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Farming the Bronx: The Potential for Controlled-Environment Agriculture to Address Environmental Degradation and Urban Social Issues

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Farming the Bronx: The Potential for Controlled-Environment Agriculture to Address Environmental Degradation and Urban Social Issues

by Reyna Wang
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Abstract

This paper and design proposal explores the possibilities of controlled-environment agriculture (CEA) to address the issue of impending global food insecurity and widespread loss of ecosystem services while providing communities in the Bronx with tools for social empowerment. Chapter 1 presents quantitative data from sources like the Millenium Ecosystem Assessment regarding the widespread environmental impacts of industrial agriculture and shows how these harmful impacts can be limited or reduced through a transition to CEA in urban areas. Chapter 2 describes CEA design methods and technologies that can be combined in different ways to suit a diverse variety of settings and functions in dense urban areas, focusing on making use of underutilized spaces and creating closed-loop systems. Chapter 3 shows the potential cultural, health, and economic benefits of CEA in urban areas, with a focus on the Bronx. Chapter 4 consists of a design proposal for an urban CEA complex to be situated in the South Bronx, drawing from the research presented earlier in the paper.
In the last 50 years, the burgeoning human population has changed the earth’s ecosystems more rapidly and dramatically than at any other point in human history, largely to meet growing demands for food. From 1960 to 2000, the world population doubled to 6 billion, and food production increased about two-and-a-half times to meet the growing demand. This was made possible by increases in the area of cultivated land, improvements in genetic technology, the expansion of irrigation infrastructure, and the increased use of mechanization and agrochemicals characteristic of industrial agriculture.¹ Today, the total land we use for growing crops is equivalent in area to the continent of South America. Including animal husbandry, this means about 80 percent of all available dry land is used for agriculture. Population experts predict that within the next 40 years, the population will have grown by three billion people. If agricultural productivity per unit of land does not change, this additional three billion people will need to be fed by a land mass the size of Brazil.²

Though industrial technologies combined with increased land and water use have allowed food production to keep up with population growth in the past, it seems that we have come to an impasse, as a Brazil’s worth of arable land simply does not exist.³ The continued availability of fossil fuels and raw materials used in chemical fertilizers, on which dominant agricultural methods are heavily reliant, is also highly uncertain.⁴ Furthermore, increasing food production using current methods has come at the cost of many other ecosystem services and is a leading

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³ Despommier, The Vertical Farm, 96.
cause of climate change, which will, in turn, lead to an aggregate decrease in agricultural productivity since more and more crops are rendered unable to grow to maturity due to the rising incidence of extreme weather events like hurricanes, droughts, and floods.\textsuperscript{5} Increased fluctuation in patterns of temperature and precipitation will cause crops that were once able to grow in a certain region to quickly become unfit for that region, resulting in greater likelihood of crop failure as farmers struggle to adapt to these changes in climate.\textsuperscript{6} Even if greenhouse gas emissions were halted immediately, greenhouse gases already released into the atmosphere will inevitably contribute to the earth’s warming over the next hundred years. Genetically modifying crops has helped to protect them from environmental hazards, but such modification is time consuming and expensive and thus unlikely to defend crop yields against rapid environmental changes in the coming decades.\textsuperscript{7} In addition to food shortages, water shortages, which are largely a result of our reliance on massive irrigation schemes to grow crops, are expected to increase: the United Nations predicts that that severe water shortages, which currently affect at least 400 million people, will affect 4 billion people by 2050.\textsuperscript{8} Continuing to rely on mainstream intensive farming techniques to meet the demands of a growing population does not bode well for the sustained well-being of humans or the biosphere, whose fates are inextricably linked. There must be a new agricultural revolution—one driven by the development of technologies that can increase crop yields without increasing harmful environmental impacts.

It is also important to note that food insecurity is not an issue of the future. Although enough food is currently produced to feed the entire human population, inequitable distribution

\begin{itemize}
\item \textsuperscript{5} Millennium Ecosystem Assessment, \textit{Ecosystems and Human Well-Being}, 6.
\item \textsuperscript{6} Intergovernmental Panel on Climate Change, \textit{Climate Change 2014 Synthesis Report: Summary for Policymakers} (Geneva, Switzerland: IPCC, 2014), 16.
\item \textsuperscript{7} Despommier, \textit{The Vertical Farm}, 108-16.
\item \textsuperscript{8} Despommier, \textit{The Vertical Farm}, 234.
\end{itemize}
means that many less industrialized countries have already been suffering from severe food shortages, and even under-resourced communities in the United States, one of the wealthiest nations in the world, face challenges related to food security. One of these communities is the Bronx in New York City. A recent study ranked the South Bronx as the most food insecure neighborhood in the nation due to its residents’ lack of access to affordable, healthy food compounded by poor nutritional education. This lack of access is directly linked to health risks like obesity, diabetes, and heart disease. The Bronx is also disproportionately impacted by other public health hazards like air pollution, which causes it to have higher rates of asthma hospitalizations than any other borough.⁹

Controlled-environment agriculture (CEA) in urban areas could be an effective way to address both impending global food insecurity and current urban health concerns. CEA is a method of food production that uses an enclosed growing structure to protect crops from averse outdoor conditions and to allow for the careful maintenance of factors such as temperature, humidity, light, and nutrient concentration so crops can be grown under optimal conditions year round.¹⁰ Urban CEA systems can exist in various configurations, from a traditional greenhouse structure to a forward-thinking vertical farm, a building that supports food-production on multiple floors. CEA is often paired with hydroponics or aeroponics, methods of growing plants without soil that require controlled conditions and are advantageous in that they produce faster plant growth while using significantly less water than traditional soil-based agriculture. With the exception of aquaponics, which involves fish farming, I will primarily be discussing strategies

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for crop production, for though it is possible to raise certain animals in urban CEA systems, this process is less researched and less practical in the formative years of CEA.

Controlled-environment farms can be constructed on rooftops, converted from vacant buildings, and integrated into existing urban infrastructure, preserving ecosystems that would have otherwise been destroyed for agriculture while providing ecosystem services like stormwater management and air purification, which improve health in urban environments. Urban agriculture can also provide a variety of social benefits to urban communities, especially marginalized ones. Commercial farms can create jobs and improve access to fresh, nutritious food, while community gardens strive to educate and build community. While one may not expect to see hi-tech CEA systems pop up in the Bronx, with the appropriate design, funding, and community support for these systems, the neighborhood could be very well-suited to pioneering the future of urban agriculture. Perhaps the most important role of urban CEA in its early stages is to act as a catalyst for systemic shifts in food production and consumption throughout the world, moving us towards a more globally sustainable and food secure future.

In Chapter 1, I will present quantitative data regarding the widespread environmental impacts of industrial agriculture and show how these harmful impacts can be limited or reduced through a transition to CEA in urban areas. In Chapter 2, I will describe CEA design methods and technologies that can be combined in different ways to suit a diverse variety of settings and functions in dense urban areas, focusing on making use of underutilized spaces and creating closed-loop systems. In Chapter 3, I will show the potential cultural, health, and economic benefits of CEA in urban areas, with a focus on the Bronx. In Chapter 4, I will synthesize the
ideas presented earlier in the paper by presenting design proposal for a CEA project to be situated in the South Bronx.

Chapter 1: Widespread Environmental Impacts

As the United States Department of Agriculture states, “Agricultural nonpoint source pollution is the primary cause of pollution in the U.S.” The main forms of pollution that result from agriculture are water pollution due to agricultural runoff and air pollution due to greenhouse gas emissions, both of which have far reaching, harmful impacts on the world’s ecosystems. Other environmental impacts of current agricultural practices include the intensive use of fresh water, the generation of large amounts of waste, and deforestation. 60 percent of the ecosystem services examined in the Millennium Ecosystem assessment are being degraded or being used unsustainably, including fresh water, capture fisheries, air and water purification, and the regulation of regional and local climate, natural hazards, and pests, and this is largely an expense of actions taken to increase the ecosystem service of food provision; in fact three of the only four ecosystem services that have been enhanced since 1960—crops, livestock, and aquaculture—involves food production. As the ecosystem service of food provision ultimately depends on other ecosystem services, our current method of food production threatens its own ability to be sustained.

The vast majority of agricultural practices involve the use of large quantities of chemical fertilizers to make nutrient-depleted soils viable for growing crops. Commonly used irrigation methods such as flood irrigation contribute to millions of tons of agricultural runoff, which are

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11 Despommier, The Vertical Farm, 151.
12 Millennium Ecosystem Assessment, Ecosystems and Human Well-Being, 2-6.
laden with these fertilizers as well as leftover salts, silt, herbicides, fungicides, and pesticides.\textsuperscript{13}

When this runoff eventually reaches lakes and estuaries, it causes overloading of nutrients found in fertilizers like nitrate and phosphates, a process called cultural eutrophication. Once a threshold of nutrient loading has been reached, eutrophication can lead to explosive algae blooms during hot weather or drought that reduce the amount of dissolved oxygen in the water when the algae decomposes, creating oxygen-depleted hypoxic zones. Some types of algae blooms, including red, brown, and green toxic tides, also release waterborne and airborne toxins that can poison aquatic animals as well as some fish-eating birds. According to the U.S. Environmental Protection Agency, about 85 percent of large lakes near U.S. population centers experience some degree of cultural eutrophication.\textsuperscript{14} Estuaries typically function as nurseries for marine fish, crustaceans, and mollusks, but in the last 30 years, most of the world’s estuaries have lost this ability because they have been overwhelmed by runoff.\textsuperscript{15} A 2008 study by marine scientists Robert Diaz and Rutger Rosenberg found that at least 400 oxygen-depleted zones form in coastal waters around the world every year due to harmful algae blooms, and about 43 of these occur in U.S. water.\textsuperscript{16} The resulting collapses of marine ecosystems as well as the bioaccumulation of agrochemicals in fish and shellfish have forced the U.S. to import around 80 percent of it’s seafood.\textsuperscript{17} Transitioning to urban CEA would improve the health of aquatic ecosystems by producing no agricultural runoff, and systems that include rainwater collection strategies would additionally reduce water pollution by mitigating stormwater runoff and flooding in urban areas.

\textsuperscript{13} Despommier, \textit{The Vertical Farm}, 31.
\textsuperscript{14} G. Tyler Miller and Scott Spoolmann, \textit{Living in the Environment} (Boston: Cengage Learning, 2018), 535-44.
\textsuperscript{15} Despommier, \textit{The Vertical Farm}, 30.
\textsuperscript{16} Miller and Spoolmann, \textit{Living in the Environment}, 544.
\textsuperscript{17} Despommier, \textit{The Vertical Farm}, 152.
Related to the issue of runoff is the rapid depletion of fresh water for agricultural use. Since 1960, water withdrawals from rivers and lakes have doubled along with the amount of water being impounded behind dams. 70 percent of this fresh water worldwide is used for agriculture. Most farms rely on water intensive methods of irrigation to supplement rainfall, the exception being drip irrigation, which is much less common than other methods. The use of fresh water is already well beyond a level that can be sustained at current demands, and 15 to 35 percent of irrigation withdrawals exceed supply rates. The unsustainable use of fresh water poses great risks to ecosystems as well as food security around the world. For example, around 20 percent of agriculture in the U.S., including the cultivation of more than half of the country’s fruits, vegetables, and nuts, takes place on large-scale farms in California, especially in the Central Valley. Farming in this region requires massive irrigation schemes since the its climate is hot, dry, and naturally suited for semidesert plants. The transportation of large quantities of fresh water over great distances accounts for about 20 percent of California’s electricity usage. The combined use of agrochemicals and flood irrigation and has caused salts and toxins to seep into the groundwater, threatening crops as it rises towards their taproots. As the aquifer has been contaminated and availability of fresh water from snowpack in the mountains is decreasing every year due to climate change, Department of Energy Secretary and Nobel Prize winner Steven Chu predicts that the entire agricultural sector of California will become obsolete in less than 40 years due to the lack of a source of non-contaminated fresh water, and and he warns that

19 Despommier, *The Vertical Farm*, 151.
the same will happen to other Western U.S. states.\textsuperscript{24} This would result in an estimated loss of more than 30 billion dollars in agricultural revenue.\textsuperscript{25} Most CEA systems would conserve significant amounts of water by using non soil-based methods of growing, such as hydroponics, which uses around 70 percent less water than traditional soil based agriculture, or aeroponics, which uses around 70 percent less water than hydroponics.\textsuperscript{26} Ideally, they would also be equipped with rainwater catchment and water purification systems, potentially creating a closed-loop system in terms of water use.

