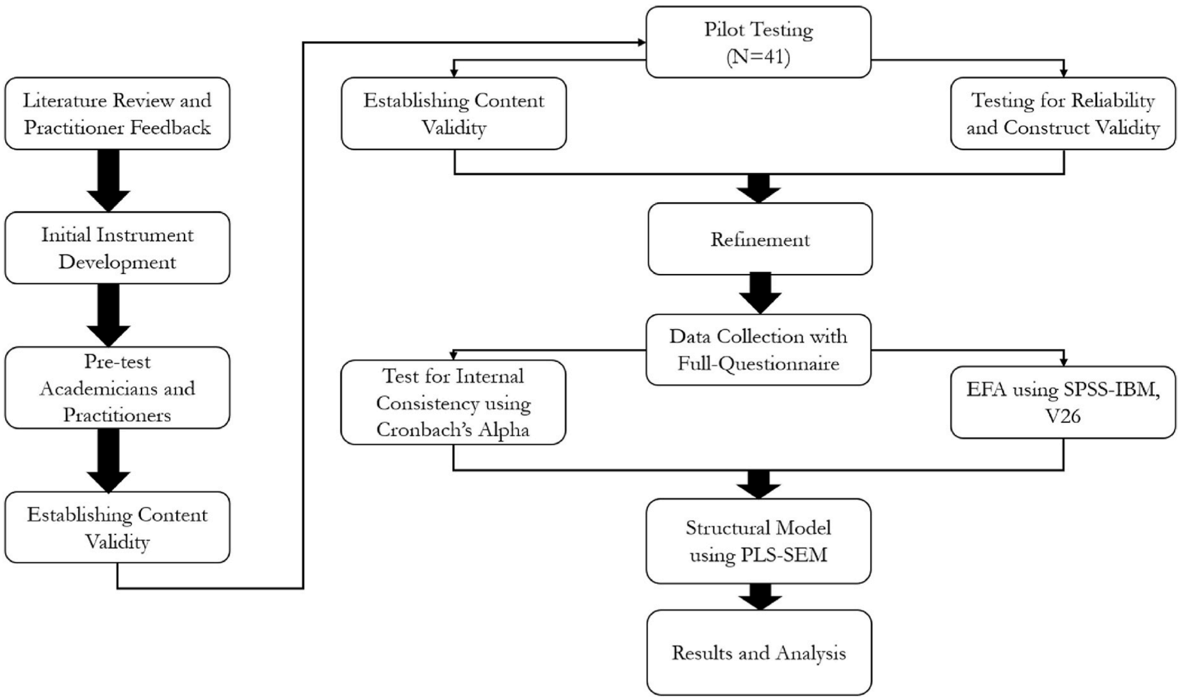

Fig. 2. Flowchart of the methodology used in this study.

Table 3
Demographics.

Classification	Responses	%
Emirate		
Abu Dhabi	77	26
Ajman	15	5.1
Dubai	151	51
Fujairah	7	2.3
Ras Al Khaimah	10	3.4
Sharjah	34	11.5
Um Al Quwain	5	0.7
Total	**299**	**100**
Organization Size		
Small	91	30.6
Large	123	41.4
Medium	85	28
Total	**299**	**100**
Catering to		
Export market	38	12.8
Domestic market	109	36.7
Both	152	50.5
Total	**299**	**100**

the pattern matrix that exhibited cross-loading however, the test performed to manually identify cross-loading values revealed values exceeding 2, which can be disregarded according to the criteria presented by Hair et al. (2019). The KMO value was 0.946, and the approximate chi-square of Bartlett's measure test was 10,663.715 (df. 1378; p-value <0.0001), indicating that it was statistically significant (Yong and Pearce, 2013). Notably, the SOC and ECON constructs were loading under the same factor, which is expected because they both measure the sustainability dimension; for which they are referred to as the SOC_ECON construct.

3.2.2. Structural model

Smart PLS-3 was used to investigate the mediation effect of RE on the relationship between IUFS and SUFP, and the relationship between RCP and SUFP. Moreover, Hayes PROCESS macro (model number 8) was used to perform moderated mediation analysis. According to Hair et al. (2017), the data, PLS-SEM algorithm, model properties, and model evaluation issues are the four most critical issues to consider when using PLS-SEM. PLS-SEM is effective with small sample sizes and complex models, and it makes almost no assumptions concerning the data (Cassel et al., 1999). According to Hair et al. (2017), PLS-SEM can handle both reflective and formative measurement models, along with single-item constructs, with no identification issues. Therefore, it can be used in several studies. Researchers who use PLS-SEM benefit from high efficiency in parameter estimation, evidenced by the method's higher statistical power than that of CB-SEM. Because PLS-SEM has more statistical power, it is more likely to indicate a particular relationship significantly when it is significant in the population. This is also applicable to regressions based on sum scores, which have less statistical power than PLS-SEM (Hair et al., 2017).

4. Validity assessment of reflective measurement models

4.1. Internal consistency assessments

Cronbach's alpha and composite reliability were used to measure internal consistency. Cronbach's alpha estimates reliability based on the inter-correlations of the observed indicator variables, whereas composite reliability considers the indicator variables' different outer loadings (Hair et al., 2017). Both measures reported values above 0.7, which is considered satisfactory (see Table 4).

