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Smart Urban Farming: A Triangulation-based Framework for the Practices Identification

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Abstract: The agriculture sector in Malaysia faces structural challenges that contribute to food insecurity due to uncertainties in farm ownership, labour shortages, low productivity, limited automation and heavy reliance on foreign labour. To address these issues, the Malaysian government promotes smart urban farming (SUF) techniques. However, the technique requires higher initial costs due to its advanced technology. Evaluating these technologies through life cycle cost (LCC) assessment is crucial for informed decision-making. However, the accuracy of LCC data remains a challenge, necessitating in-depth research to identify relevant cost components. This study emphasised the use of a triangulation method, namely a Delphi survey and a case study, to identify SUF practices concerning LCC phases. This approach is effective in achieving expert consensus in areas with limited studies. The process included multiple rounds of semi-structured interviews, starting with problem area identification and panel member selection, followed by iterative Delphi rounds to reach a consensus on SUF practices to identify LCC components and phases. Each round refined the questions based on expert feedback to reach a final consensus on critical components and practices. The case study method provided practical insights and real-world validation, enhancing the robustness of the findings. The methodology ensured a comprehensive, unbiased and expert-driven identification of LCC components, offering a robust framework for enhancing the effectiveness of SUF practices. The findings highlight the structured process involved in each method used, emphasising the importance of comprehensive and expert-driven approaches in developing sustainable and economically viable urban farming systems.

Keywords: Delphi survey, Case study, Methodology, Smart urban farming practices, Life cycle cost phases

INTRODUCTION

Urbanisation has led to a significant shift in population concentration in urban areas globally. In 2022, urban populations grew by 800,000, with an average annual growth rate of 1% (The World Bank, 2022). Asia, in particular, is expected to have 12 to 15 megacities by 2025 and by 2050, 9.7 billion people are projected to live on Earth, with one-third in cities (Al-Kodmany, 2018;

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Nafisi et al., 2020). In Malaysia, the urbanisation rate reached 75.1% in 2020, with Selangor having the highest urban population (Department of Statistics Malaysia, 2023). Consequently, urbanisation presents significant challenges worldwide, especially in developing countries. It leads to social issues such as rising crime rates, health problems and energy consumption, all due to poor access to jobs, housing and sanitation. Urban growth also worsens environmental issues like pollution and carbon dioxide emissions (Shahbaz et al., 2016). Among the many challenges caused by urbanisation, one of the most critical is the risk to food security.

As cities expand, agricultural lands are often lost to development, reducing the capacity for local food production. This leads to a reliance on imports, resulting in higher food prices and difficulties in accessing affordable, nutritious food, particularly for low-income urban populations. Cano-Hila (2020) revealed that as of 2020, 1.05 billion people globally faced moderate or severe food insecurity and hunger, seeing a 13% increase compared to 2019 (von Braun, 2023). As a result, Malaysia, like countries such as Canada, the Netherlands and Singapore, has begun to integrate urban farming (UF) to address these challenges (Akaeze and Nandwani, 2020; Tacoli, 2020). UF has emerged as a solution, offering the potential to combat food insecurity and support the achievement of Sustainable Development Goals (SDGs), particularly in creating sustainable cities and reducing poverty.

Smart urban farming (SUF) involves a larger initial investment. It is expected to deliver high-quality yields, be profitable, protect the environment, conserve resources and promote social responsibility for long-term success (Keyvanfar et al., 2020). To close gaps in the SUF sector, research on the life cycle cost (LCC) components of SUF is essential. Moreover, understanding the influence of B40 community behaviours on LCC components is critical. Given the data shortages of LCC analysis, in-depth research should be conducted to develop an LCC model concerning B40 behaviour in residential neighbourhoods. Therefore, in-depth research is necessary to identify the comprehensive LCC components in SUF. In identifying the comprehensive LCC components, the methods used for the data collection are crucial. Therefore, this paper aimed to explain in detail the triangulation-based framework for SUF practices.

LITERATURE REVIEW

Smart UF refers to the application of advanced agricultural technologies to monitor and manage crops and livestock in urban environments (Birkby, 2016). This approach leverages innovations such as automation, data analytics and Internet of Things (IoT) to enhance the efficiency, productivity and sustainability of UF (Birkby, 2016; Al-Kodmany, 2018). Smart UF aims to optimise resource use, minimise waste and improve crop yields by integrating modern techniques and systems. According to Birkby (2016), Al-Kodmany (2018), Lakhiar et al. (2018) and Khan (2019), there are four main techniques in SUF:

1. Fertigation: This technique combines fertilisation and irrigation by delivering fertilisers through the irrigation system. This method ensures precise and timely nutrient delivery to plants, promoting optimal growth conditions. The high flexibility in fertigation frequency, efficient nutrient use, reduced labour costs and improved crop yield and quality.
2. Hydroponics: This technique is a soil-less cultivation technique that uses a nutrient-rich solution to grow plants. Plant roots are either submerged in or supported by an inert medium (e.g., perlite, rock wool) and receive nutrients directly from the solution. Efficient water and nutrient use, faster plant growth, reduced risk of soil-borne diseases and suitability for indoor and vertical farming. This method is particularly effective for growing vegetables like onions, lettuce and radishes.
3. Aquaponics: This technique integrates aquaculture (fish farming) with hydroponics. Fish are raised in tanks. The nutrient-rich wastewater they produce is used to nourish plants in a hydroponic system. Plants absorb these nutrients, effectively filtering and cleaning the water before it is recirculated back to the fish tanks. This method is a sustainable and efficient use of water and nutrients, reduces waste and the production of both fish and plants in a single integrated system.
4. Aeroponics: This technique is a method of growing plants without soil or any growing medium. Plant roots are suspended in the air and misted with a nutrient-rich solution. This system provides an ideal environment for plant roots to access oxygen and nutrients simultaneously. It enhances nutrient uptake, faster growth rates, reduces water and nutrient use and allows the plants to grow in a controlled environment. This method is suitable for high-value crops and research applications.

