GROWING NEW CONNECTIONS

An STS Assessment of Controlled Environment Agriculture

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Abstract

I de kommende 30 år forventes det at jordens befolkningstal vil stige til mere end 9 milliarder mennesker og dette vil resultere i en estimeret forøgelse af vores nuværende fødevarebehov med 50 procent. I mellemtiden er vores globale landbrugssystem ved at nå grænsen for hvad der er muligt ift. Produktions kapacitet og mulighederne for at udvide vores nuværende landbrugs praksisser er smalle pga. færre tilgængelige ressourcer som agerjord og vand reserver. Til trods for at moderne landbrug har opnået store forbedringer mht. produktion af fødevare, så er landbrug i dag en af de største udladere af drivhusgasser og de intensive praksisser ved moderne landbrug skader miljøet.

I det seneste årti har konceptet controlled environment agriculture gjort drastiske fremskridt inden for hvad der er muligt at dyrke indendørs. Det har ført til udviklingen af konceptet vertical farming, der ved hjælp af kunstig belysning, automatisering og klima styrings teknologier gør indendørs dyrkning i flere muligt. Ved at kontrollere alle aspekter af det indendørs miljø, denne type produktion er i stand til at dyrke store mængder af planter hele året, uden brug af pesticider og jord og med et minimalt vandforbrug.

I dette speciale udforsker vi konceptet controlled environment agriculture, de teknologiske udviklinger gennem tiden og hvordan disse teknologier påvirker relationer mellem landmænd og ingeniører. Ved at tilgå konceptet controlled environment agriculture ud fra en STS vinkel, studerer vi hvordan forskellige aktører skaber forskellige realiteter i form af netværk. Vi supplerer denne vinkel med kvalitative forskning metoder og en teoretisk ramme der adresserer, hvordan integrering af nye teknologier påvirker relationerne mellem landmand og ingeniører samt reformer dyrkningsmiljøet. Vi anvendte aktør-netværk teori og konceptet heterogenitet sammen med farmer-back-to-farmer modellen som analytiske redskaber til at forstå feltet vi undersøger. Vi har yderligere anvendt ekspertviden i form af interviews og seminarer for at kunne producere en detaljeret beskrivelse af konceptet og dets implikationer.

I dette speciale, konkluderer vi at relationerne mellem landmand, ingeniør og dyrknings miljøet er stærkt påvirket af teknologi. Ydermere, Vi konkluderer at teknologi kan agere som en drivkraft for at forandre forskellige aspekter af controlled environment agriculture, især når det gælder transition fra et semi- til et fuldt-kontrolleret dyrkningsmiljø. Den respektive ekspertise associeret med de forskellige praksisser kan i samarbejde være en drivkræft for bæredygtig omstilling.

Abbreviations

ANT: Actor-Network Theory

CEA: Controlled Environment Agriculture

Ca: Calcium

CO2: Carbon Dioxide

FAO: Food and Agriculture Organisation of The United Nations

FB2F: Farmer-back-to-farmer

GHG: Greenhouse Gas Emissions

HPS: high-pressure sodium

HVAC: heating, ventilation, and air conditioning

K: Kalium

kg: Kilogram

kWh: Kilowatt-hour

LEDs: Light Emitting Diodes

MH: Metal halide

Mg: Magnesium

nm: nanometer

N: Nitrogen

n.d.: no date

NFT: nutrient film technique

NYSERDA: New York State Energy Research and Development Authority

PAR: photosynthetically active radiation

PFAL: Plant Factory with Artificial Lighting

P: Phosphorus

PPFD: photosynthetic photon flux density

STS: Science and Technology Studies

UA: Urban Agriculture

UN DESA: United Nations Department of Economics and Social Affairs

$: American dollar

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1. Introduction

1.0 Climate Change and Food Security

According to the Food and Agriculture Organisation of The United Nations (FAO), the world population is expected to grow by over a third from 2009-2050, making us over 9 billion people in 2050 (FAO 2009a). As the global population grows and income grows across the developing world, overall food demand is projected to increase by more than 50 percent. Demand for more resource-intensive foods like meat and dairy is projected to rise even faster, by nearly 70 percent (Searchinger et al. 2019). Meanwhile, more than 800 million people lack sufficient calories or are malnourished in today's world (ibid.)

Meeting the growing global populations' demand for food and securing people's access to nutritious food is a multifaceted and wicked problem that will require action on multiple fronts (ibid.). According to the World Resources Institute (WRI), we need to re-access agriculture on many levels, as our current agricultural system and its productions methods will struggle to produce enough calories, find enough arable land for farming, reduce its greenhouse gas emissions (GHG) and the negative impact on the environment in order to meet the demand of 2050 (ibid.).

According to FAO, croplands cover 1.53 billion hectares (about 12% of Earth's ice-free land), while pastures cover another 3.38 billion hectares (about 26% of Earth's ice-free land). Altogether, agriculture occupies about 38% of Earth's terrestrial surface—the largest use of land on the planet. These areas comprise the land best suited for farming: much of the rest is covered by deserts, mountains, tundra, cities, ecological reserves, and other lands unsuitable for agriculture (Foley et al. 2011, p. 1). The sheer magnitude of global agriculture tells a story of how we ended up with such a huge amount of available food in the developed world. Through scientific advancements over the past century, we managed to increase agricultural yields manyfold, allowing us to successfully transition from rural to urban environments, where we could allocate our resources to creating new things instead of worrying about growing our food (Despommier 2010).

However, the tale of modern agriculture also has a darker side when it comes to its impact on the environment. The expansion and intensification of global agriculture have been a major contributor to climate change. Today, agriculture is responsible for 30-35 percent of global GHG, largely stemming from tropical deforestation, methane emissions from livestock and rice cultivation, and nitrous oxide emissions from fertilized soils (Foley et al. 2011, p. 2). The expansion of worldwide agriculture has already cleared or converted 70 percent of the grassland, 50 percent of the savanna, 45 percent of temperate deciduous forest, and 27 percent of the tropical forest biome (ibid.).

Nowadays, agriculture is mainly expanding in the tropics, which has led to a significant loss in biodiversity, wildlife, and damaged ecosystems (ibid.). The intensification of agriculture has dramatically increased in recent decades, more so than the actual expansion of land use for agriculture. This intensification has resulted in a significant increase in yields, resulting in more calories produced per acre, but it has also caused water degradation, increased energy use, and widespread pollution (ibid.). In the past 50 years, global fertilizer use increased by 500 percent (800 percent from nitrogen alone). Presently, 70 percent of global freshwater is devoted to irrigation and rain-fed agriculture is the world's largest consumer of water (ibid.). The excessive practices of modern-day agriculture are now more than ever becoming a growing concern around the world, as we see its negative impact on the environment growing stronger every year. From soil depletion, eco-systems destroyed to widespread pollution of drinking water and livelihoods, we have to reshape agriculture, so it becomes more environmentally friendly and sustainable.

The overall consensus is that the transformation of global agriculture must deliver sufficient food and nutrition to the world, by strengthening people's relation to their food and improving distribution and access. Furthermore, global agriculture needs to; cut GHG by at least 80 percent, reduce biodiversity and habitat losses, reduce unsustainably water usage, especially in areas where water is scarce, and phase out water pollution from agricultural chemicals (Foley et al. 2011, p. 3) (Searchinger et al. 2019, p. 9-10).

As previously stated, the problems facing our global agricultural system are wicked and multifaceted, but by addressing some of the global trends, we can make the solutions more tangible. One aspect of notable concern is food waste and food loss. According to FAO, roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to 1.3 billion tons per year (FAO 2011, p. 6). This staggering amount of food loss and food waste is happening in the food supply chain, during agricultural production and during final household consumption (ibid.). But looking closer at this trend, we see that food loss and food waste are very different around the world. In the medium- and high-income countries, food is wasted at the consumption stage, meaning that it is discarded even if it is still suitable for human consumption. Furthermore, we also discard large quantities of food early in the supply chains of the industrialized regions, due to strict requirements for appearance (such as size and shape of produce) and overproduction. In low-income countries, food waste occurs in the early and middle stages of the supply chain, and very little is wasted at the consumer level. This is mainly due to financial, managerial, and technical limitations in harvesting techniques, storage and cooling facilities in difficult climate conditions, infrastructure, packaging, and marketing systems (ibid.).

These tendencies are troublesome, as it not only means that huge amounts of resources used in food production are used in vain, but the GHG emissions of said production are also emissions in vain (ibid.). Furthermore, we are showing strong signs of being severely disconnected from our food supply and the value we attribute food in the developed world is somewhat perverse. Meanwhile, the developing world is struggling to maintain a steady supply of food due to technological and knowledge constraints which have been available in the industrialized world for decades.

According to a report by the United Nations Department of Economics and Social Affairs, 55 percent of the world's population lives in urban areas as of today (UN DESA 2018). This percentage is expected to increase to 68 percent in the year 2050, and could potentially add another 2.5 billion people to urban areas. Most of this increase will take place in Asia and Africa (ibid.). Today most urbanized regions include Northern America (with 82% of its population living in urban areas in 2018), Latin America and the Caribbean (81%), Europe (74%), and Oceania (68%). The level of urbanization in Asia is now approximating 50%. In contrast, Africa remains mostly rural, with 43% of its population living in urban areas (ibid.)

This expected urbanization also means that the vast majority of the food consumed will be in urban environments and that raises questions on how cities can be more sustainable when it comes to producing and consuming food and managing waste (Ellen MacArthur Foundation (2019). Rethinking how cities operate in terms of consumption and waste management can be a key driver for enabling more sustainable practices both in urban, peri-urban, and rural areas (ibid.). One of these drivers is the concept of Urban Agriculture (UA). UA is the concept of growing food and other crops within cities (excluding livestock) (Clinton et al. 2018, p. 2). According to a paper by Clinton et al. 2018, UA has the potential to ameliorate a variety of urban environmental problems by increasing vegetation cover, improving the livability of cities, and providing enhanced food security (ibid.). Furthermore, it has been suggested that UA can alleviate poverty, increase the resilience of cities to climate change, serve as a repository of agricultural knowledge and the usage and an incubator of new technologies, provide measurable improvements to human health and wellbeing, and reunite urbanites with natural systems from which they have been separated (Clinton et al. 2018, p. 2) (Kozai et al. 2016, p. 8)

With UA having the potential to make cities more sustainable and increasing the wellbeing of its inhabitants, We sought to examine further how UA has developed throughout the past decade and more specifically how new technologies make the concept of UA a potential game-changer for urban areas across the globe.

Over the past decade, there has been a substantial increase in urban agricultural initiatives such as rooftop greenhouses, indoor vertical farms, container farms, and modular farming units (Kozai et al. 2016, p. 35-66). These new farming methods apply an array of technologies to grow crops year-round using up to 95 percent less water and significantly fewer resources than traditional agriculture (Kozai 2018, p. 16). This type of growing is formally known as Controlled Environment Agriculture (CEA) and is defined as:

a combination of engineering, plant science, and computer-managed greenhouse control technologies used to optimize plant growing systems, plant quality, and production efficiency. CEA systems allow stable control of the plant environment including temperature, light, and CO2. CEA also provides separate control of the root-zone environment. CEA provides secure, healthy, and cost-effective year-round production of many premium edible, ornamental, and high-value plant species (NYSERDA n.d.)

With the premise of supplying healthy nutritious food on a year-round basis using significantly fewer resources and land, the new concepts applied in CEA intrigued us. As Techno-Anthropologists, we examine how humans and technologies co-exist and what makes a concept function in a particular setting. With an increasing number of technologies being applied to growing food in controlled environments, it is of importance to access how these technologies affect modern agriculture as we know it, and what this will mean for farmers, horticulturists, and consumers alike.

As some of the most promising works within Science and Technology Studies (STS) have shown, we can uncover many interesting things about how knowledge is made, by examining how humans and technologies co-exist and how they organize to create a specific reality (Law 1992, p. 381). Although traditional greenhouses have been around in millennia, the advancements within CEA over the past decade are so substantial that it has spawned an entirely new industry. An industry that is still shrouded in mystery due to the competitive nature of technological development around the world (Kozai et al. 2016, p. 35-66).

With CEA growing bigger roots around the globe, we want to use this report to uncover some of the mysteries of what makes up the concept and what the role of the farmer will look like in the near future.

1.2 Problem formulation

With the overall problems associated with global agriculture and the future demand for food being described, We have chosen to focus on the emergence of CEA across the world. The following research questions are our attempt to shed light on a concept in a way that uncovers the complexities and provide academic knowledge from the perspective of STS that will benefit everyone.

Research question:

How does the emergence of new technologies and growing methods used in controlled environment agriculture alter the intersecting relations of farmer, engineer, farm and technology?

Sub research questions:

What is the concept of controlled environment agriculture and how has it evolved over the past century?

What is the role of expertise in the context of controlled environment agriculture?

1.3 Delimitations

As with any scientific research, there is a need for narrowing down the scope of the research in order to produce proper academic work. Though our thesis is addressing the problems associated with global agriculture's impact on the environment and how new technologies can generate new ways of producing food, we are narrowing our focus to the concept of CEA, and more specifically the production of plants in a controlled environment.

In doing so, we will not involve the practices of conventional agriculture and the production of plants in open fields, as well as staple crops such as wheat, rice, and corn. Furthermore, we are excluding the production of livestock and fisheries from our report, as the magnitude of the problems associated with animal farming is too broad to include in this report. However, We are well aware that the production of livestock is the biggest emitter of GHG emissions in agriculture and that reducing agriculture's negative impact on the environment means reducing meat production and consumption.

Although CEA is producing a myriad of different crops, we are not focussing on mushroom cultivation and the production of medicinal plants (the primary one being cannabis). However, we acknowledge the scientific contributions to the field of CEA provided by these types of productions to be of great value. The cannabis industry alone has been a great incubator for technological growth and concept development over the past decade and they continue to play a vital role in the development of the CEA industry.

Lastly, our theoretical framework and methodology are used as a means of describing a phenomenon and uncovering how technologies and humans intersect. We do not strive to end up with a final solution to the problem we address throughout the report but shed light on a phenomenon in a way that can provide guidance for people interested in the concept of CEA.

