PRELIMINARY DESIGN FOR HIGH DENSITY MODULAR INDOOR FARMING SYSTEM

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ABSTRACT

The integration of sustainable agricultural practices within constrained urban environments presents an imperative challenge in addressing the growing demands for fresh produce while minimizing the environmental footprint. This study try to present preliminary design for high density modular indoor farms, which serves as a pioneering solution to urban food production. Emphasizing the principles of sustainability, efficiency, and design innovation, the research seeks to bridge the gap between conventional agriculture and urban agriculture. The research begins with desk study and site visit to existing indoor farming practices. By synthesizing the literature, it identifies the gaps and unexplored aspects of modular indoor farming. The proposed preliminary design encompasses critical facets of indoor farming, including site selection, space planning, modular unit design and related control systems. This study serves as base for the development of next modular indoor farming systems that can significantly contribute to sustainable urban agriculture, food security and environmental conservation.

Keywords: Indoor farming, modular system, urban agriculture, control environment

INTRODUCTION

As the world struggles with the challenges of population growth and climate change, a revolution in agricultural practices is imperative. High density planting emerges as a compelling response to these intertwined challenges. Their potential to enhance resource efficiency, reduce carbon emissions, and alleviate land use pressures positions them as a transformative force in food production.

Cultivation in controlled environment buildings is a concept that is increasingly explored and developed around the world (Shamshiri et al., 2018) and have advantages over traditional farming because it produces safer crops all year round due to the clean environment and it is easier to hire workers at the factory (Kim, 2010). Two elements were given particular emphasis: artificial light and spacing. Reductions in the usage of land, water, pesticides, fertilizers (Van Ginkel et al., 2017), cultivation energy, and transport energy are all advantages of plant factories (Shamshiri et al., 2018). Figure 1 shows the classification of plant production system adopted (Kozai, 2019)

Figure 1. Classification of plant production

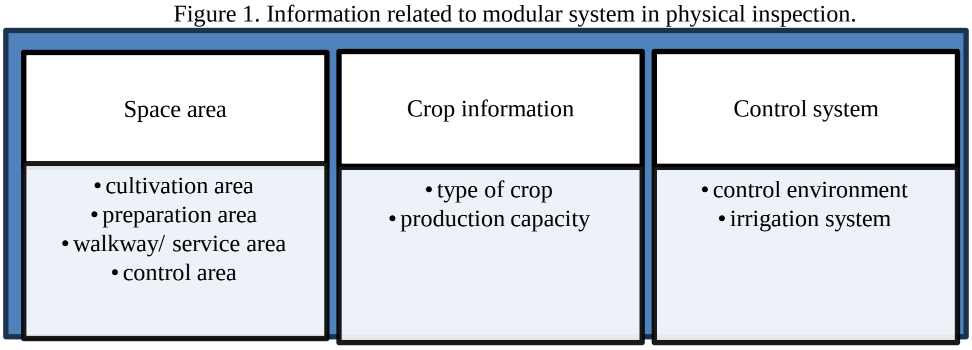
Cultivation in controlled environment building are also known as PFALs (plant factory with artificial lighting). This system is better suited for urban farming, which would mitigate desertification and deforestation while enabling our expanding urban areas to feed their citizens. Meanwhile, the commercial farming sector would create jobs in urban areas, helping to counteract the unemployment brought on by the closure of traditional rural farms (Benis & Ferrão, 2018). In recent study, there is reduction of environmental impact of fresh produce, rather than increase for container aeroponic system (Schmidt Rivera et al., 2023).

Malaysia Agricultural Research & Development Institute (MARDI) has developed three plant factory models with different designs and production scale. The first model was a warehouse design and complete with six layers vertical planting system. Another system was developed using cold storage container type and the last one is the shop house model which more appeal to the urban grower for instant. Container farms are one plant factory system that supports crop production regardless of the weather and availability of daylight. They are vertically stacked hydroponic farms that are artificially lighted (Liebman-Pelaez et al., 2021).However the system not so flexible to extent if either in the shape or by the system. In this paper it will conceptually discuss how to leverage the system to make sure the system extend further with modular system.

METHODOLOGY

Information on modular design will be based on desk study and physical inspection. Desk study approach is to collect information from company through websites which are related to indoor farming and have modular concept adaptation. Secondly, a physical inspection was conducted at an indoor farming container in MARDI Serdang. This site inspection is to get information such as space area, crop information and related control system will be evaluated and used as benchmark for the design process. Finally proposed conceptual will be presented to address objective of the study.

Figure 1. Information related to modular system in physical inspection.