Smart Urban Farming Practice in Malaysia

SUF is a modern approach to urban agriculture that integrates technology, automation and data-driven methods to optimise food production in urban settings (Yusoff, Hussain and Tukiman, 2017). By incorporating advanced farming techniques such as hydroponics, fertigation and automated irrigation systems, SUF maximises productivity while minimising land use, water consumption and environmental impacts (Ramaloo et al., 2018; Shariff et al., 2022). This innovative farming practice not only ensures efficient food production in densely populated areas but also contributes to sustainability by promoting waste reduction, renewable energy use and eco-friendly practices.

In Malaysia, the evolution of community farming has played a crucial role in urban food security, with programmes such as Program Semai Indah (1997), Program Bumi Hijau (2005) and Urban Community Garden Policy (DKKB) (2020) serving as key initiatives that pave the way for SUF implementation in urban areas (Kementerian Perumahan dan Kerajaan Tempatan, 2021). These initiatives have encouraged urban communities to adopt farming techniques that enhance self-sufficiency and local food production while fostering environmental stewardship. As community UF evolves, SUF projects flourish, incorporating high-tech agricultural systems to improve efficiency and crop yield. The projects in Malaysia (as shown in Table 1) demonstrate the successful adoption of these methods, particularly in community-driven initiatives. These projects illustrate the growing interest in SUF among various sectors, including education, religious institutions and emergency services, highlighting its versatility and scalability in different community settings.

Table 1. Smart UF projects in Malaysia

Location	UF System/Plant	Source
Kebun Komuniti 1 (Taman Rimba Desa Presint 9), Kebun Komuniti 2 (Presint 8), Kebun Komuniti 3 (Presint 9) and Kebun Komuniti 4 (Presint 14), Putrajaya (2017)  	Smart UF techniques: ● Hydroponic system ● Fertigation Plants: ● Vegetables ● Chili ● Rock melon Programme initiator: Program Pertanian Bandar Putrajaya	Asia (2017)

(*Continued on next page*)

Table 1. *Continued*

Location	UF System/Plant	Source
Kebun Komuniti Garden 8, Taman Perwira Gombak, Kuala Lumpur (2021) 	Smart UF techniques: Hydroponic system Plants: ● Vegetables ● Herbal plant ● Flower Programme initiator: University Community Service, Universiti Putra Malaysia	*DagangNews.com* (2022)
Balai Bomba dan Penyelamat, Temerloh, Pahang (2021) 	Smart UF techniques: ● Hydroponic system ● Fertigation Plants: Vegetables Programme initiator: Program Pertanian Bandar Kategori Kebuniti	*Sinar Harian* (2022)
Madrasah Tahfiz Raudhatul Baiduri, Bukit Changgang, Banting, Selangor (2022) 	Smart UF techniques: Fertigation Plant: Rock melon	Malik (2022)

The increasing popularity of SUF in Malaysia is attributed to its ability to provide high-quality produce, ease of implementation and technological advancements that simplify farm management. By integrating smart technology, SUF enhances urban food security, reduces reliance on imported produce and fosters economic empowerment among urban communities. However, as SUF deals with technology or techniques and is higher in initial cost, it is very important for users to investigate the effectiveness of the technology/system (Hamidon et al., 2020; Keyvanfar, 2020). The decision-making process is effectively aided by the LCC assessment, which is used to analyse economic factors. However, Haugbølle and Raffnsøe (2019) mention that the data problem of LCC continues to be a challenge. Therefore, in-depth research is necessary to identify the LCC components in SUF.

METHODOLOGY

Triangulation Approach

As there was no study in the area, the triangulation approach was used to get comprehensive results. According to Noble and Heale (2019), triangulation is particularly useful in areas with limited existing research, where relying on a single method may not provide a comprehensive understanding of the subject. By integrating various approaches, researchers could capture a more holistic view of the phenomena under study. In this study on SUF practice, the triangulation method was applied using the Delphi survey and case study approaches. To address these challenges, the Delphi method is a valuable research approach that facilitates consensus-building among experts. On the other hand, the case studies provided practical, real-world insights into the application and impacts of SUF practices. The triangulation method, combining the Delphi survey and case study approaches (as shown in Figure 1), provided a comprehensive and robust framework for identifying and analysing SUF practices and LCC components. Accordingly, the purpose of this paper was to discuss the modified Delphi survey and case study as a triangulation research approach in identifying the LCC components for SUF.

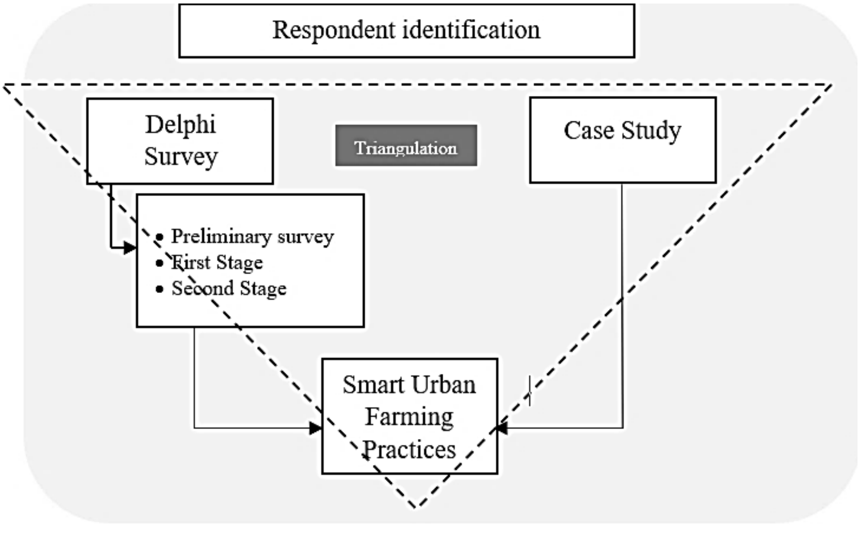

Figure 1. Sequential exploratory and explanatory

Modified Delphi Method

Background of the Delphi method

The modified Delphi method was adopted from the classical Delphi method. The word "Delphi" originated from Greece (Avagianou, 1998), named after the ancient Greek town where the temple of Apollo is located, home to the famous oracle. For thousands of years in Greek history, individuals and official ambassadors visited Delphi to seek guidance from the prophetess Pythia, who was believed to convey divine messages that shaped future events (Kim and Yeo, 2018).

