Modified Fuzzy Delphi Method to Select Decision Variables for Vertical Farming in Thailand

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ABSTRACT

The purpose of this paper was to identify the decision variables involved in innovative construction and product development. Exploratory research investigated the opinions of 11 experts of 3 different paradigms and found that the vertical farming concept could be adopted innovatively and systematically by linking the variables and sub variables that were identified. This research also modified the Fuzzy Delphi Method to collect and find consensus among the 19 experts in 3 different but related paradigms, and to overcome the fuzziness inherent in the 15 key variables and 52 sub variables investigated. The evaluation and screening of variables revealed that the seven most important key variables were food quality, plant surviving factors, plant selection, planting method, cost/benefit, food accessibility, and energy and environment management. These significant factors were useful in decision making with regard to new product and construction development.

Keywords: vertical farming, urban agriculture, soilless culture, decision variable, Fuzzy Delphi Method

บทคัดย่อ

วัตถุประสงค์ของงานวิจัยนี้เพื่อระบุตัวแปรที่สำคัญของนวัตกรรมด้านการพัฒนางานก่อสร้างและการพัฒนาผลิตภัณฑ์ใหม่โดยทำวิจัยเชิงสำรวจความคิดเห็นของผู้เชี่ยวชาญใน 3 กระบวนทัศน์จำนวน 11 คนพบว่าแนวคิด Vertical Farming สามารถทำได้อย่างมีนวัตกรรมและเป็นระบบโดยการเชื่อมโยงตัวแปรหลักและตัวแปรรองที่ได้สำรวจพบ การวิจัยนี้ยังได้นำวิธีการฟัซซี่เดลฟาย (Fuzzy Delphi Method - FDM) มาใช้เพื่อรวบรวมและสรุปความคิดเห็นส่วนใหญ่ของกลุ่มผู้เชี่ยวชาญจำนวน 19 คนใน 3 กระบวนทัศน์และเพื่อลดความสับสนของตัวแปรหลัก 15 ตัวแปรและตัวแปรรอง 52 ตัวแปรที่ได้พบจากการสำรวจในขั้นแรก การประเมินและกลั่นกรองตัวแปร พบว่าตัวแปรหลักที่สำคัญที่สุดมี 7 ตัวแปร ได้แก่ คุณภาพของอาหาร ปัจจัยในการดำรงชีวิตของพืช การเลือกพืชพรรณ วิธีการปลูก ความคุ้มค่า การเข้าถึงอาหาร และการบริหารการใช้พลังงานและสิ่งแวดล้อมซึ่งตัวแปรเหล่านี้เป็นปัจจัยที่สำคัญต่อ

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การตัดสินใจในการพัฒนางานก่อสร้างและผลิตภัณฑ์ใหม่สำหรับนวัตกรรม Vertical Farming ในอนาคต
คำสำคัญ: เกษตรกรรมในแนวตั้ง เกษตรกรรมในเมือง การปลูกพืชไร้ดิน ตัวแปรการตัดสินใจ ฟัซซี่เดลฟาย

INTRODUCTION

After the industrial revolution, climate change and global warming altered agricultural production in many ways (Wittwer & Strain, 1985). Like many countries, Thailand is affected by climate change, while at the same time urban expansion also is reducing the country's cultivation capabilities (Kamonpatana & Anuntavoranich, 2013a). Due to a major drought in 2010 and calamitous floods in 2011, many agricultural areas were destroyed and Thailand's paddy rice production had declined by 2 percent during 2008–2010 (ASEAN Food Security Information and Training Center, 2010). These facts suggest that the effects of climate change are likely to become worse. In 2001, Despommier introduced the vertical farming concept to reduce the ecological footprint of agriculture and to produce food and expand the agricultural area in the city (Despommier, 2010). Urban agriculture improves food sustainability (Condon, 2010) and the economic and political environment of a city (Redwood, 2009) and affects urban forms, such as planning, design, and construction (Pearson, Pearson, & Pearson, 2010). Still, the adoption of the vertical farming concept and the construction of urban agriculture is not a simple process. There are many variables to consider; for example, cultivation quantity and quality, design, and supporting technology in order to implement vertical farming.

