Growing Up: An Exploratory Study of the Role of CEA Technology in the Urban Food Landscape

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ABSTRACT

Vertical farming refers to the practice of growing agricultural products indoors using a method called controlled-environment agriculture. This term encompasses a variety of systems that take a technology-based approach to farming, in which climate conditions can be almost completely controlled using advanced monitoring systems. The agricultural industry, and global food systems more broadly, have faced severe criticism for their exacerbation of climate change and their disposition to social instability, as we've seen most recently during the Covid-19 pandemic. This study explores the role of controlled-environment agriculture as new agro-technology and seeks to understand its impact as an alternative food source, within the urban landscapes, particularly on the local level. I review the different dimensions of controlled indoor vertical farming and how it relates to other forms of agriculture, in both urban and rural settings. Original qualitative research was conducted in the form of a content analysis of CEA farm websites and interviews with CEA users, in order to understand how the role of CEA technology is framed by users and to determine what the benefits and challenges are of implementing CEA technology at the local level. This study informs policy recommendations for how CEA technology can be made more accessible to urban communities, and how it can be better integrated into the urban food landscape.

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Introduction

The practice of growing plants vertically has existed since Ancient Mesopatamia dating back 2500 years ago. The Hanging Gardens of Babylon were built on four terraces and each level was equipped with artificial irrigation with bituminous insulation and a layer of earth where shrubs and trees were planted. Other civilizations engaged in similar practices. Aztecs had their own variation of hydroponic farming created on floating rafts made of reeds, stalks, and roots; Romans, in the 3rd century BC, grew vines so that they would climb over the bars and the walls of houses. In the seventeenth century, the hydroponic method of plant cultivation was scientifically documented in books, such as *Sylva Sylvarum* written by Sir Francis Bacon; however, for the first time, the term of "vertical farming" was coined in 1915, when the American geologist, Gilbert Ellis Bailey, used the concept in his book, *Vertical Farming*, to describe multi-story buildings which are dedicated to indoor plant cultivation. The modern concept of vertical farms was developed by Dickson Despommier, a professor at Columbia University in New York in 1999 who proposed cultivating multi-story crops inside buildings. His project is a proposal of a thirty-story, artificially lit building, which, according to Despommier's calculations, could feed as many as 50,000 people. Under his influence, the first practical implementations of vertical crops under a roof appeared (Zaręba et al., 2021). As the threat of climate change and food security worsens, indoor vertical farming, also more broadly coined as controlled-environment agriculture (CEA), has grown in popularity as a promising remedy for the environmental and social challenges that many cities currently face; advocates of CEA technology and vertical farming frame these new growing technologies as means of developing vibrant and sustainable food networks in urban centers.

LITERATURE REVIEW

Global Food System Crisis

Rise of Global Food System

Food systems can be defined as “the sum of actors and interactions along the food value chain—from input supply and production of crops, livestock, fish, and other agricultural commodities to transportation, processing, retailing, wholesaling, and preparation of foods to consumption and disposal” (*Food Systems, IFPRI : International Food Policy Research Institute*, n.d.). In the first half of the twentieth century, American food systems were dramatically more localized than they are today. Approximately 40% of Americans lived on farms in the early 1900s compared to only 1% just a hundred years later. After World War II, the United States saw a dramatic shift from a reliance on local food sources to national and global food sources. This is the result of advances in technology that made the transportation of food over great distances more feasible, as well as neoliberal policy that supported free-trade agreements. Prior to World War II, few foods were processed and packaged and consumption was dictated by the seasons and local climates. Lower transportation costs coupled with technological advancements in food preservation and shipping made foreign agricultural products more accessible to domestic consumers, thereby increasing the demand for a global food system (Martinez, 2010). Agricultural industries, across the world, developed specializations in certain agricultural products as determined by the climate and environment of that given region. This ultimately facilitated the culture of monocropping–growing the same plant type in the same area for long durations of time– that exists today.

For decades, food was not considered an “urban issue", and was, therefore, excluded from the policy of city governments and lacked any departmental representation. High rates of food insecurity, and other food-related issues, demonstrate the extent to which food impacts the physical, mental, and environmental wellbeing of urban residents; this reaffirms the significance of food as an actor within cities, and recognizes its power to dramatically improve or completely disrupt daily urban life (Bedore, 2010; Pothukuchi & Kaufman, 1999). If cities are to fully address social inequality, as it relates to community health, then food must be considered more actively within a political context. In recent history, several movements– the environmental movement, community food-security movement, and the slow food movement– have been critical of hyper-globalized food systems due to the resulting socio-cultural and environmental damages, such as: deforestation, loss of arable land, intense water consumption, food insecurity, poor nutritional health, and labor abuses.

Environmental Impact of Global Food Systems

Globalized industry is a major culprit responsible for our current climate crisis, and agriculture is one of the largest contributors to greenhouse gasses of any of them. When considering the combined emissions released from agriculture management, deforestation, transportation, packaging, and food waste in the global food supply, this translates to approximately 30% of the total global emissions. This amount is 3x greater than emissions from the building sector and equal to the emissions released from all other industrial sectors combined. Industrial agriculture is only surpassed in its cumulative emission release by the energy sector whose share is 37%. It requires the use of obscene amounts of natural resources to operate farms on this scale, especially land and water. On average, global farming accounts for 70% of freshwater that is consumed annually, and 40% of this water is lost to the environment due to poor irrigation systems, evaporation, and overall poor water management (Balsom, 2020). One environmental report estimates that there will be an increase of agricultural emissions by at least 30% by 2050, if we proceed to meet growing food demand as we have in the past ("How Does Agriculture Change Our Climate?," n.d.). This has called for a cultural shift in the minds of many Americans, especially those who live in urban environments, and to reevaluate our current food systems and their role in exacerbating the instability of our environment.

Furthermore, as the global population experiences rapid rates of urbanization, one of the largest considerations for the future of cities is how urban land can be utilized to sustainably support increasing urban populations. Keep in mind that we are also undergoing a period where we are seeing high rates of deforestation and the loss of arable land. Rapid population growth naturally translates into an increased food demand. Currently, there is approximately 800 million hectares of land that is designated to soil-based farming globally, which constitutes about 38 % of the total global land area. Currently, 80% of the world's arable land is used, while the remaining 20% is wasteland, whose cultivation potential has virtually disappeared due to poor land management in recent decades (Zaręba et al., 2021). Climate change is making growing conditions more volatile and as a result making food productions less secure. It is predicted that for every 1 degree increase in atmospheric temperature, 10% of the land where we currently grow crops will be lost (Despommier, 2011). Climate change is raising temperatures, intensifying drought periods, increasing the rate of flooding and soil erosion across the globe, and, subsequently, placing more pressure on the internal structures that comprise our global food system. One could argue that the size of the system reveals its fragility; operating on international-scales makes it so that our food systems are more susceptible to global instability. In order to appropriately respond to the changes in our environment, food systems must be reimagined in a way that promotes sustainability.

Health Impacts of Global Food Systems

Food insecurity refers to a person's inconsistent access to food and little to no access to healthy, high-quality food–these are considered to be foods that are calorically-dense and nutrient-dense. Food insecurity is a systemic issue and disproportionately affects: households with children, Black and Hispanic households, low-income households, and college students (*Impact-of-COVID-19-on-Food Insecurity-6.28.2022.Pdf*, 2022). Two factors that influence food insecurity rates are unemployment and poverty. In a report released by Feeding America, food insecurity differed dramatically across racial and ethnic lines. Nationally, 15.8% of Latinos, 19.3% of African-Americans, and 23.5% of American Indians all live in a food insecure household. These communities are at higher risk to certain health conditions associated with food insecurity: diabetes, hypertension, obesity, anemia, mental health issues, and developmental delays in children (Communications, 2021). A projected 13.1% of urban residents, in 2020, experienced food insecurity, this number dropped to 12.1% in 2021 ((*National Projections Brief_3.9.2021_0.Pdf*, 2021). Interest in food-system localization is a reaction to the destructive, disempowering and alienating effects of large-scale political economic forces. Over generations, people have gradually lost control over the production and quality of their food, and, as a result, have become increasingly disengaged from food systems all together. Neoliberalist agendas have compromised the ability of governments to effectively meet community needs; the subsequent response has been to organize at local scales (Allen, 2010).

The fragility and failures of the global food system have most recently been exposed by the Covid-19 pandemic. The percentage of food insecure households in the United States, prior to the pandemic, was approximately 11%, and this number increased to approximately 14.8% soon after the onset of the pandemic in Spring of 2020. This equates to almost 38.8 million people, with 11.7 million of them being children (*Impact-of-COVID-19-on-Food Insecurity-6.28.2022.Pdf*, 2022). The pandemic contributed to food insecurity in a few key ways: more Americans became dependent on food banks, as a primary food source, with increased rates of unemployment, long supply chains were disrupted, and children no longer had access to regular meals that would otherwise be provided during the school day (Communications, n.d.). Climate change and the pandemic have called the effectiveness of our global food systems into question, prompting communities worldwide to consider the viability of alternative food systems and their potential at remediating the degradative agricultural practices that dominate the industry today.

The Rise of Local Food Systems

What are Local Food Systems?

Across literature there is no single definition of a local food system, apart from a couple shared criteria: first, that the entire process from when food is produced to when it is recovered happens within the same locality and, second, that the system in place is sustainable. ATTRA– the National Sustainable Agriculture Information Service–describes local food systems as the "collaborative and overlapping processes that connect sustainable food production, processing, distribution, consumption, and waste management/recovery. A functioning local food system integrates the five sectors to serve the values of enhancing the environmental, economic, social, and nutritional health of a particular place and its inhabitants". Urban agriculture is the term used to describe food systems that are localized to urban centers. This research will primarily explore and analyze the role of controlled-environment agriculture as an emerging technology in the agriculture industry, and seek to understand its impact as an alternative food source, within the urban landscapes, particularly on the local level. We currently live in a reality where communities are more removed from their food sources than ever before; the localization of food systems is proposed by communities, with the intention of restoring the social connection that's been lost between consumer and product.

