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Feasibility and community acceptance of modular urban farming in Singapore:

Design, prototyping, and pilot testing

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ABSTRACT

Food security is a growing global challenge, intensified by urbanization and industrialization that encroach upon valuable agricultural land. In Singapore, a city-state with limited land and heavy reliance on food imports, ensuring nutritional self-sufficiency for its 5.9 million residents is an increasingly critical concern. This study investigates community attitudes toward the implementation of urban farming structures in residential areas and explores the feasibility of integrating space-saving farming solutions, such as urban, rooftop, and vertical farming, into Singapore's urban landscape. A survey conducted among local residents revealed a 73.4% positive outlook toward the concept of community urban farms, with respondents expressing strong support for the idea of localized food production. However, the survey also highlighted a significant gap in opportunities for residents to engage actively in the operation and maintenance of urban farms. Community involvement is a critical factor that influences the long-term sustainability and scalability of urban farming projects. These findings underscore the importance of developing strategies that foster and incentivize resident participation in these initiatives to enhance their success and viability. Based on the positive survey feedback, a modular urban farming unit was conceptualized and prototyped. With a focus on adaptable design and speed of installation, the designs focus on the integration of agricultural spaces with minimal to zero modifications required for existing architectures. In particular, Housing Development Board (HDB) rooftops in Singapore, often have uneven terrain. To optimize environmental conditions for crop growth, advanced design tools such as Revit BIM for architectural modeling, IESVE for computational fluid dynamics (CFD) simulations to optimize airflow, and BIM HVAC for assessing lighting conditions were utilized to study the environmental conditions critical to crop growth. Following the successful digital prototyping phase, a physical prototype was constructed at SIT@Dover campus, in Singapore. Between March and August 2023, Kailan and Bok Choy were cultivated, averaging an annual yield of 25.6 kg/m^2. A second prototype, optimized for maximum yield per floor area, was installed at the Oasis Living Lab between September 2023 and February 2024, achieving a yield of 130.2 kg/m^2 per year. These results demonstrate the feasibility and adaptability of modular urban farming systems in high-density environments. With supportive policies and collaboration among stakeholders, the widespread adoption of such systems can be realized in the near future.

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1. Introduction

Singapore's food supply is heavily reliant on imports, with approximately 90% of its food sourced from over 170 countries, due to its limited land area and lack of arable land for large-scale agriculture.

The primary suppliers include Malaysia, the largest source of fresh produce, poultry, and seafood, benefiting from geographic proximity; Australia, which provides meat, dairy, grains, and some fruits and vegetables; China, a key supplier of fruits, vegetables, and processed foods.

Thailand and Indonesia, which contribute fruits, vegetables, seafood, and rice; and Europe and the US, offering a variety of processed foods, cereals, and specialty products like dairy, meat, and grains [1]. This dependency on imports makes Singapore vulnerable to global supply chain disruptions, price fluctuations, and geopolitical tensions. To mitigate these risks and enhance food security, Singapore has been exploring local food production strategies, including urban farming, vertical farming, and aquaculture, though these efforts currently address only a small fraction of the country's food needs.

Agriculture in Singapore faces significant challenges due to its limited land area, high population density, and urbanization. With only about 728.6 square kilometres of land, much of which is already used for infrastructure and residential purposes, there is little space for traditional farming. The high cost of land further exacerbates this issue, making agricultural ventures financially challenging.

Additionally, Singapore's tropical climate, characterized by high humidity and frequent rainfall, poses risks such as plant diseases and waterlogging, while its reliance

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on imported water adds another layer of complexity. Labor shortages, especially with restrictions on foreign workers, and the capital-intensive nature of advanced farming technologies also create barriers to scaling up local food production [2].

Urban farming holds significant potential to provide a more reliable and sustainable source of food for Singapore, offering a promising solution to enhance local food production. By leveraging space-efficient agricultural techniques, such as vertical farming, rooftop gardens, and hydroponics, food can be produced in dense urban environments [3]. These methods allow for the use of underutilized spaces, such as rooftops, vacant lots, and even indoor areas, to grow crops.

Vertical farming, in particular, is well-suited to Singapore's urban landscape of high-rise buildings, offering the possibility of growing food in stacked layers, thus making efficient use of vertical space. This can enable the integration of urban farming into the fabric of the city, particularly in areas where traditional farming is not feasible, such as in high-density residential neighbourhoods. These systems allow for the production of food within the city's urban landscape without requiring large expanses of arable land.

Urban farming can also make significant contributions to Singapore's sustainability goals by reducing the environmental footprint of food production. Techniques like hydroponics and aeroponics minimize the need for water and pesticides as compared to traditional farming. Additionally, many urban farms utilize organic waste recycling methods, such as composting, and rely on renewable energy sources, like solar power, for operation [4].

These practices align with Singapore's broader efforts to promote a circular economy, where waste is minimized, and resources are efficiently used. Urban farming could thus reduce the environmental impact of food production while promoting sustainable urban living practices.

However, methods like vertical farming, while promising for urban agriculture, face several drawbacks. It requires significant capital investment for setting up infrastructure, specialized equipment, and climate control systems, making it expensive to establish. The systems also consume high amounts of energy, particularly for artificial lighting and climate regulation, which can reduce its environmental benefits, especially in Singapore where energy costs are high.

Additionally, the technology demands a high level of expertise to operate efficiently, limiting its accessibility. Vertical farming is also more suited to high-value crops like leafy greens and herbs, with limited capacity for larger-scale production of staple foods. Operational costs remain high, and waste management can pose environmental challenges. Scaling vertical farming to meet broader food supply demands remains economically challenging due to its higher production costs compared to conventional farming. Moreover, the ability to scale such projects and make them economically viable remains uncertain, given the high operating costs associated with energy, water, and labor [5].

Beyond the technical and financial hurdles, urban farming also carries significant socio-economic implications. The adoption of urban farming technologies could contribute to local economic growth by generating new employment opportunities, fostering entrepreneurship, and promoting sustainable business practices. On a societal level, urban farming has the potential to strengthen community ties by encouraging local participation in food production, education, and sustainability initiatives.