The classical Delphi method was developed by Norman Dalkey at RAND Corporation in the 1950s for a US military project. The goal was to gather expert opinions on selecting optimal US industrial targets from a Soviet perspective and estimating the number of A-bombs needed to reduce munitions output (Dalkey and Helmer, 1963). According to Chan and Lee (2019), Rowe and Wright (1999) and Sourani and Sohail (2015), the classical Delphi method is characterised by four key features:

1. Anonymity: Participants express opinions freely, without social pressure to conform.
2. Iteration: Participants refine their views over several rounds.
3. Controlled feedback: Participants are informed of others' perspectives, allowing them to clarify or adjust their own.
4. Statistical aggregation: Group responses are analysed quantitatively.

The Delphi method is a structured process designed to elicit expert opinions, aiming to reach a reliable consensus among a panel of experts. It is typically conducted through a series of questionnaires over multiple rounds. Throughout the process, panel members remain anonymous and their interactions are carefully managed to ensure impartiality (Sourani and Sohail, 2015). After each round, responses are analysed and the resulting feedback helps shape the next questionnaire. This iterative process provides new information and enables panellists to revise their previous responses, encouraging reflection and adjustment based on the group's overall feedback. Rowe and Wright (1999) argue that only studies incorporating these features should be classified as Delphi studies, while others suggest that modifications can be made to meet study-specific needs (Adler and Ziglio, 1996). The perspective is further supported by Chan and Lee (2019), Kim and Yeo (2018) and Sourani and Sohail (2015), who agree that adjustments to the Delphi method can be made depending on the requirements of the research.

Position of Delphi within the qualitative or quantitative

Sourani and Sohail (2015) engaged in a debate regarding the position of the Delphi method. In this debate, Sourani summarised the arguments between researchers. First, although the Delphi method shares some similarities with traditional quantitative techniques such as questionnaire surveys, it has been predominantly viewed as a qualitative tool by several scholars, namely Feret and Marcinek (1999) and Padel and Midmore (2005). However, Delphi has the potential to generate quantitative or semi-quantitative data as well. Critcher and Gladstone (1998) argue that Delphi holds a position close to a constructionist approach, while also being capable of producing quantified results within a positivist tradition, giving it a "hybrid" status that straddles the line between qualitative and quantitative methods. Also, Mullen (2003) highlights that many criticisms of Delphi arise from a quantitative perspective, yet it is this hybrid nature that provides Delphi with certain advantages over traditional quantitative approaches. In comparison to questionnaire surveys, Delphi enables better interaction with respondents and offers deeper insights into complex problems (Mullen, 2003).

In short, although the Delphi method shares characteristics with traditional quantitative techniques like surveys, it has often been classified as a qualitative tool due to its flexibility as a hybrid method. Thus, to align with the study's objectives, certain modifications were made to the classic Delphi method based on previous research in similar areas (as shown in Table 2). These adjustments accommodated the specific needs of the research while maintaining the core principles of the Delphi method, such as anonymity, iteration, controlled feedback and statistical aggregation (Chan and Lee, 2019; Sourani and Sohail, 2015). By incorporating lessons from related studies, these changes ensured that the method remained flexible and rigorous. To make an informed decision on the research approach, six prior studies in related areas were referred to for guidance (as shown in Table 2). The method was then tailored to meet the specific needs of various research contexts and social realities. Previous studies, such as those by Chan and Lee (2019) and Kim and Yeo (2018), have shown that modifications were possible in terms of communication modes and feedback mechanisms between rounds to fit the needs of the study.

Table 2. Summary of the modified Delphi approach used in the related study area

No.	Study	Task(s) /Purpose(s)	Panellists Components	Number of Rounds	Size of Panel	Consensus/ Convergence	Analysis of Results	Pre-test /Pilot Test	Triangulation
1	Chan and Lee (2019)	Validation of sustainable building criteria using Delphi consensus	Experts on sustainable building	3	25	Mean; SD; % of agreement	Multiple regression; Mean value	None indicated	None indicated
2	Musa, Yacob and Abdullah (2019)	Delphi exploration of subjective well-being indicators for strategic urban planning	Urban planning experts and policymakers	2	20	Mean; SD	Extraction of factors	None indicated	None indicated
3	Rittirong et al. (2024)	Develop key indicators for sustainable food system	Agricultural policymakers and stakeholders	2	45	Mean; SD; Thematic coding	Descriptive and thematic analysis	Yes	Follow-up interviews
4	Yoshida and Yagi (2023)	Examine sustainability practices on farm continuity in urban agriculture	UF experts and policymakers	3	205	Mean; SD; % of agreement	Multiple regression; Factor analysis	None indicated	None indicated
5	Nie and Wang (2024)	Assess sustainability of urban agriculture in Shanghai's nine agriculture districts	Urban agriculture experts and policymakers	1	30	Analytical hierarchy process (AHP)	Mean values; Standard deviation	None indicated	Case study
6	Chen et al. (2024)	Explore the motivations of urban dwellers to engage in UF	Urban farmers and community experts	3	53	Mean values	Thematic analysis; Mean values	None indicated	None indicated

Data collection instrument

A modified Delphi method uses a pre-structured question based on a thorough literature review or initial expert interview. This approach expedites the research process and ensures content validity from the start (Altınpulluk, Kesim and Kurubacak, 2020). Despite the classical approach, some studies have successfully integrated structured or semi-structured interviews into the Delphi process. For instance, research by Brown (2018) demonstrates how interviews can be incorporated into Delphi studies to gather more valid data. Additionally, Brown (2018) and Mullen (2003) used structured and semi-structured interviews within the Delphi method found flexibility in data collection. Overall, the Delphi method's adaptability is one of its greatest strengths, allowing researchers to use a combination of approaches, including interviews and questionnaires (Smith et al., 2011). This flexibility ensures that the method can be adjusted to fit a wide range of research requirements and objectives, contributing to its widespread application in various fields.