Agriculture is also a major source of greenhouse gas emissions, which are the leading cause of rapid climate change. Since 1750, atmospheric concentration of carbon dioxide has increased about 32 percent, primarily as a result of the combustion of fossil fuels and land use changes.\textsuperscript{27} Climate change has the potential to cause drastic and permanent damage to ecosystems and the services they provide. It also threatens agricultural productivity by increasing the prevalence of extreme weather events, raising sea levels, and making crops more susceptible to weeds, diseases, and pests.\textsuperscript{28} While the U.S. consists of under 5 percent of the world’s population, it accounts for 25 percent of the world’s energy consumption.\textsuperscript{29} Thus, the country bears greater responsibility for reducing greenhouse gas emissions and mitigating climate change, the effects of which are already decreasing quality of life in less wealthy areas of the world. Since more than 20 percent of all fossil fuels in the U.S. is consumed by the agriculture industry, it is necessary to transition to less energy intensive methods of food production in order

\textsuperscript{24} Tankersley, “Chu.”
\textsuperscript{25} Despommier, \textit{The Vertical Farm}, 122.
\textsuperscript{26} Despommier, \textit{The Vertical Farm}, 208.
\textsuperscript{27} Millennium Ecosystem Assessment, \textit{Ecosystems and Human Well-Being}, 4.
\textsuperscript{29} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 66.
to avoid reaching climate change tipping points that could lead to widespread social unrest.\textsuperscript{30} A large portion of agricultural greenhouse gas emissions result from processes like transporting water great distances, the use fertilizers and pesticides, extensive food miles, and mechanized plowing, seeding, weeding, and harvesting. With regard to the use of fertilizers, greenhouse gas emissions result from more than just industrial manufacturing and mechanized application; after fertilizers have been applied to plants, further emissions of nitrous oxide ensue, a greenhouse gas that is 310 times more potent than carbon dioxide.\textsuperscript{31} All of these energy intensive processes would be diminished or rendered unnecessary by CEA in urban areas.

One of the clearest benefits of urban agriculture is its ability to significantly reduce food miles. The concept of food miles is the distance food has traveled from farm to plate through all stages of the supply chain. An often cited statistic claims that on average, food travels 1,500 miles from farm to fork. While this number may already seem high, it is in reference to fruits and vegetables sold at Chicago Terminal Market in 1998; considering that globalization of the food industry has increased and that primary growing regions are located in the West, it is probable that produce sold in New York City today travels a much greater average distance.\textsuperscript{32} Furthermore, processed foods have greater food miles since the journey of their ingredients from farm to plate involves transportation to processing and packaging plants. Generally, the more heavily processed a food is, the greater its food miles. More food miles typically means more fossil fuels are burned during the transportation process. Even if shipping produce across the country by rail may in some cases be more energy efficient than transporting the same amount

\textsuperscript{30} Despommier, \textit{The Vertical Farm}, 100.


\textsuperscript{32} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 66.
regionally in small trucks, the shorter amount of traveling time associated with local agriculture allows for the decreased use of energy intensive preservation methods like refrigeration, processing, packaging, and pesticide spraying, and it also limits noise pollution. Moreover, long distance transport leads farmers to specialize in growing a small number of crops, creating monocultures that are more susceptible to pests and diseases, which quickly develop resistance to fertilizers and pesticides and cause farmers to be stuck on an increasingly energy demanding “chemical treadmill” as they are forced to apply more and more agrochemicals to maximize crop yields. A study by Peter Chapman in 1975 showed that fertilizers and transport accounted for 37.6 percent of the nonrenewable energy used to produce a loaf of bread, and the percentage would probably be higher for an average loaf of bread today. Urban CEA systems would not require the use of chemical fertilizers, and by installing these systems above or next to grocery stores, restaurants, schools, hospitals, prisons, and apartment complexes, food miles could be eliminated altogether, saving fossil fuel that would have traditionally been burned for transportation and refrigeration. A proposal for a combined farm, grocery store, and restaurant, named Agropolis, explores the concept of offering shoppers the unique experience of harvesting their own produce, as it would be grown directly in the store. Additionally, since consumers in wealthy, industrialized countries like the U.S. are accustomed to having a wide variety of food options year round, many foods must be imported if or when growing conditions within the country cannot support their production, leading to significant greenhouse gas emissions from air

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33 Ackerman, *The Potential for Urban Agriculture in New York City*, 69.
34 Viljoen, Bohn, and Howe, *Continuous Productive Urban Landscapes*, 41.
35 Viljoen, Bohn, and Howe, *Continuous Productive Urban Landscapes*, 23.
36 Gorgolewski, Komisar, and Nasr, *Carrot City*, 155.
and boat transport. CEA supports the complete or near complete regulation of growing conditions, allowing crops from around the world to be locally produced during any season.

Current large-scale agricultural practices also contribute to large amounts of waste, much of which ends up in landfills. More than 40 percent of food produced in the U.S. is not consumed, which is lamentable considering the energy and resource intensive nature of mainstream food production and the presence of food insecurity around the world. CEA can reduce waste generated by the production and distribution stages of the food supply chain, including inorganic waste like transit packaging. Production losses account for 20 percent of the losses in fruits and vegetables. Crops may not be harvested due to damage by pests, disease, and adverse weather conditions, and often, farmers will plant more crops than there is demand for as a defense against these losses. Though unharvested crops are usually plowed under so that their nutrients returned to the soil, this consequence still represents an inefficient use of water and energy. In the U.S., around 7 percent of planted fields are not harvested, and Feeding America estimates that 6 billion pounds of fresh produce go unharvested or unsold each year. CEA systems would shelter crops from these environmental threats, reducing the amount of food waste that results from damage during the farming process. Distribution and retail account for 12 percent of losses in fruits and vegetables. Since much produce is perishable, losses occur when truck malfunctions and accidents lead to inconsistent refrigeration or when produce sits on loading docks for too long. The more time perishable food spends in transit, the shorter its shelf 

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37 Viljoen, Bohn, and Howe, *Continuous Productive Urban Landscapes*, 41.
38 Ackerman, *The Potential for Urban Agriculture in New York City*, 71.
39 Viljoen, Bohn, and Howe, *Continuous Productive Urban Landscapes*, 44.
life, and the shorter its shelf life, the more likely it will spoil before it is purchased and end up in a landfill. By minimizing food miles, urban agriculture would reduce losses in this sector. The issue of food waste is linked to climate change because in the U.S., the anaerobic decomposition of uneaten food in landfills accounts for 23 percent of emissions of methane, a greenhouse gas at least 25 times more powerful than carbon dioxide in global warming potential.42

Today, one fourth of the earth’s terrestrial surface is covered by cultivated systems, defined by areas where at least 30 percent of the landscape consists of croplands, shifting cultivation, confined livestock production, or freshwater agriculture. More than two thirds of the area of 2 of the world’s 14 major terrestrial biomes and over half of the area of 4 others have been converted primarily to agriculture, and this destructive human activity has increased the species extinction rate by as much as 1,000 times faster than background rates typical of the planet’s history. Currently, between 10 and 30 percent of mammal, bird, and amphibian species are endangered.43 By integrating agriculture into the urban fabric, less land would need to be converted to farmland to support the growing population, preserving ecosystems and their ecosystem services. If enough food can be produced in urban areas, farmland could even be converted back to its original ecosystems, and the regrowth of what would in most cases be forests could sequester carbon from the atmosphere, moderate severe weather events like floods, and increase biodiversity.44 Though this may seem like an unlikely prospect considering the vast amount of land required to produce food traditionally versus the limited space available in urban areas, raising crops indoors requires 10 to 20 times less acreage than raising the same amount of crops outdoors because crops in controlled environments can be grown year round, crops grow

42 Gunders, Wasted, 14.
43 Millennium Ecosystem Assessment, Ecosystems and Human Well-Being, 2-4.
44 Despommier, The Vertical Farm, 145.
faster using hydroponic or aeroponic methods, and no crops would be lost due to adverse weather.\textsuperscript{45} History has shown that in many cases, abandoned farmland quickly returns to its previous ecological state without the need for human restoration efforts. For example, after the dust bowl in the American Midwest, farmland naturally returned to tall- and short-grass prairie in 20 years, and in the American Northeast, hardwood forest has regrown after being clear-cut 3 times for failed attempts at farming. If all the cultivated land in Ohio, Indiana, Illinois, and Iowa were to be converted back to hardwood forest, the forest would consume about 10 percent of U.S. carbon emissions per year once it reached maturity in 30 to 40 years.\textsuperscript{46}

Controlled-environment urban farms can also reduce the ecological footprint of urban areas. Rooftop greenhouses provide passive insulating benefits to existing buildings. In the winter, rooftop greenhouses decrease energy use for heating in the building below by reducing thermal energy lost through the building roof. Unlike open-air green roofs, whose insulating capacity decreases in the winter when plants become dormant, rooftop greenhouses store excess heat on cold but sunny days to insulate the building below. In the summer, demand for air conditioning in urban areas is especially high due to urban heat island effect, which raises local temperatures due to the prevalence of non-reflective, impervious surfaces like concrete that absorb a high percentage of incoming solar radiation. Urban heat island effect increases New York City’s temperature by an average of 2 to 4 degrees Celsius throughout the year compared to surrounding suburban and rural areas, and, exacerbated by climate change, it increases energy used for air conditioning, which accounts for one sixth of all electrical energy use in the U.S. Rooftop greenhouses help to mitigate this effect while providing insulation through passive and

\textsuperscript{45} Despommier, \textit{The Vertical Farm}, 100.
\textsuperscript{46} Despommier, \textit{The Vertical Farm}, 155-60.
low-energy cooling methods, such as ventilation and evaporative cooling. These methods can yield net energy savings since the energy inputs needed for water and fans are lower than the energy inputs needed to cool buildings through conventional air conditioning. By reducing energy inputs needed for heating and cooling, a rooftop greenhouse can save a building 13 to 41 percent of its original energy load year round.\textsuperscript{47} Urban CEA systems should also be built with rainwater catchment systems to reduce water needs and mitigate stormwater runoff, which is a significant problem in New York City because it causes combined sewage overflow to pollute the city’s waterways. Furthermore, by increasing access to fresh fruits and vegetables and reuniting consumers with the origins of their food, urban agriculture can raise overall awareness about the food system and shift dietary choices away from energy intensive and generally less nutritious foods like meats, oils, and highly processed foods.\textsuperscript{48}

All people are entirely dependent on the world’s ecosystem services, which provide us with necessities and amenities like food, water, disease management, spiritual fulfillment, and aesthetic appreciation. In order to feed a rapidly growing population, we have drastically transformed terrestrial biomes for agricultural purposes, increasing the provision of food at the cost of most other ecosystem services. Though this transformation has resulted in significant net gains in human well-being by increasing food security around the world, the harmful trade-offs of expanding and intensifying agriculture are deferred to poor people in developing countries.\textsuperscript{49} These trade-offs are also deferred to future generations, as ecosystems exhibit substantial inertia, meaning that a long period of time often passes after a disturbance before the magnitude of its consequences becomes fully apparent. The impact of the accumulation of phosphorus in

\textsuperscript{47} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 66-69.
\textsuperscript{48} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 69.
\textsuperscript{49} Millennium Ecosystem Assessment, \textit{Ecosystems and Human Well-Being}, 1-10.
agricultural soils on the eutrophication of aquatic ecosystems, for example, may not become
fully apparent until decades after the damage has been done. An ecosystem’s response to
disturbances may also be nonlinear, a phenomenon that increases in frequency when biodiversity
loss decreases resilience or when there are multiple types of pressure exerted on an ecosystem.
For instance, deforestation, driven primarily by the expansion of agriculture, leads to decreased
rainfall, which, in turn, decreases forest heath, forming a feedback loop that could lead to a
decrease in forest cover that is nonlinear in relation to rates of deforestation. Thus, our current
agricultural practices seem to be improving human health in the short-term, but they could inflict
unpredictable amounts of damage upon ecosystems in the long-term.