An Overview of Urban Agriculture

Over the last several decades, urban agriculture has grown in popularity as a remedy for environmental harm and as one solution to inadequate healthy food access for urban residents in cities. Urban farms are described as "horticultural, agricultural, and farming activities carried out on small plots of land in and around urban centers" (Ackermann, 2014). Typically, academic literature related to urban agriculture evaluates the ways in which traditional farming methods have been modified to operate in urban settings and the subsequent effects of such–the term 'traditional farming methods' refers to common growing practices like growing outdoors in the ground and in garden beds, or using familiar watering systems like hoses, sprinklers, or drip irrigation etc. With that being established, it is still important to recognize that every urban farm is different with its own unique physical and social conditions that require a specialized combination of growing techniques in order to best address its needs and insure its success; however, across literature there are certain commonalities in the types of growing techniques employed by urban farmers. Urban agriculture is considered a form of green infrastructure or a "nature-based solution". This refers to the practice of implementing nature-derived concepts into cities to meet various urban and environmental needs. The International Union for Conservation of Nature defines nature-based solutions as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits" (*Urban Nature-Based Solutions*, 2021). Examples of nature-based solutions can range from actions as simple as using rain barrels or planting trees, to more advanced projects such as the installation of green roofs and green streets. The ecological services provided by nature-based solutions can have a number of outcomes on the built environment, to name a few: reducing urban heat island effects, managing urban stormwater impacts, and decreasing the amount of energy expended on food transportation.

The hope is that by introducing more nature-based solutions into urban environments, cities can better address global challenges, like urban sustainability, climate change, food resilience, the biodiversity crisis and other emerging challenges (Carvalho et al., 2022). Urban agriculture is a leading example of the efforts of urban communities to introduce nature-based solutions into cities, and address the environmental and social disparities related to food production practices and food accessibility. There is currently little discussion about how CEA farming fits into the context of urban agriculture and how it compares to other urban agricultural practices. It is important to note that much of the existing research on the environmental and social impacts of urban agriculture are not necessarily representative of the role that CEA technology plays in changing urban food landscapes. This in-part because literature does not provide a clear explanation of whether or not controlled-environment agriculture can be considered a nature-based solution by definition. Nature-based solutions are usually defined by their direct remediation of the environment. This is different from CEA farms which are contained within buildings or other types of infrastructure. This is not to suggest that controlled-environment agriculture exists mutually exclusive from other forms of urban agriculture and nature-based solutions; however, it has a more passive influence over the social and environmental landscapes of cities, as described in more detail later in the literature review. Identifying this gap has been important in framing the literature review as well as creating the questions that inform this research. This study focuses exclusively on CEA technology, exploring how it compares to other agriculture systems, as well as uniquely addresses the social and environmental challenges of the urban environment.

Controlled-Environment Agriculture Revolution

Defining Controlled-Environment Agriculture

The College of Agricultural and Environmental Sciences at UC Davis defines controlled-environment agriculture (CEA) as a term that “encompasses a variety of systems that take a technology-based approach to farming”(Perla, 2021). CEA can range from simple shade structures to fully-automated indoor farms that operate within closed-loop systems, and use advanced technology to control lighting, watering, and ventilation. Vertical farming is a type of controlled-environment agriculture; literature does not clearly differentiate between the two terms, and, in most instances, uses them interchangeably. This research is focused on indoor vertical farms that use advanced CEA technology to grow agricultural products for urban areas. Vertical farming is the practice of cultivating fruits, vegetables and other agricultural products on top of each other in some kind of vertical configuration–examples of which are green walls, stacked trays, and cylinder towers (*Vertical Farming*, 2017.). CEA technology is distinctly scalable, operating on domestic, community and commercial-level scales; this has in-part contributed to its viability as an alternative farming system compared to what is normally observed of urban agriculture. The design of controlled-environment agriculture allows farmers to monitor and enable certain environmental conditions that best meet plant needs, thereby ensuring optimal plant growth that would otherwise be impossible to control in an outdoor setting (Benis & Ferrão, 2018). It was briefly mentioned that CEA technology allows farms to operate as closed-systems with reuse as a fundamental application in their design. Hydroponic and aeroponic systems manage to save up to 90% more water than traditional agriculture through the implementation of recycled water techniques (Kalantari et al., n.d.). The emergence of CEA technology in farming provides a remarkable opportunity to create and exercise ingenuitive solutions to the world's water crisis, and indoor vertical farms provide an exciting opportunity to bring food systems into urban centers, thereby reducing the harmful, environmental effects of a transnational food industry.

Differences in CEA Product Type

However, some of the largest benefits of CEA technology mitigates common issues that arise for many types of outdoor urban agriculture projects. Soil contamination is a common challenge for growing food in an urban environment. Many urban farms seek to repurpose and transform underutilized land into viable green space. However, the process of transitioning brownfield sites into operating urban gardens and farms can be difficult; even in the case that land is successfully re-developed for agriculture, there is always the risk of re-contamination. Therefore, eliminating soil as a factor of growing agricultural products, ensures a greater capacity for a larger crop yield. Furthermore, outdoor farming is subjected to various levels of attack from a wide variety of microbes and plant pests, often resulting in significant loss of many types of annual harvest. Well-engineered indoor growing facilities can minimize or even eliminate the possibility of such losses, and without the use of toxic pesticides. CEA facilities can be secured using positive pressure systems, similar to the defensive barrier one would find in a hospital to protect patients. In the case that an outbreak or infestation occurs, facilities can be sanitized and crops replaced. This is drastically faster than the rate at which an outdoor farm could recover, potentially taking upwards of a year (Despommier, 2011) .

A key difference between controlled-environmental agriculture and industrial farming is in the variety of products that can be produced at a given time. Industrial farming typically operates within a monocropping culture, whereas vertical farms are able to grow multiple types of crops simultaneously on different levels (Benis & Ferrão, 2018). Some major drawbacks of monocropping include: soil degradation, water loss, erosion, plant susceptibility to pests and disease (Gebru, 2015). Another advantage of CEA technology is that, unlike traditional outdoor farming which can only be carried out at particular times of the year, plants inside CEA farms can grow at any point throughout the year (Kalantari et al., 2017). Controlled environments facilitate growing conditions for greater plant diversity in any given season. Eight types of crops can be harvested yearly, however in industrial farming, only a maximum of three crops can be harvested in a year (Kalantari et al., 2017). This can help cities meet the needs of consumers without totally relying on a hyper globalized food system to supply grocery stores with different agricultural products. All of these practices contribute to greater crop recovery than industrial agriculture. Across literature, some of the agricultural products listed as the most compatible with CEA technology are different types of leafy greens, like lettuces, chards, kales, and microgreens, as well as strawberries, herbs, and cucumbers. This provides insight into one of the greatest limitations of CEA technology as it compares to traditional, outdoor growing, which is that vertical farmers are going to have a shorter list to choose from when deciding what to grow using CEA technology. So, although indoor vertical farms can grow more products at once and at any time during the year, these products are going to be limited to plants that do not require a lot of space and can be stacked. For example, fruit trees and root vegetables are not as adapted to growing in an enclosed structure, in comparison with lettuce, because they require a certain amount of space vertically and/or horizontally, that is not always provided by indoor growing facilities.

CEA Technology Design

Stacked horizontal trays are probably the most widely-used CEA growing system among commercial vertical farms, and have also become very popular among many community-based nonprofit farms as well. This system is composed of multi-level horizontal growing trays that are stacked on top of one another inside buildings. Ponic systems are the most common method for growing agricultural products indoors: hydroponics, aeroponics and aquaponics. Ponic systems are soil-less methods of farming that use nutrient-dense water-solutions to feed crops. All ponic systems grow plants in a substrate–a growth medium that supports the root system as well as captures moisture and oxygen. Sand, gravel, clay and perlite are all examples of substrate materials that acts as a container for plant roots to be fed a nutrient-dense water solution (Kalantari et al., n.d.). However, ponic systems vary amongst each other in a few notable ways: 1.) Hydroponics administers nutrients through a complete submersion of the plant roots in a water solution. 2.) Aeroponics administers the nutrients through a misting of the solution directly onto exposed plant roots. Aeroponics is highly compatible with the cylinder tower vertical farming system. 3.) Aquaponics is the process of growing plants symbiotically with fish. Fish waste creates a nutrient-dense water solution that is pumped from the fish tank to a horizontal growing tray, where bacteria convert ammonia to nitrates for plants to consume. This results in purified water that is then captured and re-pumped into the fish tank creating a mutually beneficial, re-circulatory system (Kalantari et al., n.d.). When conducting preliminary research on vertical farms that are currently in operation within urban areas, hydroponics was overwhelmingly the most used CEA growing system by farms, as described on their websites. The literature does not expand on the ways in which these systems differentiate, so there is very little known about why one system might be more preferable over another. This offers up another avenue for research on the credibility of CEA technology and the ways in which it can be used.

CEA & Water Conservation

One of the strongest, and most recurring, arguments in favor of CEA farms is that it uses a fraction of the water that traditional, outdoor farming does; this point is mostly in reference to the water usage of industrial-sized farms. CEA technology conserves water through a recycling process, in which water that has been evaporated from the crops is condensed and recaptured, in an air handling system. This, now, purified water is returned to the growing trays as a freshwater source for the plants. This is a huge benefit of growing crops indoors compared to traditional agriculture and other forms of urban agriculture where recovering water is much more difficult in an outdoor setting. Many traditional farms rely on sprinkler systems to water fields, and much of this water is not absorbed by plant roots and is ultimately lost to the environment. Furthermore, ponic systems have improved water management, due to an improved accuracy of water application to plant roots. This results in optimized water usage and the elimination of excess waste. Some literature theorizes that city wastewater can be recovered and treated for the purpose of supplying indoor vertical farms. This includes captured water from rain, from building roofs, and gray water–water from faucets, showers, bathtubs, washing machines that isn't laden with human waste, food or toxic chemicals (*One Way around California's Water Restrictions*, 2022). However, this research was unable to find an exemplary indoor vertical farm that performed any of the waste water treatment methods mentioned above in its operation. Another benefit to indoor vertical farming is large reductions of agricultural runoff. The controlled-environment feature of vertical farms eliminates the potential of water contamination from pesticides and herbicides, phosphorus and nitrogen, fecal matter, toxic metals, and trash, thereby eliminating the risk of polluting and harming urban and natural ecosystems (Ackermann, 2014). However, this last point is less relevant, due to the elimination of chemical use from most, if not all, CEA farms in which the contained and controlled environment protects the plants, acting as a barrier from disease and pests.