Therefore, this study explored important variables in three different paradigms—1) urban agriculture and vertical farming, 2) science and technology, and 3) architecture and designs—in order to identify and evaluate crucial variables related to the development of new products and construction development for vertical farming.

Objectives

To verify the variables related to the construction and product development of vertical farming in Thailand.

To evaluate and screen the variables by utilizing an expert panel and the Fuzzy Delphi Method.

To propose the collection of the variables relevant to vertical farming to be used as the criteria in decision making with regard to product development and construction of vertical farming.

LITERATURE REVIEW

Variables

Key variables can be derived from related publishing to render a study framework. Variables were found in three areas: vertical farming and urban agriculture, science and technology, and architecture and design.

1) Variables in vertical farming and urban agriculture

The literature on urban agriculture in the areas of vertical farming, food security, city self-reliance, urban agriculture, and food miles was investigated.

Food security

FAO (2006) considered food security from 1967 to 1979, and defined food security as having four dimensions: sufficiency, accessibility, utilization, and stability. Isvilanonda (2009) found food poverty in Thailand in the northern and northeastern rural areas, where those living in poverty used land to grow basic and essential food such as rice for household use, but still there was not sufficient for their own consumption. Important variables in this subject are quantity, quality, and accessibility.

Urban agriculture

Urban agriculture refers to growing crops or raising livestock in the city and suburban areas

(Resource Centers on Urban Agriculture and Food Security, 2014). Urban agriculture is different from agriculture in rural areas by virtue of the mixture of the two variables of economy and ecosystem (Sharanbir & Grewal, 2011). The key variable is the ability to create food in the city for self-reliance.

Food miles

Sutheetorn (2011) explained that food miles provide an estimate of the distance which food travels from the farm to the consumer and is usually calculated as the weighted average source distance or by using the distance and the amount of food transported (Pirog, Pelt, Enshayan & Cook, 2001) to calculate the total distance. The greater the distance that is food transported, the greater the greenhouse gas emissions that will be created. Food miles are indicators of the impact of food production on the environment, society, and the economy, which affects sustainable development of the city (Smith *et al*., 2005). An important variable in this subject is the distance of food transportation from producers to consumers.

Concept of vertical farming

In 2001, Dickson Despommier, proposed the concept of the vertical farm as a means of reducing agriculture's ecological footprint, by which an intensive-production agricultural structure is built up in the city and expanded vertically (Despommier, 2010). He was concerned about the limited availability of land for urban agriculture and to solve this problem, he proposed the alternative of creating crop cultivation in buildings. If applied in Thailand, vegetables do not need to be cultivated inside the controlled atmosphere of a building as is necessary in a cold country (Sunakorn, 2010). Key variables are: economy feasibility, food security, urban agriculture, architecture, design, and technology.

2) Variables in science and soilless culture technology

Kamonpatana and Anuntavoranich (2013a) had study variables related to vertical farming and found that in the past, Thailand has embraced hydroponics technology. The general practice of hydroponics has been applied and tested to simplify or enhance the technology and to develop new knowledge of the system from the basic necessities required by plants, such as water, light, and nutrients. In a hydroponics system, the system's performance and the design of the greenhouse are related to the investment capital in terms of costs and benefits. Therefore, the variables in soilless culture technology are capital and the planting method, which depend on the soilless culture technology used (Critten, 2002). The key variables are: plant selection, factors essential to the survival of plants, cost-benefit, capital, and the planting method.

