sustainability

MDPI

Article

Effects of Urban Smart Farming on Local Economy and Food Production in Urban Areas in African Cities

Alireza Moghayedi [1,*], Isabell Richter [2], Folasade Mary Owoade [3], Kutemba K. Kapanji-Kakoma [4], Ewon Kaliyadasa [5], Sheena Francis [6] and Christiana Ekpo [1]

[1] Department of Construction Economics and Management, University of Cape Town, Cape Town 7700, South Africa
[2] Department of Psychology, Norwegian University of Science and Technology, 7049 Trondheim, Norway
[3] Department of Crop Production and Soil Science, Ladoke Akintola, University of Technology, Ogbomoso 210214, Nigeria
[4] National Institute for Scientific and Industrial Research, Kenneth Kaunda International Airport Road, Lusaka P.O. Box 310158, Zambia
[5] Department of Export Agriculture, Faculty of Animal Science and Export Agriculture, Uva Wellassa University, Badulla 90000, Sri Lanka
[6] Natural Products Institute, Faculty of Science and Technology, University of the West Indies, Kingston 7, Jamaica
* Correspondence: alireza.moghayedi@uct.ac.za

Abstract: African cities are growing rapidly into inefficient, unsustainable, resource-starved ecosystems that negatively affect the local economy and food production. Food as a critical resource needs to be produced and managed more efficiently by local communities in the urban area. Urban smart farming (USF) has emerged as an important mechanism to address these challenges to achieve sustainable, resilient, and inclusive cities. USF has the potential to be the industry 4.0 green revolution in agriculture, which embodies innovative digital technologies. However, it is unclear how local African communities and key stakeholders perceive this novel solution and if they are willing to engage in its uptake. This study examines the relationship between the perceived benefits and challenges of USF and the willingness of local African communities to actively participate in USF projects as a potential mechanism to improve local economy and food production. To assess this relationship, a causal model was developed. In this causal model, the local economy and food production were defined as dependent variables. The conceptualized model and the inherent causality between the constructs were validated through a survey administered among African cities' residents. The results of structural equation modelling indicate a significant positive impact of perceived benefits of USF as well as the willingness of African communities to engage in this technology on local economy and food production. Only minimal adverse effects of the perceived challenges of USF on the local economy and food production have been found. The study concludes that the benefits and willingness of local communities are the key drivers for implementing urban smart farms in African metropolitans. Therefore, it is recommended to focus on the benefits and the motivation of local communities in African cities where USF shall be further developed, rather than on the barriers. The validated causal model can be used as a framework to facilitate the adoption of USF in Africa and consequently enhance the local economy and food production in African cities.

Keywords: food production cities; local economy; African community; sustainable production; urban smart farming

check for updates

Citation: Moghayedi, A.; Richter, I.; Owoade, F.M.; Kapanji-Kakoma, K.K.; Kaliyadasa, E.; Francis, S.; Ekpo, C. Effects of Urban Smart Farming on Local Economy and Food Production in Urban Areas in African Cities. *Sustainability* **2022**, *14*, 10836. https://doi.org/10.3390/su141710836

Academic Editors: George Mavrotas and Piotr Prus

Received: 3 June 2022
Accepted: 18 August 2022
Published: 31 August 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Food production in a controlled indoor environment without using soil or sunlight while utilizing minimal water and energy alongside technological innovation, within proximity to urbanized areas, has the potential to be one of the main drivers of the next-generation agricultural revolution [1]. Crop production in an isolated building, where abiotic factors such as wind and temperature are controlled via innovative technologies, which eliminate the risk of natural disaster, requires less space (50%) and water (80%) compared to traditional farming uses. This technologically driven farming in urban areas, or urban smart farming (USF), can be considered a sustainable method of agriculture in line with Sustainable Development Goal 2 (SDG 2), which focuses on food security and zero hunger as its primary objective. Sub-target 2.3 explicitly focuses on doubling the agricultural productivity and incomes of small-scale food producers, particularly women, indigenous peoples, and family farmers, through equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition, and non-farm employment [2].

USF also has the potential to tackle some of the challenges in developing cities throughout Africa in the post-pandemic era. These challenges include the shortage of food production, low local economy and job creation for marginalized populations (such as youth and women), and a high vacancy rate of commercial buildings. Integrating the concept of sustainable development, indoor vertical farming, innovative technologies, and urban regeneration can mitigate some of these problems [3].

This research will contribute to the body of knowledge on this topic by investigating how to best facilitate the opportunity of regenerating urban spaces by converting vacant buildings into indoor smart farms, and what future interventions should focus on. To the best of our knowledge, research is still failing to explicitly examine urban smart farming in Africa, its perceived benefits and barriers, the willingness of African communities adopt and participate in USF projects, and how these factors affect local economy and food production. Therefore, this study seeks to identify the key constructs and factors that influence the local African communities' adoption and participation in USF and evaluate the impacts of these key factors on local food production and the local economy through developing the USF causal model.

It is anticipated that such understanding will provide valuable knowledge on how to promote the willingness of local communities to adopt and participate in USF projects.

This research has the following objectives:

- Explore the key factors that influence the adoption of urban smart farming by local communities in African cities.
- Explore the benefits and challenges and the willingness of local African communities to implement this farming method.
- Determine the effect of influential factors of urban smart farming on local food production and the local economy of African cities.

The study outlines a review of the African urban economy and food production, the benefits and challenges of USF, and the willingness of local communities to adopt or participate in USF projects, followed by the research method used in the study and the development of the causal model, data analysis, and results, finishing with a discussion of the findings and a conclusion.

2. Overview of African Urban Economy and Food Production

Africa is projected to have the fastest urban growth rate in the world, and it is expected that more than 60% of the African population will be living in cities by 2050 [4]. A fast-growing population can result in uncontrollable urbanization, leading to a burden on fresh and clean water systems and a risk to individuals' food security [5], thus impacting most African cities that are struggling to identify their future economic drivers [6]. There is reduced interest in traditional farming in rural African areas, where most farmland is located. Therefore, promoting other farming alternatives such as USF in cities, where more labor is available, might prove beneficial [7].

A decline in agricultural production negatively impacts food supply and increases unemployment rates in Africa [3]. Additionally, poorly performing supply chain systems, the seasonality of certain crops, and volatility in production lead to high prices and other supply factors that limit access to these basic nutrients, both economically and physically for most of the African population [8]. National policies, such as the National Policy on Food and Nutrition Security [9], have endorsed efforts aimed at addressing food security in Africa through the following: creating a reliable data collection and analysis process; reinforcing current strategies and policies that relate to food security; advancing market accessibility for smallholder farmers; and raising awareness on agro-ecological approaches to farming. Hence, innovative solutions such as USF are supported by the Africa Agenda 2063 [10]. African urban economy and food production characteristics are summarized in Figure 1.

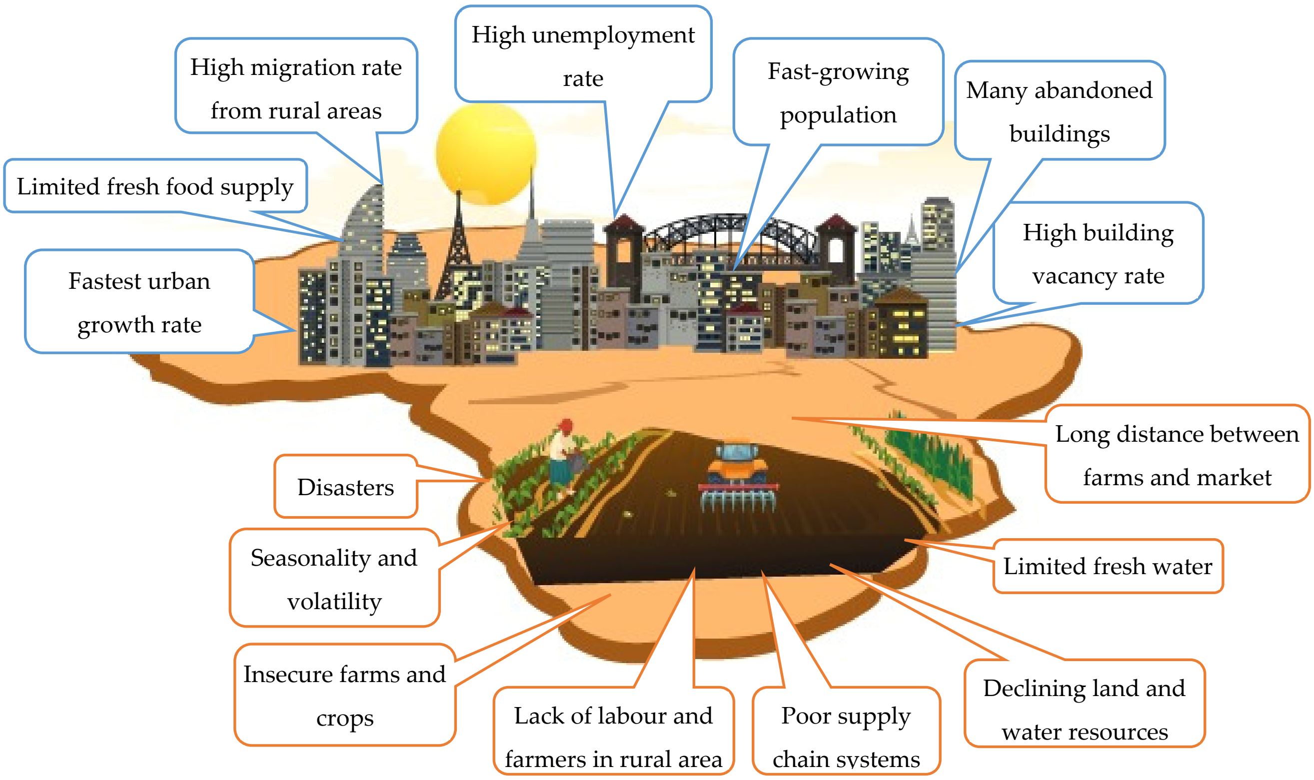

Figure 1. African urban economy and food production characteristics. Source: various.