4.2. Individual indicator reliability

High outer loadings on a construct indicate that the associated indicators share a lot of content, which the construct captures. The outer loading size reflects the item's reliability (Hair et al., 2017). All indicators' outer loadings should be statistically significant, and the standardized outer loadings should be ≥ 0.708 (Hair et al., 2017). All the items had a value exceeding 0.708, except RE6 (0.698). This item will be continually observed and will not be disregarded because the composite reliability is satisfactory (0.895) (Hair et al., 2017). All AVE values exceeded 0.5, confirming the convergent validity of the measurement model.

Table 4
Convergent validity values.

Construct	Items	Standardized factor loading	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
AOP	AOP1	0.751	0.838	0.84	0.886	0.608
	AOP2	0.732				
	AOP3	0.822				
	AOP4	0.806				
	AOP6	0.785				
CPP	CPP2	0.883	0.725	0.725	0.879	0.784
	CPP5	0.888				
ENV	ECON5	0.768	0.764	0.767	0.85	0.586
	ENV1	0.774				
	ENV2	0.716				
	ENV4	0.8				
IUFS	IUFS1	0.784	0.896	0.899	0.92	0.658
	IUFS2	0.768				
	IUFS3	0.834				
	IUFS4	0.81				
	IUFS5	0.844				
	IUFS6	0.825				
RCP	RCP1	0.815	0.9	0.901	0.921	0.626
	RCP2	0.784				
	RCP3	0.738				
	RCP5	0.788				
	RCP6	0.802				
	RCP7	0.805				
	RCP9	0.804				
RE	RE1	0.782	0.859	0.865	0.895	0.587
	RE2	0.751				
	RE4	0.806				
	RE5	0.767				
	RE6	0.698				
	RE7	0.786				
SOC_ECON	ECON1	0.791	0.938	0.938	0.946	0.574
	ECON2	0.787				
	ECON3	0.722				
	ECON4	0.73				
	ECON6	0.741				
	ECON7	0.766				
	SOC1	0.713				
	SOC2	0.765				
	SOC3	0.775				
	SOC4	0.771				
	SOC5	0.74				
	SOC6	0.782				
	SOC7	0.763				
TECH	TECH1	0.781	0.848	0.848	0.892	0.622
	TECH2	0.769				
	TECH5	0.789				
	TECH6	0.795				
	TECH7	0.809				

Finally, based on the results of the convergent validity tests, we confirmed that the reflective measurement model convergent validity was met (see Table 5).

4.3. Test of collinearity

In contrast to reflective indicators, which are highly interchangeable, formative measurement models are not expected to have high correlations between items. High correlations between two formative indicators, called collinearity, could be problematic from a methodological and interpretive perspective (Hair et al., 2017). To test the collinearity, the VIF should be examined (Hair et al., 2017). If the VIF value is ≥ 5, the level of collinearity is considered remarkably high, necessitating the removal of one of the corresponding indicators (Hair et al., 2017). In this study, all the VIF values in Table 4 were below 5 and even below 2.5, indicating a lack of multicollinearity between the formative items.

Afterwards, and after confirming the lack of multicollinearity, the significance and relevance of outer weights in the formative measurement models must be investigated (Hair et al., 2017). The outer weight values must be close to each other within the construct to confirm the lack of collinearity (Hair et al., 2017). In this study, all the outer weights of the formative measurement constructs were close to one another; for example, all the SOC ECON values were approximately 0.1, while the four items that constitute the ENV construct were approximately 0.3 as seen in Table 4. Therefore, the previous values confirm the validity of the formative measures.

4.4. Discriminant validity

In the present study, none of the items reported any cross-loading problem. The outer loading on the related construct, according to Hair et al. (2017), must be higher than any of the indicator's cross-loadings on all other constructs. Moreover, none of the items reported any problem and all the square root of the construct AVE were larger than the maximum correlation with each construct. The criterion reported by Fornell and Larcker (1981) examines the latent variable correlations to the square root of the AVE values. The square root of the individual construct's AVE must be larger than the maximum correlation with other constructs (Hair et al., 2017). In this study, all the hetero-trait–monotrait (HTMT) values reported a value below 0.9, indicating the existence of discriminant validity and lack of multicollinearity (see

Table 5
Formative measurement model convergent validity result.