In order to protect people, both present and future, from the harm of diminished
ecosystem services, we must revolutionize our agricultural methods, reducing their
environmental impacts while increasing the quantity and quality of food produced. Minimizing
land use, water use, agricultural runoff, food miles, and weather-related crop failures while
supporting year-round crop production and ecosystem restoration, urban CEA is a promising
candidate for the future of sustainable agriculture, and farmers, researchers, architects,
community leaders, educators, and entrepreneurs are increasingly exploring and embracing its
potential.

Chapter 2: Strategies for Design
The design of urban CEA systems should follow the principle “form follows function.”
This principle has its roots in process of evolution, which led to the formation of the nutrient

50 Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being*, 11-12.
cycles that have sustained life on Earth as we know it for more than 400 million years.\(^5\) Directly speaking, the function of urban agriculture is to produce fresh, local food for the residents of a city, but in a more comprehensive sense, the goal of urban agriculture is to integrate bioproductivity into the urban fabric so that cities can mimic ecological recycling processes, which have proven to be tremendously resilient. Ecosystems cannot exceed the limits of their bioproductivity, which is determined by the amount of solar energy captured by primary producers that allows nutrients to be cycled through the food web.\(^5\) This means that cities cannot become the self-sufficient, closed-loop functional equivalents of ecosystems unless they produce their own food, and the consequences of leaving production and consumption loops open are manifested in the ecologically devastating impacts of conventional large-scale agriculture. Thus, the form of CEA structures should be determined by how they can incorporate innovative design methods and emerging technologies to maximize bioproductivity while relying as much as possible on renewable energy and recycled inputs of nutrients, including water. Since there is no waste in ecosystems, the CEA design must also facilitate the efficient conversion waste back to energy and nutrients.

Another crucial design consideration is how to integrate CEA into a preexisting urban areas. The factor of limited space presents challenges to incorporating a significant amount of urban agriculture into an area like the Bronx, where development is dense, land is extremely expensive, and there is much competition for land use, but pioneers in urban farming have overcome this challenge by making opportunistic use of urban waste spaces, such as rooftops, abandoned buildings, vacant lots, and intersections of urban infrastructure. These marginal

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5 Despommier, *The Vertical Farm*, 180.
52 Despommier, *The Vertical Farm*, 17-19.
landscapes are often more commonly found in low-income communities and can increase social isolation and crime rates.\textsuperscript{53} A study by the New York City Department of Information Technology and Telecommunication in 2007 showed that the Bronx had 529 acres of unused roofs, 629 acres of vacant land, and 32 acres of underutilized open space.\textsuperscript{54} Thus, there is an abundance of opportunities to transform these idle spaces into productive urban farms.

Considering the social benefits of urban CEA brings up another important question: What social benefits should be prioritized when designing an urban farm? A commercial farm maximizes local food production and paves the way for the future of agriculture, and in many cases it also stimulates the local economy and increases access to healthy food. However, a community garden, while less efficient for food production, yields a different but equally important set of social benefits. The socially empowering effects of community gardens are typically realized immediately, while the economic and public health benefits of commercial urban farms typically manifest in the long term. Furthermore, the high upfront costs of commercial CEA may in some cases make community gardens a better solution to food insecurity. Growing seasons of community gardens can be extended through the use of CEA structures, and there are innovative ways of building greenhouses cheaply and without professional skills. This chapter primarily describes technologically advanced design strategies for sustainable urban CEA aimed to maximize food production in dense urban areas like the Bronx, but it will also explore potentially practical applications of CEA strategies in community gardens, as their importance should not be overlooked.

\textsuperscript{53} Gorgolewski, Komisar, and Nasr, \textit{Carrot City}, 34.

\textsuperscript{54} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 15.
It is most practical for urban controlled-environment farms to use non-soil-based methods, namely hydroponics or aeroponics, to grow the majority of crops. One reason is that most soils in industrial or previously industrial cities contain contaminants like lead, so it is too risky to cultivate the ground.\textsuperscript{55} The most common soil-based alternatives are raised beds or container growing, but these typically only yield shallow root crops, and often in smaller quantities than would be possible in the ground.\textsuperscript{56} Meanwhile, virtually any plant can be grown through hydroponic or aeroponic systems, and they accelerate plant growth by optimizing the aeration of plant roots,\textsuperscript{57} doubling or tripling biomass yields per square foot compared to soil-based agriculture.\textsuperscript{58} Another reason soil is limiting in urban settings is that its weight often challenges the structural capacity of roofs. The weight of wet soil is around 50 to 100 pounds per cubic foot,\textsuperscript{59} while load limits are generally 50 pounds per square foot for buildings built before 1970, and they are lower in newer buildings.\textsuperscript{60} Hydroponic and aeroponic equipment is much lighter than soil, allowing it to be compatible with any roof or configured on multiple floors of a vertical farm.\textsuperscript{61}

Given that plants can access nutrients through some other medium, soil itself serves only as a physical support structure onto which plants can spread their roots. Dr. William Frederick Gericke recognized this and developed hydroponics in 1937 at the University of California, Davis.\textsuperscript{62} In the simplest hydroponic systems, plant roots are submerged in a nutrient solution, but

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\bibitem{despommier162} Despommier, \textit{The Vertical Farm}, 162-63.
\end{thebibliography}
only partially, as to allow them access to oxygen.\textsuperscript{63} Most commercial systems use nutrient film technology, which slowly pumps a thin stream of nutrient-laden water over the roots.\textsuperscript{64} Most hydroponic systems use substrates to provide plant roots with structural support and to help retain soluble nutrients that pass through.\textsuperscript{65} Developed by Richard Stoner in 1982 through research funded by NASA, aeroponics uses small nozzles located under plants to spray a fine mist of nutrient-laden water onto their roots, which are enclosed in a chamber that maximizes humidity.\textsuperscript{66} In hydroponic and aeroponic systems, nutrients dissolved in the water are highly purified and carefully tailored to fulfill the specific nutritional requirements of each crop, allowing for the production of any crop regardless of the local soil quality.\textsuperscript{67} This solution is usually pumped through piping made of a low-cost plastic such as polyvinyl chloride, or PVC. There is a risk of phthalates from the PVC leaching into the nutrient solution, but this can be minimized by treating the PVC with a dilute sulfide solution, which crosslinks the plastic and traps the phthalates permanently. An innovative way to eliminate this risk while reducing the generation of non-biodegradable waste is to make piping out of bamboo since it is one of the strongest natural materials, it does not rot when wet, it grows very quickly, and it can be harvested to any diameter of choice.\textsuperscript{68}

The configuration of growing systems in the vertical farms will depend primarily on the type of crop that is being grown. Crops like tomatoes, lettuce, spinach, green beans, peppers, zucchini, cucumbers, and cantaloupes are comfortable growing in traditional hydroponic piping.

\textsuperscript{63} Gorgolewski, Komisar, and Nasr, \textit{Carrot City}, 206. \\
\textsuperscript{64} Despommier, \textit{The Vertical Farm}, 31. \\
\textsuperscript{65} Gorgolewski, Komisar, and Nasr, \textit{Carrot City}, 206. \\
\textsuperscript{66} Despommier, \textit{The Vertical Farm}, 165. \\
\textsuperscript{67} Despommier, \textit{The Vertical Farm}, 161. \\
\textsuperscript{68} Despommier, \textit{The Vertical Farm}, 204-5.
with evenly spaced holes, while grains are best suited to growing in sheets of inert material that have a similar consistency to a spongy fiberglass air conditioner filter. An emerging approach for growing grains aeroponically involves spreading seeds onto a Dacron-based, clothlike sheet that acts as a matrix onto which roots take hold and onto which a nutrient solution is sprayed from below. Corn is best grown hydroponically in large tubs, typically with six plants in each.\textsuperscript{69} Non-soil-based growing systems are also spatially advantageous since they can be arranged in three dimensions to make the most efficient use of vertical as well as horizontal space.\textsuperscript{70} Multiple layers of grain sheets can be grown on the same floor, and tubs of corn can be attached to a vertical conveyor belt-like structure. Potted plants like strawberries, eggplant, and avocado can be grown in hydrostackers, which use a form of hydroponic drip irrigation and save floor space. A Florida farmer, whose traditional farm was destroyed by hurricane Andrew, was able to replace the 30 acres of outdoor farmland he previously used to grow strawberries with a single acre of hydrostacker-grown strawberries in greenhouses.\textsuperscript{71} For an indoor food production space of a Whole Foods in New Jersey that only receives natural light from one side, BrightFarm Systems installed an assembly of tower systems by EzGro, which consist of flower-shaped pots stacked on central poles that can turn to provide plants with an even distribution of sunlight.\textsuperscript{72} The omega garden carousel, an extremely resource efficient innovation for hydroponic growing, rotates plants around a central LED light to develop oils in the plants that enable faster growth and better taste. This mechanism uses 99 percent less water than traditional agriculture to raise crops and takes up only 14 square meters of floor space.\textsuperscript{73} As most crops can tolerate a relatively

\textsuperscript{69} Despommier, \textit{The Vertical Farm}, 203.
\textsuperscript{70} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 15.
\textsuperscript{71} Despommier, \textit{The Vertical Farm}, 203.
\textsuperscript{72} Gorgolewski, Komisar, and Nasr, \textit{Carrot City}, 244.
\textsuperscript{73} Despommier, \textit{The Vertical Farm}. 
broad range of temperatures and humidity levels as long as their root systems are held at ideal
temperatures, multiple varieties of crops can be grown within a single room or greenhouse.\(^74\)

Hydroponic living wall systems can be integrated into the vertical surfaces of any
building, taking up minimal space while improving indoor air quality, adding biophilic
aesthetics, and providing shade if placed in front of windows. The Urban Agriculture Curtain,
designed by Bohn and Viljoen Architects in collaboration with Hadlow College, is hydroponic
living wall system composed of eight trays hung by cables and connected to tubes that supply
them with nutrient-laden water stored in a nearby tank. This design is compact, customizable,
low maintenance, and plumbed in a similar way to a washing machine, making it ideal for small
spaces where food production is not the primary function, like residences, offices, and cafes. NY
Sun Works, Arup Engineers, and Kiss + Cathcart Architects teamed up to design a theoretical,
more ambitious living wall system that makes use of the large air space between layers of
glazing in double-skin facades, which are becoming more prevalent in the construction of
buildings with large curtain walls to improve insulation. Intended for south-facing, unobstructed
facades of tall buildings, this system, named the Vertically Integrated Greenhouse, features
hydroponic planters attached to cables that cycle between the layers of glazing in a conveyor
belt-like fashion, forming a double-layered living wall on which planters can be tilted like
Venetian blinds to control the amount of sunlight that enters the building. This system would be
planted in stages, as the harvesting would be done from a single point, and ideally, each full
rotation would correspond with the length of time it takes a plant to bear a crop.\(^75\)