2. Literature Review

The following section will outline the key traits of CEA as well as the history of the concept of vertical farming. To better understand the complexities of how modern-day CEA functions, we will first present an overview of how vertical farming came about, how it has evolved during the past decade and how it is projected to evolve during the next decade.
Then we will outline and describe the key technologies that make CEA possible as well as the procedures that go into cultivating plants in a controlled environment.
The literature used in this section consists of state of the art literature on CEA published by some of the leading academic researchers around the world.

2.1 Controlled Environment Agriculture over the last decade

Concerned with the way modern agriculture was harming the environment and the lack of land and natural resources needed to expand agriculture, Dickson Despommier, a professor of public health and microbiology at Columbia University started addressing how we might change agriculture for the better. Together with his students, Despommier envisioned a different future where farming was part of the urban environment and did no harm. The solution was coined *vertical farming* and its implications would change agriculture for good:

...grow crops indoors, under rigorously controlled conditions, in vertical farms. Plants grown in high-rise buildings erected on now vacant city lots and in large, multistory rooftop greenhouses could produce food year-round using significantly less water, producing little waste, with less risk of infectious diseases, and no need for fossil-fueled machinery or transport from distant rural farms. Vertical farming could revolutionize how we feed ourselves and the rising population to come. Our meals would taste better, too; "locally grown" would become the norm.

(Despommier 2009, p. 4)

Although the vision sounded outrageous at the time, most of the technologies and methods needed to make vertical farming a reality had been explored by engineers, urban planners, horticulturists, and agronomists for years (Kozai et al. 2016, p. 35-66). Throughout the past decade, Despommier's vision has become somewhat of a reality. Today, indoor vertical farms, rooftop greenhouses, container farms, and modular farming units are being implemented into urban and peri-urban environments across the globe, providing hyper-local nutritious produce to urbanites (ibid.)

The concept of CEA is best described as an umbrella, covering multiple concepts that each share similar traits (i.e. technologies and materials used for production), but vary in terms of size and the level of control over the environment where the plants are being grown.
For clarification, we go by the definition of CEA enlisted by Agritechture and NYSERDA (see section 1): *CEA is the growing of crops while controlling certain aspects of the environment including lighting, temperature, humidity, irrigation, fertigation, and other factors that influence plant physiological responses* (Agritecture 2019, p. 8).

The different types of CEA are defined as the following:

- GREENHOUSE refers to a climate-regulated structure with walls and roof made out of a transparent material (glass) in which crops are grown.
- ROOFTOP GREENHOUSE refers to a greenhouse located on top of another building.
- SHIPPING CONTAINER refers to a climate-regulated shipping container using only supplemental lighting (no sunlight) for crop production.
- HIGH TUNNEL refers to crops covered with a canopy for protection against the elements and sometimes referred to as hoop houses or tunnel houses (not small backyard hobby tunnels).
- INDOOR FARM refers to crop production that utilizes artificial lighting instead of sunlight. This can include rooms, warehouses, factories, and other converted indoor spaces.
- VERTICAL FARMING is crop production that uses the vertical space. Plants can be stacked horizontally or in tall towers.

(Agritecture 2019, p. 8)

These different types of CEA all control certain aspects of the growing environment, but concepts such as indoor farming, vertical farming, and shipping containers apply more technologies than the others, due to their design. For this reason, we will describe the vertical farm as it is the most technologically advanced concept of CEA and it provides a better overview of how technology is used to control the environment and how it differs from the more traditional elements such as sunlight and soil.

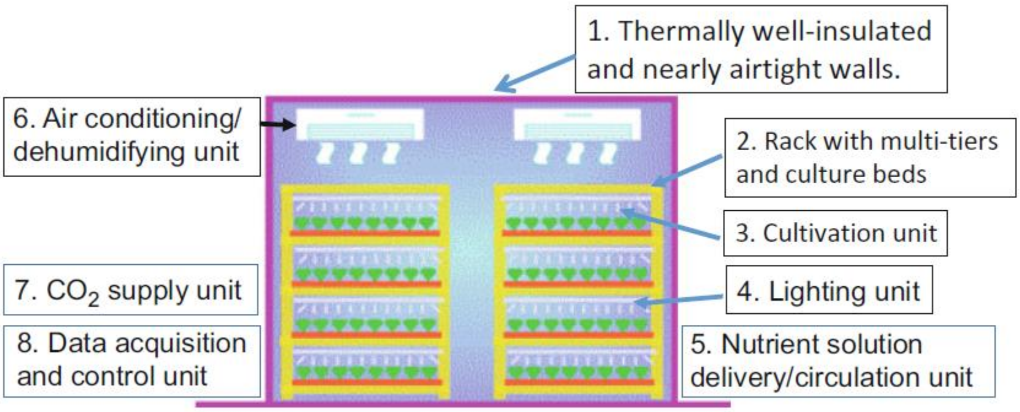

Fig. 1.3 Configuration of the culture room in a plant factory with artificial lighting (PFAL) consisting of eight main components (units). Machines for automation are not shown in the figure. Most electric energy is consumed by lighting and air conditioning units. The numbers in the diagram correspond to those in Table 1.1. This is a revised version of Fig. 4.1 in Chapter 4 of Kozai et al. (2015)

Figure 1 Main components of a Vertical Farm Cultivation Room. Excerpt from Kozai 2018, p. 7

As the above illustration shows, a vertical farm or Plant Factory with Artificial Light (PFAL) as it is called in Southeast Asia (Kozai et al. 2016, Kozai 2018), applies a multitude of technologies in order to produce plants. The premise is to take the traditional components of a greenhouse and apply technology in order to gain more control over the plants' growth. It is well known that plants with green leaves grow by photosynthesis, and the essential resources for photosynthetic growth at moderate temperatures are water, CO2, light energy, and inorganic fertilizer consisting of 13 nutrient elements (including N, P, K, Ca, and Mg).

In a traditional greenhouse, solar radiation passes through the transparent roof and walls and is absorbed by the floor, earth, and contents, which become warmer. As the structure is not open to the atmosphere, the warmed air cannot escape via convection, so the temperature inside the greenhouse rises. As the plants' uptake water in order to grow, the process of transpiration occurs, which creates higher levels of humidity due to evaporation through the leaves. This creates an ideal growing environment for most plant species. What is drastically different about indoor and vertical farming is their use of artificial lights, hydroponic irrigation, and climate control technologies for heating, ventilation, and air conditioning (HVAC).

In order to take full control of every aspect of the plants' growth, indoor and vertical farmers have designed unique facilities that can achieve these objectives. In a traditional greenhouse, you are still at the mercy of the weather, as you rely on sunlight and its heat. In a vertical farm, you apply artificial light in order to produce photosynthesis and you control the climate of the growing room via HVAC technologies. Replacing sunlight with artificial light also means that you do not rely on sunlight from above, but instead can fit your lights close to each plant. By having the ability to fit a light source to each plant you can now stack trays with plants on top of each other, creating a vertical growing effect (Kozai 2018, p. 7). Growing vertically in multilayers effectively means that you achieve a 100-fold annual productivity per unit land area without the use of pesticides, compared to the annual productivity per land unit in open fields (Kozai 2018, p. 17).

The ability to grow vertically has created many differently designed grow rooms around the world (Kozai et al. 2016, p. 35-66). In a traditional greenhouse, you mostly grow in soil and often you irrigate the plants manually. However, in most modern indoor and vertical farms, you use automated hydroponic growing. Hydroponics is a method of growing plants without soil, by dissolving mineral nutrient solutions into the water and irrigating the root zone of the plants. By using hydroponics in various forms, indoor and vertical farms can automatically control how much water is given to the plants on a daily basis. You can also control the pH and nutrient concentration of the water, ensuring optimal conditions for the root zone of the plants as they uptake water and nutrients for growth. A hydroponic irrigation system is essentially a closed-loop, where all water not absorbed by the roots of the plants are circulated back into the reservoir for reuse. This is how CEA is able to achieve up to 95% water use efficiency (Kozai 2018, p. 16).

Replacing soil also significantly reduces the weight of the trays where the plants grow, making it easier to stack them on top of each other (Kozai 2018, p. 7). To further enhance the growing conditions, modern CEA also applies various sensors that monitor CO2, humidity, and temperature of the growing room in order to make sure the right conditions are met. All of these technologies and their respective data are then compiled into computer software that monitors and presents an overview of the growing room in order to maximize control.

Today, most indoor and vertical farms produce leafy vegetables such as salad greens, microgreens (plants harvested just as they start producing leaves), herbs, and kale (Agritecture 2019, p. 26). The reason for this is their relatively short height (maximum of 40), which makes them ideal for stacking multiple layers on top of one another. Furthermore, they grow relatively fast and well under artificial light (7-60 days depending on variety) and most of the fresh weight

of the plant can be sold i.e. salad mostly consists of water and has a low dry mass in comparison to wheat (Kozai 2018, p. 9).
The reason why these are the ideal types of plants to be grown in vertical farms is due to the overall cost of production. The major components of the production costs in vertical farms are electricity, labor, and depreciation of initial investment. Together the sum of these three components accounts for 80% of the total production cost (Kozai 2018, p. 18). Therefore, the production costs can largely be summed up as electric energy productivity (kg of produce per kWh of electricity consumption), labor productivity (kg of produce per labor hour), and space productivity (kg of produce per floor area or cultivation area) (ibid.). To evaluate whether or not something is economically viable for production Dr. Toyoki Kozai lists for following:

A simple index to evaluate the economic suitability of plants to PFALs is the electric energy productivity, PE in units of kg/kWh, which is the yield of marketable produce (kg) per unit electric energy consumption (kWh = 1000 x 3600 s/h = 3.6 MJ) for lighting and air conditioning. The electric energy productivity on a monetary basis, PM, can be roughly estimated by (PE/UE) where UE denotes unit electricity cost ($/kWh). The electric energy consumption is roughly proportional to the days of cultivation, photoperiod (hours per day), and PPFD (photosynthetic photon flux density).

(Kozai 2018, p. 19)

Therefore, vertical farms and most of the CEA industry are not used for growing commercial production of staple crops such as wheat, rice, and corn as the market price per kg of functional plants are generally 10-100 times higher than that of staple crops (ibid.) However, there is room for significant improvements in multiple areas within the CEA industry, which will inevitably lead to more crops being reliable for indoor and vertical farm production in the future (ibid.)

Despite some of the current limitations associated with indoor farming, it is important to remember that the industry is only half a century old and much of the technological advancements have occurred during the last decade. As the illustration below shows, the third wave with the invention of the Light Emitting Diode (LED) grow light is where the industry took off, as this new type of artificial lighting greatly outperformed previous artificial lights in terms of heat mitigation, energy consumption, durability, and size (Kozai 2018, p. 10). Furthermore, the fourth wave with the introduction of ‘’Smart’’ farming is set to greatly improve the entire CEA industry (ibid.).

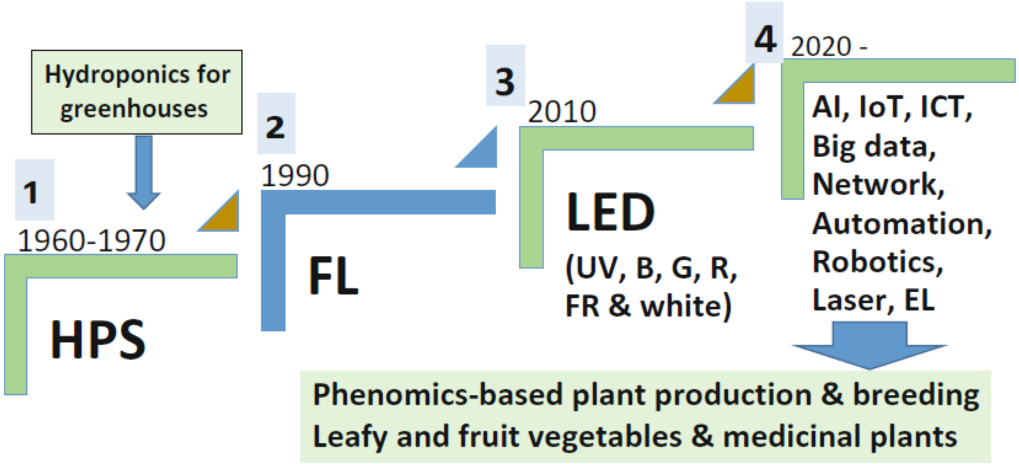

Fig. 1.6 The fourth wave of PFAL R&D and business will start around 2020
HPS high-pressure sodium lamp, *FL* fluorescent lamp, *LED* light-emitting diode lamp, *UV B, G, R, and FR* ultraviolet, blue, green, red, and far-red, respectively. *AI* artificial intelligence, *IoT* Internet of Things, *ICT* information and communication technology. Phenomics: methodology of plant trait measurement and its applications

Figure 2 Timeline of Vertical Farming and Applied Technologies. Excerpt from Kozai 2018, p. 11

2.2 Technological Components in CEA

The following section will outline more how an array of key technologies used in CEA control environmental factors.

2.2.1 Lighting

Light is one of the most essential components of CEA due to its significance for photosynthesis in plants. Visible light is electromagnetic radiation that is visible to the human eye and it is measured in frequencies. Light is defined as a particle called a photon and its energy is referred to as quantum (Geilfus 2019, p. 44). To better understand visible light we can present it as a spectrum of electromagnetic radiation (see illustration below).