Furthermore, it could contribute to improving public health by providing fresh, locally grown produce, which may have a positive impact on nutrition and well-being. However, the degree to which these benefits can be realized depends on the effective integration of urban farming into Singapore's social fabric and economic structure. For urban farming to thrive, it must be supported by comprehensive policy frameworks, public-private partnerships, and community engagement.

This study investigates local sentiments regarding the integration of urban agriculture within residential areas, focusing on community willingness to engage in the maintenance and labor required for such projects. A key challenge for urban farms is managing operational costs, which are often exacerbated by the need for climate control and artificial lighting systems.

These issues can be mitigated through engineering design innovations and the incorporation of renewable energy sources. For successful crop cultivation, factors such as lighting, airflow, and nutrient supply are crucial, and these elements not only affect plant health but also determine the types of crops that can be cultivated in urban farms. To optimize these parameters, this research employs computational fluid dynamics (CFD) simulations and digital twin technologies, which allow for precise modeling and testing of environmental conditions in virtual prototypes.

While digital prototyping informs design decisions, the study also emphasizes the need for physical prototypes to validate the theoretical outcomes and assess empirical crop yield. The construction of a physical prototype will enable an evaluation of the annual yield potential of the proposed urban farming systems, providing real-world insights into their feasibility and scalability.

2. Results and discussion

2.1. Public perception survey

A survey was conducted with 120 participants from various demographic backgrounds. 52.5% of the respondents are male and 47.5% are female as seen in Figure 1(a). The age groups of the respondents are summarized in Figure 1(b), showing a large representative group of working-age adults of around 83.4%. The survey questions cover topics like space accessibility, practicality, and concerns about urban farming in the community.

Out of the respondents, 70.9% are employed, 16.2% are retired and the rest are students. 59.2% of the participants are aware of urban farming in their local community, while the other 40.8% might not have come across farming in their residential areas. When asked about their perceptions on having an urban farming unit built near their homes, 73.4% of the participants were optimistic about it, 25.5% were neutral and 1% were negative about it. About 83.3% of the respondents feel that urban farming contributes to the well-being of the community. This is different from the 73.4% received for the positive perception of urban farming. This is likely due to a small portion of the respondents who have reservations about urban farming due to concerns about encroachment into shared space, maintenance, and conflicts between users. The respondents also raised concerns about waste management and the cost of produce. However, they agree that urban farming units have great potential benefits to the community.

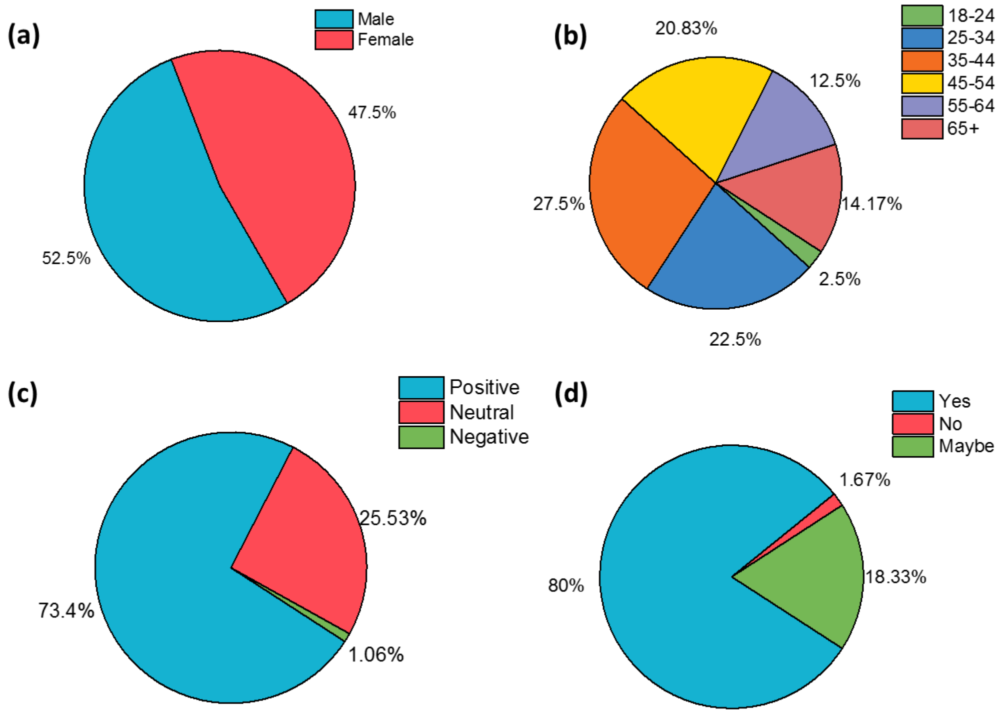


Figure 1. (a) Gender ratio of respondents (b) Age groups (c) Perceptions of urban farming spaces in the neighborhood (d) Willingness to establish more urban farming units in the community.

The respondents' perspectives on the potential social benefits of urban farming facilities in their locality are summarized in Figure 2. A significant portion of the respondents, 78.3%, believe that urban farming would improve access to fresh, locally grown produce, which is particularly relevant in the local context to reduce dependency on imported food essentials. Additionally, 79.2% of respondents perceive urban farming as a means to enhance community engagement and social interaction, a key factor in fostering community cohesiveness.

This is especially important in a rapidly urbanizing context such as Singapore, where the transition from traditional kampungs to modern urban environments has gradually eroded community spirit. Furthermore, 63.3% of respondents view urban farms as a vehicle for boosting community pride and fostering stronger bonds among neighbors. Another noteworthy finding is that 78.3% of respondents recognize the educational potential of urban farms, with the opportunity for both students and residents to learn about agriculture and sustainability. However, only 46.7% of respondents consider urban farms as a significant source of job creation and economic development.

In contrast, 64.2% of respondents acknowledge that urban farming can offer residents opportunities to remain active and healthy through volunteerism or part-time work at the farms.

