REVIEW ARTICLE

FEASIBILITY OF GREEN COMMERCIAL VERTICAL SYSTEM FOR CLIMBING FOOD PLANT IN URBAN AREA

Muhammad Shafiq Mokhtar Baharudin[1], Rahinah Ibrahim[1*], Khalina Abdan[2] and Ali Rashidi[3]

[1]Department of Architecture, Faculty of Design and Architecture,
Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[2]Department of Biological and Agricultural Engineering, Faculty of Engineering,
Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[2]Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products,
Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[3]Discipline of Civil Engineering, School of Engineering,
Monash University Malaysia, Selangor, Malaysia

* Corresponding author:
rahinah@upm.edu.my

ABSTRACT

Urban development and overpopulation have created a serious issue towards food security in the urban area. One of the potential solutions to solve this problem is by bringing food production nearer to the cities. In the past decade, vertical farming has caught our attention as an innovative system to produce food in a high amount with little land space. However, the existing systems are only limited to a certain type of crops. The main purpose of this study is to evaluate the potential vertical farming systems for cultivating the climbing food plants using hydrophobic green material. This is a review article presenting selected literature investigating vertical farming capability, natural fiber-based hydrophobic green material, and potential manufacturing processes of hydrophobic green materials. The results include determination components on the vertical farming systems for climbing food plant, potential natural fiber based on the hydrophobic green material preparation, and potential mass manufacturing of green materials to support vertical farming concept in urban cities. This study contributes in varying crops when developing urban farming by using the future vertical farming systems.

Keywords: *Vertical farming, smart farming, natural fiber-based material, biocomposite, manufacturing process.*

1. INTRODUCTION

The total world's populace is postulated to exceed 9.15 billion people in 2050. In 2100, the United Nations gauges that it will increase to 11.2 billion people. Thus, the total population growth in urban areas is expected to reach 66% by 2050, with almost 89% of it spreading across Asia and Africa. Consequently, urban development and advancement have raised concerns over food production and processing, its transportation and utilization. However, populace and per capita consumption tend to increase faster initiating the agricultural industry to hasten its development's pace faster than ever before. Nevertheless, demanding food supply would cause extreme ecological harm. A large-scale urban farming factory plant production could offer new landscape opportunities and take some pressure off the agricultural lands. An innovative strategy, ordinarily known as vertical farming (Despommier, 2009 and 2010), has been developed and now has potential in creating sustainable urban agribusinesses. This investigation concurs with Specht (2014) who sees vertical farming as an inventive form of a smart urban where the aim is combining design, food, and production to deliver sustenance on a bigger scale in urban areas.

In typical rock melon large-scale farm in Malaysia, the farmers encounter some issues related to the climbing structure sustainability which are associated to material and structure design. There are few materials that they use for the climbing structure: raffia rope, fish netting (made up from polypropylene), bamboo stick and many more but most of them still relying on raffia rope. However, based on good agriculture practice, the raffia rope need to be removed together with the plant before new cycle starts in order to avoid unexpected diseases spread and the reducing strength of raffia rope that may break in any time. Per year 1-acre farm can plant 4000 polybags and can complete 3 to 4 cycle of rock melon plant, each cycle taking about 3 months and could produce 8000 fruits. Each cycle could use up approximately 6 roles of agriculture grade raffia role. Even though the material is a low cost, rope replacement incurs high labour. This practice eventually will cost more money for the farmers rather than looking for a sustainable solution for the climbing structure issue.

In order to build vertical farms in building-related forms for climbing food plant, the additional weight in the building may lead to the new problems. The authors foresee the implementation of water-resistant green materials biocomposites in the agricultural sector permanent climbing structure that same part as the main structural framing system. Biocomposites are recommended because it is known worldwide due to its lightweight, reliability, strength, and sustainability. The possibility to reduce the dead load would make the vertical farming concept more plausible in a confined building. Hence, this study is foreseen mass production of hydrophobic biocomposites in advancing the idea of sustainable urban agriculture besides reducing further environmental impacts.