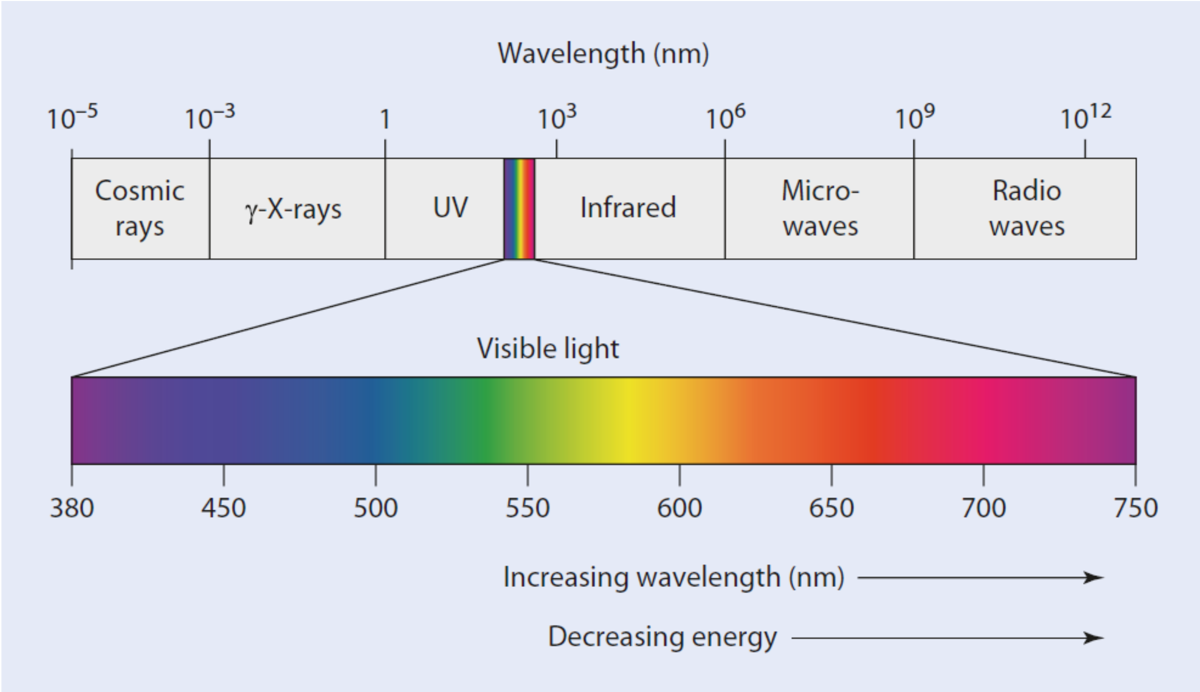

Fig. 5.1 Spectrum of electromagnetic radiation. (Bresinsky et al. 2013. Reprinted by permission from Springer Nature, license number 4406981227879 issued August 13, 2018)

Figure 3 Spectrum of Electromagnetic Radiation. Excerpt from Geilfus 2019, p. 44

As the illustration shows, visible light ranged from 380 to 750 nanometer (nm). The shortest and longest wavelengths that humans perceive are violet light (about 380 nm) on the left end of the spectrum and red light (750 nm) on the right end of the spectrum (ibid.). Visible sunlight appears white because of the way wavelengths mix when perceived by the human eye. When light passes through a prism, the lightwaves become refracted into visible bands of color, producing the rainbow effect.

When plants use light for photosynthesis, we refer to it as photosynthetically active radiation (PAR). The PAR ranges approximately from 400 to 700 nm and is an indicator of what specific wavelengths a plant uses for photosynthesis. Not all wavelengths in sunlight are used equally in photosynthesis. Plants contain several pigments that absorb specific wavelengths of light while reflecting others (ibid.). The baseline is that plants absorb blue wavelengths from 400 to 480 nm and red wavelengths from 600 to 700 nm in order to grow. The green wavelengths of the spectrum are not absorbed by plant leaf pigments (but is reflected), and that is why a plant leaf appears green to the human eye (Geilfus 2019, p. 45). When a plant is exposed to the right wavelengths, the plant pigment absorbs the light particles and becomes energized possessing electrons. This initiates what is called the photosynthetic electron transport chain, which is the process of plants transforming physical energy (sunlight) into chemical energy. This process is essentially how plants produce various chemical compounds that provide energy, flavor, and nutrients when consumed by humans (ibid.).

Light controls not only photosynthesis but also how a plant develops and takes on a physical appearance. Although the sun is the main source of natural light, the invention and application of artificial lighting in CEA has shown to be very efficient in the past decades, especially in areas where natural light is scarce during most seasons (i.e. the northern regions of the world). When it comes to the way light affects plant growth and morphology (appearance) we go by three parameters; *intensity, quality,* and *photoperiod* (Geilfus 2019, p. 46). *Light intensity* is the amount of light supplied to the plant and it is measured by the photosynthetic photon flux density (PPFD) and daily light integral (DLI). PPFD measures the amount of photons received by the plant and utilized for photosynthesis, whereas DLI measures the total daily number of photons received per growth area of the plants (ibid.) *Light quality* describes the wavelengths of light (the color) the specific light is producing. Here we note again that red light activates photosynthesis and blue light suppresses stem elongation and encourages leaves to grow towards the light, resulting in healthier plants (Geilfus 2019, p. 53). *Photoperiod* measures the duration of light that a plant receives throughout the day and how it influences growth, photosynthesis, and morphology. Manipulating the photoperiod (the amount of light exposed to the plant) is used to elicit a change in how plants grow in certain stages of their life (flowering, producing fruits etc.) (Geilfus 2019, p. 48). With these parameters listed and how they affect plant growth, we can now address how and what types of light are used in CEA.

According to Christoph-Martin Geilfus, artificial light is used for three main purposes:

1. *Under replacement lighting, solar radiation is completely substituted in indoor growth rooms and growth chambers (Kozai et al. 2016). Although sunlight offers a full spectrum of photosynthetically active wavelengths and its input is free of charge, some growers prefer to create completely artificial environments in order to control optimally all environmental factors and to improve quality parameters.*
2. *Supplemental or production lighting is used in greenhouses to supplement periods of low natural light (Schwend 2017).*

3. *Photoperiodic lighting is used to stimulate or influence photoperiod-dependent plant responses such as flowering or vegetative growth (Schwend 2017).* (Geilfus 2019, p. 48)

Depending on the type of CEA production and the geographical position, artificial light might be crucial in order to secure proper photosynthesis and growth of plants. However, despite significant technological advancements within light technologies over the years, no light source converts electrical energy entirely into light (ibid.). When light sources convert electrical energy into light, they also produce thermal energy (heat) that can negatively affect the plants. Therefore, it is important when evaluating artificial light sources to consider the following parameters: lamp efficiency, intensity, spectral quality, costs, electrical requirements, maintenance demand, and life span (ibid.).

The most commonly used types of artificial lights in CEA are *Fluorescent lamps*, *High-pressure discharge lamps*, and *LEDs*. *Fluorescent lamps* produce light from the excitation of low-pressure mercury vapor in a mixture of inert gas. They are light-efficient and have a long life span and produce a balanced wavelength range in the PAR spectrum. They are used in CEA because they operate in relatively cool temperatures, allowing them to be fixed close to the plants (Geilfus 2019, p. 49). *High-pressure discharge lamps* function by applying an electrical arc into an elemental gas mixture. The gases are heated under high vapor pressure and temperatures, resulting in high light-intensity and efficiency. Metal halide (MH) and high-pressure sodium (HPS) lamps are still commonly used in CEA due to their full spectrum of emitted light and high electrical efficiency (ibid.). LEDs are the newest type of artificial light and also the most advantageous. They are characterized by having a long life span, being robust, stable, compact, and lightweight. They also offer good spectral composition by combining multiple colored LEDs. LEDs also offer the ability to control the light output and they use significantly less energy and produce less heat than other types of artificial lights, making them the most ideal type of light used in CEA (ibid.). According to Geilfus *''LEDs are likely to substitute traditional lighting systems in horticulture, including both fluorescent and high-intensity discharge lamps, and revolutionize controlled environment horticulture''* (Geilfus 2019, p. 50). Furthermore, it cannot be understated how big of an impact the advancement within LEDs have had on CEA during the past decade. The group of scientists who invented the blue LED was rewarded with the Nobel Prize for Physics for their work (Webb, 2014).

2.2.2 Irrigation

Hydronic systems are essential tools for plant production in CEA. A hydroponic system or hydroponics is a method of growing plants using mineral nutrient solutions in water without soil. In modern CEA, hydroponics is used in array ways depending on the types of plants being grown and the level of complexity of the specific farm. In hydroponics, the plants are growing in small cubes (growing medium) of various materials that act as a sponge in order to make sure the roots of the plants are kept moist. These cubes are placed in large trays, also known as a cultivation panel, which directly exposes the plant shoots to the air and the plant roots to the nutrient solution (Kozai 2018, p. 32). Depending on the crop variety and the design on the farm, the cubes of growing medium might be made out of materials such as; Rockwool, clay pellets, perlite, peat moss, or vermiculite (ibid.). The most common types are hydroponic irrigation methods are; Drip System, Flood and Drain System, Nutrient Film Technique, and Aeroponic System (Geilfus 2019, p. 36-39).

Drip system

In a drip system, the nutrient solution is dripped onto the medium to provide nutrients and keep the roots moist. The nutrient solution is pumped through drip emitters from above to the individual. plants (Geilfus 2019, p. 36). This type of system is ideal for potted plants, flowers, and strawberries (Kozai 2018, p. 36).

Fig. 4.1 Drip system, schematic drawing. (Modified according to Sharma et al. 2018); *P* water pump, *N* nutrient solution

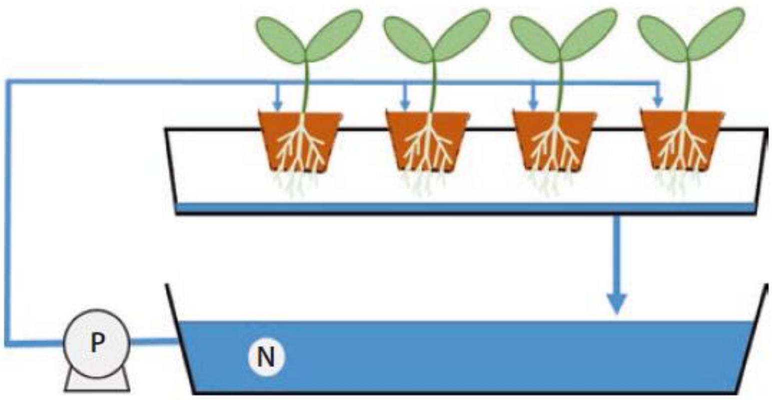

Figure 4 Drip System, Schematic Drawing. Excerpt from Geilfus 2019, p. 36

Flood and Drain system

In a flood and drain system, the plants periodically flooded with nutrient-rich water in such a way that it completely covers the growing medium containing the plants for a period of time. To stop the flooding, the solution is returned to the reservoir by opening a valve at the bottom of the growing tray (Geilfus 2019, p. 36). With the help of an automatic timer, the trays are flooded for 20-30 minutes at a time, multiple times a day in order to provide enough water to the plants. This type of system is good for water-craving plants such as lettuces or various types of spinach (ibid.).

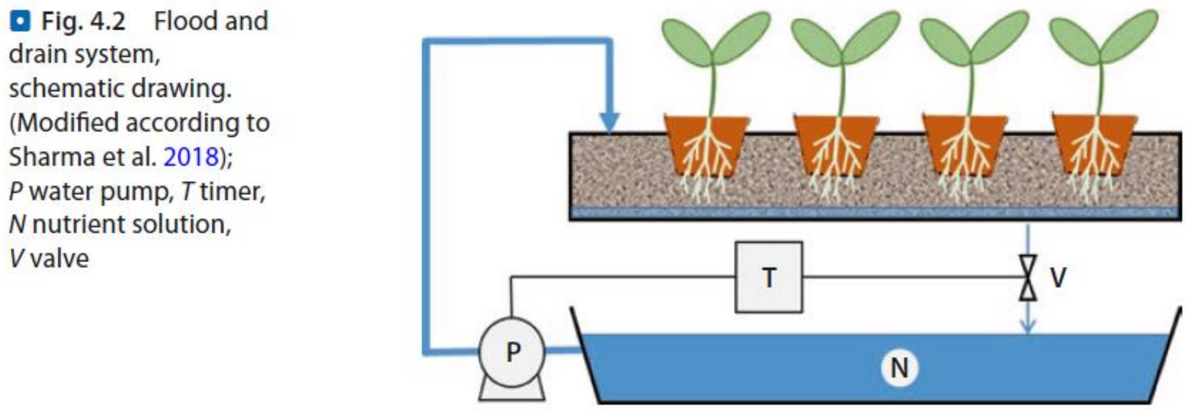

Figure 5 Flood and Drain System, Schematic Drawing. Excerpt from Geilfus 2019, p. 37

Nutrient Film Technique

With a nutrient film technique (NFT) system, the plants are grown in canals or pipes that have a slight slope. The nutrient solution is pumped circulation system from the reservoir into the canals and then flows as a thin film down the canal and back into the reservoir by gravity. The plants are fixated so that some parts of the roots are always immersed in the flowing nutrient solution and some are surrounded by air. This provides the plants with a sufficient mixture of nutrients and oxygen resulting in better growth (ibid.). This type of system is well suited for the majority of plants as it can be adjusted to fit the needs of the specific species.

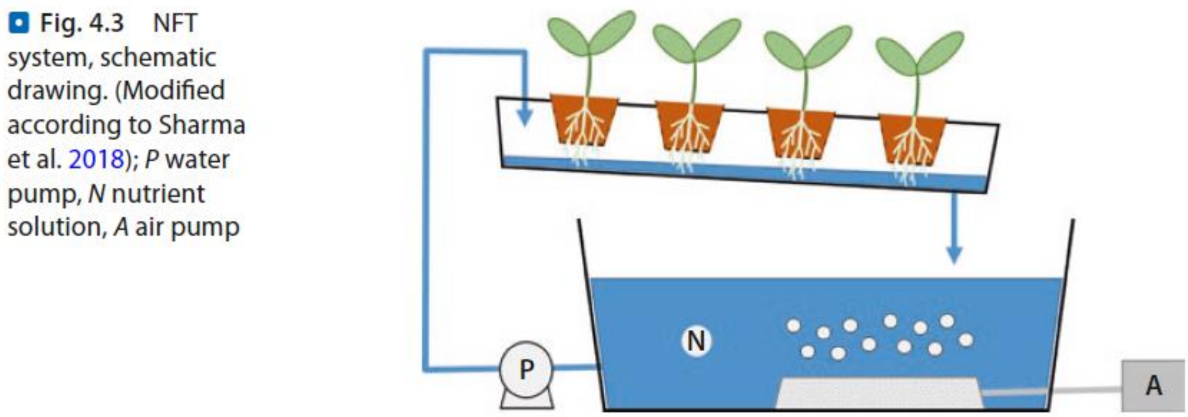

Figure 6 Nutrient Film Technique (NFT), Schematic Drawing. Excerpt from Geilfus 2019, p. 37

Aeroponics

In an aeroponic system, the plants are fitted into a growing tray containing a growing medium like other hydroponic systems. However, in aeroponics, the roots of the plants are being sprayed with an aerosol of nutrient solution pumped from a reservoir. By using pressure, the nutrient solution is pumped through the tubing and into an array of spray heads, which makes the nutrient solution into a fine mist. The spraying method ensures excellent aeration of the roots and high oxygen levels, resulting in fast growth. Aeroponics is the most advanced type of hydroponics, and it can be very useful for growing plants fast, but it also requires a high level of maintenance (Geilfus 2019, p. 38-39).

