

Farmworks: Building as a Machine for Growing Food

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Traditional agricultural production is impacted by the fertility and availability of land, length of the growing season, access to freshwater, pests, CO2 fertilization, and extreme weather events. On the other hand, if a farming operation were to be integrated with the built environment in a high-performance building, then the growing operation would not be bound by season or weather conditions. Further, if this farming operation were to be attached or adjacent to a major food supplier, then transportation costs and carbon emissions would be significantly reduced. Most importantly, with today's technology the building interior could be tuned to optimize a particular plant's needs for light and the appropriate wavelengths for germinating, growing and flowering; the interior temperature could be adjusted to support the different temperature requirements for growing, harvesting, packaging and shipping (with temperature ranges from 38-75°F); water could be supplied with the appropriate nutrients for a specific plant, eliminating the need for organic fertilizer, which also reduces the likelihood of introducing bacteria or insects into the food; the planting beds could be stacked vertically, accessed via a forklift; and the growing day could be shifted with respect to the outdoor environment to equalize the heat produced by the lighting indoors with outdoor temperatures and seasonal variation. Farmworks is a machine for growing: the wavelength of the lighting in this indoor environment is tuned to optimize plant growth and moves vertically in pace with the plant's height, the HVAC system keeps temperature and humidity optimal, and the building envelope is insulated and pressurized to balance interior and exterior conditions and to prevent water from condensing in the exterior wall. Here, the entire supply chain of food production occurs in one building, producing the equivalent of one acre of land using only two-and-a-half 4'x9' towers.

INTRODUCTION

The Farm Works is an indoor vertical farming enterprise. As a food production facility, this one is a value-added localized integrated farming enterprise, or V-LIFE.¹ This means that The Farm Works is the integration of an extremely high yield next

generation indoor farm and an automated food manufacturing and distribution facility.

Traditional food production grows food on land using fertilizer, manure and pesticides. The food is harvested and shipped to a manufacturing facility to process and package, the packages of which are then shipped to a distributor who ships the packages to a store. On average, this food travels about 1500 miles, if not 3000 miles when coming out east from California to Philadelphia where The Farm Works indoor vertical farming enterprise was born. The Farmworks itself is one building where all these aspects of food production occur – from the receipt of the seeds, to the growing of produce, to harvesting and packaging for distribution (Figure 1). In some instances, the food can be distributed “next door” to a leading grocer, thereby eliminating the shipping of produce entirely from the production of food. Most importantly, building operations are sync'd with growing operations and tuned to the outdoor environment to ensure low-energy use by this food production industry. The following considers the Farmworks as a machine for growing, harvesting and distributing fresh produce for a future world faced with climate change and the need for regenerative architecture with a low-carbon footprint. Therefore, the Farmworks is architecture that is not just about the building, but is about the entire process of agricultural production in a world that is now faced with climate change and the worldwide need for access to fresh food.

BUILDING AS MACHINE

A great epoch has begun.

There exists a new spirit.

Industry, overwhelming us like a flood which rolls on towards its destined end, has furnished us with new tools adapted to this new epoch, animated by the new spirit.....

We must create the mass-production spirit.

The spirit of constructing mass-production houses.

The spirit of living in mass-production houses.

The spirit of conceiving mass-production houses.

If we eliminate from our hearts and minds all dead concepts in regard to the houses and look at the question from a critical and objective point of view, we shall arrive at the “House-Machine,” the mass-production

