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ORIGINAL ARTICLE

Potential Drone Applications for Urban Agriculture in Smart City: A Discussion

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ABSTRACT - Drone is often featured with autonomous mobility, high portability and compatible with varies types of sensors, and low maintenance costs. It is popular in the smart city and the smart agriculture applications for the enhancement of monitoring capability, management efficiency, and quality of production. The smart city and smart agriculture developments have contributed to the issue of forest degradation. Rapid urbanization for smart city developments further degrades the agriculture productivity that causes serious impact the global food crisis. Urban agriculture, which conducts agriculture activities within a (smart) city, has been one of the solutions to reduce forest degradation and improve food productivity. Besides, the urban agriculture has shown positive impacts in low-carbon economy, green infrastructures, and food security. However, the issues of limited space, contaminated soil, and limited access to resources delayed the development of urban agriculture. The primary objective of this study is to highlight the potential drone application for urban agriculture in smart city development. This study includes a discussion on the three main production strategies of urban agriculture (home gardening, community gardening, and rooftop farming), two value intensification strategies (direct producer-consumer relation, and resource utilization) and three key challenges of smart city (environmental monitoring, efficient management, and quality of production) with regards to sustainability. Then, the potential drone applications are highlighted with the correlation between the urban agriculture strategies and smart city challenges. The results shown that the drone application for urban agriculture in smart city are highly potential to optimize and sustain urban agriculture productivity.

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INTRODUCTION

Smart city aims to provide a practicable initiative for increasing the economic and environmental protection, via leveraging the advancement in the Information and Communication Technology (ICT), especially the Internet of Things (IoT). IoT, which connects sensors, actuators, and computational devices using an established communication network, is extensively implemented to improve energy efficiency [1], communities' and urban innovation networks [2], and urban green total factor productivity [3]. The key characteristics of IoT [4] include heterogeneity (establish wireless connections with IoT infrastructure at ease), scalability (flexible to increase the connections to cater large quantity of IoT devices), autonomicity [5] (able to response automatically or autonomously), and interpretability (able to extract relevant knowledge or reveal or highlight important information with human understandable form).

Implementing the IoT concept in an agricultural application is often known as the smart (or precision) agriculture system [6]. It is a revolution to the agricultural industry from the conventional farming [7], which emphasizes cultural heritage, self-sustainability, and low environmental impact, to the modern farming [8], which emphasizes the sustainable development goal [9] in terms of environmental, economic,

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and sociological perspectives, that includes soil quality improvement, agricultural waste reduction, and agricultural information sharing by leveraging the advancements in science, innovation, and space technologies. The challenges of the smart agriculture [10] are often related to the issues of disparate standards and protocols in devices' internal processing, lack of awareness in IoT technology, devices' hardware compatibility or adaptability to the local environments, network and security in preventing system failures, and optimization in IoT device distribution for minimum costs.

The implementation of drone, i.e., unmanned aerial vehicle (UAV), has been popular to overcome the challenges [11- 14] with equipment used of the IoT devices, camera, and sensors that are easily mounted on the drone to collect precise ground truth information, conduct systematic irrigation and pesticidal processes remotely or autonomously. The implementation of drone often yields high quality and quantity of crop productions in the modern farming, and it is often implemented in the large area of agriculture field to manage large quantity of crops. To optimize the efficiency of the drone, it is always featured with portability for drone and equipment's transportation, mobility for drone flying actions control, scalability for the flexibility to increase the number of drones operating in the field, maintainability for drone and equipment's low cost maintenance, and compatibility for the mounting of varies type of sensor and agriculture equipment [12].

ISSUES AND CHALLENGES

Agricultural industry has contributed to deforestation due to land clearing for large scale agriculture lands, resulting in the degradation of habitat and loss of biodiversity, impairment of water quality and quantity regulation services, air pollution, and emissions of climate change inducing greenhouse gases [15]. While agriculture is highly demanding in the 21st century [16], agricultural industry face a great challenge to produce more food for the growing population without increasing humanity's agricultural footprint. Thus, deforestation activities are actively conducted, especially at the developing countries.

The urban agriculture that grows crops within cities for human consumption, has been the solution to increase global food production without further deforestation by utilizing urban lands for the modern farming. However, most researches findings have highlighted at the positive social outcomes, rather than productive and sustainability values [17].

This paper is conducted with the objective to reveal the potential drone applications for urban agriculture activities that satisfy the sustainability goals of the smart city.

SCOPE OF STUDY

The scope of study includes a study on the recent urban agriculture strategies implementation in most cities around the globes, the challenges of smart city development in terms of IoT systems, and the precision agriculture technologies.