Fig. 4.5 Aeroponic system, schematic drawing. (Modified according to Sharma et al. 2018); *P* water pump, *N* nutrient solution, *S* spray heads, *A* air pump

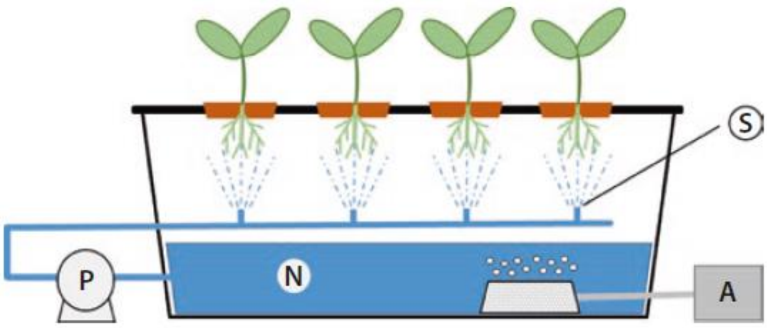

Figure 7 Aeroponic System, Schematic Drawing. Excerpt from Geilfus 2019, p. 38

2.2.3 Indoor Climate Control

When it comes to producing plants in a controlled environment, it is essential to understand the nature of each of the environmental factors and how to measure and quantify them. The main environmental factors that need to be monitored and controlled in order for plants to grow are *temperature, humidity, CO2 concentration*, and *ventilation* (the movement of air) (Kozai et al. 2016, p. 129). For the sake of simplicity, we have chosen to highlight the key features that need to be controlled in a simple matter, as a full in-depth description of the science behind these environmental parameters is a report in itself.

Maintaining the right temperature is crucial, as it affects the physiological processes of the plants and their well-being. If plants are exposed to too high or low temperatures, it can lead to the plants being stressed, resulting in the development of several defense mechanisms that (depending on the plant species) can have desired or undesired results on the plants' morphology (Geilfus 2019, p. 99-113). However, in CEA the air temperature is often controlled at a relatively constant level using air conditioners, resulting in constant plant temperature and, therefore, consistent physiological activity (Kozai et al. 2016, p. 129).

When plants grow, they add water vapor to the air through transpiration, which is the evaporation of water from plant surfaces to the atmosphere (Kozai et al. 2016, p. 132). In a controlled environment, plants transpire a lot of water, resulting in high water vapor content and humidity. Without proper management of the humidity of the environment, plant transpiration can stop if the humidity is too low or too high, resulting in lack of growth (ibid.)

During photosynthesis, plants assimilate CO2 and release CO2 during respiration. When growing plants in a controlled environment it is important to monitor the CO2 levels, as a lack of CO2 will result in plants growing slowly (CO2 starvation) (ibid.). In some cases of CEA, it is necessary to add CO2 to the growing environment in order to meet the atmospheric level, which is the ideal CO2 concentration.

In an open field, air travels great distances over a short period of time, resulting in a steady supply of oxygen. However, in an indoor climate, the air exchange rate needs to be constantly monitored in order to secure proper ventilation. Insufficient supply of fresh air suppresses gas diffusion in the plant leaves, which subsequently reduces rates of photosynthesis and transpiration and hence the plant growth (Kozai et al. 2016, p. 138).

Controlling an indoor climate requires high technical expertise but with the aid of various sensors and computer software that monitor the above-listed parameters, engineers are working on automating every aspect of indoor climate in CEA.

3. Theoretical Framework

3.1 Actor-Network Theory

3.1.1 What is Actor-Network Theory?

Actor-network theory is, as suggested by Law (1992) *"…a relational and process-oriented sociology that treats agents, organizations, and devices as interactive effects."* (Law 1992, p. 389). This definition connects with the topic of our research, as we aim to analyze two very different organizations that have, over time, formed various networks through the interaction of their agents. We hypothesize that the cohesion of these two organizations is crucial or the future viability of the field in which they operate.

The first definition is synthesized, in a simpler, more intuitive way, through a statement that Law has made later on in the same work: *"...social structure is better treated as a verb than as a noun."* (Law 1992, p. 389). This reflects the action, process-oriented nature of actor-network theory. It showcases 'structure' as a result of a previous, and most likely still continuing, activity, and perceives it not as a given fact but rather as an ongoing process. Actor-network theory, therefore, allows us to trace back to the origins of a 'structure', and tie it to interactions, rather than entities.

Another way to describe actor-network theory is by directly addressing its take on the concept of 'power'. The theory, in Law's (1992) words *"…is concerned with the mechanics of power. It suggests, in effect, that we should analyze the great in exactly the same way that we would anyone else."* (Law 1992, p. 380).

The analysis in actor-network theory starts from seeing the actors as no different from one another, stripping them from any preconceived notions that we, as researchers, might have about them. This, in turn, allows us to instead look at the interactions between actors, and through that determine the origins of what might or might not actually make them different, generate differences in power in a given network. The interactions must be seen as the ones who generate change in an organization (Law 1992).

In the following part, we will look at the central notions in actor-network theory, and how they are used in the analysis process.

3.1.2 Central concepts in actor-network theory

Networks in actor-network theory

One of the most important concepts in actor-network theory is the one of ‘heterogeneous networks’ (Law 1992). The metaphor of ‘heterogeneous network’, according to Law, “…is a way of suggesting that society, organizations, agents and machines are all effects generated in patterned networks of diverse (not simply human) materials.” (Law 1992, p. 380).

An extension to this is the fact that networks can be perceived to be ‘materially heterogeneous’ (Law 1999). That, in the context of our paper, helps organize the actors, as well as their interactions, into a more fluid, more translatable way, as it gives artificial light, as well as farmers, their habits, engineers, and ventilation, the same interactional status, making it easier to see the connections and how they affect the entire structure of CEA itself.

Translation in actor-network theory

Actor-network theory has an interesting take on the concept of ‘science’, seeing it as “…a process of ‘heterogeneous engineering’ in which bits and pieces from the social, the technical, the conceptual and the textual are fitted together, and so converted (or "translated") into a set of equally heterogeneous scientific products.” (Law 1992, p. 381).

Here, we also encounter the concept of ‘translation’, which in the aforementioned theory addresses the process whose *“...object is to explore and describe local processes of patterning, social orchestration, ordering and resistance.”* (Law 1992, p. 386).

Referring to the concept of ‘translation’, we have to also mention the concept of ‘scripts’. Law (1999), touches upon the fact that in actor-network theory, networks may be looked at as scripts. A script can be a role that is ascribed to an actor in a network, by another, that may or may not be a machine, and the actors are expected to play according to that script (Law 1999, p. 3).

Law (1999), when referring to Madeleine Akrich’s work on a case of technology transfer between Sweden and Nicaragua, states that *“...translation implies both similarity and difference”* (Law 1999, p. 3). This will allow us to reflect on the ways in which technologies tied to controlled environment agriculture undergo changes under the influence of new spaces of implementation, and new social and professional structures.

Organizations in actor-network theory

Organizations in actor-network theory are perceived as a result of a continuous process, and are meant to be analyzed as such:

"...organization is an achievement, a process, a consequence, a set of resistances overcome, a precarious effect. Its components – the hierarchies, organizational arrangements, power relations, and flows of information – are the uncertain consequences of the ordering of heterogeneous materials." (Law 1992, p. 390).

In this context, rather than analyzing the organization itself as a whole, what needs to be paid attention to as a first is the ordering of these parts/ materials/ agents.

Since the organization consists of many elements, it is crucial to ask the right questions, so as to more easily differentiate between them. Thereafter, this facilitates the analysis of their interaction, and helps the researcher to fully understand and describe how the organization came to be:

"…it is convenient to distinguish, on the one hand, between questions to do with the materials of organization, and on the other, with those to do with the strategy of organization. So when actor-network theory explores the character of organization, it treats this as an effect or a consequence – the effect of interaction between materials and strategies of organization." (Law 1992, p. 389)

The distinction between materials and strategies becomes ever so more apparent when analyzing a multidisciplinary field such as the one which is the topic of this report, and we predict that it will help us pinpoint the similarities and differences when attempting to translate the networks and the actors that are parts of the organizations being analyzed.

It is important to note that, in actor-network theory, an organization is never in its final form, as it is part of an ongoing process: *"The insistence on process has a number of implications. It means, for instance, that no version of the social order, no organization, and no agent, is ever complete, autonomous, and final."* (Law 1992, p. 389). 'Organization', in this sense, is a fluid concept, and their form is highly dependent on the interaction of the elements that comprise it.

3.1.3 How to do a good description

Signe Vikkelsø (2007) affirms that the current concern towards social sciences nowadays is that they steer away from action, and practical applications, having more of a descriptive, even sterile nature. This statement is later on partly refuted by addressing the fact that an ANT analysis can interfere quite radically with the field, as compared to any other type of research, even the action-oriented ones:

"By symmetrically focusing on the heterogeneities and particularities of the object of study and describing closely the shifting relations between concrete elements and the simultaneously emerging or corroding qualities, the object is elucidated and examined without employing any preset benchmark or universal scale. This examination has both practical and political implications." (Vikkelsø 2007, p.302)

The characteristics of an ANT oriented research make a description more impactful through the sheer fact that they address the field through a process, action-oriented lens. The essence of ANT is contained in its focus on the action and interaction of the agents, materials, networks, and organizations.

Vikkelsø (2007), citing Barad, states that *"no description leaves the described untouched, as the object and the agency of observation are inseparable—they intra-act (Barad, 1998)."*.

We are steering towards a multiplicity-oriented ANT analysis. The benefit of such an analysis, as Vikkelsø (2007) states, is that it analyses multiple practices and allows us to see and understand how these can interact with an observed phenomenon. Through this kind of description, what can be achieved is a clearer view of how these practices interact, how they are being kept separate, what is different about them and how do they address the concept of 'identity' (Vikkelsø 2007):

"By exploding the case into many 'versions' of reality, this type of analysis points to the trade-offs and political choices that accompany any attempt to push forward or expand a certain practice, but also to the concrete ways in which different practices can be enacted simultaneously". (Vikkelsø 2007, p.302)

Vikkelsø (2007) also suggests that a detailed, or thick empirical description is mostly only advisable if the target audience of said description is extraordinarily interested readers. If however, one wants to interest other types of readers, they have to transform their descriptions into ‘executive summaries’ (Vikkelsø 2007).

3.2 Accessing Nature Culture

When addressing the action of us making the real, in making nature, Law (2004) asks the question ‘What are we actually doing?’. In terms of STS, his answer is that we are *“...involved in building particular and provisionally stable versions of this hybrid real, natureculturetechnics.”* (Law 2004, p. 5). This brings us to the idea that what we are building is, in reality, a version of our own reality, that is stable as long as it is constructed in accordance to the actors, materials, and interactions that make it possible for it to exist. If the reality that is built ceases to, overtime, fit these parameters, it is replaced by another reality:

“Early in the process of building a world there may be a series of equi-probable reals, but as the web of constraints grows, so, too, does a kind of path dependency. The other realities, the things that don’t quite make it, become less and less real and fade into the endless limbo of the might-have-been. It simply becomes too expensive to make other realities, other natures. Until something is upset there is convergence.” (Law 2004, p.5)

In this sense, it is also true that, while a reality exists, there are other realities that can be built and have the potential to replace it. The only reason they are not is that it would take too many resources to sustain many similar realities that serve/host one or another set of materials/actors and their interactions, as well as their interactions, links, and networks if we are to speak in ANT terms. As long as there is convergence, a reality will exist, and will only be replaced if there is something to upset the equilibrium. That is one of the aspects of the reality of farming nowadays that we will be tackling in this paper.

What upsets the convergence can be both a new issue or new opportunities. In the case of farming, the reality of it was convergent with the fact that it was done a certain way, dependent on certain natural conditions. Namely, it was dependent on factors such as climate, sun exposure, soil, etc. With technological development, it became possible to control these factors and alter them. Another aspect that is upsetting the convergence in farming is the fact that the world cannot sustain the need to produce any longer and has to find more efficient ways of growing plants. That is what upset the convergence, but also something that created a path to a new reality of farming.

That does not mean though that these realities cannot coexist and have to replace each other. It is a possibility, but, as for now, those realities exist in parallel, and influence each other.

Gad et al. (2015) referred to Vivieros de Castro's study of the Amerindian Araweté when making an argument for the switch from epistemological multiculturalism to ontological multinaturalism:

"In a famous example, Viveiros de Castro explains how animals in the Amazon see themselves as human. But, having different bodies, they see things differently from one another. When, for example, a jaguar sees itself as human, it sees what the Araweté see as blood as manioc beer. Viveiros de Castro suggests that taking multinaturalism seriously requires a rethinking of the modern anthropological project: it poses the question what such a project would come to look like if it ceased being multicultural and perspectival." (Gad et al. 2015, p.70)

In this regard, the view is useful for our report as it enables us to see the actors and the materials that make the organizations, as entities that can have different origins and can see or perceive things differently, be they human or non-human. Later, Gad et al. (2015) returns to this idea, by mentioning that the point of such a view is to make researchers be able to see 'alterity, or 'otherness' (Gad et al. 2015).

