A Utopian Vision for Metabolic Cities: The Future of Farmscraping in New York City

by

Sara Bajelan

Submitted in partial fulfilment of the requirements
for the degree of Master of Architecture

at

Dalhousie University
Halifax, Nova Scotia
June 2022

Dalhousie University is located in Mi’kmaq’i,
the ancestral and unceded territory of the Mi’kmaq.
We are all Treaty people.

Contents

Abstract

This thesis turns to radical architecture for drawing visionary solutions to future problems. An issue that faces cities in the not-so-distant future is access to food. Compared to other industries, farming lags in technological advancement, making current farming practices unable to keep up with the demands of a growing population. As urbanization increases, arable land becomes scarce; therefore, the thesis argues for vertical farming in skyscrapers to make room for agriculture within cities. For cities to sustain the demands of their growing population, they must develop an urban farming system capable of expansion, making Metabolism an appropriate framework for designing this flexible system. New York City acts as the prototype for future cities; being the densest American metropolitan area, the issue of feeding its growing population is a dilemma the city is currently facing. Therefore, the farmscraper typology offers a potential solution for feeding the city.

Acknowledgements

I want to thank my thesis supervisor, Susan Fitzgerald; I genuinely appreciate the valuable insight, guidance and support you have given me.

I would also like to thank my advisor, James Forren, for taking time from his sabbatical to be on my thesis committee. Thank you for all you have taught me.

To my parents, thank you for providing me with the support I needed to succeed.

To my friends, for the unforgettable memories we shared during our time together, thank you for being there for me.

Chapter 1: Introduction

Food Sovereignty

This thesis explores food sovereignty, an issue predominantly affecting high-density cities that cannot dedicate space to agriculture. While this issue affects nearly every city worldwide, the scope of the thesis is limited to the United States. The state of California dominates the agricultural industry across the country, as every city relies on this one region to supply and distribute its food. If the food flow network connecting California to the rest of the country is disrupted, cities would be in trouble, especially New York City, the farthest distance from the food hub of America. NYC relies exclusively on its food being imported from California and dedicates virtually no space to agriculture; therefore, this thesis uses NYC as the site for testing approaches to growing food within cities. Food movement across the city happens exclusively along bridges and tunnels; furthermore, the city relies on just-in-time inventories as its food distributors only stockpile a couple of days' worth of food. The city hardly has enough space for its residents, let alone for food production and storage; therefore, the infrastructure of food distribution in NYC requires an upheaval to make it more resilient and less dependent on the West coast for its food supply.

Metabolic Farmscarping: Future or Fantasy?

Metabolism offers an architectural solution for accommodating future growth within a city; the human population is growing at unprecedented rates. By 2050, the population will increase by three billion; increased urbanization decreases arable land. Current farming practices cannot keep up with the demands of the future population, meaning the farming industry requires new technologies to develop food production methods to sustain the future of humanity. Humankind's survival has always depended on its ability to invent agricultural technologies to support the diets of its populations. Despite being the last surviving hominid species on Earth, humankind continues to develop technologies to ensure its survival; in the future, this new technology is the vertical farm. The godfather of vertical farming, Dr. Dickson Despommier, defines this invention as indoor farming integrated into the vertically stacked surfaces yielding more food than traditional outdoor agriculture. This thesis investigates integrating the vertical farm into the skyscraper, creating a new typology: the farmscraper. In order to ensure the farmscraper is capable of meeting the demands of a growing population, the thesis takes the building typology a step further by applying principles of Metabolism to design the metabolic farmscraper—this ensures farming in the city functions as an interconnected system capable of expansion and growth.

Feeding New York City

Currently, New York is the densest American metropolitan area in the United States and is already facing this food dilemma; therefore, it serves as the archetype for future cities.

Thesis Question

How can Metabolism be applied to designing a vertical farm integrated into the New York City skyscraper typology to make food growing part of everyday life?

Chapter 2: From Bone to Satellite: The Importance of Technology in the Evolution of American Agriculture

Food Sovereignty as a Strategy for Achieving Food Distribution Resiliency in American Cities

More than one billion people go hungry each night, and with another three billion more people joining them over the next thirty years, the issue of food security becomes an even more pressing issue as time goes on. While increasing food production is essential to addressing this lack of food, one must examine food distribution throughout the United States. The complexity of these supply chains highlights the importance of American cities being able to produce their food and becoming independent of other states and, at times, different countries for their food supplies. However, this paper will limit the scope of its analysis of American food distribution to the national scale. This section highlights that food flows through many different modes of transportation, sometimes travelling thousands of miles before reaching the plates of American households. Cities in states that dedicate virtually no land to agriculture are particularly precarious. Any disruption to the American food supply chain would be disastrous since these cities only have limited food supply storage at any given time, relying heavily on continuous deliveries.

National Food Distribution: The United States

As mentioned earlier in this paper, most existing research on food security focuses exclusively on methods of

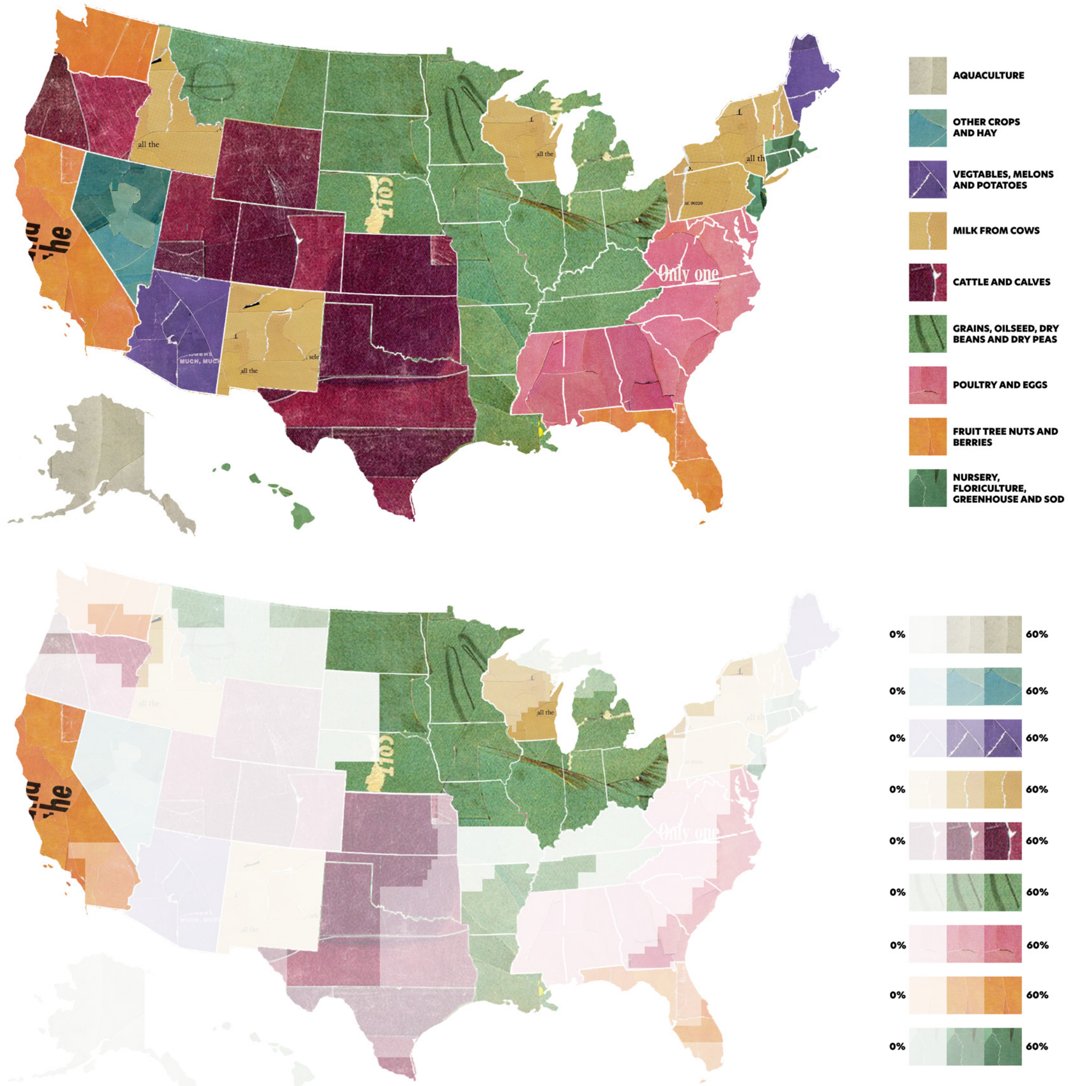

Figure 1: Agricultural landscape of the United States (data from Rankin 2007), (data from Amoros 2019)

increasing food production. However, as outlined in *Food Flows between Counties in the United States*, researchers aimed to investigate the issue of food security from another lens, specifically by analyzing the food supply chains of the United States (Lin et al. 2019, 1). In addition, their research sought to spatialize data on these supply chains, otherwise referred to as food flows, as this paper focuses exclusively on the national food trade within the United States, not its relationship to the global food trade. Nevertheless, the

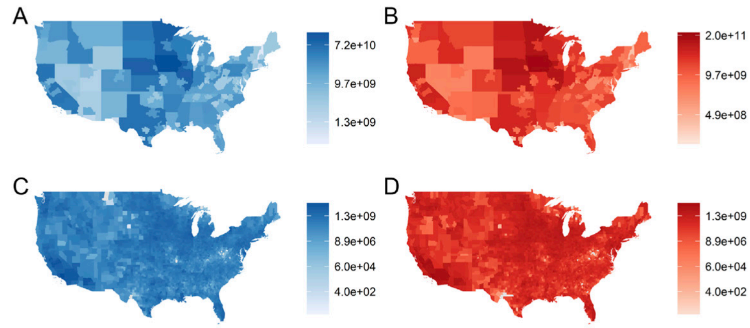

Figure 2: Mass of national food inflows (A), national food outflows (B), regional food inflows (C) and regional food outflows (D) in the United States (Lin et al. 2019, 10)

United States is a crucial contributor to the worldwide food system in the global economy. For example, the country contributes to global grain supplies; over thirty percent of corn and over fifty percent of soybeans are grown in the US. In addition, the US contributes to the world export market for these food staples: sixty percent for corn, forty percent for soybeans, twenty-five percent for wheat and seventy percent for sorghum (Lin et al. 2019, 1). For grains to be one of the country's main exports comes as no surprise; the maps in Figure 1 illustrate that the Midwestern United States dedicates the most land to agriculture, with the primary agricultural commodity being grains, oilseed, and dry beans and dry peas. The US can maintain its position as a global trade power in the farming industry due to its supporting transportation infrastructure, otherwise referred to as the Freight Analysis Framework (FAF). The FAF spatializes the data provided by the US Census Bureau and Bureau of Transportation Statistics that quantifies the movement of food commodities by factoring in the value, weight, mode of transportation, origin and destination of manufacturers, mining, wholesale and retail establishments. The research identified 132 FAF zones across the country, and estimated food flows between the 3142 counties within the US (Lin et al. 2019, 2-3). The research examines food inflow and outflows at two scales: the national scale, which investigates food flows between states, and the regional scale, which reads food flows between counties.

Figure 2 illustrates food inflow and outflows highlighting that California and the Midwestern United States are regions of significant outflow locations. Counties within these FAF areas also have high food outflows and inflows (Lin et al. 2019, 9). These two regions of the country being dominant traders in the agriculture industry makes sense when referring to Figure 1. Along with the Midwestern United States, California dedicates more than sixty percent of its land to farming. Despite the considerable size difference between these two parts of the United States, California is an even more critical player in the food supply chain. The map in Figure 3 further reinforces the significance of California's counties in the production and distribution of agricultural commodities. It illustrates the spatial food flows at both the FAF and county scales. The map indicates that the most prominent link in the food flow network is the self-loop of food transfer from Los Angeles to Los Angeles. This massive inflow and outflow of food in Los Angeles come as no surprise since cities are essential for food flow. Food flows occur each time a commodity is transformed from one product into another. For example, cornmeal transformed into biscuits. Cities are essential for manufacturing crops into food commodities (Lin et al. 2019, 9-12).

The research reveals that the counties at the heart of the food manufacturing industry in the United States are predominantly located in California. These nodes in the food flow map are the most interconnected to the rest of the

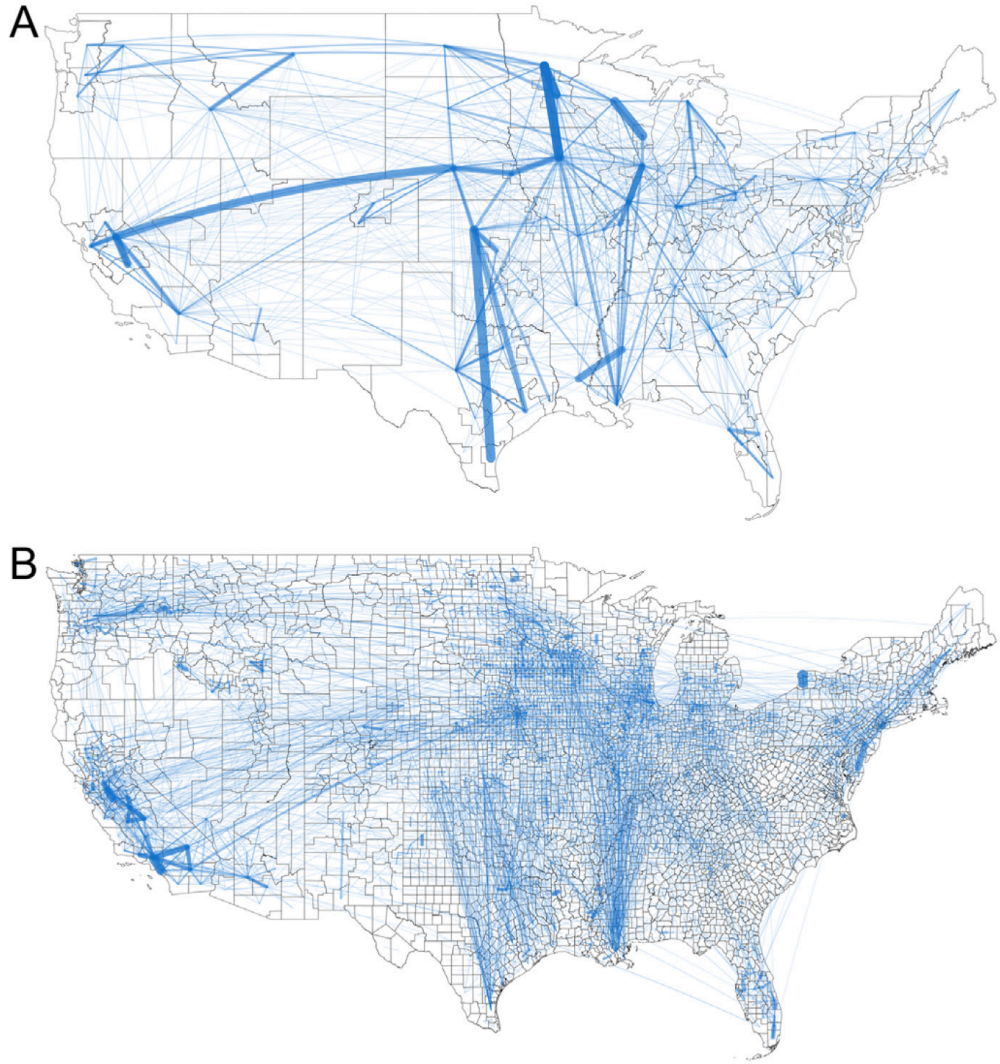

Figure 3: United States food flow network at national scale (A) and regional scale (B) (Lin et al. 2019, 11)

food supply network, making them integral to the production and distribution of food across the country. If there is a disturbance to food manufacturing in these counties, the effects would be disastrous for food distributors across the United States. The following section turns to the East Coast, a region of the United States that is particularly vulnerable in its food resiliency.