These results suggest that the respondents hold generally favorable views on the social benefits associated with urban farming, particularly in terms of community engagement, education, and health.

However, the respondents' understanding of the economic implications of urban farming seems limited. While the positive perception of social interaction is evident, many respondents fail to recognize the broader economic opportunities that urban farming could present, especially in industries such as design, engineering, and technology, which are critical to the development and maintenance of these farming initiatives. There is a prevailing sentiment that community involvement would likely be voluntary or minimally compensated, reflecting a lack of confidence in the commercial viability of urban farming.

This perception, if left unaddressed, could hinder the sustainable growth of urban farming initiatives. It will also limit the future generation's involvement in the sector as they still perceive urban farmers-related traits to be less economically rewarding.

Nonetheless, urban farms could offer opportunities for supplemental income, particularly for retirees and homemakers, who may seek part-time work. Additionally, the proximity of such farms to residential areas could reduce transportation costs and carbon emissions, further enhancing the sustainability of these farming systems by addressing local nutritional needs.

In terms of prior engagement with urban farms, only 42.5% of respondents reported having visited urban farms, while 45% indicated no prior involvement. Furthermore, only 21.7% supported locally produced goods. To achieve the goal of 30% self-sufficiency in local food production by 2030, it is essential to increase consumer support for local farm products. Concerns regarding the quality and pricing of local produce need to be addressed to build consumer confidence and stimulate demand.

Furthermore, only 19.2% of respondents had participated in workshops or educational programs at urban farms, and a mere 9.2% had volunteered or worked at an urban farm. This indicates a need for greater community involvement and engagement with urban farming initiatives to facilitate their integration into local neighborhoods.

Increased community participation in activities such as harvesting could play a significant role in improving public perceptions of locally produced crops and enhancing the viability of urban farming as a long-term, sustainable practice.

In conclusion, while there is strong support for the social benefits of urban farming, particularly in terms of community engagement, education, and health, there is a need for greater emphasis on addressing economic opportunities, quality, and consumer support for local produce. Increasing community involvement and participation is crucial for ensuring the long-term success and sustainability of urban farming initiatives.

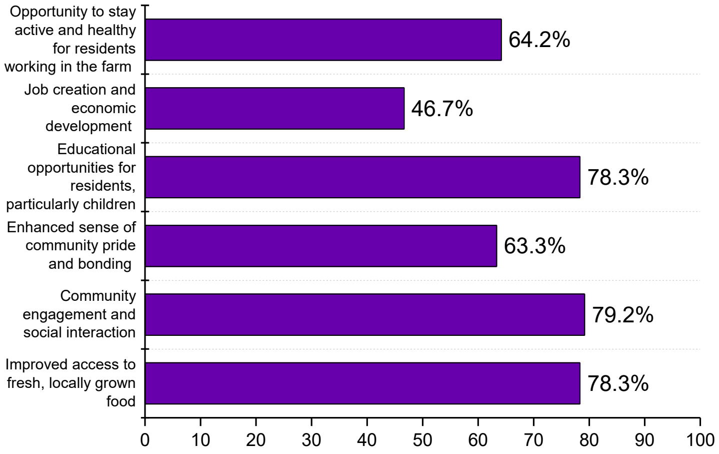


Figure 2. Degree of positivity about potential social benefits of urban farming units in the community

2.2. Digital, physical prototyping and simulations

A potential site for the first urban farming prototype (UmFm 1.0) was identified on our campus at Dover, as highlighted by the red squares in Figures 3(a) and 3(b). This location features a curved, terraced planter bed as part of the original architectural design. In response to the site's uneven terrain, a 3D model of a modular farm was developed, designed to optimize the use of available floor space for planting.

The model, which was created using Revit Building Information Modeling (BIM) software, is shown in Figures 3(c) and 3(d). This modular farm design allows for the efficient integration of farming infrastructure within the constraints of the site's topography while maximizing planting capacity. Figures 4(a), (b), and (c) present the front, side, and back views of the UmFm 1.0, respectively.

The UmFm structure consists of two storeys, with the primary planting chamber located on the second storey. The UmFm features a three-layered, tilting roof design, and is equipped with angle-adjustable louvers on the front, left, and right sides, allowing for natural ventilation control. The back side of the UmFm is enclosed with a mesh net, and two ventilation fans, powered by solar panels on the roof, are installed to facilitate air circulation within the structure.

The adjustable louvers surrounding the UmFm play a critical role in ensuring that rainwater is effectively prevented from entering the structure, while simultaneously allowing for adequate air movement to maintain optimal environmental conditions for plant growth. This design prioritizes both climate control and structural efficiency. The urban farming structure measures 6050 mm in height, 4400 mm in width, and 7800 mm in length. One key feature of this UmFm 1.0 design is that the structure is constructed from modular scaffolding material that can be assembled and dismantled in a short amount of time. Similarly, the louvers are easily attached and removed. The entire structure was built in about one month.