Another point that has much value in regards to the perspective that we employ in our paper, on nature-culture, is presented beautifully in this quote by Myers, where she is addressing the views that scientists working with plants can have on the plants themselves:

"Is it possible that practitioners' sensoria get 'vegetalized' over the long duration of their experimental inquiry? If so, how might their vegetalized perceptions and imaginations shape the direction of their inquiry and the ways they think and talk about plants?" (Myers, 2015, p.42)

This makes us question if farmers have this vegetalized view on the world and what if engineers that make the technology for controlled environment agriculture actually need this kind of perception and view on the world in order to make good technologies.

3.3 The Farmer-Back-To-Farmer Approach

The Farmer-Back-to-Farmer (FB2F) approach was introduced by Robert Rhoades and Robert Booth. It involves encouraging the usage, by the technologists, of "farmers' knowledge and practices as both the starting point for technological innovations as well as the ultimate measure of the value of innovation." (Crane 2014, p. 45).

Figure 1.
The farmer-back-to-farmer model for generating acceptable technologies (from Rhoades and Booth 1982). Shading in the circles is meant to indicate the degree of overlap between farmers' and scientists' perspectives regarding the goals and activities in the coproductive process.

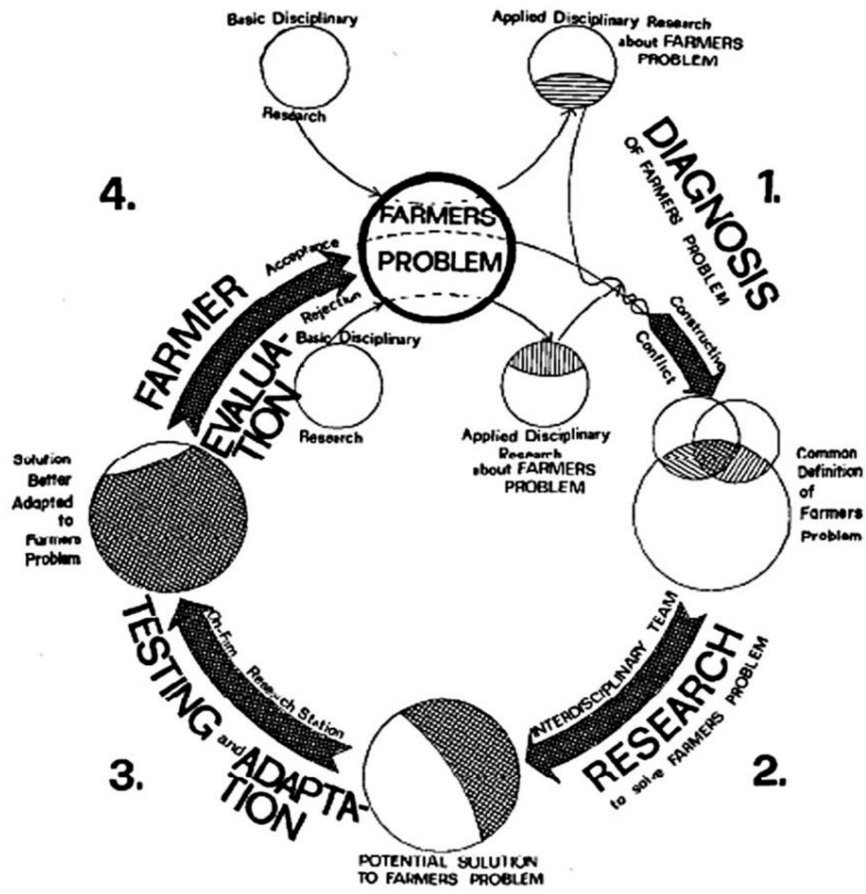

Figure 8 The Farmer-Back-To-Farmer Model. Excerpt from Crane 2014, p. 46

In this figure, we can see the cycle through which the design of technology should go according to the FB2F approach, in order to become acceptable from a farmer's standpoint. It starts off with the diagnosis of a farmer’s problem, normally through prior research of the field. The problem is defined and the next step is taken, which is research to solve the farmer’s problem. This should generate a potential solution that has the farmer’s perspectives and interests in mind. The solution is tested and adapted to the design of the technical solution. The last step of this process, the ‘back to farmer’ part, is the one in which the farmers evaluate the result produced by the firm/organization working on the technical solution. According to the feedback that is received, the solution is either accepted or rejected. In the latter case, the cycle ensues once again (Crane 2014).

The issue with the old FB2F approach, according to Crane (2014) is that, as it tends to prioritize the ‘local knowledge’ that is possessed by the farmers, it tends to give less importance to the scientific side of it, the one of, in our case, the engineers:

“However, the original “farmer-back-to-farmer” approach left the “expert” practice of science and technology as an implicitly practical and apolitical space rather than as a subject of ethnographic study.” (Crane 2014, p. 45).

Due to that, an imbalance is produced, one that in hindsight can harm. Crane (2014) proposes that, just as we attempt to research and apply ‘local knowledge’ in a scientific context, we should try to apply and research ‘scientific knowledge’ in the same kind of fashion:

“...an updated FB2F must analyze scientists just as it analyzes farmers in order to make a complete picture of the process of coproduction of technologies.” (Crane 2014, p. 52).

Prioritizing only one part of the equation - the farmers, while diminishing the importance of the engineers and scientists, will only transfer the burden from one side to the other, while not arriving at the desired, optimal outcome from a participatory standpoint. We intend to use Crane’s suggestions for improvement of the theory in our research, in order to arrive at a satisfactory result for all of the researched groups in the field of CEA.

4. Methodology

4.1 Qualitative research

Qualitative research boasts to have many qualities, of which the most important ones for us is that it can help provide 'an insider's view of an experience' (Charmaz 2004, p. 980), and that it has the ability to discover 'taken-for-granted' meanings in the fields that are being researched (Charmaz 2004). In order to analyze the field of CEA, we have to be able to understand the inside workings of it, and the perspectives of the participants in the workings of it.

The hallmark of good qualitative research is being able to enter the phenomenon, observe and analyze it from the inside, and as Charmaz states: *"Entering the phenomenon means being fully present during the interview and deep inside the content afterward."* (Charmaz 2004, p. 981). In a sense, the mission of a researcher is to understand the object of research as closely as possible, while also keeping an objective distance. Congruent with our own intentions of research, we have found that the most suitable qualitative research method for us would be interviewing.

Interviews

We will be using interviews as a source of qualitative data. We will proceed with the strategy of semi-structured interviews, as we believe it to be optimal for our type of research.

Semi-structured interviews have characteristics that make it quite beneficial for anthropological research. *"A semi-structured interview is open-ended, but follows a general script and covers a list of topics."* (Russell Bernard 2011, p.156).

Semi-structured interviewing *"...has much of the freewheeling quality of unstructured interviewing and requires all the same skills, but semi-structured interviewing is based on the use of an interview guide. This is a written list of questions and topics that need to be covered in a particular order."* (Russell Bernard 2011, p.158).

Semi-structured interviewing will allow us to target themes and subjects that we intend to discover or analyze, and will also enable us to occasionally probe into a certain topic that pops up unexpectedly, or steer the conversation into a different direction if we see that it can provide us more insight into a different domain.

We will be using webinars that we have discovered through our online search, as sources of qualitative data, and will treat them, for simplicity in terms of coding, as interviews. This is possible because most of the webinars are in an interview format.

Coding of qualitative interviews

Coding is an important part of an analysis process when dealing with data from interviews, so much that some refer to coding as an analysis in itself: *"there is general agreement that analysis is a matter of 'coding'."* (Packer 2010, p. 58). Coding, therefore, will enable us to proceed with analyzing the qualitative data that we have gathered and ease our journey into discovering insights into the field of controlled farming.

One of the defining features of a coding process is that it involves finding themes and using them as a thread to connect and compare the different data sources:

"Ryan and Bernard explain that coding involves "finding themes," and "themes are abstract (and often fuzzy) constructs that investigators identify before, during, and after data-collection" (Ryan & Bernard, 2000, p. 780). Charmaz says that to code requires "defining actions or events" within the data (Charmaz, 2000, p. 515)." (Packer 2010, p. 58)

Some themes are better represented as actions/ events, and we will specifically make use of that in order to code, as we are employing ANT as our main theory and will tend to focus on processes and interactions rather than the objects/entities that make them happen.

Our coding will also involve content analysis, which we will refer to mostly as a quantitative research method, due to the different nature of the coding that we will be employing in its case.

4.2 Quantitative research

We intend to perform quantitative analysis of both qualitative and quantitative data, through the use of content and descriptive analysis. This combination will help us have new insights that would likely be omitted in purely qualitative analysis. It will also aid us in making conclusions that are more grounded in the reality of numbers and frequency.

Content analysis

Content analysis is a quantitative method that we will be using in our research, which will help us reveal some of the latent content hidden in the data sources that we have selected. We intend to analyze the frequency at which some materials/actors, from an ANT perspective, appear in texts/videos related to CEA.

„Content analysis is a set of methods for systematically coding and analyzing qualitative data. These methods are used across the social sciences and the humanities to explore explicit and covert meanings in text – also called manifest and latent content – and for testing hypotheses about texts. " (Russell Bernard 2011, page 443).

We also plan to find common themes across different sources such as texts and videos on the topic of CEA and observe what number of times these themes occur across the set of texts that we have selected. This will be done in order to get a better understanding of the elements that form the organizations and networks in the CEA field, from an ANT standpoint. We will structure the information that we obtain through this method, for both semi-controlled and fully-controlled environments, and see how each of these compare between each other, and potentially what is the importance these themes have in the field, and what materials they have an effect on.

Descriptive analysis

Descriptive analysis *"…involves understanding data through graphic displays, through tables, and through summary statistics. Descriptive analysis is about the data you have in hand."* (Russell Bernard 2011, page 458). Descriptive analysis is generally a good choice in cases where the data is highly technical/ scientific and there is an abundance of graphs and tables that showcase important information relevant to the understanding of the field.

We intend to employ the analysis of tables, graphics, and summary statistics in order to better understand the often highly technical and data-heavy field of CEA. This will, we hope, also help us determine who are the central actors in this field, in terms of technology, business and science, and will improve our analysis of the networks that form between these actors, and how strong of an influence they have on each other and on the field itself.

4.3 Empirical data

In the early stages of writing this thesis, we focused on gaining as much knowledge and expertise on the concept of CEA and its developments over the decade. By compiling state of the art literature on an array of topics associated with CEA, we were able to uncover some of the complexities related to the concept as well as discovering challenges and opportunities within the industry.

After our initial literary studies, we began contacting multiple companies and experts within the CEA industry. Our goal was to conduct multiple interviews with people from different areas of the industry as it would present us with multiple points of view on the topic at hand. Furthermore, we wanted to do participant observation in modern greenhouses, research facilities, and vertical farms located in Scandinavia.

However, as COVID-19 rapidly spread across the world in the early months of 2019 and consequently shutting down most countries in the western world, our scope for the project shifted dramatically. Due to severe constraints on how humans could interact and society going into a complete lockdown for a prolonged period of time, we were no longer able to conduct ethnographic research (i.e. participant observation). Furthermore, the spread of COVID-19 also meant the majority of the CEA industry had to either shut down their operation or work with significantly fewer resources for a prolonged period of time. This meant that the majority of companies we were planning on working with had to decline.

In the early stages of lockdown in Denmark, we were able to conduct an interview with Mads Andersen, head of R&D at Senmatic, a Danish manufacturer specializing in mechanical, electronic and software technologies for CEA. The interview worked as a guide on the complexities of modern-day CEA and how various technologies such as LEDs are being applied in horticulture today.

As a result of COVID-19, the CEA industry chose to adapt to the pandemic by going digital. As part of their mission to spread awareness about the CEA industry and its development, the agricultural consultancy firm and news hub Agritecture decided to host a digital conference on controlled environment farming and urban agriculture. The digital conference took place from the 23rd of March to the 19th of May and contained 41 different interviews with industry leaders, scientists, and entrepreneurs working with CEA and UA around the world. We selected a couple of interviews from the digital conference as they help us assess our research questions.

Lastly, the industry-leading LED grow light manufacturer Heliospectra, hosted a selection of webinars on CEA and how artificial light and data science is changing the industry. The seminars took place in June 2020 and we attended. We have selected two of the seminars as they help us assess our research question.

The full list of our empirical data can be found on the following pages. The transcription of the interview with Mads Andersen of Senmatic is in the appendix and the links to the video recordings of the Agritecture interviews and Heliospectra seminars can be found in the reference list.

List of interviews/seminars

Type of data	Source	Topics
Interview	Mads Andersen - Head of R&D at Senmatic. A Danish manufacturer specializing in mechanical, electronic and software technologies for CEA	Lighting in CEA. LEDs. Growing methods. Trends in CEA.
Webinar	Heliospectra online seminar on Vertical Farming with: Andreas Wilhelmsson, CEO, Ljusgårda. A 7000m2 Vertical Farm in Tibro, Sweden.	Building a Vertical Farm. Designing a growing environment. Farmer’s role in the production. Engineer’s role in the production.

