THE REVIEW OF CURRENT VERTICAL FARMS

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Abstract

With the population explosion and the acceleration of urbanization, the growth of land area and agriculture development has not kept pace with the development. In order to feed more people with fewer resources, vertical farms have emerged. Vertical farms refer to the cultivation of vegetables by hydroponic or aerobic methods in indoor structures such as vertically stacked layers.

The advantage of a vertical structure is that it maximizes the use of space and water and soil. Vegetables produced there are fresher and easier to transport because of its urban location. Since there are no harmful insects indoors, there is no need to use pesticides.

But early equipment and artificial lighting inputs created obstacles to the beginning of vertical farms. Failure to accurately match demand for continuous production is also a difficulty for farm operations.

This paper reviews the current strengths and weaknesses and development status of vertical farms, and proposes possible solutions to existing problems in order to lay the foundation for its development.

Keywords: *vertical farm, hydroponic method, aerobic method, strengths and weaknesses*

1. INTRODUCTION

With the population explosion and the acceleration of urbanization, the growth of land area and agriculture development has not kept pace with their development. Howard's Garden City (Howard et al., 1994)tries to solve the contradiction between city and country from a general direction. But the Garden City's programs, and a series of new urban planning solutions such as the later Broadacre City (Wright, 1935), need to rebuild the city totally. However, vertical farms can be retrofitted to the existing structure of the city.

Vertical farms refer to the cultivation of vegetables by hydroponic or aerobic methods in indoor structures such as vertically stacked layers. Simply put, because of the higher utilization of land, vertical farms can produce more food with less land (and other resources) and feed more people.

Unlike today's situation, agriculture first appeared in human gathering places. In the Neolithic Age, with the semi-settlement of human beings, agriculture emerged and human beings became producers from food collectors. Johan Heinrich von Thunnen proposed the agricultural location theory (Johan Heinrich von Thunnen, 1826) in 1826, and his discussion of the relationship between urban and agricultural production laid the economic foundation for the separation of agriculture from the city (Changan L et al.,2016). The development and evolution of the city is characterized by “non-agricultural industries and non-agricultural population gathering”, which makes agriculture and cities gradually face the opposite (Changan L et al.,2016). In this process, humans are constantly trying various methods for the desired traits and yields, but it also caused bad consequences. Irrigation consumes 70% of fresh water(Cirillo et al., 2014), turning forest into arable land to cause soil erosion, and agricultural runoff caused by fertilizers and pesticides into the ocean. In addition, rapid extreme weather changes can severely reduce crop yields(Despommier, 2010). The vertical farm proposed by Professor Despommier Dickson can avoid the bad consequences above and extreme weather effects because of its indoor characteristics and various conditions that can be controlled.

Although vertical farms have many advantages that traditional agriculture does not have, there are still many obstacles to their development. This paper reviews the current development status of several large companies in vertical farms, the advantages they have, and the possible proposes for some critical issue are discussed.

2. DEVELOPMENT

In the United States, there are currently at least 50 startups focus on the vertical farms (http://opinion.hexun.com/2018-08-26/193892321.html). As of 2013, there are about 165 commercial plant factory with artificial lights in Japan and 45 in Taiwan (Toyoki K et al. 2016). The global vertical farming market size was valued at USD 2.51 billion in 2018 and is anticipated to expand at a CAGR of 21.3% over the forecast period (https://www.grandviewresearch.com/industry-analysis/vertical-farming-market).

Of the top ten companies in the agricultural technology sector with total financing, three of them are focused on vertical farming, namely Plenty, AeroFarms and BrightFarms.

Softbank's vertical farm, Plenty, plans to build 300 new vertical farms near major Chinese cities for the middle class there who prefers to pay for the healthier and fresher food in 2019 (https://agfundernews.com/ag-industry-brief-plenty-makes-plans-china-remote-sensing-startups-merge-ex-cisco-ceo-invests-agtech.html).

In October 2017, AeroFarms, established in 2014, completed a $40 million Series D round of financing. At this point, AeroFarms financing totaled $130 million. Investors have diverse identities, including the old-fashioned professional investment bank Goldman Sachs, and IKEA who is famous not only for their furniture but also for their food. This shows that it not only has unlimited potential in concept, but also has potential for practical application.