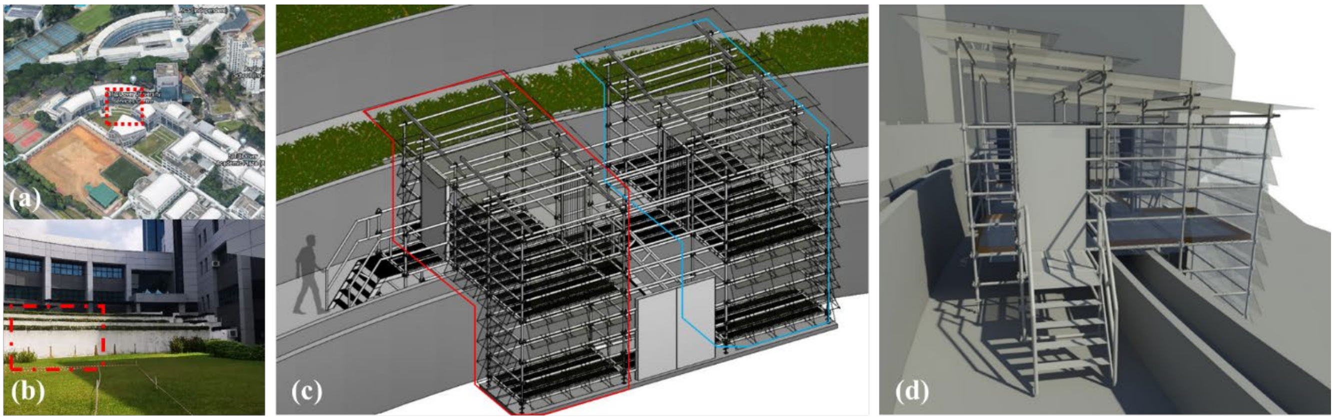


Figure 3. Architectural design of UmFm 1.0 (a) Satellite image of potential prototyping site (b) Ground floor image of the proposed site (c) 3D digital model of the prototype (d) Side view of the 3D model.

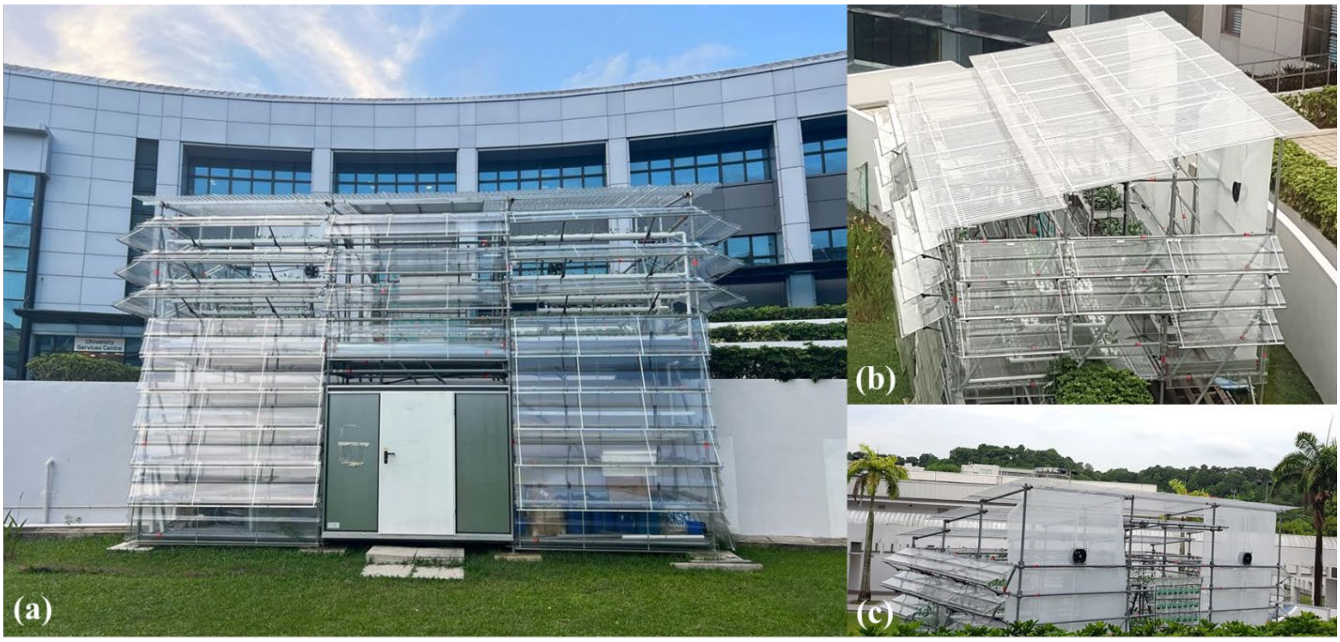


Figure 4. Actual photos of the UmFm 1.0 (a) Front view (b) Side view (c) Back view.

The use of tilt angle-adjustable louvers on both the side and front façades of the modular chamber farm unit enables some degree of airflow regulation within the system. This approach ensures a balanced airflow and, in conjunction with ventilation fans, mitigates the risk of compromised crop health due to insufficient space between planter units [6].

To optimize the airflow dynamics, the Integrated Environmental Solutions Virtual Environment (IESVE), a comprehensive suite of building performance simulation tools, was employed to model and analyze the airflow characteristics within the setup. The simulation tool was specifically employed to examine the impact of varying louvre angles on airflow distribution at the plant level.

A broader airflow simulation was conducted across the entire campus to assess wind speeds around the UmFm prototype, as illustrated in Figures 5(a) and 5(b). The wind direction in Singapore exhibits seasonal variation, with predominant winds from the north or northeast between December and early March and from the south or southeast between June and September [7]. For this simulation, conditions were configured to simulate southerly winds. Under these conditions, wind primarily enters the farm from the left side, where its interaction with the

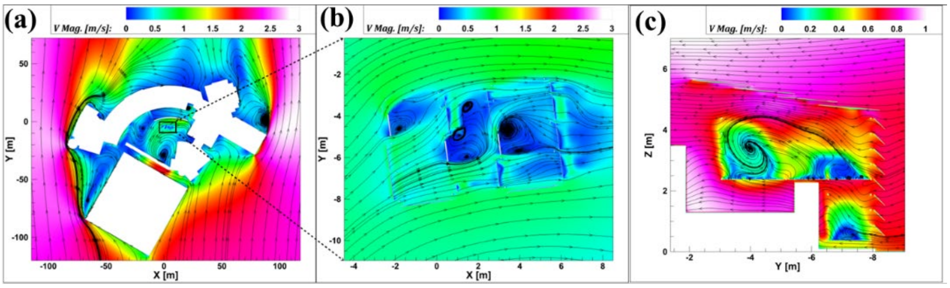
UmFm prototype and planter structures causes notable changes in both wind speed and direction.

Additionally, the simulation results revealed the formation of air voids, a consequence of recirculating airflow within the system, specifically in areas with low wind velocity, as depicted in Figure 5(c).

From the simulation data, it was determined that a louver tilt angle of 60° was optimal for minimizing dead air zones within the structure.