Case Study

According to Zheng et al. (2019), a case study investigates contemporary phenomena, especially when the boundaries between the phenomenon and its context are not clearly defined. It allows for an in-depth examination of complex issues in real-world contexts, using various data collection methods such as interviews, observations, document reviews and surveys to gather comprehensive insights from multiple perspectives (as shown in Table 3). The method is particularly useful in exploring multifaceted issues like urban agriculture, where farming practices, community engagement and environmental impacts are closely interconnected. The flexibility of the case study method makes it suitable for exploring issues with limited existing research or for addressing real-world problems with practical implications, such as those seen in urban agriculture (Sroka, 2024).

Table 3. Summary of the case study approach in the related study area

No.	Study	Task(s)/Purpose(s)	Panellists Components	Data Collection Methods	Analysis of Results	Triangulation
1	Wallace et al. (2022)	Evaluate the social impact of UF on low-income communities in London	Local residents and community leaders	Document review and interviews	Content analysis; Thematic analysis	Field observations
2	Campbell (2016)	Study environmental benefits of rooftop UF in New York	Urban agriculture experts	Surveys, focus groups and interviews	Thematic analysis	Environmental data triangulation
3	Whittinghill and Sarr (2021)	Explore practices and barriers in sustainable UF in Louisville	Urban farmers and gardeners	Interview and observation	Thematic analysis; Chi-square test	None indicated
4	Zhou, Wei and Zhou (2023)	Examine UF's benefits for food security and healthy aging in Taipei	Community gardeners and urban planners	Interview and participant observation	Thematic analysis	None indicated
5	Chen et al. (2024)	Investigate urban dwellers' motivations to engage in UF in Japan	Urban farmers and residents	Interview and observation	Thematic analysis	None indicated

RESULTS AND DISCUSSION

Delphi Method

The Delphi survey stands as a systematic and effective approach to forecasting, relying on the collective wisdom of a panel of experts. This structured method, known as the Delphi methodology, has acquired extensive consensus by collecting the thoughts and insights of the experts across various fields, including agriculture (Humphrey-Murto and De Wit, 2019) (as shown in Figure 2)

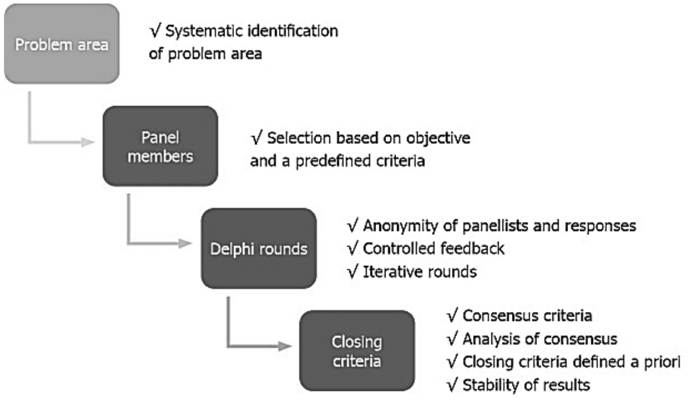

Figure 2. Stepwise quality assessment of Delphi studies

Source: Nasa, Jain and Juneja (2021)

Problem area

The Delphi study is useful in situations with a lack of evidence, uncertain or incomplete knowledge and human expert judgment holds more value than individual opinions (Humphrey-Murto and De Wit, 2019). Nasa, Jain and Juneja (2021) utilised three steps to pinpoint the problematic areas, namely: (1) conducting a thorough systematic literature search, (2) facilitating group discussions within a defined steering group and (3) engaging in open-ended discussions among panel members.

A literature review search was employed at the beginning stage of this study to thoroughly investigate issues and challenges related to SUF (Chan and Lee, 2019). Following this, close-ended questions were developed based on these findings and distributed to five practitioners appointed as panel members for the Delphi survey (as shown in Table 4). These practitioners, who were directly involved in community farming, were asked to respond to questions regarding the identified problem areas. This step aimed to validate the issues before proceeding with the main data collection phase of the study. By involving practitioners with firsthand experience, the survey ensured that the most relevant and practical insights were captured.