2. URBAN FARMING AND FOOD SECURITY

In 2015, Badami et al. described that urban farming plays a significant role in food security. This study agreed with Eigenbrod et al. (2015) who points out that in order to assure food security in urban areas, the agricultural sector should move nearer towards the city development. Despite these novel suggestions, Morgan (2010) debated that adopting urban farming in the city would bring huge challenges to urban city planning, particularly in the developed countries. Herewith, this study finds an opportunity to explore this idea in developing countries. Badami et al. (2015) had also stressed that urban farming can only make a limited contribution to achieve urban food security among low-income countries only. The scholar believes that it could meet food requirements at the household level, compared to rural agriculture that can provide larger quantities and therefore has broader distribution pathways (Opitz et al., 2016). The authors agree with Badami et al. (2015) that most urban farming developments still focus on farming in conventional ways. Collectively, these studies outline a critical role in furthering developing different means of bringing food nearer to the cities where smaller land or working within confined spaces can be turned into mass agricultural production schemes.

2.1 Vertical Farming as New Practice in Cities

The introduction of a novel agricultural practice, such as indoor commercial vertical farming could improve global food security and health by assimilating various new technologically efficiency (Lu et al., 2017). Vertical farming is an innovative level of agriculture knowledge that promotes new practices, harvesting techniques, water management, crop cultivation and yielding (Jegadeesh et al., 2014). He also said that vertical farming is an emerging consideration as an innovative approach in agriculture technology and also thought as an agricultural revolution (Möller Voss, 2013). An earlier study by Despommier (2012) who had identified numerous advantages of the vertical farming system. It brings more benefits even though there are few major limitations that could jeopardize sustainable urban food production in the future. Based on existing commercial vertical farming model, such as Sky Greens in Singapore, such vertical farming system provided proof that it can radically increase vegetative plant yield per unit area by extending crop production into vertical dimension (Touliatos et al., 2016) with a very minimal usage of high technology.

Overall, there is a need to implement the vertical farming system in urban cities to make them more independent and efficient as an ultimate remedy against any risk of future food security crisis. This study found that the vertical farming implementable in an urban area. Since, it could minimize the cost and combine various technologies to produce an efficient vertical farming system to produce high number of yield even with the minimal usage of technologies. All these issues of bringing food back to the cities are creating major challenges for architects and urban planners to reduce the distance traveled by the food (Podmirseg, 2014). However, the concept of vertical farming is still novel and the opportunities can be explored further since there are not much crop varieties currently being farmed with the vertical farming system.

2.2 Limited Type of Crop in Vertical Farming

From the above, there is a little argument on the existing commercial vertical farming concept as a universal food supply component for the cities. However, one outstanding argument involves the limited types of crops that can be cultivated with the vertical farming systems for commercial purposes. Existing vertical farming is much concentrated in small footprint crops which growing time is short from planting to harvesting. According to Kalantari et al. (2017), 10 out of 10 effective vertical farming producers in the world are concentrated on leafy green vegetables, whether they are in or on the building-oriented vertical farming system. These limitations are due to the leafy greens could give a higher overall revenue as opposed to any other types of crops. Leafy greens are extremely popular as an agribusiness in urban areas, based on the demand created by restaurants and local markets that are always on the lookout for fresh locally planted greens. However, the authors believe there will be possibilities where creation of spatial intervals between the vertical farming systems will allow the cultivation of taller and climbing crops without decreasing any productivity compared to the leafy green-based vertical farming systems.

2.4 Vertical Farming Capability

According to Kamonpatana et al. (2015), in order to produce a successful vertical farming system, it is imperative to define selected components and necessary decisions. There are five components that made up a successful vertical farming system: (i) a water circulation system (ii) a sustainable energy (iii) a climate control system (v) a growth system, (iv) a lighting system (Kozai et al., 2016).

The resources fertilizer, water and energy (water circulation system, climate system, and sustainable energy system) need to be used efficiently with minimal waste. New technological exemplars, driven by innovations in sustainability, are the main factor for resource use efficiency (RUE) in closed control based systems, such as in vertical farming (Lu et al., 2017). The more well known systems in hydroponic systems, such as the deep flow technique, nutrient film technique or aeroponic systems are the essential tools in vertical farming plant factories (Son et al., 2016). On the other hand, another study believes the increasing input usage of commercial nutrients in a closed system cause less harm to the environment after some time of operation (Stewart et al., 2005). Son et al. (2016) stated that with efficient climate system the electrical conductivity (EC), pH, dissolved oxygen, humidity, and environment temperature can be controlled to ensure a better closed control system. Hence, this system eliminates the unstable whether disaster that directly affects the whole world crop production.