3. Urban Smart Farming (USF)

Indoor farming was originally developed from conventional greenhouse farming systems; today, it has deviated radically, and comprises many variations. Al-Kodmany [11] described the urban smart farm as a system that is often called 'vertical farming', which allows food to be grown under smart climate-controlled indoor environments by using technological innovation.

Generally, three indoor vertical food production methods are applied, namely hydroponics, aeroponics, and aquaponics [7]. These methods require the sheltering of the structure that accommodates the production facility without the need for soil and production land. The closed system of these three methods allows for water containing nutrients that were not absorbed the first time around to be recycled instead of being lost [12]. From a nature preservation and restoration perspective, USF supports environmental sustainability, as the ecological water system is restored [12]. Thus, indoor food production can be undertaken in urban areas using a controlled indoor environment that eliminates problems such as seasonality, and requires small footprints and delivers high yields [1].

USF can positively impact SDGs 2, 5, 10, 11, and 12 directly and affects others by improving Gross Domestic Product (GDP). USF enhances the energy efficiency rate, contributes to the sufficient availability of nutritious food, and empowers marginalized populations, particularly youth and women. Moreover, USF can assist in achieving sustainable development in developing countries and population growth, urbanization, and poor agricultural practices, which are all factors that place stress on the local resources and ecosystem [13].

Critics of USF point towards its low practicality. However, the outdoor open environment and conditions are often more uncontrollable than those inside high-performing buildings [11].

Musa and Basir [7] mention a few applications where urban smart farms are likely to be implemented quickly. These include desert and drought-struck areas such as African and Arabian countries as well as smaller, densely populated countries, followed by countries struggling with pollution and soil depletion [14].

Buildings used for USF can either be newly constructed structures designed with an intended purpose or existing vacant buildings that have been modified to fit the purpose [15]. O'Hara and Toussaint [16] suggest that using abandoned and vacant buildings can solve food shortages. This can be achieved by viewing buildings as self-sufficient producers (instead of consumers) that generate their own energy, food, and water while reducing greenhouse gas emissions. Therefore, USF is particularly relevant in areas such as most African cities where there are many vacant and unused buildings and a scarcity of fertile and non-polluted land areas [17].

The deployment of the 4th Industrial Revolution (4IR) and outbreaks of pandemics have spiked the vacancy rates in African commercial properties. The vacancy rate in office blocks is even greater than the previous highest vacancy rate during the economic recession in the early 2000s [18]. An initiative such as USF could provide a solution to redevelopment that allows for buildings to be reused by remodeling them to fit changing needs while preserving their historic character and embracing their growth for new opportunities [17].

The perceived benefits and challenges to USF from a community perspective are discussed in the following section.

3.1. Benefits and Challenges of USF

Xiang, et al. [19] have suggested combining nature-based solutions with community-based solutions to represent local socio-economic problems and guide urban planning practitioners. Saad, Hamdan, and Sarker [1] proved that urban smart farms provide lower environmental costs than traditional farming, especially when renewable energy sources are used. USF has a reduced impact on water sources and related water and soil pollution [1]. African countries, whose citizens often battle with sourcing nutritious fresh vegetables and fruits, are also constantly challenged with water and soil management difficulties and can benefit from the 95% water usage reduction [20].

In terms of sustainability, USF meets the requirements of all-year-round sustainable food production and helps mitigate the food loss risks associated with natural disasters such as floods, droughts, and pest attacks and human-made disasters including fires and the stealing of crops [12,14]. Africa's battle with these disasters causes damage to ecosystems, water supply systems, and food security [21]. Thus, traditional farming issues are more controllable indoors than outdoors [20]. Although technology costs are high in Africa, the advantages of a guaranteed disaster-free harvest as a risk mitigation strategy re-evaluates the cost of such technologies [14].

Urban smart farms can produce authentic organic food, which is healthy and not contaminated by chemicals [22]. The harvested nutritional products contribute positively to the local community by promoting health, well-being, and social benefits [3]. In addition, the crop returns per area are much higher in indoor farms than in conventional outdoor farming and resultantly imply higher capital return on investment [7].

The development of a smart farm that incorporates the Internet of things (IoT), big data, and Artificial Intelligence (AI) can adjust the growing conditions of urban indoor farming according to the changing growth requirements of each plant in the producing facility [23]. This provides an educational opportunity for local youth and, at the same time, makes food production more independent and convenient, thus increasing the engagement of local communities [24]. USF provides an opportunity for innovative technologies such as IoT to monitor various variables such as the water and air quality, illumination, humidity, temperature, and other visually noticeable growth elements by creating a traceable record to refer to in the future, enabling the improvement of future productivity [1]. Advancements in the fields of lighting, sensors, temperature control, and nutrient monitoring on a user-friendly farming computer dashboard not only make this method of farming easier for local communities but also reduce operational costs while providing USF opportunities with trackable growing cycles [14,24]. Moreover, the technological innovation of USF helps the buildings to be more efficient, healthier, and sustainable [7,25].

Another key benefit of USF is the potential to reduce transportation distances and costs, which results in less fossil fuel being burnt [14] and a reduction in greenhouse gas emissions caused by trucks. Furthermore, scholars have highlighted certain social benefits for local communities adopting USF [1,3,7,14,22]. These benefits include abating social isolation and strong community feeling and engagement, all of which consequently improve the community's well-being. For this reason, there is an international focus on retaining the interest of the local community, particularly women and youth, in this innovative initiative, as local communities should drive innovation, energy, and creativity in developing environmentally responsible and highly productive practices [3].

Additionally, USF is powering innovation beyond the agricultural division. It can redevelop local and global food supply systems while pushing changes in architecture, facility management, crop science, energy, technological innovation, data analytics, and urban planning [1]. In addition, USF is closely related to some fields that contribute to the complexity of urban redevelopment, such as knowledge from real estate economics, land usage, community benefits, ecology, transportation, sustainability, place-making design, politics, and other related disciplines [17].

With regards to the challenges, several factors that threaten traditional farming in Africa have been identified, including access to resources, unemployment, price sensitivity of products, credit risk, food insecurity, market access, diversification, financial safety nets, security of farms and crops, alternative land options [26] and the water issue, especially in a drought-stricken region [12]. These challenges further shift the burden to traditional land-based farming, increase agriculture-related costs such as fertilizer, fuel, and pesticides, and reduce soil quality as a result of depletion and degradation caused by continuous farming and poor production practices in Africa [14].

Headrick [22] and Van Delden et al. [26] identified the high costs in energy, associated labor, and urban properties as the main challenges of USF, while Benke and Tomkins [14] reaffirm that capital costs are excessively high in many cities due to high prices of real estate compared to rural land prices. However, the output production yield from USF is much more than conventional farming in rural areas, and USF focuses on retrofitting vacant and abandoned buildings. Therefore, the initial cost of land will certainly be recouped in the future. At the same time, USF input costs are further reduced as there is no need for traditional farming machinery input and related maintenance costs. According to Pinstrup-Andersen [8], the main challenge of USF is the energy outlay, which could be significantly minimized by utilizing more efficient equipment, technologies, and renewable energy.

Due to the high capital cost of USF technologies in Africa, mainly due to non-availability of local technologies, Benke and Tomkins [14] believe that growing low-value field crops indoors is not financially viable under the current economic conditions. Therefore, future farmers should carefully select crops with a higher return on investment. Yet it is predicted that the capital cost of USF will be significantly reduced by supporting local government through financial incentives [24]. Furthermore, when local technology manufacturers supply technology within Africa, it might change the narrative in the future. The challenges and benefits of USF are summarized in Figure 2.