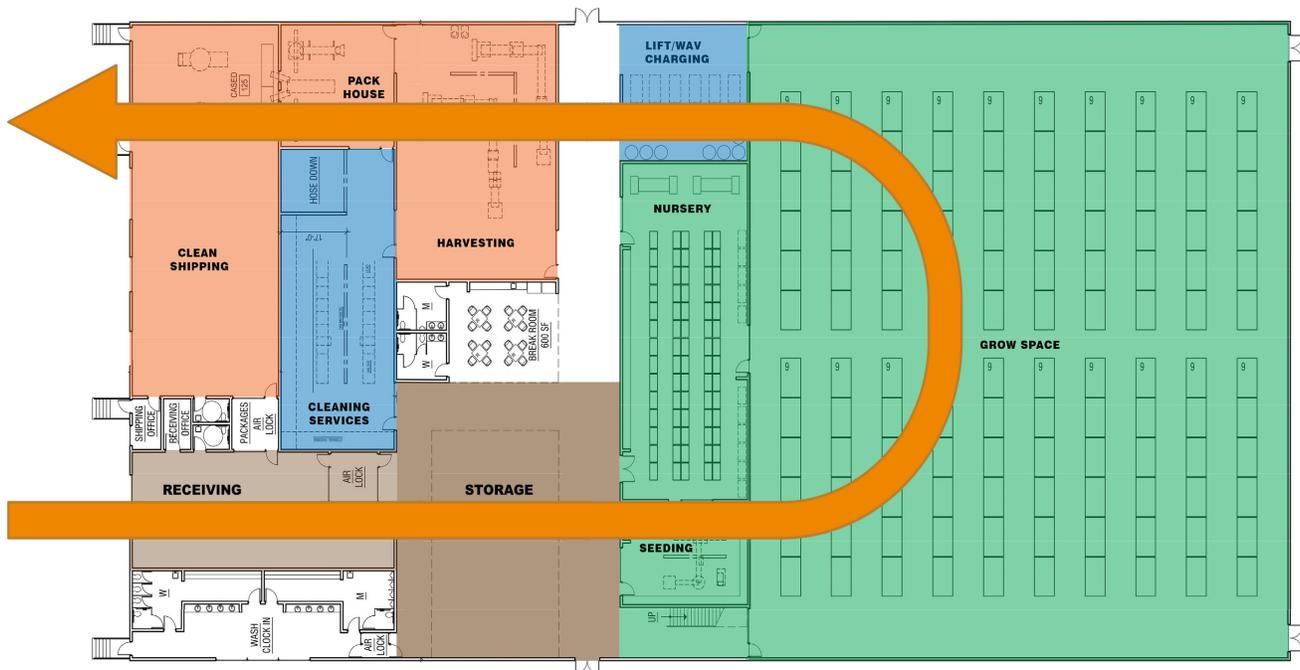


Figure 1. The Farm Works food production process. Image by author.

house, healthy and beautiful in the same way that the working tools and instruments which accompany our existence are beautiful.

—Le Corbusier, *Towards a New Architecture*, 1921²

In this excerpt from *Towards a New Architecture*, Le Corbusier was talking about the “new” materials of reinforced concrete and steel with respect to the ability to construct houses on a mass-production scale and the technological advances that had been made with respect to central heating and electricity. Bear in mind, he was writing in 1921, which was not all that long after alternating current electric lighting became popularized for domestic architecture.

The new mode of living of which Corbu spoke derived from a post-WWI industrial age that was mass producing armaments, airplanes, and cars in factories. To Corbu, this created a new spirit that demanded a rebirth of architecture based on function and a new aesthetic based on pure form – housing that incorporated the principle of mass-production of its individual components and required large-scale industrialization. In this way, the house made of mass-produced or “machined” components becomes itself a “machine for living.” Corbu’s idea of this machine was that it fulfilled its functional purpose for human well-being.³ He developed this idea through his project Maison Citrohan, which was comprised of standard building elements.⁴ However, his idea went much further than mass production and standardization. Corbu’s *machine à habiter* was conceived as a technologically enhanced machine for healthier living that allowed for light and air to circulate through.⁵ This architecture machine could provide humans

with a new, hygienic environment for living that responded to the problems of bodily comfort, ergonomics and health.⁶