One of the latest example are the plant factory with artificial lighting (PFAL) that was designed and adapted for efficient production of food crops with the objective to grow food in indoor environment (Kozai et al., 2016). For the substitution of natural sunlight, artificial lighting (climate system) plays an important role in sustaining crop life especially in indoor vertical farming systems. The resource use efficiency (RUE) of closed plant production systems work best with artificial light (Kozai, 2013). Hence, this study agrees that a new form of plant production via a flexible system is recommended. Kamonpatana et al. (2015) claim that the vertical farming concept could be innovatively and systematically adopted by linking its identified components and subcomponents in a closed system.

In lieu of this, this paper recommends further exploration on the other component in vertical farming system to include provision for climbing food plants. Despite all of this components, there is another components that the researcher recommend to complement structure system as a fundamental part of designing a successful vertical farming for climbing food plant. In exploring new niche of vertical farming system, structure system plays an important role to support the new concept of vertical farming system for climbing food plant. It would like to propose hydrophobic green materials to create new possibilities in developing an alternative structural vertical farming system plants as a crucial component of creating a successful vertical farming system for climbing food.

3. HYDROPHOBIC GREEN MATERIALS FOR VERTICAL FARMING

This section elaborates on hydrophobic materials requirements. There is a lot of natural fiber available to be implemented in the new hydrophobic material recommendation. However based on a study by Ali et al. (2016) and Saba (2015), kenaf is among the top natural fiber that exert the highest tensile strength (Mpa) that can reach 1200 Mpa (bark fiber) compared to other natural fiber that remain below 1000 Mpa. Besides, kenaf is among the lowest density mean it will be resulting in lower total weight. According to Mahjoub et al., et al (2014) there are three types of kenaf/thermoset composites were tested: kenaf/epoxy, kenaf/polyester, and kenaf/vinyl ester. Among these there composites, kenaf/epoxy has higher ultimate tensile strength than kenaf/polyester and kenaf/vinyl ester composite when total fiber content is 40%. Thermoset resins have a unique combination of properties such as high modulus, excellent chemicals, low shrinkage, heat resistance and relatively high strength that are suitable for applications in harsh farming environment (Alamri et al., 2012).

Water absorbency is one of the most important aspects in determining the mechanical properties and strength of natural fiber-based biocomposites. Therefore, a proposal for new material is recommended to be resistant to water and able to bear with a higher amount of structural and live loads. In view of using the proposed biocomposite for agricultural structures, it is crucial to understand their hydrology and absorbency properties due to their innate biological characteristics.

Table 1: Comparison of natural fibers mechanical properties (Ali et al., 2016)

Plant fibers	Tensile strength (MPa)	Young modulus (GPa)	Specific modulus (GPa)	Tenacity (MN/m²)	Density (g/cm³)	Moisture regain (%)
Cotton	400–700	6–10	4–6.5	–	1.55	8.5
Kapok	93.2	4	12.9	–	0.45	10.9
Bamboo	571	27	18	–	1.52	–
Flax	510–910	50–70	34–48	–	1.45	12
Hemp	300–760	30–60	20–41	–	1.43	12
Jute	200–460	20–55	14–39	440–553	1.34	12
Kenaf	300–1200	22–60	–	–	1.30	17
Ramie	915	23	15	–	1.55	8.5
Abaca	14	41	–	–	1.52	14
Banana	530	27–32	20–24	529–754	1.35	–
Pine apple	414	60–82	42–57	413–162	1.44	–
Sisal	100–800	9–22	6–15	568–640	1.45	11
Coir	100–200	6	5.2	131–175	1.15	13

A unique critical awareness is performances of these composites may deteriorate when the materials are exposed to the adverse environments for a long period of time (Rashdi et al., 2010). In his study, he has tested and found that water absorption does affect the tensile strength directly. The specimen of his study was immersed in distilled water for four months to study the effect of water absorption towards the tensile and flexural strength. According to their studies, the higher amount of water it absorbs, the weaker the tensile strength becomes. Additionally, water absorption can be include water uptake attributed to the presence of natural fibers which contain cellulose, hemicellulose and lignin (Anuar H et al., 2011). Rashdi et al. (2010) showed a great loss in the mechanical properties of humid samples, compared to the dry samples. The water absorption behaviour of composites was found to follow the Fickian behaviour (Osman et al., 2013). The law of Fickin behaviour is defined as the higher the percentage of natural fiber, the higher the water is absorbed.