Figure 5(d) summarizes the average airflow velocities for three different louver angles, demonstrating the efficiency of the 60° setting in maintaining optimal airflow conditions throughout the system. The desired airflow for most leafy greens is about 0.3-0.5 m/s. Air flow and air movement are important for facilitating gas exchange between the crops and the environment.

Air movement helps to deliver carbon dioxide to the leaves while transporting away water vapor produced by evapotranspiration. Hence, air movement enhances photosynthesis, and nutrient delivery within plants and promotes growth by building up the cellular structure within the vegetative structures of leafy green especially its leaves and stems. Air movement also transports moisture away from the plant, preventing the growth of pathogens such as mold and bacteria.



(d) South Wind Scenario	AWAV magnitude [m/s]					
	Façade panels at 25°		Façade panels at 45°		Façade panels at 60°	
	LHS	RHS	LHS	RHS	LHS	RHS
Plane 1(at 1.35m height)	0.357	0.201	0.489	0.316	0.531	0.439

Figure 5. Airflow simulations using IESVE (a) Top view of global wind flow and speed of natural wind around the campus (b) Localized airflow around UmFm prototype (c) Cross-sectional view of the airflow within the second storey of the UmFm with louvers at 60° (d) Calculated Airflow within the second storey of the UmFm at the estimated plant height.

To investigate and understand the environmental conditions encountered by crops within the UmFm, simulations were conducted using ClimateStudio, an advanced software tool that enables the simulation of daylighting, electrical lighting, and conceptual thermal analysis. For these simulations, the urban farming structure was modeled with an envelope composed of clear polycarbonate, which exhibits a visible light transmission (Tvis) value of 90%.

The planters inside the structure were represented by white plastic, with a Tvis value of 0%. Due to the limitations of ClimateStudio in creating customized material properties, a material that closely approximated the actual Tvis value was selected for the simulation. All results from the simulation were expressed in lux, a unit of illuminance.

Figure 6(a) provides a top view of the 3D model, highlighting the perspective from which the simulations were conducted. The Sun's trajectory across the UmFm structure moves from right to left. The structure was divided into three distinct sections; the front, middle, and back—each containing different planter arrangements. The simulation results for light conditions at 9:00 am, 12:00 pm, and 4:00 pm are shown in Figures 6(b) through 6(d). These results revealed minimal variation in light intensity across the three sections, except at noon when sunlight is most intense and predominantly affects the front section of the UmFm.

A critical aspect of the simulations involved evaluating the light levels at crop height, as light intensity diminishes with increasing distance from the roof of the structure, and an optimal light condition is necessary for healthy crop growth [8]. Simulations specifically targeted light intensity at crop height, as depicted in Figure 6(e).

As shown in Figure 6(a), the Sun's trajectory moves from right to left over the course of the day. At 8:00 am, sunlight is relatively weak and evenly distributed across the structure. By 12:00 pm, the planters on the left side receive slightly less light than those on the right side.

However, this pattern reverses by 2:00 pm, when the right side receives less light. This shift in light distribution is primarily attributed to the shading effects from surrounding buildings, which cast shadows on the UmFm as the Sun moves from east to west throughout the day. By 6:00 pm, light intensity diminishes to approximately one-third of its noon value.

Overall, the positioning of the planters, whether in the left, middle, or right sections of the structure—had a minimal effect on the light conditions. This observation suggests that the position of the planters does not significantly influence the photosynthetic photon flux density (PPFD) or daily light integral (DLI) values for our proposed site. Such findings indicate that while shading from adjacent buildings impacts light intensity, the relative positioning of the planters within the structure does not substantially affect crop light exposure.

As a result, uniform growing conditions are maintained across the UmFm, ensuring that light distribution remains relatively consistent throughout the day.

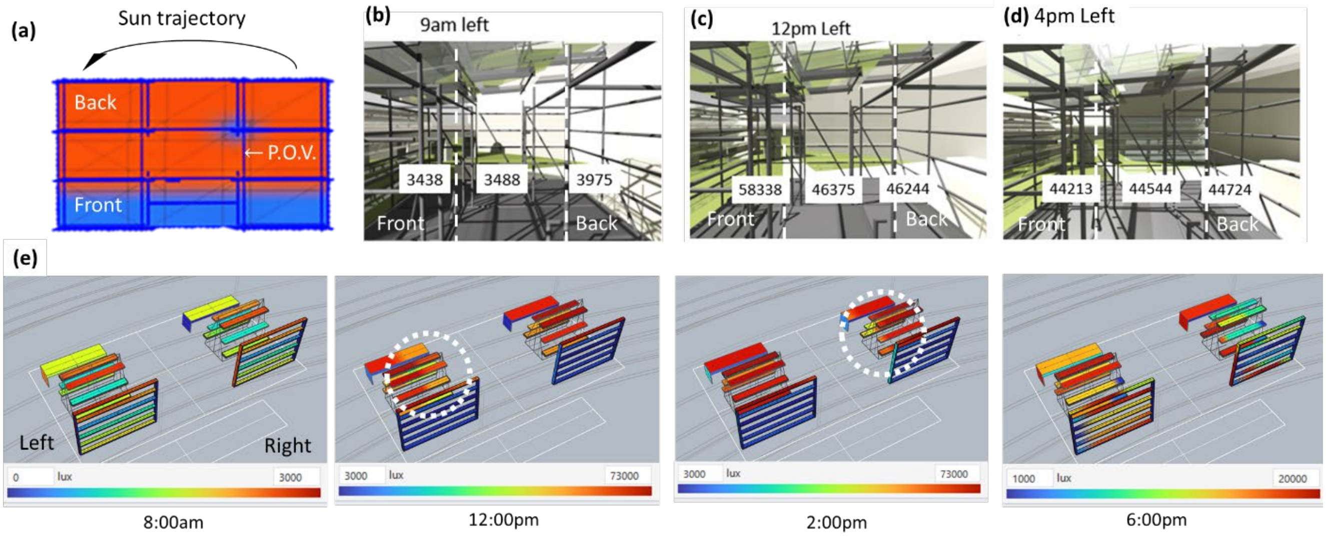


Figure 6. (a) Top view of UmFm structure (b) Simulation of the lighting conditions in each section at 9am (c) Simulation of the lighting conditions in each section at 12pm (d) Simulation of the lighting conditions in each section at 4pm (e) Simulation of lighting conditions on the furniture within the UmFm.