The energy use of a building was not considered at this time of rapid industrialization. The energy used to power heating and air conditioning systems for a building was not considered and neither was the waste that occurs during construction, the waste that occurs during renovation of an existing building, nor the environmental costs associated with importing building materials. But things are a lot different now than they were 100 years ago when Corbu wrote this for publication in *L’Esprit Nouveau*. Today, all these things need to be taken into consideration and even more – not only do architects need to design sustainably, they need to design regeneratively which in addition to sustainability considers the whole of the social-ecological system within which the built environment is designed.⁷ This regenerative sustainability paradigm requires a shift from a ‘mechanistic’ to an ‘ecological’ or living systems worldview.⁸ This paradigm shift not only considers the mechanisms of low-energy, low-carbon design but also the connections between living systems themselves so that the built world itself can function analogously to an ecosystem that continuously regenerates itself. Surprisingly, this shift towards a regenerative sustainability paradigm is not too distinct from Traditional Ecological Knowledge, a worldview held by indigenous peoples that all things are connected and all things are related; that people and their creations are indistinguishable from the natural world.⁹ Along these lines, what if a building could be designed as an ecosystem that continuously regenerates plant life for human consumption while using minimal energy for heating, cooling and water?

In the year 1900, only 13% of the world’s population lived in cities. By the time Corbu was writing, 20% of the world was urban. The ratio of urban to rural living reached 50-50 by 2007 and by 2050 it is projected that 68% of the world’s population will live in urban areas.¹⁰ Which means the world’s cities, their land use and supporting infrastructure is growing to meet this demand. Which also means that global energy consumption is increasing, if only with respect to there being more people living on the earth in urban areas who require food and infrastructure to survive.¹¹

CLIMATE CHANGE AND NEW MODES OF BUILDING PRODUCTION

However, the greatest responsibility of the planner and architect, I believe, is the protection and development of our habitat. Man has evolved a mutual relationship with nature on earth, but his power to change its surface has grown so tremendously that this may become a curse instead of a blessing..... Until we love and respect the land almost religiously, its fatal deterioration will go on.

—Walter Gropius, *Scope of Total Architecture*, 1945¹²

As it turns out, buildings are responsible for approximately one-third of global energy consumption and one-third of Greenhouse Gas (GHG) emissions worldwide.¹³ Which means that it is largely up to architects to affect a change in the way buildings are built – by taking into consideration the thermal properties of buildings and the energy buildings will use to keep humans comfortable and healthy, where building materials are sourced, how construction contracts are written to ensure the proper disposal and recycling of building materials for both new construction and renovation, and how architects consider, to quote Gropius, the “scope of total architecture” in how the building operates. When it comes to indoor agriculture, the big question is, “Is it possible to tune a building and its internal operations with the outdoor environment to ensure the lowest possible energy use?”

This is something absolutely critical for architects in the United States to consider. In looking at this country’s energy consumption with respect to the world together with the energy consumed by people in the United States individually, then, for example, while China might be responsible for twice the emissions worldwide as the United States, Americans generate twice as much GHG per capita as China and more than any other country worldwide.¹⁴ Then, how does agricultural production fit into this scenario?

Food production accounts for over a quarter of global GHG emissions. Half of the world’s habitable land, which does not include deserts, the Arctic nor Antarctica, is used for agriculture, which uses 70% of the world’s freshwater. Called eutrophication, 78% of the pollution of our oceans and fresh waterways with fertilizers is due to agriculture (Figure 2).¹⁵

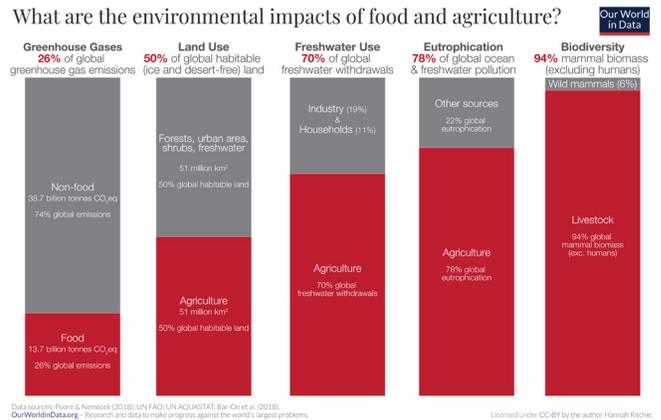


Figure 2. What are the environmental impacts of food and agriculture? Our World in Data.