Table 4. Questions on the problem area

No.	Questions	Adopted Issues and Problems
1.	Can SUF technology improve the economy?	Objective of community UF (Kementerian Perumahan dan Kerajaan Tempatan, 2020).
2.	Can SUF improve social interaction?	Objective of community UF (Kementerian Perumahan dan Kerajaan Tempatan, 2020).
3.	Can SUF improve environmental conservation?	Objective of community UF (Kementerian Perumahan dan Kerajaan Tempatan, 2020).
4.	Can SUF generate a family economy?	Objective of community UF (Kementerian Perumahan dan Kerajaan Tempatan, 2020).
5.	Is it important to know the costs involved in the phases before buying SUF technology?	Smart UF has a larger initial investment, it must provide sufficient yields of good quality (Keyvanfar et al., 2020).
6.	Smart UF technology (e.g., fertigation, hydroponics, aquaponics) involves high investment at the initial stage but can produce good and quality crops.	Techniques can produce high-quality crops while having a low environmental impact due to the control of technology in a limited space but require a higher initial cost (Hamidon et al., 2020; Keyvanfar, 2020).
7.	Are there guidelines that list the practices of urban agriculture starting from the planning stage up to the marketing of the product?	The data problem of LCC continues to be a challenge (Haugbølle and Raffnsøe, 2019).
8.	Knowledge and skills in SUF management are important before starting a project.	Knowledge of UF practices is crucial (Dorr et al., 2017; Hashim, Hussain and Ismail, 2018; Zainal and Hamzah, 2018; Hamidon et al., 2020).
9.	Starting a smart urban agriculture project without adequate information, guidance and skills is a major factor in the failure of a project.	Life cycle cost is crucial to avoid false decision-making that affects the operation and production of the smart UF (Dorr et al., 2017; Hashim, Hussain and Ismail, 2018; Hamidon et al., 2020).
10.	The failure of an SUF project will result in high losses.	Wise decisions shall be made in choosing the best techniques of smart UF (Dorr et al., 2017; Hamidon et al., 2020).

Panel Member

In this phase, a total of 20 panellists were selected based on specific criteria such as. They were practitioners, policymakers and academicians. In terms of the number of respondents, hence, a Delphi study is not standardised and can vary widely. This variability enables the consensus-building process.

Purposive sampling, also known as selective sampling, is a non-probability sampling technique. According to Sourani and Sohail (2015), a total of 8 to 10 members was an accepted minimum for Delphi panels. The flexibility in panel size allows researchers to adapt the Delphi method to the specific needs and scope of their study (as shown in Table 2). The technique was adopted in this research to deliberately choose panellists based on specific criteria relevant to the research objectives to make sure only experts were selected for the survey. As a result, a panel of 20 experts with experience in SUF or involvement in policymaking related to SUF were carefully selected throughout Malaysia to serve as the study respondents. These experts represented a diverse range of sectors, including practitioners, academicians and policymakers. In short, the selection of participants in this study was not random; instead, it was purposefully made to meet the research goals and obtain specific information.

The inclusion of individuals from different fields ensured a comprehensive perspective on the topic. Each individual had unique insights and expertise, contributing to a more holistic understanding of the subject matter as follows:

1. Practitioners, with their hands-on experience, bring practical insights into the real-world challenges and opportunities in implementing SUF practices. Their input ensures that the research is grounded in the day-to-day realities of the field.
2. Academicians contribute theoretical depth and research-based perspectives, enriching the study with conceptual frameworks and the latest academic insights. Their involvement facilitates the integration of existing literature.
3. Policymakers, on the other hand, provide crucial insights into the regulatory landscape and policy implications for SUF. Understanding their perspectives is essential for aligning research findings with the regulatory framework and ensuring practical applicability.

The criteria selection of the expert was based on their experience as a SUF practitioner or policymaker (e.g. working in Pejabat Petanian) or a researcher in UF/horticulture in Malaysia. Experience is not solely measured by the number of years spent in a role but by the depth of involvement and the practical knowledge gained through specific tasks. According to Emmett (2021), workers are generally considered experienced after three to five years in their roles, during which time they are expected to independently manage complex tasks, reflecting both job progression and task complexity. In the context of community farming, the Food and Agriculture Organization stresses that experience involves not only the passage of time but also continuous participation in activities such as planting, harvesting and resource management, with a particular emphasis on sustainability and understanding of life cycles (Canton, 2021). Therefore, experience includes time, active participation and the ability to contribute effectively to a role, especially in complex or specialised environments.

As a result, for this research, the criteria for defining the experience of practitioners included those who have been actively involved in the entire cycle of farming, from planting to harvesting, ensuring they possessed a comprehensive understanding of the process. On the other hand, for policymakers and academicians, the experience criteria involved a minimum of five years of relevant experience in their respective fields, ensuring they had specialised knowledge and expertise in the research. This approach ensured participants' involvement, either through leadership or specialised knowledge in policy and academia in practical farming (as shown in Table 5). Table 6 lists the details of panellists.

Table 5. Delphi panellist criteria

No.	Category of Panellist	Criteria
1.	Practitioner	i. Minimum three years of experience in community farming ii. Leader of a community farm iii. Suggested by policymakers
2.	Policymaker	Minimum five years of experience in UF division
3.	Academician	i. Minimum five years of experience as an academician ii. Involved as a researcher in SUF field

Table 6. List of panellists for Delphi survey

Code	Category of Panellist	Position and Organisation	Years of Experience
R1	Practitioner	Project leader, Kebun Komuniti	4
R2	Practitioner	Project leader, Kebun Komuniti	4
R3	Practitioner	Project leader, Kebun Komuniti	4
R4	Practitioner	Project leader, Kebun Komuniti	4
R5	Practitioner	Project leader, Kebun Komuniti	4

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Table 6. *Continued*

Code	Category of Panellist	Position and Organisation	Years of Experience
R6	Practitioner	Project leader, Kebun Komuniti	4
R7	Practitioner	Project leader, Kebun Komuniti	4
R8	Practitioner	Project leader, Kebun Komuniti	4
R9	Practitioner	Project leader, Kebun Komuniti	4
R10	Practitioner	Project leader, Kebun Komuniti	4
R11	Policymaker	Assistant agricultural officer, Department of Agriculture	6
R12	Policymaker	Assistant agricultural officer, Department of Agriculture	8
R13	Policymaker	Deputy director, Department of Agriculture	10
R14	Policymaker	Deputy director, Department of Agriculture	9
R15	Policymaker	Assistant agricultural officer, Department of Agriculture	10
R16	Academician	Senior lecturer, Universiti Teknologi MARA	17
R17	Academician	Senior lecturer, Universiti Teknologi MARA	15
R18	Academician	Senior lecturer, Universiti Teknologi MARA	20
R19	Academician	Senior lecturer, Universiti Teknologi MARA	18
R20	Academician	Senior lecturer, Infrastructure University Kuala Lumpur	13

The decision for the panellist components was based on Kolb's Experiential Learning Theory (as shown in Table 7), proposed by David Kolb in the early 1980s. The theory describes how individuals acquire knowledge through a cycle of concrete experience, reflective observation, abstract conceptualisation and active experimentation, as illustrated in Figure 3. It is based on the idea that learning is a continuous process involving the transformation of experiences (Morris, 2020).