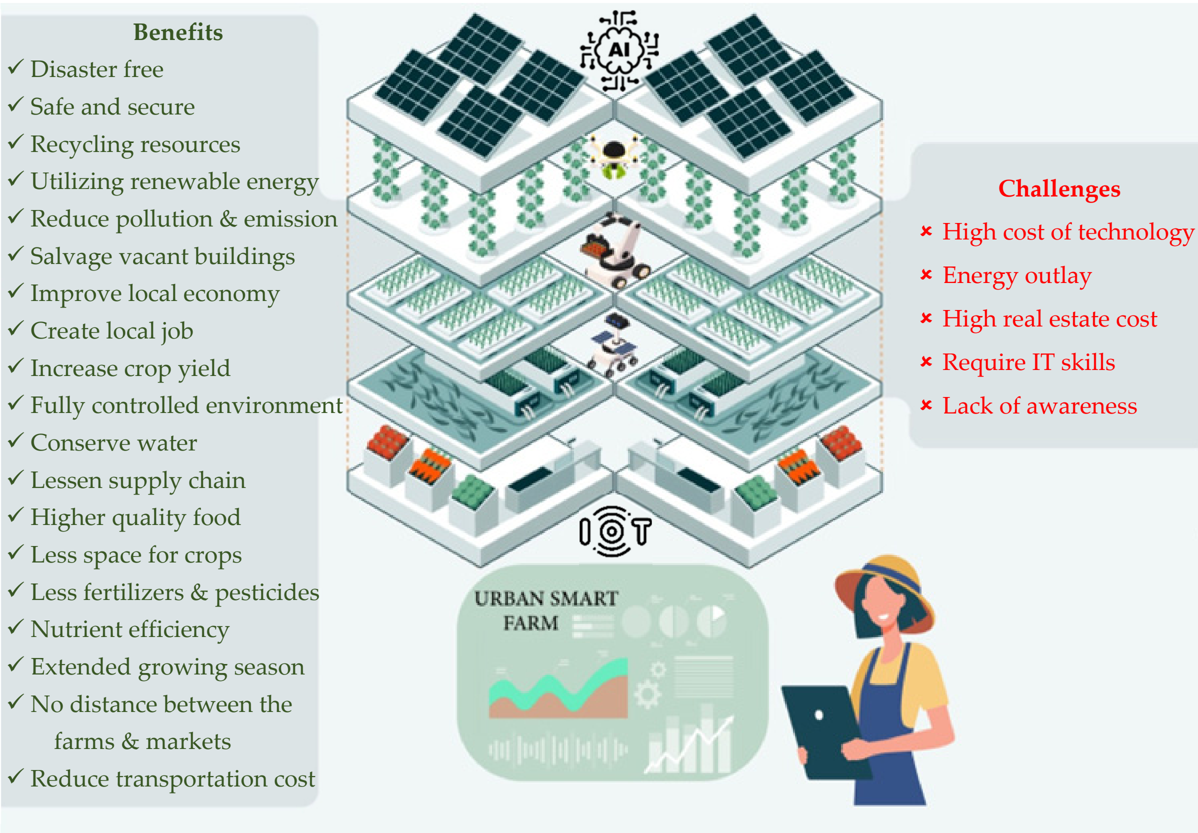

Figure 2. Urban smart farm's benefits and challenges. Source: various.

3.2. Local Communities' Willingness to Adopt or Participate in USF Projects

The social and community response to USF and its products is one of the primary considerations. Therefore, it is vital to know the community's views and potential level of participation in this innovative initiative, as future farmers and main consumers [12]. USF perceived representation can be improved through general education and involvement of local communities [23], which is a strategic approach to encouraging the extent of the level of adoption [27].

Local community participation in initiatives take on various forms that include actively participating, encouraging family members and friends to participate, promoting the initiations through different channels, and leading and managing or participating in training [28,29]. Therefore 'Technical efficiency' is required. Danquah, et al. [27] describes technical efficiency as the ability of individual economies and communities to adopt technologies that already exist and apply them locally.

Since USF located in cities will allow for fewer trips for future farmers to deliver the foods to markets. further solving some of the critical issues of African communities and cities. Shorter travel distances between supply food networks mean that food can reach consumers quicker, while reducing the carbon footprint caused by long-distance transport pollution [7,22]. Several studies have demonstrated that consumers prefer locally produced nutrient-dense, freshly grown products from non-rivals [20,28].

4IR and pandemic have changed people's lifestyles [30]. As a result, many millennials now live in a live–work–play urban environment and are employed in technology, media, education, art, and health care. In the meantime, local private developers now drive redevelopment while working with local communities and the public sector. Some of the careers expected to arise from USF include local specialist technologists, facility managers, innovative farmers; maintenance workers; marketing, and retail staff. These career opportunities provide massive economic and social advantages to local communities [14]. However, USF requires a higher-skilled workforce and professional disciplines such as biological and material sciences, which is likely to increase the total employment in the food production sector [14].

The economic benefits of USF, previously discussed, play a significant role in communities' willingness to participate in urban regenerative ventures. Hersh [17] stated that redevelopment differs from traditional development, considering that conventional developments are usually driven by business principles, with profit being the primary motive. Conversely, redevelopments generally involve the community and government from the beginning, with shared goals as the main priority and without neglecting the importance of compensation for the impacts of migration. For instance, Xiang, Yang and Li [19] have noted that numerous communities often suffer from emigration as most African individuals and businesses migrate from central urban areas to suburban areas, a phenomenon that many other countries have also experienced since the mid-1940s.

Based on the above discussion, it is advocated that USF is a possible solution to African cities' issues such as urban regeneration, food production and improving the sustainability of cities and citizens' quality of life. Furthermore, a cleaner production of crops promotes consumers' desire to support environmentally friendly and high-tech production practices.

4. Research Methods

This study adopted a positivist philosophical research approach to employ empirical methods and involved extensive use of quantitative analysis. Furthermore, it developed logical analyses to build formal explanatory theory for elucidating the relationship between the willingness of the local community to participate in smart urban farms and the potential benefits and challenges of USF. These factors were identified as the influential constructs to address the local food production issues and to improve the local economy in African cities.

An electronic survey was conducted to collect the responses of local communities in major African cities across gender, economy, and education. The questionnaire survey was randomly sent to local community members living in Johannesburg, Cape Town, Lagos, and Lusaka. There were 409 valid responses collected across the African cities and used for data analysis. The collected data is larger than the minimum sample size recommended for the unknown population, with a 95% confidence level and ±5% margin of error (385) [31]. The questionnaire consisted of four sections: general information of participants, willingness to participate, benefits of USF and challenges of USF. To develop the profiles of the selected criteria, the collected data were analyzed using descriptive and inferential statistical techniques. Furthermore, structural equation modelling (SEM), as a robust statistical method that fits networks of constructs to data, was used to validate the relationship between local food production's willingness, benefits, and challenges and the economy. In fact, SEM is the most efficient method for handling the confirmatory factor analysis for measurement models, analyzing the causal relationships among multiple latent constructs in a structural model, estimating their variance and covariance, and testing the hypotheses for mediators and moderators in a model. It is distinguished from other types of analyses by its ability to examine many relationships while simultaneously reducing measurement errors [30].

4.1. Conceptual Model Projects

According to Moghayedi et al. [30], using technological innovation is a function of the level of readiness and awareness for the technology and incentives as well as the challenges of adopting that technology. Figure 3 illustrates the developed conceptual model for evaluating the relationship and impact of utilizing USF on local food production and the economy of developing African countries. As shown in the developed conceptual model, the benefits and Challenges of USF are independent constructs, willingness to participate is a mediating construct and the local food production and local economy are dependent constructs.

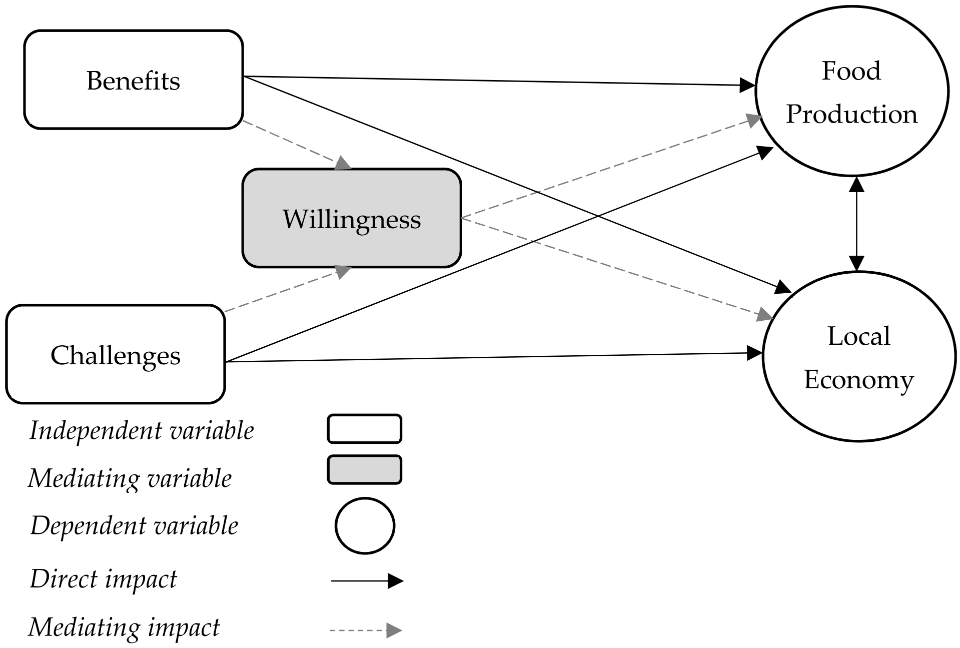

Figure 3. Urban smart farm conceptual framework. Source: authors.