CONTRIBUTION OF STUDY

This paper highlights the potential or feasibility of drone application in the urban agriculture, in terms of productivity and value intensifying strategies to ease monitoring, management, and controlling plans, by utilizing the smart city facilities and the agriculture technologies of the precision agriculture.

PAPER ORGANIZATION

The paper organization is conducted based on a review methodology. Firstly, the urban agriculture strategies are reviews with regards to two main aspects, i.e., the production and the value intensification strategies, for long term sustainability practices. At the production strategy, home gardening, community gardening, and rooftop farming strategies are studied to elaborate the to increase crops productions. On the other hand, the value intensification strategies studied the direct producer-consumer relations and resource utilization strategies to increase the revenue and logistic. Secondly, smart city is discussed with regards to the three key challenges, i.e., environmental monitoring, management plan, and controlling action. Thirdly, the potential use of drone is described based on its applications at the urban agriculture and smart city. Lastly, a conclusion of the findings is summarized.

PRODUCTION STRATEGIES OF URBAN AGRICULTURE

While primary challenges of urban agriculture are the limited land space and high land cost, systematic agricultural production strategies must be well-planned. It is categorized into the soil-based farming, non-soil-based farming, building-borne farming, and vertical farming to ease mutual understanding at the concepts, motivations, and aims of each farming strategy.

HOME GARDENING

Home gardening [18], often known as household gardens [19], kitchen gardens [20], or homestead gardens [21], is the growing of fruits and vegetables at the backyard of house, to enable farmers to secure their food availability, increase consistency of social-cultural values, and protect species provenance. It is often integrating land use management system, i.e., agroforestry [22], which is a land use management system which integrate trees and shrubs into crop farming systems to create more diverse, productive, profitable, healthy, and sustainable land-use systems.

While restoration and sustainable management of the physical, chemical, and biological properties of urban soils is critical to improving agronomic productivity and nutritional quality of vegetables and fruits grown on these soils [23], man-power is often used to maintain the plantation health in the home garden. For instance, farmers [24-25] manage the trees or vegetations at the home garden to reduce light competition by means of pruning. They are often use excrement of cattle and humans [24-25] to keep the garden fertile and productive while maintaining sanitation.

Such efforts are often motivated the demanding of nutrient-rich food within the household. Therefore, the intervention of home gardening, which combine hands-on training in vegetable gardening and the provision of quality vegetable seeds and nutrition education are often popular among the farmers [26]. This approach aims to simultaneously increase the year-round supply of nutrient-rich food within the household.

COMMUNITY GARDENING

Community gardening [27] manages soil-based farming by subdividing a plot of community land into individual plots within the neighborhood. These plots are cultivated by each individual gardeners who are responsible for their own plot including the yield and production. Community gardens often exist, based on the garden space size of the garden space and landscape feature [28], particularly located in the proximity of neighborhoods within a limited land areas.

The general goals of community gardens are to provide local healthy food [29], regenerate the public space [30], promote participation in community public affairs [31], and establish teams for community self-governance [32] for self-sufficiency of food within cities.

ROOFTOP FARMING

Rooftop farming [33] switches farming to above ground to the rooftops of buildings, by utilizing the unused resources or capacities of cities, especially the flat roofs. It is a popular strategy used by densely populated cities [34; 35] to achieve green city concept with the green factor tool [36] that measures the area of green spaces within a city landscape in term of habitats or corridors for wildlife in ecological benefits, temperature control, hydrological benefits [37] and recreational opportunities.

In additional to the green city concept, food security issue are discussed in [34; 38], specifically during lockdown and movement restrictions. This includes the re-emergence of urban agriculture production for partial self-sufficiency in vegetables through short food supply chains [39] to overcome the problems related to insufficient and consistency food supply.

VALUE INTENSIFICATION STRATEGIES OF URBAN AGRICULTURE

For an economical sustainable urban agriculture, innovative marketing strategies are implemented to optimize income generation from agricultural production. Two main innovative marketing strategies were discussed, with regards to direct producer-consumer relations, and resource utilization, in this section.

DIRECT PRODUCER-CONSUMER RELATIONS

Producer-consumer relations [40] were highlighted as the new alternative food retail chains that connect consumers and farmers or agriculture producers with regional and national food products as the initiative for economical sustainability in agricultural industry. Leveraging the advantage of urban agriculture, which is location next (closer) to consumers, contributes to the direct producer-consumer relations, known as the local food system [41], where consumers have direct access to the origins of their food production (farms) from the neighborhood, or the farmers is directed to the local markets rather than export oriented [42].