3) Variables in architecture and design

Variables in this category involved the design of the plant used in a vertical manner to achieve either building decoration or to promote a better environment surrounding the building and to reduce the impact of the building on the environment. Referring to the bioclimatic theory by Ken Yeang, in order to build the shell of the building by utilizing the local environment, it is first necessary to derive the optimum conditions for a comfortable living temperature and visibility of users within the building shell (Jahnkassim & Ip, 2006). Second, the natural resources need to be managed rationally, which preserves the environment (Jahnkassim & Ip, 2006). Sunakorn (2010) tested the performance of carbon dioxide absorption of three types of ivy on a screening wall. Blue Trumpet vine had the best performance followed by Confederate vine, and gourd. Sunakorn and Yimprayoon (2011) also conducted experiments to test the performance with regard to heat reduction of shading using tropical vines by selecting the Blue Trumpet vine. The results showed that the temperature could be reduced. Important variables in this category are plant selection, efficiency of temperature reduction, management of energy consumption, and the environmental impact.

Fuzzy Delphi method

The Delphi Method has been used in

prediction and decision making since 1963 when the concept was developed by the RAND Corporation (Dalkey, 1969; Dalkey & Helmer, 1962). Its goal is to obtain consensus by a group of experts. The disadvantages of the traditional Delphi Method are low consistency of expert opinions, the long time, and the high cost, with a tendency to force the experts to modify their individual opinions in order to reach an overall opinion. Hence, the Delphi Method has been modified and expanded by several techniques. The Fuzzy Delphi Method (FDM) was piloted by Murray, Pipino, & Gigch (1985) it combined Delphi and Fuzzy theory in order to overcome the disadvantages of the traditional Delphi Method. (Ishikawa *et al*., 1993) integrated experts' opinions by utilizing fuzzy numbers based on the concepts of cumulative frequency distribution and fuzzy integrals. Wu (2011) stated that applying the FDM will decrease the number of surveys, avoid distortion of individual expert's opinions, obtain more reasonable and proper responses from the experts, and involve a simple calculation process. The FDM eases the handling of multi-level, multi-attribute, and multi-solution decision problems. In project management, it has been applied in urban development, environmental management, and real estate (Damigos & Anyfantis, 2011; Constantino, Amato, & Pellegrino, 2009).

RESEARCH METHODOLOGY

Based upon the vertical farm concept by Despommier (2010) and the publications and research papers related to vertical farming described above, the study framework was conducted based on information from the literature on the three paradigms found in many areas. Then a system model and linkage of the key and sub variables were confirmed by interviews with 11 experts, consulting the literature, and by observation. Next, variables were evaluated by 19 experts and the more important variables were selected using the expert panel's evaluation. The research was divided into two phases:

Phase 1: Key and sub variables

Part I involved identifying the key and sub variables which are relevant to vertical farming development by conducting a literature review of available academic research and case studies in three paradigms; 1) urban agriculture and vertical farming, 2) science and technology, and 3) architecture and design.

Part II involved investigating the possibilities of vertical farming in Thailand and testing the validity of the key and sub variables at two related levels by performing semi-structured interviews with 11 Thai experts in 3 areas. Data were analyzed together to create system model and linkage of variables (Kamonpatana & Anuntavoranich, 2013a) and confirmed (Kamonpatana & Anuntavoranich, 2013b).

Phase 2: Verification and screening of variables using FDM

Part III consisted of verifying and screening the proposed key and sub variables by performing FDM with 19 experts in 3 areas.

Sampling method

Phase 1: Initial expert selection

Purposive and snowball sampling methods were used to select 11 experts who were interviewed in the 3 study paradigms. The subjects were required to have more than five years' experience and to be a recognized member of an institution. The subjects must have been working in urban agriculture, the design of plant, the science and technology of soilless culture, or environmental areas and their expertise is summarized in Table 1.

Phase 2: Further multi-level selection

Purposive and snowball sampling methods were again used to select 19 experts in the multi-levels of decision maker, scholar, and lead user in urban agriculture. The number of experts required in this phase is at least 17 to optimize between error in consensus and the panel size (Macmillan, 1971). The criteria applied, the position /occupation and work experience required are shown in Table 2.