Until recently, there has been no reliable confirmation that natural fiber-based biocomposites could really survive the normal harsh and humid agriculture environment. Most of the studies in hydrology and absorbency properties have only been carried out in research laboratory areas or tested in small scales. However, laboratory data by Rashdi et al. (2010) highlighted that the overall amount of moisture absorbed from natural weather simulations was too low compared to the samples that totally immersed in distilled water. Their study found that the strength of bond between fibers and matrix has influenced the water absorption of fibers due to micro gap in between the fibers and its matrix. The authors are recommending further investigation on the exact nature of the resin-water interaction. Their results are expected to lead towards the setting up of a standard production procedure of natural fiber-based biocomposite techniques for producing highly durable composites that could support the development of vertical farming structural framing system.

3.1 Pre-Treated Process of Green Materials

Pre-treatment of biocomposite preparation has been explored and found to influence its mechanical properties in several studies. One of the commonly used is Sodium Hydroxide (NaOH) pre-treated process that improve physical bonding and chemical bonding. Firstly, it is the physical bonding could improve rough surface of kenaf fibers resulting in better interlocking between matrix and fiber. Secondly, the chemical bonding such as hydrogen bonding, between fibers and matrix would occur due to the chemical reactions between the hydroxy groups of cellulose and epoxy molecules in the matrix (Mahjoub et al., 2014). The pre-treatment process is regarded as a fundamental factor in increasing the mechanical properties of natural fibers (Khalina et al., 2017). Recent evidence suggests that treated natural fiber based biocomposites produce better mechanical properties compared to untreated natural fibers (Ibrahim, 2010). It is proven that pre-treatment with 4% Sodium Hydroxide (NaOH) removes the lignin, hence can improve the bonding between kenaf fibers and the resin matrix (El-Shekeil et al., 2012). The results show that 40% of fiber loading improves the tensile strength and natural fiber treated with 4% of NaOH enhance the tensile and flexural properties compared to untreated fibers. At the lower concentrations of NaOH, the efficiency to remove the impurities on fiber surfaces is not good enough, which results in poor bonding between fibers with matrix. However, a higher percentage of NaOH does not ensure better biocomposite properties since it can destroy all of the lignin and reduce its bonding area. Author suggests to explore more on combining NaOH pre-treated processes with other types of pretreatment process since each leads to the different effects on natural fibers.

3.2 Manufacturing Vertical Farming Material

Less attention is paid to mass produce natural fiber-thermoset biocomposites despite fact of the biocomposites market is estimated worth more than 5.6 billion dollars in 2019 (Ali, 2016). Literatures indicate multiple ways to fabricate natural fiber-based biocomposites. They include hand lay-up, injection molding and hot press. First, this section presents selected findings on the manufacturing process of natural fiber-based biocomposites using thermoset resin. More than 50% of prior studies found that fabrication of natural fiber-thermoset biocomposites begins with hand lay-up owing to its simplicity (Azamana, 2013). Yet, the uneven fiber distribution in the natural fiber-based biocomposite system become major obstacles as it leads to fabrication difficulties during the manual separation (Zampaloni et al., 2007). However, the authors found a lack of studies aimed towards mass production particulary in structure materials.

Several studies have attempted discovering the best manufacturing process to produce strong biocomposite using less materials (Azamana, 2013). However upon review of prior studies, this paper is unable to specifically identify the most potential manufacturing procedure for mass production of natural fiber-based biocomposites. Authors have suggested to implement pultrusion method. Pultrusion is a fabrication technique that uses continuous fiber soaked with thermoset resin through heated die to form a composite (Memon & Nakai, 2013). Pultruded profiles of natural fiber-based biocomposites have proven to be better with a higher mechanical properties compared to the synthetic fibers (Azamana, 2013). Those were structurally crucial requirements in industrial and engineered products (Velde & Kiekens, 2001). Therefore, the potential manufacturing process of natural fiber-thermoset biocomposites shall uplift biocomposites to a whole new level (Saba et al., 2015).