Crop One Holdings produced nine different leafy green retail products serving 38 different supermarket and home delivery services since 2016. In June 2018, it signed a $40 million joint venture with the catering arm of global airline Emirates to build the world's largest vertical farm in dubai to supply Emirates Flight Catering clients (https://agfundernews.com/breaking-crop-one-signs-40m-jv-emirates-build-worlds-largest-vertical-farm.html).

Dr. Toyoki Kozai of Chiba University in Japan, known as the "Father of Modern Plants", believes that the artificial light source plant has many advantages: high air tightness, high insulation, and high hygiene, which can produce clean, high-quality vegetables. It can be eaten without washing (https://baijiahao.baidu.com/s?id=1609707451930058675&wfr=spider&for=pc).

In addition to the above large companies that have been invested in actual production, there are some other ideas for vertical farms. Ken Yeang (https://www.architecture.org.au/news/enews/354-ken-yeang-and-bioclimatic-architecture) proposed an Open-air-skyscrapers, unlike the commercial uses mentioned above, it can serve individuals and communities. Its unsealed nature also determines that the growth of plants depend on the local weather. Ken Yeang aims to make it respond to the climate of the local site and build a relationship between the architecture and the nature.

3. ADVANTAGES

The advantages of vertical farms have been summarized by many people, so they are not too detailed here. This section categorizes its strengths into three broad categories, from the impact on the environment, crops, and society.

3.1 On the environment

First of all, although vertical farms have been criticized for their high cost, their current awareness of environmental friendliness is actually more important. The concept of saving resources and reducing pollution is no longer illusory. With the profitable entity vertical farm and the crops it produces, the environmentally conscious add-on them is closer and more effective.

On the one hand, vertical farms will reduce the consumption of resources. Since water is recycled, it can save a lot of water resources, and the saved land resources will also restore the ecosystem under the natural action due to the withdrawal of human intervention. On the other hand, it helps to reduce pollution. The enclosed environment in the interior makes it unnecessary to use pesticides to avoid agricultural runoff polluted water sources, and the perfect vertical farm system can even treat plants

through sewage. The carbon dioxide produced by plant respiration can be recovered and the greenhouse gases emitted over long distances are also reduced.

3.2 On the crops

For consumers, crops are fresher and healthier (no pesticides). For producers, since all objective conditions are controllable, crops are no longer affected by the weather and can even be produced and harvested throughout the year.

3.3 On the society

The emergence of vertical farms can increase multi-level job opportunities, requiring multidisciplinary experts and intellectuals such as botany, agronomy, engineering, as well as routine maintenance, harvesting and transporting workers. Moreover, as it is closer to the city or even the living area, the 'local production' label which was originally popular with all human beings will be deepened, inducing consumers' pride in their region.

4. SHORTAGES AND SOLUTIONS

Among the many vertical farm startups in the United States, some well-known companies like FarmHere and PodPonics have closed down. The high upfront investment and operating costs are the cause of many vertical farm closures. (http://opinion.hexun.com/2018-08-26/193892321.html)

Early facility agriculture, greenhouses, can be seen as a single-story vertical farm. For vertical farms, the development and management of greenhouses is worth learning. The cost of production and operation is also high, but “the greenhouse finds a good balance between cost and profit”. (http://www.sohu.com/a/233027305_235422).

This section will advise on the rapid profitability of vertical farms from three aspects: increasing profit, reducing costs, and flexible module operation.

4.1 Flexible module operation

Professor Despommier's vertical farm concept is complete and large, so it is costly, long-term, and risky. Splitting its huge structure into a single small and simple module may lose some of its functionality, but the application of the module is more flexible and profitable. And here are three examples of modularization in different ways.

4.1.1 Crop One Holdings

Crop One Holdings (Crop One) is the vertical farm that modularly grows vegetables in sealed containers. In fact, more than half of the vertical agricultural market in 2018 is using containers as production space (https://www.grandviewresearch.com/industry-analysis/vertical-farming-market). Today, Crop One is producing green leafy vegetables equivalent to 19 acres of farmland using a planting unit that is less than 30 square meters and converted from a refrigerated container (http://opinion.hexun.com/2018-08-26/193892321.html).