Item	Outer weights	T Statistics	P Values	Outer loadings	VIF
ECON1 <- SOC_ECON	0.106	25.568	0	0.791	2.495
ECON1 <- SUFP	0.087	20.618	0	0.784	2.58
ECON2 <- SOC_ECON	0.105	25.413	0	0.787	2.484
ECON2 <- SUFP	0.09	19.809	0	0.774	2.527
ECON3 <- SOC_ECON	0.098	22.012	0	0.722	2.019
ECON3 <- SUFP	0.081	18.092	0	0.721	2.081
ECON4 <- SOC_ECON	0.098	21.687	0	0.73	2.117
ECON4 <- SUFP	0.077	16.807	0	0.721	2.195
ECON5 <- ENV	0.317	19.375	0	0.768	1.518
ECON5 <- SUFP	0.073	18.78	0	0.604	1.785
ECON6 <- SOC_ECON	0.099	23.853	0	0.741	2.185
ECON6 <- SUFP	0.083	21.782	0	0.731	2.201
ECON7 <- SOC_ECON	0.102	21.648	0	0.766	2.376
ECON7 <- SUFP	0.082	16.783	0	0.748	2.43
ENV1 <- ENV	0.34	16.672	0	0.774	1.526
ENV1 <- SUFP	0.079	19.599	0	0.648	1.767
ENV2 <- ENV	0.301	16.555	0	0.716	1.389
ENV2 <- SUFP	0.071	16.318	0	0.574	1.547
ENV4 <- ENV	0.346	18.462	0	0.8	1.614
ENV4 <- SUFP	0.079	21.06	0	0.66	1.886
SOC1 <- SOC_ECON	0.099	24.337	0	0.713	2.002
SOC1 <- SUFP	0.083	23.355	0	0.729	2.21
SOC2 <- SOC_ECON	0.101	24.537	0	0.765	2.3
SOC2 <- SUFP	0.083	20.696	0	0.741	2.317
SOC3 <- SOC_ECON	0.103	27.258	0	0.775	2.29
SOC3 <- SUFP	0.085	21.988	0	0.761	2.316
SOC4 <- SOC_ECON	0.104	26.904	0	0.771	2.225
SOC4 <- SUFP	0.085	22.556	0	0.769	2.398
SOC5 <- SOC_ECON	0.099	23.796	0	0.74	2.146
SOC5 <- SUFP	0.08	19.617	0	0.725	2.191
SOC6 <- SOC_ECON	0.103	23.693	0	0.782	2.387
SOC6 <- SUFP	0.085	19.315	0	0.758	2.557
SOC7 <- SOC_ECON	0.102	25.654	0	0.763	2.362
SOC7 <- SUFP	0.085	22.394	0	0.751	2.396

Table 6). However, the HTMT value between SUFP and ENV constructs were 0.968, and between the SUFP and SOC_ECON constructs were 1.047, indicating the presence of multicollinearity between the two constructs. However, upon reviewing the relationships among these constructs through the repeated indicator approach, we found that both SOC_ECON and ENV constructs form the formative construct (SUFP), which could explain the multicollinearity between them. A violation of discriminant validity among these constructs is expected, according to Agyapong (2020), because the measurement model of the higher-order component replicates the indicators of its two lower-order components.

Finally, based on the results of the three previous discriminant validity tests, we confirm that the reflective measurement model discriminant validity has been met.

4.5. Structural model estimation evaluation

The quality of the measures was determined by evaluating reflective and formative measurement models; therefore, we proceeded to the structural model estimation evaluation (Hair et al., 2017). The PLS-SEM assessment of the structural model includes the model's capacity to predict the variance in the dependent variables. The coefficients of determination (R^2 values), and the size and significance of the path coefficients, are the primary evaluation criteria for PLS-SEM outcomes upon the establishment of reliability and validity. Table 7 highlights the final model summary.

4.6. Bootstrapping results

The data in PLS-SEM are not assumed to be normally distributed as in this research case. Because of the absence of normality, we cannot use parametric significance tests like those used in regression analyses to determine the statistical significance of coefficients like outer loadings, outer weights, and path coefficients. Therefore, PLS-SEM employs a nonparametric bootstrap procedure to test the significance of the coefficients (Davison and Hinkley, 1997; Hair et al., 2017). Therefore, unlike OLS regression, PLS-SEM does not provide t or p values for evaluating the significance of the estimates in the beginning. Instead, researchers must depend on the bootstrapping process, which offers bootstrapped standard errors (Hair et al., 2017). After the bootstrapping process (5000 times), the path model with t-statistics was generated.

4.7. Process macro

Andrew Hayes designed the PROCESS macro for IBM SPSS or SAS (Hayes, 2017), providing a template-driven set of models for calculating mediation, moderation, and a broad range of combined effects (Hair et al., 2019). Owing to the complex nature of the effects in this study (moderated mediation relationship), the accurate specification of the estimation model correctly using Process macro was challenging (Hair et al., 2019). The PROCESS macro offers three measures of relative impact: the indirect-to-total effect ratio, the indirect-to-direct effect ratio, and a measure of indirect effect size (Hayes, 2017). Moreover, to evaluate the statistical significance of the confidence intervals, bootstrapped estimates are provided in the Process macro-output (5000 times). Although these measures can only be classified as high, medium, or low, they offer some relative size measurements that can be used as comparative metrics (Hair et al., 2019).

4.8. Model summary

Model 8 was used to estimate the moderated mediation effect as seen

Table 6
Fornell-Larcker criterion test and Heterotrait-Monotrait (HTMT) ratio test.