Table 1 Phase 1 studied subjects

Group of expertise	Alias	Position/Occupation	Experience (years)	Specialist
Urban agriculture / Urban farming	A	Environmental consultant/Scholar	36	Urban agriculture, biodiversity in the urban environment
	B	Staff training programs in agriculture	15	Techniques for growing a roof top vegetable garden
Science and Technology	C	Chief of hydroponics project	30	Hydroponics technology of roof top hydroponics
	D	Consultant and engineer and patent holder of hydroponic systems	35	Hydroponic systems and greenhouse system engineering
	E	Inventor and owner of the substrate culture material	25	Substrate culture material
	F	Soilless culture system trainer	6	Soilless culture technology
	G	Product research and development (R&D) in a construction material company	6	Plant science, roof top gardens, and vertical gardens.
Designers Architecture and Landscape architecture	H	Chief of Building Technology Innovation / University professor, Scholar	30	Vertical gardens, roof top gardens, Bio facade
	I	University professor, Urban design, Urban landscape	20	Ecology
	J	Landscape architect	14	Vertical garden design
	K	Contractor of vertical gardens	20	Vertical garden technique

Table 2 Sampling of Phase 2

Group expertise	Occupation	Related Experience	No. of experts	Average experience (years)	Average age (years)
Urban Agriculture/Urban farming	Consultants, Scholars, Urban farm owners	Urban agriculture, biodiversity in the urban, green area	7	12.5	40.6
Science and Technology	Project managers, Product R&D, Scholars, Inventors	Hydroponics technology/ rooftop hydroponics	5	18.3	47.5
Group of designers. Architecture and Landscape architecture	Scholars, Landscape architects, Architects, Contractors	Vertical gardens, Roof garden, Bio facade	8	14.1	39.1

Data collection

Phase 1: Key and sub variables

1. Preparing the semi-structured questions of variables related to the decision making by conducting the literature review.

2. Confirming the reliability of the variables found by determining the centers of different data sources (data triangulation) to compare the data collected from the 11 different experts in the 3 fields at the beginning of the study.

3. Conducting in-depth interview sessions with the 11 experts. Each session was approximately 45 to 60 minutes, with semi-structured questions about variables related to decision making. The sessions were recorded and short notes were taken.

4. Performing transcriptions of the interview sessions, classifying information, and reducing irrelevant and redundant information. Data were then analyzed and summed in a formatted table.

5. Identifying secondary data from research papers and publications to verify the data received.

Phase 2: Verification and screening of variables using FDM

1. Constructing survey questionnaire and evaluating the key and sub variable factors.

2. Testing the questionnaires with three experts to check their validity and consistency by first, expert reviewing and second, pilot testing with another three experts and obtaining feedback.

3. Collecting 19 experts' evaluated values by 12 individual face-to-face interviews and 7 interviews using the telephone call method.

4. Analyzing experts' evaluated values to propose variables to be utilized in the decision making.

RESULTS

Phase 1: Key and sub variables

Part I: All 15 key variables from the in-depth interviews were confirmed by the literature reviewed. The sub-variables identified based on the interviews with experts were then reduced from 137 sub-variables to 52 variables by merging variable details described into general terms. Limitations on the investigated variables in this study were framed based on geography and the cultural contexts of Bangkok, Thailand with the expectation that they can be used in other countries with similar contexts (Kamonpatana & Anuntavoranich, 2013a). Variables were confirmed by the literature, experts, and observation (Kamonpatana & Anuntavoranich, 2013b).