Based on the research questions and developed conceptual model, the research is designed to test the following hypotheses:

Hypothesis 1 (H1). *The potential benefits of urban smart farming have a significant positive impact on the local food production.*

Hypothesis 2 (H2). *The potential benefits of urban smart farming have a significant positive impact on the local economy.*

Hypothesis 3 (H3). *The possible challenges of urban smart farming have a significant negative impact on the local food production.*

Hypothesis 4 (H4). *The possible challenges of urban smart farming have a significant negative impact on the local economy.*

Hypothesis 5 (H5). *The potential benefits of urban smart farming have a significant positive impact on the local food production through willingness of local communities.*

Hypothesis 6 (H6). *The possible challenges of urban smart farming have a significant negative impact on the local food production through willingness of local communities.*

Hypothesis 7 (H7). *The potential benefits of urban smart farming have a significant positive impact on the local economy through willingness of local communities.*

Hypothesis 8 (H8). *The possible challenges of urban smart farming have a significant negative impact on the local economy through willingness of local communities.*

Hypothesis 9 (H9). *Food production in urban area has a positive impact on the local economy.*

Hypothesis 10 (H10). *Local economy has a positive impact on the food production in urban area.*

4.2. Research Constructs and Sub-Constructs

The study constructs and sub-constructs used in measuring the study constructs and their corresponding measurement scale are shown in Table 1. In addition, the literature review identified five variables for the willingness of the local community and 10 potential benefits and possible challenges of USF, as listed in Table 1.

Table 1. Sub-constructs used in measuring the study constructs.

Constructs	Sub-Constructs	Source	Measurement Scale
Willingness (W) to participate in urban smart farming	Actively participate (W1)	[2,28,29]	Respondents were asked to indicate their willingness to participate on a 4-point Likert scale
	Encourage my family members and friends to actively participate (W2)	[2,28,29]	
	Promote it (e.g., on social media) (W3)	[2,28,29]	
	Help leading and managing (W4)	[2,28,29]	
	Participate in workshop/training (W5)	[2,28,29]	
Benefits (B) of urban smart farming	Makes community more independent (B1)	[17,22,28,29]	Respondents were asked to indicate the degree of their agreement with potential benefit of urban smart farming in their local communities on a 4-point Likert scale
	Sustainable/environmentally friendly (B2)	[7,8,14]	
	Convenient (B3)	[2,28,29]	
	Provides opportunities for local women and youth (B4)	[23,28]	
	Supports community wellbeing (B5)	[2,7,17]	
	Supports community health (B6)	[2,14,17]	
	Provides educational opportunities (B7)	[1,7,22]	
	Provides financial benefits (B8)	[2,7,8,17]	
	Makes room for community engagement and interaction (B9)	[3,14,22]	
	Strengthens community feeling (B10)	[22,28,29]	
Challenges (C) of urban smart farming	Lack of responsibility (C1)	[32]	Respondents were asked to indicate the degree of their agreement with possible Challenges of urban smart farming in their local communities on a 4-point Likert scale
	Water supply (C2)	[26]	
	Crop and seed supply (C3)	[26]	
	Technological equipment (C4)	[1,23,26]	
	Collides with local farming traditions (C5)	[26,32]	
	Lack of knowledge (C6)	[3,22,26]	
	Lack of funding (C7)	[1,3,26]	
	Security (C8)	[26]	
	A lack of trust (C9)	[32]	
	Diseases (C10)	[26]	
It is able to address the local food production issues			Respondents were asked to indicate the degree of impact of USF on the local food production and economy on a 4-point Likert scale
It is able to improve the local economy by generating more jobs			

5. Data Analysis and Results

5.1. Profile of Respondents

Figure 4 summarizes the demographic analysis of the 409 participants obtained across Africa.

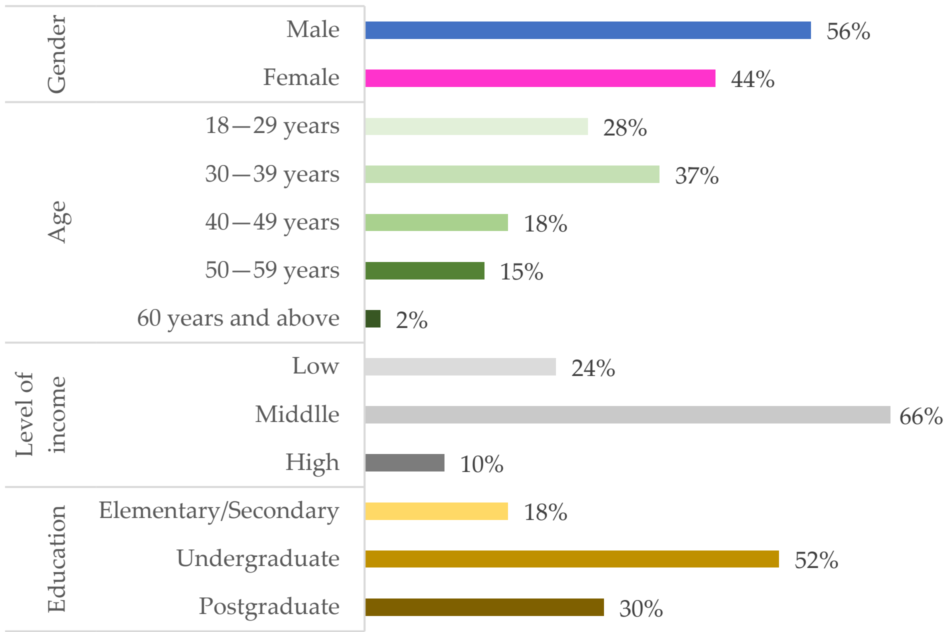

Figure 4. Profile of respondents. Source: authors.

As illustrated in Figure 4, the frequency of male participants (56%) is higher than female participants (44%). The majority of the respondents belong to the tricenarian group (37%), followed by vicenarian (28%) and quadragenarian groups (18%). The portfolio of respondents shows that the majority of the respondents belong to the middle-income class (66%), followed by the low-income class (24%) and finally the high-income class (10%), respectively. Moreover, most respondents (82%) hold a higher education degree (undergraduate 52% and postgraduate 30%).

5.2. Familarity with Urban Smart Farm Concept

As shown in Figure 5, the majority of the African participants (54%) are familiar with the concept of USF, particularly the young generation (18–39), which shows the high awareness of African communities of new indoor farming methods.

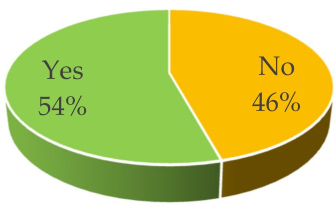

Figure 5. Familiarity of African's communities with urban smart farming. Source: authors.

5.3. Willingness of Communities to Participate in USF

The willingness of African communities to participate in USF is analyzed using the Relative Importance Index (RII) to quantify the overall importance of each question. The results are illustrated in Figure 6.

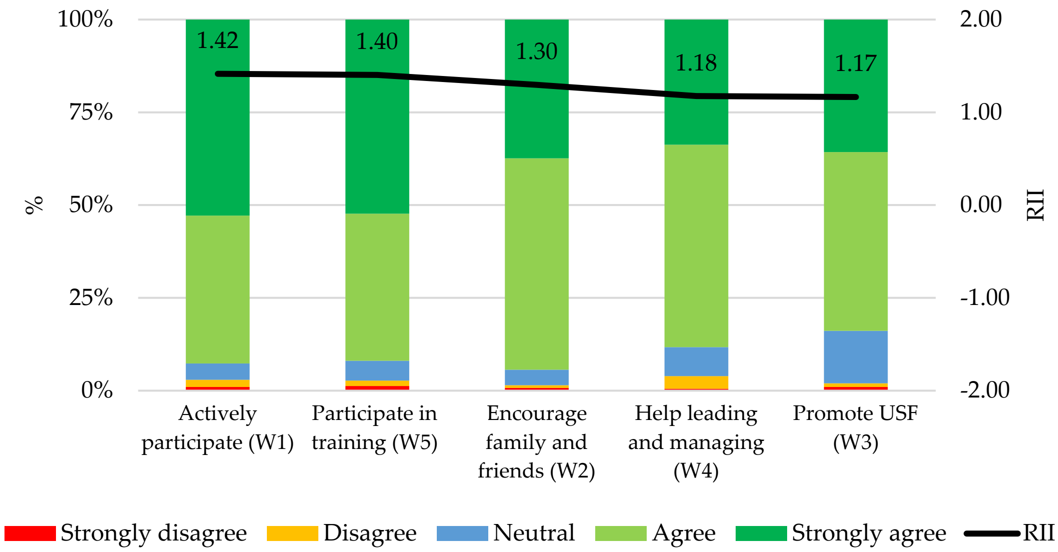

Figure 6. Willingness of African communities to participate in USF. Source: authors.

