Vertical Farms: A Sustainable Solution to Urban Agriculture Challenges

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Abstract. Vertical farms are considered to be a powerful response to the shortage of future agricultural cultivation space, which can achieve higher agricultural output in cities and alleviate food shortage. This paper focuses on the characteristics of vertical farms, takes the Plant vertical farm in Chicago as an example, describes its design and performance, analyzes its advantages and design principles, and raises some problems that need to be solved. Vertical farms can expand the yield of crops and simulate the environment required for crop growth and development. The success of The Plant is mainly due to the following aspects of the design: saving raw materials and waste disposal costs through the use of waste, staggered electricity consumption and the use of insulated structures to maximize the savings in energy costs, and ultimately enabling the vertical farm to achieve the ability to compete with traditional agriculture. The vertical farm finally achieved the ability to compete with traditional agriculture. It is worth noting that although the small-scale pilot projects of vertical farms have achieved some success, there are still many constraints to be overcome in expanding the scale of vertical farms because of their high construction and operation costs and high technical level.

Keywords: Vertical farm; Plant vertical farm; Urbanization; Urban agriculture.

1. Introduction

With the rapid increase of urban populations and global urbanization, the destruction of ecological systems and the high demand for resources are forcing people to find ways of sustainable development. The issue of food is prominent among the many resource shortages facing humanity. According to the Food and Agriculture Organization of the United Nations (FAO), the world population is expected to reach 8.5 billion in 2030 and 9.7 billion in 2050. It has been calculated that only a 70% increase in food production will be able to feed such a large population. It is estimated that by 2050, the urban population will account for two-thirds of the total population, and the arable land area will further shrink. The shortage of cultivated land is the main reason for the decrease of grain production. In order to make full use of cultivated land space, some new agricultural concepts are put forward, such as vertical farms, which provide suitable growth and maturity conditions for different crops, thus effectively expanding crop production area and output.

"Vertical farm" is to solve the problem of shortage of cultivated land, expand the production area and output of crops, make rational use of agricultural labor skills, and use modern science and technology to simulate the environment needed for crop growth and development in high-rise buildings, and provide a place for crops to grow through scientific control and artificial management, so as to increase the production area and output of modern agriculture. It is considered to be a powerful means of coping with the lack of space for agricultural farming in the future. Cities can achieve higher agricultural production.

This paper analyzes the characteristics of vertical farms, takes the Plant Chicago vertical farm as an example, analyzes its design and performance, and analyzes the advantages and design principles of vertical farms. At the same time, the problems that need to be solved in order to further develop the vertical farm under the current situation are put forward.

2. Vertical Farm Concept and Advantages

The modern term "vertical farm" was created by American geologist Gilbert Ellis Bailey in 1915. However, what caught everyone's attention was a course project by Professor Dixon Despommier of Columbia University in 1999. The course required students to design a farm proposal that would utilize a 13-acre rooftop garden to feed 50,000 people, and the project proposal, dubbed the "vertical farm," was ultimately completed with Despommier's proposal to grow crops vertically on each floor (Figure 1).

Fig. 1. Vertical farm proposed by Prof. Dickson Despommier.

2.1. Full utilization of land

Different from the traditional horizontal farming methods, which require a large area of flat land, vertical farms can be built in urban environments and reused buildings, effectively transforming underutilized space into high-yield agricultural areas. Specifically, traditional farms only use one layer of land on the ground, while vertical farms use buildings stacked in vertical space. This vertical layout makes use of three-dimensional space, allowing multi-layer crops to be planted in an occupied area, which can effectively improve agricultural output without horizontal expansion (Figure 2). According to Despommier, a 30-story building on 2.02 hectares (5 acres) would produce the traditional agricultural output equivalent of 971.2 hectares (2,400 acres). This means that a high-rise farm would produce the output equivalent to 480 traditional-level farms [1].

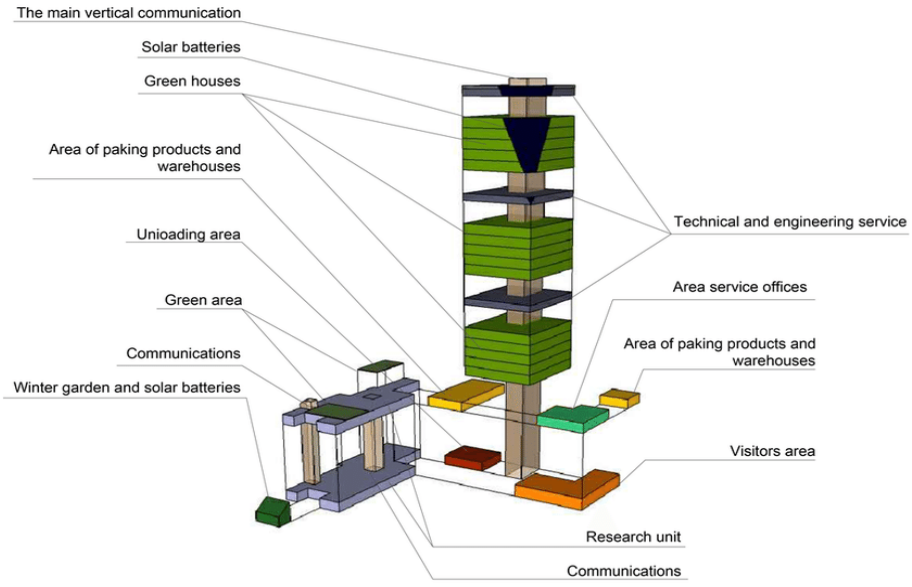

Fig. 2. Vertical farm structure.