\(^{74}\) Despommier, *The Vertical Farm*, 183.
\(^{75}\) Gorgolewski, Komisar, and Nasr, *Carrot City*, 209-11.
Aquaponics, a system that simulates the nutrient cycling of wetlands, can be used in conjunction with hydroponics to raise a variety of fish, crustaceans, and mollusks. The effluent of aquatic animals grown in enclosed tanks creates a nutrient-rich water that is toxic to the animals but conducive to plant growth. To create artificial symbiosis, aquaponic systems feed nutrient-rich water from the tanks to hydroponically grown crops, which then purify the water before it is returned to the tanks, preserving a healthy aquatic environment. To create an even more closed loop system, waste portions of cultivated plants can be fed to worms, which are then fed to fish, and the compost generated by the worms supplies additional nutrients for plants.\textsuperscript{76} A 5,600 liter tank can raise a total of 800 fish at once.\textsuperscript{77} Sustainable fish farming avoids the health risks associated with bioaccumulation and is environmentally beneficial, as capture fisheries are one of two ecosystem services that are well beyond levels that can be sustained even at current demands.\textsuperscript{78} The local production of seafood also means it does not have to be frozen before it is sold. Additionally, it is possible to raise poultry in urban CEA systems, though many municipalities have limitations on keeping poultry and livestock. In New York City, it is legal to raise hens but not roosters, geese, ducks, and turkeys.\textsuperscript{79} Dutch architecture group MVRDV has even imagined a series of vertical farms specifically designed to raise pigs.\textsuperscript{80} However, husbandry of four-legged animals, especially cattle, in indoor urban settings raises concerns related to practicality and ethics.\textsuperscript{81} Fungiculture is, of course, possible in CEA systems, as the vast majority of commercial mushrooms are already grown indoors.

\textsuperscript{76} Gorgolewski, Komisar, and Nasr, \textit{Carrot City}, 209.
\textsuperscript{77} Despommier, \textit{The Vertical Farm}.
\textsuperscript{78} Millennium Ecosystem Assessment, \textit{Ecosystems and Human Well-Being}, 6.
\textsuperscript{79} New York City Government, Health Code §161.19.
\textsuperscript{80} Gorgolewski, Komisar, and Nasr, \textit{Carrot City}, 56.
\textsuperscript{81} Despommier, \textit{The Vertical Farm}. 
Analyses have shown that, in most cases, producing food in artificially heated greenhouses in colder regions is more energy intensive than shipping food from warmer regions. Since New York City experiences very cold winters, heating CEA systems during the colder parts of the year is one of the largest obstacles to its cost-efficient implementation. However, passive solar design and strategic placement can significantly lower the energy inputs needed for lighting, heating, and cooling in CEA systems. To maximize energy efficiency, the exterior structures of these systems should be designed to maximize plant exposure to natural light while regulating indoor temperatures. In terms of construction materials, glass is an obvious choice due to its transparency. However, glass is very heavy and can be expensive, especially considering that it must be double-glazed in order to provide adequate insulation. High-tech transparent plastics are emerging as lighter, more durable alternatives to glass that decrease construction costs as well as the amount of steel or aluminum needed to provide structure. These plastics have a high tensile strength and do not not yellow over time as a result of long-term exposure to UVB radiation like most common plastics do. Ethylene tetrafluoroethylene, or ETFE, is a notable example that is only 2 percent of the weight of glass, is a “selfCleaning” material due to its electrostatic charge, is extremely transparent, allowing more sunlight to pass through to facilitate photosynthesis, and has been used in iconic structures including the Eden Project and the Beijing National Aquatics Center. Maintaining a positive pressure inside ETFE creates cushions of isolation that are very effective for regulating indoor temperatures, and a double- or even triple-glazing can be used to ensure insulation quality without significant added weight. The Solar Bubble Greenhouse is an innovative CEA design that consists of a light double-hoop frame

82 Ackerman, *The Potential for Urban Agriculture in New York City*, 15.
83 Despommier, *The Vertical Farm*, 188-91.
supporting two layers of plastic sheeting between which liquid soap bubbles generated at the top of the structure can flow. In the winter, the bubbles serve as an insulating layer, and in the summer, they act as a screen that reduces solar radiation while drawing excess heat out of the farm through a process similar to transpiration in plants. To further regulate temperatures, insulation can be combined with a passive solar design technique that involves constructing floors and other building components from materials with a large thermal mass, like brick, stone, and concrete, which absorb heat during the day and release it at night. Many rooftops are conveniently already constructed of materials with a large thermal mass, helping to stabilize temperatures in rooftop greenhouses.

Renewable heating may also be supplied by geothermal heat pumps, which are not specific to any geological formation and consist of pipes buried in the ground that circulate fluid. This fluid, typically water or a mixture of water and antifreeze, absorbs heat from or relinquishes heat to the surrounding soil, using it as a heat source or sink to regulate indoor temperatures depending on the season. A proposal called Greenhouse Village by the Innovation Network in The Netherlands entails a similarly piped system that stores excess heat from greenhouses in aquifers, which can raise the groundwater temperature from 11 to 27 degrees Celsius while maintaining a maximum of 30 degrees in the Greenhouses. The stored heat can be used to warm the greenhouses at night and in the winter as well as nearby homes. The Innovation Network’s calculations suggest that a excess heat from a 5-acre greenhouse could provide heating for up to 200 residences.

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86 Despommier, *The Vertical Farm*, 192-93.
87 Gorgolewski, Komisar, and Nasr, *Carrot City*, 41-43.
The integration of urban CEA structures with existing buildings is common due to high land values, but it is also beneficial because it offers energy saving benefits. In dense urban areas, building a greenhouse on a roof rather than at ground level increases the amount of natural light that plants receive.\textsuperscript{88} Furthermore, the integration of CEA structures with existing buildings can help to reduce overall energy use for heating and cooling. While heating a standalone greenhouse in the winter can be very energy intensive, a rooftop greenhouse can capture waste heat from the building below while insulating it. Since New York has a relatively short growing season, it would be most energy efficient to locate greenhouses on top of buildings that generate significant amounts of heat, like kitchens and bakeries.\textsuperscript{89} Certain industrial buildings may also be good sources of waste heat, but it is important to ensure that noxious fumes do not enter the greenhouse. According to Future City Lab director Kubi Ackerman, ideal roofs for food production should also be 10 stories or lower since increased building height makes transporting farming materials and construction equipment less practical, and for commercial food production, he recommends that roofs be at least 10,000 square feet because the economic viability of farming on smaller roofs is less certain.\textsuperscript{90} In the summer, rooftop greenhouses can also reduce the use of air conditioning by employing passive methods, like ventilation and shading systems, as well as active, low-energy ones, like evaporative cooling. In standard evaporative cooling systems, hot, dry air from outside enters the evaporative pad wall, where it is met with water. This increases the humidity of the air while lowering its temperature after it passes through the wall. If the greenhouse is directly integrated with the heating, ventilation, and air conditioning (HVAC) system of the building below, the cooler air is circulated throughout the

\textsuperscript{88} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 15.

\textsuperscript{89} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 14-15.

\textsuperscript{90} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 40.
rest of the building. New York City’s humid summers make evaporative cooling less effective than it would be in a dryer region, but it could still contribute to significant energy savings.\textsuperscript{91}

CEA structures should be oriented with consideration for the sun’s daily path across the sky to take advantage of natural light. For vertical farms or large greenhouses that use layered or stacked growing configurations and aim to maximize the use of natural light, plastic parabolic mirrors, such as those produced by Sunlight Direct, can be installed outside to concentrate and direct overhead sunlight towards plants deep in the interior of the growing structures. These mirrors can be connected to fiber optics that lead into the interiors of the structures to provide supplemental lighting.\textsuperscript{92} However, even with these technologies, the sun alone will not provide energy light to support optimal plant growth in the New York area. Sunlight is sufficient in regions that are almost perpetually sunny, like the American Southwest,\textsuperscript{93} but New York’s Atlantic Coastal Region receives only 65 percent of possible sunshine hours in the summer and 50 percent in the winter.\textsuperscript{94}

Artificial lighting can be used to provide light to plants on cloudy days or at night to allow for 24 hour plant growth. Vertical farms repurposed from vacant industrial buildings, such as Metropolis Farms’ South Philadelphia site, may rely entirely on artificial lighting to grow plants.\textsuperscript{95} In plants, chlorophyll a and b capture primarily red and blue wavelengths of light and convert them into the chemical energy that fuels the process of photosynthesis. Thus, rather than the whole visible spectrum, plants need only to be provided with wavelengths of light around

\textsuperscript{91} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 69.
\textsuperscript{92} Despommier, \textit{The Vertical Farm}, 187-88.
\textsuperscript{93} Despommier, \textit{The Vertical Farm}, 187.
\textsuperscript{94} National Climatic Data Center, “Climate of New York,” 7-8.
400 and 700 nanometers to support growth. While traditional tungsten and fluorescent lightbulbs emit around 95 percent of their energy as heat and the rest as a broad spectrum of light that is largely unnecessary for plant growth, light-emitting diodes, or LEDs, can be designed to emit wavelengths that are tailored to the plants’ needs while generating very little waste heat, reducing energy use for lighting. Organic light-emitting diodes, or OLEDs, are growing in commercial use and are even more energy efficient for growing plants, as they contain stable organic compounds that allow for the emission of even narrower spectra of light. Since OLEDs are made of thin, flexible plastics, they can configured in a wide variety of ways, including wrapped around plants, making it easier to place light sources at optimal distances for growing.96

In commercial CEA, temperature, light, humidity, and nutrient levels are generally monitored and regulated automatically to maximize efficiency, and many of the mechanisms of regulation, including water pumps, fans, and artificial lighting, are electrically operated, which means that a constant supply of electricity is crucial to maintaining productivity and preventing crop failure.97 As with all sustainable design approaches, CEA should ideally rely as much as possible on renewable energy, and there are many possible methods for integrating on-site generation. Though these methods generally come with high capital costs, funding can be aided by grants and loans for renewable energy, and they can contribute to significant energy savings in the long run, as the cost of electricity from the grid in New York City is 47 percent higher than the national average.98 Metropolis Farms’ warehouse farm and Gotham Greens’ rooftop greenhouses in Greenpoint and Gowanus harvest electricity from on-site solar panels installed on

96 Despommier, *The Vertical Farm*, 185-87.
97 Gorgolewski, Komisar, and Nasr, *Carrot City*, 206.
} A new development in photovoltaic technology replaces standard crystalline silicon cells with cells made of perovskite, a material that is much less expensive to process and is increasing in developed efficiency faster than any other solar cell material, being almost on par with silicon today. Though silicon cells and perovskites each have their own advantages, the use of the latter in greenhouses or other predominantly transparent structures has immense potential for on-site electricity generation: unlike silicon solar cells, which are opaque, very thin films of perovskites can be printed onto glass or plastic to create photovoltaic windows and walls while preserving their transparency. This would allow CEA systems to make use of solar power even if they lack open space for traditional solar panels. Furthermore, perovskites are more suitable for New York’s only moderately sunny climate since they are much more effective than silicon cells at harnessing solar energy on rainy or cloudy days.\footnote{Laurel Hamers, “Perovskites Power Up the Solar Industry,” \textit{Science News} 192, no. 1 (2017): 22.} Since wind turbines have also broken out of their traditional mold, generating wind power on site in urban agricultural settings is also possible. Recently developed horizontal double-propeller turbines, which resemble traditional reel lawn mowers, are lighter, quieter, more attractive, and require less speed to operate than windmill-shaped turbines, allowing them to be added to virtually any structure.\footnote{Despommier, \textit{The Vertical Farm}, 195.}