The analysis of the five questions showed that most African communities would actively participate in USF projects (W1, 1.42), participate in an introductory workshop/training about USF (W5, 1.40), encourage their family to participate in USF projects (W2, 1.30), help lead and manage the projects (W4, 1.18) and talk about the projects (W3, 1.17). This high level of willingness is because of the familiarity of most communities with concepts of USF and the challenges encountered in traditional farming in Africa.

5.4. Benefit of USF

Participants' responses about the potential benefits of this innovative farming method are analyzed, and the overall RII of each benefit is illustrated in Figure 7.

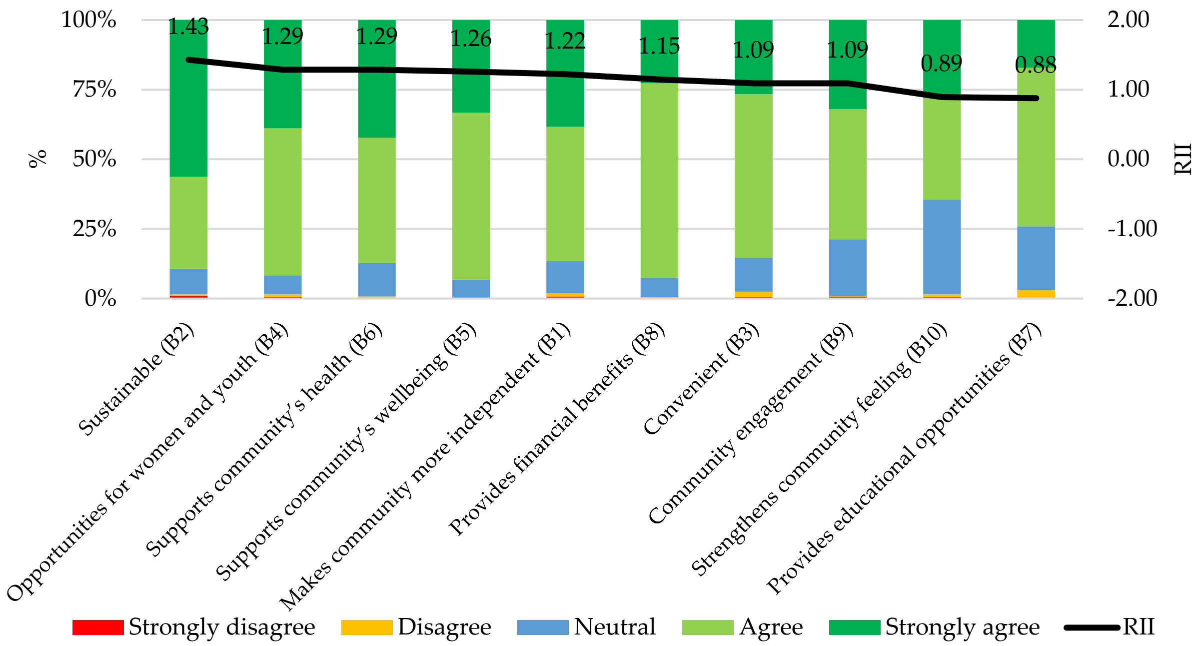

Figure 7. The potential benefits of USF to African's communities. Source: authors.

Overall, the African participants agreed (RII ~1.00) with all 10 potential benefits of USF considered under this study. The results reflect that the following are seen as the top five benefits of USF: sustainable/environmentally friendly (B2, 1.43), provides opportunities for local women and youth (B4, 1.29), supports community's health (B6, 1.29), supports community's wellbeing (B5, 1.26), and makes the community more independent (B1, 1.22).

The remaining five benefits of urban smart farming are identified as considerably important for local communities: provides financial benefits (B8, 1.15), convenient (B3, 1.09), makes room for community engagement and interaction (B9, 1.09), strengthens community feeling (B10, 0.89), and provides educational opportunities (B7, 0.88).

5.5. Challenges of USF

The level of potentially hindering challenges to adopting USF by local African communities is identified from the responses of participants, and the RII of each challenge is presented in Figure 8.

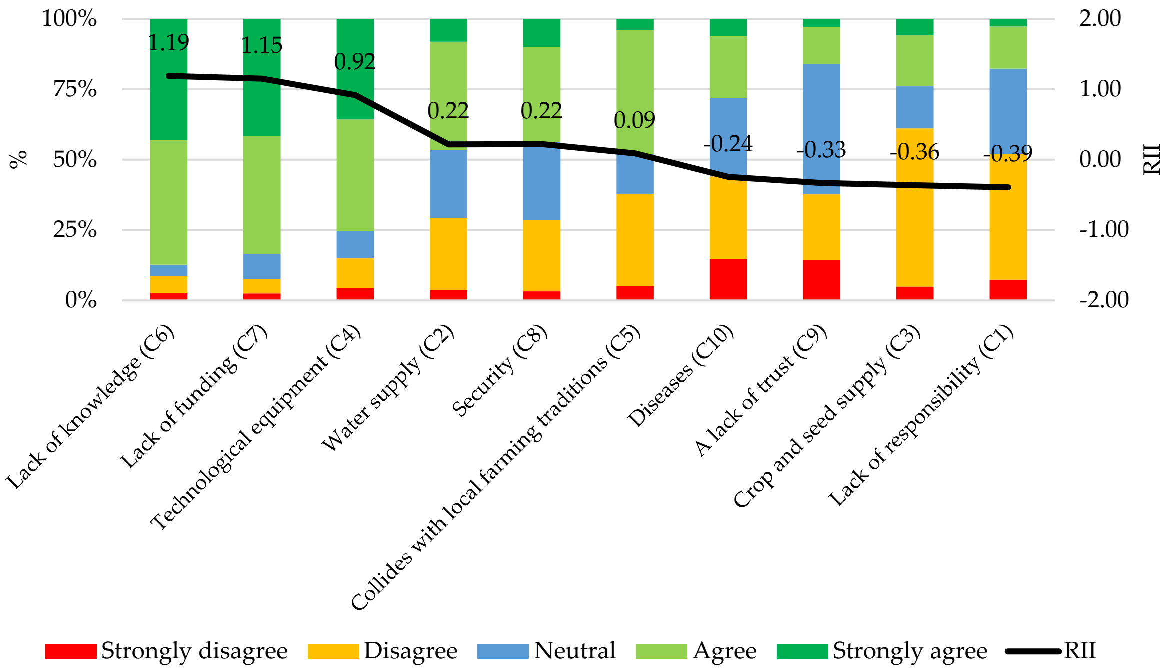

Figure 8. The possible challenges of USF to African's communities. Source: authors.

As illustrated in Figure 8, the results concerning challenges reveal that lack of knowledge (C6, 1.19), lack of funding (C7, 1.15), technological equipment (C4, 0.92), water supply is a problem (C2. 0.22), security (C8, 0.22), and collides with local farming traditions (C5, 0.09) are possible challenges that communities faced in adopting USF in Africa. Conversely, the communities do not perceive diseases (C10, −0.24), lack of trust (C9, −0.33), crop and seed supply (C3, −0.36), and no one wants to take responsibility (C1, −0.39) as possible challenges for USF in Africa. This is because of the high degree of familiarity and knowledge of African urban communities with indoor farming, particularly innovative urban farming concepts.

5.6. Impact of Urban Smart Farm on Local Food Production and Economy

Finally, the analysis of responses to the potential impact of USF on food production and the local economy is presented in Figure 9.

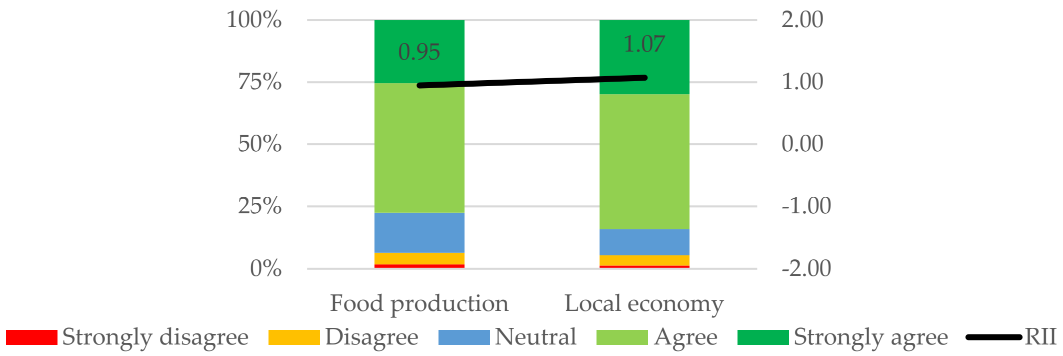

Figure 9. Potential impact of USF on African's cities food production and local economy. Source: authors.