Part II: Opinion related to feasibility of vertical farming

Thailand's vegetable production exceeds the consumption needs of the Thai population, but agriculture in the past has been affected due to the use of chemicals and monocultures which have affected the food safety of vegetables especially of the inexpensive kinds which often were transported from suburban areas. In addition, more recently, Thailand has been affected by weather conditions; climate change has impacted on agriculture through floods and droughts. This was highlighted in Thailand's worst recorded flood in 2011, causing widespread damage to agricultural areas and vegetation which severely disrupted supply and resulted in very high prices for vegetables. This also revealed that Bangkok did not have sufficient local access to vegetables. Recent developments in urban farming and agricultural technology in Thailand can provide supplementary food sources for the urban population, Although these developments may not be able to provide large amounts of food, vertical farming in urban areas could be especially beneficial to the poor inhabitants of cities, providing them with sufficient quality of life, generating additional income, reducing food costs, and reducing environmental problems which effect the health and mental well being of the population as a whole.

In terms of technology, hydroponics and substrate culture have great potential to increase yields, but due to the problems of appropriateness and its optimum application and its effects on the economy, society, and culture of Thailand, the application of the technology is limited currently to some leading growers in urban areas. Finding a proper technology to be used in urban areas and considering the way of life of the population must be taken seriously. However to address the increasing demand for a better quality of life and food safety and accessibility, the plants to be grown should be easy to maintain as it is difficult to find labor in the city.

Nonetheless, in terms of design, it is possible to utilize the concept. Data from the interviews revealed that it is possible to grow vegetables in buildings and it can be cost effective, but the scale of food production has to be the least concern. Urban agriculture has been initiated in Bangkok for a period of time through the creation of vegetable gardens on roofs, or roof gardens. These will help to eliminate food shortages. The cost of maintenance must be reasonable. At present, Bangkok's rules and regulations give no clear guidance regarding the environment. For example, from the carbon credit perspective, vertical farming in a building is possible. To keep the initial investment reasonable, vertical farming could be initiated within abandoned buildings and by utilizing the free space around such buildings in addition to designing whole dedicated buildings, depending on the objectives of the project. Another significant trend that supports vertical farming is the social awareness and concern for the environment, which is related to concerns about climate change and its impacts on nature in the form of natural disasters like the catastrophic flooding in 2011.

Variables were detected during the interviews that were derived from the concept of vertical farming in Bangkok, Thailand. The interviews revealed major differences in the expert's opinions with regard to several aspects such as; the outcomes of cost-benefit analysis of the system; the efficiency of the planting system and its relation to the environment (Kamonpatana & Anuntavoranich, 2013b). The suggestions from each expert were different as they were based on each individual's thoughts and the way the variables were considered. The different variables suggested by experts in this phase were analyzed using the Fuzzy Delphi Method in Phase 2.

Phase 2: Verification and screening of variables using FDM

Part III: Using the variables identified from Phase 1, this study performed the following steps in order to obtain evaluation values from the experts.

1. Questionnaire survey utilizing a scale ranging from 0 to 10, with 0 as extremely unimportant, 5 as neutral, and 10 as extremely important; The survey sought the expert's forecasts on the future, ranging from 5 to 10 years out.

2. Evaluation values were calculated using the Fuzzy Delphi Method proposed by Hsu & Yang (2000) to denote experts' triangulated fuzzy numbers for each variable with geometric means. The experts' opinions were collected and the triangular fuzzy number $\tilde{T}_A$ was created as follows:

$$\tilde{T}_A = (L_A, M_A, U_A) \qquad L_A = \min(X_{A_i})$$

$$M_A = \sqrt[n]{\prod_{i=1}^{n} X_{A_i}}$$, i denotes the i^{th} expert, i =1, 2,…, n

$$U_A = \max(X_{A_i})$$

where X_{Ai} indicates the evaluation value of the i^{th} expert for variable A, L_A indicates the lowest value of all the experts' evaluations for variable A, M_A indicates the geometric mean of all the experts' appraisal values for variable A, and U_A indicates the ceiling for all the experts' evaluation values for variable A.

3. Defuzzification of the evaluation values utilized the center-of-gravity method (Glumac, Han & Schaefer, 2011; Shen, Lin, Tzeng, 2011), where consensus of the evaluation value (D_A) denotes the clear, crisp value as:

$$D_A = \frac{L_A + M_A + U_A}{3}$$

The results are shown in Table 3. The higher the defuzzification value the more important the variable will be to the vertical farming decision making.