Constructs	AOP	CPP	ENV	IUFS	RCP	RE	SOC_ECON	SUFP	TECH
AOP	0.78								
CPP	0.566	0.885							
ENV	0.599	0.552	0.765						
IUFS	0.531	0.408	0.325	0.811					
RCP	0.61	0.647	0.499	0.428	0.791				
RE	0.655	0.601	0.639	0.436	0.627	0.766			
SOC_ECON	0.649	0.641	0.708	0.42	0.726	0.694	0.758		
SUFP	0.672	0.655	0.813	0.421	0.714	0.719	0.987	0.72	
TECH	0.633	0.597	0.628	0.418	0.674	0.686	0.772	0.781	0.789

Table 7
Final model estimation results.

Analysis method	Hypothesis	Path	B-coefficient	T Statistics	P Values	Conclusion
PLS	H3	AOP - > RE	0.26	3.297	0.001	Supported
	H5	CPP - > RE	0.159	2.678	0.008	Supported
	H2	IUFS - > RE	0.04	0.936	0.349	Not Supported
	H1	IUFS - > SUFP	0.052	1.244	0.214	Not Supported
	H10	Moderating Effect 1 - > RE	0.032	0.626	0.532	Not Supported
	H6	RCP - > RE	0.136	1.54	0.124	Not Supported
	H7	RCP - > SUFP	0.42	8.113	0	Supported
	H9	RE - > SUFP	0.433	8.409	0	Supported
		SUFP - > ENV	0.813	26.536	0	Supported
		SUFP - > SOC_ECON	0.987	552.73	0	Supported
PLS&PM	H8a	TECH - > RE Tech moderates between IUFS and RE	PM (.376) PLS (0.987)	4.73	0	Supported
PM	H8b	(Process macro) Tech moderates between IUFS and SUFP	−0.012	−0.8	0.422	Not Supported

in Fig. 3. The independent variable (X = IUFS), the outcome variable (Y=SUFP), the mediator (M = RE, and the moderator (W = TECH). Three covariates (AOP, CPP, and RCP) were incorporated in the analysis as they influence the outcome variable.

4.9. Analysis

In the present study, we found a slight significance index of moderated mediation and a slightly moderated mediation or conditional indirect effect as shown in Table 8.

Table 8 represents the total moderated mediation effect of the following variables: the independent variable IUFS, the dependent variable SUFP, the mediator RE, and the moderator TECH. The variables AOP, CPP, and RCP were incorporated in the analysis as covariates that influence the SUFP.

4.9.1. Conditional indirect effects of X on Y

According to Hair et al. (2019), we should consider the indirect effect from three different perspectives of the moderator. Although these measures only have three classifications: high, medium, and low, they provide relative size measures which can be used as common metrics for comparison. The software calculates a mean of −1 and +1 standard deviation because the moderator is centred at zero. As a result, we must consider the confidence interval, which shows that the independent variable (IUFS) has no significant indirect effect on the dependent variable (SUFP) at two moderator values (low and medium level of TECH) (Table 9). However, IUFS only influences SUFP only at the high level of the moderator (see Fig. 3).

Table 8
Index of moderated mediation.

Effect	BootSE	BootLLCI	BootULCI	Outcome
0.0097	0.0070	.0003	0.0286	Significant

4.9.2. Conditional direct effect(s) of X on Y

The conditional direct effect(s) of X on Y is determined (Hair et al., 2019). As shown in Fig. 4, the direct effect of IUFS on SUFP is not statistically significant at ONE-SD below the mean (b = 0.0011, se (HC4) = 0.0307, p = 0.9703), at the mean (b = −0.012, se (HC4) = 0.0243, p = 0.6208), or at ONE-SD above the mean (b = −0.0252, se (HC4) =

Table 9
Indirect effect M_IUFS > M_RE > M_SUFP.

M_DigiTech	Effect	BootSE	BootLLCI	BootULCI	Outcome
−0.7339	0.0002	0.0087	−0.0191	0.0164	Not Significant
0	0.0073	0.0072	−0.0055	0.0231	Not Significant
0.7339	0.0144	0.009	0.0009	0.0359	Significant