CEA & Land Conservation

Land conservation is an intrinsic value of indoor vertical farming as demonstrated by its upright design. If outdoor farming goes indoors, there will be a 20x reduction in land use (Kalantari et al., 2017). Advocates of CEA growing argue that, overtime, land that has been developed for agriculture can be eventually restored to its original state. This can have very beneficial impacts in terms of rebalancing atmospheric gasses and tempering the effects of climate change. Vertical farming optimizes land space to the point that large-scale vertical farms are competitive with industrial agriculture in terms of its crop yields. For example, a vertical farm can achieve lettuce yields per square meter of more than 80 times the yield of open-field agriculture and more than 12 times that of greenhouses (Gerrewey et al., 2022). The construction of new buildings is not required to house vertical farms; existing, underused spaces can be repurposed to accommodate the installation of indoor farms. It is becoming more of a common practice that abandoned buildings and storage crates are retrofitted with CEA technology to sustain indoor vertical farms (Kalantari et al., 2017). The influence of climate change on crop production is less severe in an indoor, controlled-environment compared to an outdoor environment. Informed by advanced monitoring technology, growing conditions such as feeding, sun exposure, temperature etc. can be adjusted to certain levels that are most conducive for growth stimulation. Installing these technologies is important in establishing sustainable practices, managing resources and minimizing waste. Limited access to vital resources is a challenge faced by many, but urban residents are particularly vulnerable (Carvalho et al., 2022). Shortages in land and water not only put strain on individual urban farms, but also hinder the development of a sustainable, local urban food network of producers, sellers and consumers. Vertical farming is a promising solution due to its adaptability and scalability in establishing local food production in urban environments.

Energy Limitations

One of the largest limitations of indoor vertical farming is that it uses a lot of energy. With no energy from the sun to support plant life, vertical farms supplement using artificial light; the most common light and energy source for indoor vertical farms is LEDs. LED equipment can be controlled throughout a growing season to emit a programmed spectrum of light that is optimal for photosynthesis for different types of crops. When coupled with regulation of temperature and humidity, the effects of seasonality can be minimized or eliminated (Benke & Tomkins, 2017). Plant response to different wavelengths of light from LED sources suggests very significant improvements in productivity are possible. In addition to wavelength, controlled lighting with respect to intensity and time duration is another area where potential optimization strategies are possible (Benke & Tomkins, 2017). There are disputes over the cost of LEDs. It is hypothesized that if the agriculture industry of the United States followed a vertical approach, the electricity required for lighting would be eight times that of the amount generated by all power plants annually in the United States (Kalantari et al., 2017). Taking full advantage of additional lighting in vertical farming still remains a challenge. Critics of LEDs argue that its costs outweigh its benefits, but others reply that LEDs have been and continue to drop in prices. If we assume that the price will continue to steadily decrease then the concern of LEDs costs may not be long lasting.

CEA as a Social Tool for Urban Communities

There are undoubtedly significant social benefits resulting from localized urban agriculture: increased social participation, building a strong local community that cares about its surroundings, and creating a new urban and human-friendly space in environmental education . Urban agriculture also stimulates physical activity of the inhabitants and facilitates the consumption of fruit and vegetables, thus contributing directly to improving the quality of life and health of society (Zaręba et al., 2021) However, these benefits might not be present among all vertical farming enterprises. The vertical farms that are often spotlighted in literature and in media are usually private and commercial-sized, which warrants skepticism about how accessible this technology will be made to the communities that they are located in. However, the scalability of vertical farming systems compensates for this dilemma by providing local organizations and households the opportunity to produce their own food using these same technologies on a level that meets their needs. Vertical farming cylinder towers are probably one of the most scalable and beginner-friendly vertical farming systems that exists. Its simple design consists of pvc pipes that are configured to house plants in small, individual notches located around the tower's exterior. The plants are contained in their growth medium, and the roots are exposed on the inside of the tube. Water travels down the inside of the chamber, running over the roots and delivering nutrients. The towers can be built to a desired height, ranging from domestic-scales to commercial-scales.

Generally, there is still a gap in literature on the role of CEA technology as a socially sustainable farming system for urban residents. The term food security has come under criticism for not accurately portraying all of the systemic factors that makes accessing healthy food difficult for some communities. Some critiques posit that true food security can be achieved only through food systems that are environmentally sustainable, healthy, fair and democratically controlled (Diekmann et al., 2020). Participation is one of the greatest mechanisms for community empowerment and resilience, especially for low-income communities of color that are disproportionately susceptible to food insecurity. Collectively seeing to the success of a farm not only provides communities with a stable source of food but also a sense of autonomy over their own health and well-being. Food is socially transformed, representing more than just its caloric or nutritional value.

Furthermore, urban farmers maintain cultural integrity through the enacted food values in their agriculture–relating to health, knowledge, control, trust, freshness, flavor, organic production methods and sharing. Food values are strongly held by people of all income levels – despite popular claims that low-income people lack knowledge about what constitutes healthy or good food or that interest in food that is fresh, organic, local and/or seasonal are largely white, middle-class concerns (Diekmann et al., 2020). In order to have the greatest social impacts, CEA technology needs to be made available to communities that experience or are at-risk of experiencing food insecurity. Urban agriculture has historically been co-opted by white, middle class communities. If indoor vertical farms were to follow a trajectory that primarily serves white communities, it would not have the desired outcome of creating a socially and environmentally sustainable local food system. Furthermore, CEA food production should be sensitive to the cultural and spiritual needs of the neighborhoods in which they are located. Diets preserve history and reflect culture for many communities, serving as another form of community empowerment. As previously mentioned, CEA farming systems are compatible with only certain plant species, particularly tomatoes and peas, leafy greens, herbs, and certain berries. The absence of soil in a confined space, makes indoor farming less suitable for fruit trees, root vegetables, and beans which require a lot of space. These limitations in plant production type could make it more difficult to wholly support and sustain cultural diets if vertical farms are unable to supply communities with their desired culturally-relevant foods.

It is argued that the expansion of the vertical farming industry will create new job opportunities for farmers, technologists, project managers, maintenance workers, marketing, and retail staff, and promote local industries. According to one journal, a survey revealed that vertical farmers have mentioned the need for more specialist employers educated in plant science, growing, and plant maintenance, as the vertical farming industry mainly attracts technically-skilled staff who lack a lot of agricultural expertise (Gerrewey et al., 2022). There is a wide range of jobs that are available at indoor vertical farms: managing seed production, transplant of seedlings in vertical farms, managing resources ranging from water to light, machinery, etc., supervising the growth of plants, pollination techniques, harvesting, managing waste, managing energy, quality control , distribution control, managing IT personnel and other human resources (Kalantari et al., 2017). By contributing to the development of localized food systems in urban centers, vertical farms can, also, indirectly support the creation of jobs at other steps in the food system that relate to processing, distribution and consumption. Depending on location-siting and business practices, CEA farms can provide opportunities in job training for low-skilled workers, thereby making far-reaching improvements to all urban communities.

Across academic literature, advocates of CEA technology label it as the future of agriculture, using primarily an environmental framework to measure its associated benefits; the social impacts of CEA technology are less researched, and therefore more speculative than anything. Furthermore, there are limitations in the type of vertical farm model that is surveyed by researchers. The majority of vertical farms studied and featured in academic literature are commercial-sized, private farming operations. Very little data has been conducted on the ways in which CEA technology is used on community and household scales, as well as on how these models can also support local urban food systems. This research seeks to address these gaps through an exploratory study of CEA as a new agricultural technology within urban landscapes, with a focus on its impacts at the community-level scales: *How do farms that use controlled-environment agriculture (CEA) portray the role of CEA technology in local urban food systems? What are the benefits and challenges of using CEA on a community-level scale, with special consideration of food production and food education?*

Methods

Concept-Content Analysis

To answer the first part of the research question: "How do farms that use controlled-environment agriculture (CEA) portray the role of CEA technology in local urban food systems?" I performed a conceptual content analysis of 31 different CEA farmers and their official websites to better understand the self-perceived role of CEA technology as a new form of agriculture that is local to urban environments. A content analysis was chosen for its ability to identify and examine common themes, across CEA farms websites, related to how they portray their role to the public. Farms who fit the scope of this content analysis were chosen based on the proximity of their farming operations to urban centers–websites qualified if farms were located in cities or in greater urban areas. The majority of websites that were analyzed were of CEA farms located in different cities across the United States; however, two websites analyzed were of farms located in urban centers abroad. There were varying degrees of scale for the CEA farming operations analyzed in this study ranging from small-scale non-profits, to small businesses to the larger-scale operations of commercial businesses. The content analysis was limited to information found on the official websites of CEA farming operations; I excluded blogs, news articles, and journals from the analysis to maintain uniformity across the data sample. I felt that focusing the analysis on official websites would offer the greatest insight into the different ways in which CEA farmers perceive the role of CEA technology in the landscape of urban agriculture and how they portray CEA's viability to fulfill that role.

In preparation for the data collection, I created a working dictionary of codes that would guide the analysis of each website. These codes were informed by themes found in existing literature on CEA. There were, in total, 10 codes used in the analysis of the websites. Each code fell into one of two categories: 6 codes fell into the "Social Role" category, and 4 in the "Environmental Role" category. The context unit–the largest amount of information that might be taken into consideration when evaluating under what category/code an individual segment belongs–was a sentence. Within each context unit there could be one or multiple coding units–individual text segments that a code is assigned to–which were at most a phrase. I coded language–words and phrases–based on the degree of similarity to the descriptive language of the code. For example, the Aerofarms website has a header titled "Cutting-edge innovation", this phrase would be coded as "technological innovation" due to its high similarity in word choice as the descriptive language of the code. Concepts were also coded based on the degree of similarity to the definition of the codes (See Appendix X for code dictionary). For example, in a summary of how they grow, Aerofarms describes their process as "optimized for year-round production, no matter the season or weather". This phrase would be coded as "technological innovation", because, despite not explicitly stating those words, it refers to a specific feature of CEA's design that makes it technologically innovative.