The authors would like to propose a better understanding of various types of manufacturing processes that are potentially benefitting in development of natural fiber-thermoset resins. Over for many years, the authors found few studies exploring new manufacturing processes for natural fiber-thermoset biocomposites thus limiting their huge potential and wide applications in various industry. This study recommends further identification of other types of potential manufacturing processes in order to produce independent structurally hydrophobic biocomposite materials for vertical framing systems.

4. DISCUSSION

Vertical Farming for Climbing Food Plants is the Next Frontier of Agriculture. The investigation of food security shows that the concentration on vertical farming can contribute to attain urban food security in urban areas. The researchers are proposed a solution by concentrating on legitimizing the urban and peri-urban regions as agribusiness regions. Such efforts are expected to bring food closer to the urban communities. Coordination of the new different innovations in terms of urban agribusiness and costs related to such development is needed when considering practical and efficient vertical farming systems for climbing food plants. Nonetheless, this study posits that vertical farming can develop a higher stature climbing plants without diminishing the system's efficiency and food productivity. A real scale prototype is proposed for future study where precise information can be harnessed. Later, the results can become a guideline to establish a larger urban agribusiness space inside an urban space. A new mechanical ability will need to be adapted into the vertical farming plant factory using a modular system framework. Therefore, this study points out the need for practical management without creating additional environmental issues when vertical farming is confined in the cities.

This survey on selected literature has highlighted how vertical farming is emerging as a potential solution to dispose biodiversity treats by creating a modern urban agriculture approach inside the confinement of buildings. Despite its exploratory nature, this study offers a degree of insight into extending the success factors of rooftop greenhouses in urban agribusiness and implementing them as vertical farming structural innovation. Moreover, the feasibility of soilless farming is possible in urban areas by minimizing the cost and consolidating future new material innovations that could deliver functional vertical farming framing structures for varied climbing food plants. In general, the most effective vertical farming system method is to be fully autonomous and structurally independent without eliminating the golden rule of resource use efficiency (RUE).

Preparation of Green Material for Structural System Manufacturing. Literature highlighted that water absorbency is one of the main characteristics to produce suitable natural fiber-based biocomposite materials in an agricultural farm environment. The percentage and diameter of natural fiber in any biocomposite play a significant role in determining the strength of its mechanical properties. However, it is vital to ascertain the precise mixture of its natural fiber content in order to obtain the highest possible mechanical properties in natural fiber-thermoset biocomposites. This study notes the extent of water absorption in natural fiber-based biocomposites that correlates to its natural fibers content. This indicates a strong need to understand the hybridization of biocomposites with two or more natural fibers that possess different lengths and diameters. This is due to each fiber having its own innate characteristics to fill the microscopic gaps in between the fibers. To date, most of these methods have only been applied to thermoplastic biocomposites. This study recommends setting up a standard natural fiber-thermoset manufacturing procedure that is capable to produce high-quality biocomposites. Future study will further modify and improve the fiber content to fortify its mechanical properties and fatigue stress levels.

In view of extensive research carried out on the pretreated chemical processes, NaOH pretreated process still shows more potential and by far, the simplest to apply for the fiber chemical treatment. These studies recommend refining the percentage of the chemical used by another 0.1 decimal point in order to confidently identify the optimal alkaline solution concentration. Thus, the improvement could strengthen the structural material in a pretreated process. Moreover, this study agrees that a combination of pretreated processes could increase the mechanical properties and fiber matrix bond strength since each chemical used has its unique effect on natural fibers. Such enhancements are recommended to increase their mechanical performances of this group of materials by extending their capabilities and applications.

5. CONCLUSION

The trend of globalization and urbanization has inadvertently jeopardized food supply security, thus creating serious issues to feed billions of people in limited spaces around the world. In designing and implementing greener vertical farming systems, new green materials are required in order to build a fully sustainable green environment. New biocomposite structure materials have the strength of steel, yet at a fraction of its weight. This study foresees traditional materials may need to be replaced while green materials emerging as economical in the future. Newly enhanced hydrophobic biocomposite materials manufactured through mass production could provide an alternative solution to the current farming practices. The use of raffia ropes as climbing support are recommended to be replaced and new vertical farming structure design are called for different categories of crops planted. Thereby, the new vertical farming component with emerging material supporting climbing system is recommended in future studies. This paper contributes in developing foundations for designing alternative vertical farming system in an urban setting. Expected results would lead to provision of food in cities thus supporting the development of sustainable smart cities concept.

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