RESULTS & DISCUSSION

Modular structure typically describes buildings or systems constructed in separate segments and composed of individual modules that can be customized and expanded to meet user needs. These modules are usually fabricated off-site and later assembled on-site, allowing for quicker construction, design versatility, and cost savings. The popularity of modular construction has grown across different industries, including residential and commercial buildings, industrial facilities and agricultural applications such as modular indoor farming.

Modular design approach has been used in crop production, particularly for urban agriculture with a combination of control environments. They are used in urban area particularly is because of space limitation and food demand from urban community. Authors have selected three companies as samples for this study which they already develop the system with modular concept. Mostly the company webpage or related not showing everything, perhaps to keep the sensitive information. Therefore, this desk study can only see the modular structure adaptation in general perspective.

Firstly, company named Boomgrow which originated from Malaysia, (www.boomgrowfarm.com) uses containers to grow leafy varieties in the shipping container within control environment. They believed that this concept can make it easier for people to find food by placing the container system in the middle of the community in urban areas. From our observation the system used a control environment system, led light, and special trough or box for planting system. They also used multilevel racking systems to produce higher capacity of crop. They produce leafy vegetables for the market segment. Figure 2 shows the inside view in the container farm.

Figure 2. Inside Boomgrow's container farm

The other company is Square Root (www.squarerootgrow.com), from United States which also uses a container system to do urban farming with a hydroponic system. The observation on the website shows that the wall planting method is also adopted in containers in addition to the traditional horizontal planting system. The wall planting system is rarely used instead of horizontal planting system due to popularity among the farmers. The author also assuming they used control system such as control environment system, LED lighting and fertilizer delivery system to grow the crop. Figure 3 shows the outside image of container system for Square Root. Thirdly, Green State (www.greenstate.ch) has also introduced a modular system in its product to optimize crop production. Similarly, this company also adopted the same concept system for indoor farming which included the control environment system, LED light system etc. Figure 4 shows the image of the modular system produced by this company.

Figure 3. Outside view for Square Root modular system

Figure 4. Outside view for Green State modular system.

At this point, we can see the adoption of urban farmers is more straight forward indoor farming, which is based on small scale modular system, where they can expand the scale depending on the production needs. In summary this company has adapt the modular system to suite their business model to offer their product to the customer.

The authors also conduct physical inspection of the existing indoor farming facilities to obtain data such as space dimension, materials, and systems. The indoor farming model developed by MARDI has been selected based on availability for physical survey and has a complete system for design information (Figure 5). Information for space audit is shown in Table 1.

Table 1. Space audit information

USAGE SPACE		Area (m^2)
CULTIVATION AREA		11.36
PREPARATION AREA		5.45
WALKWAY / SERVICE AREA		7.45
CONTROL AREA		3.75
	TOTAL	28.01

Figure 5. MARDI's modular unit container

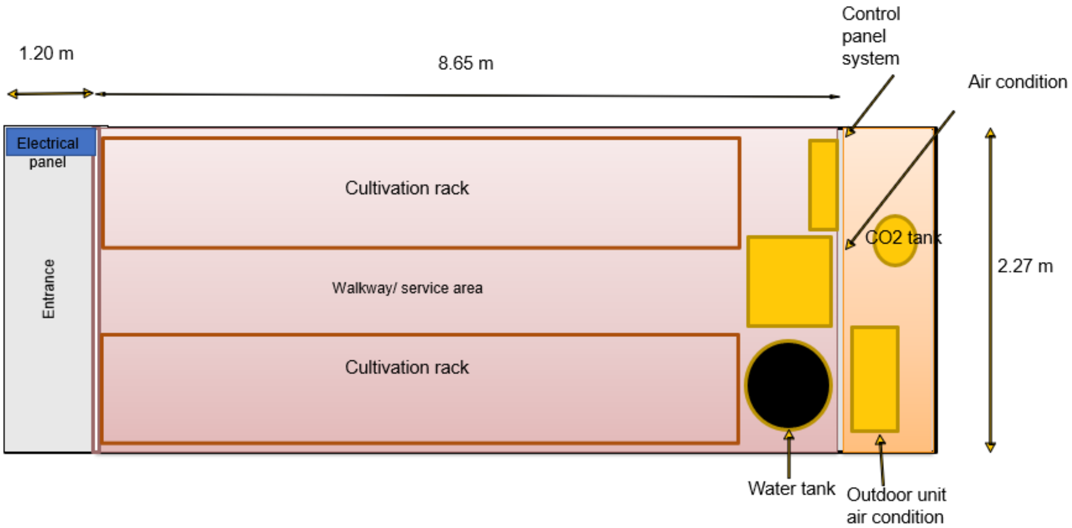


Figure 6. Layout plan for container system

Layout arrangement for container system as shown in Figure 6. Small space provides for entrance at the front of the modular and separated by aluminum doors to control the temperature inside the cultivation area. Cultivation area has two sides for crop production complete with multilevel racking system and LED lighting. At the back of the modular system is located the control panel system to control fertilizer, water tank, water pump, carbon dioxide tank, indoor and outdoor unit air condition.