The number of times a code appeared, for each website, was logged in an Excel spreadsheet. After every website was entirely analyzed, an average frequency was taken for each code to determine which were the most popular. By identifying the most popular codes, we can better understand how CEA farmers position CEA as a new form of urban agriculture by understanding which social and environmental elements are most frequently emphasized. Averages were taken for all 31 websites together, as well as taken, independently, for big businesses, small businesses, and non-profit organizations to identify thematic differences across the scale of CEA operations and business models.

Semi-Structured interviews

To answer the second part of the question: “What are the benefits and challenges of using CEA on a community-level scale, with special consideration of food production and food education?” I have conducted qualitative primary research informed through 4 semi-structured interviews with representatives of small-scale businesses, nonprofit organizations and institutions that utilize CEA technology for the purpose of growing agricultural products for education and/or distribution to urban communities. Initially, it was intended that the interviews would be more representative of varying degrees of CEA production scales–ranging from community-level scales of production to commercial-level scales of production. However, after reaching out to 15 CEA farms, of both community and commercial levels, no large-scale CEA farm agreed to participate in this study. The subsequent result was that all of the participants I acquired were small-scale CEA farms, shifting the focus of my research to the ways in which CEA is deployed on community levels. Interviews with both for-profit and nonprofit users of controlled-environment technology provides a more holistic portrayal of how this specific form of agriculture fits into the context of urban agriculture. This research explores the various environmental and social influences controlled-environment agriculture has not only in the support of local food systems but also in daily urban life. I selected and interviewed one small-scale business, two nonprofit organizations and one high school that use CEA technology across 4 different states and cities:

Table 1. List of interviewed CEA farm representatives and their business model

Name	Type	Representative	Role	Location
The Plant Chicago	Non-profit	Eric Weber	Director of Operations	Chicago, IL
Pillsbury United Communities	Non-Profit	Micah Helle	Operations Manager	Minneapolis, MN
Interboro High School	Institution	Thomas Speer	Teacher of Technology Education	Prospect Park, PA
Hammock Greens	Business	Max Chuvalas	Chief Project Officer	Miami, FL

All interviews were recorded with participant consent, and later transcribed using Zoom, Otter.ai, and by hand. Subject selection was performed through internet research of "urban indoor vertical farms" using, primarily, Google searches, the Freight Farms website, academic journals, and personal references. I have chosen companies using a couple criteria: first, that they are located within urban centers or in greater urban areas. This study seeks to understand the ways in which CEA contributes to food systems and food education of urban communities; therefore, CEA farms that are in closer proximity to cities will have a greater impact on urban populations than CEA farms that are not. The second criteria is that urban farms must use some method of controlled-environment agriculture to grow food and other agricultural products for free distribution or for sale. Third, community health and development are working elements of their business model, as depicted from mission statements on their websites. The diversity in location amongst the participants offers an opportunity to better understand CEA's growth in popularity as a national urban trend, and to identify the common benefits and challenges of acquiring and using this technology on small-scales in order to meet the needs of urban communities. Groups were contacted via email for interviews performed either in-person, on Zoom or on the phone. I have asked interview questions related to location siting and design, policy, community engagement, financing, food production and distribution, consumer demographics, environmental impacts.

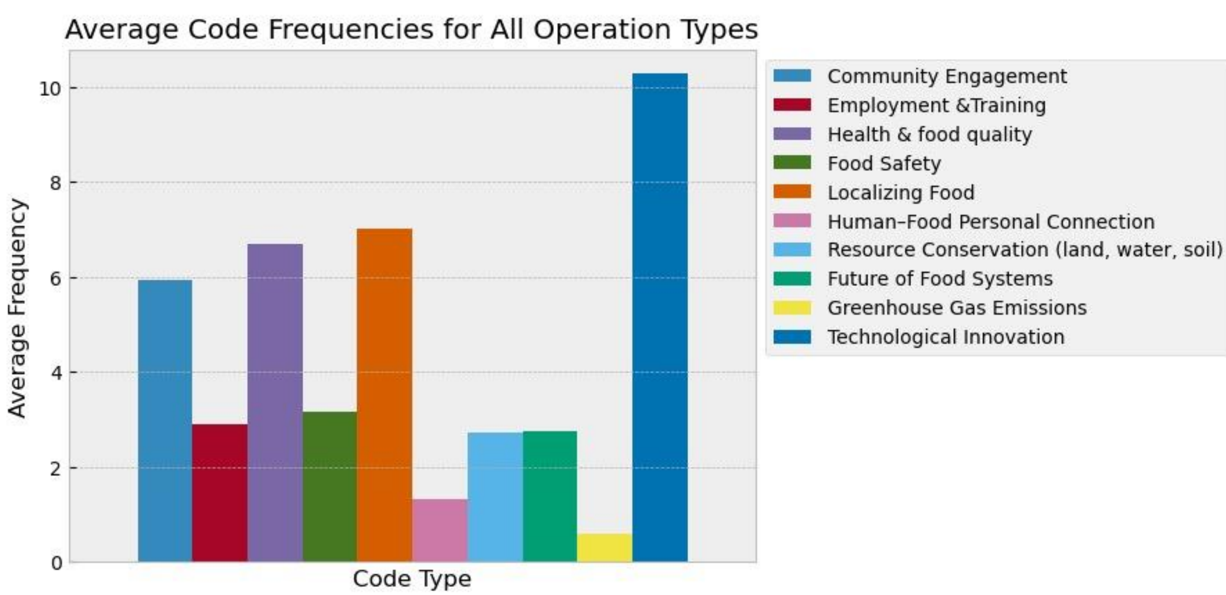
DATA FINDINGS & ANALYSIS

Findings & Analysis from Content Analysis

<u>Total Average Frequency of all 30 CEA Farm Websites</u>

The codes that appeared most frequently across all websites and stakeholders were, in order from most to least: Technological Innovation, Food Localization, and Health & Food Quality.

Graph 1. Average Code Frequencies of all CEA farms



1. CEA as Technological Innovation

Technological innovation was, on average, the code with the highest frequency, being mentioned an average of 10.35 times per website. This demonstrates user perception of CEA's role as a modern, and innovative technological solution to farming in urban areas. Technological innovation refers to the advancements of CEA as a distinctive agro-technology, whose physical design facilitates optimal food production all year-round in any place. Common concepts found across CEA user's official websites that implied "technological innovation" and coded as such were: accurate data analytics, increased yields per acre, user control of growing conditions, and season extension for growers.

> "Our latest greenhouses are advanced, data-driven, climate-controlled facilities — the most efficient production systems available today. These greenhouses are some of the highest-yielding farms around and use less energy, less land and less water than other farming techniques. Plus, advancements in machine learning and data analysis allow us to monitor our crop's health and progress, so we can deliver a fresher, more delicious product. Happy greens make happy people." (Gotham Greens)

All of these concepts speak to the distinctive features of CEA's physical design that distinguish CEA from other forms of agriculture, portraying its role as a technologically-advanced, more reliable method of food production for urban communities. As mentioned in the literature review, CEA technology allows for increased user power over the climate that produce is grown in. Website descriptions of CEA technology explain how advanced monitoring systems provide ongoing data about the state of plants to farmers, in which the environmental conditions of vertical farms can be modified to meet various plant needs and optimize growth. Across all of the websites, "technological innovation" is framed as a unique feature that separates and elevates the viability of CEA technology against traditional farming methods which are subject to regional weather conditions and the effects of climate change. These findings are consistent with the information found in pre-existing literature, which positions CEA as a technological revolution of food production. CEA users celebrate it for its ability to accommodate the changes in environmental conditions, and continue to be an environmentally-conscious, sustainable food source of local produce for urban communities.

2. CEA Localizes Food Production to Urban Centers

Food localization was the code with the second highest frequency, averaging approximately 7.04 mentions per website; it refers to an increased access to local, fresh foods for urban consumers. Local food is usually defined by an increased physical proximity between the locations where food is produced to where it is consumed; this analysis was focused on food systems that are localized to a city or that city's greater urban area. When discussing local food systems within an urban context, CEA users are referring to a localization of all interactions within a food chain– production, transportation, processing, distribution, and consumption–to any given urban area. This is an important distinction being made by CEA users across websites about the benefits of CEA as compared to more traditional models of agriculture, which rely heavily on the importation of food products from distant rural areas, both domestically and abroad.

"So instead of shipping fresh food halfway across the world (like most food is today), we bring farms closer to people." (Square Roots).

"Currently most food is grown a long way from where it's eaten. This is hugely wasteful, both in terms of fuel costs and the amount of shelf-life lost to transportation. Plenty Farms™ can be established anywhere in the world. We aim to eliminate food deserts and make healthy calories accessible to people everywhere." (Plenty)

These are just two examples which reflect the overarching perception, shared amongst vertical farms, that CEA technology provides an important opportunity to help the development of local urban food systems. Local distribution is described in a number of different ways across official CEA websites: agricultural products can be purchased by consumers directly from CEA farmers or through local grocery retailers, products can also be purchased by local restaurants as ingredients for menu items. The frequent appearance of "food localization" across CEA websites demonstrates how CEA farmers perceive the role of this technology as, also, being social in nature–providing opportunities for increased food accessibility to urban residents. Localized food systems are encouraged for a number of reasons: they support local economies, they deliver higher quality products, they decrease food miles which are closely related to CO2 emissions. We see that the assessments made in literature about the prominence of CEA technology as a tool for localization are upheld in the perceptions of vertical farms who use CEA technology to grow products for urban areas. Vertical farms accredit CEA technology with the ability to bring food production into cities, in a way that traditional farming has failed to do so. The elimination of soil from the growing process really sets CEA systems apart from traditional outdoor systems, because it offers an alternative growing method that is more compatible with the physicality of the built environment.