	Ida Fällström, Plant and Light Research Director, Heliospectra AB.	
Webinar	Heliospectra online seminar on Growing Tomatoes in an Autonomous Greenhouse with: Dr. Silke Hemming, Wageningen University. Leonard Baart de la Faille, R&D Engineer, Van der Hoeven. Jan Prins, Head Grower, Pure Harvest Smart Farms. Daniel Bånkestad, Research and Development Engineer and Project Leader, Heliospectra AB.	Competition on growing tomatoes in an Autonomous Greenhouse. Monitoring growth using sensors and applying data science. The role of AI in Horticulture. The role of the farmer in production.
Online Interview	Agritecture Digital Conference Greenhouse Energy Solutions with Bill Zanoni of Ceres Greenhouse Solutions	Breakdown on state of the art greenhouses. Air system and earth system for heating and cooling greenhouses year-round. Designing for more light utilization in greenhouses.
Online Interview	Agritecture Digital Conference iFarm - Virtual Vertical Farm Tour in Finland With Kiril Zelenski	Using software that works in combination with hardware to monitor and automate vertical farms.
Online Interview	Agritecture Digital Conference Black & Veatch – NextGen Agriculture With Zack Olson	The importance of scale and how to do it Scale-up and scale-out
Online Interview	Agritecture Digital Conference Vertical farming systems With John Leslie, CEO, Vertical Farm Systems	Tour of a vertical farm in Australia. Breakdown of vertical farming systems. Breakdown of a fully automated indoor farming system.
Online Interview	Agritecture Digital Conference	On the risks involved with vertical farming. Breakdown of software to create a

	Addressing Risk in Vertical Farming With Francis Baumont de Oliveria – Ph.d. researcher at the University of Liverpool	business plan for your operation based on all the parameters and risks involved. Technological standards. Knowledge sharing.

The transcribed interview with Mads Andersen can be found in the appendix. The recordings of the Heliospectra webinars can be accessed via links in the reference section of the report. The interviews conducted during Agritecture's Digital Conference are referenced by speaker name in the report and the recordings can be accessed via links in the reference lists.

Coding and content analysis

Initially, we have transcribed the interviews and webinars that we intend to use in our analysis, in order to be able to code them.

With the aim of uncovering the most important materials that make up the networks, we have used literature on the topic of CEA. We have determined that the areas of interest most relevant to this field are: Expertise, Technology, Economics, and Farming Methods and scanned the texts both through reading and through word search, to find the words that associate best with these fields. Through that, we were able to make a list of the materials that a typical ANT network for a semi-controlled and a fully-controlled farm would be composed of. These are listed in Figure 9 and 10 in this report.

We have also scanned the webinars and interviews for the most frequent themes, as well as the topics that were addressed in the most frequent manner. We have done that in order to make more realistic networks for semi-controlled and fully-controlled environment farming. We have used those themes in order to improve the depiction of the networks in Figures 9 and 10.

We have performed coding as well through reading the transcriptions and categorizing quotes according to the themes that were addressed. The themes that we chose prior to this activity are more general in nature, as our pool of data is formed by interviews and webinars that, while covering the field of CEA, are formed of questions that are very specific to the main interest of the interviewers that have hosted these webinars, and are not the result of our own interview guide.

Themes for qualitative coding:

- Expertise
- Knowledge
- Automation
- Data (from technologies)
- Learning
- Decision-making

In this sense, we have coded the interviews both quantitatively and qualitatively, so as to be able to build realistic networks and understand the covert meanings behind the words of the interviewees, and address those meanings in our analysis and discussion from a theoretical standpoint.

5. Analysis

5.1 Mapping the network

Drawing upon our theoretical framework and our empirical data we will aim to show the way multiple practices coexist in relation to the concept of CEA. By illustrating and describing the practices and their mutual interlocking, we will be able to showcase the differences in practices and identities related to CEA and how actors (human and non-human) are connected or kept separate in a symmetrical network (Vikkelsø 2007, p. 305). By doing so, we aim to provide a good description of how one scenario of CEA might consist of one network, whereas another scenario and its network are vastly different, even though they operate within the same practice.

In order to understand this approach and why it is useful when it comes to uncovering the complexities and clashes associated with a phenomenon, we start by applying the premise that networks are materially heterogeneous. This suggests that society, organizations, agents, and machines are all effects generated in patterned networks of diverse (not simply human) materials (Law 1992). In CEA, there exist multiple agents, machines, and materials that in combination make the practice of producing plants in a controlled environment possible. The way they combine creates a unique network that showcases how one actor is related to another and how their connection shapes a specific reality. The uniqueness of the network is a representation of how actors and their relations are different in a given scenario and it tells us stories of how things came to be a certain way and how they might change (ibid.).

To put this into an example, we have chosen to create two illustrations of how a heterogeneous network might look when addressing the phenomena of CEA. The first illustration is our representation of a traditional greenhouse using sunlight and a moderate amount of technologies (semi-controlled environment). The second illustration is our representation of an indoor farming operation, using artificial light and high amounts of technologies for control (fully-controlled environment).

In our interview with Mads Andersen from Senmatic, we discussed what makes up a modern greenhouse production facility and how the respective technologies are applied to produce plants (Appendix 2). We chose to combine our knowledge gained from the interview with Bill

Zanoni’s presentation on modern greenhouses (Zanoni 2020) and our gathered scientific literature in order to map out a network of a traditional greenhouse operation. The illustration is presented on the following page.

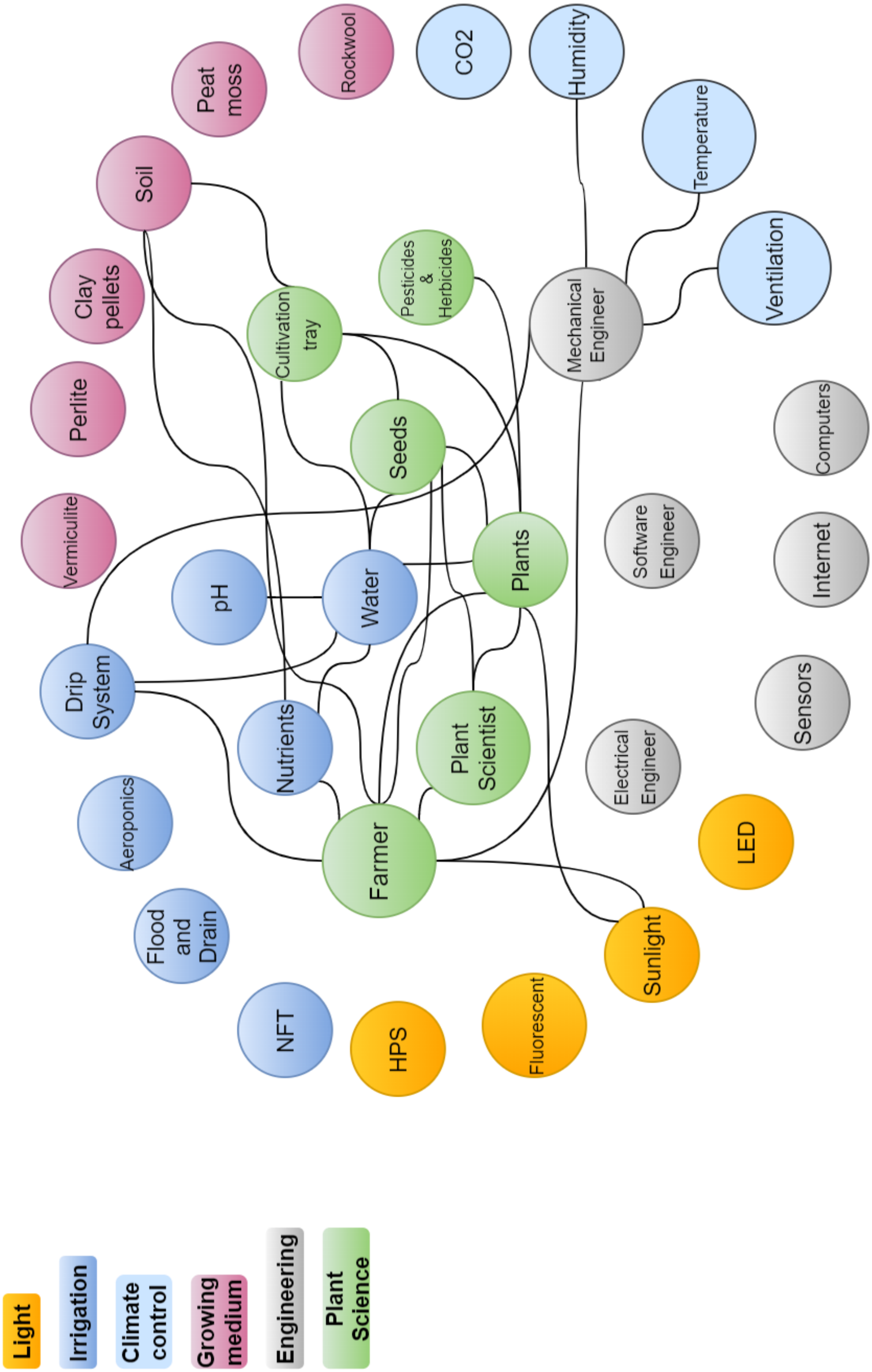

Figure 9 Network of Semi-Controlled Environment

In this network, the essential elements for plant growth are sunlight, water, and soil containing nutrients. In order to grow plants, the actors arrange in a way so that plants have the optimal growing conditions. These arrangements make up what Vikkelsø refers to as a socio-material collective that showcases the performative effects, conflicts, and dilemmas associated with the network (Vikkelsø 2007, p. 304). The lines between the actors illustrate their connectivity and are presented in a way that highlights their symmetry.

The human actors of this network consist of the farmer(s), plant scientists and mechanical engineers. They are present in the network due to their respective practices and role in plant production. The farmer(s) are in charge of the treatment of the plants (sowing, germination, watering, pruning, pest management and harvesting). They maintain most of the production and day-to-day interaction with the plants. The plant scientists provide expert knowledge on how to grow specific plants and work as consultants for farm operations, hence their connection to plants and farmers in the network. (Appendix 2, p. 12-13). The mechanical engineers are associated with installing and maintaining irrigation and HVAC systems.

The remaining actors are non-human and their connectivity is an example of how we perceive a semi-controlled environment production. The concept of a semi-controlled environment is still applying a variety of technologies, however, modern greenhouses are still reliant on sunlight and ventilation by windows. This is beneficial due to the free energy provided by the sun and steady supply of fresh air from the outside, however, long periods of low sunlight is occurring in certain parts of the world (i.e. northern regions of the world), which is not ideal for plant growth. Furthermore, the use of windows for ventilation brings the possibility of contamination and disease of the plants by pests (i.e. insects) and pathogens. To accommodate these uncertainties, the farmer is dependent on the use of pesticides and herbicides in order to secure the plants' well-being. Although we chose not to draw a connection between plants and a type of artificial lighting in our first illustration, most greenhouses located in the northern regions of the world use artificial lights as supplementary lighting (Appendix II, p. 7).

The way the actors co-exists in this network also indicates that control is partially split between the humans and the weather, creating a sort of power-relation. If the weather conditions are ill-suited for plant growth, the farmer has to achieve control by adapting the environment according to the weather. This means the farmer has to block off the sunlight for a period of time to provide shade, run air conditioners in order to lower temperature and open up the greenhouse to generate enough airflow. In some cases, the monitoring and adaptation of the growing environment are based on the farmers' expertise and their knowledge on plant growth alone and they would rely on simple thermometers and humidity meters for precision. As our illustration of a semi-controlled environment (with its actors and network) shows, there are many possibilities when it comes to designing a facility where nature is utilized to its fullest potential. However, the dependence on the weather also brings a lot of uncertainties into plant production. As presented in previous sections of this report, multiple people within the CEA industry are implementing new technologies into plant production in order to take full control over the growing environment and quantify the production.

Whether it is indoor farming or vertical farming, taking full control over the growing environment is a complicated task that requires interdisciplinary collaboration and high expertise in order to succeed. In order to describe how the concept of indoor and vertical farming works, we will present how the network, its actors, and their connectivity differs from a greenhouse production.

In order to illustrate this network, we drew upon our empirical data associated with indoor farming and the application of new technologies. The respective tours of vertical farms provided by Kiril Zelenski (Zelenski 2020) and John Leslie (Leslie 2020), along with the Heliospectra seminars on vertical farming (Heliospectra 2020a) and the application of new technologies in autonomous greenhouses (Heliospectra 2020b) served as a good source of knowledge. Furthermore, the extensive work done by Dr. Toyoki Kozai helped us uncover the complexities associated with indoor farming (Kozai et al. 2016) (Kozai 2018). This illustration is presented on the next page.