Table 7. Kolb's Experiential Learning Theory

Learning Process in Kolb's Experiential Learning Theory	Parties Involve
1. Concrete Experience: The learning process begins with practitioners engaging in the direct implementation of SUF techniques. This involves hands-on experiences with technologies like IoT sensors, automated irrigation systems and data analytics. Policymakers may have concrete experiences in crafting and implementing policies that support SUF, while academicians/researchers actively participate in or observe real-world smart farming projects.	i. Practitioner ii. Policymaker iii. Academician/researcher
2. Reflective Observation: After implementing smart farming practices, practitioners, policymakers and researchers reflect on the outcomes. Practitioners observe crop yields, resource efficiency and technological performance. Policymakers reflect on the impact of their policies and academicians/researchers analyse data to draw insights into the effectiveness of SUF in the specific context.	i. Practitioner ii. Policymaker iii. Academician/researcher
3. Abstract Conceptualisation: In this stage, practitioners conceptualise and develop improved smart farming practices based on their reflections and experiences. Policymakers may devise advanced policies to support the evolving landscape of SUF. Academicians and researchers contribute by formulating theoretical frameworks that capture the underlying principles and patterns in successful smart farming endeavours.	i. Practitioner ii. Policymaker iii. Academician/researcher
4. Active Experimentation: Building on their conceptual understanding, stakeholders actively experiment with new strategies. Practitioners may integrate cutting-edge technologies, policymakers implement innovative policies to support experimentation and academicians/researchers test theoretical models to advance the knowledge base of SUF.	i. Practitioner ii. Policymaker iii. Academician/researcher

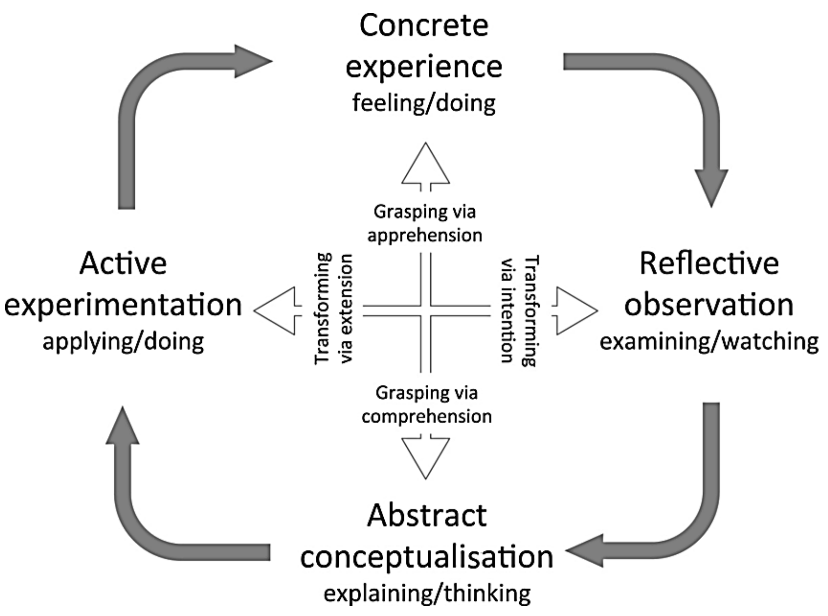

Figure 3. Kolb's Experiential Learning Theory

Source: Morris (2020)

Delphi Rounds

Generally, most Delphi studies benefit from multiple rounds to refine expert opinions and achieve stronger consensus. Chan and Lee (2019), Musa, Yacob and Abdullah (2019) and Yoshida and Yagi (2023) utilised two to three rounds to consider experts' views and improve the agreement. However, a single round can also be effective, particularly when robust methodologies like the AHP are employed (Nie and Wang, 2024). Hence, the number of rounds depends on the study's goals and methodology.

In the research, the Delphi survey was structured in two stages to comprehensively explore SUF practices and LCC phases (Rampasso et al., 2021). Prior to the survey, face validation was employed to ensure the suitability of survey questions for respondents. Taherdoost (2016) added that this type of validity assesses the overall appearance of the questionnaire in terms of its readability, style, formatting consistency and the clarity of the language used, all of which are evaluated before the test undergoes content validity checks. The Delphi survey was conducted in two rounds to address these research objectives, beginning immediately after face validation was completed.

Delphi first round: Identify smart urban farming practices and life cycle cost phase

In the first stage, a semi-structured interview was carried out with panel members through either face-to-face or online interaction, taking between 30 minutes to 60 minutes for each session. The objective was to identify the level of agreement among the listed practices, discover additional SUF practices and suggest descriptive names for each phase within the context of SUF. In the first stage, a semi-structured interview was conducted, encompassing 25 Likert scale interview questions, shown in Tables 8. Open-ended questions on additional SUF practices were highlighted according to five different phases, along with five open-ended questions on LCC phases. The questions for the second stage of the Delphi survey were finalised based on the insights gained from the first stage of interviews.