3. CEA Improves Health & Food Quality

Health & Food Quality was the third most frequently mentioned code, averaging approximately 6.72 mentions per official website of CEA farms. Health & Food Quality refers to improvements relating to human bodily health, as well as improvements in food quality: food freshness, nutritional food value, and food taste. Across websites, there was a clear portrayal of an increase in the quality of food that is produced by CEA farming systems as compared to traditional agriculture. Food that is produced by vertical farms is often described as having a "longer shelf-life" and being "more flavorful". This is supported, in tandem, with the websites' framing of the benefits of food localization, which argues that food that needs to spend less time traveling is harvested and served at its most fresh state, in comparison to food that needs to travels longer distances, resulting in it being prematurely picked in order to avoid spoiling and excessive food waste. CEA users attach this to points made about the subsequent positive effects in the health of consumers. Fresh food retains more of its nutritional value, as compared to food that has been prematurely harvested.

> "Our microgreens are grown from seed and harvested as soon as the true leaves have emerged, yielding a beautiful and flavorful product. This translates into the freshest, most delectable ingredients possible." (Farmbox Greens).
>
> "Local cultivation and regional distribution help us deliver our products quickly after being harvested to ensure they are fresh tasting, nutritionally dense and long-lasting. Our farms are unconventional. But so is our commitment to taste, quality and sustainability" (Gotham Greens).

An emphasis on improved food quality strengthens the credibility of CEA as an effective model of food production. It supports this idea that urban food landscapes can be reimagined to account for environmental and social needs, while continuing to offer consumers products that rivals that of traditional agriculture in both taste and nutritional value.

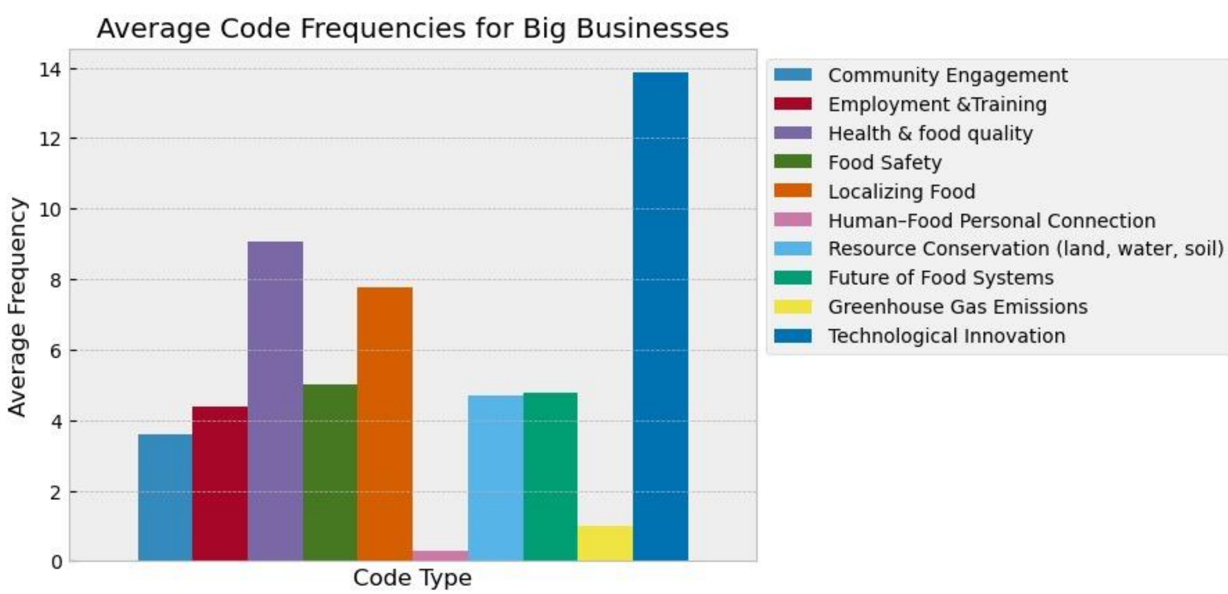
An important divergence to note is that among the most popular codes found amongst CEA vertical farm websites, 2 out of the 3 were codes that fell under the category of "social role". This was interesting, because, as previously mentioned, social impacts were less relevant to the discussion of CEA technology presented in academic literature. Whilst "Technological Innovation" prevailed as the most frequently mentioned code, "Food Localization" and "Health & Food Quality", both of which are socially-related, outranked all other codes that were categorized under "Environmental Role of CEA". This demonstrates that vertical farms percieve their usage of CEA technology as having profoundly social implications within urban communities. This is not very surprising as the primary mission of all stakeholders, businesses and nonprofits alike, is to provide a product to consumers. Therefore, CEA technology is valued for its capacity to effectively serve society.

<u>Difference in Code Frequency Across Stakeholders</u>

An average code frequency was taken for each stakeholder–big business, small business, and non-profit organizations–to determine if there were any noticeable thematic differences between the various business models that use CEA technology. The codes "Food Localization" and "Health & Food Quality" continued to rank highly in terms of frequency among all the stakeholders. Where there were noticeable differences was most clearly evident between the business model and the non-profit model. Non-profit's put a greater emphasis on community engagement as being a component of the role of CEA in urban food systems; whereas, businesses more greatly emphasized CEA's role in terms of food safety and technological innovation.

1. Average Code Frequencies across websites of Big Business CEA farms

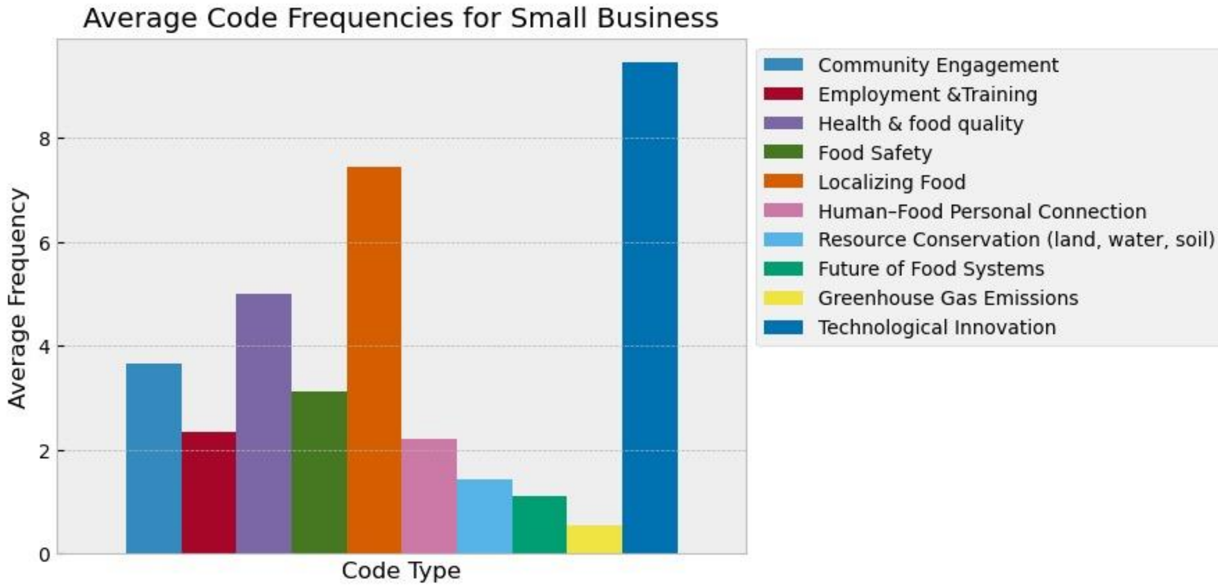
Graph 2. Average Code Frequencies of Big Business CEA users



When looking at the code frequencies of big business CEA users we can see that the code with the highest average frequency is "Technological Innovation" with approximately 13.85 mentions per official website, averaging higher than what was seen across all 30 websites combined. Some other meaningful code frequency averages are "Health & Food Quality" with approximately 9.08 mentions per website, then “Food Localization” with 7.77 mentions, and lastly “Food Safety” with 5 mentions. These codes are similar to what was seen from the overall averages; however, food safety proved to have much more visibility across big business official websites than what was observed from the total. Food safety relates to improvements made toward cleaner and safer food production practices, the most common example of which is the elimination of the use of pesti/herbi/insecticides. We can assume that the observed numbers are the result of these codes aligning more closely with the values of a for-profit business model. Out of the 30 CEA official websites analyzed, 13 belonged to “big” CEA businesses that operate on commercial-level scales, feeding urban populations in mass quantities. The primary retailers, in partnership with these big CEA businesses, are big-box, corporate grocery stores that service substantial portions of urban populations as compared to smaller, more independent grocery stores or farmers markets that may cater to specific communities. This lends explanation as to why we see a greater emphasis on CEA’s role as an alternative food source aimed at feeding whole cities, specifically with regards to the influence of modern technology in its food production efficiency and its subsequent product quality.