The direct producer-consumer relations of urban agriculture are intensively studied in [43], aimed to intensify the income generation to sustain the expensive land cost. Three main approaches [43] are highlighted, where (1) farmers are paid up front by the consumers, whereas agriculture products are shared among the parties, (2) the group ordering by the associations of consumers, in which deliveries of the agriculture products by the farmers are conducted in regular basis, and (3) self-harvesting by the consumers directly from the agricultural plots.

RESOURCE UTILIZATION

Besides agriculture products delivery, urban agriculture has become a new cultural-political expression and land-use fashion as a source of social cohesion, environment education, and as a recreational hobby around the globe [44]. Moreover, utilizing the urban facilities and resources, the spatial connectivity of agricultural activities, i.e., reuse of urban wastewater [45], and solid waste produced by urban agriculture [46] management can be optimized.

Studies in [47; 48] have highlighted the aims of urban agriculture in sustainable cities and community through the sustainable park design through the intersection of urban planning, urban agriculture, and food security.

KEY CHALLENGES OF SMART CITY

The smart city concept aims to overcome the challenges of modern cities [49], which includes uncontrolled urban sprawl, environmental population, urban logistics, technical infrastructures, waste management, aging population, stratification of wealth levels, low level of citizen participation in the management of public affairs, through environmental monitoring [50], management plan [51], and controlling actions [52]. Thus, the environmental monitoring, management plan, and controlling action are highlighted as the primary features through the drone intervention in smart city and smart agriculture for urban agriculture in the context of the production strategies and value intensification strategies.

ENVIRONMENTAL MONITORING

The desired environmental monitoring desired is a complete, real-time monitoring and data recording system [53]. It automatically measures and records environmental parameters [54], that may include air quality, humidity, temperature, humidity, illumination, growing rate, crop health, and ecological condition of agriculture plots. Advance computation models, typically the artificial intelligent tool [55], and the machine learning [56], are used at the measurements, and stored in cloud- [57] and/or blockchain-based [58] platforms.

The environmental monitoring system comprises three main components [53], namely, a Standard Transducer Interface Module (STIM), Graphical User Interface (GUI), and Transducer Independent Interface (TII), that are used to read IoT devices, transform sensor data into electrical signals, and interpret into human understandable format on an interface display from a remote device. Energy-efficient wireless communications [59], i.e., WI-FI, broadcast radio, microwave, mobile communication, and satellite communications, are typically being used to establish the connections between the remote device to the IoT devices.

MANAGEMENT PLAN

The management plan is highly heterogenous [60] based on the information given at the environmental monitoring at particular area in the city or urban agricultural field. It is an optimizing solution for urban agriculture development to achieve better economical sustainability and boost productivity.

Two primary key components of the management plan [61] include human-computer interaction [62], and decision support or decision making tools, which enable data analytics and solution optimization to be conducted based on both sensors data and human (consumers and farmers) feedbacks.

CONTROLLING ACTION

The controlling action is the execution process of the management plan. It is imperative to ensure reliable information exchange to be conducted at all time to ease maintenance works, especially on weed spraying [63], fertilization [64], and goods delivery [65].

Two key components of the controlling action include data security and privacy management [66], and consent manager [67], which authorizes confidential consumer or management data to be shared to authorized individual for controlling action execution.

DISCUSSION ON THE POTENTIAL DRONE IN URBAN AGRICULTURE

Table 1 shows the summarized potential drone implementation in urban agriculture that tackle challenges of smart city to highlight the features of the existing drone technologies.

ENVIRONMENTAL MONITORING

Drone is often used as a platform for aerial sensing [68; 69], which equipped with sensors of electromagnetic spectrum, i.e., visible light, infrared, and ultraviolet, to efficiently collect data remotely (wireless) from above ground (low altitude). These data are beneficial at the study on the unpredicted weather monitoring, forest fire detection, traffic control, emergency search and rescue, and water quality monitoring. Crop health is monitored through the collected data by extracting information of to water system, soil variety, and fungal infestations, through infrared and visual spectral aerial images [63; 70; 71].

Instead of the drone implementation at the urban agriculture production, the other type of drones that are specifically designed for recreation and leisure purposes are greatly beneficial at the value intensification strategies of the urban agriculture. For instance, direct adopting the drones that are featured with surveillance and tracking monitoring system [72; 73] to interact with farmers and consumers in direct producer-consumer relations and resource utilization are highly feasible.