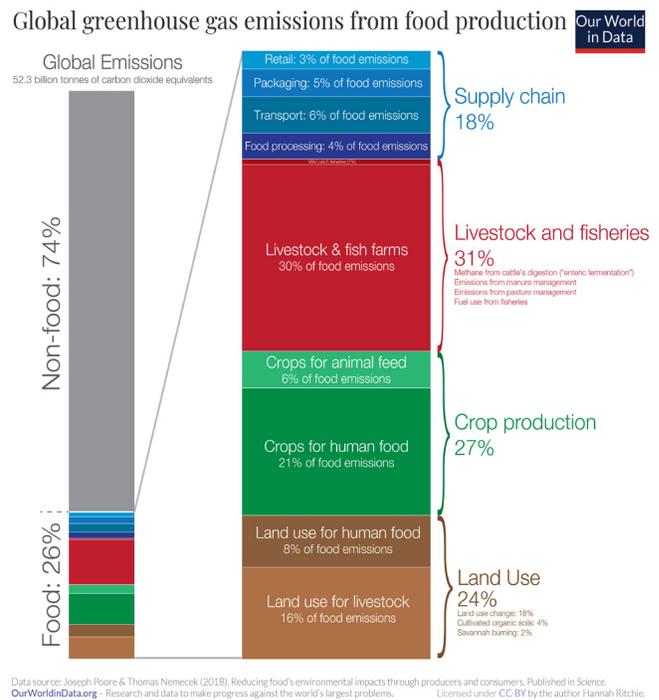


Figure 3. Global greenhouse gas emissions from food production. Our World in Data.

As such, food lies at the very heart of trying to tackle climate change, reducing water stress, pollution, restoring lands back to forests or grasslands, and protecting the world’s wildlife. This is not the first time this has happened in the history of the world. With the introduction of agriculture has come deforestation, soil erosion, disease, and the degradation of vegetative cover. So much so, that in 2,000 BCE occurred the salinization of southern Mesopotamia. So, today’s is not the first civilization to mess things up for the earth.

The global food system, which encompasses production and

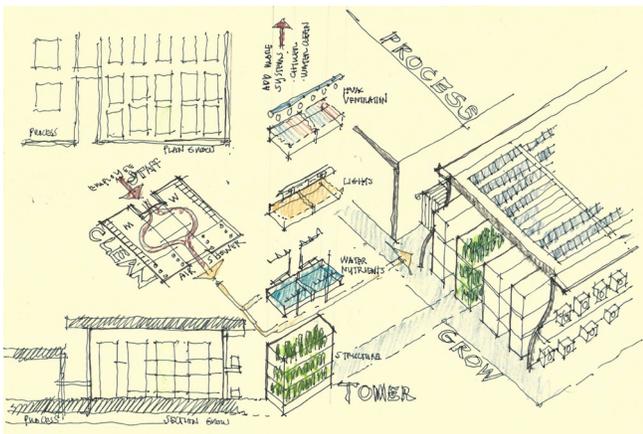


Figure 4. The Farm Works operations. Image by author.

post-farm processes such as processing and distribution, is a key contributor to GHG emissions and is responsible for approximately 26% of global GHG emissions. There are four key elements to the GHG emissions that come from the production and consumption of food: livestock & fisheries, crop production, the use of the land itself for agriculture, and the supply chain (Figure 2).¹⁶

