

VERTICAL FARMS, BUILDING A VIABLE INDOOR FARMING MODEL FOR CITIES

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Automated vertical farm Techno Farm Keihanna, capable of producing 30,000 heads of lettuce per day in Kyoto, Japan - ©Spread

Dickson Despommier is an Emeritus Professor of microbiology and Public and Environmental Health at Columbia University (New York City, USA). After conducting research on ecology and intracellular parasitism, he has developed the concept of vertical farming since 1999 with graduate students in his medical ecology class. He is the author of the 2010 book *The Vertical Farm: feeding the world in the 21st Century*.

The number of vertical farms has grown to several hundred farms across Asia, Europe, and North America since the first appeared back in 2010. Using different types of technologies, vertical farms are a new type of Controlled Environment Agriculture (CEA) that could be described as a stack of greenhouses on top of each other, multiplying the plant yield by the number of floors comprising the vertical farm. It has now become a solution to most of the issues deriving from traditional outdoor farming: by occupying less land, it can contribute to the restoration of forests and by operating within a circular economy framework, it uses fewer resources and reuses organic waste. Impacts on health could also be significant as outdoor farming contributes to the spread of global infectious diseases. While vertical farms require a high-tech environment, which can mostly be acquired in wealthy countries, the model could rise in the coming years as a viable solution to increase food sufficiency of cities across the world with the support of local authorities and international organizations, as well as with the multiplication of large commercial growers.

You have been working for several years on the concept of vertical farming. Could you elaborate on what qualifies as a “vertical farm”? Do different types of vertical farms exist?

Dickson Despommier: Vertical farms are a type of Controlled Environment Agriculture (CEA). CEA strategies are far from new, as they emerged in the 1700s. They have traditionally taken the form of greenhouses, which have greatly contributed to the global food supply over the last decades. Vertical farms differ from greenhouses in terms of their height. Indeed, a vertical farm can be simply perceived as a stack of greenhouses on top of each other. Therefore, for the same amount of ground space used, the plant yield is multiplied by the number of floors of the vertical farm. The higher the vertical farm, the more produce it yields, albeit with the same footprint. Consequently, they are now capable of producing millions of tons every year.

Vertical farms mainly differ amongst each other in terms of the technological methods used to grow edible plants indoors.

- (1) The first one, hydroponics, consists of growing plants on a neutral and inert substrate (e.g. sand, clay, and rock material), which is regularly irrigated by a liquid fortified with minerals and nutrients that are necessary to sustain plant growth. Hydroponic systems use 60-70% less water than traditional outdoor agriculture. They are widely employed by hundreds of thousands of commercial greenhouses and vertical farms throughout the world.
- (2) The second process of vertical farming is aeroponics, through which plants are grown without the use of any soil (or soil replacement): their roots, hanging down in the air inside a closed container, are exposed to a fine mist of nutrient-laden water, regularly sprayed through a nozzle. While this is a relatively new method for growing edible plants – it was first developed in 1983 – it is increasingly employed by commercial vertical farms such as Aerofarms and Tower Garden in the US.
- (3) Finally, a hybrid method, aquaponics, integrates fish production into the hydroponic growing scheme. More precisely, it uses fish waste as a nutrient source for the plants after treatment, operating as a closed loop ecosystem for indoor farming. However, this system's complexity and high cost hinder its widespread use. The former two methods are the most common forms of CEA.

Is there a particular model of vertical farming you perceive as more optimal for the future than others?

D.D.: In terms of methods, aeroponics has two advantages in comparison to hydroponics: it uses approximately 70% less freshwater, and aeration of the nutrient solution is unnecessary through this technology so that the system becomes more profitable and easier to monitor. Aeroponics is a more efficient process of vertical farming. Nevertheless, farmers using aeroponic systems have faced a challenge for some time: the nozzle used to spread the nutrient-enriched water mist used to clog regularly. However, Shanghai-based AEssenceGrows developed a nozzle design that would not clog when delivering water to aeroponic plants, improving the reliability of the mist system. AEssence today supplies an in-house engineered patented aeroponic system which allows vertical farms to grow numerous kinds of produce.

But besides the technological aspect, to be promising and sustainable, the business model of an urban vertical farm should be viable. For instance, Infarm offers a high-potential commercial design for vertical farms. Infarm, for which I consult, is a startup created in 2013 in Germany that has now expanded to several European countries and has over 200 employees. It designs high-tech indoor gardens in supermarkets produce aisles employing hydroponic systems and a biomimicry design for its growing-trays, which are stacked vertically and housed in a protected environment. The Infarm app monitors all aspects of grow technology, such as pH levels. Supermarkets such as Metro have partnered with Infarm to build small-scale LED-powered grow modules in their stores so that consumers can themselves pick the fresh vegetables they want to consume, albeit these are more expensive and hence tend to be purchased by the upper middle class.