MANAGEMENT PLAN

Drone has been implemented on the evapotranspiration estimation, which include the surface water resources monitoring and assessment [74], urine-enriched biochar-based soil fertility and water management [24], due to its primary benefits in terms of flexible, relatively cheaper, and spaceborne remote sensing that can fly at low altitudes, to capture high spatial resolution data with high prospects of timely and accurately characterizing water quality and quantity. With regards to field mapping [75], autonomous navigation system on the pre-programmed flightpath, that is communicated through internet connection, enabling user to choose the number of waypoints, photo shooting with regards to the orientation of the camera at the desired flight altitude, and post-processing images based on overlap, side lap, and ground sampling distance. Water stress is analyzed with the multispectral imaging with measurement of physiological processes and environment driver to determine the drought and recovery response from the photochemical reflectance index [76] . Yield estimation is obtained through the prediction at with the single stage vegetation indices, and multi-temporal vegetation indices, that are derived from multispectral and digital images [77; 78].

Crowd management uses the mobile ad-hoc network with drones to provide better coverage to the ground (crowd) details through multimedia data for better management planning [78; 79]. Swam-based method is proposed for the path planning to enhance commercial activities through environment modeling and the flight rules of drones [80].

CONTROLLING ACTION

The controlling action of drone includes mounting the aerial spraying system [79], that utilize the injection pump and nozzles designs [80], for pesticide, fertilize, and irrigation applications. The spraying system typically consists of a water, fertilizer or pesticide liquid tank, controller, pump, DC motor, spray boom, tube, and nozzle that are to be mounted on the drone for low altitude spraying.

Besides, the controlling action in urban agriculture may include the drone delivery system [65], which aims for crops or goods delivery that reduce delivery time and cut down labor cost through e-commerce in IoT platform [81]. The delivery protocol is often optimized with the travelling salesman problem [82], and vehicle routing problem [83].

Table 1. Correlation of urban agriculture and smart city with regards to drone applications

Urban agricultural strategy	Environmental Monitoring	Efficient Management	Quality of production
Home gardening Community gardening Rooftop farming	Aerial sensing [68-69], Crop health [63; 70; 71]	Surface water resources monitoring and assessment [74], Urine-enriched biochar-based soil fertility and water management [24], Field mapping [75], Water stress [76], Yield estimation [77-78]	Pesticide, fertilize and irrigation [79; 80]
Direct producer-consumer relations Resource utilization	surveillance and tracking monitoring system [72-73]	Crowd management [78-79] Path planning [80]	Delivery system [65; 81; 82; 83]

CONCLUSION OF FINDINGS

This study provides an overview of the urban agriculture strategies in response to the smart city concept for IoT-based drone application that might be used to enhance urban agriculture productivity and development across the cities. The findings revealed the key features of drone in urban agriculture that helps in production sustainability using high mobility aerial sensing unit as an alternative to the conventional (wired or installed) sensing units, to monitor crops' health, fertilize crops, inspect farm at high altitude (root top), and effective planning on crop planning through digitalized field mapping. Besides, utilizing the advantage of drone to direct interacting with consumers may contributes to the economical sustainability, in the sense of aerial photography in recreation, crowd tracking and monitoring in safety concern, and delivering goods in logistic.

Despite the potential use of drone are enlighten from the literature study, it is often not realistic in the real applications, due to the drone's capability that heavily dependent on the mechanical and agile robotic system to fast response to the changes of surrounding environment or task requirements [84]. To enable drone implementation in urban agriculture, further research studies shall focus on these challenges to increase flexibility of drone movements or trajectories, short flight and significant battery charging time constraints, and automatic or intelligent navigation system. Moreover, digital twins concept [85] should be setup to enable easier operational of drones in the real environment.

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REFERENCES

[1] Y. Yu and N. Zhang, "Does smart city policy improve energy efficiency? Evidence from a quasi-natural experiment in China," *J. Clean. Prod.*, vol. 229, pp. 501–512, 2019.

[2] A. Von Richthofen, L. Tomarchio, and A. Costa, "Identifying communities within the smart-cultural city of Singapore: A Network Analysis Approach," *Smart Cities*, vol. 2, no. 1, pp. 66–81, 2019.

[3] H. Jiang, P. Jiang, D. Wang, and J. Wu, "Can smart city construction facilitate green total factor productivity? A quasi-natural experiment based on China's pilot smart city," *Sustain. Cities Soc.*, vol. 69, p. 102809, 2021.

[4] E. Borgia, "The Internet of Things vision: Key features, applications and open issues," *Comput. Commun.*, vol. 54, pp. 1–31, 2014.

[5] K. M. Lee, K. I. Kim, and J. Yoo, "Autonomicity levels and requirements for automated machine learning," in *Proceedings of the International Conference on Research in Adaptive and Convergent Systems*, 2017, pp. 46–48.