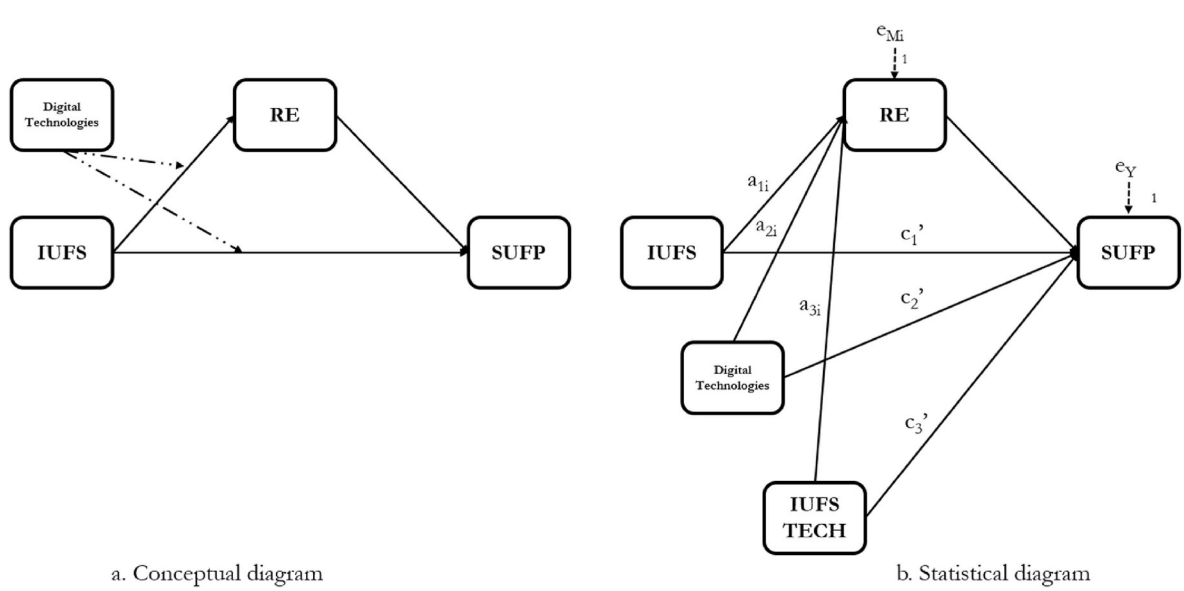

Fig. 3. Model 8 conceptual and statistical diagrams.

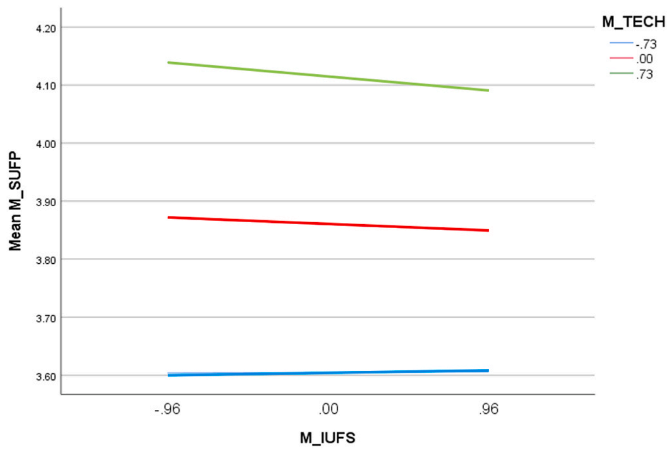

Fig. 4. Conditional effect of Tech on SUFP.

0.0278, p = 0.3658). Generally, no direct effect of IUFS on SUFP appears in the proposed model with various levels of TECH as seen in Fig. 3.

4.9.3. *Outcome variable: SUFP*

As shown in Table 10, the model reveals that the predictors accounted for significant variation in SUFP (R-square = 0.7210; F (HC4 = 109.1449, p < 0.0001). Moreover, RE is a positive and significant predictor of SUFP (b = 0.1885, se (HC4) = 0.0532, p = 0.0005). The impact of IUFS (at the mean of TECH) was not significant (b = −0.0120, se (HC4) = 0.0243, p = 0.6208), while the impact of TECH (at the mean of IUFS) was positive and significant (b = 0.3476, se (HC4) = 0.0606, p < 0.00001). The interaction between RE and TECH was not statistically significant (b = −0.0179, se (HC4) = 0.00233, p = 0.4224), suggesting that TECH does not moderate path c′ between IUFS and SUFP. The previous results were in line with the bootstrapped results (5000 times). The model results are highlighted in Table 11.

4.9.4. *Outcome variable: RE (moderation effect)*

Drawing inferences from Tables 12 and 13, the mediator RE was regressed on to IUFS, TECH, and the interaction between the two. This shows that IUFS has a positive conditional effect on RE, but it is not statistically significant (b = 0.0385, p = 0.2749). However, TECH has a positive and statistically significant conditional effect on RE (b = 0.3763, p < 0.0001). The interaction between the IUFS and the TECH (Moderation effect) reveals a positive slope, but is not statistically significant (b = 0.0513, p = 0.1579), which means there is no proof that TECH mediates the path between IUFS and SUFP. The visualization of the interaction is presented in Fig. 5, which shows that the significance of the interaction; however, it works as an enhancer especially at a high level of technology.

5. Discussion

In this study, the analysis outcomes supported H3, H5, H7, H8a, and H9; and did not support H1, H2, H6, H8b, and H10. Technology has been found to have a partial indirect effect on SUFP. The explanatory powers are illustrated in Table 11. All f^2, R^2, and Q^2 scores are within the guidelines as highlighted in Hair et al. (2019). This study revealed that AOP is positively associated with RE (b = 0.26, t = 3.297, p = 0.001); CPP is associated positively with RE (B = 0.159, t = 2.678, p = 0.008); RCP is positively associated with SUFP (b = 0.42, t = 8,113, p < 0.001).

Table 10
Model summary for outcome variable M_SUFP.

R	R^2	MSE	F(HC)4	df1	df2	p
0.8491	0.721	0.1353	109.1449	7.0000	290.0000	.0000

Table 11
Model result.