Table 8. 25 interview questions for the first round

Phase	SUF Practices		Sources of Practices
Phase 1	1.	Training and workshops	Systematic literature review
	2.	Technology and techniques	
	3.	Transportation	
	4.	Capital	
	5.	Crop area	
	6.	Available resources or facilities	
	7.	Plant type	
Phase 2	1.	Equipment selection	
	2.	Test the equipment	
	3.	Solar system	
	4.	Automation system/"sensor"	
Phase 3	1.	Fertiliser	
	2.	Water usage	
	3.	Electricity consumption	
	4.	Seeding	
	5.	Pest control	
	6.	Monitoring and inspection	
	7.	Sensor calibration	
	8.	Irrigation system maintenance	

(*Continued on next page*)

Table 8. *Continued*

Phase	SUF Practices		Sources of Practices
	9.	Pest and disease management	
	10.	Nutrient management	
Phase 4	1.	Disposal of damaged and expired equipment	
	2.	Pick the plant	
	3.	Substrate production	
Phase 5		Sell the production	

Second stage: Finalise smart urban farming practices in relation to life cycle cost phases

In the second stage, a structured interview session was conducted. Participants provided responses to Likert scale questions within a duration of 20 minutes to 30 minutes. The aim was to finalise the practices linked to SUF in relation to LCC phases and select descriptive names for each phase in the context of SUF. The second stage transitioned to a questionnaire survey, focusing on 51 Likert scale questions related to results from the first round of interview sessions, as shown in Table 9. This round aimed to finalise SUF practices and LCC phases by capturing the level of agreement among the respondents.

Table 9. 51 Likert scale interview questions in the first round

Phase	SUF Practices		Sources of Practices
Phase 1	1.	Crop area	Existing and refine
	2.	Microclimate	New
	3.	Approval from local authority	New
	4.	Estimated cost	New
	5.	Capital	Existing
	6.	Technology and techniques	Existing
	7.	Plant type	Existing
	8.	Committed community or team	New
	9.	Experienced team member	New
	10.	Training and workshops	Existing
	11.	Involvement from agency	New
	12.	Visit to the established project	New

(*Continued on next page*)

Table 9. *Continued*

Phase	SUF Practices		Sources of Practices
Phase 2	1.	Clear and prepare areas	New
	2.	Installation of utilities	New
	3.	Installation of irrigation system	New
	4.	Installation of rainwater harvesting	New
	5.	Setup the storage area	New
	6.	Installation of fencing	New
	7.	Equipment selection and installation	Existing
	8.	Automation system/"sensor"	Existing
	9.	Installation of solar system	Existing
	10.	Implementing IoT	New
	11.	Test the equipment	Existing
	12.	Training and workshops by agency	New
	13.	Knowledge exploration	New
Phase 3	1.	Planting media	New
	2.	Seeding	Existing
	3.	Planting techniques	New
	4.	Fertiliser	Existing
	5.	Water usage	Existing
	6.	Electricity consumption	Existing
	7.	Schedule monitoring and inspection	Existing/Refine
	8.	Pest and disease management	Existing
	9.	Irrigation system maintenance	Existing
	10.	Sensor calibration	Existing
	11.	Maintain cleanliness in the farming area	New
	12.	Maintain the safety in the farming area	New
	13.	Waste management of damaged equipment/material	New
	14.	Waste management of dry leaves and yard trimmings	New
	15.	Producing compost	New
	16.	Knowledge exploration	New
	17.	Workshop and training	New

(*Continued on next page*)

Table 9. *Continued*

Phase	SUF Practices		Sources of Practices
Phase 4	1.	Technique in picking plants	Existing
	2.	Grading of the product	New
	3.	Packaging technique	New
	4.	Media treatment	New
	5.	Workshop and training	New
	6.	Products from the crop	New
Phase 5	1.	Promotion	New
	2.	Sell the product	Existing
	3.	Record the production and financial status	New

Closing the criteria

To conclude the criteria, a checklist presenting SUF practices in relation to LCC phases was developed. This checklist served as a practical tool to guide and evaluate the implementation of SUF practices during the case study survey, ensuring consistency and thorough assessment throughout each LCC phase.

Case Study

A case study via semi-structured interview and observation involved systematically examining and recording specific criteria or factors related to the subject of study, in this case, UF practices. In the research, one successful SUF site was selected for evaluation, as suggested by Department of Agriculture. Finally, as a finding, comprehensive SUF practices were used to produce LCC components of SUF.

Preliminary stage

In the preliminary stage of the research, the focus was on selecting appropriate case studies for in-depth exploration. Zahro, Irham and Degaf (2021) recommend that one case study is sufficient for validation purposes. In this research, purposive sampling, also known as selective sampling, is a non-probability sampling technique where researchers purposely choose participants based on specific criteria relevant to the research objectives to make sure the best community farms were selected for the case study. Therefore, a case study was carefully selected throughout Malaysia. The case study was selected based on a few criteria (Velten, Jager and Newig, 2021).

The criteria were: (1) a project that collaborated with and was recommended by a local agency (e.g., agricultural office), (2) a project duration of at least three years, and (3) achieving the social, economic, and environmental goals (as shown in Figure 4).

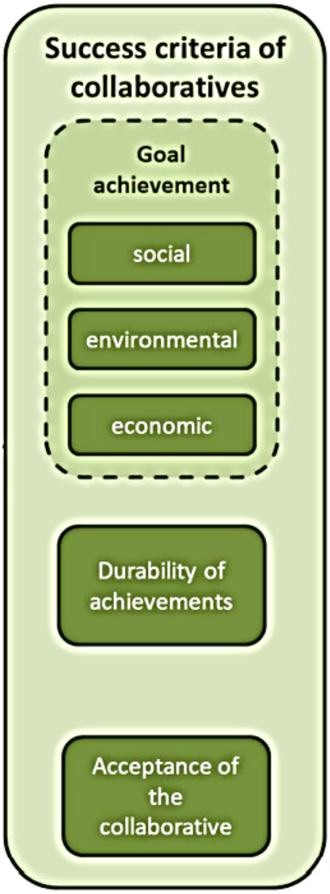

Figure 4. Success criteria of collaboratives

Source: Velten, Jager and Newig (2021)

The case study selection process was guided by specific criteria aimed at ensuring a comprehensive examination of impactful SUF at community farm projects. All three shortlisted projects, as shown in Table 10, Kebun Komuniti A, Kebun Komuniti B and Kebun Komuniti C, successfully met the criteria of collaboration with Pejabat Pertanian of having a project duration exceeding three years and achieving goals in social, economic, and environmental aspects. Particularly, Kebun Komuniti B stood out among the selected projects as it incorporated IoT technology, received various awards, involved in agrotourism, and produced valuable products from its community farm. This additional recognition highlighted its contributions and innovation within the field of SUF in residential neighbourhoods.