[6] R. Kumar, C. Shekhar, S. Vishnoi, and R. Rastogi, "Smart agriculture–Urgent need of the day in developing countries.," *Sustain. Comput. Informatics Syst.*, vol. 30, p. 100512, 2021.

[7] J. Sumberg and K. E. Giller, "What is 'conventional'agriculture?," *Glob. Food Sec.*, vol. 32, p. 100617, 2022.

[8] R. E. Hester and R. M. Harrison, Eds., *Environmental impacts of modern agriculture (Vol. 34)*. royal society of chemistry, 2012.

[9] H. Eckert, G. Breitschuh, and D. R. Sauerbeck, "Criteria and standards for sustainable agriculture," *J. Plant Nutr. Soil Sci.*, vol. 164, no. 4, pp. 337–351, 2000.

[10] B. Bahadur and R. Dhanalakshmi, "Recent advancements and challenges of Internet of Things in smart agriculture: A survey," *Futur. Gener. Comput. Syst.*, vol. 126, pp. 169–184, 2022.

[11] A. K. Saha *et al.*, "IOT-based drone for improvement of crop quality in agricultural field," in *2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC)*, 2018, pp. 612–615.

[12] U. M. R. Mogili and B. B. V. L. Deepak, "Review on application of drone systems in precision agriculture," *Procedia Comput. Sci.*, vol. 133, pp. 502–509, 2018.

[13] V. Puri, A. Nayyar, and L. Raja, "Agriculture drones: A modern breakthrough in precision agriculture," *J. Stat. Manag. Syst.*, vol. 20, no. 4, pp. 507–518, 2017.

[14] M. H. M. Ghazali, A. Azmin, and W. Rahiman, "Drone implementation in precision agriculture–a survey," *Int. J. Emerg. Technol. Adv. Eng.*, vol. 12, no. 4, pp. 67–77, 2022.

[15] K. G. Austin, A. Schwantes, Y. Gu, and P. S. Kasibhatla, "What causes deforestation in Indonesia?," *Environ. Res. Lett.*, vol. 14, no. 2, p. 024007, 2019.

[16] Beltran-Peña, L. A., Rosa, and P. D'Odorico, "Global food self-sufficiency in the 21st century under sustainable intensification of agriculture.," *Environ. Res. Lett.*, vol. 15, no. 9, p. 095004, 2020.

[17] R. Mcdougall, P. Kristiansen, and R. Rader, "Small-scale urban agriculture results in high yields but requires judicious management of inputs to achieve sustainability," *Proc. Natl. Acad. Sci.*, vol. 116, no. 1, pp. 129–134, 2018.

[18] A. B. Mehari and M. W. Abera, "Opportunities and challenges of adopting home garden agroforestry practices in Ethiopia: A review," *Cogent Food Agric.*, vol. 5, no. 1, p. 1618522, 2019.

[19] P. Z. Ngema, M. Sibanda, and L. Musemwa, "Household food security status and its determinants in Maphumulo local municipality, South Africa," *Sustainability*, vol. 10, no. 9, p. 3307, 2018.

[20] H. D. Wallace, "Transdisciplinary learning in a kitchen garden: connecting to nature and constructing a path to ecoliteracy?," *Int. Res. Geogr. Environ. Educ.*, vol. 28, no. 4, pp. 309–323, 2019.

[21] B. Y. Tesfamariam, E. Owusu-sekyere, D. Emmanuel, and T. B. Elizabeth, "The impact of the homestead food garden programme on food security in South Africa," *Food Secur.*, vol. 10, pp. 95–110, 2018.

[22] R. Nair, B. M. Kumar, V. D. Nair, F. Decades, and S. Developments, *An introduction to agroforestry: four decades of scientific developments*, Second Edi. Cham: Springer.

[23] R. Lal, "Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic," *Food Secur.*, vol. 12, no. 4, pp. 871–876, 2020.

[24] I. Sutradhar *et al.*, "Introducing urine-enriched biochar-based fertilizer for vegetable production: acceptability and results from rural Bangladesh," *Environ. Dev. Sustain.*, vol. 23, no. 9, pp. 12954–12975, 2021.

[25] J. Pettersson and J. Wikström, "Human fertilizer and the productivity of farming household," *Agroecol. Sustain. Food Syst.*, vol. 40, no. 1, pp. 48–68, 2016.

[26] L. Depenbusch *et al.*, "Impact of home garden interventions in East Africa: Results of three randomized controlled trials," *Food Policy*, vol. 104, p. 102140, 2021.