Relationship	Outcome	f-square	R-square	Q^2 predict	p values	Outcome
SUFP - > ENV	ENV	1.735	0.662	0.41	0	Significant
IUFS - > SUFP	SUFP	0.001	0.633	0.694	0.214	Not Significant
RCP - > SUFP		0.103			0	Significant
RE - > SUFP		0.107			0	Significant
TECH - > SUFP		0.275				
TECH x IUFS - > SUFP		0.002			0.422	Not Significant
SUFP - > SOC-ECON	SOC-ECON	39.369	0.973	0.681	0	Significant
AOP - > RE	RE	0.077	0.588	0.558	0.001	Significant
CPP - > RE		0.031				
IUFS - > RE		0.003				
RCP - > RE		0.019				
TECH - > RE		0.115			0	Significant
TECH x IUFS - > RE		0.006			0	Significant

Table 12
Model summary for outcome variable M_RE.

R	R^2	MSE	F(HC)4	df1	df2	p
0.7532	0.5673	0.2622	69.3446	6.0000	291.0000	.0000

Table 13
Model result for outcome variable RE.

	Coefficient	se_(HC4)	t	p	Outcome
constant	1.8927	0.3335	5.6759	.0000	
M_IUFS	0.0385	0.0352	1.0938	0.2749	Not Significant
M_TECH	0.3763	0.0727	5.1769	.0000	Significant
Int_1	0.0513	0.0363	1.4159	0.1579	Significant
M_AOP	0.2807	0.0899	3.1219	0.002	Significant
M_CPP	0.065	0.0693	0.9387	0.3487	Not Significant
M_RCP	0.1354	0.101	1.3399	0.1813	Not Significant

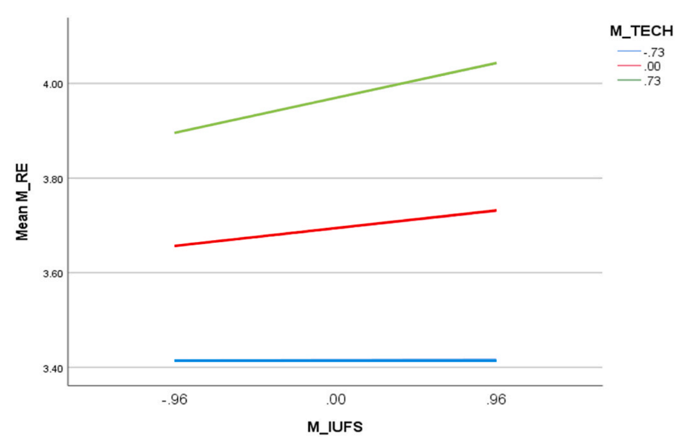

Fig. 5. Conditional effect of TECH on RE.

Technology moderates between IUFS and SUFP (process macro (b = 0.376), and Smart-PLS (b = 0.987, t = 4.73, p < 0.001)). RE is associated positively with SUFP (B = 0.433, t = 8.409, p < 0.001). Conversely, IUFS is not associated with SUFP (b = 0.052, t = 1.244, p = 0.214). IUFS is not associated with RE (b = 0.04, t = 0.936, p = 0.349). RCP is not associated with RE (b = 0.136, t = 1.54, p = 0.124). Digital Technology does not play a moderating role between RCP and SUFP (b = −0.012, t = −0.8, p = 0.422). RE does not mediate between independent variables and SUFP (b = 0.032, t = 1.244, p = 0.532).

Furthermore, the present study highlights various facets that highlight critical components in urban farming systems, these are.

5.1. Technology based, resource efficient urban farming approaches

Urban farming is a closed or controlled environment farming (Benke and Tomkins, 2017), where all activities operate within a limited geographical area. The urban farming model is unique in that the entire supply chain is located close to the consumer and producer, thus reducing the strain on logistics and planning (de Oliveira et al., 2021). In urban farming, the producer (seller/farmer) has numerous opportunities for directly selling fresh product to nearby customers, thus eliminating the need for intermediaries and storage facilities. Furthermore, it reduces the delivery lead time to the customer. Lead time deviation is a significant problem affecting agricultural products because of the perishable nature of the products. If the farm product is not stored appropriately, the whole production cycle fails. However, in the urban farming system, this lead time depends on the demand for the product in the local market. Countries like UAE have high local demand for locally produced food instead of imported food (Ghonima, 2021). This situation requires a logistics strategy that directly connects the local farmer with the customers with technological support. For example, an internet or mobile platform service provider connects the consumers directly to the farmer through a mobile app. Consumers place the order using the app, and farmers instantly harvest fresh farm products and send them to the customers. In this logistics strategy, the transportation of goods from farmer to consumer is conducted by the local logistics partners or the platform service provider (Petrovics and Giezen, 2022). This strategy facilitates the farmers to not invest in transportation facilities, and the customers can receive the products at their doorsteps. This local delivery strategy possibility suits the controlled environmental urban farming. In this study, a scale designed to measure the logistics strategy for urban farming yielded no significant results, which was the reason underlying the removal of LS from the analysis section. All four items under the LS construct were eliminated due to cross-loading issues with multiple constructs, as shown in the initial rotated component matrix below (please add the table to the response to comment document for the auditors to understand the reason). According to Yong and Pearce (2013), items that cross-load with other constructs should be eliminated; therefore, the LS construct was removed from the conceptual framework, and H4 was therefore not included in the subsequent analysis. Furthermore, we suggest alternative questions or scales measuring the logistics strategy for future research.