2.3. Harvesting yield and space-use efficiency

Three types of planters were installed in the UmFm 1.0, as illustrated in Figure 7(a). These include the A-Frame units, suspended units, and planter units, with respective capacities of 64, 108, and 138. Between March and August 2023, Kailan and Bok Choy were cultivated in monthly cycles, yielding an average of 25.6 kg/m^2 annually across the UmFm, irrespective of planter type.

The selection of these leafy greens was based on their high consumption rates in Singapore [9]. Figure 7(b) summarizes the average monthly yield of Bok Choy by planter type, indicating that the suspended unit achieved the highest yield per crop, with a mean of 81.4 ± 22.9g. This higher yield can be attributed to the increased light concentration around noon at the front of the UmFm, as simulated in Figure 6.

However, the yield of the suspended unit was not significantly greater than that of the A-Frame unit, which produced 80.0 ± 25.2g per crop but spread over a larger floor area. The planter unit, in contrast, yielded the lowest per crop at 53.5 ± 12.8g.

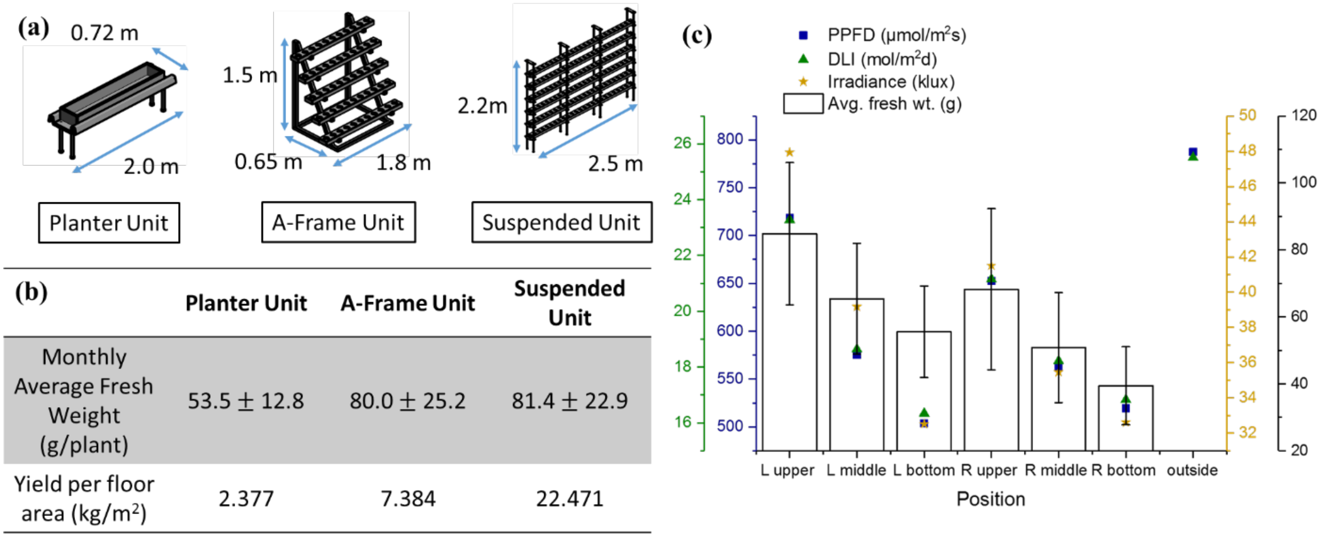
Yield per floor area is a key performance metric in assessing the efficiency and productivity of agricultural systems, particularly in controlled environments such as urban farms. This measure is essential for evaluating space utilization efficiency and comparing the productivity of various farming systems or crop varieties [10]. As shown in Figure 7(b), the suspended unit exhibits the highest yield per floor area, followed by the A-Frame unit, while the planter unit performs the least efficiently. Although the average yield of the A-Frame and suspended units are not significantly different, the A-Frame's larger surface area results in decreased space efficiency despite ensuring adequate light distribution to all crops.

Photosynthetic photon flux density (PPFD) measures the intensity of light available for photosynthesis and directly influences plant growth and energy efficiency. Daily light integral (DLI), on the other hand, represents the total light exposure over the course of a day, affecting overall crop productivity, yield, and quality by sustaining sufficient light for photosynthesis [11].

Figure 7(c) illustrates the yield variation concerning the height of the planters, with data drawn from the A-Frame planter units. Light sensors were placed at the top, middle, and bottom tiers of the planter unit to measure the light intensity received by the crops.

The results indicate a direct correlation between light intensity and harvest yield, with higher light levels leading to increased photosynthesis, more efficient energy utilization, and higher crop yields. This correlation holds for crops grown on both the left and right sides of the modular UmFm 1.0.

However, it is important to note that light intensity has an optimal range for each crop; excessive light beyond this range may lead to detrimental effects such as leaf burn or photoinhibition. Furthermore, factors such as temperature, CO_2 concentration, and water availability interact with light intensity to influence crop yield [12]. From these findings, two major conclusions can be drawn. First, the suspended unit is the most space-efficient planter, yielding the highest crop output per unit of floor area. Second, while crops planted at lower tiers in stacked planter units receive less light, the overall yield remains sufficiently high, suggesting that the benefits of its design outweigh the trade-off in light distribution.



(b)	Planter Unit	A-Frame Unit	Suspended Unit
Monthly Average Fresh Weight (g/plant)	53.5 ± 12.8	80.0 ± 25.2	81.4 ± 22.9
Yield per floor area (kg/m²)	2.377	7.384	22.471

Figure 7. (a) Schematic diagrams including the dimensions of the three types of planter units used in the UmFm 1.0 (b) Average monthly yield of leafy greens and the yield per floor area (c) Yield with respect to the amount of light received at varying heights.