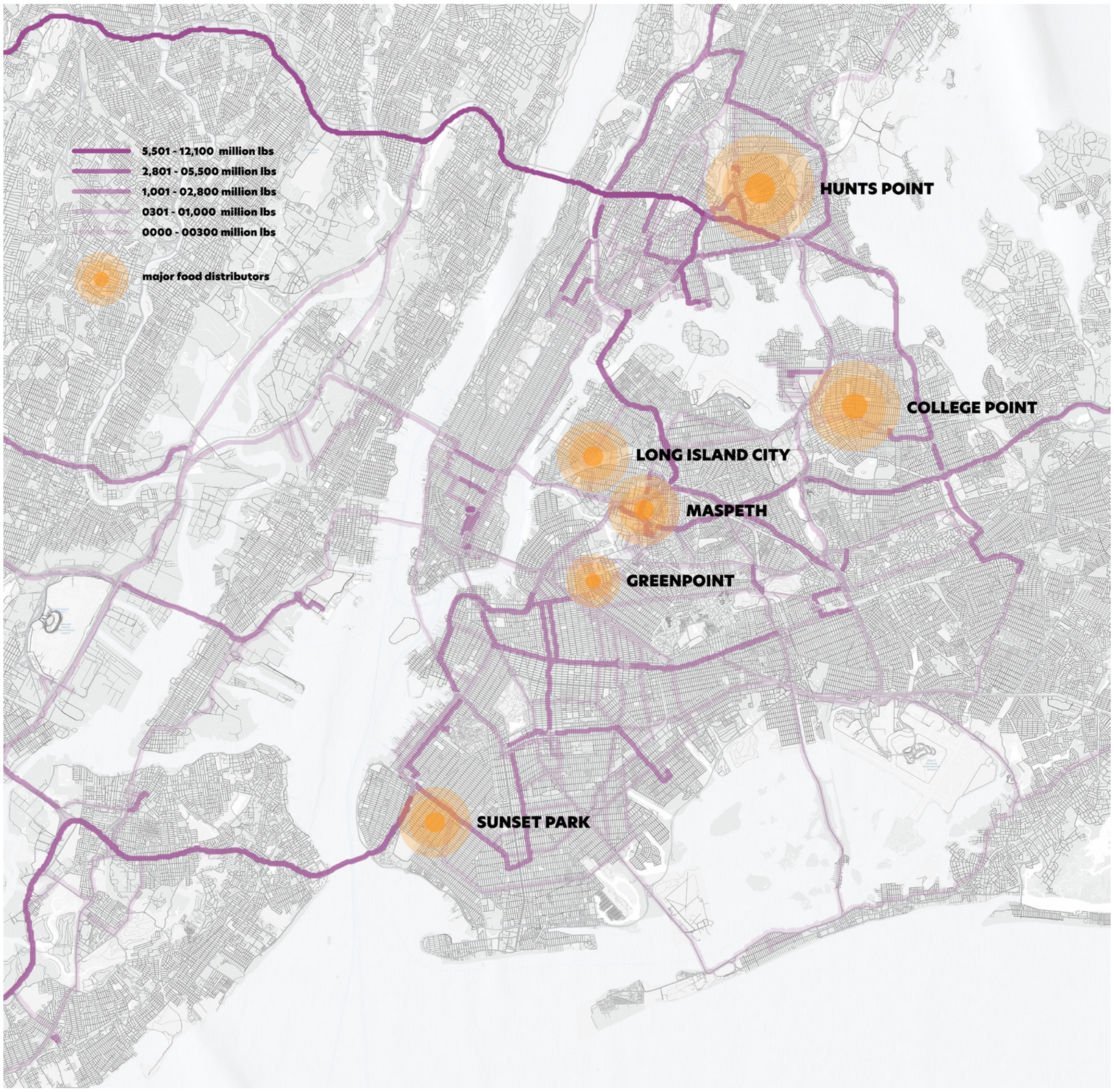

Figure 4: Food flow network of New York City (base map from Cheng n.d.)

Regional Food Distribution: New York City

New York City is one city entirely dependent on its food being supplied from California. The map in Figure 1 indicates that the state of New York dedicates nearly no land to agriculture. The lack of food manufacturing in this region comes as no surprise regarding the city's population density affords virtually no space for traditional horizontal farming.

Therefore, the thesis turns to New York, particularly at risk since most of its food is imported from California.

On an annual basis, approximately 19 billion pounds of food is transported into NYC and is distributed to 42,000 retailers, everything from bodegas to franchise supermarkets. NYC's food distribution system relies on bridges and tunnels to reach its consumers. A combination of four major bridges and two tunnels carries over 50% of the city's total food volume (Figure 4). It is estimated that the last mile of food delivery occurs almost entirely by truck, which is an issue considering the city cannot reduce traffic congestion, improve roadway safety and protect state bridges and tunnels from disruptions. Not only is this method of food transportation inefficient due to unpredictable delays, but it also contributes to the carbon emissions released by vehicular traffic. If food growing became a local industry in NYC, it would shorten the distance food travels and ultimately reduce air pollution and greenhouse gas emissions. It would also reduce the costs associated with transportation; this is possible by concentrating on farming practices within the city and investing in regional transportation infrastructures to facilitate the movement of food across the city. NYC's food is stockpiled in only six food distribution centres: Hunts Point, College Point, Long Island City, Maspeth, Greenpoint and Sunset Park (Cohen, Wiskerke and Verhoeven 2018, 60). However, the six major food distributors only stockpile 4-5 days' worth of food and rely heavily on just-in-time inventories (City of New York 2016).

For a city like NYC, which hardly has enough space for its people, it is no surprise that the city's food distributors have limited space for stockpiling food supplies. However, this poses a real threat to the city in the event of disrupting the national food flow network. NYC is currently facing a problem that all future cities will need to address; feeding a growing population with no space for traditional horizontal farming. This thesis proposes that farming within cities is the solution to becoming food resilient. It requires innovation in agriculture, one that would be achieved through vertical farming integrated into the skyscraper building typology: the farmscraper.

History of Farming

Technology has played a significant role in the evolution of humankind; the most important innovations have emerged as a response to meeting the demands of food production. However, while agricultural technologies have propelled humanity forward, it has come at the cost of tremendous ecological damage, at times posing the threat of extinction. The human population is growing at unprecedented rates; unfortunately, current farming practices fail to meet the increasing food production demands. Once again, humankind must turn to technological innovation to ensure the survival of its species; this time, the new invention is the farmscraper.

Prehistoric Farming Practices

The opening scene of *2001: A Space Odyssey* (1968) begins with humanity's earliest ancestors, the ape, rising on its hind legs, demonstrating the first step in human evolution, and upon wielding a bone, it strikes a competing hominid species (Kubrick 1968). The scene illustrates the tool critical to humankind's survival: the bone. According to physical anthropologists, evolution favoured herbivore hominids as the high protein diet enabled them to develop a larger brain rapidly. In addition, their opposable thumbs allowed them to acquire dexterity, inventing and manufacturing tools they wielded as weapons. Ironically, the bone as a weapon is not what ensures humankind's survival; by making hand-held devices, early humans were able to break open the long bones of abandoned animal carcasses. The nutrient-rich bone marrow supplemented them with enough energy and protein to supplement the diet of the local edible fruit, nuts, and grains. This transition to an omnivorous diet is evident in later human evolution during the existence of the last competing hominid species, the Neanderthals. They were not farmers; instead, they migrated with the animals as the Central European and Eastern Asian climates did not favour the cultivation of an agrarian society. They collected wild grains and edible plants to sustain themselves when game animals were short in supply. At some point during their migration, after accidentally dispersing seeds onto nearby fields next to a water source, it "clicked" that there was an alternative, more sustainable option for cultivating food. Farming did not gain traction in early civilization until humans adopted settlements as they recognized the social advantages associated with this lifestyle. They began producing crops that could feed their people all year round (Despommier 2010, 39-48).

Farming practices worldwide indicate that agriculture shaped much of human civilization, from calendars, astronomy, mathematics, written language and religion. However, as humanity began to transform every corner of the Earth into landscapes dedicated to food production, the ecologies on this planet also began to suffer irreversible damage. To compensate for destroying the natural systems that sustained humankind's ancestors, civilizations across the globe started developing technological innovations to maintain a food production that would keep up with its relentless population growth.

In the Fertile Crescent of modern Iraq, some seven to eight thousand years ago, the process of artificial selection was in its earliest practice. This desert region managed to grow wild grains and cereals along the floodplains of the Tigris and Euphrates rivers. Farmers would select the seeds of the largest and most nutritious grains to plant next year's crops. However, without awareness of conserving the soil, the land became increasingly depleted of valuable nutrients each year. This agricultural dilemma gave rise to religions centred around worshipping gods who dictated the weather and crops' success. Over time, the prolonged droughts and nutrient-deficient floodplains made agriculture near impossible in this region.

Alternatively, the Nile sustained Egyptian civilization for millennia due to the river's periodic flooding that replenishes its banks with nutrient-rich silt. The Egyptians keen observation of nature made them recognize the importance of using animal waste as a fertilizer; the god Khepri is named after the scarab beetle, an insect impregnating the soil with animal droppings and enriching the nutrient content of the land. The Egyptians worshiped the god Ra, named after the Sun, emphasizing their ability to identify the essential components in nature required to sustain life. They invented an irrigation system that transported water from the Nile to inland regions allowing them to expand their farming practices.

Around eight thousand seven hundred years ago, farmers cultivated maize, Mexico's parent grain for modern corn. Corn is a staple in the diets of many New World cultures, considering more than fifty percent of food products consist of maize, such as beer. Over in Peru, the Nazca and Inca cultures invented innovative irrigation systems to combat the challenges of living in the aridest environments. The Nazca developed a language of abstract figures solely to mark the geographic location of their water for irrigation. Despite living in isolated mountainous regions, the Incas constructed a high-altitude water irrigation system to grow a wide variety of plants: potatoes ground into powder to make breadlike food, tomatoes, peppers, avocados, fruits, nuts and chocolate (Despommier 2010, 49-58).

Modern Farming Practices

In the twenty-first century, the origins of current agricultural practices are an amalgamation of four critical historical events: the American Civil War, the discovery of oil, the design of the incombustible engine and the invention of dynamite (Despommier 2010, 79).

The American Civil War took place on April 12, 1861, and ended on April 9, 1865, claiming nearly four million lives. The Civil War was a fight over the country's cotton industry, the South's leading agricultural product. New England textile and clothing manufacturers wanted unlimited access to gin-milled cotton; meanwhile, the Southern cotton growers had the highest price for their product. As a result, the South sold their cotton production to Europe at substantially higher prices than the North was willing to pay. In addition, southern plantation owners could earn outrageous profits from their cotton harvest since labour was incredibly cheap. Their primary labour force consisted of enslaved people brought from West Africa; opposing slavery was an afterthought during the War. Over time, the North began to sense a lack of support from the public, and army recruiters had to devise a motive that would resonate with people. They tapped into the Northern protestant morality by promoting the War to end slavery. Abolitionists have been petitioning Congress to outlaw slavery long before the War. While the anti-slavery movement was finally gaining traction, it was for the wrong reasons. On January 1, 1863, President Abraham Lincoln issued the Emancipation Proclamation making slavery illegal. Without slavery, plantation owners lacked their cheap labour, and the entire economy of the South sank into a slump that lasted nearly twenty years. For the South's agricultural economy to rise again, a new way of farming had to be invented. Moreover, it did with the discovery of oil that powered the internal combustible engines of farming equipment. The development of machines powering farming technologies was the catalyst for the second agricultural revolution (Despommier 2010, 79-82).

Oil was first discovered in 1854 in Poland; it was not until 1859 that the American oil harvest began in Titusville, Pennsylvania. Oil has been monopolized mainly by the Middle East, and it is an energy source that is highly sought after by nearly every nation across the globe. Oil and natural gas are the most sought-after energy sources, including operating farming equipment (Despommier 2010, 82-83).

Following the discovery of oil was the invention of internal combustion engines. In 1861, the German native Nikolaus August Otto discovered that compressing air and gasoline in a confined space and igniting it produced enough energy to run a car engine. Before this discovery, steam alone propelled cars; however, this caused numerous technical difficulties, including boiler explosions and meltdowns that made vehicles unreliable. Henry Ford's inventions led to the creation of assembly lines, standardized parts and cheap, manufactured, affordable cars that could run on either gasoline or ethanol. However, due to the Prohibition of 1920, that temporality stopped ethanol production; oil became the fuel of choice. In 1907, Henry Ford invented the first gasoline-powered tractor, quickly replacing the heavy steam-powered tractors that often got stuck in the soggy soil during springtime planting. Those old-fashioned tractors had to be hauled out by herds of horses routinely. Ford's tractors were reasonably priced, lightweight, small, and rarely got stuck in the soil, and they completely revolutionized the agriculture industry. John Deere Company manufactures most tractors in the United States; however, hundreds of other manufacturers exist worldwide. These machines operate on gasoline resulting in the agriculture industry using twenty percent of the United State's fossil fuels (Despommier 2010, 83-85).

In 1847 Italy, Ascanio Sobrero synthesized the first batch of nitroglycerine to produce the most explosive compound until that point in time: dynamite. In the early stages of dynamites development, the mixture was volatile and caused some deaths in Nobel's Stockholm factory. Between 1864 and 1867, Nobel discovered that mixing nitroglycerine with clay produces a stable molecule that is harmless no matter the circumstance, allowing the product to be shipped anywhere worldwide. The invention of dynamite allowed farmers to clear land; stumps that once required herds of animals to pry the tree out of their roots strongholds could now be removed with little to no effort and less time. Due to dynamite, any field or forest could be transformed into land for agriculture (Despommier 2010, 85-87).

According to the Food and Agriculture Organization of the United Nations (FAO), humankind lives in a world where food is in abundance. However, the Earth’s rapidly changing climate indicates that current agricultural practices are not sustainable. Therefore, over the next twenty to thirty years, humanity will undergo a transition period where current farming practices will no longer meet the food demands of a growing population. However, society has dedicated nearly every terrestrial ecosystem to agriculture, a landmass equivalent in size to the continent of South America. Furthermore, almost all farming practices require irrigation which consumes around seventy percent of the Earth’s freshwater. Irrigation compromises the availability of drinkable water; farming spoils the water it uses by producing runoff water full of salts, agrochemicals and animal waste. Farm runoff is the most damaging source of pollution, killing nearly all aquatic life that comes into contact, an issue that will only be heightened once ocean levels rise. Humankind is the most ecologically disruptive species this planet has inhabited. Moreover, with another three billion more people on the way, it is estimated that with current farming practices, another landmass equivalent to the size of Brazil is required to sustain the human population. Additional arable land does not exist; something has to change (Despommier 2010, 94-96).

Future Farming Practices

The opening scene of *2001: A Space Odyssey* ends with an image of a satellite hovering around the Earth’s stratosphere, reminding the audience that even though humankind is the last surviving hominid, its advancement as a species continues to rely on manufacturing superior weapons (Kubrick 1968). Humanity itself has become the biggest threat to its very own survival. Its shift into an agrarian society has made humans the most destructive force on the natural world, making the planet hostile to traditional agriculture. It requires disrupting the ecological landscape through irrigation and many additives such as agrochemicals and farm machinery that disturb the soil to the point where farming can not repeat on the same plot of land. Furthermore, these foods will no longer be grown in the rapidly changing climate due to interfering with natural selection and selectively breeding domesticated plants with high-yielding productive structures that cannot withstand harsh growing conditions. In farmland, competing wildlife such as insects and weeds reduces crop yields; although agrochemicals effectively combat the competition, these critters become more resistant to pesticides over time. Essentially, farming on soil is no longer a sustainable solution to meeting the demands of a growing human population as it relies on using more unavailable land in a hostile climate (Despommier 2010, 135-137).

Technology has facilitated the destruction required to encroach on natural systems to produce food throughout human history. Currently, societies living in the technosphere have been using technology to further isolate themselves from the natural world at the expense of the biosphere. Once again, another technological breakthrough is required for humankind to procure food in a changing climate—however, this time, a permanent overhaul is needed. The future of sustainable food generating systems must occur within the urban landscape; a city-based agricultural system allows humanity to release a sizable amount of food-procuring land back to nature—ultimately regenerating ecological systems. Integrating farming into the city’s landscape would involve developing state-of-the-art controlled environment agricultural technologies within a multistory building: the farmscaper. Placing these buildings within cities ensures a shorter distance between food production and urban centres, reducing the ecological footprint. As with any new invention, the first edition will be expensive; however, it is an investment that will last for generations. Over time, as this technology becomes popular and its demand increases, the price will drop. Implementing a farmscraper that employs large-scale hydroponics and aeroponics has two main advantages. First, it increases food production without further damaging the environment. Second, it frees up farmland, allowing the environment to recover from years of devastation. Other benefits include year-round crop production, no weather-related crop failure, no agricultural runoff, allowance for ecosystem restoration, no use of agrochemicals, seventy to ninety-five less water and fewer food miles (Despommier 2010, 140-145).

The farmscraper will consist of multiple megastructure complexes constructed close to each other. They will contain space for growing food; offices for management; a control centre for monitoring the overall running of the facility; a nursery for selecting and germinating seeds; a quality-control laboratory to monitor food safety, document the nutritional status of each crop and monitor for plant disease; staff rooms for the workforce; an education centre for the public; a farmers market; and restaurants. Farming will need to be segregated into three different facilities: aquaculture, livestock, and plant farming (Despommier 2010, 179-181). Dr. Despommier's research on the vertical farm outlines the essential ingredients a building requires to farm indoors;

this writing will further discuss the architectural criteria for a vertical farm in Chapter 4.

According to Despommier's research, one sixty-story farmscraper can feed 100,000 people (Lerner 2008, 46). The combined population of New York City and Long Island is approximately 16 million; therefore, roughly 160 farmscrapers would be required to sustain the city. Currently, a farmscraper, like the one described above, does not exist. However, notable design projects have attempted to create prototypes of the farmscraper.

The most famous example of the farmscraper comes from the architect who coined the term: Vincent Callebaut. The Belgian architect explored the idea of integrating vertical farming into the skyscraper typology through his project Dragonfly (Figure 5). A farmscraper designed in the shape of a dragonfly's wing and set in New York City's East River, at the south edge of Roosevelt Island. The tower spans one-hundred and thirty-two floors, reaching a height of six-hundred meters. It adopts the biomorphic form of a dragonfly wing which offsets loads of the building. In addition to structural benefits, the Dragonfly's superstructure can provide wind and solar power. It is estimated to accommodate twenty-eight different agricultural fields capable of growing various fruits, vegetables, grains, meat and dairy. The building hybridizes these farming programs with non-farming programs such as housing, offices and laboratories in ecological engineering. The types of food farmed are based on the seasons. The farmscraper reuses the biodegradable wastes from previous crops to create a closed-loop system; organic humus generated from livestock wastes fuels bioreactors. Everything in the tower is recycled, making it a metabolic and self-sufficient system (MGS Architecture 2009).