[27] X. Ding, Y. Zhang, J. Zheng, and X. Yue, "Design and social factors affecting the formation of social capital in Chinese community garden," *Sustainability*, vol. 12, no. 24, p. 10644, 2020.

[28] E. C. Anderson, M. H. Egerer, N. Fouch, M. Clarke, and M. J. Davidson, "Comparing community garden typologies of Baltimore, Chicago, and New York City (USA) to understand potential implications for socio-ecological services," *Urban Ecosyst.*, vol. 22, pp. 671–681, 2019.

[29] M. T. Garcia, S. M. Ribeiro, A. Claudia, C. Gonçalves, and C. M. Bógus, "The impact of urban gardens on adequate and healthy food: a systematic review," *Public Health Nutr.*, vol. 21, no. 7, pp. 417–425, 2018.

[30] A. Cumbers, D. Shaw, J. Crossan, and R. McMaster, "The work of community gardens: Reclaiming place for community in the city," *Work. Employ. Soc.*, vol. 32, no. 1, pp. 133–149, 2018.

[31] J. Kingsley, E. Foenander, and A. Bailey, "'You feel like you're part of something bigger': exploring motivations for community garden participation in Melbourne, Australia," *BMC Public Health*, vol. 19, pp. 1–12, 2019.

[32] D. Lu, "Cultivating Vibrant Gardens in Urban Communities: Success Factors of Community Gardens in Beijing and Shanghai," *J. Undergrad. Ethnogr.*, vol. 12, no. 2, pp. 106–125, 2022.

[33] F. Orsini, M. Dubbeling, H. De Zeeuw, and G. Gianquinto, Eds., *Rooftop urban agriculture*. Berlin/Heidelberg, Germany: Springer International Publishing, 2017.

[34] A. Huang and F. Chang, "Prospects for rooftop farming system dynamics: An action to stimulate water-energy-food nexus synergies toward green cities of tomorrow," *Sustainability*, vol. 13, no. 16, p. 9042, 2021.

[35] B. J. Grard, C. Chenu, N. Manouchehri, S. Houot, N. Frascaria-lacoste, and C. Aubry, "Rooftop farming on urban waste provides many ecosystem services," *Agron. Sustain. Dev.*, vol. 38, no. 1, p. 2, 2018.

[36] S. Juhola, "Planning for a green city: The Green Factor tool," *Urban For. Urban Green.*, vol. 34, pp. 254–258, 2018.

[37] J. R. Kumar, B. Natasha, K. C. Suraj, S. A. Kumar, and K. Manahar, "Rooftop farming: an alternative to conventional farming for urban sustainability," *Malaysian J. Sustain. Agric.*, vol. 3, no. 1, pp. 39–43, 2019.

[38] E. Appolloni *et al.*, "The global rise of urban rooftop agriculture: A review of worldwide cases," *J. Clean. Prod.*, vol. 296, p. 126556, 2021.

[39] A. Doernberg, A. Piorr, I. Zasada, D. Wascher, and U. Schmutz, "Sustainability assessment of short food supply chains (SFSC): Developing and testing a rapid assessment tool in one African and three European city regions," *Agric. Human Values*, vol. 39, no. 3, pp. 885–904, 2022.

[40] M. Schermer, "From 'Food from Nowhere' to 'Food from Here:' changing producer–consumer relations in Austria," *Agric. Human Values*, vol. 32, pp. 121–132, 2015.

[41] E. Papaoikonomou and M. Ginieis, "Putting the farmer's face on food: governance and the producer–consumer relationship in local food systems," *Agric. Human Values*, vol. 34, pp. 53–67, 2017.

[42] J. W. van der Schans and J. S. Wiskerke, "Urban agriculture in developed economies," in *Sustainable food planning: Evolving theory and practice*, Wageningen Academic, 2012, pp. 243–258.

[43] I. Opitz, K. Specht, A. Piorr, R. Siebert, and I. Zasada, "Effects of consumer-producer interactions in alternative food networks on consumers' learning about food and agriculture," *Morav. Geogr. Reports*, vol. 25, no. 3, pp. 181–191, 2017.

[44] J. Langemeyer, C. Madrid-lopez, A. Mendoza, and G. Villalba, "Urban agriculture—A necessary pathway towards urban resilience and global sustainability?," *Landsc. Urban Plan.*, vol. 210, p. 104055, 2021.

[45] R. C. Wielemaker, J. Weijma, and G. Zeeman, "Harvest to harvest: Recovering nutrients with New Sanitation systems for reuse in Urban Agriculture," *Resour. Conserv. Recycl.*, vol. 128, pp. 426–437, 2018.