Urban CEA systems can generate their own energy while eliminating waste by utilizing waste to energy processes. Anaerobic digesters can be used to process organic waste, like inedible post-harvest portions of crops and feces. In an anaerobic digester, anaerobic bacteria break down organic feedstock in an airtight container, producing a digestate and biogas, a source of renewable energy that is 60 to 70 percent methane and can be used in place of natural gas.
Combined heat and power systems use steam generators to convert heat from the combustion of biogas into electricity while using the hot water and steam to heat indoor spaces as well as the digester. Each cubic meter of biogas can generate around 7 kilowatt hours of electricity, enough to power a 100 watt light bulb for 70 hours. If scrubbed to remove carbon dioxide and impurities, biogas can also be used to fuel the distribution vehicles of commercial farms. Though burning biogas produces carbon dioxide, this is offset by the carbon sequestering services of the plants that produced the organic material digested in the first place, and it reduces the use of fossil fuels. The liquid portion of the digestate can be directly applied to soil as fertilizer, and though it is possible to apply the solid portion of the digestate directly as a soil amendment, anaerobic bacteria cannot break down certain types of organic material as fully as organisms involved in aerobic composting, so it is more effective to compost the solid digestate before applying it. This multi-step process is more efficient and sustainable than composting alone since the latter converts most of the energy from organic material to heat that is too insignificant to be harnessed as a practical energy source. Composting also releases methane, a potent greenhouse gas, into the atmosphere. However, for smaller-scale CEA with limitations on space and funding, composting may remain the most viable way to make use of organic waste. Leftover post-harvest portions of crops may also be used as animal feed in farms that include animal husbandry, depending on the crop.

Larger urban CEA systems can also recover energy from solid waste through incineration, which is employed prominently thoroughly Europe to generate electricity while

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103 Despommier, The Vertical Farm, 196.
104 Despommier, The Vertical Farm, 175.
reducing the amount of solid waste that must be sent to landfills.\textsuperscript{105} Though they reduce the use of fossil fuels, conventional “open burning” incineration methods still produce harmful emissions as well as residual solids that must be disposed of. Plasma arc gasification, which has been used in recent years for the treatment of hazardous waste, has potential as a more efficient and closed-loop system of recovering energy from waste. By passing it through high-energy plasma of around 4,000 to 7,000 degrees Celsius, plasma arc gasifiers can vaporize any form of waste while using the resulting heat to generate electricity in combined heat and power systems. Plasma arc gasification generates around 6 times the energy it uses and produces significantly more electricity per ton of waste than conventional incineration as well as significantly less harmful emissions and residual solids. If these solids are immediately whipped into a plasma wool before they cool and harden, they can potentially be used as a plant growth medium, eliminating waste altogether. Though the residual material contains heavy metals and other inorganics, a study by the Materials Analysis Center at Georgia Tech showed that the wool was highly resistant to leaching. Since plasma arc gasifiers can be as small as a home boiler unit, they may be a viable option for commercial urban agriculture in a high-density city. However, even large-scale CEA farms do not produce significant amounts of waste, so on-site plasma arc gasifiers would additionally be fed with municipal waste from the surrounding area. Plasma arc gasifiers for these farms would likely be too small to support highly efficient electricity production, but they can produce more than enough heat for the farms, and the excess hot water and steam can be sold to buildings in the surrounding area.\textsuperscript{106}

\textsuperscript{105} Despommier, The Vertical Farm, 196.

To mimic the stormwater management and water purification services of an ecosystem and maximize self-sufficiency with regard to water use, urban CEA systems should incorporate rainwater catchment and greywater recycling systems. Rainwater collection can provide on-site irrigation for urban farms while reducing stormwater runoff and thus the costs of water disposal through municipal infrastructure. Most rainwater catchment systems consist of rooftop downspouts that connected to cisterns for storage and include a first flush chamber to which the initial runoff, which has the most contaminants, is diverted. Even with the use of a first flush chamber, testing has found low levels of lead and bacteria to be present in the collected rainwater, so it is generally considered safe for farming but not potable. Rainwater catchment systems are typically low-tech and inexpensive, and the only maintenance they require is the cleaning of roof gutters and the first flush filter. The water needs of CEA farms that use primarily hydroponics and aeroponics will be minimal since water is continuously recycled, and as New York City receives an average of 46 inches of rain per year, a significant portion of farms’ water needs can be met with rainwater.

Urban CEA systems can also meet their water needs by remediating wastewater on-site. Since these systems are generally integrated with residential and commercial buildings, they can draw additional wastewater from connected facilities. Greenhouse Village, an urban design proposal that aims to emulate the carbon, energy, water, and nutrient cycles of ecosystems, involves the use of an aerobic reactor to purify water from household showers and kitchens as a water supply for greenhouses. Plants grown indoors can also be used as “living machines” for purifying water, a phrase first coined by John Todd in reference to the ability of plants to

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107 Gorgolewski, Komisar, and Nasr, *Carrot City*, 197.
109 Gorgolewski, Komisar, and Nasr, *Carrot City*, 43.
remediate damaged aquatic ecosystems. Blackwater refers to municipal sewage, and greywater refers to blackwater with the solids removed. A system can be implemented to filter out the solids from blackwater and to feed the resulting greywater to hydroponically grown plants. Nutrients in the greywater help these specially selected plants grow, and through transpiration, these plants release pure water vapor, which can be condensed and collected with cold-brine pipe systems and dehumidifiers in enclosed spaces like CEA structures.\(^\text{110}\) This potable water can then be supplied to the CEA system as well as to connected residential and commercial spaces if enough is collected. Although it is too much of a health risk to consume plants grown with greywater, plants employed as “living machines” can be digested or incinerated to produce energy and/or compost, or they can be sold as decorative plants.\(^\text{111}\) Local floriculture is a more sustainable alternative to the conventional flower market, which often involves shipping flowers by air from operations that use water and agrochemical intensive growing methods and have poor labor rights records.\(^\text{112}\) Decorative plants can also be sold at a greater profit margin, which helps to offset operational costs and allows produce to be sold at more affordable prices. Dr. Dickson Despommier, a pioneer of the vertical farming concept, suggests the construction of vertical farms that are solely dedicated to water purification. Although no such a farm currently exists, making it hard to predict the cost efficiency of this process, recycling wastewater within the city is an idea worth considering given that New York City’s current solution to increasing the supply of potable water, Water Tunnel No. 3, will cost more than 6 billion dollars.\(^\text{113}\)

\(^{110}\) Despommier, \textit{The Vertical Farm}, 6-7.
\(^{111}\) Despommier, \textit{The Vertical Farm}, 173-74.
\(^{112}\) Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 27.
\(^{113}\) Despommier, \textit{The Vertical Farm}, 239-40.
Another major benefit of CEA is the presence of physical barrier that protects crops from pests, microbial pathogens, fungal diseases, and competition from weeds through exclusion rather than through the use of pesticides, herbicides, fungicides, and other agrochemicals. For maximum security, barrier design for CEA structures can be modeled after the barrier design of intensive care units, which involve positive-pressure buildings with filtered air supplies and secure entryways.\textsuperscript{114} Some urban CEA systems additionally apply biological pest control. CEA systems also isolate crops from animal pathogens such as E. coli, increasing food safety. If a crop does become contaminated, it can be destroyed and replanted immediately, whereas a traditional outdoor farmer would often have to wait for the next growing season to replant the crop.\textsuperscript{115} Vertical farms and large commercial greenhouses may also include a quality-control laboratory and a nursery.\textsuperscript{116} The laboratory would serve to surface decontaminate seeds, test for the presence of pathogens before and after germination, and monitor the health status of each crop. In the nursery, seeds would be germinated and tested for their ability to grow in order to ensure maximum crop productivity.\textsuperscript{117}

While the Bronx has over 100 community gardens, almost all of them are completely open to the air.\textsuperscript{118} This may provide a more pleasant recreational environment during the warmer seasons, but being unable to shield plants from weather conditions means that that outdoor gardens must remain unproductive for around half of the year. Growing food in exposed environments also limits the feasibility of taking advantage of rooftops for this purpose, as

\textsuperscript{114} Despommier, \textit{The Vertical Farm}, 169-70.  
\textsuperscript{115} Despommier, \textit{The Vertical Farm}, 199-200.  
\textsuperscript{116} Despommier, \textit{The Vertical Farm}, 179.  
\textsuperscript{117} Despommier, \textit{The Vertical Farm}, 206-7.  
environmental conditions just a few stories above ground can be harsh, with greater sun exposure and stronger winds that are very drying to plants. Though the design of community gardens is primarily concerned with what methods and materials can be implemented with a low upfront cost and with basic skills, it must also be aesthetically pleasing so that the gardens can be sources of pride and dignity. In some cases, community gardens face opposition because members of the community do not like the way they look, and landlords fear that they may decrease surrounding land values as a result.

Building a greenhouse from salvaged materials can be an appealing strategy for community gardeners in terms of both cost-efficiency and sustainability. Roberto’s Pizza, a restaurant in Brooklyn with its own farm, pieced together discarded windows from local industrial buildings on a timber frame to form the walls of a greenhouse, and they constructed a lightweight roof from corrugated polycarbonate sheets. Such improvised, do-it-yourself greenhouses are highly functional yet do not require advanced skill or expensive machinery to be put together. If designed well and constructed neatly, greenhouses made from recycled materials can add a charming accent to a cityscape. Adaptive-reuse of an existing vacant structures for CEA is another strategy that may be appealing to community groups with limited funds. For example, the Community Garden Society of Inuvik converted a former hockey arena in Northern Canada to a 4,000 square foot greenhouse. The only main adaptation that required the purchase of new materials was the replacement of the original tin roof with polycarbonate glazing, meaning the group was able to reuse an estimated 61,000 dollars worth of building materials from the original structure. Another adaptive-reuse feature of the greenhouse is a passive solar

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119 Gorgolewski, Komisar, and Nasr, Carrot City, 154.
121 Gorgolewski, Komisar, and Nasr, Carrot City, 154.
heating system consisting of water-filled garbage bins that release stored heat at night. The Kingsbridge Armory in the Bronx has been vacant for more than 20 years and is similar in shape to the Inuvik Community Greenhouse, albeit several times larger. A adaptive-reuse greenhouse could be conceived for the top floor if the roof is replaced with transparent glazing, creating a 5 acre urban agriculture space that could serve a significant portion of the Northwest Bronx, whether as a commercial farm or community garden.