4. The distinguished threshold was then used for each paradigm. The arithmetic mean less the standard deviation was used as a threshold to identify important variable factors (Table 3).

5. Variables with a higher defuzzification value than the threshold value of the group indicated that these variables are important to all experts in three paradigms. Variables with a lower defuzzification value than the threshold value of the group indicated that the variables are less important to all experts in three paradigms. These less important variables were discarded.

The results of the screening process showed that the seven most important key variables were: food quality, plant surviving factors, plant selection, planting method, cost/benefit, food accessibility, and energy and environment management. (Table 4)

DISCUSSION

According to the results summarized in Tables 3 and 4, the most important key variables selected by the experts were aligned with the data from the in-depth interviews conducted in Phase 1 and were applied to formulate the development strategies that responded to most of the important needs of the different disciplines. In the next 10 years, Thailand will most likely develop vertical farming as revealed by the variables identified, regardless of the values of the original concept of vertical farming that were excluded from the screening process such as food quantity and food miles.

From Phase 1, the acquired variables were closely linked to other key and sub variables in the system. These provided an overview of the decision making criteria for the vertical farming system construction and product development to be implemented in Bangkok Thailand as follows: efficiency of plant system, cost-benefit, start-up cost, energy and environment management, planting method, market needs, plant selection, quality (especially food safety), and economic feasibility. The sub variables that were associated with the key variables were maintenance, food safety, area, and flexibility.

Consideration of product strategies to be implemented

Currently, there are not many vertical planting products nor construction development in the market. The data surveyed suggested a preference for a non-toxic planting system, preferably, a system that could serve the mid-to-low-income population, enable the development of a better quality of life, reduce the need for health care, and provide toxin-free vegetables.

Table 3 Result of consensus variable selected using the Fuzzy Delphi Method

Key Variable	Defuzzification value	Threshold	Sub Variable	Defuzzification value	Threshold
Food quantity (X 1)	6.45*	6.5	Area (X 1,1)	7.56	6.1
			Weight (X 1,2)	6.49	
			Size (X 1,3)	6*	
			Continual Production (X 1,4)	6.84	
Food quality (X 2)	7.48	6.5	Physical (X 2,1)	6.2*	6.7
			Freshness (X 2,2)	8.05	
			Food Safety (X 2,3)	7.8	
			Uniformity (X 2,4)	6.3*	
Food accessibility (X 3)	6.55	6.5	Food shortage (X 3,1)	6.28	6.3
			Household economy (X3,2)	6*	
Food miles (X 4)	5.4*	6.5	Transportation cost (X 4,1)	5.18	6.1
			Chilling cost (X 4,1)	5.1*	
City self-reliance (X 5)	5.3*	6.5	Resource for planting(X 5,1)	7.03	6.8
			Time for maintenance (X 5,2)	7.69	
			Food requirements (X 5,3)	7.44	
			Cooperation of community (X 5,4)	6.5*	
Economic feasibility (X 6)	6.3*		Reduce energy expenses (X 6,1)	5.13	4.7
			Business in vegetables, fertilizers, service, and know how (X 6,2)	4.7*	
Plant surviving factors (X 7)	7.34	6.66	Water (X 7,1)	8.65	8.3
			Light (X 7,2)	8.59	
			Weather (X 7,3)	7.7	
			Nutrient (X 7,4)	8.5	
Start-up cost (X 8)	6.6*	6.66	System cost (X 8,1)	7.62	7.5
			Structure cost (X 8,2)	7.5*	

Table 3 Result of consensus variable selected using the Fuzzy Delphi Method (continued)