Although food is transported long distances in general, the GHG emissions associated with food are largely due to the production phase itself which contributes 83% of the average U.S. household's yearly carbon footprint. Transportation of the food itself represents only 11% of its life-cycle GHG emissions and only 4% of those emissions are due to final delivery from the producer to the retail store.¹⁷ Food production considered as a whole, including fruits, vegetables, fish and livestock, produces 26% of all global GHG emissions. Of these emissions, the 31% of GHG emissions from livestock production and fishing are due to the methane produced from the digestive processes of livestock, manure management, pasture management, and the fuel consumption from fishing vessels. The 21% of food's emissions from crop production come directly from fertilizers and manure, methane emissions from rice production, and carbon dioxide from the agricultural machinery itself. Land use accounts for 24% of food emissions, but twice as much comes from land use for livestock as for crops for human consumption. Surprisingly, emissions from transportation are only one-third of the 18% of GHG emissions due to the supply chain – the other 12% comes from food waste, either from consumers themselves or supply chain losses due to how the food has been packaged, refrigerated or processed (Figure 3).¹⁸ However, still two-thirds as much energy is consumed transporting food as is used to grow the food itself.¹⁹

In summation, agriculture produces 26% of the world's greenhouse gasses, uses 50% of global habitable land, and uses 70% of available freshwater worldwide – and, the population of the earth is increasing, which means that more resources will be

needed to feed the world. To follow is an exploration of the Farmworks as a building-machine for growing food that significantly reduces the carbon footprint of agricultural production and the amount of land used for growing food, which also has the potential to feed the world's growing urban population while reducing the production of greenhouse gases.

HOW THE FARMWORKS WORKS

We will now inquire of *Plants* or *Vegetables*: And we shall do it with diligence..... But the most admirable *Acceleration* by *Facilitating* the *Nourishment*, is that of *Water*.... It seemeth by these *Instances* of *Water*, that for *Nourishment*, the *Water* is almost all in all, and that the *Earth* doth but keep the *Plant* upright, and save it from *Over-heat*, and *Over-cold*....

—Francis Bacon, *Sylva Sylvarum*, 1626²⁰

Water is the most important ingredient in the production of food, important enough for Francis Bacon to include it as part of his natural history research in the 17th century. Although agriculture is the largest consumer of fresh water, hydroponic agriculture is the most water-efficient form of agricultural production because it surprisingly consumes up to ten times less water than traditional agriculture. Growing vegetables without the use of soil, a hydroponic system can decrease water usage by up to 97% from traditional farming. Further, hydroponics eliminates eutrophication, pollution that comes from the chemical pesticides and fertilizers associated with farming the land.²¹

The Farmworks is a building which is a machine for producing nutritious food that addresses the adverse environmental impacts of food production from two aspects of GHG emissions: from agricultural production and from building operations to maintain ideal growing conditions 24 hours per day. Located within this singular 40,000 square foot building are all farming operations, from receiving the seeds, to germinating them in the nursery, growing the produce in vertical towers in the grow space, to harvesting and then packaging the produce in novel recyclable containers, and palletizing the product for shipping, even if shipping to a grocery store that could be located next door (Figure 4). When integrated with the urban environment, this farm has the potential to significantly reduce fossil fuel consumption, reduce GHG emissions, conserve building energy and improve urban ecology. Further, the Farmworks also has the potential to enhance food safety, security and access thereby enriching the lives of city dwellers, especially when located nearby those living in underrepresented areas of the city.