2.2. Freedom from climatic constraints

Traditional agriculture must be planted and harvested in specific seasons according to the annual climate changes. This not only limits the yield of crops at a specific time but also leads to great uncertainty because climate change will determine the crop harvest at a specific critical time in the crop growth cycle. Besides, the erosion of climate disasters cannot be ignored. According to relevant data, the economic losses caused by natural disasters such as drought and floods in China reach several trillion yuan annually [2].

However, many vertical farms use intelligent management systems, such as temperature control, to operate in a controlled environment unaffected by external weather patterns. This advantage allows farming all year round and provides a stable and reliable supply of fresh agricultural products. It is not affected by natural disasters, such as droughts, floods and insect pests.

2.3. Reducing geographical constraints on agriculture

Traditional agriculture has a high demand for geographical location. Geographic conditions such as soil type, topography, altitude, and water distribution, determine which areas are suitable for agriculture, and few areas meet these requirements for agricultural production, making the supply of crops dependent on traditional food-producing areas.

At the same time, urban residents are increasingly looking forward to eating local food. In 2016, data from a study in the United States showed that a large number of chefs (44%) in the country believed that the most important food trend of the last decade was people's thirst for local food [3]. This is because of the taste and health of fresh agricultural products. Imported fruits and vegetables will lose their nutritional value in the process of transportation. For example, even if spinach is stored at 4°C, it will lose 47% folic acid after 8 days. Folic acid is an important vitamin B required for RNA and DNA synthesis [4].

However, vertical farms have basically broken the geographical restrictions and provide a way for agricultural production in modern cities with high population and building densities. However, vertical farms have basically broken the restriction of geographical factors and provide a way for agricultural production in modern cities with high population and building densities. Shan put forward and demonstrated the idea of developing a "vertical farm" in an uncompleted residential building [5]. Guangzhou also put forward a plan to transform the village-in-city into vertical farms, thus solving the problem of the village-in-city while providing food supply [6].

3. Typical Case Study From Chicago Vertical Farm

In 2010, entrepreneur John Edel bought a four-story 94,000-square-foot factory in an auction. Today, it is home to the Plant, a vertical farm that houses 11 small food businesses, ranging from bakers and kombucha brewers to hydroponic farms that grow vegetables and fish for local restaurants (Figure 3). This is the first urban vertical farm in the U.S. and is an important step in the exploration of the vertical farm concept. By using advanced technology, the building is very energy-efficient, comfortable and environmentally friendly, and agricultural production is carried out within the factory. A successful vertical farm success story that has been operating commercially for so many years, it has many noteworthy features.

Fig. 3. The Plant vertical farm in Chicago, USA.

3.1. Waste utilization

The goal of the Plant is to achieve "zero waste" large-scale agricultural production in the city, and it has reached a high level of resource recycling.

(1) The Plant absorb oxygen released by plants and exports carbon dioxide to plants to produce black tea fungus (drink).

(2) The turbine generator converts electricity into light energy for plant lighting. Carbon dioxide produced by the turbine generator also supplies plants. Steam with a temperature of 850 degrees Celsius generated by the turbine generator can be used to adjust the temperature of buildings.

(3) The purified water from plant is supplied to the fish ponds. Nitrogen produced by fish supplies plants. Plant wastes are sent to the anaerobic digester for further treatment. The plant waste is sent to the anaerobic digester for further treatment, and the plants itself is used for food.

(4) The anaerobic digesters treat waste and leftover food from plants, fish, commercial kitchens and wineries, and produce biogas, which can be used by the turbine generator. At the same time, the biogas sludge produced by biogas fermentation can be used as feed for fish.

(5) Business kitchens serve businesses that have just started up, and the food residues produced are fed into the anaerobic digesters.

(6) When beer is produced in a brewery, distiller's grains can be used in anaerobic digestion of esters, absorbing the high temperatures generated by the turbines to do work, and distiller's grains can be used for mushroom cultivation [7].

3.2. Energy conservation

Vertical farms are power-intensive. Except for certain vertical farms in special locations, such as in Singapore, where the sun shines brightly and is close to the equator, entrepreneur Huang Heshun's vertical farm doesn't need artificial light at all to promote the growth of crops. Most vertical farms consume a lot of electricity to maintain the operation of light sources, temperature, humidity and other regulating devices. So it is important to keep energy costs down to a very low level to keep vertical farm sustainable. The Plant has taken two major steps to conserve energy. Although this design does not use natural light, it can keep heat well. Energy-efficient glazing blocks most heat exchange, and well-insulated brick buildings are very conducive to retaining heat inside the building during the winter months.