Overall, African respondents agreed that adopting urban smart farming improves the local food production (0.95) and enhances their local economy (1.07).

5.7. Causal Model of USF

Finally, to validate the developed conceptual model of USF, the impact of independent and modelling constructs is evaluated using collected data.

The research hypotheses were tested using T-Statistics. The *p*-values of independent (benefits and challenges) and mediating (willingness) constructs are less than 0.05, which indicates that none research hypotheses are statistically significant (Table 2).

Table 2. Hypothesis testing results.

Hypothesis	T Statistics	*p* Values	Decision
Benefits +> Local food production	5.212	0.000	Significant
Benefits +> Local economy	5.718	0.000	Significant
Challenges –> Local food production	4.325	0.000	Significant
Challenges –> Local economy	4.688	0.000	Significant
Benefits +> Willingness of local communities +> Local food production	10.260	0.000	Significant
Benefits +> Willingness of local communities +> Local economy	6. 743	0.000	Significant
Challenges –> Willingness of local communities –> Local food production	3.674	0.000	Significant
Challenges –> Willingness of local communities –> Local economy	3.230	0.001	Significant
Local food production +> Local economy	5.937	0.000	Significant
Local economy +> Local food production	1.208	0.092	Insignificant

Since only the last hypothesis (path) is not statistically significant as presented in Table 2, this path is eliminated from the model and the remaining nine hypotheses (paths) are considered for path analysis.

First, the outer loading of each factor is examined. Since all the factors have a good contribution on relevant constructs (outer loading more than 0.7), all initial factors are included in the final model. In the second step, the constructs and sub-constructs' consistency, reliability, and validity are tested (Table 3).

The results of Cronbach's Alpha are between 0.7 and 0.95 as listed in Table 3, which indicates an excellent internal consistency between the sub-constructs under the same constructs (>0.7) and sub-constructs that are not highly intercorrelated (<0.95).

The coefficients of rho-A are between Cronbach's Alpha and Composite Reliability which proves satisfactory internal consistency between the sub-constructs. Furthermore, the AVE and composite reliability test results are above 0.5 and 0.7, respectively, which demonstrate the convergent validity and reliability between sub-constructs and indicate the reliability of the developed model is adequate. Finally, the AVE square root of each measured sub-construct is greater than the correlation coefficient between the sub-constructs, which implies that measures of sub-constructs are not highly related to each other. Subsequently, the model's goodness-of-fit was assessed. The R2 values for the constructs are greater than 0.7 which show the robust relationship between developed model and the dependent variable. Furthermore, the analysis of the USF model indicates that all fit indices of model are above the recommended values x^2 = 2141.127; x^2/dF = 3.779; p = 0.000, Root Mean Square Error of Approximation (RMSEA) = 0.040, Comparative Fit Index (CFI) = 0.967; Goodness of Fit (GFI) = 0.942 (x^2/df < 5, CFI & GFI $\geq$ 0.90, RMSEA and p < 0.5).

Table 3. Reliability, consistency and validity of the constructs and sub-constructs.

Construct	Sub-Constructs	Benefits	Challenges	Willingness	Local Food Production	Local Economy
Benefits	B 1–10	0.893				
Challenges	C 2, 4, 5,6,7,8	−0.712	0.886			
Willingness	W 1–5	0.731	−0.826	0.892		
Local food production		0.795	−0.791	0.869	1.000	
Local economy		0.775	−0.757	0.888	0.761	1.000
Internal	Cronbach's Alpha	0.894	0.776	0.887	1.000	1.000
Consistency	Rho-A	0.912	0.779	0.883	1.000	1.000
Composite Reliability		0.913	0.841	0.910	1.000	1.000
Convergent validity (AVE)		0.516	0.587	0.760	1.000	1.000

Ultimately, the path analysis for the USF model was developed. As shown in Figure 10, the loading factors of sub-constructs are above 0.8, indicating good associations between sub-constructs in the reflective measurement of constructs and the model. Since all the sub-constructs are higher than satisfactory levels, they were utilized to examine the importance of each sub-construct for the defined constructs in the model. This was to identify which sub-constructs are the key influencers of adopting USF in Africa. Overall, the results of the above tests validated the developed causal model of USF in this study.

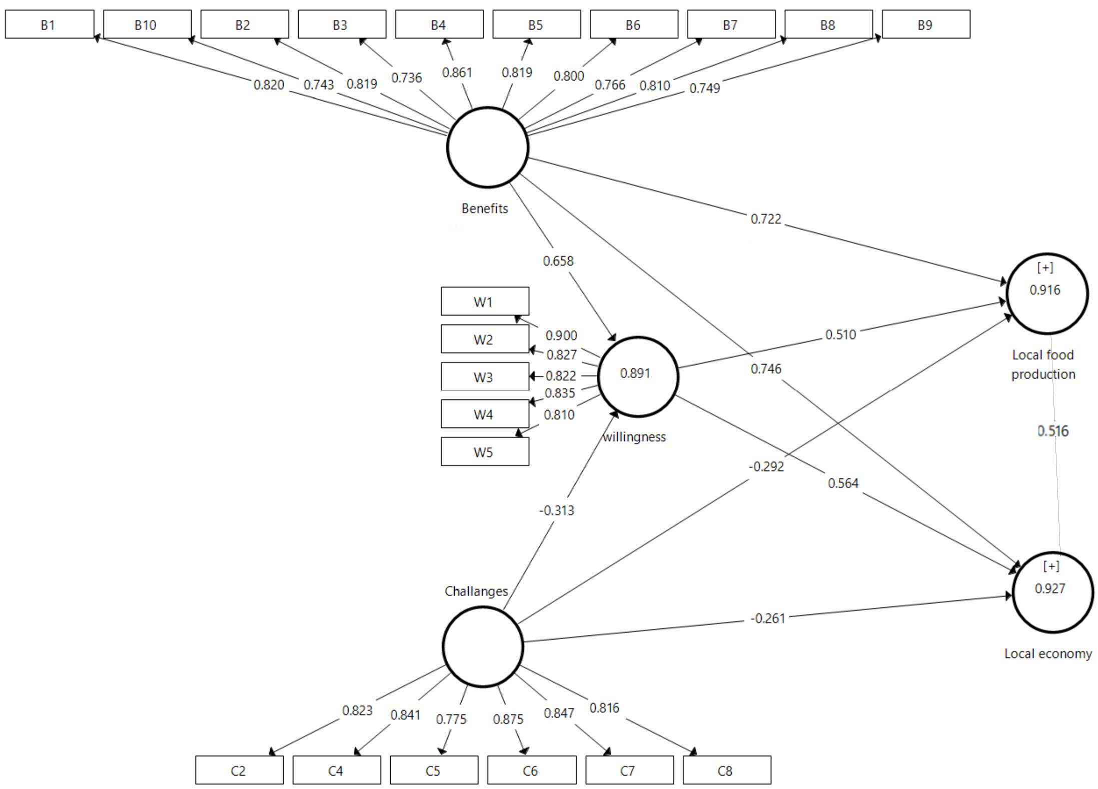

Figure 10. Path analysis of USF. Source: authors.

Based on the results of path analysis illustrated in Figure 10, it can be deduced that the benefits of USF and the willingness of communities have significant positive impacts on local food production and local economy. Conversely, the challenges of USF have significant negative impacts on the local food production and local economy.

Furthermore, the indirect impact of dependent sub-constructs (through the community's willingness) on independent sub-constructs of the study proved that the benefits of USF positively mediate the effects of the community's willingness to adopt and participate in USF. Ultimately, local food production has a significant positive impact on the local economy of African's cities. Therefore, the total impact of the community's willingness on local food production in the local economy were increased, as shown in the final urban smart farm causal model in Figure 11.