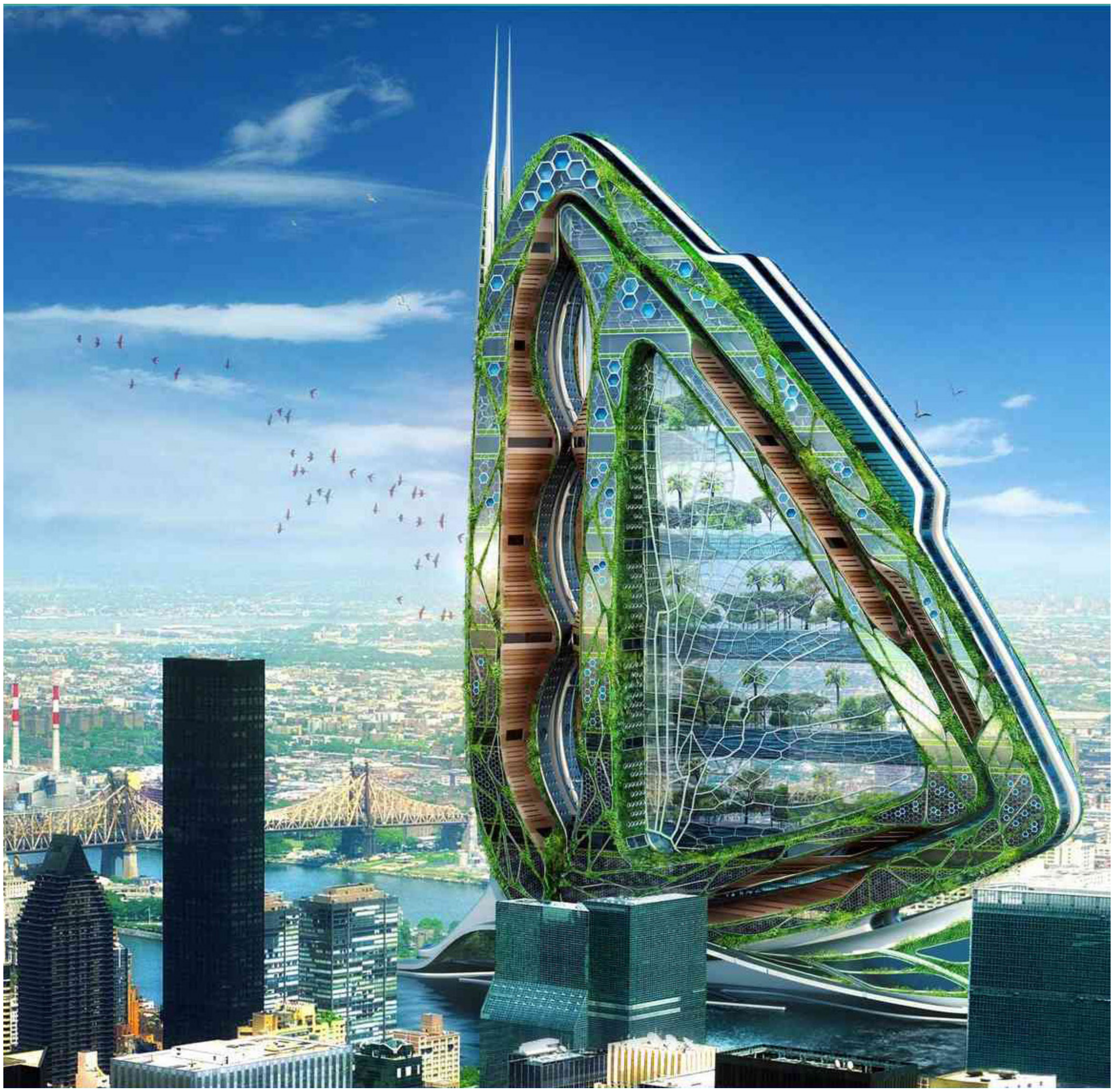

Figure 5: Dragonfly by Vincent Callebaut (Callebaut 2009)

The second example of a prototype farmscraper comes from a Los Angeles-based designer, Chris Jacobs. The project pictured in Figure 6 was initially one of many concepts pitched to him as an advertisement for a campaign featuring innovative technology concepts that promote alternative energies. However, upon introducing the project to the scientist who invented the concept of vertical farming in towers, his prototype became the emblem for Despommier’s research. The proposed tower houses

Figure 6: Vertical farm by Chris Jacobs (Mohr and Jacobs 2007)

several types of agriculture, including plants and livestock farming. In addition, the building integrates a hydroponic system to aid in the growth of plant life, eliminating the need for fertilizers and pesticides. As a result, a hydroponic farming system can increase farming yield by upwards of 300% by only using 10% of the water used in traditional horizontal farming. Furthermore, the vertical farm maximizes the potential of life cycles within the building by recycling all organic matter, including animal waste. Finally, the building

Figure 7: Pig city by MVRDV (Maas 2001)

has the potential to generate power through a variety of cutting-edge technologies that involve wind turbines, solar energy, tidal power and biogases generated from livestock (Surman 2015).

The final example is Pig City by MVRDV (Figure 7), an architecture firm based in the Netherlands. The farming of porkers is a lucrative industry in the country; the Netherlands is the chief exporter of pork in the European Union, producing

16.5 million tons of pork. However, the farming of porkers raises environmental and health issues, which the project Pig City aimed to address. It is one of the most famous prototypes for farmscrapers dedicated exclusively to livestock farming. The project argues for changing the production methods into a new type of farming that concentrates all aspects of pig production in one facility, reducing transportation and distribution and spreading diseases. The building is designed around the food production demands of an industrial-scale animal farm. It would need to house approximately 138,500 pigs to yield the equivalent amount. The building employs a modular construction method stacked vertically to provide enough space for the porkers. The building utilizes various mechanisms designed to circulate the animals' hay, food and water in a tower. Furthermore, the building recycles the biogas produced from the wastes of the porkers to power the building (Maas, Siegei, and Wall 2001).

The above prototypes are precedents for the farmscraper (Figure 8). The first example, Dragonfly, offers insight into how the metabolic outputs of the various farming programs can be recycled, creating a closed-loop system, a concept that will be further explored in the next section. It also demonstrates an ability to hybridize farming programs with non-farming programs such as retail and office spaces. The ability of these two programs to engage with one another is an essential factor in ensuring farming is viable in a city environment. However, the most noteworthy prototype is Jacobs' vertical farm, which has received approval from Despommier. The building prototype offers insight into strategically placing farming programs. For example, in terms of systems layout, placing the plant growing near the fish tanks can create a large-scale aquaponics system. In addition, the circular form chosen for the building is designed to maximize sunlight for growing crops, an architectural feature that also benefits other climatic factors such as wind tunnel mitigation and program factors such as internal circulation. The project also hints at recycling wastes from livestock; however, Despommier's research does not delve into the mechanics of raising animals within a skyscraper. For this reason, the thesis takes cues from Pig City, as it is the most developed project that explores livestock farming in a tower. It offers creative design solutions to moving supplies required for feeding the livestock, such as conveyor belts rotating hay and mechanisms containing drinking water, feeders and tools for waste management.

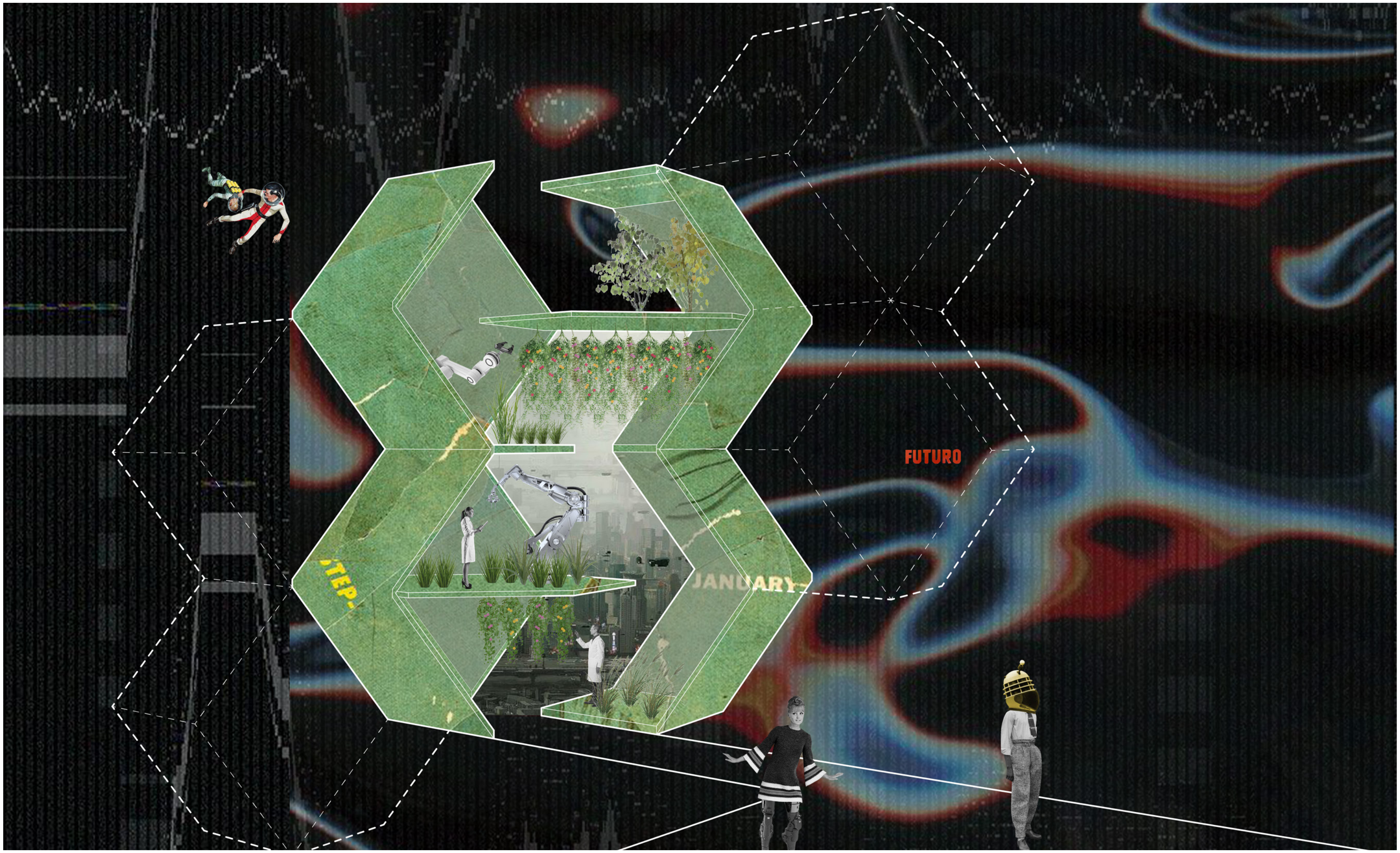

Figure 8: Conceptual collage of metabolic farmscraper

Chapter 3: Techno-Utopian Agricultural Cities: The Three Ingredients for Metabolic Farmscraping

Infrastructure for Addressing Population Growth in Cities

Utopian projects often emerge when a society is undergoing a dramatic shift politically, economically or aesthetically. For example, during the 1950s to 1960s, Japanese culture was transforming in response to the aftermath of the Second World War; the urban population in Japan was growing at unprecedented rates, and the development of urban infrastructure was lagging (Lin 2010, 70). The nation's political and cultural transitions gave rise to visionary urban designs proposed by a group of young architects and designers that referred to themselves as the Metabolists: Kiyonori Kikutake, Kisho Kurokawa, Fumihiko Maki, Masato Otaka, Noboru Kawazoe, Kenzo Tange and Arata Isozaki. In 1960, the group published their manifesto "Metabolism: The Proposals for New Urbanism" at the World Design Conference in Tokyo and prompted Metabolism (Lin 2010, 1). Their ambitions for the utopian future of post-industrial society include humans inhabiting the sea and sky, claiming that the city would grow like evolution and the metamorphosis of an organism. The city is thought of as a living organism, and the different systems consist of metabolic cycles: some things are permanent while others are temporary. The Metabolists argue that accommodating a city's rapid growth means advancing technologies for prefabricated components and replacing obsolete parts according to a building's life cycles. The futuristic tone of Metabolism reflected the technological optimism of the 1960s, a decade that was known for innovation in technology, such as developments in genetics and life sciences, explorations of the moon and space, inventions of robots and computers and communication technologies (Lin 2010, 1-7). This generation's newfound faith in technology's ability to transform societies led the Metabolists to develop a vision for a techno-utopian future.

The Metabolic Farmscraper

As mentioned earlier, historically, Metabolism emerged as a response to an urban landscape left in ruins. Currently, the ecological landscape is in ruins from the environmental damage caused by traditional farming practices. Therefore, this thesis adopts Metabolism as a theoretical framework that informs the design of the farmscraper. However, in this instance, it is being re-appropriated to develop the technology required to rebuild the environment. With vertical farming in cities, the environment can be left alone to recover from centuries of ecological damage caused by horizontal farming. However, a significant limitation of vertical farming is its ability to meet the food production demands of a rapidly growing population. This limitation further reinforces the argument that Metabolism is an appropriate method for designing the farmscraper as it outlines approaches to designing architecture that can accommodate a growing population through technology. Furthermore,farmscraping is a new technology; Metabolism is concerned with advancing technologies in prefabricated components, which is helpful since farmscraping an entire city would require employing modular construction methods, allowing for the building to be replicated anywhere. The intersection between Metabolism and farmscraping appears in three motifs:

megastructures, capsules and circularity. In this thesis, these three motifs central to Metabolism are re-imagined as the three ingredients for designing the infrastructure capable of feeding a future population of over nine billion people.

Megastructures

The rapid population growth of the nineteenth and twentieth centuries gave rise to a building typology common to science fiction depictions of future cities: giant buildings called megastructures. Metabolist architect Fumihiko Maki defines the megastructure as a colossal building: a “large frame in which all the functions of a city or part of a city are housed” (Gardner 2020, 9). By this definition, the most iconic New Tower of Babel in Fritz Lang’s film *Metropolis* would fit the description of a megastructure. Lang’s Tower of Babel inspired the iconography of towers in Japanese science fiction, such as in Haruo Satō’s “A Record of Nonchalant” (1929), Katsuhiro Ōtomo’s and Rintarō’s film *Metropolis* (2001) and Osamu Tezuka’s manga *Metropolis* (1949). The most influential architectural adaptation of the megastructure is Le Corbusier’s high-rise buildings in Ville Contemporaine, Ville Radieuse, and plans for Voisin and Algiers. He influenced the development of architecture and urban planning through Congrès Internationaux d’Architecture Moderne (CIAM). This organization promoted functionalist approaches to city planning, such as efficiently dividing urban spaces into work, dwelling, and leisure zones. The projects of the Metabolists represented a continuation of Le Corbusier’s work for CIAM. They also inherited the idea of architects designing buildings and cities capable of responding to urban crises and transforming societies through innovative, bold urban designs. However, CIAM’s functionalist city was often criticized for being inflexible,

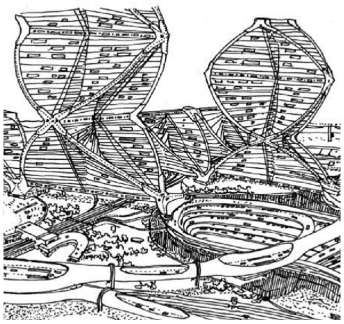

Figure 9: Helix city by Kisho Kurokawa (Cameron 2018, 36)

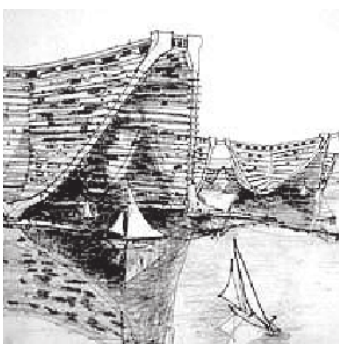

Figure 10: Floating city by Kisho Kurokawa (Pernice 2009, 1849)

hierarchal and authoritarian. The critics argued that instead of forcing people to inhabit someone else's design, citizens should be given more autonomy to develop their own space for dwelling, work and play. Metabolism responds to this criticism by designing buildings that accommodate the future; the architecture can change, grow, and adapt according to the inhabitant's needs. Maki further defines a megastructure as "discrete, rapidly changeable functional units which fit within the larger framework" (Gardner 2020, 9). The building frame must be flexible enough to accommodate the reconfiguration of the units, which function to withstand varying temporal or metabolic cycles. This definition of megastructure is evident in many of the Metabolists' projects. Kiyonori Kikutake's Tower-Shaped Community adopts the plug-in principle in the design of the housing units. Kishō Kurokawa's Helix City Plan for Tokyo and Floating City Kasumigaura comprises a transportation infrastructure frame designed after a DNA molecule's double helix structure (Gardner 2020, 7-9).