Hydroponic and aeroponic systems with nutrient stream technology are generally expensive, and operating them properly requires extensive training. Since community gardens are focused on accessibility, they usually employ soil-based growing methods, which are easily learned and allow the participation of people of all skill levels. Since the soil in previously industrial cities like New York are at high risk of being contaminated with toxic pollutants, plants for consumption cannot be grown directly in the ground. Raised beds are one of the most common configurations of urban soil-based agriculture, as they can be used anywhere the ground is not accessible for growing, including parks, brownfields, and rooftops. They can be easily assembled from inexpensive or recycled materials like scrap lumber and can be painted to increase individuality and attractiveness. Raised beds can increase accessibility for the elderly or disabled by being elevated to waist height or notched so that people in wheelchairs do not have to overreach.122

Container systems have become a popular alternative to full scale horticulture systems because they offer flexible design options and are easily transportable, making them a popular choice for rooftops. Growing containers can be repurposed from readily available objects like car

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122 Gorgolewski, Komisar, and Nasr, Carrot City, 214-16.
tires, packing crates, recycling bins, old washing machines, and inflatable pools, or even smaller items like soda bottles, cooking oil containers, and soil-filled plastic bags for single plants. A key consideration for choosing repurposed containers is their ability to allow for water drainage, which can often be improved simply by puncturing holes in their bases. Containers can also be custom-designed to be self-watering systems, which typically involves adding reservoirs to the bottoms of containers, decreasing water use. Constant access to water also optimizes the health and growth of most vegetable plants as long as it does not prevent oxygen from being present in the soil, as inadequately aerated soil leads to root rot. A team led by Ismael Hautecoeur of Alternatives, a leading Montreal-based NGO, designed a system that adds a false bottom hiding two water reservoirs to the interior of a conventional plastic recycling bin. The reservoirs are filled through an upright tube, and an overflow hole ensures that the roots remain adequately aerated at all times. A small portion of the soil remains in contact with the water in the reservoir, acting as a wick to transport water to the roots. Alternatives and the Rooftop Garden Project also published a guide that explains how to create a similar planter from any rigid container, as well as how to create a simple hydroponic grower, a garden of connected containers with a central reservoir, and a rainwater collection system, all from inexpensive and readily available materials.

Another self-watering container system, designed by Biotop, allows containers to be joined together, forming a network of planters that spread moisture through gravity and capillary action. This modular, low-maintenance system aims to produce three times as much as conventional container systems while using half the water. Simple hydroponic growers and containers that

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124 Gorgolewski, Komisar, and Nasr, *Carrot City*, 221-23.
126 Gorgolewski, Komisar, and Nasr, *Carrot City*, 221-23.
use soil replacement growing media are lighter than containers filled with traditional soil, making them ideal for rooftop gardens that have challenging load limits. This challenge can also be overcome by strategically placing containers above structural columns. By combining efficient urban gardening vessels with a low-cost greenhouse structure, community gardeners can take advantage of rooftops and access recreation and fresh produce for a greater portion of the year.

Chapter 3: Health, Social, and Economic Impacts

Since urban CEA is a relatively new phenomenon, there is little literature on its impacts on urban communities. However, many studies conducted in cities throughout the world have documented the impacts of urban agriculture in general, and they have shown that it can bring significant benefits to communities, especially those in low-income areas. Urban agriculture includes both commercial farms and community gardens, which have different but overlapping sets of interests and benefits. The most widely cited benefits include improvements in safety, food security, education, and overall health as well as increases in available jobs and opportunities for community building across diverse demographics. Controlled-environment growing structures should extend the seasonal duration that many of these benefits are made available to communities by outdoor gardens and farms, though they often come with the challenge of higher upfront costs. Increasing the presence of urban CEA could be an efficient way to improve the overall wellness of marginalized communities in the Bronx, as urban

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127 Gorgolewski, Komisar, and Nasr, Carrot City, 157.
agriculture simultaneously provides solutions to environmental, health, social, and economic problems.

A major health benefit of urban agriculture is increased food security. In the U.S., food security has come to refer to not only the ability to avoid hunger but also the ability to access healthy food.¹²⁸ The South Bronx has often been described as a “food desert,” a term used to describes areas, typically in low-income and minority neighborhoods, where residents have little or no access to fresh, nutritious foods, especially fruits and vegetables. In high density municipalities like New York City, a supermarket should be within 5 to 10 blocks of a person’s home for it to be considered accessible. In low-income neighborhoods there are often few large supermarkets and specialty health stores, and a greater distance to food vendors is more prohibitive since less residents can afford to travel by automobile. Zoning requirements for food retailers in these neighborhoods are often met by fast-food restaurants and convenience stores, which carry foods of high caloric but low nutritional value, and residents are forced to turn to these foods due to lack of access to healthier alternatives.¹²⁹ In the Bronx, less than a quarter of food retailers are likely to sell fresh food.¹³⁰ However, accessibility also depends on how much people are willing to pay for healthy food, so simply increasing the density of supermarkets in areas deemed “food deserts” may not solve the issue if the food being sold is unaffordable to surrounding residents. As stated by a key informant from the Bronx in the 2014 Community Needs Assessment (CNA), “It’s cheaper to eat rice and chicken” than “to buy oranges, grapes, strawberries, and watermelon,” and living in a poor community, finances have a large influence on food choices since “you want the food to go longer or further with the number of people in

¹²⁸ Ackerman, *The Potential for Urban Agriculture in New York City*, 50.
¹³⁰ Ackerman, *The Potential for Urban Agriculture in New York City*, 50.
Another informant stated that due to low incomes and a lack of access to nutritious food, there are people in the South Bronx “who are obese who are starving because they’re eating empty calories.” Thus, discussion of food insecurity is often framed around the related crises of hunger and obesity, which some have dubbed “the Bronx Paradox.” In addition to issues of access, consumer preferences also have a large impact on food choices. Residents of South Bronx and other “food deserts” often have cultural preferences for fried foods and other specific high calorie foods, which in some cases may be learned preferences from previous lack of access to healthier alternatives. Diets that are low in fresh fruits and vegetables and high in refined starches, fats, and sugars are directly related to increased risks of obesity, type 2 diabetes, hypertension, appendicitis, coronary heart disease, and stroke. In a survey, 24.5 percent of residents in the South Bronx reported “no fruit or vegetable consumption yesterday,” which was the highest rate of any neighborhood in New York City. It is thus unfortunate but unsurprising that Bronx neighborhoods also have the highest rates of obesity and hospitalizations for cardiovascular disease, diabetes, and hypertension.

Urban agriculture can be a promising solution to “food deserts” and their serious health implications. A lack of quality supermarkets in low-income areas is typically the result of food industry consolidation and redlining, which causes supermarkets to pull out of areas in which they predict insufficient return and a high risk of crime. Much of the city’s vacant,
marginalized land is also located in these areas. This gives local community groups and entrepreneurs the opportunity to supply fresh produce to their community in the absence of chain grocery stores by creating urban agricultural projects on land that is usually of low value since large businesses deem it unfit for development. Due to their high initial capital costs, urban CEA, in the traditional high-tech sense, is predominantly commercial and driven by the goal of establishing high-yield urban food production as a profitable enterprise. Commercial urban farms are advantageous to increasing food security since they maximize the number of consumers that can benefit from locally grown produce, but making this produce affordable for members of food-insecure communities is one of the largest challenges that these farms face. The costs of producing food in rooftop greenhouses and vertical farms are typically higher than those of traditional farms, often simply because urban land is more expensive. Those that reduce upfront costs by investing in less energy saving or renewable energy technologies incur higher operational costs, especially for heating CEA systems through New York City’s cold winters. Food justice activists have criticized urban farming projects that claim to increase accessibility to healthy food in the neighborhood where they are located but, in reality, distribute it to wealthier residents that can afford to pay off the higher costs of production and who did not have a food security issue in the first place. However, this counterproductive effect can be avoided with support from government incentives, partnerships with nonprofit organizations, and strategic pricing strategies. Sky Vegetables, a commercial hydroponic greenhouse on the roof of an affordable housing site in the South Bronx, makes a portion of its produce available at low cost to neighborhood residents by subsidizing it with the profits earned from selling another portion

139 Ackerman, *The Potential for Urban Agriculture in New York City*, 8.
140 Ackerman, *The Potential for Urban Agriculture in New York City*, 15.
141 Campbell, *City of Forests, City of Farms*, 268.
of the produce at a premium in other markets. The company is also SNAP and WIC certified and accepts EBT cards, increasing accessibility to those receiving food-purchasing assistance. This is particularly important for households in the Bronx, 35.8 percent of which received SNAP benefits according to the 2015 Census. Though Yara Nagi from Agritecture consulting acknowledges that a farm the size of Sky Vegetables is only a small step in solving the problem of food insecurity in the South Bronx, pioneering CEA projects can act as catalysts for more comprehensive improvements of food access. For instance, by offering free tours, or simply by virtue of being visible, urban farms reduce the psychological distance between food production and food consumption, causing people to question the implications of their food buying habits and building support for sustainable and local agriculture.

The bodegas and discount stores common in “food deserts” are primarily unable or unwilling to sell fresh produce due to the additional costs of storage and refrigeration this would require as well as concerns about a lack of demand. However, these additional costs could be significantly reduced if they partner with local CEA initiatives that can provide frequent, year-round deliveries of produce with a longer shelf-life, and community outreach to encourage healthy eating can assuage fears about consumer preferences. This dynamic would allow for increased access to healthy food without displacing locally owned bodegas with corporate supermarkets. Urban farms can also partner with schools to provide locally grown produce for school lunches. Preliminary results of programs that require school cafeterias to purchase locally

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144 Viljoen, Bohn, and Howe, Continuous Productive Urban Landscapes, 41.
145 Ackerman, The Potential for Urban Agriculture in New York City, 52.
grown produce show that the programs are significantly changing youth diets because students like the new, more nutritious offerings.\textsuperscript{146}

Fruits and vegetables grown in urban CEA systems are healthier than those grown on conventional large-scale farms since the former are free of harmful agrochemical residues.\textsuperscript{147} Locally grown produce is also of higher quality since large-scale farmers choose to grow varieties that can best withstand long periods of transport and storage, which are often inferior in taste and nutritious value.\textsuperscript{148} In addition, foodborne illness is a major ongoing health problem in the U.S. because food regularly travels so far that an outbreak can strike anywhere, and the source of contamination would be very hard to trace. Localizing food production makes it much easier to control the spread of foodborne disease and identify its source, and CEA allows for better protection of crops against contamination by infectious agents like salmonella, cyclospora, and E. coli.\textsuperscript{149}

Community gardens also effectively increase food security by offering highly affordable fresh produce to those who wish to participate, and in many cases, participants share their excess fruits and vegetables with other community members or donate them to local food banks.\textsuperscript{150} Some consider the most important health impact of community gardens to be its impact on food choice and dietary knowledge. While community gardens may not produce as much food as commercial operations, they are valuable in their ability to directly engage community members in programming, like a culturally relevant cooking class, that increases food and health literacy. A study conducted in Flint, Michigan showed that adults who participated or had a family

\textsuperscript{146} Lopez, \textit{The Built Environment and Public Health}, 178.
\textsuperscript{147} Viljoen, Bohn, and Howe, \textit{Continuous Productive Urban Landscapes}, 45.
\textsuperscript{148} Lopez, \textit{The Built Environment and Public Health}, 186.
\textsuperscript{149} Despommier, \textit{The Vertical Farm}, 188.
\textsuperscript{150} Golden, \textit{Urban Agriculture Impacts}, 11-12.
member who participated in a community garden program consumed 1.4 times more fruits and vegetables per day than those who did not. A study of community gardens in California found that the number of students who began gardening at home after participating in a school gardening program increased by 20 percent. In multiple studies, youth discussed eating more fruits and vegetables and less junk food as a result of participating in community garden programs.