What has not yet been discussed is the nutritional value of this type of agricultural production. Vegetables in the grocery store are expected to be the right color, ripe and ready to eat, which is difficult to obtain due to the shipping time that occurs

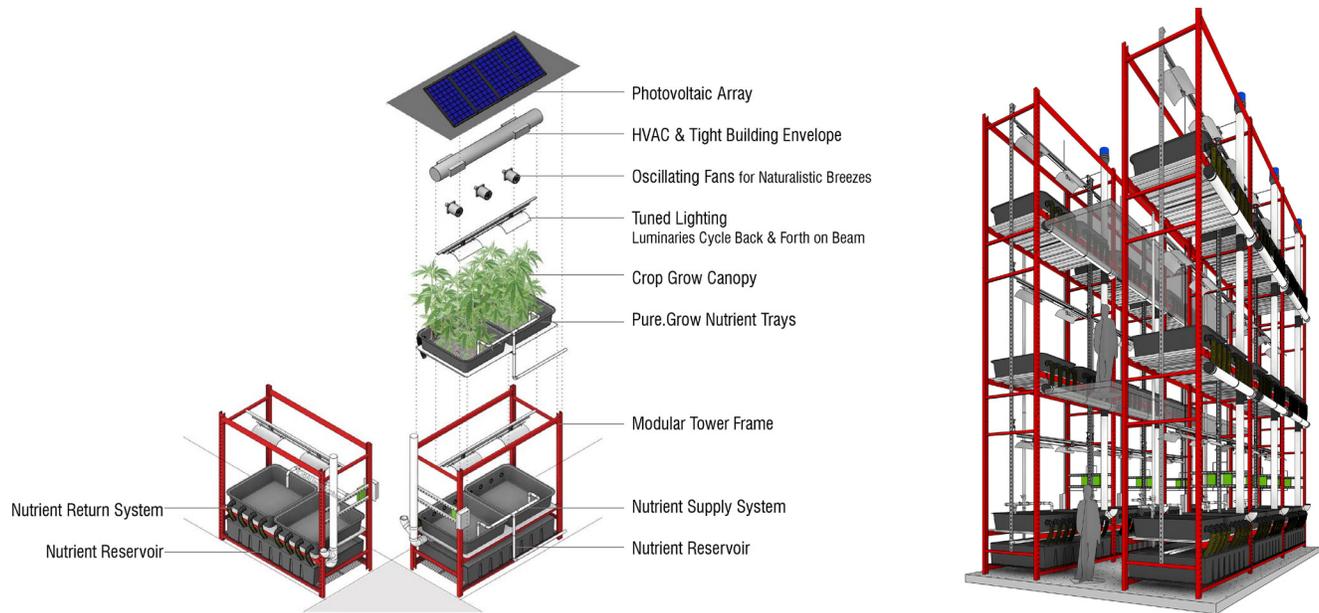


Figure 5. The Farm Works Grow Tower. Rendering by Dylan Catino.

with transportation distances of up to 3000 miles. For example, tomatoes on the shelf are expected to be red and ripe, but instead are harvested with shelf life in mind while still green and are allowed to ripen during transportation, or worse, in ethylene chambers, which damages flavor, nutritional quality and can have a negative impact on health.²²

The Farmworks is building-integrated agriculture with indoor environmental conditions that vary from traditional temperature and humidity settings for the general work environment to the grow spaces which are set at 75 degrees Fahrenheit with 50% humidity and the harvesting and packaging areas which are set at 38 degrees Fahrenheit. Additionally, cleaning services require the use of 165-degree Fahrenheit water. In other words, within this one facility one can move from environments as diverse as a tropical rainforest to the arctic north. This means that, unequivocally, the Farmworks must be designed like a well-oiled machine to prevent moisture from condensing in the building envelope due to these vast temperature differentials with respect to outdoor thermal conditions and seasonal variation. In sum, water, temperature, humidity, carbon dioxide levels, light and nutrients need to be precisely controlled by the HVAC system together with thermal design of the building envelope itself to prevent moisture from condensing in the exterior walls.²³

There are 120 towers in the Grow Space that vary in height from three levels to eight levels depending on the crop (Figure 5). The 8-level, 120-tower Grow Space (Figure 1) in this facility produces 26 crops per year, yielding thousands of pounds of produce in this approximately one-acre, 40,000 square-foot facility. The growing process itself has two stages: the seeds are germinated in the nursery and then transplanted to trays

for the vertical towers. This itself is old technology – in 30 AD farmers figured out that if they first germinated the seeds and then transplanted them outdoors, they could decouple the plant from the first part of the growing cycle, which then could extend the growing season to two harvests, if not three, weather permitting. Research Francis Bacon continued centuries later in *Sylva Sylvarum*.