The first ingredient of the metabolic farmscraper is the megastructure. A vertical farm to produce food yields equivalent to a horizontal farm would require multiple massive building structures planted throughout the city. Multiple megastructures are evident in many projects, more famously in Kurokawa's Helix City and Floating City; both consist of interconnected towers linking to the surrounding transportation infrastructure. In Figure 9, a drawing of Helix City illustrates that a portion of the megastructure is dedicated to funnelling the city's transit system through the buildings. The illustration of Floating City seen in Figure 10 demonstrates that the megastructures connect the building to vehicular transportation along with the rooftop and ferry transportation along the base of the building submerged

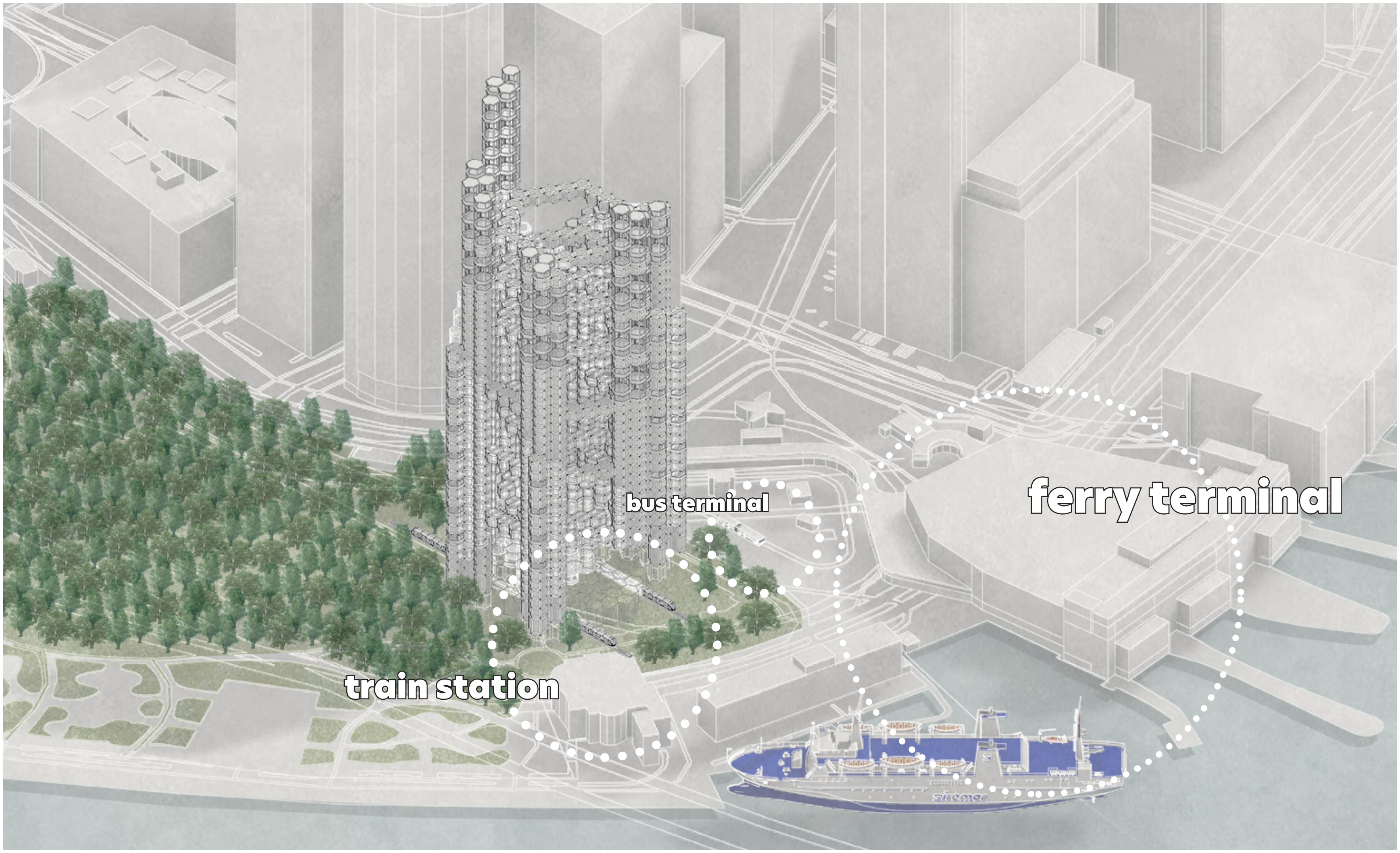

Figure 11: The megastructure connecting to transportation infrastructure

Figure 12: Nakagin capsule tower (Lin 2011, 14)

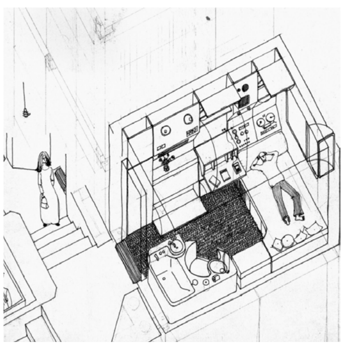

Figure 13: Axonometric of capsule (Lin 2011, 21)

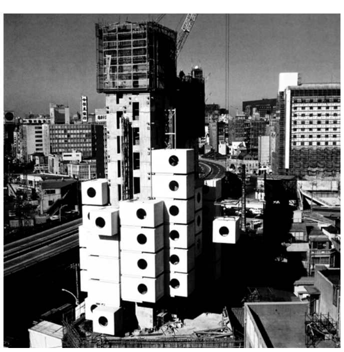

Figure 14: Construction of nakagin capsule tower (Lin 2011, 24)

into the harbour. Therefore, much like the Metabolists' adaptation of the megastructure, the metabolic farmscaper also clusters a series of towers that integrate the city's transportation network into the building; this urban strategy argues for Metabolism being the theoretical framework that informs the farmscraper (Figure 11). Ensuring the architecture behaves as a system interconnected to the city is crucial when designing a food production system that connects to other farms, manufacturers, and distributors. For example, suppose it would require approximately one-hundred and sixty farmscrapers to feed the combined population of both Manhattan and Long Island. In this case, a single metabolic farmscraper would not suffice as many of these vertical farming towers are required to meet the food production demands. Planting these farmscarpers along the city's transportation infrastructure facilitates food movement between other farmscrapers and allows rapid delivery of goods to food manufacturers and distributors. By plugging into the city's railway lines, the metabolic farmscaper satisfies the first part of Maki's megastructure definition as it houses a vital part of the city; transportation. The second part of Maki's megastructure definition speaks to the building's ability to house functional units that accommodate changes in user needs. These functional units refer to the second motif of Metabolism, the capsule.

Capsules

The second motif in Metabolism is capsule architecture. The most famous example of capsule architecture is Kurokawa's Nakagin Capsule Tower (Figure 12), which consists of a central core providing infrastructure and access to the capsules, units designed for dwelling (Figure 13). Maki's definition of the megastructure is an extensive framework containing

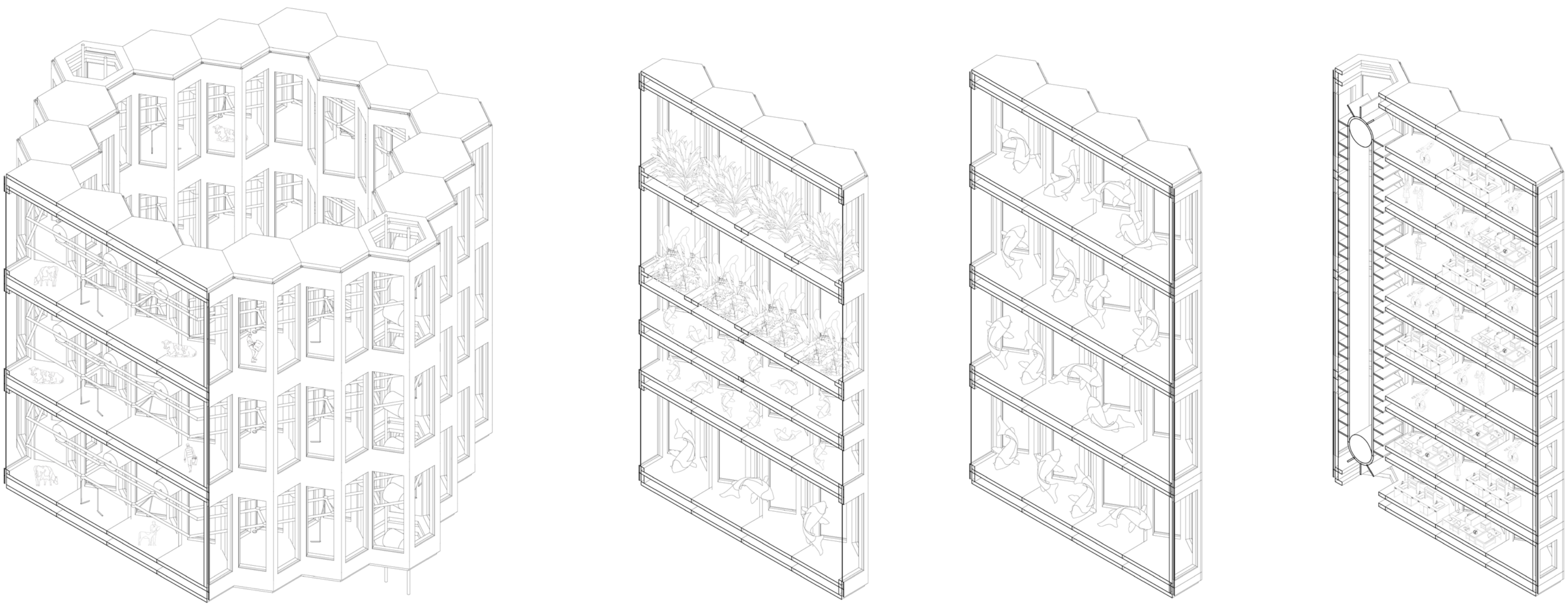

Figure 15: Left to right: the capsule housing livestock, aquaponic system, aquaculture tanks and high-tech farming laboratories

“discrete, rapidly changeable functional units.” These units could be best described as capsules. These capsules are self-contained prefabricated units plugged in or removed from the framework. It includes qualities of enclosure and mobility and has been conceptualized as a cybernetic node in the broader information system. The Latin word *capsula* translates to a small box or case; therefore, its primary quality is an enclosure that functions as a carefully calibrated membrane between the inhabitant and the outside world. Japanese industrial designer and fellow Metabolist group member, Kenji Ekuan, defines capsules as an enclosure that maintains equilibrium. He draws from the language of cybernetics to explain that capsules seek balance creating a sustainable relationship between the occupying organism and the surrounding environment through artificial means. He likens this to deep-sea environments and rapidly moving vehicles where the inhabitants find it challenging to survive the climate without artificial interventions. This definition makes sense considering that the source of inspiration is space capsules designed to protect astronauts from radiation, temperature extremes and vacuum from outer space. However, contemporary terrestrial cities do not compare to outer space’s harsh climate—instead, the biggest threat to urbanites is pollution, noise and information overload. Therefore, the Metabolists view the capsule as positive valence to the psyche; rather than just functioning as a protective shell, the capsule provides the technology for the inhabitants to thrive in the information society. Kurokawa coins the term “cyborg architecture” to describe the function of a capsule; it is a feedback mechanism where its defensive role helps capsule dwellers filter unwanted information while also assisting the user in obtaining helpful information. Another desirable feature of the capsule is mobility; Kurokawa describes the capsule as a dwelling for “Homo movens,” the next stage of humanity that is increasingly more nomadic. The capsule is radical because, unlike conventional buildings, it promotes expansion into the environment, which dismantles the idea of a solid and permanent building (Gardner 2020, 14-17).

The second ingredient of the metabolic farmscraper is the capsule. In addition to accommodating transportation infrastructure, the megastructure also functions as a space frame housing the capsules. The Nakagin Capsule Tower in Figure 14 captures the building during mid-construction, demonstrating the megastructure’s secondary function of housing the capsules. It gives insight into the construction method; a modular prefabricated capsule plugs into a site-cast megastructure. Likewise, the metabolic farmscraper capsules are prefabricated modular units containing various farming and non-farming programs that plug into a site-cast megastructure. The modularity of the capsule is another critical argument for Metabolism informing the design of the farmscraper; its expansive quality allows for the architecture to be replicated anywhere. If we return to the supposed one-hundred and sixty farmscrapers required to feed the entire population of NYC, in this case, implementing a modular prefabrication construction method allows this building to be easily reproduced across the entire city. The capsules offer flexibility in being easily inserted and removed from the megastructure. This architectural feature is valuable to the farmscraper. It allows the farmers to choose different capsules depending on the foods they need to grow. This freedom further reinforces adopting Metabolism for the farmscraper’s design as the capsule can act as a carefully

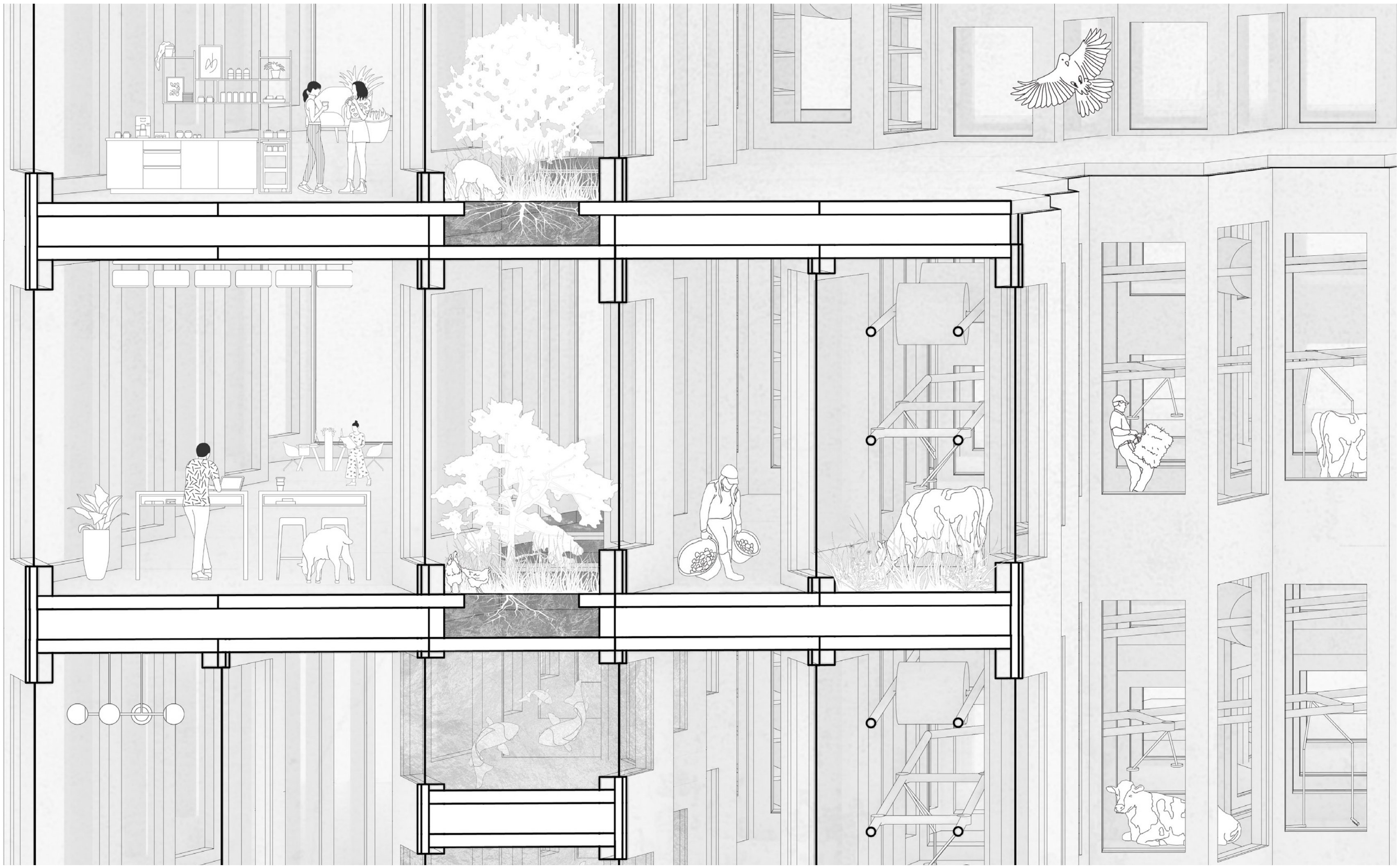

Figure 16: Circularity for farming and non-farming programs

calibrated membrane capable of housing various programs with varying climatic needs. Figure 15 illustrates how individual capsules can house various farming programs (i.e., aquaculture, plants or livestock). The envelope is a critical design feature for a single capsule to house anything from a fish tank of salmon, a plant nursery growing kale or commercial office space. However, the metabolic farmscraper departs from traditional metabolic architecture because the envelope offers enough permeability to interact with these diverse programs. As a result, their life cycles begin to benefit one another mutually.