As a recreational activity, community gardens have also been widely noted to improve both physical and mental health. Participating in gardening involves sustained physical activity, which helps to combat obesity and other ailments. Many community gardeners also reported that gardening helps them reduce stress. A study of community gardens in the Bronx revealed that participants saw their garden as a form of “therapy,” as it offers a place for them to be productive, to be with others, and to enjoy nature. In the Bronx, 7.1 percent of residents, as opposed to 5.5 percent in New York City overall, reported experiencing serious psychological distress, and this percentage is as high as 8 to 9 percent in areas like Pelham-Throgs Neck and the South Bronx, where overwhelming stresses related to low incomes were most prevalent and contributed to high levels of depression. Community gardens can be valuable mental health

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resources in these neighborhoods, as mental health services are reported to be limited, and as community gardens do not carry the stigma that mental health services do.¹⁵⁷

Other health benefits of urban CEA result from improvements to urban environmental conditions. Trans-shipping centers, where food arrives in a city before being shipped to food retailers, are disproportionately located in low-income areas like the South Bronx, causing increased truck traffic in surrounding neighborhoods that not only increases the frequency of asthma attacks but also discourages the active play of children, exacerbating the childhood obesity epidemic.¹⁵⁸ In the Bronx, the asthma hospitalization rate is more than twice the citywide average,¹⁵⁹ and the highest rates are concentrated along Grand Concourse, a major road and source of toxic emissions.¹⁶⁰ By reducing the distance food travels and the need to distribute food by truck, urban agriculture reduces air pollution near trans-shipping centers and major roadways. Plants in urban farms and community gardens also help to purify the air, further improving outdoor air quality. Controlled-environment farms with rainwater catchment systems help to mitigate basement flooding and prevent the growth of mold and mildew, fungi that affect indoor air quality and can also aggravate asthma and other respiratory diseases. Furthermore, by decreasing the area of non-reflective, impervious surfaces, CEA structures built on roofs and paved lots reduce the urban heat island effect, lowering the incidence heat-stroke as well as asthma attacks since higher temperatures accelerate the formation of smog.¹⁶¹

The most universally observed effect of urban agriculture is its impact on the social dynamic of communities. Urban agricultural projects can be productive spaces for increasing

¹⁵⁸ Despommier, *The Vertical Farm*, xi-xii.
¹⁵⁹ *Community Health Needs Assessment and Implementation Plan*, 17-18.
social capital, value derived from networks of relationships within a community that enhance its functioning and resilience. This is especially true of community gardens, which provide a place for neighbors to socialize, share knowledge, and develop relationships. In one study, gardeners reported that the presence of plants broke down social barriers and encouraged interactions between previously unacquainted community members, leading to the formation of friendships. In a survey of community gardeners in the Bronx, 96 percent of gardeners indicated that they participate in community gardens to stay closer to their families. Seasoned gardeners disseminate practical skills and knowledge to others who visit gardens primarily to enjoy the environment. Providing people of all backgrounds the opportunity to be productive and make visible contributions to their community promotes self-confidence and strengthens leadership skills. Urban regeneration and beautification can act as an agent of change that reduces crime and increases morale and a sense of self-determination, particularly when gardens replace vacant, blighted lots in traditionally neglected communities. Urban agriculture sites also cultivate a sense of local distinctiveness, increasing people’s self-identification with and pride in their community. Community gardeners report that gardens give them a sense of belonging and that they are spaces where they “feel at home.” In addition to food production, most community gardens also engage communities by hosting a variety of social, educational, and cultural events, such as church gatherings, holiday parties, concerts, cooking classes, composting workshops, and voter registration drives. A study of Latino community gardens described them as “participatory

162 Golden, Urban Agriculture Impacts, 9.
164 Gorgolewski, Komisar, and Nasr, Carrot City, 60-63.
165 Gorgolewski, Komisar, and Nasr, Carrot City, 60.
landscapes,” which combine movements supporting urban food production, social justice activism, and the development of social capital.  

By improving a community’s interconnectedness, expanding its skill set, and fostering a sense of “can do,” urban agriculture can encourage community members to better their communities by participating in public affairs. Studies have observed that community gardening involves planning and decision-making processes that require consensus, which make gardens valuable spaces for cultivating democratic values and skills for civic engagement. Both community gardens and urban farms require advocacy and coalition building to overcome the structural barriers of resource shortages, zoning, land-use conflicts, creating “networked movements” that equip people with organizing skills and encourage them to get involved in other forms of local activism.

Since food and gardening appeal to people of a wide range of ages, genders, abilities and cultures, community gardens are conducive to increasing social inclusion and cohesion among diverse groups of people, which is especially beneficial to groups that are typically socially marginalized, like women, immigrants, the elderly, and the disabled. Studies suggest that community gardens can help prevent the elderly from becoming isolated, as it is one of the few places they can interact meaningfully with people of other age groups. Since the elderly are likely to have a background in gardening, community gardens allow many elders to revisit skills developed in their youth and pass them on to younger generations.  

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168 Viljoen, Bohn, and Howe, Continuous Productive Urban Landscapes, 84-85.
170 Golden, Urban Agriculture Impacts, 11.
urban farms that grow culturally significant produce and host culturally relevant programming can be a powerful means of expressing a local or ethnic identity and are thus a way for immigrants and ethnic minorities to resist the hegemony of Western culture. These urban agriculture projects often give immigrants the opportunity to sell culturally specific foods in neighborhood markets, which helps them network with other immigrants as well as non-immigrant members of their community. The Bronx is one of the most diverse counties in the nation: more than a third of its residents were born outside of the U.S., and more than half of births among Bronx residents in 2014 were to foreign-born mothers. Its immigrant population comes from countries dispersed throughout the globe, the most common being the Dominican Republic, Jamaica, Mexico, Ecuador, Guyana, Ghana, Honduras, Italy, Trinidad and Tobago, and Bangladesh. Thus, urban CEA in the Bronx should provide opportunities for these diverse ethnic groups to participate in cultivating culturally significant foods year round, promoting equitable representation and transformative cultural exchange.

Though their economic focus is maximizing crop performance to achieve profitability, many commercial urban agriculture projects share the broader social goals of community gardens and have empowered communities by ensuring that members of the local community are involved as leaders and engaging the community through free programming. It is important for any urban agriculture project in a marginalized community to recognize the expertise of the community’s farmers and gardeners and to give authority to these members, as they are more familiar with the needs the needs of their own community. In fact, many residents of areas

171 Viljoen, Bohn, and Howe, *Continuous Productive Urban Landscapes*, 57.
173 Community Health Needs Assessment and Implementation Plan, 17.
considered to be “food deserts” are former farmers who have moved to the city to seek a better living. Food justice activists have criticized commercial urban farming companies that put young, white, middle class professionals in higher positions instead of promoting community-based leadership by hiring equally qualified members of the local community.\textsuperscript{175} Furthermore, commercial farming and community gardening projects are not necessarily mutually exclusive. A study from the University of California was dedicated to exploring the operations of “entrepreneurial community gardens,” which describe urban farms and gardens that sell products while collaborating creatively with communities to serve their social needs, such as by offering job training and educational programming.\textsuperscript{176} Some commercial urban farms have a nonprofit branch or partner with local nonprofits to offer community programming. In New York City, Eagle Street Rooftop Farms provides free education programs during the growing season through its sister nonprofit, Growing Chefs, and Brooklyn Grange partners with the Refugee Immigrant Fund to provide agricultural training to immigrants as well as horticultural therapy for victims of torture and persecution.\textsuperscript{177} Conversely, projects that primarily serve as community gardens can also improve their financial viability by incorporating a commercial operation. For instance, the Inuvik Community Greenhouse in Northern Canada covers the costs of its 75 raised beds used by community members with the profits from a commercial hydroponic farm on the second floor that grows vegetables and ornamental plants.\textsuperscript{178}

\textsuperscript{175} Campbell, City of Forests, City of Farms, 269.
\textsuperscript{176} Gail Feenstra, Sharyl McGrew, and David Campbell, Entrepreneurial Community Gardens: Growing Food, Skills, Jobs, and Communities (Oakland: University of California, Sustainable Agriculture and Research Program, 1999).
\textsuperscript{177} Cohen, Reynolds, and Sanghvi, Five Borough Farm, 57.
\textsuperscript{178} Gorgolewski, Komisar, and Nasr, Carrot City, 69.
Urban agriculture initiatives are sometimes used as a tool by community organizations that support specific social equity movements. For example, Recovery Park is a developing project in Detroit that plans to use hydroponic greenhouses on a 30 acre site to provide job training to recovering drug addicts. Neighbors Coalition for Shelter, a nonprofit that provides supportive housing and services to the homeless, commissioned a rooftop garden structure, named bronXscape, for the roof of the Louis Nine House, an apartment designed to house 46 young adults who are aging out of the foster care system. bronXscape’s forward-thinking design provides residents with areas for growing and composting, cooking, vocational training, and leisure. School gardens are becoming increasingly popular in the U.S., and they provide the social benefit of enhanced environmental and health education. Students can learn about the food cycle and sustainability through gardening, which is often accompanied by cooking programs to improve nutritional literacy. Activities related to gardening can also be used to teach subjects like math and writing in a more engaging way. Some gardens, such as the rooftop laboratory at the Manhattan School for Children, are incorporating greenhouses and sustainable technologies, like aquaponics and evaporative cooling, to allow gardens to be productive for the entire school year and to increase opportunities for hands-on, up-to-date science education focused on sustainability. Nonprofit and institutional urban agriculture projects that allow community members, who are often disadvantaged, to access more advanced CEA technologies show that these technologies do not have to be reserved for use in commercial farms.

179 Gorgolewski, Komisar, and Nasr, Carrot City, 19.
180 Gorgolewski, Komisar, and Nasr, Carrot City, 184.
182 Gorgolewski, Komisar, and Nasr, Carrot City, 179.
Urban farms stimulate the local economy by keeping more money spent on food within the community and creating jobs. When consumers buy conventionally produced food from supermarkets, the only money spent that stays within the local economy is the very small portion that covers the wages of supermarket employees. The rest of it exits the local economy to pay for transportation, refrigeration, agrochemicals, irrigation, the fossil fuels burned in these processes, and wages of remote, large-scale farms.\textsuperscript{183} When consumers buy food produced by urban farms, much more of the money spent stays within the local economy as wages for local farm staff. Every 10 dollars spent on locally produced food is actually worth 25 dollars to the local economy due to the multiplier effect, which results when local farm staff then spend their earnings on other local goods and services.\textsuperscript{184} Urban farms tend to be located where land is least expensive, which is typically in poor neighborhoods with high unemployment.\textsuperscript{185} Entrepreneurial urban agriculture endeavors have decreased rates of unemployment in these communities by providing jobs to their members and in some cases by employing youth and providing paid skills training.\textsuperscript{186} An expansion of the job market would be highly beneficial to the Bronx, as according to the Bureau of Labor Statistics, the unemployment rate in 2015 was 7.7 percent, the highest in all of New York State.\textsuperscript{187} Urban greenhouses and vertical farms generate a wide variety of skilled and unskilled jobs, including those in the fields of management, finance, marketing, architecture, engineering, agronomy, urban farming, education, security, sales, maintenance, and transportation.\textsuperscript{188} These local businesses provide ideal job opportunities for the large population

\textsuperscript{183}Despommier, \textit{The Vertical Farm}, xii-xiii.
\textsuperscript{184}Viljoen, Bohn, and Howe, \textit{Continuous Productive Urban Landscapes}, 45.
\textsuperscript{185}Despommier, \textit{The Vertical Farm}, xiii.
\textsuperscript{187}Community Health Needs Assessment and Implementation Plan, 16.
\textsuperscript{188}Despommier, \textit{The Vertical Farm}, 227-28.
of former farmers that have moved to cities as a result of crop failures.\textsuperscript{189} Urban revitalization strategist Majora Carter states that commercial activity from urban CEA would be “a welcome relief from the type of economic development we generally see driven into low-income neighborhoods—low wage retail, waste handling facilities, stadiums, and jails.”\textsuperscript{190}

It should be noted that due to the high costs of new CEA technologies, higher land values and wages in urban areas, and the energy intensiveness of operating CEA systems in cold climates, only a few crops grown through CEA in more developed areas have successfully competed with traditionally grown crops in the free market, including tomatoes, lettuce, spinach, zucchini, green peppers, green beans, and strawberries.\textsuperscript{191} Thus, government support is crucial to the economic viability of urban CEA. Governments, recognizing their economic benefits, have already provided support to many urban agriculture projects through incentives, subsidies, grants, and loans. Many agency reports have noted that urban agriculture can save municipalities money by maintaining vacant lots. A San Francisco advocacy group estimated that the management of vacant lots by urban agriculture sites saved the Department of Public Works 4,100 dollars a year per site by preventing vandalism, dumping, and labor intensive upkeep.\textsuperscript{192} In addition, since CEA structures are built on waste spaces like brownfields and rooftops, they bring tax revenues to the city from spaces that would otherwise lack economic activity.\textsuperscript{193} Moreover, by mitigating urban environmental problems like flooding, combined sewer overflow, urban heat island, and air pollution, sustainable CEA systems save both governments and individuals money on hazard management as well as healthcare.