Together, AEssence and Infarm are good examples of startups providing an extremely strong growing system for urban settings, both technically and commercially.

What factors have contributed to the emergence of vertical farms, historically and geographically?

D.D.: As far as I am aware, the first vertical farm appeared in Japan in 2010. Rather than a commercial enterprise, it was established as an experimental farm at Chiba University by Dr. Kozai and his research team. Following the 2011 earthquake, tsunami and nuclear crisis, 5% of the farming in Japan was destroyed or unusable due to saltwater and nuclear contamination. The government made a public call for a solution, and Dr. Kozai suggested his vertical farming model which grows food in a controlled, safe indoor environment, clean from contaminated water or soil. The Japanese government started to provide widespread support to vertical farms and their numbers have greatly

increased. As of 2018, there are several hundred commercial vertical farms operating throughout Japan's islands, such as Spread Co. Particularly easy to grow in this sort of setting, leafy green vegetables, became a key element of the Japanese food habits.

The second country to engage in vertical farming was South Korea. It started with an experimental seed bank complex based in Suwan and then expanded to provide agricultural training so that people could replicate the model themselves. This has resulted in a strong industry that has spread throughout the country.

The third known case of vertical farming was a 3-story building in the old meatpacking district of Chicago. Each story grew a particular kind of product: fish, mixed greens, and fish foods and barley. This initiative, which started in 2013, was fully dedicated to educational purposes.

Since then, a large number of vertical farms have mushroomed across the world. They doubled in one year, and since then have been experiencing incredibly rapid growth. Over the next five to ten years, the number of vertical farms has the potential to increase at a geometric rather than at an arithmetic rate. That means that vertical farming is on the way to become a common feature of city landscapes and that cities will have the capacity to produce significant quantities of food for more than 60% of the urban population.

I would explain this recent development through two main factors:

- The first (1) is that the time for innovation in urban agriculture is right. Indeed, although the idea of a vertical farm might have been developed several years before 2010, it may not have gained the attention necessary for its survival and expansion. However, the market today is receptive to vertical farms, driving its success.
- This is enhanced by a second factor: (2) rapid climate change. It should not come as a surprise that the number of vertical farms is evolving at a similar pace to anthropogenic climate changes. Planners of vertical farms are motivated by the realization that the earth's environment and climate are being disturbed by current modes of food production so that innovative ways to grow food are necessary. At the other end, environmentally-aware consumers and citizens welcome vertically farmed products into their food consumption habits. As the climate continues to be disrupted, populations continue to multiply, and cities continue to expand – all of which are unlikely to slow down – food production and consumption are forced to assume new and more sustainable patterns, in which vertical farming plays a central role. Thus, vertical farming is expected to continue expanding and scaling across the world.