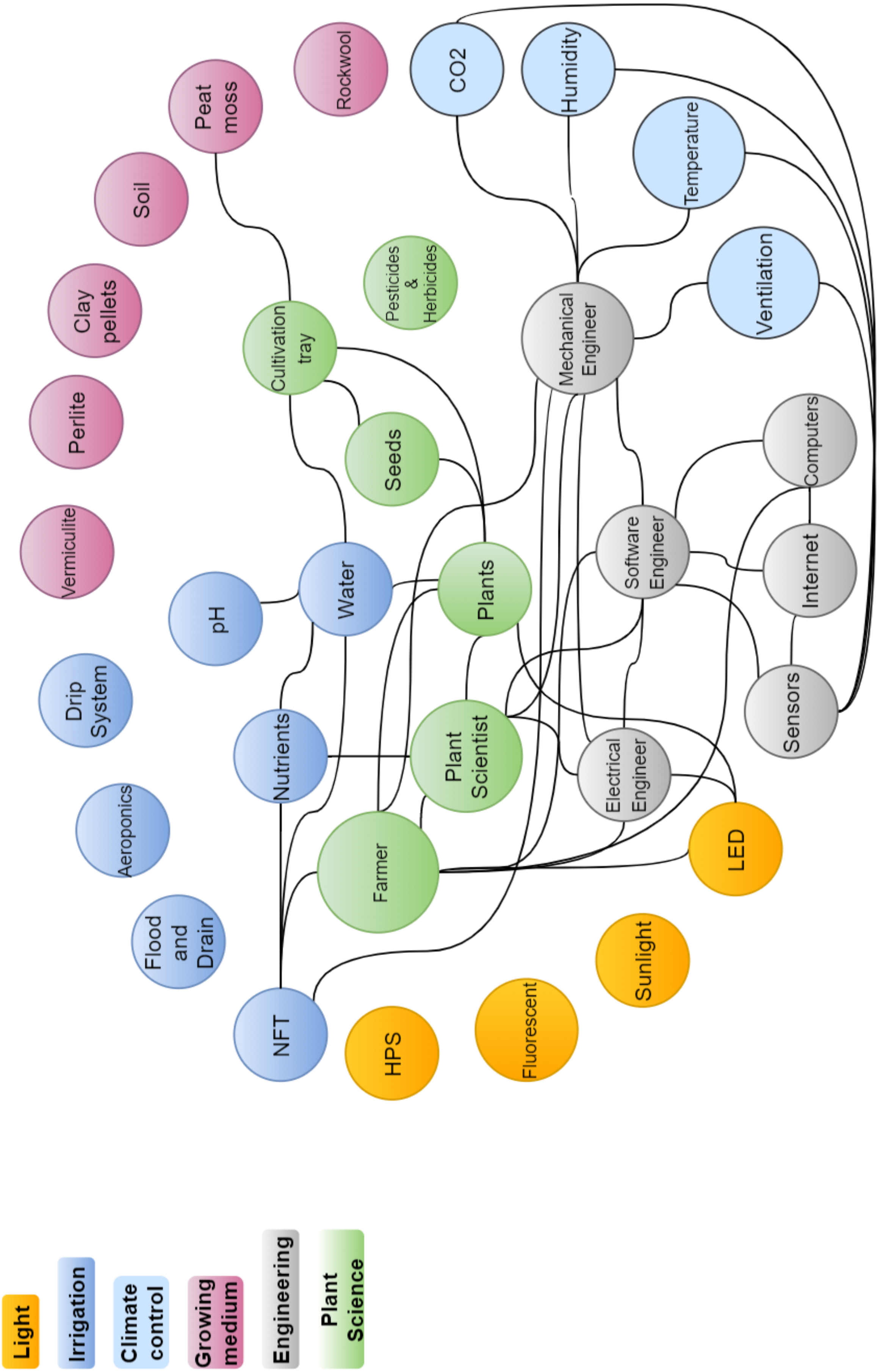

Figure 10 Network of Fully-Controlled Environment

In the network of a fully-controlled environment, we see that many new actors are connected. This is a result of the added complexity and needs for different types of expertise when it comes to controlling the environment. Some noticeable difference between the two illustrations is that in the fully-controlled environment, the sun is no longer connected to any actors. The use of LED light has replaced the need for natural sunlight and is now one of the key actors associated with plant growth. By replacing the sun as an actor in the network, we also see a shift in how other actors connect, mainly the use of a different type of growing medium than soil (we chose peat moss for this illustration), and a different type of irrigation system. The way these actors connect in the network enables the possibility of growing vertically. Regarding climate control, we see that the ventilation, temperature and humidity are also part of this network, but their connection to other actors is an indication of how this network differs from the previous illustration. In this network, all aspects of the indoor climate (including CO2) is controlled using HVAC technology and sensors for monitoring. By controlling the supply of air to the growing room, you drastically decrease the possibility of pests and pathogens spreading to the plants, causing disease and death. Therefore, the use of pesticides and herbicides are not needed, hence its missing connection to other actors in this network.

How the human actors are connected is also a representation of how the control of more environmental factors add new connections and more complexities. The farmer(s) is still associated with the growing and maintenance of the plants, and the plant scientists provide expertise on plant growth. However, in this network, the farmer(s) and plant scientists are also connected to mechanical, electrical, and software engineers. These connections make the use of artificial lights, climate control sensors, computers, and automation possible, as the different expertise associated with the different human actors are brought together in order to create an indoor vertical farm. How these human and non-human arrange and form a symmetrical network might differ from farm to farm. What is essential is that we understand how changing one element of the environment drastically changes how other actors connect to each other.

To summarize, we see that the two networks share some actors, but where CEA drastically shifts its actors and their connectivity is when the farmer(s) want to control the weather. On a final note, we also want to clarify that the problem with making networks using ANT is not knowing where to stop. We chose, for the sake of simplicity, to focus on the indoor climate of two types of CEA production. We chose to illustrate the concept on a micro level, but We are aware of the macro level, meaning that these types of network are part of a bigger network associated with food production (i.e. economics, logistics, marketing, sanitation, etc.).

5.2 The Implications of Expertise and Collaboration

Controlled environment agriculture (CEA), is, as we have already revealed, a field which requires a considerable amount of expertise in various areas.

Throughout the many interviews and webinars that we are using as sources for our qualitative data, it is noticeable that the participants are experts in different, yet intersecting fields. As an example, the webinar that has as its topic "Growing tomatoes in an autonomous greenhouse", the participants are a university researcher in greenhouse technologies, the head grower for the company Pure Harvest, and a research and development engineer. This already covers a wide range of professions, that have different requirements in terms of expertise but are all important in the process of building and operating a greenhouse.

One of the main topics of this webinar is the competition called "Wageningen University's Autonomous Greenhouse International Challenge", where six international teams of growers competed in growing tomatoes in the most optimal way. What is interesting in terms of the issue of expertise, is the fact that five out of the six teams were using modern, artificial intelligence algorithms, and one team was manually operating the greenhouse. Their performances were all analyzed and compared according to various factors, such as

"Usually a grower has to make all kinds of decisions. He has to adapt the climate computer and he has to put the settings what he wants over there, he has to decide - when do I want to use what and how much resources do I want to use for that. That is quite complicated, and therefore we would like to see if AI computer algorithms could help the grower to make these decisions. And in our challenge we go beyond that, we try to replace the grower as much as possible." (Heliospectra 2020B, min 8:40)

That points us to the fact that there exists a necessity in elements that potentially help a farmer optimize their work, or at least aid them in making better, more accurate decisions. This competition in itself was targeted at determining whether the expertise provided by engineers and researchers in the form of technologies that gather and analyze data makes a difference in the growth of plants in controlled environments. An interesting detail is the fact that, even though the technologies being used were the same, the data that was obtained from them were used differently by the teams, and yielded sometimes wildly different results.

The engineer present at the webinar, who was also part of the team that won the said competition, made an interesting mention in this regard. Referring to his team's failure to increase the temperature at the appropriate time, he said that *"...there we also learned that the limits are really subject also to a specific variety, specific location"* (Heliospectra 2020B, min 56:30). In this case, we observe that the expertise of the team in terms of farming, as well as the way they apply the data obtained from the sensors and analyzed by the AI, is sometimes considerably affected by the context of the growing activity, the location and the type of plant being grown. So there are other, non-human actors in this network that affect the way the expertise is being applied. This brings us to the idea that a multitude of actors has to be considered, from an ANT perspective, when estimating the levels of expertise and using them, especially in an interaction heavy process such as a competition.

One of the interesting mentions in this seminar is the example from the results of the competition that was brought to our attention by, again, Dr. Silke Femming:

"The growers doubled the stem density at some moment in time, and actually dutch growers would do that so that's not completely unusual, however, was it wise? well, you can see that they had a good production with that, but they lost on net profit because this is a very labor-intensive exercise (Heliospectra 2020B, min 57:20)".

This brings forth the revelation that the absence of the data provided by the sensors and the AI, therefore, the absence of the expertise of the researchers and engineers, has affected the results of the growers that were adhering to more traditional methods. They were deprived of an important piece of information, and, in the end, their results lacked as compared to the ones of the other growers, not necessarily because of a difference in the expertise itself, but more so because the expertise of the others was empowered by the data analysis of the AI.

Another webinar that we are analyzing is the one titled 'Ljusgårda, The Ultimate Vertical Growth: From 0 - 7000m2 in 3 years' hosted by, again, Heliospectra. In this webinar, the question about the strategies of automation of Ljusgårda is what generated a valuable insight for our research. The response is as follows:

"A lot of indoor farmers, they do the two extremes - they either go for no automation at all, except for plant automation, or they try to automate everything from the beginning, and when you do that, that costs money… because automation never works from the beginning, you need to get the learnings, you need to get it step by step. So, I should mention, we have a lot of expertise when I'm saying our approach here…" (Heliospectra 2020a, min 27:35).

This quote brings us to several realizations. First of all, the gaining of the expertise required to run an automated farm, for a traditional farmer, is a gradual process. This begs for other questions though: 'Why is it so?'. Is it because the technologies are not 'farmer-friendly' enough? Is the FB2F approach not used in the design of the technologies? We can only assume, but one thing that is sure is that gaining that expertise is a learning process and that it is best done step-by-step. Here, we arrive at the second realization, and that is that the step-by-step adoption of automation by the farmers is surprisingly similar to the Farmer Back to Farmer cycle that we have described previously. The farmers go through a similar cycle, where they purchase and study the technology developed by the engineers, try to implement it in their farms, go through a 'testing' phase, and the success or failure to use the technology is the feedback in the cycle. The cycle may repeat with another, more suitable technology at a later point, developed, again, by the engineers.

An interview that provided us with a new insight on the expertise required to operate a vertical farm, a fully controlled environment., is the one hosted by Agritecture, where the interviewee was Kiril Zelenski.

As he was presenting the farm to the audience, and taking a tour inside, Zelenski mentioned something curious that made us reconsider our perspective on the expertise:

"…I am (the) only one who is working here. I have also engineer who is helping with this equipment, but I don't even know how it working, sometimes he comes and checks if everything is working, but there are two web cameras and he's usually looking at it from home." (Zelenski 2020, min 3:45)

Not only that, but he also presented a software called iFarm, with a very intuitive interface, through which he can easily make orders of the plants he needs, see the growth phase of the plants and the situation in the vertical farm, the system telling him of any issues with the farm, when he can harvest, etc. (Zelenski 2020, min 4:30-5:50).

This data suggests that less expertise on the farmer's side is necessary in this kind of situation, and, taking into consideration that, as the previous interviewee stated that farmers go for fully automated farms right away have a high chance to fail. We can assume that the ease of use for this particular farmer is most likely not because of the fact that the environment is fully automated. One of the obvious reasons, hinted at by the interviewee as well, is the presence of an engineer that helps with the operation of the farm and supervises it. This means that the combination of these two fields of expertise can, in some cases, be sufficient to fully operate a farm. The software that the interview presented might also play a role, as he made it clear that it makes his activity and interaction with the farm a lot easier. Such software is most likely a result of feedback between the needs of the farmers and the solution given by the engineers, and if it is not, it should certainly be a thing to develop through the FB2F model.

This ties even more into the FB2F model in the context of the aim and vision of the iFarm project, that is, in Zelenski's words, to: *"make technology which could be used everywhere, even without any special kind of agricultural knowledge, and it started two years ago with lots of experiments…"* (Zelenski 2020, min 7:00). Zelenski calls the company a 'purely technology, software one' (Zelenski 2020). Zelenski also later states that he is working here for the farming side feedback: *"Farming… because I have to check how it works, and I have to check different crops, fertilizers, everything…"* (Zelenski 2020, min 8.20). In that sense, we can state that this project is one that is an FB2F process where engineers team up with farmers in order to develop software that can make growing plants as easy as possible.

A similar type of vertical farm, that is fully automated, has been presented in the interview by Agritecture with John Leslie from the Australian company Vertical Farm Systems. When talking about the farm, he mentioned that: *"This system has a level of automation that allows one person to operate it, with six hours out labor required in total per week…"*(Leslie 2020, min 2:33). We observe a common trend throughout these interviews, where the more a system is automated, the less human interference is required, in terms of labor. It is a detail that most would consider self-evident, in terms of the concept of 'automation' itself, but we think it is important to mention it, as it has implications not only on the 'labor' aspect.

We observed the fact that in farms such as the ones presented so far, where the level of automation is very high, there are systems in place, such as sensors and AI that analyze and process the data and offer valuable insight and suggestions to the farmers working with them. In this context, there is a tradeoff of less expertise required from the farmers in terms of traditional farming knowledge, in exchange for more expertise in terms of working with the technologies in place and understanding their specific feedback.

From the interview with Kiril Zelenski, we have uncovered that the software iFarm works with has been built and is being tested based on farmer's feedback. This is a classic FB2F model. We observe here that the results of the farmers providing their knowledge, over time, in a FB2B model, in order for the engineers to develop working, useful technologies, reduces the need for high traditional farming expertise for a farmer working with these technologies. The knowledge and expertise are, therefore, inscribed, transferred into the technology through the FB2F model, at least in the case of highly automated systems, as we can see from the three webinars/interviews that we have quoted in this section. Over time, more and more technologies that are accepted by the farmers are ones which carry their knowledge and expertise, and that might point to a trend where, because less and less farmer expertise is required in operating the automated farms, the role of the farmer, or the notion of 'farmer' itself, is rewritten. The knowledge transfer between the farmer and the engineer gives birth to a new reality, where what we know as a 'farmer', and the conditions that one must fulfill in order to be a farmer, are very different from what they used to be until recently. We will touch more upon the topic of new realities in the following discussion part.

6. Discussion

6.1 Reflection on our findings and their implications

6.1.1. The networks and how they tie up into their own realities

In the analysis section, we have uncovered two different networks - one for semi-controlled farming and the other for fully-controlled farming - both built in an ANT fashion. We have done that in order to picture the materials that make up these networks and their interactions. Visualizing these networks has enabled us to uncover several interesting findings in connection to CEA.

The first curious aspect of these networks, when we perform a comparison, is the fact that they are quite similar in terms of components, with some structures and links even intact from one network to another. The absence of some actors, and the presence of others, between these two networks, generate quite a considerable difference, with crucial changes in the interaction between the human and non-human actors, and even human to human interactions.

Following the observation of the networks, as well as the analysis of the interviews, we have noticed that, in a network, materials/actors can and often are generated by other materials/actors, and that in turn changes the network itself, with the risk of transforming it into an entirely new reality. Such is the case of traditional farming, where the appearance of technologies that can control certain factors that influence the outcome of the activity of the network made it so that the practice itself changed, and with it, the network. So, it turned into semi-controlled farming, and then, in the end, into controlled farming. Not only that, but the actors that are similar across the networks have quite different interactions with the network itself now, and with the other actors that comprise it. For example, the interaction between farmer and mechanical engineer in the case of a semi-controlled farm, versus a fully controlled one, is one of increased reliance in the latter case and a reduced one in the former, and we can see that from the interview with Kiril Zelenski, where he mentions how important is the engineer's help in the maintenance of the farm. Some actors may be a part of the network, but not have an influence on it any longer, such as the 'sunlight'.