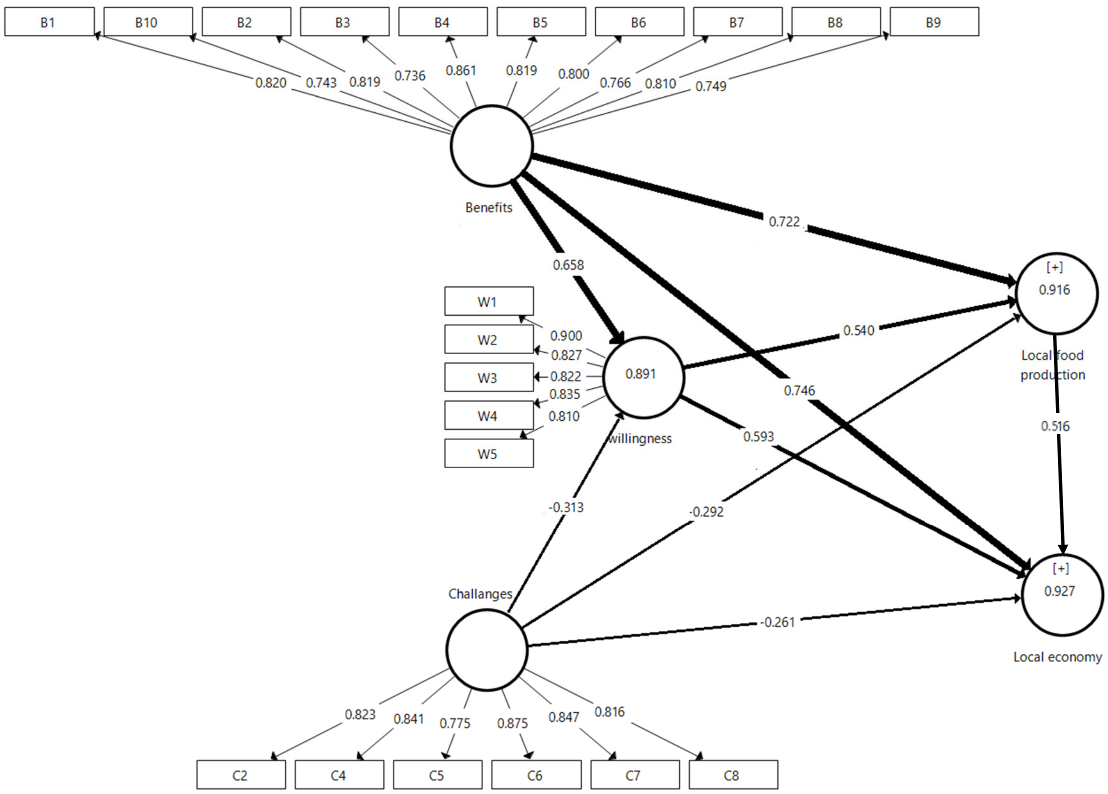

Figure 11. Final urban smart farm causal model. Source: authors.

Figure 11 illustrates the total impact coefficient of constructs on dependent sub-constructs. The benefits of USF have high (0.7 < e < −0.9) positive impacts on the local food production and local economy. Moreover, communities' willingness to adopt and participate in urban smart farms has moderate (0.5 < e < 0.7) impacts on both dependents sub-constructs of the study. On the other hand, challenges have a low (−0.5 < e < −0.2) negative impact on the local food production and local economy. Consequently, the local food production has moderate (0.5 < e < 0.7) impact on the local economy of cities. Furthermore, the comparison of path analysis and the final causal model proved that the positive impacts of benefits on the willingness of communities are higher than the negative impacts of challenges.

Ultimately, the outer weights of the dependent and mediator sub-construct are calculated and ranked according to their relative importance in Table 4. Outer weights are the results of multiple regression of a construct on its set of indicators that demonstrate each variable's importance [30]. For example, the outer weights of sub-constructs indicate that actively participating (W1) and encouraging family members and friends to participate (W2) are the predominant factors in the community's willingness, whilst providing opportunities for local women and youth (B4), making the community more independent (B1), and Sustainable/environmentally friendly (B2) are the most effective benefits of USF. Conversely, the most significant challenges consisted of lack of knowledge (C6), lack of funding (C7), and water supply is a problem (C2).

Table 4. Outer weights of sub-constructs.

Sub-Constructs	Willingness	Benefits	Challenges
Actively participate (W1)	0.316		
Encouraging family members and friends to participate (W2)	0.238		
Promote it (e.g., on social media) (W3)	0.232		
Help leading and managing (W4)	0.290		
Participate in workshop/training (W5)	0.225		
Provides opportunities for local women and youth (B4)		0.200	
Makes community more independent (B1)		0.183	
Sustainable/environmentally friendly (B2)		0.155	
Supports community's wellbeing (B5)		0.154	
Provides financial benefits (B8)		0.151	
Supports community's health (B6)		0.149	
Provides educational opportunities (B7)		0.132	
Makes room for community engagement and interaction (B9)		0.112	
Strengthens community feeling (B10)		0.101	
Convenient (B3)		0.092	
Lack of knowledge (C6)			0.356
Lack of funding (C7)			0.297
Water supply is a problem (C2)			0.220
Technological equipment (C4)			0.261
Security (C8)			0.197
Collides with local farming traditions (C5)			0.174

As listed in Table 4, the outer weights of influential variables of the urban smart farm are close (~0.2–~0.3 for willingness, ~0.1–~0.2 for benefits, and ~0.2–~0.3 for challenges), which confirms the significance of all identified influential sub-constructs on the USF initiative.

6. Discussion of Findings

The primary aim of this research was to scrutinize the relationship between the willingness of the local community to participate in urban smart farm projects and the potential benefits and possible challenges as the influential factors on USF's ability to address the local food production and enhance the local economy. The developed causal urban smart farm model was validated using structural equational modelling.

The results of the community's questionnaire survey revealed that most African communities are familiar with the USF concept and the community's willingness to participate in these projects among African communities is high. African communities are aware of existing challenges and difficulties of traditional farming in Africa, such as security issues and high-uncertainty problems such as climate conditions, rainfall, disease, and wastage. These findings align with those of Moghayedi, Awuzie, Omotayo, Le Jeune, and Massyn [30], which proved that the level of awareness significantly impacts the community's willingness to adopt new concepts and/or methods. Moreover, the community's high awareness and willingness caused the African communities to be very optimistic about the positive effects of this initiative on their local food production and local economy.

Analysis of the benefits of smart farming verified that, overall, the participants agreed with all 10 potential benefits of urban smart farms extracted from the literature. However, some benefits, such as being sustainable/environmentally friendly, the provision of opportunities for local women and youth, supporting the community's health, supporting community's well-being, and the provision of financial benefits stand out as particularly encouraging.

Furthermore, the findings of urban smart farm benefits supported the findings of Kalantari and Akhyani [28] and Poulsen, Neff, and Winch [29] that USF mainly impacts the local communities and provides several advantages for the local community conditions, such as making the community more independent, supporting the community's well-being, promoting the community's health, providing educational opportunities, making room for community engagement and interaction, and strengthening community feeling.

The analysis of challenges of USF also revealed that the participants evaluated did not consider diseases, lack of trust, crop and seed supply, and community responsibility as either possible or extremely hindering challenges for engaging in USF, which aligns with the findings of Van Delden et al. [26].

Statistical analysis of possible challenges verified that lack of knowledge, lack of funding, technological equipment, water supply, security, and collisions with local farming traditions are significant barriers to adopting USF in Africa. Goel et al. [3] and Halgamuge et al. [24] found similar results, suggesting the necessity of educating stakeholders (including community and traditional farmers).

Local manufacturers should be encouraged to produce the required innovative technologies to cater to local demand, which would address the lack of funding and technological equipment reflected in our results.

Reducing real estate taxes is one option that local municipalities can apply to encourage innovative redevelopment, such as in USF [17]. In addition, offering tax abatement incentives rewards developers for undertaking redevelopment projects instead of punishing the development with higher taxes. Governments' intervention to relocate subsidies that are given to some limited crops towards supporting USF products and farmers can help with the uptake of controlled environment farming [20].

Urban Smart Farm Causal Model

The results of the structural equation modelling verified the high validity and consistency of the developed causal model. The total effect coefficients in the final urban smart farm causal model confirmed the high positive impacts of urban smart farms and moderate positive impact of communities' willingness on local food production and the local economy. Furthermore, the results of SEM revealed the low negative impacts of challenges on local food production and the economy. The positive effects of USF on local food production and the local economy directly depend on the benefits of urban smart farms and the level of local communities' willingness to adopt and participate in it.

Moreover, comparing the urban smart farm path coefficient and total effect coefficients verified the positive mediating effect of benefits on the association between willingness and independent sub-constructs of the model. The total effect analysis and the outer weights of sub-constructs reveal the extent to which local food production and the local economy are strongly associated with the advantages of USF. The positive impact of benefits on willingness and local food production and economy indicates that the benefits are critical for implementing this initiative compared to the challenges. Since the USF is driven by the benefits and the willingness of local communities and not by challenges, this initiative is a sustainable system that can propagate rapidly; this finding is aligned with Moghayedi, Awuzie, Omotayo, Le Jeune, and Massyn [30].

In other words, the extent of implementation of the urban smart farm in Africa could be significantly increased by enhancing the benefits of this innovative indoor farming. Consequently, this initiative can address the issue of local food production in African cities and improve the local economies. These positive outcomes result from the direct, highly positive impact of USF's benefits on independent constructs and the positive mediator impact of its benefits on local communities' willingness to adopt USF.

7. Conclusions

This research is one of a pioneering research projects conceptualizing the perceived influential factors of USF and evaluating their impact on local food production and the local economy using structural equation modelling.

The findings showed that local communities actively participating in USF could improve the sustainability of local African communities by enhancing the local food production and local economy through local community participation. It can be deduced from the study's findings that appropriate national and local strategies and policies are required for implementing urban smart farms by enhancing the adoption of technological innovations.

- To address the possible challenges and enhance the sustainability performance of such innovative indoor farms, the community awareness and public incentives for urban smart farms must be improved.
- To stay economically viable, the public and private sectors and local authorities need to support African urban smart farms.