Resource conservation practices significantly contribute to the urban farming ecosystem. Our results support this argument because urban farming happens in a closed environment with minimum space, water, and soil. In this resource-constrained environment, we need to produce crops with both high quantity and quality. The conservation method controls resource utilization appropriately for the crop; for example, drip irrigation is a method to prevent excessive or inadequate water supply to the plant (Capra and Scicolone, 2007). This method even contributes to minimizing water wastage and reducing evaporation in the field. Nowadays, these irrigation practices are supported by various smart technologies to control the irrigation system precisely (Burnett, 2022). Smart fertigation systems have sensors to remotely communicate the status of soil moisture, temperature, and humidity among other properties through a website or mobile platform (Cui et al., 2022). Urban farmers benefit from smart systems to maximize their production in a resource-constrained environment. Countries like the UAE are developing research and development on smart urban farming systems and focusing on unconventional water resources to generate more water. This is a supplementary water harvesting practice to increase water supply to the urban area (Qadir et al., 2007). This method is more promising for adopting proper resource conservation practices. Desalinated water is the primary source of drinkable water in many highly solar-exposed countries such as the UAE (Assad et al., 2022). However, the desalination method is only promising with high-cost implementation with conventional energy sources, which are harmful to the environment. However, the UAE has difficulty in identifying desalinated water sources (Hussain et al., 2019). Many researchers are working on renewable energy sources to provide a sustainable solution (Mokri et al., 2013) for resource-constrained countries. Banhidarah et al. (2020) elaborated on the interlinkage between energy and water conservation on UAE farms and suggested a water-energy efficiency and conservation policy. They reported that key factors like workers, salary, and water cost are interrelated in the increase of water, energy, and conservation. This indicates the need for countries with arid climates to focus highly on sustainable practices to strengthen food supply and production and efficiently meet future demand.

5.2. Negative impacts of the agricultural sector

Current agricultural practices (such as excessive fertilizer applications) consume high amount of resources and thereby put a lot of stress on the AFSCs. The agricultural activities (planting, harvesting, and transportation) consume excessive energy and thereby add to carbon emissions. It is also said that agriculture sector is one of the major contributors in global greenhouse gas emissions. Therefore, innovative urban farming practices such as agrochemical optimization, agroecological crop production practices, and precision agriculture practices help in minimizing the carbon emissions and can effectively mitigate climate change.

Agrochemical optimization is an effective practice for urban farming (Xi et al., 2022), specifically for countries with limited geographical farming resources (Degefa et al., 2021). Most urban farming depends on rooftops, backyard gardens, community gardens, and other unused spaces (Capra and Scicolone, 2007). Therefore, utilization of these limited spaces necessitates optimal combination of agrochemicals to enhance high yield in urban areas (Ouyang et al., 2022). Agrochemical optimization involves the application of the right amounts of chemical ingredients to the crops at the right time, thereby increasing the crop's productivity. However, the impactful combination of fertilizer systems to the crop depends on the biological characteristics of the culture, variety, soil, and weather conditions. This poses a challenge for urban farming companies and individual farmers in the UAE. Various research studies have stressed this factor to provide appropriate agrochemical combinations according to the plant's biological characteristics and the region's nature (Zhao et al., 2020). Therefore, urban farming depends on bio-pesticides and bio-fertilizers. Specifically, agrochemical-based nanomaterials play a vital role in achieving the goals of sustainable agriculture (Hassanisaadi et al., 2022) in urban areas. The interaction of nanomaterials with plants positively impacts the morphology and physiology of plant organs and may increase crop production through the efficient use of resources and minimization of the environmental impact associated with crop and food production.

Urban farming companies majorly adopt agroecological crop production practices, including crop rotations, intercropping, cover cropping, mixed cropping systems, and a range of soil conservation practices. In urban farming activities, crop rotation resulted in the efficient utilization of soil nutrients and consequently, a high production rate. This practice requires sufficient knowledge and training with respect to irrigation (Mkhize et al., 2022). Farmers should know the combination of crops, specifically the horticultural crops that have high productivity and enrich the soil with the relevant nutrients. Usually, the fertilizer is mixed with nitrogen, phosphorus, and potassium (NPP), but different crop combinations require many other nutrients (Khan et al., 2020). Crop rotation will help enrich the other nutrients in the soil and control pests and fungal diseases on the farm. Geographically constrained agricultural systems necessitate crop rotation and crop mix practices which enrich crop production intensification and achieve the estimated production (Arnold, 2022). Certain countries have shown long-term evidence that agroecological crop production increases agricultural resilience (Bowles et al., 2020). It improves environmental health and reduces the risk related to threats of climate change.

Space, soil, and water in the urban region require precise planning for farming activity. Utilizing these resources efficiently to achieve a high production rate is challenging for countries like the UAE (Gavahian et al., 2021). The research communities propose many methods for improving resource efficiency to achieve SUFP. SUFP was measured in our study and the positive impact of resource efficiency on sustainable practice in urban areas was reported. Sustainability practice and its performance depend on the procedures followed during farming, particularly the application of an optimal combination of fertilizers and pesticides, and the appropriate quantity and quality of water, soil health, and nutrients will result in the achievement of effective and sustainable urban farming (Alkon, 2008). Urban waste utilization and minimization of the urban generated contaminants are among the essential parameters for the sustainability of countries like the UAE. Following an appropriate irrigation system and production practices like crop rotations, intercropping, cover cropping, and mixed cropping systems, aid in the achievement of the expected quantity of food products (Diacono et al., 2021).