Another measure used by the factory to reduce energy costs is to use electricity at the wrong time. The advantage of relying on artificial light is that you can artificially control the day and night when the plants grow. Artificial light is turned on when electricity consumption and bills are low. At the same time, night conditions are artificially created when the electricity price is the highest during the day. This mode of using "peaks" and "trough" of electricity consumption can save half of electricity bill.

3.3. Successful experiences

The success of the Plant shows that cost control is the most important reason for the success of the project. Whether it is to save the cost of raw material and waste treatment by recycling waste, or to save energy to reduce electricity bills. In a market economy, if vertical farms are to be accepted by investors and consumers, they must first prove that they have lower costs and higher profit rate than traditional farms. In this respect, the design of the vertical farm is not as sci-fi as people expected, but makes the best use of existing facilities, which is cost-conscious and worthy of any innovative project.

4. Problems with vertical farms and discussion

Although The Plant has achieved some success, there are still many problems with the global expansion of vertical farms, which are mainly concentrated in 2 aspects.

4.1. High cost

The cost of building and consuming energy for vertical farms is high. According to expert 'estimation, vertical farm costs as high as $ 5,000 to $ 10,000 per square meter, and a high-quality vertical farm may need billions of dollars. In addition, it is assumed that the amount of electricity needed for lighting in a vertical rural area is 8 times the total amount of electricity produced by all the power stations in the United States in 1 year, if vertical farming is utilized to replace year-round wheat production in the United States [8]. Countries that can succeed in vertical farms, such as Japan and the Netherlands, often have high economic levels and limited land resources, so they need to save land for agricultural production, so they can afford the high construction costs of vertical farms. Singapore has sufficient light sources, which can save a lot of electricity and can relatively easily afford the operating expenses. In addition, many vertical farms will consider matching some of the more profitable products to balance the cost. In contrast, countries with vast territory and poor economic levels are unsuitable for vertical farms. Therefore, vertical farms will be difficult to promote in such countries unless the cost can be greatly reduced in other means.

Therefore, it is only when costs are kept below those of traditional agriculture that there is a possibility of competing with traditional agriculture for markets for the products it produces, which in turn can lead to investment and development. For the time being, however, traditional agriculture still has a significant cost advantage over vertical farms in most areas. However, in most areas, traditional agriculture still has obvious cost advantage over vertical farms.

4.2. High technologies

Although traditional agriculture has developed for thousands of years and various tools and seed cultivation have undergone tremendous changes, it still relies on various natural resources to complete the whole process from germination to harvest, which involves agricultural production according to the changes in natural conditions.

Vertical farms eliminate dependence on nature, simulate suitable natural conditions, dynamically adjust at any time according to the suitable growth environment of animals and plants, and keep monitoring. For example, the greenhouse environment control system of Priva in the Netherlands can effectively analyze the sensor data, automatically control temperature, light quantity, wind speed and other indicators, and link data according to meteorological information such as rainfall or sunny days, so as to improve the quality and yield of crops [9]. Therefore, vertical farms usually adopt high-tech equipment to realize agricultural automation and intelligence, use big data for production management, and improve agricultural integration and industrialization.

It is assumed that the high-tech industry restricts the promotion of vertical farms, especially in developing countries and backward countries with low technical levels. Taking China as an example, in the production of protected vegetables in China, the proportion of manual participation in the production process, such as ploughing, sowing and fertilization, is high, the scale of the farm operation is small, the agricultural equipment is not perfect, and the scientific and technological

means for building vertical farms are still insufficient [10]. It takes a lot of time and money to get the information technology and automation equipment that can meet the needs of vertical farm construction at a lower price.

5. Conclusion

With the development of human beings and the construction of urbanization, the reduction of agricultural land has been an irreversible trend. The food problem is becoming increasingly prominent in this trend, which can greatly improve the utilization of land resources and the output per unit of land. Vertical farm is bound to be more and more attention.

Vertical farms is one of the solutions to this problem. Through multi-storey buildings, vertical farms can expand the production area and output of crop, and simulate the environment needed for crop growth and development using modern science and technology. Because vertical farms can take buildings as carriers, there are not many requirements for topography.

The Plant plant is a Chicago-based vertical farm with outputs such as beverages, beer, fish and mushrooms. This is also the first vertical farm in the United States. In this case, the vertical farm saves raw material and waste treatment costs by using waste, and saves energy cost to the maximum extent by interleaving electricity and insulation structure. With these savings, the vertical farm realized that they could compete with traditional agriculture.

Although in some countries and regions, small-scale pilot projects of vertical farms has achieved some success. For example, in the Netherlands, Singapore, Japan and other countries. However, from a global perspective, in many other regions, the promotion of vertical farms has been limited by the high construction and operation costs and high technical level. Only after overcoming these difficulties can vertical farms have room for further development.

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