Circularity

The final motif is the apocalyptic city: the future city to be destroyed and left in a state of ruins. The destruction of Tokyo is a recurring theme in many Japanese science fictions in various media, including films, novels, manga, anime, and video games. A famous example of Tokyo's destruction is Godzilla, a reappearing monster that destroys architecture. Moreover, the beast emerges from the Pacific to destroy Japan's postwar industrial infrastructure sites, the engines of Japan's economic recovery: power plants, power lines, oil refineries, factories, and freight transportation centres. Architecture critics such as Hajime Yatsuka argue the destruction of Tokyo's infrastructure is symbolic of criticizing the modern Japanese political, business and architectural elites. Furthermore, it is a reset of the urban landscape as the destruction is often accompanied by an unseen rebuilding of the city that occurs off-screen, in between films. These cycles of on-screen urban destruction and off-screen reconstruction are symbolic of the city's self-healing and rebuilding itself without any human intervention. Within Japanese science fiction is the narrative of circularity; the spontaneous regeneration of Tokyo city can be likened to biological processes which are circular in nature (Gardner 2020, 17-19). Consequently, the biomorphic model of growth and transformation central to Metabolism emerges from the cyclical nature of apocalyptic cities—everything in nature undergoes a cycle consisting of death, decay and rebirth (Lin 2010, 11).

The final ingredient of the metabolic farmscraper is the idea of circularity. This motif of cycles that often appears in the rebuilding of cities makes sense considering Japan was undergoing a period of transformation after its urban landscapes had been destroyed during World War II. Japanese society was also undergoing a period of rapid population growth; therefore, they needed infrastructure capable of growth. The Metabolists offered a solution through the idea of architecture capable of expansion; buildings that imitate this vision of self-healing through the ability to disassemble and rebuild the architecture. Likewise, the metabolic farmscraper also adopts this idea of circularity through the building's ability to expand in terms of being easily replicated across numerous sites in the city. However, the idea of circularity is taken a step further by exploring the potential in the building's life cycles. The motif of circularity is applied to the farmscraper at every project scale. Several farmscrapers would occupy nearly every corner of the city at the urban scale, akin to one sizable interconnected organism. At the scale of the building, the output from one metabolic cycle becomes the input for another metabolic cycle within the building, creating an energetically closed-loop system. For example, the manure produced from livestock farming can be repurposed as fertilizer for plant and aquaculture farming. The nutrient-rich water of the fishtanks in the aquaculture farm can be fed into the soil of the plant farm (Figure 16).

Chapter 4: Design Proposal: Farmscraping New York City

Design

While increasing food production is essential to food security, one must examine food distribution throughout the United States. Two regions of the United States dedicated more than 60% of their land to agriculture: California and the Midwest. California specifically dominates the agricultural industry and is a central node in the food flow network of the country. All American cities rely on California, which becomes an issue in the event of a disruption to the food flow network. The issue this thesis wishes to address is food sovereignty and cities becoming more resilient regarding food production. The thesis turns to New York, which is particularly at risk since most of its food is imported from California. New York City's food distribution system relies on bridges and tunnels to reach its consumers. A combination of four major bridges and two tunnels carries over 50% of the city's total food volume. The six major food distributors only stockpile 4-5 days' worth and rely heavily on just-in-time inventories (City of New York 2016). For New York City, which hardly has enough space for its people, let alone for traditional horizontal farming, the solution to becoming food resilient is through vertical farming integrated into the skyscraper building typology, the farmscraper.

The architectural theoretical framework being implemented is Metabolism, as it is an approach to designing buildings that address issues of population growth; in this case, it is designing infrastructure to feed a growing population. The dream of preserving a little bit of the country in the city is utopian; therefore, this thesis turns to the radical architecture movement, a period that turned to technology for visionary solutions to radical problems. Metabolism emerged in Japan as a response to World War Two. Cities were rebuilding their infrastructure after the destruction of their urban landscapes; therefore, the Metabolists wanted to create a theoretical framework for designing buildings that could expand and accommodate future growth. This thesis will re-adapt Metabolism as a method for rebuilding our agricultural landscapes, which traditional farming practices have destroyed. The intersection between Metabolism and farmscraping appears in three motifs: the megastructure, the capsule, and the notion of circularity.

XL: Urban Strategy

When designing a farmscraper, one refers to the scientist who invented the technology; Dr. Despommier. Based on Despommier’s research, a single sixty-story farmscraper can feed approximately 100,000 people annually (Lerner 2008). For New York and Long Island’s combined population of over 16 million, 160 farmscrapers would meet food production demands. The map in Figure 17 illustrates the urban strategy: one-hundred and sixty farmscrapers would occupy nearly every corner of the city, along the existing subway and railways networks. These farmscrapers plug into the city’s existing transportation infrastructure, facilitating rapid movement of food commodities between farms, food distributors and retailers. This urban strategy reduces the long miles food travels before reaching New Yorkers’ plates, ultimately reducing carbon emissions.

The thesis tests this idea in one of the 160 locations: Battery Park (Figure 18). Battery Park was chosen as it is in the city's heart, maximizing the farm's ability to engage with the public. Furthermore, it is a hub for public transportation as it is connected to the subway system, a ferry terminal and a bus station (Figure 19). Within the park is the Battery Urban Farm; therefore, the farmscraper acts as an extension of the city's existing urban farm. It will also further support Battery Urban Farm's efforts to educate the public on food growing but do so at a much larger scale by making farming a part of everyday life. The image in Figure 20 illustrates the site before adding a farmscraper. It will be constructed on the Battery Playscape next to the Battery Urban Farm. With the addition of the farmscraper, the project extends the green belt of the park, creating a transition from horizontal to vertical farming (Figure 21).

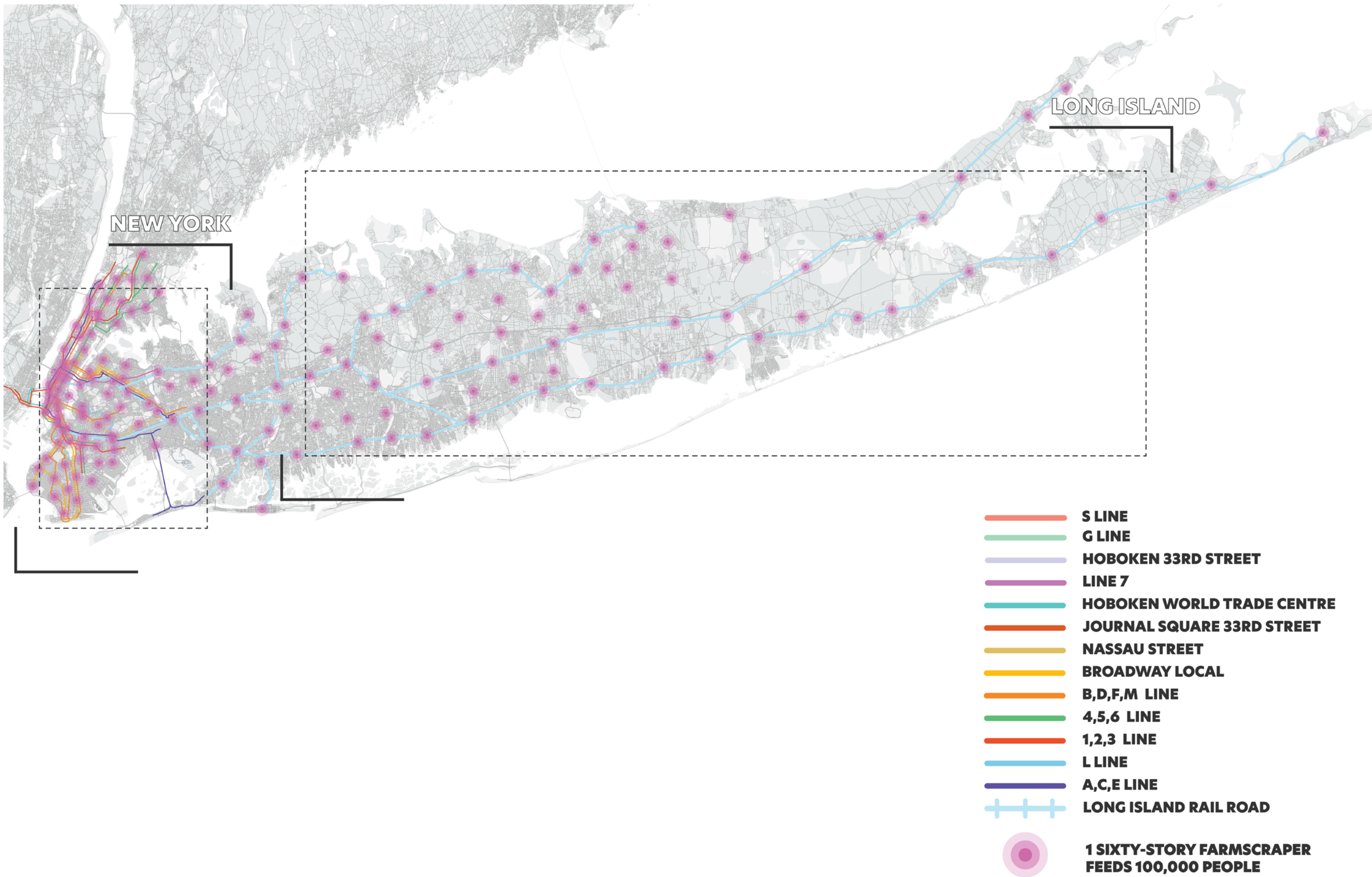

Figure 17: Urban strategy for metabolic farmscraping NYC (base map from Cheng n.d.)

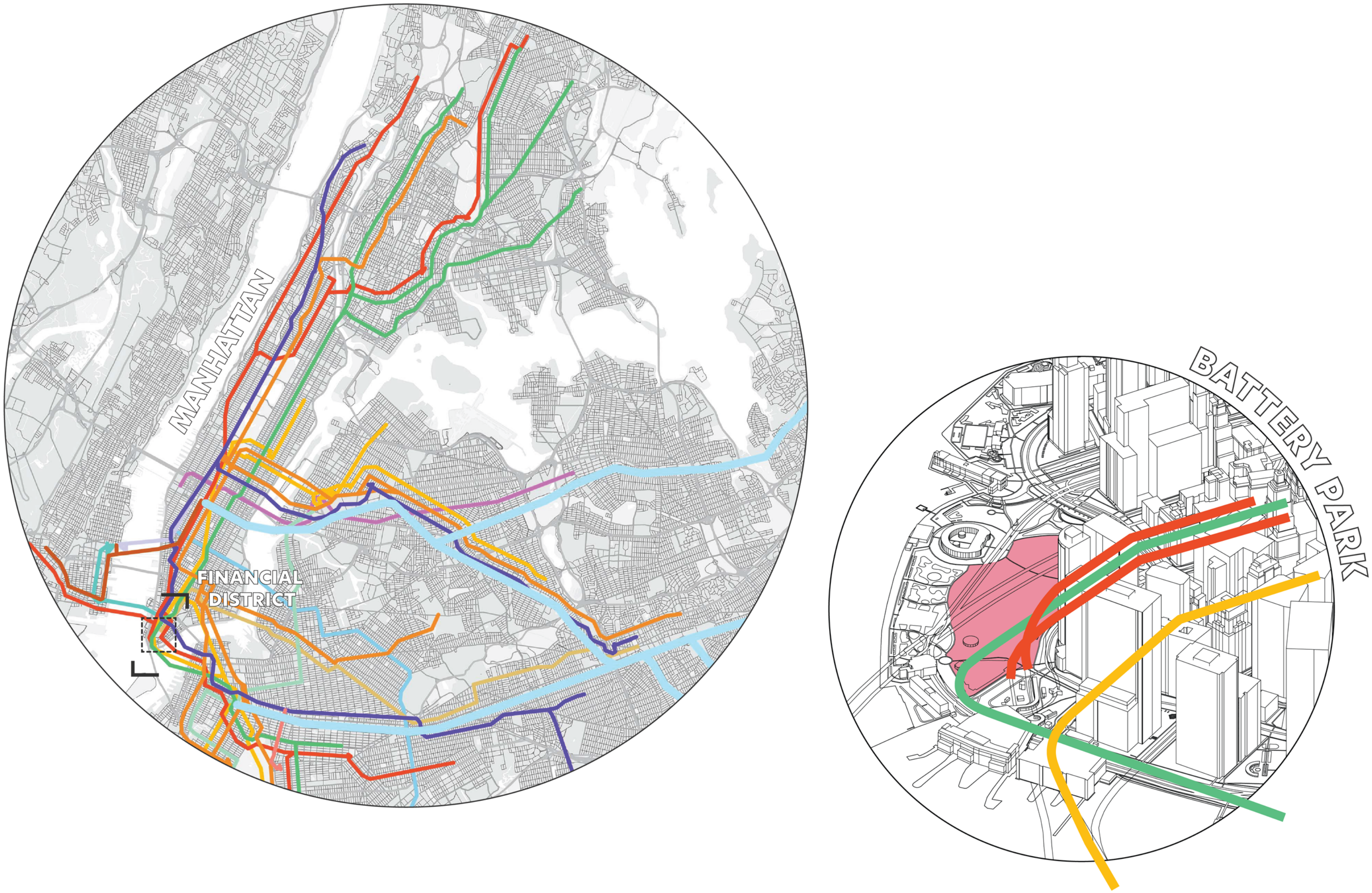

Figure 18: Map of transit system under Battery Park, NYC (base map from Cheng n.d.)

Figure 19: Map of context in Battery Park, NYC (base map from Cheng n.d.)

Figure 20: Map of Battery Park before site strategy

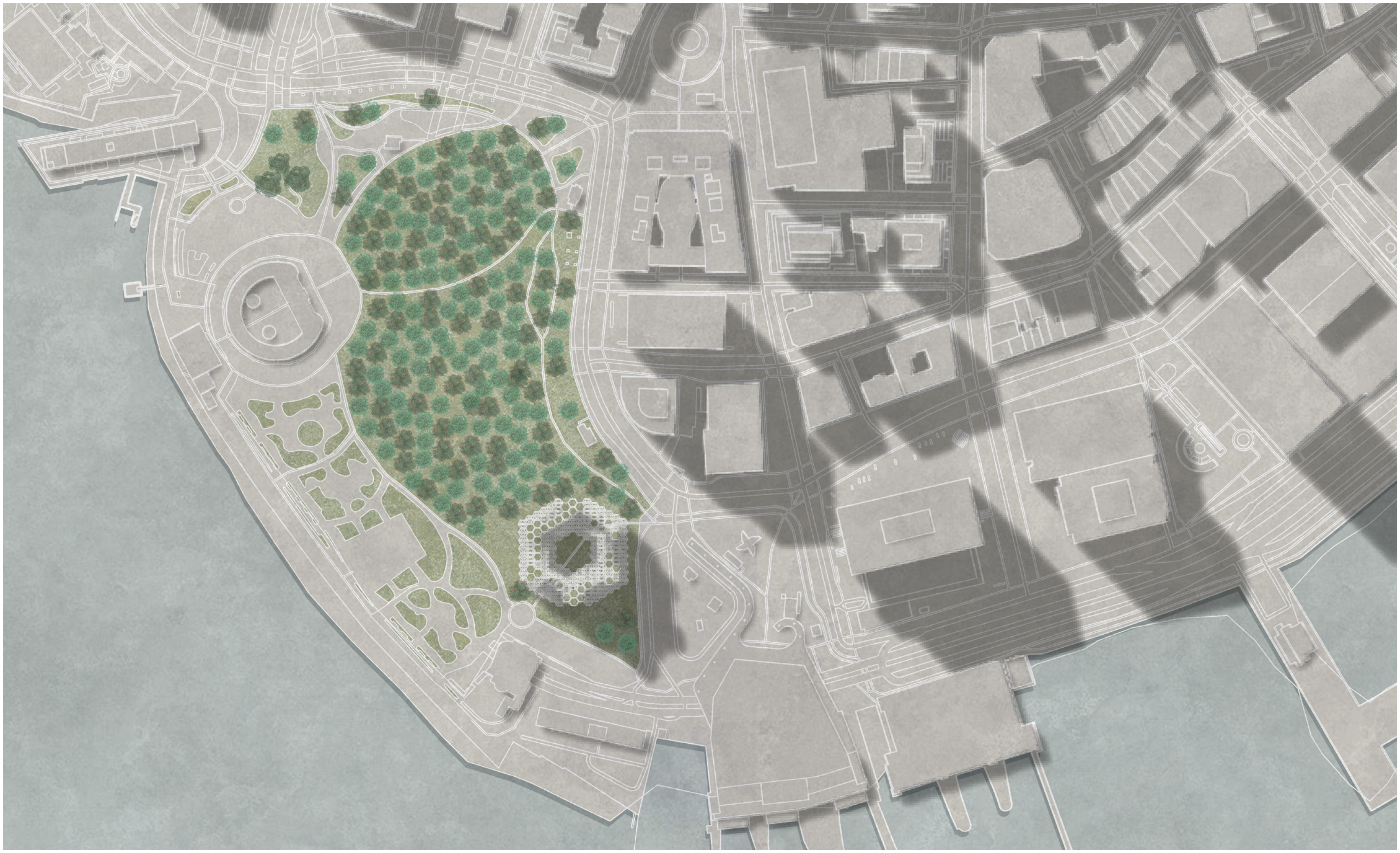

Figure 21: Map of Battery Park after site strategy

L: Site Strategy

The first ingredient of the metabolic farmscraper is the megastructure. The megastructure serves two functions: to connect the building to the city's transportation infrastructure and the building's modular capsules. In keeping with the idea of a megastructure, the building is designed to plug into the city subway system, facilitating rapid movement of goods across the city. It is also located near other popular modes of transportation that can bring more people to the site (Figure 22). Efforts have been made to design the farmscraper to respond appropriately to its site (Figure 23). The building adopts a courtyard typology, significantly benefiting the circulation of urban and building. In addition, the farmscraper comprises a series of setbacks that taper towards the top of the structure, allowing even more sunlight into the building and onto the street; it is an architectural feature required of Manhattan skyscrapers since the 1916 Zoning Law (Koolhaas 1994, 112). The farmscraper is also designed around solar radiation. Its crescent-shaped structure offers a more uniform surface, making the design most efficient for using passive sunlight in building areas where crops are grown in soil (Despommier 2010, 188). The façade of the building maximizes the growth potential using the Sun; hot areas are designated for growing warm group foods, and cool areas are designated for growing cold group foods (Figure 24). Only Metabolism can offer the framework for designing spaces that house such diverse programs with their diverse climactic needs. In addition to sunlight, the building considers the wind as a climatic factor influencing the building's form. The angles of the building's facade create a corner softening that aids in reducing wind acceleration. The setbacks that allow light to penetrate the