Key Variable	Defuzzification value	Threshold	Sub Variable	Defuzzification value	Threshold
Efficiency (X 9)	6.6*	6.66	Durability (X 9,1)	7	6.7
			Flexibility (X 9,2)	5.5*	
			Water and nutrient system (X 9,3)	7.63	
			Plant protection (X 9,4)	6.72	
			System Control (X 9,5)	7.13	
			Area arrangement (X 9,6)	6.2*	
Cost/Benefit (X 10)	6.98	6.66	Reduce food expenses (X 10,1)	5.86	5.7
			Safe food (X 10,2)	7.74	
			Aesthetics (X 10,3)	5*	
			Activity/Hobby (X 10,4)	5.97	
			Better environment (X 10,5)	6.93	
			Maintenance cost (X 10,6)	6.62	
Planting method (X 11)	7.07	6.66	Physical (X 11,1)	7	7
			Maintenance (X 11,2)	7.59	
			User ability (X 11,3)	6.4*	
Market need (X 12)	6.3*	6.66	Customer needs (X 12,1)	7.39	5.6
			Budget (X 12,2)	6.61	
			Competitors (X 12,3)	5*	
Plant selection (X 13)	7.19	5.65	Character of plant (X 13,1)	7.24	6.3
			Endurance to environment (X 13,2)	5.7*	
			Plant value (X 13,3)	5.9*	
Efficiency to reduce heat (X 14)	4.4*	5.65	Temperature reduction in building (X 14,1)	5.1*	5.7
			Temperature reduction in environment (X 14,2)	5.89	
Energy and environment management (X15)	6.03	5.65	Rules related to environment (X 15,1)	5.1*	6.1
			Recycle/Reuse (X 15,2)	6.1	
			Disposable (X 15,3)	5.3*	
			Biodiversity (X 15,4)	5.9*	
			Environment and eco-friendly (X 15,5)	6.54	

* Values are below the threshold.

Table 4 Summary of evaluation and screening process

Vertical farming decision variables			
Defuzzification value	Key variable	Defuzzification value	Sub variable
7.48	Food quality (X 2)	8.05	Freshness (X 2,2)
		7.80	Food Safety (X 2,3)
7.34	Variables for plant survival (X 7)	8.65	Water (X 7,1)
		8.59	Light (X 7,2)
		8.50	Nutrient (X 7,4)
7.19	Plant selection (X 13)	7.24	Characteristics of plant (X 13,1)
7.07	Planting method (X 11)	7.59	Maintenance (X 11,2)
6.98	Cost/Benefit (X 10)	7.74	Safe food (X 10,2)
		6.93	Better environment (X 10,5)
		6.62	Maintenance cost (X 10,6)
		5.97	Activity/Hobby (X 10,4)
		5.86	Reduce food expenses (X 10,1)
6.55	Food accessibility (X 3)	6.28	Food shortage (X 3,1)
6.03	Energy and environment management (X 15)	6.54	Environment and eco-friendly (X 15,5)

In urban agriculture in Bangkok, rooftop vegetable gardens have been in place for quite some time. Awareness about the importance of self-reliance and responsibility for the environment has been widely acknowledged among certain groups and is gaining popularity. However, the numbers of vegetable gardens in the city which are capable of reducing food transportation costs and promoting self-reliance are still limited and the concept of vertical farming in buildings is very new to Thailand and its cost of implementation is still too high.

CONCLUSION AND RECOMMENDATIONS

This research studied vertical farming in Bangkok, Thailand by synthesizing ideas and opinions from 11 experts under 3 pertinent paradigms which had not previously been reported. The results showed that the vertical farming concept could be adopted in Bangkok in a certain manner that covered several variables that were required to succeed. The relevant variables were grouped into 15 main variables with 52 sub variables. Each variable was related to the others. These variables will be utilized in the future design of vertical farming applications in the city.

This exploratory research validated the vertical farming concept in the Thai context using evaluation by 11 experts and classified the important decision variables by 19 experts. It will also contribute to the development of new products and construction.

The screening and verification of the variables among the 19 experts confirmed that vertical farming construction and product development could offer value to users in various groups. The results of this study can be used in the formulation of decision making tools to evaluate the appropriate design criteria for vertical farming construction and products.

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