Today, researchers at Cornell have maximized greenhouse growing so that at their one-level hydroponic greenhouse, they can grow 7.66 pounds per square foot of produce in one year with 10.5 harvests per year. At The Farm Works, using their proprietary hydroponic growing methods, there are 26 harvests per year at their 8-level vertical farm, which yields close to 300 pounds per square foot per year, the equivalent of 37 pounds per square foot on a single level – almost 5 times the yield at Cornell. Additionally, at Cornell it takes 80 gallons of water to yield 4.4 pounds of romaine lettuce. The Farm Works method uses 90% less water.²⁴

At The Farm Works, the building interior is tuned to optimize a particular plant's needs for light and the appropriate wavelengths for germinating, growing and flowering; the interior temperature can be adjusted to support the different temperature requirements for growing, harvesting, packaging and shipping (with temperature ranges from 38-75°F); water is supplied with the appropriate nutrients for a specific plant, eliminating the need for organic fertilizer, which also reduces the likelihood of introducing bacteria or insects into the food; the planting beds can be stacked vertically, safely accessed via a forklift; the distance between the light source and the plant varies with the height of the plant, moving higher as the plant grows taller; and the growing day can be shifted with respect

to the outdoor environment to equalize the heat produced by the lighting indoors with outdoor temperatures and seasonal variation.

CONCLUSION

Farmworks is a machine for growing: the wavelength of the lighting in this indoor environment is tuned to optimize plant growth and moves vertically in pace with the plant's height, the HVAC system keeps temperature and humidity optimal, and the building envelope is insulated and pressurized to balance interior and exterior conditions and to prevent water from condensing in the exterior wall.

At The Farm Works the entire supply chain of food production occurs in one building, the footprint of which is approximately one acre. However, The Farm Works produces the equivalent of one acre of land per year by using only two-and-a-half of these 4'x9' towers. Or, framed differently, this one-acre sized facility can produce the equivalent of an 1800-acre traditional farm.²⁵ This is land that could be freed up to return back to a natural landscape to promote biodiversity or to help restore the global forest loss due to the deforestation that has come about due to permanent land use change for commodity production such as farming.²⁶ Additionally, with The Farm Works proprietary growing methods, this farm uses a fraction of the water. Although it might use more electricity than if naturally illuminated by the sun, this farm's circadian lighting is consistent regardless of weather or season and is optimized – its LED lighting is tuned specifically for each plant type's growing needs to optimize growth, flavor and nutrition. Even though the building uses an HVAC system to maintain ideal growing conditions, the growing day itself can be shifted with respect to thermal conditions outdoors to conserve energy. While transportation is only responsible for 6% of food emissions, locating this facility near to a food distribution center, or grocery store, will still reduce greenhouse gas emissions by close to that 6%.

Integrating farms into the built environment has the potential to significantly reduce fossil fuel consumption, improve urban ecology, enhance food safety and security, enrich the lives of city dwellers and conserve building energy.²⁷ The production of food from farmland has many external factors that affect its viability and productivity including the availability and fertility of land, the length of the growing season, freshwater endowments, pest occurrences, CO2 fertilization, and the frequency of extreme events related to droughts, flooding, fire, and frost. On the other hand, a V-LIFE farming enterprise has the potential to facilitate global food production and positively impact many fundamental objectives of societies including the reduction of malnutrition and poverty, improved access to a healthy diet, better management and allocation of fresh water resources, and the protection of climate, ecosystems and biological diversity.²⁸

ENDNOTES

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