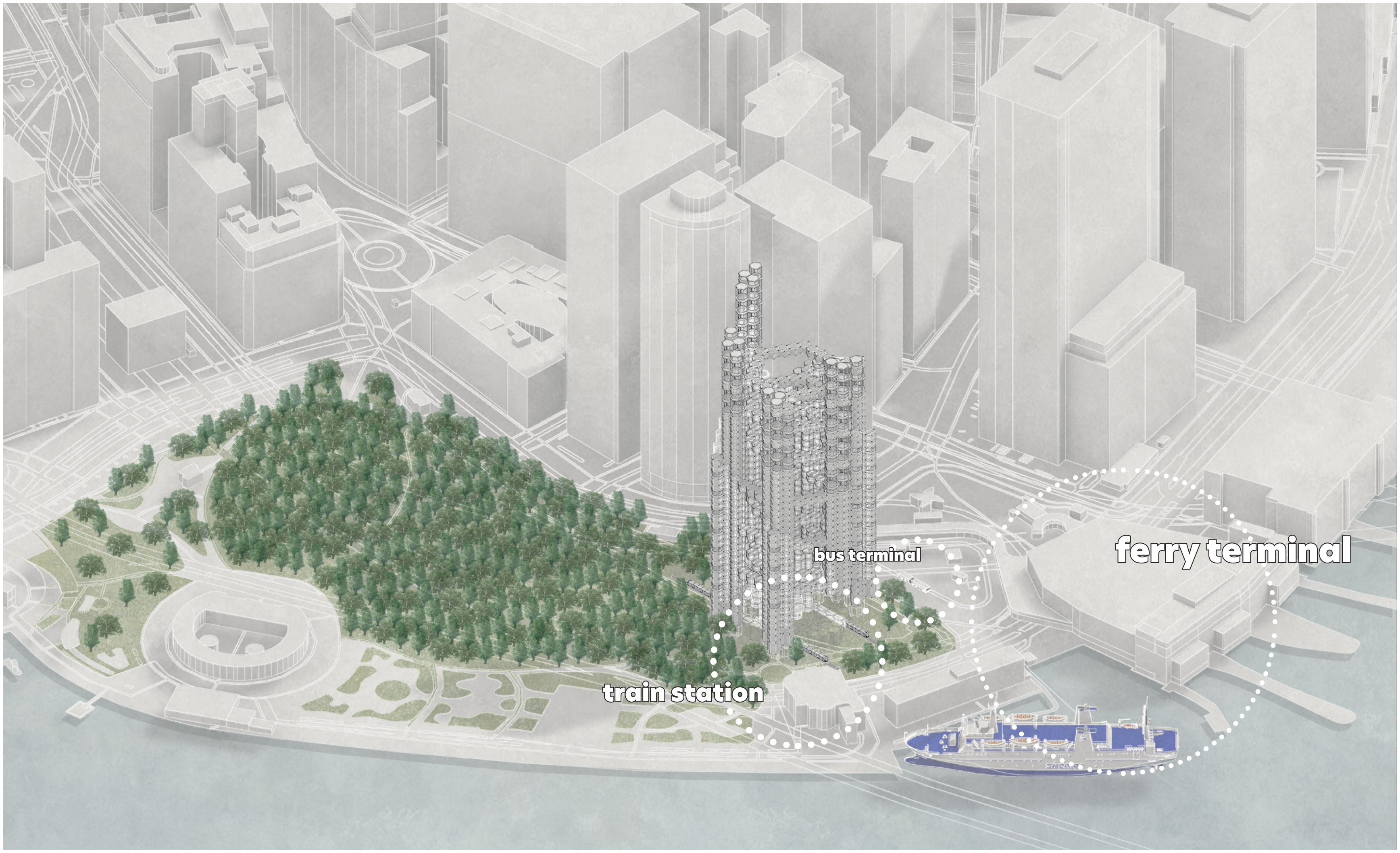

Figure 22: The megastructure plugging into site's existing transportation network.

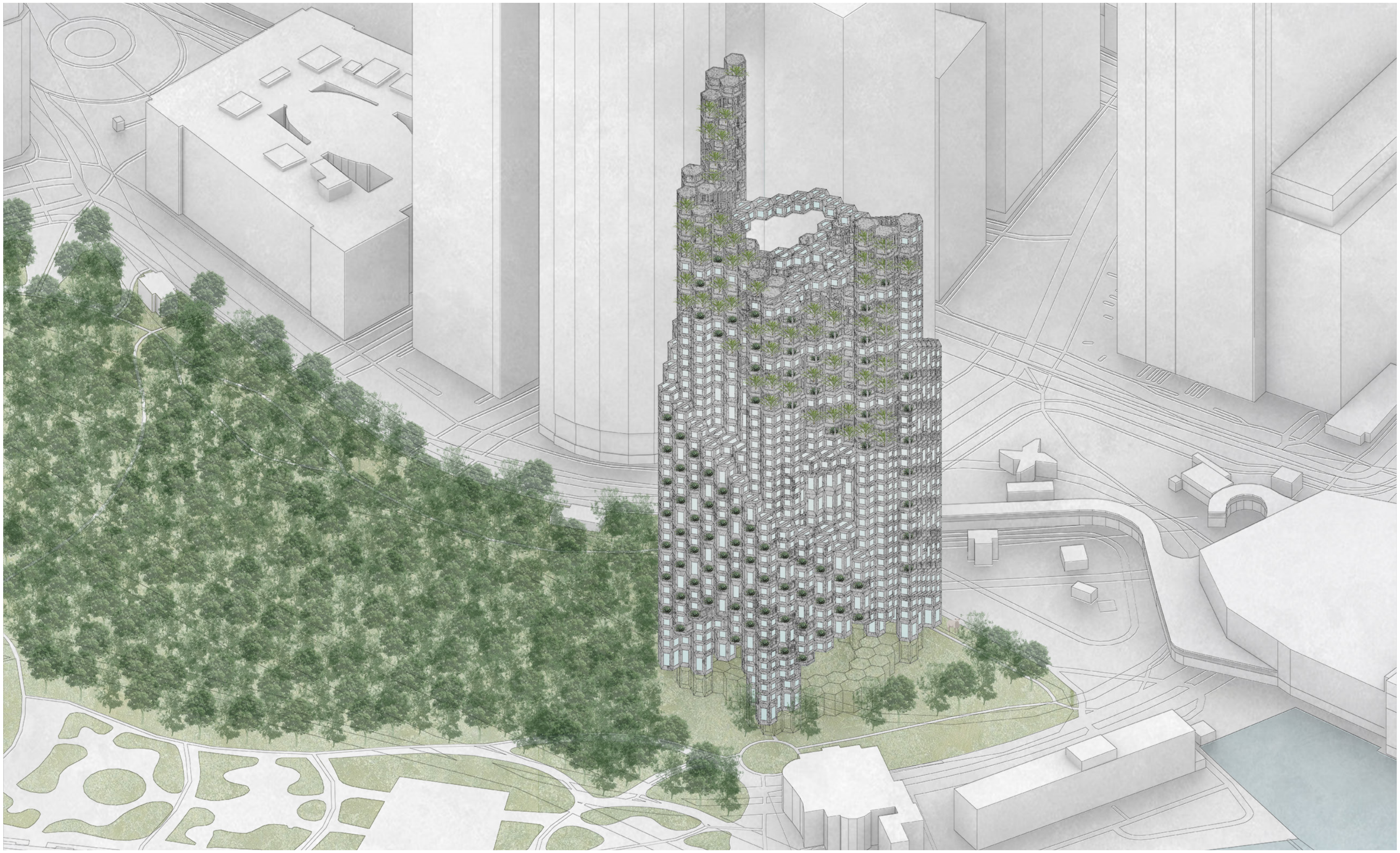

Figure 23: Facade of building

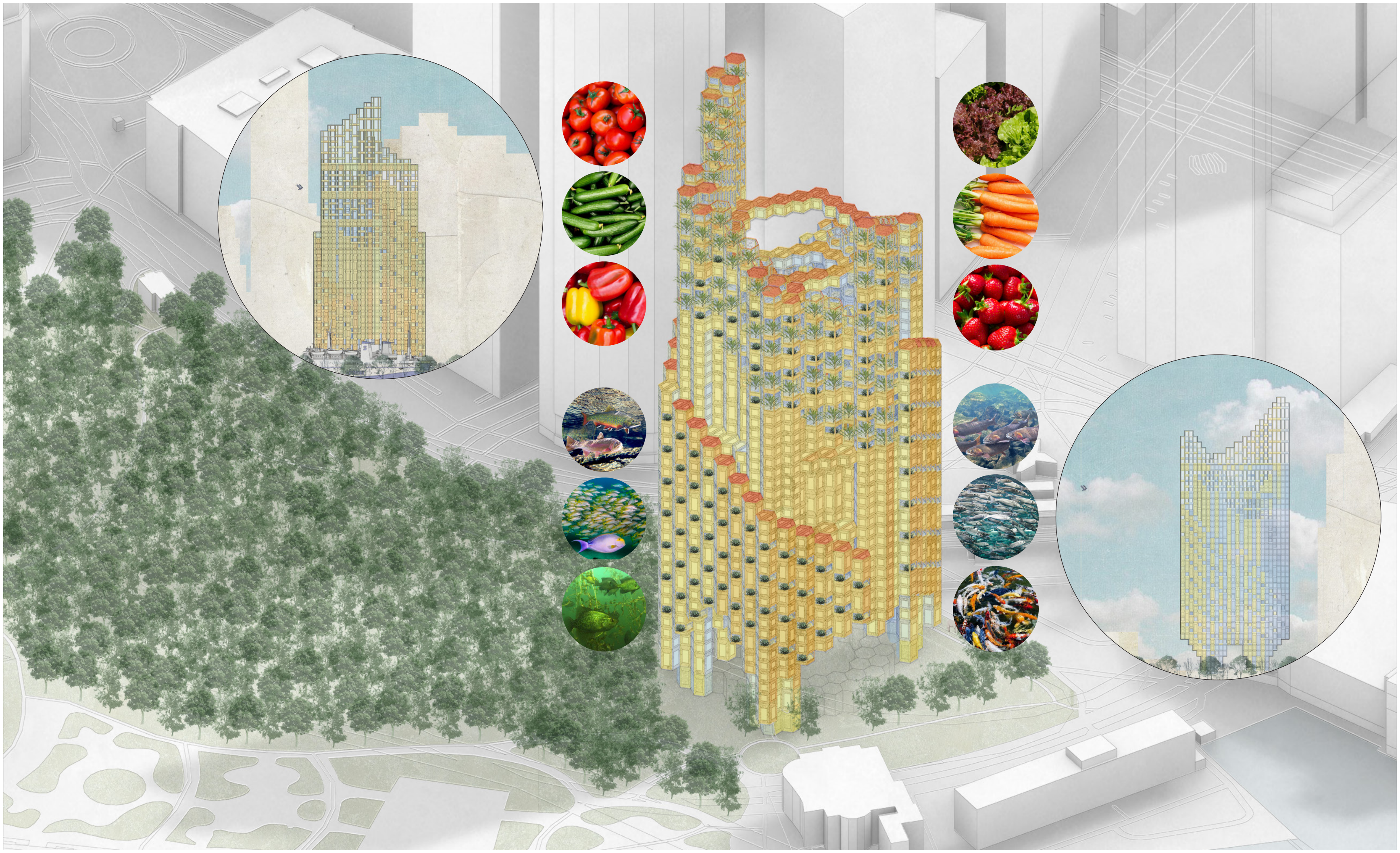

Figure 24: Solar radiation analysis determining areas for food growing

building also reduce the downdraft caused by skyscrapers. Furthermore, the building is designed with points within the structure that are entirely hollow; this allows wind to move through and around the building. Instead, these hollow spaces are designated outdoor growing spaces, covering the facade with plants and tree life (The B1M 2018).

M: Building Strategy

The second ingredient of the metabolic farmscraper is the capsule. As mentioned earlier, the capsules attach to the megastructure. In this project, the capsules are prefabricated modular units that plug into the megastructure, a site-cast element that behaves as the skyscraper's superstructure. The megastructure comprises a series of vertical cores containing the building's elevators and fire egress stairwells. Every ten stories, the megastructure contains a circular bracing system anchoring the capsules to the structure (Figure 25). These circular bracing systems contain primary mechanical equipment that redistributes air and matter to the capsules housing the secondary mechanical systems in the ceilings and floors. The modularity of the capsules offers flexibility in terms of housing a different option for farming programs; either a high-tech chemistry lab growing kale using robotics or an apricot tree being grown in soil using more traditional farming methods. This flexibility is demonstrated in the various programs within the farmscraper: an underground train station plugs into the subway system, the innermost layer containing the livestock farming, the middle layer containing the crop farming and the outermost layer containing the non-farming programs (Figure 26).

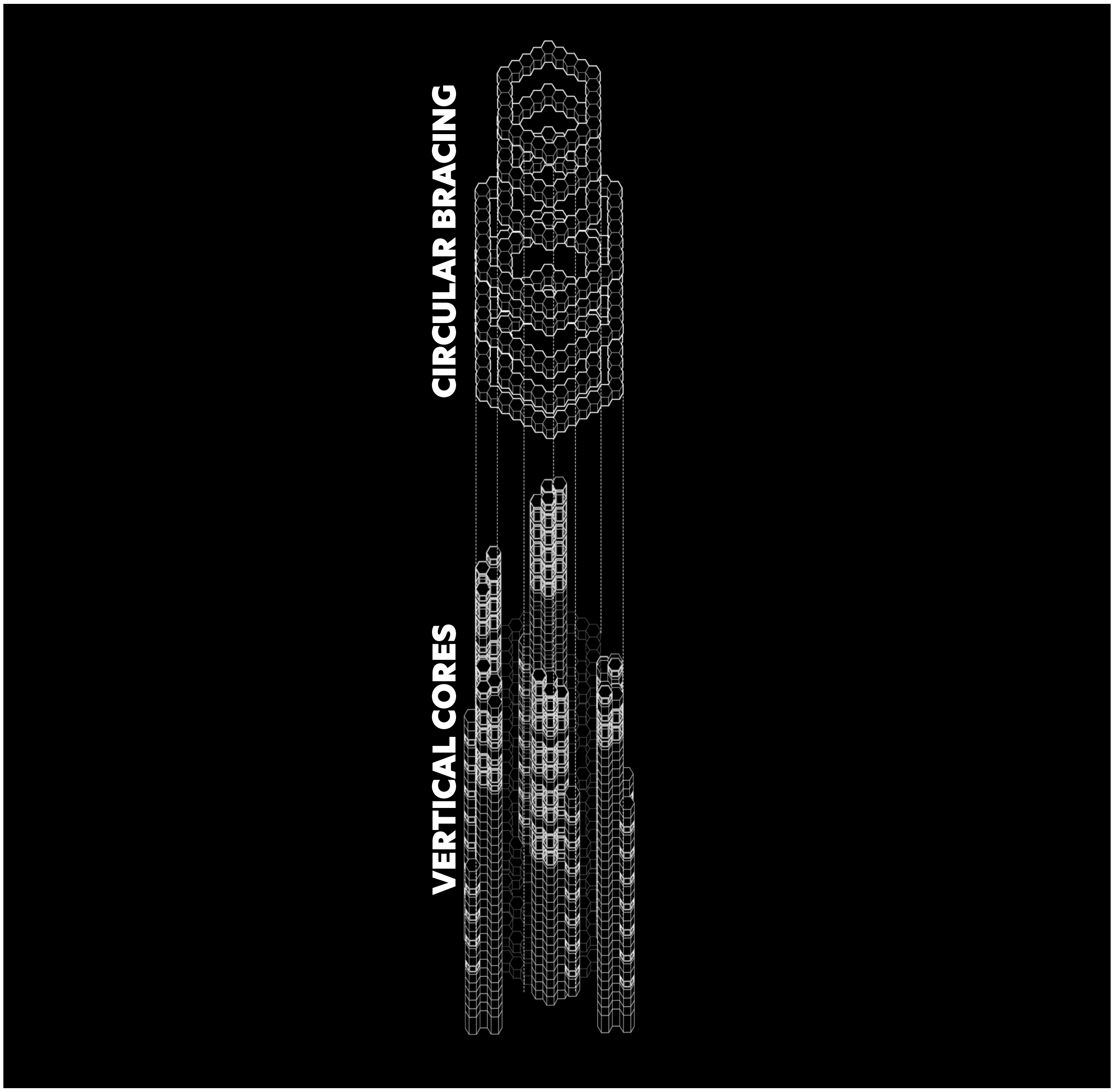

Figure 25: Structural diagram

Manhattanism inspires the programmatic layout of the building; this is the part of the project that infuses the manhattan skyscraper building typology into the metabolic farmscraper. According to Rem Koolhaas's definition of Manhattanism, the exoskeleton of the building contains programs that reflect its context to camouflage the interior, which has something unexpected; in this case, a vertical farm (Koolhaas 1994, 82-105). Manhattanism is applied to the farmscraper in the following areas. First, the building