The validation of the urban smart farm causal model attests to its applicability as a mechanism for increasing the implementation of this innovative initiative in Africa. This research provides several theoretical and practical inferences for researchers and practitioners. In practice, the developed model serves as a roadmap for local and national stakeholders to adopt an appropriate mechanism to facilitate implementing USF by local communities. Theoretically, the study extends the postulations on its benefits and communities' willingness to use urban smart farms as the main driver of implementing this groundbreaking farming system. Practically, the findings of this study help apprehend the level of local communities' willingness and technological innovation as the key factors to achieving superior sustainability in food production in African cities.

The current study provides methodical ground for future studies to evaluate the effectiveness of the identified influential factors of USF, including benefits, challenges, and willingness on the various outcomes such as local food production, local economy, social sustainability, etc. Therefore, future studies could examine the feasibility and viability of various USF techniques and crops. In addition, investigating case studies of a few existing urban smart farms in Africa will provide a more profound understanding of the current study's findings. Lastly, the urban smart farm causal model could be generalized in similar global south contexts because of the high similarity of societies and economies in the global south.

Author Contributions: Conceptualization: A.M. and I.R.; methodology: A.M. and C.E.; validation: K.K.K.-K. and F.M.O.; formal analysis: A.M.; investigation: I.R., S.F. and E.K.; resources: A.M., K.K.K.-K. and F.M.O.; data curation: A.M.; writing—original draft preparation: A.M., I.R. and C.E.; writing—review and editing, A.M., K.K.K.-K., F.M.O., I.R., E.K. and S.F.; project administration: A.M., F.M.O. and K.K.K.-K.; funding acquisition, A.M. and F.M.O. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Royal Academy of Engineering under the Distinguished International Associates (grant No. DIA-2022-155) and Royal Society under the Commonwealth Science Conference 2021 Follow-on Grant (grant No. CSC\R1\211010).

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of University of Cape Town and approved by the Institutional Ethics Committee of the Faculty of Engineering and Built Environment, University of Cape Town (Application Ref: 21760175 and 25 November 2021).

Informed Consent Statement: The study was conducted according to the guidelines of the Declaration of University of Cape Town and approved by the Institutional Ethics Committee of the Faculty of Engineering and Built Environment, University of Cape Town (Application Ref: 21760175 and 25 November 2021).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Saad, M.H.M.; Hamdan, N.M.; Sarker, M.R. State of the art of urban smart vertical farming automation system: Advanced topologies, issues and recommendations. *Electronics* **2021**, *10*, 1422. [CrossRef]
2. Gil, J.D.B.; Reidsma, P.; Giller, K.; Todman, L.; Whitmore, A.; van Ittersum, M. Sustainable development goal 2: Improved targets and indicators for agriculture and food security. *Ambio* **2019**, *48*, 685–698. [CrossRef] [PubMed]
3. Goel, R.K.; Yadav, C.S.; Vishnoi, S.; Rastogi, R. Smart agriculture–Urgent need of the day in developing countries. *Sustain. Comput. Inform. Syst.* **2021**, *30*, 100512. [CrossRef]
4. OECD/SWAC. *Africa's Urbanisation Dynamics 2020: Africapolis, Mapping a New Urban Geography*; West African Studies; OECD Publishing: Paris, France, 2020. [CrossRef]
5. Ramutsindela, M.; Mickler, D. *Africa and the Sustainable Development Goals*; Springer: Berlin/Heidelberg, Germany, 2020.
6. Moghayedi, A.; Awuzie, B.; Omotayo, T.; Le Jeune, K.; Massyn, M.; Ekpo, C.O.; Braune, M.; Byron, P. A Critical Success Factor Framework for Implementing Sustainable Innovative and Affordable Housing: A Systematic Review and Bibliometric Analysis. *Buildings* **2021**, *11*, 317. [CrossRef]
7. Musa, S.F.P.D.; Basir, K.H. Smart farming: Towards a sustainable agri-food system. *Br. Food J.* **2021**, *123*, 3085–3099. [CrossRef]
8. Pinstrup-Andersen, P.; Cheng, F. *Case Studies in Food Policy for Developing Countries: Domestic Policies for Markets, Production, and Environment*; Cornell University Press: New York, NY, USA, 2018; Volume 2.
9. Stats-Sa. *Sustainable Development Goals: Country Report*; Department of Statistics South Africa: Pretoria, South Africa, 2019.
10. Commission, A.U. *Agenda2063-The Africa We Want*; African Union: Addis Ababa, Ethiopia, 2017.
11. Al-Kodmany, K. The vertical farm: A review of developments and implications for the vertical city. *Buildings* **2018**, *8*, 24. [CrossRef]
12. Chou, L.; Dai, J.; Qian, X.; Karimipour, A.; Zheng, X. Achieving sustainable soil and water protection: The perspective of agricultural water price regulation on environmental protection. *Agric. Water Manag.* **2021**, *245*, 106583. [CrossRef]
13. Sachs, J.; Kroll, C.; Lafortune, G.; Fuller, G.; Woelm, F. *Sustainable Development Report 2021*; Cambridge University Press: Cambridge, UK, 2021.
14. Benke, K.; Tomkins, B. Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustain. Sci. Pract. Policy* **2017**, *13*, 13–26. [CrossRef]
15. Simpson, C. Updating the Building Code to Include Indoor Farming Operations. *J. Food Law Policy* **2019**, *15*, 5.
16. O'Hara, S.; Toussaint, E.C. Food access in crisis: Food security and COVID-19. *Ecol. Econ.* **2021**, *180*, 106859. [CrossRef]
17. Hersh, B. *Urban Redevelopment*; Routledge: London, UK, 2016.
18. SAPOA. *Office Vacancy Report*; South African Property Owners Association: Pretoria, South Africa, 2022.
19. Xiang, P.; Yang, Y.; Li, Z. Theoretical Framework of Inclusive Urban Regeneration Combining Nature-Based Solutions with Society-Based Solutions. *J. Urban Plan. Dev.* **2020**, *146*, 04020009. [CrossRef]
20. Pinstrup-Andersen, P. Is it time to take vertical indoor farming seriously? *Glob. Food Secur.* **2018**, *17*, 233–235. [CrossRef]
21. Smith, P.; Calvin, K.; Nkem, J.; Campbell, D.; Cherubini, F.; Grassi, G.; Korotkov, V.; Le Hoang, A.; Lwasa, S.; McElwee, P. Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification? *Glob. Change Biol.* **2020**, *26*, 1532–1575. [CrossRef] [PubMed]
22. Headrick, D. Converging innovations nourish growth of indoor farming. *Res. Technol. Manag.* **2019**, *62*, 7–8.
23. White, B. Generational dynamics in agriculture: Reflections on rural youth and farming futures. *Cah. Agric.* **2015**, *24*, 330–334. [CrossRef]
24. Halgamuge, M.N.; Bojovschi, A.; Fisher, P.M.; Le, T.C.; Adeloju, S.; Murphy, S. Internet of Things and autonomous control for vertical cultivation walls towards smart food growing: A review. *Urban For. Urban Green.* **2021**, *61*, 127094. [CrossRef]
25. Windapo, A.O.; Moghayedi, A. Adoption of smart technologies and circular economy performance of buildings. *Built Environ. Proj. Asset Manag.* **2020**, *10*, 585–601. [CrossRef]
26. Van Delden, S.; SharathKumar, M.; Butturini, M.; Graamans, L.; Heuvelink, E.; Kacira, M.; Kaiser, E.; Klamer, R.; Klerkx, L.; Kootstra, G. Current status and future challenges in implementing and upscaling vertical farming systems. *Nat. Food* **2021**, *2*, 944–956. [CrossRef]
27. Danquah, M.; Ouattara, B.; Quartey, P. Technology transfer and national efficiency: Does absorptive capacity matter? *Afr. Dev. Rev.* **2018**, *30*, 162–174. [CrossRef]
28. Kalantari, F.; Akhyani, N. Community acceptance studies in the field of vertical farming—A critical and systematic analysis to advance the conceptualisation of community acceptance in Kuala Lumpur. *Int. J. Urban Sustain. Dev.* **2021**, *13*, 569–584. [CrossRef]
29. Poulsen, M.N.; Neff, R.A.; Winch, P.J. The multifunctionality of urban farming: Perceived benefits for neighbourhood improvement. *Local Environ.* **2017**, *22*, 1411–1427. [CrossRef]
30. Moghayedi, A.; Awuzie, B.; Omotayo, T.; Le Jeune, K.; Massyn, M. Appraising the nexus between influencers and sustainability-oriented innovation adoption in affordable housing projects. *Sustain. Dev.* **2022**, *3*, 1–18. [CrossRef]
31. Desu, M. *Sample Size Methodology*; Elsevier: Amsterdam, The Netherlands, 2012.
32. Zhou, H.; Specht, K.; Kirby, C.K. Consumers' and Stakeholders' Acceptance of Indoor Agritecture in Shanghai (China). *Sustainability* **2022**, *14*, 2771. [CrossRef]