2. Average Code Frequencies across websites of Small Business CEA farms

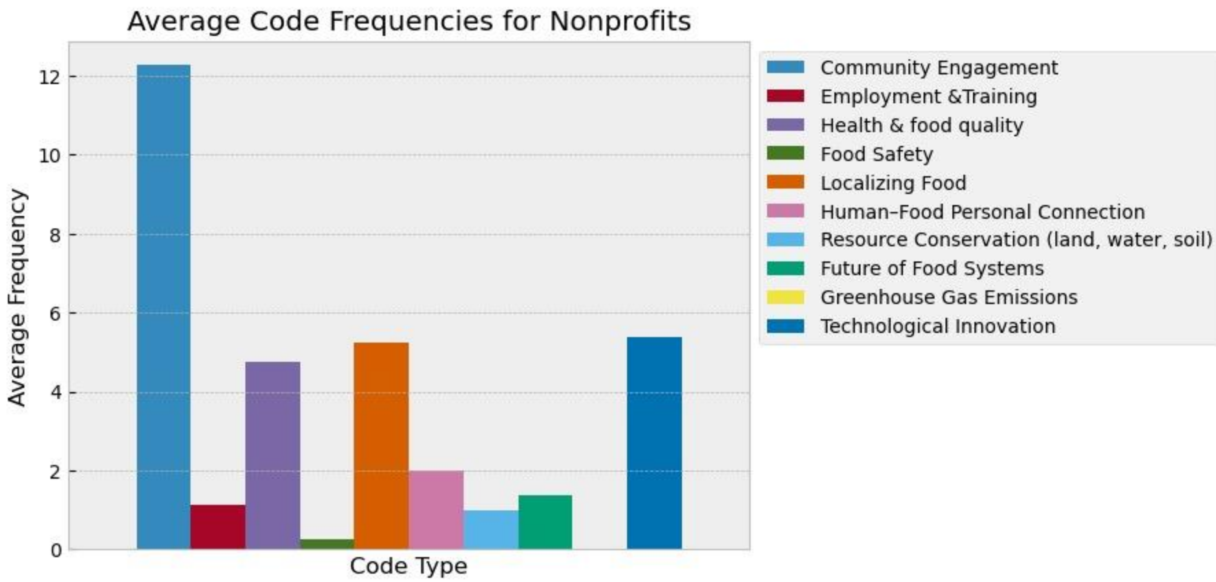
Graph 3. Average Code Frequencies of Small Business CEA farms



There are a lot of similarities in code frequencies between big businesses and small businesses. 9 websites belonged to small-business CEA farms. Small-business CEA farms, in comparison with big businesses, have smaller customer bases. They may service neighborhoods or regions of a city, but their reach does not usually extend out into the greater urban area as compared to commercial-level CEA operations. "Technological Innovation" is the code with the highest frequency averaging 14 mentions per website. We then see a significant drop in averages of the next most frequent code "Food Localization" with 7.44 mentions per website. As compared to their commercial counterparts, the distributing methods of small business CEA farms range from selling directly to consumers–households and restaurants–or to local grocery stores. Health & Food Quality narrowly takes third place with a .3 degree difference in code frequency over Food Safety.

3. Average Code Frequencies across websites of Nonprofit CEA farms

Graph 4. Average Code Frequencies across websites of Nonprofit CEA farms



There are obvious differences that can be observed in the frequency of code averages between nonprofit and business CEA vertical farms. 8 websites belonged to nonprofits. The code with the highest frequency was by far, community engagement, with approximately 12.25 mentions per website. The code "Community Engagement" refers to opportunities offered or supported through partnerships, by nonprofit CEA farms, to empower local communities by improving access to higher-quality food, promoting healthy lifestyles, and expanding educational resources. Nonprofit farms are often located in neighborhoods that have historically experienced limitations in food access and other social disparities, with the intention of using CEA technology as a way to fill these gaps. Across the websites, there was a large emphasis placed on CEA's role as a teaching mechanism. Many of the education programs–internships, camps, tours, classes–offered by nonprofit CEA farms are primarily focused towards youth outreach. These services are typically framed as a way of introducing children to modern forms of agriculture, whilst connecting topics learned from farming to lessons in schools, specifically in science curriculums. The use of CEA technology is also portrayed as a means of deepening personal connections between kids and their food. Of the nonprofit websites analyzed, several used CEA technology as a means of rehabilitation and therapy for adult communities that struggle with mental illness, substance abuse, and homelessness. Nonprofits frame CEA technology as an opportunity to combat food insecurity as an alternative food source for urban communities, but by also being a center for education. The second most frequent code was "Food Localization" with 6 mentions per website, and "Health & Food Quality" with 4.64 mentions per website. Similarly to their business counterparts, nonprofits frame "Food Localization" and "Health & Food Quality" in terms of an increased value of product; however, nonprofit models factor in the importance of affordability regarding local urban food systems.

Findings & Analysis from Interviews

In order to answer the second part of the research question, four interviews were conducted with representatives of different community-level CEA farms: one business, two nonprofit organizations, and one highschool. The most frequently cited benefits and challenges, across the interviews, were coded by theme under one of two categories–food production or food education. Food production encompasses any theme that relates to the use of CEA technology as it contributes to the development of sustainable, small-scale food sources that are local to urban centers. Whereas, food education encompasses any theme that relates to the use of CEA technology as an educational tool that teaches community members about food and the importance of developing local food systems, as well as developing skills related to indoor growing practices. The most prevalent benefits of community-level food production by CEA technology are addressing food insecurity and making local food systems more reliable; the related challenges are large upfront costs and lack of political infrastructure. The prevalent educational benefits of using CEA technology on community-level scales are the development of personal connections between people and their food, and the promotion of new skills and intellectual interests related to the practice of indoor growing; the educational challenge is accessibility and expanding educational programs in order to accommodate larger numbers of the community.

Benefits of Community-Level CEA Food Production

1. Addressing Food Insecurity

The ability of CEA technology to address food insecurity on community-level scales was touched upon in all four interviews as one of the greatest benefits of introducing CEA to urban centers. Each of these farms are located in neighborhoods that have been afflicted by limited access to healthy, higher quality produce, and every representative emphasized the importance of CEA's ability to fill these gaps. CEA farms can distribute directly to community residents, through subscription boxes, but they can also act as direct suppliers to local enterprises. One of the missions of Pillsbury United Communities (PUC), a nonprofit based in Minneapolis, Minnesota, is to develop a local food system for underserved neighborhoods. PUC owns and operates a freight container installed with CEA technology to grow and supply fruits and vegetables to their network of associated grocery stores and cafes.

> "The farm is actually connected to the grocery store. So we are literally 100 feet away from the shelves with our distribution chain, and then our mixed greens go out for free to our community cafes…But we were trying to bring kind of good healthy food options into an area that didn't typically have many options for high quality produce." --Micah Helle, PUC

Similar to what was observed from the content analysis, the data gathered from the interviews reflected a strong sentiment about the viability of CEA technology to reorganize the current design of our food systems. There is a visibly strong push, by the interview participants, towards increased localization of food production, specifically with regards to improving the social welfare of urban neighborhoods.

"I think that these kinds of farms are sort of the new hip manufacturing of our era. I think it's important that they're [in cities], because obviously they grow food, and people need healthy food, too. So that's the other important thing, you know. It's just bringing in a mass amount of people, healthy food with little space, a sustainable amount of resources." –Max Chuvalas

"And then you're not spending a lot of money on diesel for tractor trailers to ship in produce. Everything's grown in-house within the urban environment, especially places where there's no fresh produce, it puts that farm right in the middle of the city." –Thomas Speer, Interboro High School

The role of cities in food systems is no longer defined as the place where food ends up, but is, rather, being reimagined as the backdrop for which all steps in the food system can take place. The same argument can be made for city neighborhoods, more specifically, who use CEA technology as means of increasing the community's agency in determining how and from where their food is sourced.

Sourcing local food is important in addressing food insecurity, because it often provides healthier options in produce to under-resourced neighborhoods that might otherwise not have that same amount of access as their more privileged counterparts. The interviews found that the power of CEA technology lies in its democratization. It has great potential to generate a community's social independence, by maintaining the philosophy that what is taken out of the community is put back in through a process of cyclical exchange.

"And so just kind of in the vein of food and food access and making sure that people can eat as healthfully and as locally and sustainably as possible, controlled environment agriculture is just kind of part and parcel of that whole idea–if you're trying to encourage people to be as circular as they can be in their own lives. One of the easiest things that people can do, especially when it comes to their food, is purchasing food as locally as possible. And so that means supporting urban agriculture." -- Eric Weber, The Plant Chicago

As compared to commercial-sized vertical farms, using CEA technology on the community level scale is better suited to meeting the specific dietary needs of the communities in which they are located:

> "Maybe that's we're localizing foods that we only ship in from Mexico, some fruits or vanilla beans, some more exotic or more specialty foods or tribal, like, foods for indigenous communities, different medicines and stuff; so, diversifying what we're able to produce locally and thinking beyond just what's typically assumed to be what everyone wants, if that makes sense. Some more like culturally specific foods as well" --Micah Helle

Whereas commercial farms strive for palatability in order to sell the most products, CEA technology provides an opportunity to be more culturally specific, by giving communities the ability to choose the products that they want to grow locally.

2. Making Local Urban Food Systems more Reliable

One of the greatest advantages of CEA technology, as described in the interviews, is its climate control features. CEA allows growers to have a much larger input in creating optimal growing environments than would, otherwise, be possible when growing outdoors. This results in a more reliable growing method that can withstand the most severe weather conditions of different regions, supplying urban communities with fresh, local produce all year round. Additionally, CEA technology can eliminate other factors of outdoor growing that inhibit productive plant growth, like pests and diseases.

> "And there's been a lot of people wondering about hydroponics and what indoor agriculture could look like in a state that experiences so many months of winter. To have that season extension. It really has a lot of people's attention right now…It's worked great. Operates 365 days a year, we've had no issues with weather related shutdowns. Yeah. And it's been able to provide greens like every day of the year." -- Micah Helle, PUC

> "What CEA does, you know, we can grow year round. It's not susceptible to pests. It's not susceptible to harsh weather conditions. We don't have to spray pesticides on it. We don't have to spray insecticides, no herbicides as well, so everything is, to me, as fresh as possible, that we can serve it just as it is."--Max Chuvalas

Furthermore, there is some economic incentive for community-level CEA farms who can supplement the market for local produce by continuing to grow during the months that traditional outdoor growing is less active.

> "So having that season extension agent, and right now, the market for indoor greens is really actually on the shoulder seasons. So the shoulder seasons are a few months, where the outdoor growers are not producing like they've kind of shut down for the winter. Like, that's when we see the bulk of our sales"-- Micah Helle, PUC

CEA is not just posed as a complete substitute to traditional agriculture by the interview participants, but, also, presented as another means of supporting outdoor growing. The Plant Chicago operates out of an old firehouse, and has converted a section of the building into a dedicated indoor growing space called the Indoor Victory Garden. They have developed a program in which part of this space can be rented out to community members to use CEA technology. They found some success with other community growers who utilize the space for growing during months of seasonal transition.