[46] A. Manríquez-Altamirano, J. Sierra-Pérez, P. Muñoz, and X. Gabarrell, "Analysis of urban agriculture solid waste in the frame of circular economy: Case study of tomato crop in integrated rooftop greenhouse," *Sci. Total Environ.*, vol. 734, p. 139375, 2020.

[47] N. Hosseinpour, F. Kazemi, and H. Mahdizadeh, "A cost-benefit analysis of applying urban agriculture in sustainable park design," *Land use policy*, vol. 112, p. 105834, 2022.

[48] M. Horst, N. McClintock, and L. Hoey, "The intersection of planning, urban agriculture, and food justice: A review of the literature," *J. Am. Plan. Assoc.*, vol. 83, no. 3, pp. 277–295, 2017.

[49] J. Winkowska, D. Szpilko, and S. Pejić, "Smart city concept in the light of the literature review," *Eng. Manag. Prod. Serv.*, vol. 11, no. 2, pp. 70–86, 2019.

[50] Z. Lv, B. Hu, and H. Lv, "Infrastructure monitoring and operation for smart cities based on IoT system," *IEEE Trans. Ind. Informatics*, vol. 16, no. 3, pp. 1957–1962, 2019.

[51] V. Moustaka, A. Vakali, and L. G. Anthopoulos, "A systematic review for smart city data analytics," *ACM Comput. Surv.*, vol. 51, no. 5, pp. 1–41, 2018.

[52] E. Ismagilova, L. Hughes, N. P. Rana, and Y. K. Dwivedi, "Security, privacy and risks within smart cities: Literature review and development of a smart city interaction framework," *Inf. Syst. Front.*, vol. 24, pp. 393–414, 2022.

[53] H. Kumar, A., Kim and G. P. Hancke, "Environmental monitoring systems: A review," *IEEE Sens. J.*, vol. 13, no. 4, pp. 1329–1339, 2012.

[54] M. Srbinovska, C. Gavrovski, V. Dimcev, and A. Krkoleva, "Environmental parameters monitoring in precision agriculture using wireless sensor networks," *J. Clean. Prod.*, vol. 88, pp. 297–307, 2015.

[55] B. Kellenberger, D. Marcos, and D. Tuia, "Detecting mammals in UAV images: Best practices to address a substantially imbalanced dataset with deep learning," *Remote Sens. Environ.*, vol. 216, pp. 139–153, 2018.

[56] T. M. Ghazal *et al.*, "Applications of artificial intelligence and machine learning in smart cities," *Comput. Commun.*, vol. 154, pp. 313–323, 2020.

[57] J. S. Fu, Y. Liu, H. C. Chao, B. K. Bhargava, and Z. J. Zhang, "Secure data storage and searching for industrial IoT by integrating fog computing and cloud computing," *IEEE Trans. Ind. Inform.*, vol. 14, no. 10, pp. 4519–4528, 2018.

[58] H. Shafagh, L. Burkhalter, A. Hithnawi, and S. Duquennoy, "Towards blockchain-based auditable storage and sharing of IoT data," in *Proceedings of the 2017 on cloud computing security workshop*, 2017, pp. 45–50.

[59] D. Feng *et al.*, "A survey of energy-efficient wireless communications," *IEEE Commun. Surv. Tutorials*, vol. 15, no. 1, pp. 167–178, 2012.

[60] S. Y. Tan and A. Taeihagh, "Smart city governance in developing countries: A systematic literature review," *sustainability*, vol. 12, no. 3, p. 899, 2020.

[61] C. Pettit *et al.*, "Planning support systems for smart cities," *City, Cult. Soc.*, vol. 12, pp. 13–24, 2018.

[62] A. Caraban, E. Karapanos, D. Gonçalves, and P. Campos, "23 ways to nudge: A review of technology-mediated nudging in human-computer interaction," in *Proceedings of the 2019 CHI conference on human factors in computing systems*, 2019, pp. 1–15.

[63] A. Hafeez *et al.*, "Implementation of drone technology for farm monitoring & pesticide spraying: A review," *Inf. Process. Agric.*, vol. 10, no. 2, pp. 192–203, 2022.

[64] D. Radočaj, M. Jurišić, and M. Gašparović, "The role of remote sensing data and methods in a modern approach to fertilization in precision agriculture," *Remote Sens.*, vol. 14, no. 3, p. 778, 2022.

[65] W. Yoo, E. Yu, and J. Jung, "Drone delivery: Factors affecting the public's attitude and intention to adopt," *Telemat. Informatics*, vol. 35, no. 6, pp. 1687–1700, 2018.