2.4. Second prototype

Building on insights gained from the first prototype, a second prototype of the UmFm was constructed at the Oasis Living Lab, in collaboration with our project partner organization. Figure 8 provides an overview of the prototype's location, the 3D model, and the completed farm at the site. The development process followed the same methodology as the initial prototype, which involved site identification, the creation of a 3D digital model, and subsequent physical construction of the prototype. Utilizing the same modular materials, the UmFm 2.0 was designed and built at a larger scale than the UmFm 1.0, reflecting an expansion of both capacity and functionality. This iteration of the modular farm aims to test and optimize design features for scalability and efficiency in urban farming applications.

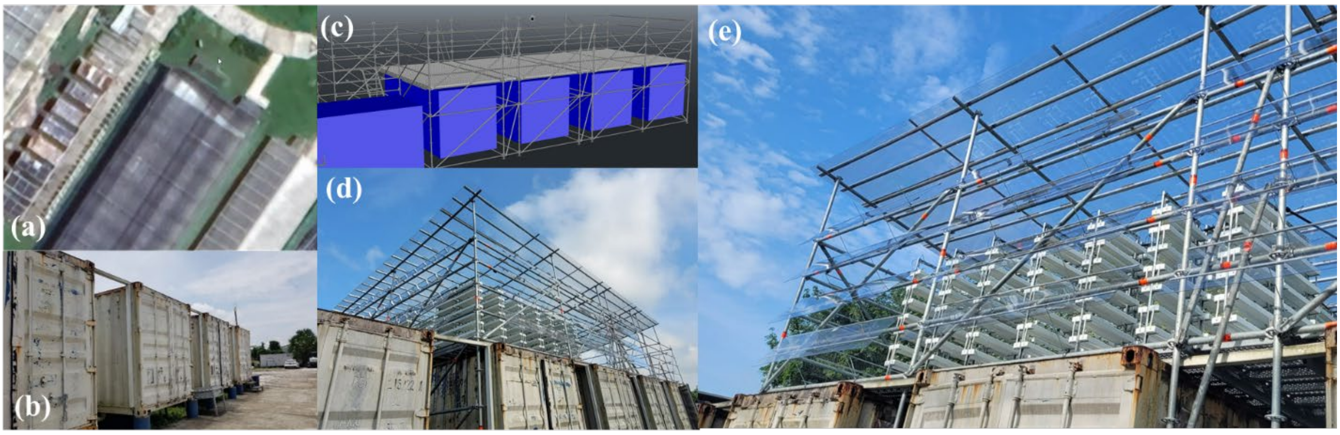


Figure 8. (a) Satellite view of the potential building site of the second prototype (b) Ground view of the containers (c) 3D model of the second prototype (d-e) Actual photos of the UmFm 2.0.

The UmFm 2.0 features a total area of 90 m^2, a substantial increase from the 34.3 m^2 of the UmFm 1.0. A simplified schematic of the UmFm 2.0, including the positions of the planters, is presented in Figure 9(a). In this iteration, the vertical planter units were installed, each consisting of seven tiers with a capacity of 196 plants per unit, with a floor area of 1.8m^2. Figure 9(b) illustrates the UmFm 2.0 with Bok Choy planted in the system. Between September 2023 and February 2024, several planting cycles of Bok Choy were carried out in the UmFm 2.0, with the corresponding yield data summarized in Figure 9(c). The histograms, differentiated by color, represent data collected from six distinct locations across the farm, revealing a consistent yield trend for each tier of the planter.

The average DLI during the growth period was measured, with the DLI at the top tier being 18.3 mol m^{-2} d^{-1} and at the bottom tier, 14.8 mol m^{-2} d^{-1}. This represents a higher DLI compared to the UmFm 1.0, primarily due to reduced shading from surrounding buildings at the new site. A key distinction between the UmFm 2.0 and the earlier version is the closer packing of the planter units, with an 80 cm spacing between planters and 15 cm spacing between each tier. Based on the data collected, the projected annual yield for UmFm 2.0 is 130.2 kg/m^2/year, reflecting a significant improvement from the UmFm 1.0. This increase in yield can be attributed to the more efficient use of available space within the larger-scale modular farm design.