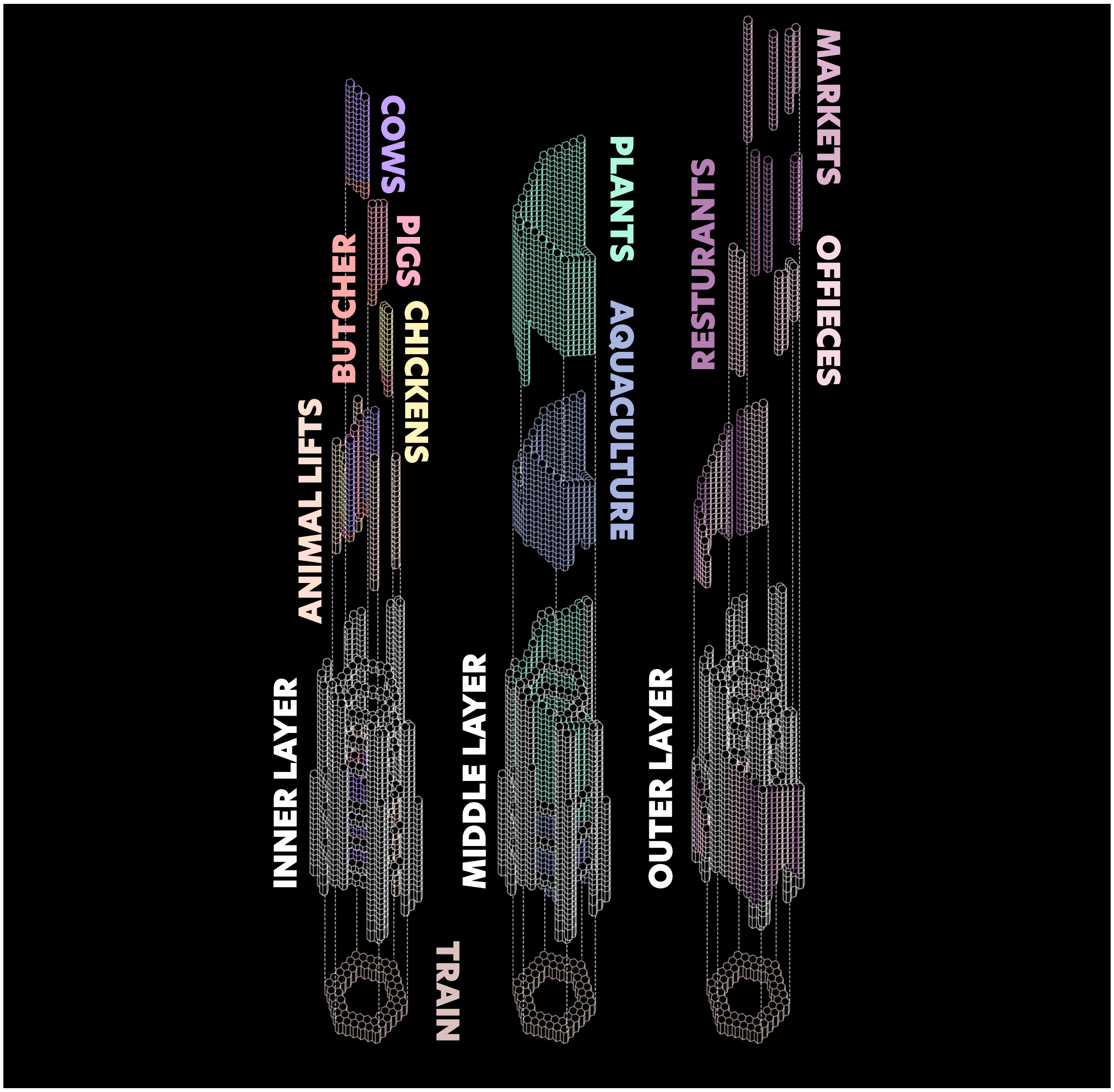

Figure 26: Program layout diagram

adheres to its neighbouring skyscrapers' "automonument" quality through its programmatic layout. The non-farming programs wrap around the livestock, aquaculture and plant farms, distinguishing between external and internal spaces. Unlike the architectural lobotomy, they are distinct and not separate. The porosity between the rooms allows cross-programming between the farming and non-farming spaces.

The innermost layer of the building houses livestock farming, which contains animal lifts that move the animals throughout

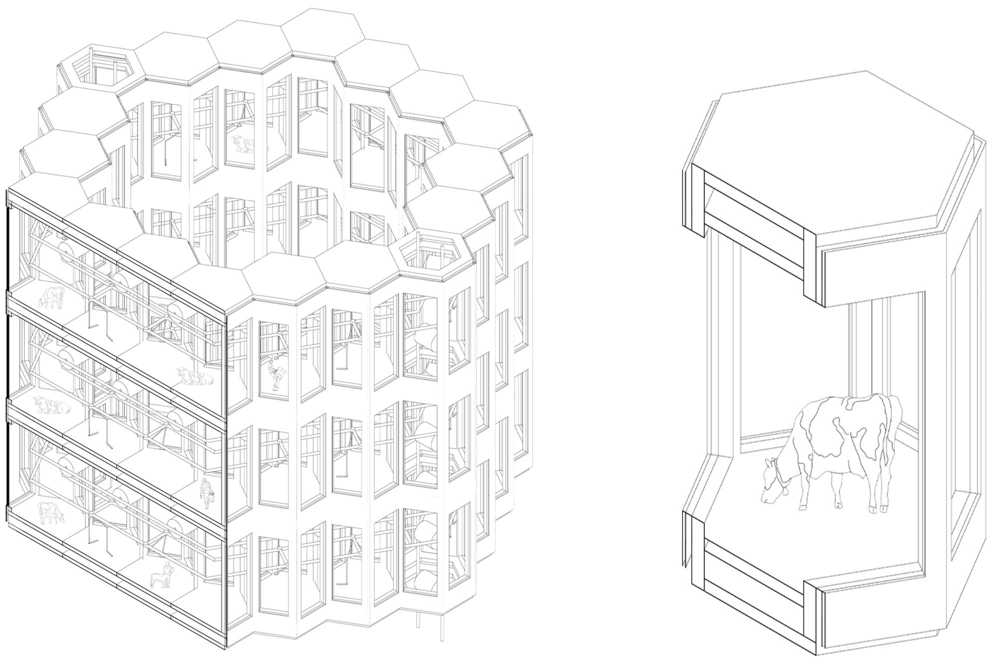

Figure 27: Livestock spaces in metabolic farmscraper (left) compared to industrial farming standards (right)

the building for fertilization and waste management of crops. These animals have the potential to house 513 cows, 1,964 pigs and 1,661 chickens at maximum capacity. At roughly 23sqm, the capsules housing these animals are designed to provide up to more than 20x the space that is typically afforded to chickens (K&H Pet Products 2020); 3x more space typically afforded to pigs (The Pig Site 2016); 4x more space typically afforded to cows (Briggs 2021). Plus, the animals have the freedom to roam throughout some regions of the building and the Battery Park itself. The middle layer of the building houses crop farming; this includes aquaculture and plant farming. Below is the fish tank for aquaculture that provides fertilizer for the plant farming above. Finally,

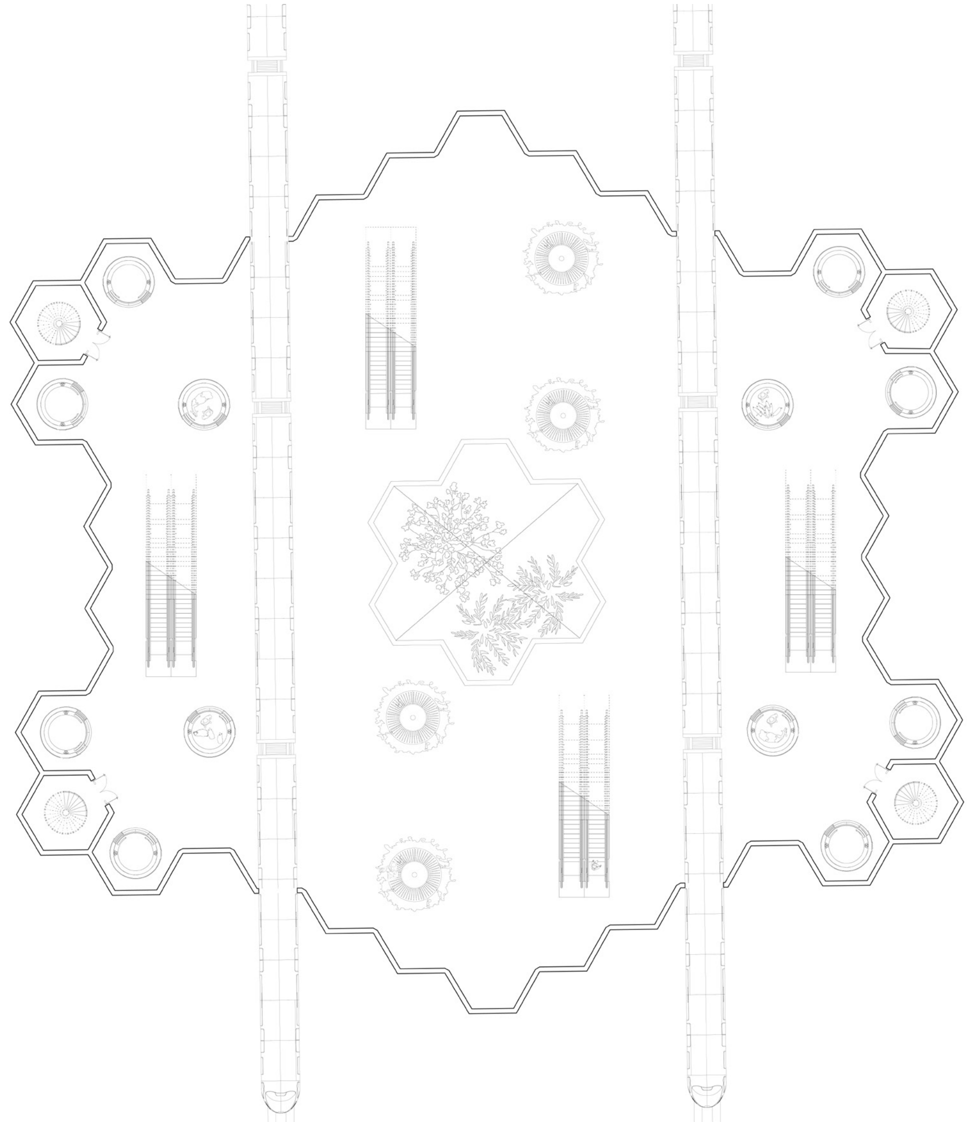

Figure 28: Underground level plan

all the city programs, such as offices, retailers and markets, exist on the outer layer of the building. A permeability exists between all layers, which is evident in the final ingredient of the metabolic farmscraper: the notion of circularity. This aspect of the project investigates how these farming and non-farming programs co-exist and mutually benefit from one another. It also begins to illustrate how farming can become a part of everyday life in the city.

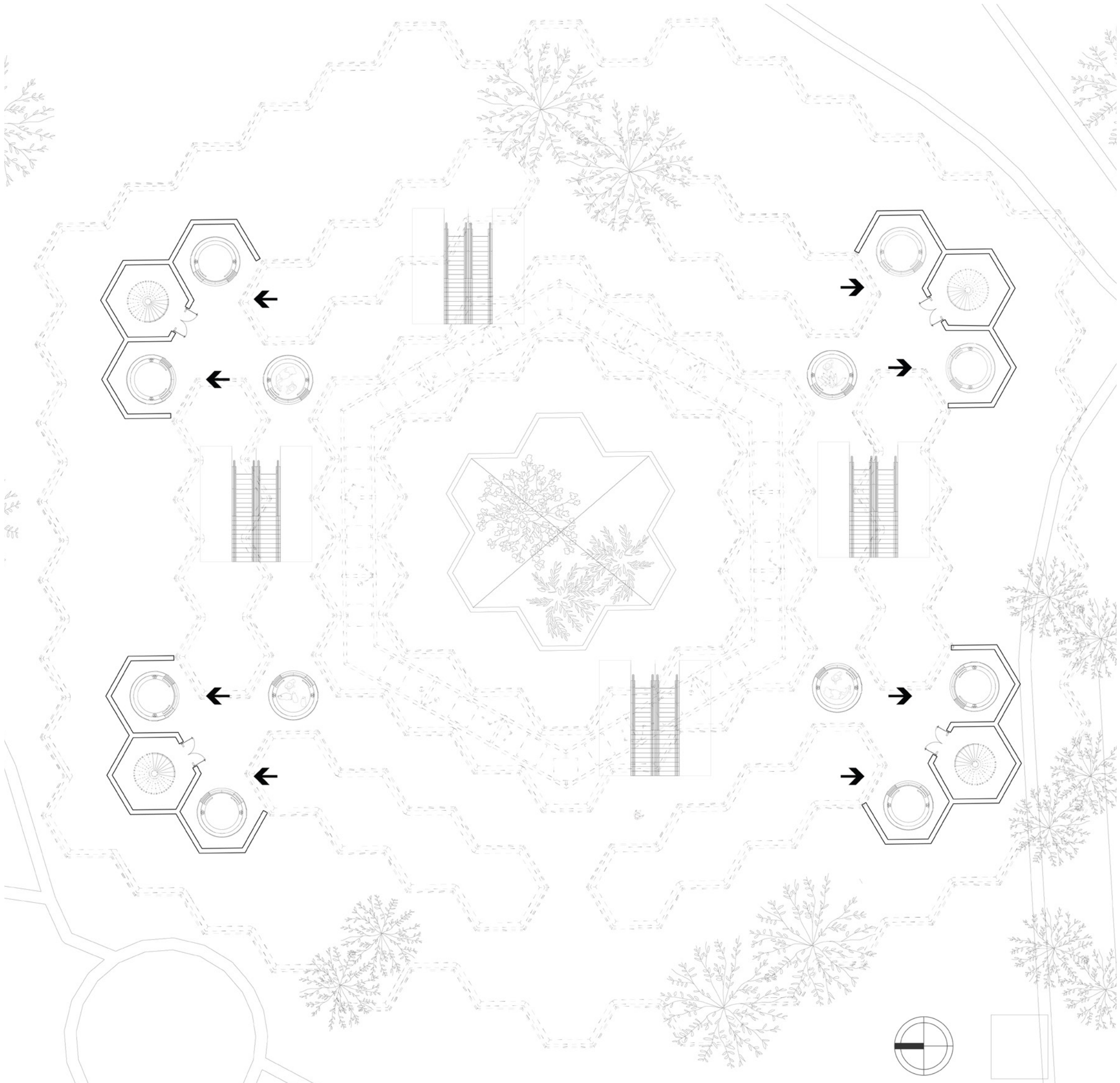

Figure 29: Ground level plan

S: Detail Strategy

The third ingredient of the metabolic farmscraper is the idea of circularity. This motif showcases that the metabolic systems within the building work together, creating a closed-loop system. The concept of circularly exists on all levels of the building, from the underground portion plugging into the metro station to the ground level that engages with the