There are many advantages to using containers as farm production modules. For example, the cost of the container itself and its modifications is low compared to other buildings, and its uniform specifications (https://www.iso.org/search.html?q=General%20container%20standard&hPP=10&idx=all_en&p=0&hFR%5Bcategory%5D%5B0%5D=standard) are advantageous for stacking or combining. Originally used for transporting heavy objects over long distances, it is easy to transport, stable and sturdy (Sawyer, 2008). And the most important one is that ready-made container make previous work saved a lot. When other farms are still building a factory, Crop One can enter the production stage as quickly as possible, thus achieving rapid profitability which is the ability to attract the most investors.

4.1.2 Herbert

Herbert is a crowd funding project on kickstarter, a hydroponic vertical garden. Up to18th April, it has

raised 258,089 euros, more than five times its target. It is positioned to be able to grow the vegetables you want by yourself efficiently (harvesting 40% more than the traditional method) and cleanly (without soil). This simple and feasible retail module which positioning of the family is also one of the ways to achieve rapid profitability.

It's a small wall-mounted open space measuring just 820 x 560 x 115 mm and a mass of 12kg. There are up to 15 plants on the top of the hole, and the bottom of the hole is connected to allow the nutrient solution to be cycled. The top is equipped with LED lights for plant photosynthesis. Herbert can also be controlled with a mobile app. And it needs to pay 299 euros.

In fact, this vertical farming into the family is not much different from the traditional cultivation methods in the pots, and even more expensive. But Herbert's precise positioning enhances its added value and makes it profitable. People are willing to pay for a good experience. Compared with the actual production of vegetables or fruits, people care more about the healthy lifestyle it represents. It is especially precious to eat fresh and pollution-free vegetables in the context of the global food industry scandal. Planting vegetables indoors seems to establish a subtle connection with nature. In addition, as a decoration, the size is right, and it seems to be alive. These characteristics also determine that it is suitable for integration into a warm family.

And the more important role of this small wall module is to pass on the awareness of vertical agriculture and water recycling to people. Physical display is more acceptable than the concept of text presentation. Although the scale and influence of Herbert are not great, it does provide us with a new idea of rapid profitability in vertical agriculture, the user experience brought by physical things and the added value. Along the way, small vertical farming devices can also be stationed in schools for education or other public places. AeroFarms built a vertical farm of 50 sq. ft. in the dining hall at Phillips Academy Charter School. (https://aerofarms.com/farms/)

If Herbert can continuously update the kickstarter page and improve the problems with the aftermarket, it will better convey the environmentally friendly value of it. (https://www.kickstarter.com/projects/1706256286/herbert-grow-fresh-organic-food-at-home?ref=discovery&term=Herbert)

4.1.3 InFarm

InFarm is a Germany vertical farm for retailers. Unlike other farms that offer crops as a product, InFarm focus on the B2B and provides modular farms directly for restaurants, supermarkets, bars and distribution warehouses where people eat. InFarm's modular farm looks like a transparent vertical freezer. The small size allows it to fit into the vast majority of the space without restrictions as there are demands. This determines that it can be widely disseminated, while at the same time 'cutting out the millions of miles often between food and fork' as described by itself. (https://infarm.com/)

There are also some points in the design of the module. First, the transparent appearance makes the actual sensory experience enhanced. Second, the tray on each layer inside the module are designed like a sunflower. The young seedlings which grow in the nursery before are planted in the inner circle of the tray. 'The seedlings slowly travel outwards towards the edge of the tray. As they progress through the various growth stages they are given more space to develop their leaves.' Convenient for picking, while maximizing space utilization.

Finally, the optimal conditions set in the module is different according to the type of crop, such as tailor light, temperature and humidity. Each module will be connected to the central farming platform for monitoring to ensure optimal conditions. (https://infarm.com/)

4.2 Increasing profit by accurately matching market demands

Since the farmland is moved indoors, all the conditions required for growth can be controlled and optimized, the plant's entire growth cycle is shortened, and the yield becomes larger. If the product is unsalable, the many advantages of vertical farms will become disadvantages. So selling food is the most important thing. An important condition for farm long-term survival is the accurate matching of farm products to market demands.