\textsuperscript{189} Despommier, \textit{The Vertical Farm}, 25.
\textsuperscript{190} Despommier, \textit{The Vertical Farm}, xiii.
\textsuperscript{191} Despommier, \textit{The Vertical Farm}, 209.
\textsuperscript{193} Lopez, \textit{The Built Environment and Public Health}, 182.
Another oft observed economic effect of urban agriculture is its likelihood to raise surrounding property values and household income, especially in low-income communities. A 2008 study revealed that community gardens can raise neighborhood property values as much as 9.4 percent within 5 years of existence, and larger, more productive, and more attractive gardens were correlated with higher housing values.\textsuperscript{194} Rooftop farms often increase the demand for residential units in the building below.\textsuperscript{195} Though raised property values can be beneficial to poor neighborhoods when it is coupled with economic empowerment within their communities, there is also an tendency for urban gardens and farms to attract younger, more affluent population to their vicinities, leading to gentrification and the cultural alienation or displacement of long-time residents.\textsuperscript{196} This emphasizes the importance of public policy that keeps housing around urban gardens and farms affordable to the residents they were originally meant to serve.

Increasing the presence of urban CEA could be an efficient way to improve the overall wellness of communities in the Bronx, as urban agriculture simultaneously provides solutions to environmental, health, social, and economic problems. The most effective urban agriculture solutions to its “food deserts” would both increase the availability of fresh, nutritious foods and engage communities in educational programming that helps them make healthier food choices. Ultimately, the public health weaknesses of the Bronx stem from socioeconomic marginalization. Community gardening can help to tackle this root problem by integrating multicultural communities and strengthening the skills and networks required for bottom-up strategies of social empowerment. Since commercial urban CEA is a new industry with vast

\textsuperscript{195} Ackerman, \textit{The Potential for Urban Agriculture in New York City}, 14.
\textsuperscript{196} Golden, \textit{Urban Agriculture Impacts}, 15.
potential, the expansion of the industry can contribute to generations of stable economic growth.

197 However, the degree to which this benefits members of the Bronx community is contingent on community representation in companies driving economic development and the affordability and cultural appropriateness of the products and services they provide.

Design Proposal

Aiming to provide tools of empowerment to the South Bronx community while helping to kindle the sustainable agriculture movement, I designed a urban CEA complex to be located in Bronx Community District 1 next to the Willis Avenue Bridge. Park of the complex, which I call the Willis Agriculture Center, is actually built under an exit of the bridge merging into Bruckner Boulevard. The idea to integrate my CEA design into existing linear infrastructure was highly inspired by the Gardiner Urban Agriculture Hub, a theoretical project designed by Chris Hardwicke and Hai Ho. The Hub is proposed to be situated under the Gardiner Expressway in Toronto, an elevated highway with contaminated wasteland along and below it. 198 Like Hardwicke and Ho, I wanted to explore a means of integrating a community’s social and economic activities with inefficient intersections of infrastructure that divide neighborhoods and create hard-to-use waste spaces. Linear infrastructure like bridges and highways should not necessarily prevent the land along and underneath them from being used; for instance, areas underneath the High Line are home to stores, public plazas, and art installations. Directly south of Pulaski Park, there is about 90,000 square feet of unkempt green space that is cut off from the surrounding community by the Willis Avenue Bridge exit, truck lots, various other industrial

197 Despommier, The Vertical Farm, xiii.
198 Gorgolewski, Komisar, and Nasr, Carrot City, 34.
uses. In its current state, the open space below Pulaski Park is mostly unwelcoming because it has been neglected and the overhead roadway framing its entrance is not very attractive, nor is the truck activity that lies to the south. Despite these unpleasant features, I saw this large tract of vacant land as having great potential as a food production site as well as a vibrant community hub.
I picked a site in the Melrose and Mott Haven neighborhood because it is one of the unhealthiest neighborhoods in the Bronx, and this is partly due to food insecurity. According to the 2015 NYC Community Health Profile for the neighborhood, only 77 percent of residents reported consuming at least one serving of fruits and vegetables per day, which is the lowest of any neighborhood in the city.\textsuperscript{199} The neighborhood also has a relatively low supermarket square footage per capita, as it has only 133 square foot per 100 people as opposed to the citywide average of 177 square feet per 100 people.\textsuperscript{200} It has the second highest rate of avoidable diabetes hospitalizations and its rate of obesity exceeds rates in both New York City and the Bronx. To combat these diet-related issues, my design for the Willis Agriculture Center combines the benefits of a commercial farm and a community garden. The commercial operation takes the form of a four-story vertical farm that employs hydroponics, aeroponics, and aquaponics to grow a variety of produce and seafood. Since vertical farms allow for completely customizable growing environments, this would include some delicate or exotic plants like certain herbs and

\textsuperscript{199} \textit{Community Health Profiles 2015: Melrose and Mott Haven} (New York: New York City Department of Health and Mental Hygiene, 2015), 8.

\textsuperscript{200} \textit{Community Health Profiles 2015}, 5.
microgreens that could be sold to specialty markets at a premium, helping to allow commonplace and culturally appropriate produce to be sold at low prices in neighborhood markets. To achieve profitability while ensuring that a portion of the food produced remains affordable to the South Bronx community, the farm would also take advantage of the fact that seasonal fruits and vegetables can also be sold at a higher price when they are “out of season,” and it would likely receive additional support from government food and sustainability programs. The vertical farm, which would create a large number of both skilled and unskilled jobs, can stimulate the local economy by hiring members of the surrounding community. As is the case for the majority of low-income communities, the unemployment rate in the Melrose and Mott Haven neighborhood, at 16 percent, is relatively high. Providing job training with a stipend may be crucial, as 45 percent of residents in the Melrose and Mott Haven neighborhood have less than a high school degree, as compared to 20 percent of New York City residents overall.\textsuperscript{201}

\textsuperscript{201} Community Health Profiles 2015, 6.
On the first floor of the vertical farm, there is a food hall, a classroom, office space, a space for food processing and storage, and a laboratory. The food hall would serve a variety of cuisines, incorporating significant amounts of the vertical farm’s produce and inspiring people to cook similarly healthy yet culturally relevant meals at home. Waste heat from the food hall’s kitchens would be used to heat the growing spaces above during the colder part of the year. Through a nonprofit arm, the Willis Agriculture Center would host cooking classes, gardening workshops, and other educational programming in its classroom. Underneath the Willis Avenue Bridge and forming the entrance to the complex would be a welcome center and marketplace for locally produced fruits, artisanal food products, and crafts, providing a place for local vendors, gardeners, chefs, artists, and consumers to share cultures and network. The nonprofit arm would also support a community garden, which includes a greenhouse extending from the marketplace as well as an outdoor growing area. These community spaces feature simple hydroponic
container systems and raised beds, some of which are elevated to waist level to increase accessibility for the elderly and those with physical disabilities. Those who wish to use the garden would pay a small fee or sign up for a number of volunteer hours in exchange for a garden plot, which increases access to fresh, affordable produce while providing recreational benefits. As an opportunity to increase regular exercise, the community garden could be a very valuable tool for improving the health of the Melrose and Mott Haven community, which ranks third lowest in the city for reporting any physical exercise in the past 30 days.\textsuperscript{202}

The Willis Agriculture Center strives for environmental sustainability by relying as little as possible on external inputs on energy and water. The glazing of the community greenhouse and the vertical farm are made of double-glazed ETFE covered in a thin layer of perovskite solar cells. The exit of the Willis Avenue Bridge conveniently runs from west to east, allowing the

\textsuperscript{202} Community Health Profiles 2015, 8.
CEA structures built along to it face south and rely significantly on natural sunlight to support plant growth. Sunlight that passes through the layer of perovskites is also harnessed as energy to power OLEDs for supplemental lighting as well as other regulating mechanisms of the vertical farm that require electricity. Solar power is also harvested by traditional silicon PV panels that double as shaded outdoor seating areas, where community gardeners can relax and share meals when the weather is pleasant. If it is found to be an efficient means of on-site energy generation, wind turbines can also be installed along the elevated roadway to make use of the wind produced by passing cars. An anaerobic digester in the basement breaks down post-harvest portions of crops, food waste from the food hall, and fecal matter from the restrooms, generating biogas that can be burned for cooking in the kitchens or to heat the greenhouse in the fall and winter. The remaining digestate is then composted and used as fertilizer in the community garden’s raised beds. Organic waste can also be vermicomposted, i.e., composted using worms, and excess worms can be fed to aquaponically raised fish. The vertical farm collects rainwater from its sloped walls, which is stored in cisterns before being circulated throughout the farm. The concrete highway above the marketplace acts as a large thermal mass to passively regulate indoor temperatures. Similarly, the north wall of the vertical farm is made of concrete bricks, which absorb solar radiation that enters the building during the day and releases it as heat during the night. On the exterior of the wall, a series of living walls facing the exit manages local air pollution from automobiles and serves as a “billboard” advertising the Center to those who pass by. Living walls also line the vertical spaces of the marketplace and the food hall, improving indoor air quality, and the water that is transpired by plants on these walls is captured by dehumidifiers for reuse in the farm. Plants will be chosen for these living walls on the basis of
their ability to grow with limited light, as neither indoor spaces nor the vertical farm’s north wall receive much or any direct sunlight. The air purification services of plants in the Willis Agriculture Center would be very beneficial to the health of the surrounding neighborhood, as the air in Melrose and Mott Haven has a high concentration of fine particulate matter compared Bronx and citywide levels, exacerbating respiratory diseases. This neighborhood has the highest rate of child asthma hospitalizations, which is more than three times the citywide rate.\textsuperscript{203} The Willis Agriculture Center provides community members with an open outdoor space for recreation that is safe and clean, unlike many of its surrounding areas.

\textsuperscript{203} Community Health Profiles 2015, 5-12.
The Willis Community Agriculture Center is an undoubtedly ambitious project, yet it can only serve as a small step towards achieving social, health, and economic equity in the South Bronx. My hope is that this project provokes discussions regarding the current state of our food systems and their environmental impacts and inspires other urban CEA initiatives that begin to build a more sustainable future for food production, as the continued survival of the earth’s growing population counts on it.
Bibliography


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Waste-to-Energy Powered Vertical Farm to Achieve Food Justice and Sustainability.