Table 10. Case study selection

Case Study	Criteria Selection		
	Project that Has Collaboration with Agricultural Office	Duration of the Project (More than Three Years)	Achieve the Goal (Social, Economic and Environmental)
Kebun Komuniti A	√	√	√
Kebun Komuniti B	√	√	√
Kebun Komuniti C	√	√	√

Data collection and data analysis

Interview sessions

The interview sessions were conducted face-to-face at Kebun Komuniti B, utilising semi-structured interviews lasting approximately 35 minutes. The interviewee was the leader of Kebun Komuniti B. A set of tools was used for data collection during the interview sessions. This included 41 checklist items, adopted from Delphi Round 2 and five open-ended questions related to SUF practices. First, the interviewee responded to the Likert scale questions on SUF practices, providing ratings for each listed practice. Following this, the interviewee was asked to share their opinions on the availability of existing practices at their site according to the checklist and to suggest any additional practices that might be required. Additionally, any new SUF practices mentioned by the interviewee were transcribed and contributed to the list of additional practices for consideration.

Observation

Observations were conducted at the community farm during visits to capture a realistic picture and gain a genuine understanding of the farming practices involved. However, given that many activities in the farming project spanned a long duration, it was not possible to observe all activities in a one-day visit. To overcome this limitation, the researcher utilised the official Facebook page of the community farm as an additional observation tool. Through the social media platform, the researcher was able to monitor ongoing farming practices and gather insights into how the community engaged with the community farming project over time. This approach allowed continuous observation without the need for constant physical presence, offering a more comprehensive view of the farm's activities and practices. The content was analysed using content analysis and grouped into appropriate themes for further data interpretation. The results from the case study were produced and compared with the findings from the Delphi survey results to finalise the SUF practices. This comparison ensured that the real-life observations from the case study aligned with the expert opinions gathered through the Delphi survey. This comprehensive triangulation approach strengthens the validity of the final SUF practices by incorporating triangulation and both practical insights and expert consensus to produce the LCC components for SUF.

Discussion

The Delphi method is widely recognised as a systematic approach for gathering expert opinions, particularly in fields with limited or uncertain evidence (Humphrey-Murto and De Wit, 2019). By engaging a diverse panel of experts, this method facilitates consensus-building through iterative rounds of feedback, enabling refinement of ideas and identification of critical factors. In this research, the Delphi method was applied in two stages to explore SUF practices and their LCC phases. In the first stage, semi-structured interviews with 20 panel members, including practitioners, policymakers and academicians, provided valuable insights into SUF practices and LCC components. The involvement of diverse stakeholders ensured a comprehensive understanding of the challenges and opportunities in SUF, as their unique perspectives contributed to identifying relevant practices, validating problem areas and enhancing the clarity of survey questions (Nasa, Jain and Juneja, 2021; Sourani and Sohail, 2015).

The second stage of the Delphi survey focused on finalising SUF practices and aligning them with LCC phases through a structured questionnaire. To ensure reliability, the findings were triangulated with a case study of a successful SUF project, Kebun Komuniti B, selected based on its exemplary performance in terms of social, economic and environmental goals. Observations and semi-structured interviews conducted at the site enriched the data by offering practical insights into SUF implementation. This triangulation between expert consensus and real-world practices strengthened the study's validity, ensuring that the identified SUF practices are both theoretically robust and practically applicable. The integration of Kolb's Experiential Learning Theory further enhanced the research by emphasising the iterative cycle of experience, reflection and conceptualisation, leading to actionable insights that support sustainable and scalable SUF initiatives in Malaysia (Morris, 2020; Velten, Jager and Newig, 2021).

CONCLUSIONS

In conclusion, the method of data collection is crucial in any research as it directly influences the quality, reliability and validity of the findings. In the context of this study on SUF practices in relation to LCC phases, the Delphi method and case studies played pivotal roles in ensuring comprehensive and robust results. The Delphi method is particularly effective in areas with limited existing research, where expert judgment is more valuable than statistical data. By using a structured process, the Delphi method helps in building a consensus among experts without the influence of dominant individuals. This method allows for refining and validating the research questions and responses through multiple rounds, ensuring that the final consensus is well-considered and robust. In this study, the Delphi method enabled the collection of diverse expert opinions on SUF practices, which were crucial for developing a comprehensive framework.

On the other hand, case studies offer in-depth insights into real-world applications and the practical impacts of SUF practices. By examining successful SUF projects, case studies validate theoretical findings and provide contextual understanding. They help in identifying best practices, potential challenges and practical solutions that might not be apparent through theoretical analysis alone. In this research, case studies of successful SUF projects highlighted practical applications of advanced farming techniques and their impacts on efficiency, sustainability and economic viability, thereby enriching the overall findings.

The integration of Delphi and case studies ensured a comprehensive approach to data collection. Each method provided complementary insights. The Delphi method established expert consensus, while case studies validated these insights in real-world contexts. This triangulation of methods strengthened the validity of the findings and ensured that the research captured a holistic view of the challenges and opportunities in SUF. This comprehensive approach ensured that the findings were well-rounded, reliable and applicable in real-world scenarios. Future research should continue to leverage multiple data collection methods to enhance the depth, breadth and validity of their findings, particularly in complex and evolving fields like SUF.

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