4.2.1 Type of plants

Accepting the order which requires rare ingredients ensures that the plants could be sold.

On vertical farm Farm.One's official website, the three most prominent words are local, rare and fresh, which are the market demand for its docking. “Farm.One is New York City's grower of rare herbs, edible flowers and microgreens for some of the best restaurants in the city”, it describes itself like this. It serves New York's finest restaurants with over 500 different kinds of microgreens, edible flowers and rare herbs year-round. Transportation after harvest can be done by low-emission mode of subway or bicycle (https://farm.one/). Some edible flowers are priced at a few dollars for a flower. On the basis of the demands, the length of time is also one of the criteria for choosing crop (https://www.grandviewresearch.com/industry-analysis/vertical-farming-market).

4.2.2 Brand influence in a specific group of people

In order to expand sales channels, cooperation with e-commerce giants with mature logistics channels is a way to explore. As a supplier, vertical farms can focus more on crop production. But as a supplier only, the profits of vertical farms are easily pushed down, making it difficult for farms to survive. At present, vertical agriculture has just emerged, and its freshness can help the establishment of independent self-owned brands. The two are not completely opposite and can be combined. However, as an independent self-owned brand, it is necessary to establish influence in the target population.

Small scale vertical farm Farm.One interacts strongly with the outside world. On the one hand, it actively promotes in the media. Farm.One works with at least 16 media outlets. Among them, there are both representative of the serious media, the New York Times and short videos news media based on social platforms NOW THIS. Serious media represents its credibility, and new media spread more widely among younger groups (https://farm.one/).

And on the other hand, the small scale allows Farm.One to be flexible and to carry out a number of interactive activities such as the class of hydroponics for grown-ups and of indoors farming for kids, events for special festival such as Mother's Day, and opened an edible bar to hold special activities such as weddings and parties (https://farm.one/).

Healthy, open, scientific and avant-garde labels could establish a good brand image.

4.3 Reducing costs

Agriculture enters the city, and its expenses are also against the city. High upfront investment and operating costs are a hindrance to profitability.

In 2014, the cost of plant factory with artificial lights (including facilities) in Japan was $4,000/m2, which is 15 times that of greenhouses; but in the case of lettuce, the productivity of factory is 15 times that of greenhouses. Although the output is also affected by other factors, it cannot be ignored that the cost is high and the productivity is also high.

4.3.1 Cooperating with companies to reduce lighting costs

Illumination closely affects the growth and development of plants, the cost of lighting equipment and running have also determined the survival of vertical farms. One of the reasons why some vertical farm startups in the United States died was that LED lighting was costly in the early days. “PodPonics, which has been closed, used compact fluorescent lamps instead of LED lighting, when the LED's lighting efficiency and its corresponding infrastructure were not complete and cheap” says Sonia Lo, the CEO of Crop One. (http://opinion.hexun.com/2018-08-26/193892321.html).

The development of lighting equipment has even largely determined the development of indoor agriculture. There are different kinds of light sources including incandescent, fluorescent, and HID lamps. Compared with other light sources, Light-Emitting Diodes (LED) has a spectral advantage, is more energy efficient (http://www.aidu360.com/5020725/20181029A1L9PS00.html), can maintain a stable output and can be highly controlled. (Toyoki K et al. 2016) In fact, more and more plant factories have used LEDs as light sources in the past decade. (http://www.sohu.com/a/233027305_235422)

However, LED as a light source still has many problems.

First of all, plants have two stages of growth, one is vegetative growth and the other is reproductive growth. Plants that mainly harvest roots and leaves should prolong vegetative growth as much as possible, while plants that mainly harvest flowers and seeds should enter reproductive growth as soon as possible. The stage of growth is affected by many factors, one of which is the photoperiod. The photoperiod is very easy to change under the fixed conditions of vertical farms. How the photoperiod of different kinds of plants changes is important for maximizing benefits, but it is still unclear.