> "Get your seedlings in March, and get those [germinating indoors] so that you can put them outside when it's warm enough out. I think most growers are down with that. And so we definitely see a lot of use of the Indoor Victory Garden from February to April, when everyone's got stuff going, until it's ready to be put out into the field.--Eric Weber, The Plant

CEA technology contributes to the localization of urban food systems by being both an alternative food source for communities, as well as offering support to other local outdoor growers. Operating on the community-scale allows for a greater capacity to create a network of both indoor and outdoor growers that together aid in the resilience of local food systems within urban neighborhoods. This empowers communities to become more self-reliant and creates buffers against any disruptions that may occur as a result of the global food system's fragility. Using CEA technology on the community-scale provides neighborhoods food autonomy, thereby, preserving their socio-cultural integrity.

Challenges of Community-Level CEA Food Production

1. *Upfront costs*

One of the most frequently cited challenges of implementing CEA technology on community-scale farms relates to the cost of its initial investment. In each of the interviews, the participants expressed that CEA technology can be very expensive to purchase and install, let alone the price of operation. The data showed that there are two primary ways that CEA farms are acquired: either by purchasing a growing unit from a manufacturer, or by designing and retrofitting an existing space to become compatible with indoor growing. Both of the representatives from Pillsbury United Communities and Hammock Greens revealed that they had purchased CEA growing units from a manufacturing company called Freight Farms. These CEA farms operate out of freight containers, with each unit costing approximately $150, 000.

> "But I think the other piece of the equation that's often really expensive is the startup cost–just how capital intensive it is to buy a unit. There are certainly ways that you know, you can go online and get a $30 system and set it up and it can grow for just your house. So you and your neighbors like, you don't have to buy the highest tech thing." – Micah Helle

The Plant Chicago, however, operates out of an old firehouse where sections of the building have been converted into an indoor growing space. The interviewee listed several design challenges that came with adapting a space not intended for growing into a productive, agricultural site:

> "Indoor growing can be pretty expensive. You're having to condition a space, potentially large space for plants. And something that we found while working with engineers and architects is that, because plants have different environmental requirements than humans do, there's not a lot of them who are comfortable with designing a building for non-human occupancy. It's so technologically dependent and investment heavy that it kind of precludes people from wanting to get into it, particularly at those larger scales" –Eric Weber, the Plant Chicago

All of the interviews touched on the cost of operation and how it can become debilitating to CEA farms. This is especially true of small scale for-profit businesses who rely on the sale of their products to offset the cost of their investments. In an interview with Thomas Spear of Interboro

High School, located in the Philadelphia area, he explained that there were early discussion about the potential of applying a for-profit model to their CEA farm class; one of the reasons they decided against this was for the fact that,

> "It requires a lot of power. Unless we had solar panels or something like that, it is using a lot of electricity. We did a rough equation, and if we were to sell the fish and sell the lettuce, we would not offset the energy costs of the electricity." – Thomas Spear, Interboro High School

There was a general consensus, among the interviewees, that the expense of CEA farming is one of the greatest difficulties when implementing this technology on a community-level. As previously mentioned, this burden is disproportionately experienced by small business owners. Representatives of the nonprofits and school accredited grants with making their farms a reality, by offering the finances to support the more costly elements of CEA technology. The manufacturers of these units have found an unlikely niche market in nonprofits using this technology to encourage sustainability within urban neighborhoods. It appears that the most profitable way of operating a CEA farm is on a commercial-scale, but this requires capturing the attention of wealthy investors who can fund this venture. With that being said, small businesses appear to experience the greatest difficulty with accessing financial support. This demonstrates that using CEA technology on community-level scales may be best suited for nonprofit models.

2. Lack of government infrastructure to support CEA

Another frequently cited challenge of implementing CEA technology on community-level was the lack of government infrastructure associated with CEA as an agricultural practice. This relates to policy and regulation that offers a framework for which growers can refer to when operating a CEA farm. There is no hard definition used by government bodies to inform how CEA farms are reviewed. Much of the existing policy has been constructed with traditional farming in mind, and has not been updated to include CEA farming. Multiple farms described it as an “industry without a manual”. This leaves many CEA farmers confused about how to operate their farms according to government code.

> “Yeah, I mean, it's a lot better than it used to be, in that, when we first started, there were–so this is going back to 2010 or so–there really were no definitions, particularly for indoor farming, within any of the city, basically, [the government] didn't know anything. You know, people go to the city to ask for a business license not to run an indoor farm. So, they didn't know what bucket to put [CEA farms] in.” –Eric Weber, The Plant Chicago

> “USDA is recognizing their program, recognizing what CEA and urban farming is, and really separating it, too. You know, if you fill out a form for the USDA right now as a CEA farmer [it asks questions about traditional farming], and we're CEA farmers, you know we don't have any of this stuff, the crop and the acreage is all we have. You know you have to calculate for that, and then you have to explain it to them. So, there are challenges for us, but there are so many of us now that they can't ignore us.” –Max Chuvalas, Hammock Greens

The data shows that as CEA farms continue to grow in popularity, government bodies are being forced to take notice and respond more appropriately than they have in the past. This is not framed exclusively as a problem at the community-level; in fact, it is urged by interviewees that CEA regulation be written to properly consider the circumstances of both commercial-scale and community-scale CEA farms.

<u>Educational Benefits of using CEA Technology on Community-level Scales</u>

1. Development of Personal Connections between people and their food

The development of personal connections between people and the food they eat was a foundational element in the missions of the nonprofits and the schools that were interviewed. This refers to the education of community members about where their food comes from, how it is grown, and by whom. It fosters a deep awareness of food for urban communities who, in our hyper-globalized society, are both physically and emotionally disengaged from the process of food production. Most of the educational programs described were curated for neighborhood youth populations. In many instances they are adapted to support school curriculum, especially STEM-based classes, teaching children about the science of growing plants.

"We're concerned about teaching people where their food comes from. One of our closed labs is called "Lifecycle of a Salad". So, the kids learn about nutrient cycles–they actually interact with one of our hydroponic systems–and they harvest the lettuce, they wash it, and they prepare a salad. So it goes farm to table in the same building."--Eric Weber, the Plant Chicago

Additionally, multiple interviewees named feelings of ownership and accomplishment as a benefit of using CEA technology to grow food on community-level scales.

"The kids get to see it firsthand, because each group of students works on their own system, and then they take home the lettuce every week to their families. And then when we harvest the fish, and then fillet and vacuum seal them. And then they also get to take home the frozen fish filet. So they experience it firsthand: you can grow your own stuff, you can package it, and then you can ultimately feed yourself or feed the community…It makes it more personable for them. They're more linked to this. It's not just you're going to the store and you're buying lettuce,they have a little more pride in the lettuce that they grew."--Mr. Spear, Interboro High School

Despite many commercial-sized CEA businesses emphasizing the importance of eating locally, there is still that same separation that exists between food production and consumers that we see with traditional food systems. Commercial-sized vertical farms are private and therefore inaccessible to the public. In the cases where we do see large-scale CEA farms engaging with the communities that they are located in, it is primarily through employment and partnerships with other community organizations. So although commercial farms may provide some opportunities to improve community welfare, it falls short of giving communities ownership over their local food production; this is especially true when considering that many of these commercial-scale farms move into these neighborhoods, rather than originating from them. This demonstrates an advantage that community-scale CEA farms have over their commercial-sized counterparts in terms of the extent to which communities are able to reap the benefit of localized products.

Development of New Skills and Promotion of Intellectual Interests

The development of new skills and the promotion of intellectual interests was listed as a benefit of implementing CEA on community level scales in all four interviews. It refers to the provision of educational services by CEA farms that seek to introduce CEA farming as a new agricultural practice, as well as seek to teach community members about its role as an alternative neighborhood food source.

"We also have community tours. And we've done a few tours with the universities and community members, we just had like an open house. And then really, we also have a social justice, like food and social justice educator that goes into some of the schools and we'll talk about hydroponics and urban agriculture" –Micah Helle

These programs are often designed to offer technical instruction, providing community members with the opportunity to operate these systems first-hand, and learn how to grow their own food. Interviewees framed CEA as a mechanism for fostering intellectual pursuits and curiosity. This was specifically relevant to the missions of the nonprofits and the high school, who valued CEA mostly for its role as a community engagement tool. As previously mentioned, nonprofit models tend to offer more room for experimentation. This gives community members the freedom to test these systems to their full extent, and discover the ways in which they best address community-specific needs. Below is a quote from the representative of the Plant Chicago describing the organization's Indoor Victory Garden and their intention for how it will be used:

"But when it's done, we're hoping to have a dozen, maybe as many as two dozen individual users of the space, whether that's an individual hobbyist or family, and a handful of small, you know, urban farms who are using it for their various experimentation and in season extension purposes."--Eric Weber

Below is a quote by another interviewee–the representative of Interboro High School–describing the learning environment and the role of his students in determining the structure of the curriculum.

"I try to keep it stress free, and even the kids, if they want to grow something, I'm like, "alright, well, let's do some research. We'll see how to germinate it. And I'll order the seeds" And that's it. A lot of kids, they'll just order their own stuff. And we'll experiment."--Mr. Spear

This education is extended beyond just individual community members to also include collaboration between other community partners and other knowledge-based institutions, in the hopes of spreading awareness about CEA farming and encouraging its adoption by various stakeholders, thereby developing a local network of CEA users.

> "So we definitely see ourselves as, kind of, community resources for people who are interested in getting involved. But also someone who's trying to collaborate with the other institutions of knowledge, and other community partners who want to learn more about hydroponics. And we're honestly stronger together when we pair our resources together." – Micah Helle, PUC

Some of the interviewees perceived community education about CEA as an economic benefit, describing their programs as a type of vocational training. As CEA emerges as a new field in the agricultural industry, small-scale CEA farms have seized the opportunity to train community residents with the prospect of employment in mind. This is particularly important for farms that are located in economically-depressed neighborhoods.