[66] Y. Qian, Z. Liu, J. Yang, and Q. Wang, "A method of exchanging data in smart city by blockchain," in *2018 IEEE 20th International Conference on High Performance Computing and Communications; IEEE 16th International Conference on Smart City; IEEE 4th International Conference on Data Science and Systems (HPCC/SmartCity/DSS)*, 2018, pp. 1344–1349.

[67] S. Daoudagh *et al.*, "Data protection by design in the context of smart cities: A consent and access control proposal," *Sensors*, vol. 21, no. 21, p. 7154, 2021.

[68] D. Gallacher, "Drone applications for environmental management in urban spaces: A review," *Int. J. Sustain. L. Use Urban Plan.*, vol. 3, no. 4, 2016.

[69] B. Potter, G. Valentino, L. Yates, T. Benzing, and A. Salman, "Environmental monitoring using a drone-enabled wireless sensor network," in *2019 Systems and Information Engineering Design Symposium (SIEDS)*, 2019, pp. 1–6.

[70] A. Tendolkar, A. Choraria, M. M. M. Pai, S. Girisha, G. Dsouza, and K. S. Adithya, "Modified crop health monitoring and pesticide spraying system using NDVI and Semantic Segmentation: An AGROCOPTER based approach," in *2021 IEEE International Conference on Autonomous Systems (ICAS)*, 2021, pp. 1–5.

[71] G. Chandirasekaran, A. David, and J. G. Sankar, "Application of Drone Technology in Agriculture: A Predictive Forecasting of Pest and Disease Incidence.," in *Applying Drone Technologies and Robotics for Agricultural Sustainability*, 2023, pp. 50–81.

[72] A. C. Winkler, E. C. Butler, C. G. Attwood, B. Q. Mann, and W. M. Potts, "The emergence of marine recreational drone fishing: Regional trends and emerging concerns," *Ambio*, vol. 51, no. 3, pp. 638–651, 2022.

[73] E. Felemban, A. A. Sheikh, and A. Naseer, "Improving response time for crowd management in Hajj," *Computers*, vol. 10, no. 4, p. 46, 2021.

[74] M. Sibanda *et al.*, "Application of drone technologies in surface water resources monitoring and assessment: A systematic review of progress, challenges, and opportunities in the global south," *Drones*, vol. 5, no. 3, p. 84, 2021.

[75] D. Cirillo, "Digital field mapping and drone-aided survey for structural geological data collection and seismic hazard assessment: case of the 2016 central Italy earthquakes," *Appl. Sci.*, vol. 10, no. 15, p. 5233, 2020.

[76] P. D. Odorico *et al.*, "Drone-based physiological index reveals long-term acclimation and drought stress responses in trees," *Plant. Cell Environ.*, vol. 44, no. 11, pp. 3552–3570, 2021.

[77] G. Or *et al.*, "Crop growth monitoring with drone-borne DInSAR," *Remote Sens.*, vol. 12, no. 4, p. 615, 2020.

[78] X. Zhou *et al.*, "Predicting grain yield in rice using multi-temporal vegetation indices from UAV-based multispectral and digital imagery," *ISPRS J. Photogramm. Remote Sens.*, vol. 130, pp. 246–255, 2017.

[79] D. Yallappa, M. Veerangouda, V. Maski, D., Palled, and M. Bheemanna, "Development and evaluation of drone mounted sprayer for pesticide applications to crops," in *2017 IEEE global humanitarian technology conference (GHTC)*, 2017, pp. 1–7.

[80] S. Yu *et al.*, "Evaluation of spray characteristics of pesticide injection system in agricultural drones," *J. Biosyst. Eng.*, vol. 45, pp. 272–280, 2020.

[81] H. Chen, Z. Hu, and S. Solak, "Improved delivery policies for future drone-based delivery systems," *Eur. J. Oper. Res.*, vol. 294, no. 3, pp. 1181–1201, 2021.

[82] G. C. Crişan and E. Nechita, "On a cooperative truck-and-drone delivery system," *Procedia Comput. Sci.*, vol. 159, pp. 38–47, 2019.

[83] Z. Wang and J. Sheu, "Vehicle routing problem with drones," *Transp. Res. Part B*, vol. 122, pp. 350–364, 2019.

[84] Deja, M., Siemiątkowski, M. S., Vosniakos, G. C., & Maltezos, G. (2020). Opportunities and challenges for exploiting drones in agile manufacturing systems. *Procedia Manufacturing*, *51*, 527-534.

[85] Pylianidis, C., Osinga, S., & Athanasiadis, I. N. (2021). Introducing digital twins to agriculture. *Computers and Electronics in Agriculture*, *184*, 105942.