Secondly, there are two parameters related to light that can affect plants growth, one is light intensity (daily light integral, DLI) and the other is light quality. For light intensity, the saturation values of different plants should be determined first, and other parameters of light should be balanced on this basis. And light quality, which is the distribution of spectral power. Plants grow under full-spectrum illumination of the sun, but not every wavelength of light has an effect on plants growth. A full-band agricultural LED lamp that simulates sunlight has been put into commercial use, but this is a sacrifice scheme with high energy consumption. It is fundamentally energy-saving to develop light receipes for different plants. Although the green plants absorb the most red-orange light with a wavelength of 600-700 nm and blue-violet light with a wavelength of 400-500 nm, it has been found that by means of the UV transparent film the content of several flavonoids could be enhanced up to similar amounts like in open-field grown strawberries. All other phenolics were not consistently affected by UV radiation. This result was independent of cultivar.(Josuttis et al., 2010)

These parameters, which are closely related to plants growth, are difficult for LED manufacturers to independently develop. Vertical farms and LED light producers work together to continuously develop light source equipment that is more suitable for farms. HEYCHOY, a vertical plants factory in Shenzhen, China, intends to work with LED light company iGrowLight to develop light recipes for plants growth. President Jingjing Jiang of HEYCHOY proposed that the plant factory itself is a system integration solution, which inevitably requires industry cooperation and communication. (https://www.sohu.com/a/233082403_235422) For LED manufacturers alone, on the one hand they need to reduce the cost of LED operation. What they can do is to maximize the conversion of LED's electrical energy into light energy, allowing plants to capture and convert photons into chemical energy as much as possible. Samsung's new LM301H plant lighting device delivers photon efficiencies of up to 3.10 μmol/J, making it the leader in current mid-power LED devices (https://www.samsung.com/led/about-us/news-events/news/news-detail-50/). On the other hand, the production cost of LEDs still needs to be reduced, although it has been reduced a lot. Existing materials science is still insufficient to support the cost reduction of LED light.

4.3.2 Government policy support

The Japan Plant Factory Association (JPFA) is a non-profit organization established with the support of the Japanese government and is committed to becoming a bridge between commercial agriculture and academic research. The onsite greenhouses it provides to its members was initially funded by the government.

(https://agfundernews.com/japans-indoor-ag-sector-is-becoming-more-collaborative.html) This is actually a small example of government support, but in fact, if the government's policy is tilted towards the vertical farms, not only will the cost be reduced, but its dissemination and development will be smoother.

5. PROBABLE PROBLEMS

In addition to being profitable, vertical farms may have the following problems due to their high plant density and high yield. Supervision should be strengthened and extra attention should be paid.

5.1 Weed problem

Opium which could be produced by poppy plants, is the principal precursor of morphine, heroin and codeine. And cannabis has long been used as an anesthetic because of the tetrahydrocannabinol

contained in it. Both the two plants can be used for the production of drugs or other neurological drugs, and illicit cultivation is very dangerous.

In the Netherlands, for example, based on the number of illegal indoor cannabis samples collected in 10 different areas of the Dutch police, two model were reasonably inferred. The model for yield per plant gave a prediction of 33.7g female flower buds per plant. The second model for yield gave a prediction of 505g flower buds per square meter for a median Dutch grow room. (Marcel et al., 2010)

If a highly regulated plant is placed in a vertical farm, suitable growth conditions will inevitably increase yield. Based on this, the types of plants planted in different areas of the vertical farm should be reported in advance. And making advance planning based on market demand is also a way to maximize corporate profits.

5.2 Safety

Since the water and other resource are nearly 100% cycling and the plants are highly concentrated in narrow space, as soon as there is a little pollution or pests, it will spread immediately. Even in an indoor closed environment, the airtightness can be destroyed by ventilation or by staff. Despommier D mentioned in the grand and complete vertical farm vision that the building should be designed with the exception of uninvited guests such as insects and microbial pathogens(Despommier, 2010). The vertical farms that are not yet complete and the modular containers mentioned above can start from the following aspects. Entering the planting area requires passing through the preparation room and changing the overalls. Install the air shower system if conditions permit as Japanese plant farm Spread (http://spread.co.jp/en/technology/) has done this. Since there are plant factories said their leafy plants can be eaten without washing. The relevant standards of the production area can also refer to the production standards of the food production workshop or the aseptic workshop.

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