> "There's a workforce here that needs work. They need education on something a little bit fresher than what your average mechanic or grocery store can add to your job life, and we want to help them get jobs." –Max Chuvalas
>
> "But how do we give opportunities, pay people to come in and learn the system and be able to leave and go find a job in the industry?" –Micah Helle, PUC

There are limitations that persist among community-level CEA farms relating to labor. The representative from Hammock Greens expressed that the farm does not have the financial capability to employ many community members as a small business. They refer to themselves instead as a "transitional farm" that provides training on technical skills to community members. Commercial vertical farms are always going to have the upperhand when it comes to providing job opportunities for 2 reasons: one, they need a larger work force to operate their systems, and, two, they have more economic power to hire and support workers. Therefore, education tends to be one of the main focal points in the mission of community-level CEA farms, especially nonprofits and institutions. It offers the freedom to be more experimental without the added burden of doing what is most profitable. More so than their commercial counterparts can community-scale vertical farms effectively reach urban residents on a personal-level and promote positive attitudes towards food production and food education, through direct community engagement that allows community members to become familiar with CEA technologies firsthand.

POLICY RECOMMENDATIONS

Creation of Political Infrastructure that supports CEA farms

In order to better support vertical farms that use CEA technology there needs to be greater efforts made by government actors to create policy and regulation that appropriately recognizes CEA as an emerging agro-technology in the agricultural industry. This includes the creation of a formal definition of CEA. As it currently stands, the USDA website does not have a formal definition of CEA technology, but rather mentions the term in passing under their “Urban Agriculture” page. CEA farms are treated in the same vein as urban agriculture. As seen in both the literature and data findings, CEA technology is a starkly different practice than traditional outdoor growing and should be treated as such. Furthermore, determining the labels attached to products that are produced by CEA technology would aid indoor vertical farms in the marketing of their products, an example of this would be to confirm whether or not agricultural products of CEA farms are considered organic. Most of the representatives of CEA farms that were interviewed mentioned that the lack of political infrastructure in place to support CEA technology made it very challenging for the farms to start up, and they find themselves navigating this field alone. There are no instructions that distinguish CEA from other forms of agriculture across government documentation; this makes it difficult for CEA farmers to accurately abide by government standards because the questions being asked of them are designed for traditional outdoor farms and do not apply to indoor growing practices.

Expansion of Funding Available to CEA Farms

Increasing the amount of funding opportunities that are available to CEA farms would assist in the development of networks of CEA users, especially at the local level. Many of the grants applied for by nonprofits and educational institutions were through the private sector. Additionally, funding to commercial-scale operations came from wealthy investors. There is not a lot of government support available to CEA farms in the forms of grants, subsidies or incentives. As previously stated, the cost of starting up a CEA operation can be relatively costly, especially if the intention is to feed populations larger than a household. This particularly harms small-business CEA farms, who are not eligible for grants nor attract a lot of investment. This sets small-businesses back in trying to make returns on the high cost of investment in CEA-fitted growing units. Offering more opportunities for funding would support the expansion of local networks of CEA farms, and diversify the labor market within urban centers.

CONCLUSION

Many researchers across academic literature and representatives of indoor vertical farms, primarily commercial-sized farms, argue that CEA technology is the future of agriculture, but this study has shown that CEA can not completely dismantle the current structure of our food systems. CEA should not be considered a substitute for traditional farming, but rather seen as a supplemental agricultural method. There are a lot of benefits to introducing CEA technology into cities: it's scalable, it is compatible with physicality of the built environment, it uses a fraction of the resources that traditional farming uses, its automated design allows for the environment to be set to the most optimal growing conditions, it can grow food anywhere regardless of regional weather conditions, it eliminates the use of chemicals, it eliminates soil and is protected against disease, and food can be grown all year round. These are all important features that should be employed in order to meet the challenges of our current environmental and sociopolitical climate. The data demonstrated that CEA possesses important social influences, as well, for urban communities. It can promote self-reliance and address food insecurity. CEA technology, like other forms of urban agriculture, offers urban communities the opportunity to redefine the narrative that characterizes their relationship with food. Ownership over these systems has the capacity to foster deeper feelings of attachment and pride between people and what they eat. This study demonstrated that educational institutions and nonprofits are advantaged with the freedom to be experimental when using these systems; this has resulted in a greater capacity of nonprofits and educational institutions to support community development in cities, as compared to their for-profit counterparts. CEA technology can be expensive and uses a lot of energy to power, especially if the operation being run is meant to feed a community or greater, and the plant species grown are limited to what is most compatible with growing in an enclosed space. Both of these things can detract from the attractiveness of CEA, but if we recognize it as a distinct growing practice then, coupled with other forms of agriculture, CEA can contribute to the development of local urban food systems thereby enriching the fabric of community life.

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Appendices

Appendix A

Questions for Vertical Farming Companies:

1. How did you first hear about vertical farming? And what about it drew your interest?
2. What is the mission of (insert company name)?

3. What is your company process when siting where your vertical farming facilities will go?

4. How does your company engage with the surrounding community? Do you have community programs? If so, what are they?

5. What has been (insert company name)'s experience with the city and/or state government? Have you encountered difficulties in starting-up an urban agriculture company? If so, what are they?

6. What are the agricultural products you grow and how are they distributed? Locally? City-wide, state-wide? nationally?

7. Who are your sellers and/or consumers?

8. What do you believe are some of the greatest benefits and perhaps some of the greatest challenges of introducing vertical farms into cities, considering their socio-economic and environmental impact?

9. In what ways do you hope to see your company progress? What are your aspirations for the future?

Appendix B

Questions for Organizations:

1. How did you first hear about vertical farming? And what about it drew your interest?

2. What is the mission of (insert organization name)?
    a. Follow-up: How does vertical farming serve your mission? What are its impacts?
3. What do you grow and who are the recipients of the produce produced by your vertical farm?
4. How do you distribute your produce?
5. How do vertical farms compare to traditional grocery stores in supplying community members with produce?
    a. Consider variety, quality, quantity

6. What do you believe are some of the greatest benefits and perhaps some of the greatest challenges of introducing vertical farms into cities considering their socio-economic and environmental impact?

Appendix C:

Code Dictionary

Categories	Codes
Social Role	• Community Engagement –Referring to opportunities offered or supported through partnerships, by vertical farms, to empower and better community access in food, health, and education. • Employment & Training–Referring to job opportunities and development of skills valuable to work. • Health & food quality–Referring to improvements relating to human bodily health, and improvements in food quality: food freshness, nutritional food value, and food taste. • Food safety–Referring to improvements made toward cleaner and safer food production practices (i.e. elimination of pesti/herbi/insecticides, improved traceability from seed to product). • Localizing Food–Referring to an increased access to local, fresh foods by urban residents. • Personal Connection–Referring to the strengthening of an interpersonal relationship between people and their food.
Environmental Role	• Resource Conservation– Referring to conservation of valuable environmental resources, including: land, water, soil. • Future of Food Systems–Referring to the ways in which we reimagine our

	food systems to protect our food-growing-future as a society. ● Greenhouse Gas Emissions–Referring to a decrease in greenhouse gas emissions, specifically CO2 and N2O, caused by transportation and fertilized soil. ● Technological Innovation–Referring to advancements made in agro-technology that make for an optimal production design that can grow food all year round anywhere. This can refer to: accurate data analytics, increased yields per acre, controlling the best conditions for growth, and season extension.

Appendix D:
Code Frequency Counts Commercial-Business CEA Farm Websites

Code Counts for Big Business Farms

Farm Name	Community Engagement	Employment & Training	Health & Food Quality	Food Safety	Localizing Food	Human–Food Personal Connection	Resource Conservation (land, water, soil)	Future of Food Systems	Greenhouse Gas Emissions	Technological Innovation
Plenty Farms	7	7	11	5	11	0	10	1	3	25
Aerofarms	11	3	15	11	9	0	9	8	0	25
Bowery Farms	5	4	7	5	4	0	5	6	2	15
Square Roots	0	9	12	3	20	2	3	2	1	14
Dream Harvest	7	2	12	9	10	0	5	9	1	15
Upward Farms	0	1	7	4	1	0	2	2	0	5
Smallhold Farms	3	2	2	1	5	2	6	2	1	10
Gotham Greens	8	4	15	8	14	0	5	7	2	25
Infarm	0	2	9	4	3	0	9	9	2	15
Agricoool	0	1	3	3	4	0	0	4	0	1
Farmbox Greens	2	0	10	5	7	0	2	2	1	8
Greener Roots	0	2	4	2	6	0	3	3	0	11
Vertical Harvest	4	20	11	5	7	0	2	7	0	11

Appendix E:
Code Frequency Counts Small-Business CEA Farm Websites

Code Counts for Small Business Farms

Farm Name	Community Engagement	Employment & Training	Health & Food Quality	Food Safety	Localizing Food	Human–Food Personal Connection	Resource Conservation (land, water, soil)	Future of Food Systems	Greenhouse Gas Emissions	Technological Innovation
Hammock Greens	1	0	4	3	4	0	1	2	0	15
Ditto Foods	3	0	2	4	8	1	3	0	1	20
Town to Table	20	1	6	4	10	5	2	1	0	16
Farm.One	2	1	8	2	3	0	0	0	1	2
Bee's Greens Compa	0	0	7	11	12	1	4	3	2	13
OD Greens	4	14	5	1	7	9	3	1	0	3
Zeponic Farms	2	5	5	1	10	2	0	2	1	3
ICA Maxi	1	0	3	0	7	1	0	0	0	4
New Age Provisons	0	0	5	2	6	1	0	1	0	9

Appendix F:
Code Frequency Counts Nonprofit CEA Farm Websites

Code Counts for Nonprofit Farms

Farm Name	Community Engagement	Employment & Training	Health & Food Quality	Food Safety	Localizing Food	Human–Food Personal Connection	Resource Conservation (land, water, soil)	Future of Food Systems	Greenhouse Gas Emissions	Technological Innovation
The Plant Chicago	30	1	1	0	6	0	5	5	0	7
Pillsbury United Communities	4	0	7	0	9	0	1	2	0	14
Harlem Grown	12	3	5	0	2	3	1	3	0	2
Boise Vertical Farm	2	1	2	0	3	0	0	0	0	0
Lotus House	3	1	5	2	2	1	0	0	0	6
San Antonio Clubhouse	15	0	3	0	3	3	0	0	0	0
Boys and Girls Club of Metro South	20	1	8	0	11	6	1	1	0	10
SEFCU & Boys and Girls Club of Troy	12	2	7	0	6	3	0	0	0	4