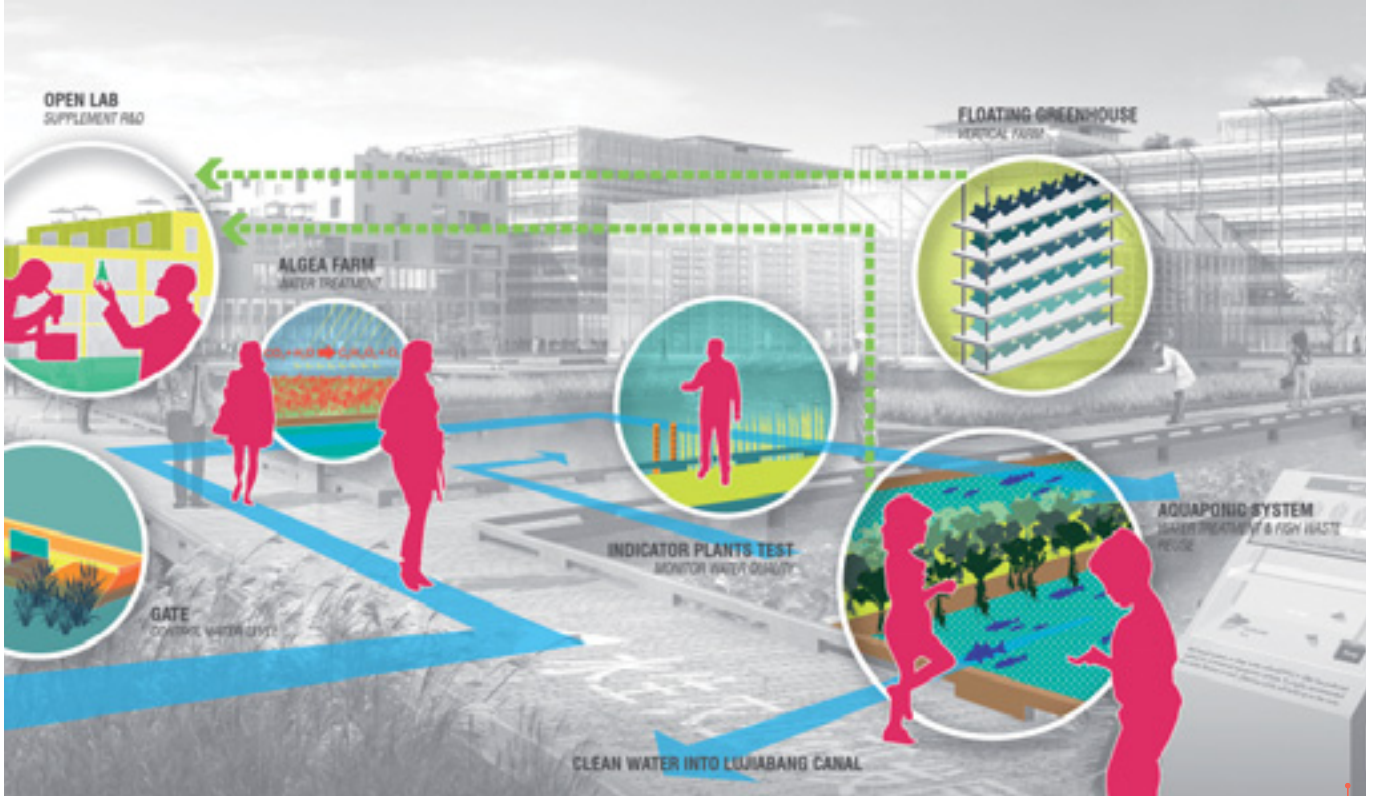
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You often depict traditional outdoor farming as an unsustainable model of agriculture. To what extent and how can vertical farming contribute to the sustainability of food systems?

D.D.: Vertical farming is a valuable solution to the issues involved with traditional outdoor farming. Its first and foremost contribution is on the environment. There is a broad consensus among academia, policymakers, international organization staff, and society in general that the contemporary system of outdoor soil-based farming is unsustainable and largely responsible for climate change. Half the world's trees – the equivalent of the size of Brazil – have been deforested for the sake of agriculture. As it is well known, trees are a core element that sequesters carbon dioxide and produces oxygen, so that the destruction of forests for agricultural land use has a considerable role to play in climate change. Indoor farming, notably vertical farming, would allow us to reduce the amount of land that is necessary to feed the ever-increasing world population, which is particularly important considering that the latter is expected to grow up to 9.8 billion in 2050. Vertical farms could even contribute to the restoration of 60 to 70% of forests (two trillion trees), which would sequester enough carbon to reverse the rate of global warming.

Admittedly, indoor farming cannot be expected to fully replace all of the 1.87 billion hectares devoted to crop production. For instance, rice is highly costly to grow indoors, while beef is almost impossible to raise indoors. However, it can become a considerable source of food which would decrease the need for excessive farmland usage. Indeed, other animals such as crustaceans, fish, and poultry can be produced in vertical farms, as well as cattle food – growing soy indoors could have a great impact on deforestation. Even if indoor farming does not fully replace outdoor farming, it may well complement the food system facing the increasing pressures of demographic growth coupled with land scarcity.

Additionally, vertical farming can operate through “zero” pollution circular reuse grow systems. Not only can urban farms contribute to land use, but also to the reduction of other natural resources such as water and energy, and to the reutilization of organic waste. Further, growing food indoor could have a significant impact on global health. Outdoor farming is one of the main causes of global diseases since half the world gets sick from vegetables contaminated with human feces. Growing food in a controlled environment would allow everyone to grow safe-to-eat, healthy food and thus decrease the number of diseases throughout the world.



The Sunqiao Urban Agricultural District integrates vertical farming systems in conjunction with research and public outreach in Shanghai, China
©Courtesy of Sasaki

Vertical farms decentralize the food system, as well as democratize the food supply, since it increases supply, lowers prices, and therefore contributes to food access to all sections of the population, including the poorest. More equitable and widespread access to food will further enhance urban systems' sustainability.