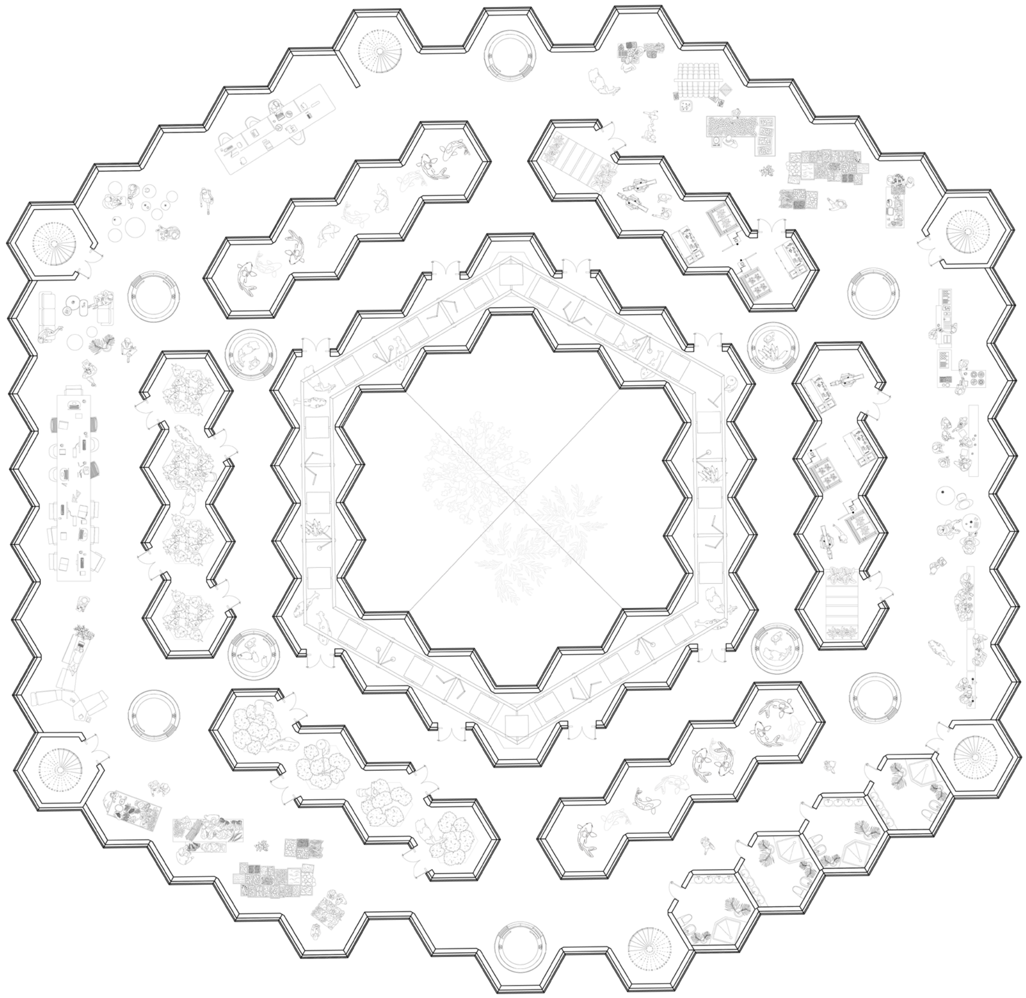

Figure 30: Floor plan of farming and non-farming program layout

site. The section suggests that the farmscraper's ability to plug into the existing transportation system across the entire city makes the building akin to one sizable, interconnected organism. For example, the underground transit can be used to transport animals or fertilizer from one farm to the next, meaning all one-hundred and sixty farmscrapers work together. Furthermore, within the courtyard of the building is an opportunity for the public to interact with the farm animals, which offers further learning opportunities on farming. It is

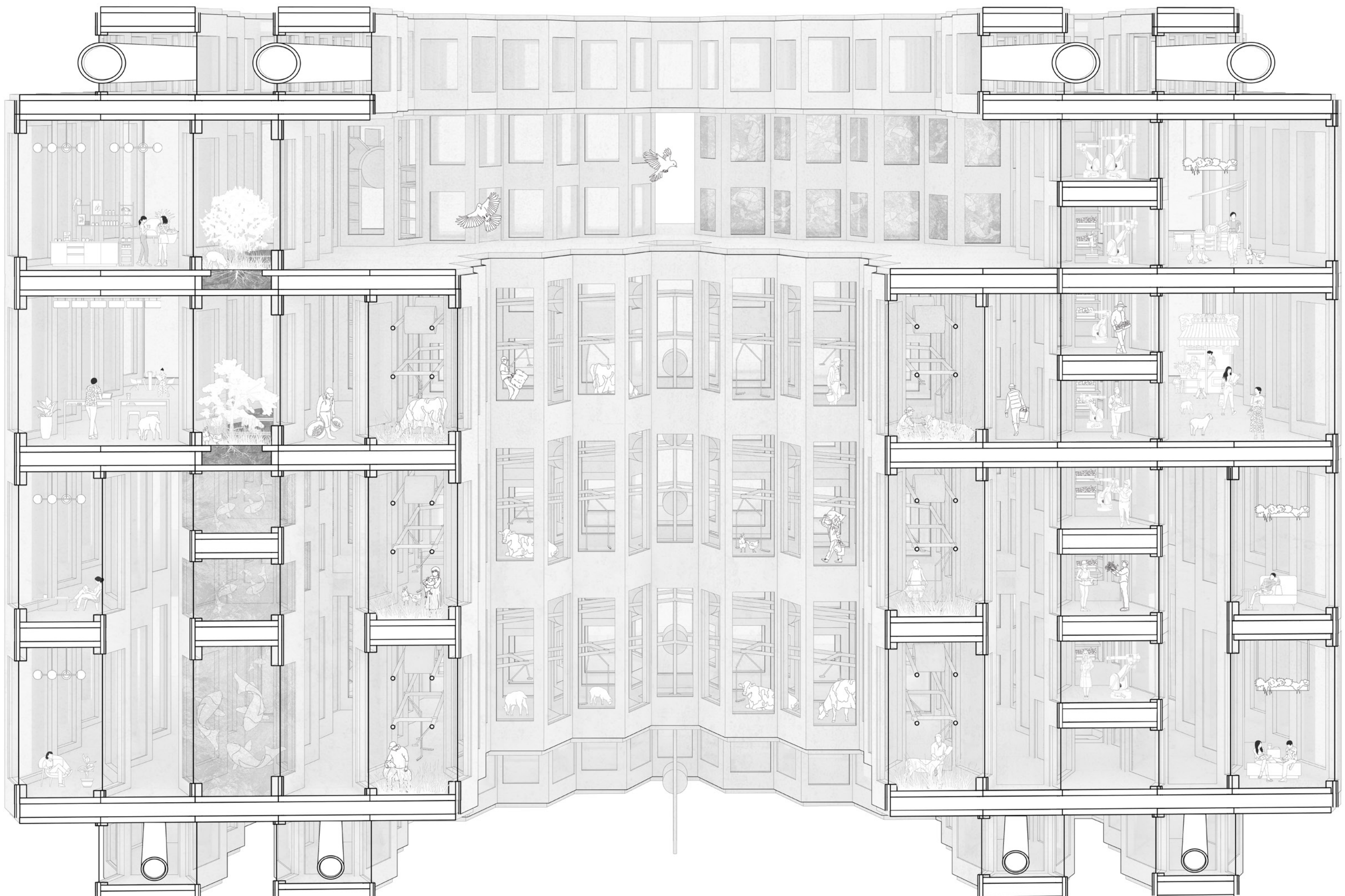

Figure 31: Section demonstrating building systems

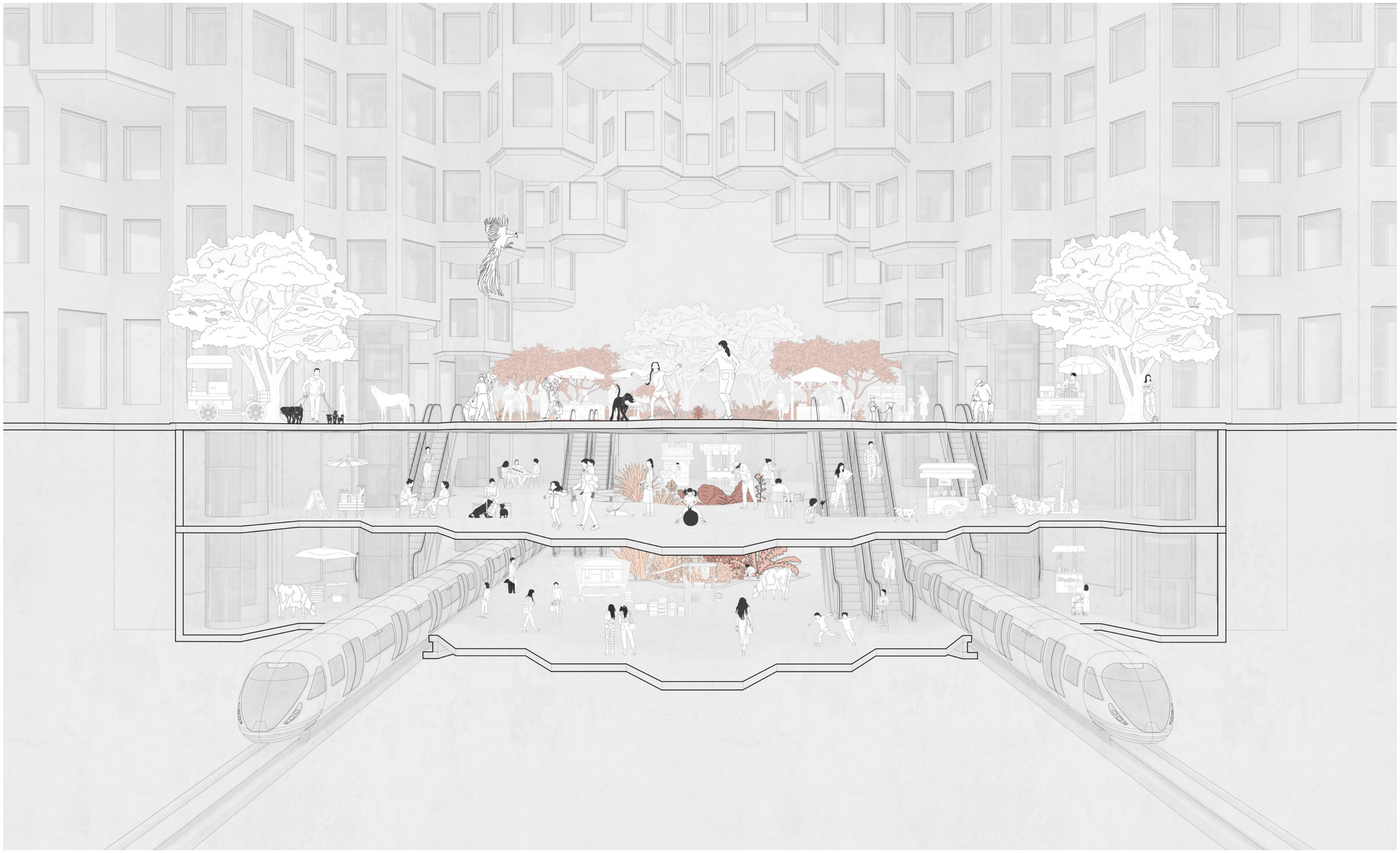
Figure 32: Underground section

also a slightly more humane approach to livestock farming as the animals receive social interaction and the freedom to roam the park. Their grazing of the park benefits the park's ecosystem, making it an even richer greenspace. The concept of circularity is even more present within the building, especially at the systems level. The section highlights how the farming programs can begin to interact with people occupying the space in their offices, markets or restaurants. The livestock farming is placed in the center of the building as it is crucial for supplying fertilizer and waste management for the plant farming. Within these capsules are conveyor belts that circulate hay, the food for the animals. It also contains conveyer belts circulating water for the animals and tools for the farmers to handle their waste. The animals have the freedom to move into the spaces growing agriculture in soil, where the animals can graze and fertilize the crops. The soil is stored in the space that would typically house mechanical, further emphasizing the flexibility of the modular capsule. Neighbouring offices and restaurants have the opportunity to engage with the animals and witness the growing processes if they wish to do so. Below the soil-based crop farming lies the aquaculture; the fishtanks are strategically placed under the spaces housing the soil so that the mechanical system running in-between the fish tanks can redistribute that water to the soil above; essentially fertilizing the plants. This idea can be thought of as a large-scale aquaponics system. Alternatively, plants can be grown using a high-tech farming method that involves using conveyor belts that circulate plants up all levels for each scientist to apply their chemical processes as the plants move up the building. Neighbouring markets and restaurants can pick food from these conveyor belts as well.

Chapter 5: Conclusion

This research began by investigating the feasibility of feeding the most densely populated American city, New York City, through a single building typology. The thesis reveals that while a single metabolic farmscraper is far from reaching its goal of feeding the targeted population of 16 million New Yorkers, it instead explores a prototype for attempting to tackle all three types of farming in one building. The current literature around farmscrapers, namely Despomier's research, investigates exclusively growing plants in a tower; however, a tower dedicated to producing fruits and vegetables only meets one aspect of people's diets. Instead, the farmscraper proposed in this thesis explores merging all three types of farming (i.e., plants, aquaculture and livestock) into a single building to test the viability of farming all food groups within a tower. Furthermore, it offers an opportunity to understand how these different types of farming can function as a system. One could imagine that of the one-hundred and sixty estimated farmscrapers needed to feed NYC, a number of them could be dedicated to exclusively growing plants, aquaculture or livestock. For example, the wastes produced from the livestock and aquaculture farmscrapers could be transported via railway to aid in growing crops in the plant farmscrapers. This allows enough food to be produced in all areas of people's diets and the metabolic outputs from each type of farming to be recycled to aid in growing other foods. Furthermore, this thesis offers an idea of how farming and non-farming programs can co-exist in the city and make agriculture a part of everyday life.

References

Amoros, Raul. 2019. “The Most Valuable Agricultural Commodity in Each State.” HowMuch.net. https://howmuch.net/articles/the-most-valuable-agricultural-commodity-per-each-state.

The B1M. 2018. “How Tall Buildings Tame the Wind.” YouTube. https://www.youtube.com/watch?v=tHMPR7flpf4.

Briggs, Nathan G. 2021. “Beef Cow Pen and Bunk Spacing Requirements.” Penn State Extension. https://extension.psu.edu/beef-cow-pen-and-bunk-spacing-requirements.

Callebaut, Vincent. 2009. *View of the Vertical Farm from the Queensboro Bridge*. Vincent Callebaut Architectures. https://vincent.callebaut.org/zoom/projects/090429_dragonfly/dragonfly_pl024.

Cameron, Sinead. 2018. “Swarm City: An Emerging Transdisciplinary Architecture.” *ResearchGate*, 1–87. https://doi.org/10.13140/RG.2.2.10995.68648.

Chamberlain, Lisa. 2007. “Skyfarming.” *New York Magazine*, March 30, 2007. https://nymag.com/news/features/30020/.

Cheng, Aaron. n.d. Map of NYC. Google Map Customizer. Accessed June 27, 2022. http://www.chengfolio.com/google_map_customizer.

City of New York. 2016. “Five Borough Food Flow: 2016 New York City Food Distribution & Resiliency Study.” https://www1.nyc.gov/site/foodpolicy/reports-and-data/five-borough-food-flow.page.

Cohen, Nevin, Johannes S.C. Wiskerke, and Saline Verhoeven. 2018. *Flourishing Foodscapes: Designing City-Region Food Systems*. Amsterdam: Valiz.

Despommier, Dickson D. 2010. *The Vertical Farm: Feeding the World in the 21st Century*. 1st ed. New York: Picador.

“Dragonfly Future Metabolic Farm for Urban Agriculture.” 2009. MGS Architecture. Sept.1, 2009. https://www.proquest.com/magazines/dragonfly-future-metabolic-farm-urban-agriculture/docview/218391599/se-2?accountid=10406.

Gardner, William O. 2020. *The Metabolist Imagination: Visions of the City in Postwar Japanese Architecture and Science Fiction*. Minneapolis, MN: University of Minnesota Press.

“How Much Space Do Chickens Need?” 2020. K&H Pet Products. https://khpet.com/blogs/farm/how-much-space-do-chickens-need.

Koolhaas, Rem. 1994. *Delirious New York: A Retroactive Manifesto for Manhattan*. New York: Monacelli.

Kubrick, Stanley, director. 1968. *2001: A Space Odyssey*. Film. Warner Bros. Entertainment. https://www.youtube.com/watch?v=mbmzyo1pLas.

Lerner, Ivan. 2008. “Up on the Farm.” *ICIS Chemical Business* 274, no.7: 46. https://www.proquest.com/trade-journals/up-on-farm/docview/203563071/se-2?accountid=10406.

Lin, Xiaowen, Paul J. Ruess, Landon Marston, and Megan Konar. 2019. “Food Flows between Counties in the United States.” *Environmental Research Letters* 14, no. 8: 1-14. https://doi.org/10.1088/1748-9326/ab29ae.

Lin, Zhongjie. 2010. *Kenzo Tange and the Metabolist Movement: Urban Utopias of Modern Japan*. London: Routledge.

Lin, Zhongjie. 2011. “Nakagin Capsule Tower Revisiting the Future of the Recent Past.” *Journal of Architectural Education* 65, no.1: 13–32. http://www.jstor.org/stable/41319216.

Maas, Winy. 2001. Rendering of Pig City. MVRDV. https://www.mvrdv.nl/projects/134/pig-city.

Maas, Winy, Cord Siegel, and Robert Wall. 2001. Pig City. MVRDV. Vimeo. https://vimeo.com/300779037.

Mohr, Rolf, and Chris Jacobs. 2007. Interior of Vertical Farm. *New York Magazine.* March 30, 2007. https://nymag.com/news/features/30020/.

Pernice, Raffaele. 2009. “Japanese Urban Artificial Islands: An Overview of Projects and Schemes for Marine Cities during 1960-1990s.” *Journal of Architecture and Planning* (Transactions of AIJ) 74, no.642: 1847–55. https://doi.org/10.3130/aija.74.1847.

The Pig Site. 2016. https://www.thepigsite.com/articles/how-to-farm-pigs-housing.

Rankin, Bill. 2007. “Crops.” Map. Radical Cartography . http://www.radicalcartography.net/index.html?crops.

Surman, Steven. 2015. “Chris Jacobs And Vertical Farming In Theory And Design.” *Steven Surman Writes*. Blog. February 15, 2015. https://www.stevensurman.com/chris-jacobs-vertical-farming/.