Referring to the Gad et al. (2015) view on the Amerindian Araweté study, that we have referenced previously in our theory section, actors can have wildly different views on the same elements of the network, just how animals can see blood as manioc beer. Similarly, human actors in these networks, such as the farmer and the engineer, can have very different views on actors such as the ‘plants’, or a piece of technology. That in itself can govern their interactions in ways which would yield very different results. The example from the competition at Wageningen University, where the growers that did not use AI technology doubled the density of the stem and ended up with a net loss, versus the growers who used AI technology, can show us the perspective of two actors on the plants - the farmers and the AI.

6.1.2 The role of the farmer and how it’s changing from network to network

Our analysis showed us that the role of the farmer is changing, and what used to be associated with the word ‘farmer’, is now very different across the different fields in which they operate, and is highly dependent on the level of automation of the farm itself.

Knowledge is crucial in a network. It fuels interactions that might not have been possible otherwise and generates dependencies that would otherwise not exist. We can observe this in the interaction between the engineers and the farmers. The knowledge that each of these groups possesses makes them indispensable in the field of CEA and is also what makes the interaction happen, and, more so, even required.

It is clear, from the analysis so far, how vastly different the work of the farmer becomes with the presence of technologies. The less automated the farm is, the more ‘adaptation’ from the farmer himself is required in order to successfully grow plants. Factors such as weather, sunlight, sources of water, the concentration of CO_2 in the air, are only some of the ones that a farmer has to adapt to. The technologies in a fully automated farm enable the farmer to be the one who controls these factors. One would say that this aspect drastically changes the role of a farmer, as it changes the essence of his interaction with several materials that are part of a ‘farming’ network.

From the recent developments in the field of farming, and in the context of the texts, interviews, and webinars that we have used as data, it is apparent that the role of the farmer is morphing into something very different from what it used to be. It might just be that in the future, the concept of ‘farmer’ as we know it will not exist, or will mean something completely different, transforming into a different name for, perhaps, an engineer. The amount of technologies that have to be operated in a modern, fully controlled farm, and the possibilities of the AI and the software, as we have noticed from the interviews with iFarm and Vertical Farm Systems, are such that more labor that would be classified as engineering maintenance is required to operate such a farm.

6.1.3 How the work between farmer and engineer is changing the reality

The interaction between farmers and engineers is one that we have analyzed in several instances throughout our paper. We have especially paid attention to how this interaction generates new materials and actors in an ANT inspired network, and have hypothesized how a FB2F approach shapes these exchanges.

In our analysis section, we have arrived at an unexpected idea: technologies, and specifically the ones that are designed in order to automate a farm, might be going through a similar cycle to the FB2F one, in the process of being adopted by farmers. If we view the technology as the input of the engineers to the farmers, it goes through similar phases such as testing, assessment, acceptance/rejection. This might be the peculiar effect of the network, in which the interaction of two actors generates a third actor - the technology, that interacts with both in a scripted way.

It is valuable to note that the views and actions of both of the actors that are the engineer and the farmer can be considerably influenced by other, non-human actors that they interact with on a daily basis. In the farmer’s case - the plants, and in the engineer’s case the technology. This points to Myers’s (2015) quote on the fact that the sensoria of practitioners working with plants might become ‘vegetalized’ over time and that might affect the way they view plants and think about them. The same goes for the engineers that have more exposure to work with technologies rather than anything else. In this regard, although they live in the same ‘reality’, the same ‘network’, their perceptions are shaped by specific elements of that network to such a degree that they might view the reality entirely through that lens, and thus, see a different reality from one another. This might explain, in part, why there is such a strong need for interaction between the two when building new technology, putting aside the need for expertise-sharing.

From the previous paragraphs, we can clearly see that technology plays a major role in shaping the reality of CEA. If we look at technology from an ANT perspective and observe how it affects a network, we can observe that it not only replaces interactions in the network but, as it joins an already existing network, it removes some of the other actors altogether. In the case of fully automated farming, the technology removed otherwise important factors in traditional farming, such as sunlight, weather, etc. After this depiction, it only makes perfect sense that the development of a technology must include the main actors in a network, so as to mitigate the considerable changes that a technology is capable of and make the disappearance of specific interactions or materials a smoother process.

6.1.4 How expertise is important in navigating a network

The human actors in the CEA networks are basing many of their interactions on the expertise that they have in their specific fields, and applicable to CEA specifically. They generate interaction and change through the use of this expertise.

An aspect of technology that we have covered in our analysis is that expertise can be inscribed, translated into the technology. This collaboration is something that has a very peculiar nature if looked at through the ANT networks that we have represented in our paper: the two human actors join forces in order to gain more control over the non-human actors. This is quite evident when comparing the semi-controlled farming network and the fully controlled farming one, as the replacement of several actors with technology is quite evident. Not only that, but also, while in the semi-controlled there are actors such as sunlight or soil, that compelled the farmer to adapt to their changes, in the fully-controlled farms these factors are removed or replaced with technology that is completely under the control of the farmer/engineer. Therefore, the expertise not only helps navigate the network, but also helps take control of it and change it in a way that keeps it convergent and stable.

Expertise can also be a factor for actors staying in a network or leaving it in order to join another, more suitable one. An easy example in the context of our research would be a farmer that would be overwhelmed by the many technologies that have to be controlled in a fully-automated farm, and opt for joining the network of a semi-automated, or even traditional farm. We are referring here to the quote in the Heliospectra 2020a interview, where it is mentioned that usually farmers either opt for full automation or no automation at all, and fail, whereas the correct approach would be to implement technologies step-by-step, so as to have a steady learning process.

The need for expertise is, though, not always the case with newcomers. According to the Agritecture and outgrow Global CEA Census (2019), in terms of a farmer's experience, "41 percent of the respondents had no experience in agriculture prior to starting their current CEA operation" (Agritecture 2019, p. 14).

Because of the fact that engineers and farmers work together in CEA, and often develop new technologies for the field in cooperation, the roles become blurred. Farmers have to incorporate some engineering knowledge into their arsenal in order to be able to operate CEA technologies, and engineers have to assimilate and understand farming expertise in order to be able to design functional, applicable technologies for CEA.

6.2 The problems associated with indoor and vertical farming

To further elaborate on our findings in the analysis section of the report and put them into a broader context, we will combine our findings with research done on CEAs role in today's food system. As described, we find that the phenomena of indoor and vertical farming rely heavily on the intersecting of the practices associated with farming, plant science, and engineering. By utilizing the strengths of these practices, it is now possible to grow food year-round independently of the weather. This is quite the achievement and should call for celebration, however, the concept of CEA still faces some significant challenges. According to Kozai, the most common resistance indoor and vertical farming encounters are that:

1. Its business would not be economically viable due to the high initial and operation costs.
2. It would not be commercially viable unless it is operated on a large scale or it produces extremely high-value crops such as medicinal plants.

3. It is not environmentally sustainable because it uses a large amount of electric energy instead of free solar light energy.
4. It is unnatural to grow plants in indoor farms, so that indoor-grown vegetables would neither be tasty nor nutritious.

(Kozai 2018, p. 433)

These four challenges are a good representation of what resistance needs to be overcome in order for this concept to become a widespread phenomenon around the world. We see the resistance as being attributed to the *economics of operation, types of plants produced, energy consumption,* and *people's perception of food.* In their 2019 consensus, Agritecture surveyed 316 companies in the CEA industry around the world on the challenges and opportunities of the industry (Agritecture 2019). Similar to Kozai, this consensus also showed that there needs to be better education of consumers and governments in order for people to understand the nutritional value of CEA crops and its vital role in our existing food chain. As our illustration of the two different networks shows, the concept of indoor and vertical farming provides the nutrients required for optimal plant growth, meaning that the plants contain the same nutritional values as plants produced in conventional agriculture. In the webinar with Ljusgårda, it was even highlighted that due to the location of the farm and the way they operate, their produce is more fresh than the other produce in the supermarket due to their close proximity to the consumers (Heliospectra 2020a, min 25:10). Furthermore, our network of the fully-controlled environment also showed that the need for pesticides and herbicides was eliminated, meaning the produce does not have to be washed, which is the case with conventional agriculture and most of the greenhouse farm operation.

The electricity consumption of indoor and vertical farming operations is still the main economic barrier that needs to be overcome for this concept to be more environmentally friendly and economically viable. However, the industry had evolved a lot over the past decade alone, and as we learned from our empirical data, LED lights are still rapidly improving their energy efficiency (Appendix II, p. 11) and the application of computer algorithms has the potential to significantly improve operational procedures of growing plants (Heliospectra 2020b).

The consensus also listed lack of funding as a challenge for the industry, and that there needs to be more governmental support as with conventional agriculture. Like our findings, the consensus also showed that the lack of available data, knowledge sharing, and technological expertise on how to do CEA is seen as a challenge that needs to be tackled in order for the industry to grow. The lack of general knowledge, scientific research and technological standards are some of the key risks associated with developing a vertical farm. In the Agritecture interview with Francis Baumont de Oliveria on the risk of vertical farming, he points out that:

''there are so many different (technological) solutions out there, and we are not really sure what works and doesn't work. What the specifications are, what the yield projections are, and that causes a decision fatigue for entrepreneurs… The technology still hasn't been validated yet and there are no standards'' (Baumont de Oliveria 2020, min 12:40).

This lack of standards is problematic, as it makes the process of obtaining the correct knowledge and expertise needed to do this type CEA more difficult, and it limits the possibility of incorporating the knowledge into schools and higher education. As Baumont de Oliveria also states that the industry in its current state is in: *''... a pre-competitive stage*, and people are quite cautious to share their knowledge, because they are worried that people would get an unfair advantage, and they would miss out'' (Baumont de Oliveria 2020, min 17). This further contributes to the lack of knowledge sharing, and it begs the questions of whether the CEA industry will remain a niche or become more widespread around the world.

7. Conclusion

The past decade of development within CEA has created new possibilities for indoor production of plants. The technological advancements of LEDs as a means of artificial lighting has made the concept of growing plants vertically a reality, and we are now starting to see the benefits and potentials of growing food in fully-controlled environments. This has led the CEA industry to grow bigger roots around the world and today multiple farming operations are designing indoor farming environments, and applying new technologies in unique ways. With the integration of sensors, software and automations, the CEA industry is changing how the farmers, engineers and plants are tied together. This brings new possibilities, but also challenges when it comes to expertise.

We have analysed the role of expertise in the context of controlled environment agriculture and have arrived at several conclusions. We have determined that the difference in expertise creates a need for collaboration between actors in CEA networks, such as engineers and farmers. As such, approaches such as the Farmer-Back-to-Farmer model become increasingly relevant, and crucial to follow. Collaboration makes it possible to create technology that is usable for the farmers and fits into the context of the CEA network with less tension between links and other actors.

Expertise can be inscribed/ translated into a technology if a FB2F model is followed, creating technologies such as AI software that analyses data from sensors and provides data and suggestions on how to operate the semi- or fully-controlled farm. This kind of technology can provide insight which is hard to obtain through traditional methods of farming, and takes away the burden of high expertise from the farmer, by aiding him in decision making.

Expertise can become less relevant with increased levels of automation, especially on the farmer’s side. A large amount of CEA companies were started by people that had no prior experience in the field of farming, which points, perhaps, to the fact that the role of the farmer in CEA has already changed, given the fact that expertise is no longer a requirement at least at the entrance level.

We have concluded that technology has a considerable influence on the relations between farmer, engineer, farm and the technology itself.

The presence of technology, and specifically heavy automation of a farming environment enables the farmer to have more control over the different elements that influence the process of growing plants. On the contrary, less automation leaves the farmer the need to adapt to elements that he could otherwise control. In this sense, the relation between farmer, engineer and farm is heavily impacted by technology.

In the same frame of thought, farmers and engineers can reframe the relations and interactions that exist in the CEA networks, with the help of technology. We have determined that, with the use of technology, elements of the semi-controlled farming network can be removed completely, just to make space for the technologies that replace them. In this sense, links and interactions that were previously part of the reality of semi-controlled farming, are altered and make space for a new reality, that is controlled by the human actors of the network, namely the engineers and the farmers.

One other aspect of the changing relations between farmers and engineers is the fact that both of their roles become more blurred with the advancement of automation and new technologies. Farmers require more knowledge in terms of the operation of the new technologies, and engineers require more farming knowledge in order to develop relevant and applicable technologies. Therefore, their relation becomes one of necessary collaboration, and the failure to do so can result in the failure to deliver good results in their activity.

Finally we conclude that controlled environment agriculture also faces significant challenges when it comes to building and operating a farm of this concept. The uncertainties regarding effectiveness and useability of the various technologies, a lack of international standards and knowledge sharing is an increasing problem for people operating within this industry. Furthermore, the increased use of technologies also requires more expertise and knowledge on how to operate these technologies. This requires extensive training and education of future practitioners and we therefore encourage more interdisciplinary collaboration between current professionals, industry leaders, research institutions and governmental bodies. This will help ensure that the challenges associated with high energy consumption and plants viable for production in controlled environments are overcome.

8. Reflections and future considerations

Our research lacks in terms of qualitative research methods such as, for example, participant-observation. This has reduced our ability to enter the field and analyze it from close proximity, and might have resulted in less of an understanding of the context of the data that we have analyzed.

We have not performed many interviews of our own and have made extensive use of secondary data. This has impacted our analysis in terms of a more complicated path towards answering our research questions.

One of the main strengths of our research is the fact that we have based it on an extensive amount of literature in the field of CEA. This has given us a very deep understanding of the technological and scientific workings of the field and has allowed us to compensate for the lack of empirical data.

We have also laid down a very detailed description of the field of CEA, and put it into the context of its challenges and advancements, and that will potentially give the average reader a considerably better understanding of the topic.

We have considered, for the future, to examine the possibilities of the concept of open-source in CEA. We see it as a potential solution to the issues that the field is facing at the moment, and consider it one of the main analysis points for a future continuation of this work.

Another line of research that would be interesting to touch upon is the possibility of action-research in the field and the observation of how such an approach can affect CEA on a local level and on a larger scale.

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