It is also interesting to compare the advantages of vertical farms with those of other types of urban agriculture. For instance, open lots are a common way of growing food in an urban environment, as seen in La Paz (Bolivia). However, open lots are in close contact with car exhaust, which penetrates the soil, is absorbed by plants, and consumed by people. Another example is that of building gardens on rooftops, which can only be done in regions of the world where winter temperatures are mild. While greenhouses deal with this issue, they cannot yield sufficient food to feed the increasing number of urban dwellers. Vertical farms can be perceived as an ideal method of urban farming, as it optimizes land use and increases food density per square foot of farming space.

There is however great hope that vertical farming can become commercially viable at a large scale. Diversifying the crop selection could further contribute to the success of vertical farms since most today focus on highly productive leafy green vegetables

What needs to be done for vertical farming to expand?

D.D.: Vertical farming faces several kinds of challenges.

- (1) First, the question of training and indoor farming skills is very important. Commercial vertical farms operate like any other business, and there are numerous reasons why businesses fail. They require constant oversight of all aspects of the growing environment, as well as employing skilled and experienced staff, who can identify and correct problems in the growing system. I would suggest that schools of agriculture should offer specialized degrees in urban farming, which could not only train city dwellers to work in urban farms, but also stimulate them to work in them, further driving growth in the sector.
- (2) Commercial viability is definitely a challenge for vertical farms. There is however great hope that it can become sustainable at a large scale. Some have suggested that the energy cost of running a vertical farm makes it difficult to realize a profit. However, as the price of electricity and LED lights become cheaper, the profitability of vertical farms will undoubtedly increase. Diversifying the crop selection could further contribute to the success of vertical farms, since most today focus on highly productive leafy green vegetables.

- (3) Next, opposition from city dwellers and politicians to urban agriculture remains common. Many assume that due to the dense, crowded, contaminated environment of cities, these are not appropriate spaces for vegetable growth. Nevertheless, as the industry matures, indoor farming gains visibility, and the advantages of vertical farming become obvious, it will get easier to get approval for their construction from city planners and other stakeholders, so that vertical farms will gain a lasting place in urban centers.

- (4) Last, vertical farms remain relatively expensive to build, maintain, and endure. These are abundant in places such as Japan, Singapore, Taiwan, and the US, where people have high purchasing power. However, the challenge now resides in spreading vertical farming to poorer populations. In places like India, Africa, South East Asia, Latin America, urban agriculture has been growing. But vertical farming, as it requires more expensive technology, has been lagging. Expanding it to larger shares of the population, large commercial growers must step in, as well as international organizations in order to encourage it and make it more accessible. It is only a matter of time for poorer people to demand what the middle class already has access to, at the right market price, and at that point, vertical farming will emerge in cheaper forms.

Vertical farming is often perceived as a “futuristic” model of urban agriculture. According to you, how will cities look like in 50 years?

D.D.: Urban dwellers need to re-imagine city planning and buildings, enabled by the current technological advances which already allow for alternative modes of production.

I believe buildings will acquire entirely new functions in 50 years. Buildings today are functionless columns of steel, glass, and concrete which endlessly consume resources such as electricity for air conditioning and heating. Instead, architects should develop buildings that integrate vertical farming systems and that are made of alternative materials such as wood timber (i.e., laminated wood). An example is the Sunqiao Urban Agriculture District, a 1,000-hectare master plan designed by Sasaki Architects in Shanghai¹. This could lead to a hyper-localized mode of consumption in which citizens buy and consume produce from their own buildings. Further, buildings could be equipped with a circular economy infrastructure. For example, they could have water harvesting systems that capture and store

¹ See more: <http://www.sasaki.com/work/>



The Living Tower is an urban vertical farm concept associated with a residential and business campus ©SOA Architectes

rainwater, contributing to the decrease of clean water usage and waste. Further, solar panels could integrate buildings, especially in regions of the world where solar light is constant and abundant throughout the year.

In sum, buildings in the future will have similar characteristics to that of trees, creating a decentralized food production system that contrasts with today's grids. We are currently on the way to developing this possibility, embraced by architects, academics, and policymakers, as seen in the *Réinventer Paris* (Reinvent Paris) conference, of which I had the opportunity to be part of the jury. SOA Architects have also designed this kind of building, named *La Tour Vivante* (The Living Tower), which associates agricultural production, dwelling and activities along the building².

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Meanwhile, supermarkets could embrace the benefits from both AEssence and InFarm: indoor growing systems could continually produce vegetables and be located in their aisles, replacing today's boxes, cans, and packages, and customers could directly order on an app the vegetables they wish to purchase and obtain them freshly grown and harvested.

Ultimately, vertical farming could contribute to climate change efforts, reduce the usage and waste of resources, enhance people's health and productivity, enabling us to depict a more positive outlook on the future of cities than commonly done.

² See more: <https://archello.com/project/la-tour-vivante-the-living-tower#stories>