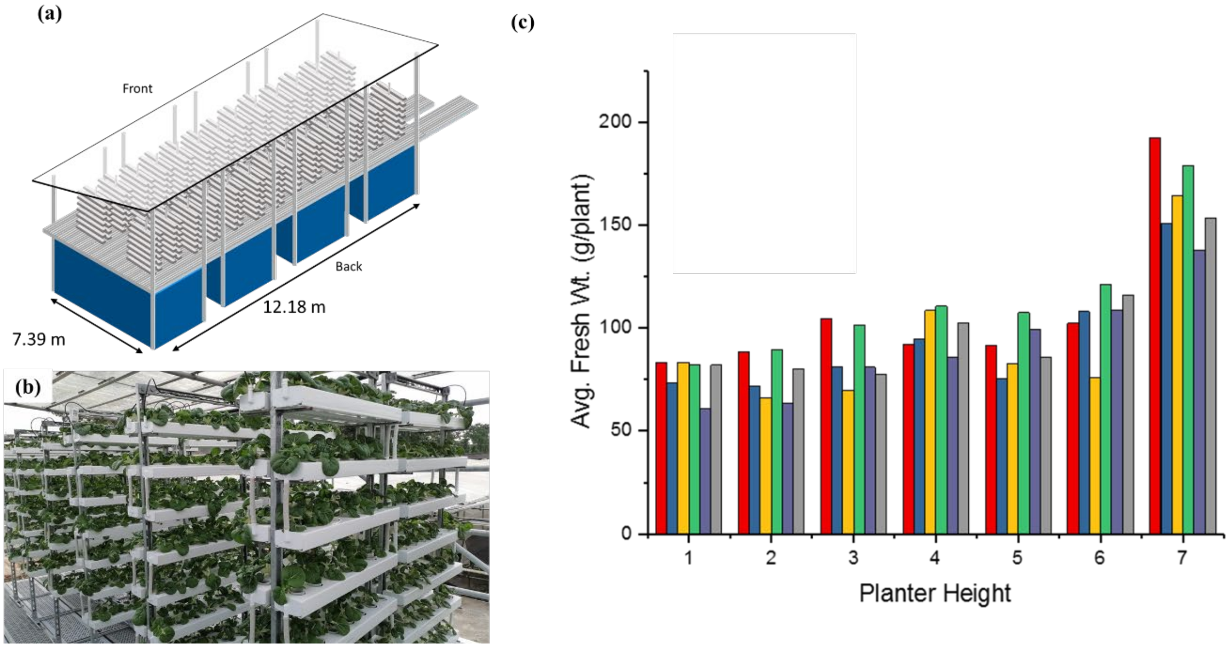


Figure 9. (a) Schematic of the UmFm 2.0 (b) Vertical planters with Bok Choy planted (c) Average yield by planter height.

3. Cost benefit analysis

In the context of Singapore, modular urban farming offers significant benefits in terms of land use efficiency, which is critical given the city-state's limited land area and high population density. By utilizing vertical farming techniques and modular systems, urban farms can maximize food production within constrained spaces, thus reducing the dependence on imported food.

This approach not only supports food security but also reduces transportation costs and associated carbon emissions. Additionally, modular systems can be customized for various crops, providing flexibility in production and enabling more targeted cultivation.

From an economic perspective, the cost of setting up such farms, comprising infrastructure, technology for environmental control (e.g., lighting, irrigation), and labor can be high. However, these initial investments can be offset by the long-term benefits of local food production, reduced reliance on imports, and the potential for year-round harvesting, which ensures a consistent supply of fresh produce.

On the cost side, while modular urban farming in Singapore requires significant capital investment in infrastructure and technology, the potential for high yields per unit of floor area can result in substantial returns on investment over time. The cost-effectiveness of these systems improves as the technology matures and operational efficiencies are realized, such as in energy use, water conservation, and labor costs.

Government incentives and support for sustainable agriculture also play a crucial role in making modular urban farming more financially viable. Furthermore, by integrating renewable energy sources and optimizing resource usage, urban farms can lower their operational costs, improving profitability. In the long run, the ability to cultivate high-value, fast-growing crops like leafy greens, herbs, and microgreens in urban settings may offer profitable avenues for local businesses while simultaneously contributing to sustainability goals.

Thus, modular urban farming presents a compelling cost-benefit opportunity for Singapore, balancing the high initial capital outlay with long-term economic and environmental advantages.

4. Conclusion

In conclusion, the development and testing of the UmFm prototypes, particularly the UmFm 1.0 and 2.0, offer valuable insights into the feasibility and potential of modular urban farming systems in Singapore's context. These systems utilize innovative design strategies, including vertical planter units, modular scaffolding materials, adjustable louvers, and solar-powered ventilation, to optimize space utilization, climate control, and energy efficiency within the constraints of limited urban spaces.

As demonstrated by the improved yields and space efficiency in UmFm 2.0, modular farming holds great promise in enhancing food security, reducing reliance on imported produce, and contributing to the sustainability goals of urban environments.

The findings from the survey of 120 participants provide a broader understanding of community perceptions regarding urban farming. A significant portion of the respondents expressed optimism about having urban farming units near their homes, with 73.4% of participants holding positive views and 83.3% acknowledging the potential for urban farming to contribute to the well-being of the community.

This highlights the social benefits of urban farming, particularly in terms of improving access to fresh produce, fostering community engagement, and promoting social interaction. These benefits are particularly relevant to a rapidly urbanizing society like Singapore, where traditional communal living is being replaced by modern urban environments, eroding some aspects of community cohesion. Urban farming initiatives provide a platform for revitalizing community bonds and enhancing public awareness about sustainable food production practices.

However, despite the strong support for the social benefits of urban farming, the economic potential of such initiatives appears to be less well understood. While 46.7% of respondents recognize urban farming’s potential for job creation, only 64.2% see it as an avenue for health promotion through volunteerism or part-time work.

There is a need to address the broader economic opportunities associated with urban farming, particularly in industries such as agriculture technology, design, engineering, and environmental management, which are integral to the success and sustainability of these systems. The limited understanding of urban farming’s economic viability may hinder its growth and integration into Singapore’s food production system.

Additionally, concerns about the cost of produce and waste management underscore the need for careful planning and support from both the government and private sector to ensure the long-term success of these initiatives.

The results of the study also highlight the importance of consumer involvement in supporting local farm products, with only 21.7% of respondents having supported locally produced goods. This suggests that consumer Behavior must be influenced to foster greater confidence in local produce and encourage the adoption of urban farming practices. Increased participation in educational programs, workshops, and volunteer opportunities at urban farms can play a crucial role in bridging this gap, allowing for a deeper understanding of urban farming's benefits and addressing misconceptions about quality and pricing.

Furthermore, the technological advancements in climate control, resource optimization, and design integration observed in both the UmFm 1.0 and 2.0 prototypes underscore the importance of continuous innovation to improve operational efficiency. By leveraging renewable energy sources, enhancing resource management, and scaling these technologies, modular urban farms can significantly reduce their operational costs and improve profitability over time.

With government support and advancements in urban farming technologies, these systems can be a sustainable solution to Singapore's food security challenges, offering local businesses and communities a viable avenue for growth while promoting environmental sustainability.

Ultimately, modular urban farming offers a promising pathway towards a more self-sufficient and sustainable food system in Singapore. By focusing on both the social and economic aspects of urban farming, addressing community concerns, and improving consumer engagement, these initiatives have the potential to contribute significantly to the nation's food security, environmental goals, and social well-being.

To achieve these objectives, however, there must be continued research, development, and public engagement to foster the widespread adoption of urban farming systems, ensuring that they can be scaled and sustained over the long term.

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