5.3. Innovative urban farming practices and sustainable urban farming performance

The innovative urban farming system, specifically hydroponic farming, aquaponic farming, and aeroponic farming system, does not impact resource efficiency because these innovative methods do not depend on soils for plant growth (Ahmed and Krishnakumar, 2018). Different combinations of other materials are required to support the roots of the plant and grow crops directly through the supply of nutrient-enriched water. Fresh water, oxygen, a small quantity of soil for initial stage route support, nutrients, and light are required (Son et al., 2020). This method supports plant growth at any time of the year, and there is no constraint on suitable climate conditions. This innovative urban farming system can be established anywhere in the urban area, such as on the top floor and on the balcony. Furthermore, the vertical farming system is applied. The water in this system must have a constant pH level ranging from 6 to 6.5, which is challenging for highly solar-exposed countries (Karanja et al., 2009). This system is entirely dependent on water, and implementation in countries like the UAE is quite challenging owing to water scarcity. However, these hydroponic plants require minimal soil support during the sapling stage with typical materials like vermiculite, perlite, peat moss, coconut fibre, and rockwool. Furthermore, the plant needs plenty of magnesium, phosphorus, calcium, and other nutrients to stay healthy and productive (Martin et al., 2019). A farmer growing the plant indoors requires special equipment and a lighting facility to maintain the proposed temperature and environment. To generate starch, the plant requires sunlight, which is impossible when farming indoors, thus necessitating artificial lighting. However, this production system provides significant output, increases the yield, and reduces cost and maintenance.

The present study found that digital technologies do not moderate the relationship between resource conservation practice and sustainable urban farming performance. To achieve sustainability in the urban farming system, appropriate technological support is required in the farming area (Pal et al., 2022). For example, resource conservation practices such as drip irrigation, rainwater harvesting, recycled wastewater irrigation, production of biomass from agricultural waste, and soil quality maintenance using organic compost require smart agricultural environmental support (Hemathilake and Gunathilake, 2022). This smart environment facilitates the farm monitoring by the farmers and real-time updates. Simultaneously, the appropriate level of moisture, water content, nutrient, fertilizers, and pesticides can be maintained to achieve high productivity from the small available space in the urban area. Many technological supports, such as sensor devices and IoT devices are available. Furthermore, AI-based research, which facilitates urban farming in achieving an optimal irrigation system, is developing rapidly (Chen et al., 2022). Numerous urban farming companies have adopted blockchain technology for safety and accountable transactions between the stockholders in the food supply chain (Silitonga et al., 2022). Various technological developments have presented numerous opportunities for the organizations to focus on vertical and innovative urban farming systems. Our results show that digital technology does not moderate the relationship between the IUFS and SUFP. One of the contributing factors can be attributed to the high adoption and implementation costs of the innovative urban farming technologies. Other contributing reasons can be because of low level of awareness among farmers pertaining to innovative urban farming technologies.

6. Conclusion

The present study highlighted that agrochemical optimization practice is positively associated with resource efficiency; crop production practice is positively associated with resource efficiency; and resource conservation practice is positively associated with sustainable urban farming performance. Furthermore, the study highlighted that digital technologies do not moderate the relationship between innovative urban farming systems and sustainable urban farming performance; resource efficiency is positively associated with sustainable urban farming performance. Conversely, innovative urban farming systems are not associated with sustainable urban farming performance and innovative urban farming systems are not associated with resource efficiency. Resource conservation practice is not associated with resource efficiency and technology does not play a moderating role between resource conservation practices and sustainable urban farming performance. Resource efficiency does not mediate between independent variables and sustainable urban farming performance. Furthermore, this study highlights the positive association between CPP and RE, which encourages urban farmers to adopt sustainable crop production intensification practices. Therefore, we recommend implementing RCP in urban farming to enhance sustainable urban farming performance. Lastly, AOP in urban farming is positively associated with resource efficiency, promoting the use of more effective and environmentally friendly agrochemicals in urban farming practices. We believe that LS will have a positive effect on RE. The study highlights that innovative urban farming systems give rise to short food supply chains. These can reduce costs and help maintain quality of the produce. Therefore, urban farmers can directly deliver products to the urban market with more optimized quality and lower prices. A resource efficient low carbon urban farming system helps in minimizing environmental impacts.

CRediT authorship contribution statement

Rohit Sharma: Conceptualization, Methodology, Formal analysis, Software, Visualization, Writing – original draft, Writing – review & editing. **Sabreen Wahbeh:** Formal analysis, Data curation, Software, Writing – original draft. **Balan Sundarakani:** Conceptualization, Supervision, Funding acquisition, Project administration, Software, Writing – review & editing. **Ioannis Manikas:** Conceptualization, Supervision, Funding acquisition, Project administration, Writing – review & editing. **Murugaiyan Pachayappan:** Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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