From Figure 7, it shows cultivation area covers 41% of the total area, followed by walkway and service area approximately 27%, preparation area 19% and equipment area for 13%. In this case we can say the cultivation area is only half of the space. However, with the vertical cultivation system, it can produce approximately 2000 heads of leafy crop in one cycle (refer to Table 2).

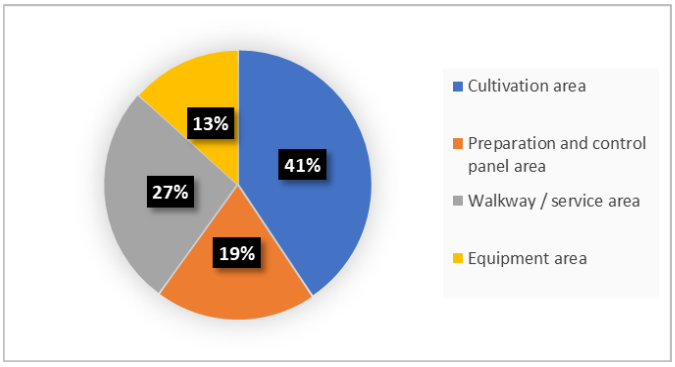


Figure 7. space utilization in the modular system

Table 2. Crop capacity for existing container systems.

ITEMS	Informations
SIZE	8.53-meter (length) x 2.35 meter (width) x 3.00 meter (height)
CROP CAPACITY	2000 numbes
CROP TYPE	Leafy vegetable

Basically, the information needed for preliminary design has been reviewed and presented as above. Therefore, from the author's perspective, shipping containers are a great idea for modular systems, but it has limitation due to fixed metal shell. Hence, the new modular system concept has been designed to adapt the needs of indoor farming so it can be more flexible and compact. The new design has been proposed as follows by incorporating segmentation of the structure and system. Authors have proposed the concept as in Figure 8. Suggested frame modular designed made from mild steel material to support load from top, side wall, and floor. Sandwich panel, which comprises polyurethane foam and metal sheet, is suitable for shell installation and has advantages for heat resistance.

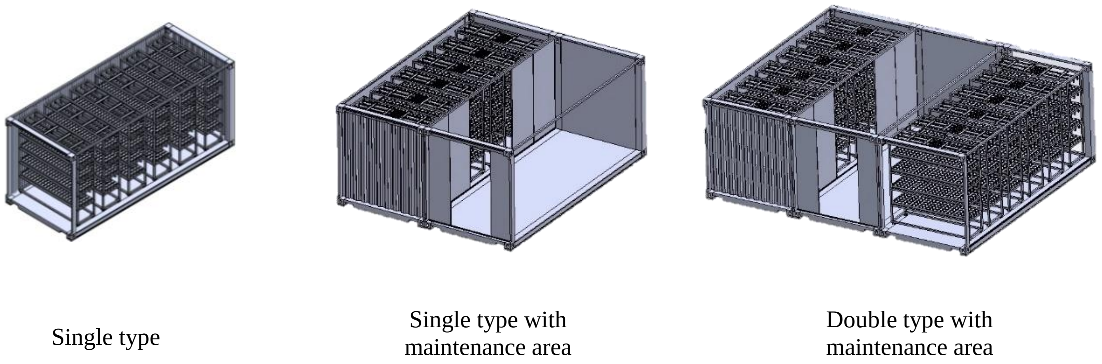


Figure 2. Shows varies conceptual combination of modular unit container system.

One unit will consist of sixes (6) modular racking system and can be added with another container to increase the production rate. The estimated production rate for leafy crops is 960 heads for one container in one cycle. Other systems such as control environment systems micro irrigation system, and sensor network can be designed accordingly as required by the user.

Conclusion

Preliminary modular structure design has been proposed accordingly for crop cultivation. It has high density crop planting to accommodate scale of needs and easy to build at designated area especially in urban area which has high population area. High density is a must to reduce space usage and produce more crops to optimize time for return of investment. Other systems also designed segmented according to the needs such as control environment system, micro irrigation system, electrical and mechanical system. In addition, this system also contributes to low carbon footprint where people can reach food within their community and reduce food transportation mileage from other areas.

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