

**Agricultural Transparency:
Reconnecting Urban Centres With Food Production**

by

Jon Ellis

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for the degree of Master of Architecture

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CONTENTS

Abstract	vi
Glossary	vii
Acknowledgements	xi
Chapter 1: Introduction	1
Thesis Question.....	1
Farming Throughout History	1
Why is there a Need for Alternatives to Modern Agriculture?	2
Vertical Farms and What they Can Offer Us	4
Why there Needs to be Food Production in Communities.....	6
Choosing an Appropriate Site.....	7
Considerations.....	10
Chapter 2: Design.....	11
Thesis	11
Site Analysis	13
Site.....	13
Waterfront Access.....	16
Renewable Resources.....	18
City Greens: The Hub.....	20
Public Engagement and Circulation.....	20
Growing	28
Distribution.....	30
Program Development.....	33
Building Façade	40
Building Structure	44
Chapter 3: Summary	48
Appendix A: Disadvantages of Modern Agriculture	50
Appendix B: Advantages of Vertical Farms	51
Appendix C: Statistics on Water Shortages.....	52
Appendix D: Hydroponic Systems	53
Appendix E: Water.....	57

Appendix F: Solar	59
Appendix G: Solar Aquatics.....	61
Appendix H: ETFE (ethylene-tetra-fluoro-ethylene) Design and Benefits	63
Appendix I: Case Studies	65
Appendix J: City Greens Food Production Per Capita	70
Appendix K: Thesis Presentation	73
Notes	74
References	77

ABSTRACT

In North America, industrial agriculture has led to cheap abundant food while separating direct links between the city and countryside. This thesis attempts to use architecture to reconnect people in Manhattan, New York City, with food production and serve as a model for sustainability. The thesis analyzes Manhattan's food network, and seeks a site which has the potential for several factors: site accessibility, renewable resources, solar exposure, and integration into the community. These factors serve as the basis in which to build a hybrid prototype that is able to expose people to the process of food production through a combination of traditional outdoor farming methods and indoor hydroponics in the form of a vertical farm. Farmers and customers can be seen together as one entity instead of two disconnected dependencies. The reintegration of food production into the city can be seen as a re-alliance of the country and the city.

GLOSSARY

Aeroponics: a plant-cultivation technique in which the roots hang suspended in the air while nutrient solution is delivered to them in the form of a fine mist. - Oxford Dictionaries.com, 2012

Agrochemicals: A chemical used in agriculture, esp. a biologically active one such as a weed killer or a fungicide. - Oxford English Dictionary, 2012

Agricultural hub: A central node within an urban centre where many different food networks and systems overlap.

Agricultural run-off: The movement of agricultural chemicals (nitrates, phosphates, pesticides, herbicides etc.), sediment, and pathogens via surface water runoff into water bodies. Runoff is a major contributor to wetland degradation and ground water reserves.

Bato bucket system: A hydroponic technique where plants grow in perlite contained in a bucket called a “bato bucket.” Nutrient rich water is from circulated through emitters in the perlite, and the overflow of water is recirculated back to a reservoir.

Complete automization: Not requiring the involvement of humans to complete a specific operation.

Esplanade: A level open area serving as a public space along a waterfront’s edge.

ETFE (ethylene-tetra-fluoro-ethylene): A man-made fluoropolymer. Its principal ingredient is fluorite, a common mineral, which is combined with hydrogen sulphate and trichloromethane. These ingredients make chlorodifluoromethane, that by pyrolysis, yields tetrafluorethylene (TFE), a colorless, odorless gas that is joined with ethylene to make the ETFE copolymer. ETFE resin is produced either in powder form or compressed into pellets. - LeCuyer, 2008

Eutrophic: The process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates. These typically promote excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decompos-

ing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish. Eutrophication is a natural, slow-aging process for a water body, but human activity greatly speeds up the process. - United States Geological Survey, 2012

Flood irrigation: When water is pumped or brought to the fields and is allowed to flow along the ground among the crops. This method is simple and cheap, and is widely used by societies in less developed parts of the world as well as in the U.S. The problem is, about one-half of the water used ends up not getting to the crops. Traditional flood irrigation can mean a lot of wasted water. - United States Geological Survey, 2012

Food miles: The distance between the place where food is grown or made and the place where it is eaten. - Cambridge Dictionaries Online.org, 2012

Hydroponics: The process of growing plants without soil, in beds of sand, gravel, or similar supporting material flooded with nutrient solutions. - Oxford English Dictionary, 2012

Hypoxia: A condition in which dissolved oxygen is below the level necessary to sustain most animal life - generally defined by dissolved oxygen levels below 2mg/l [milligrams/litre] (or ppm [parts per million]). - US Geological Survey, 2012

Light wells: An open area or vertical shaft in the centre of a building, typically roofed with glass, bringing natural light to the lower floors or basement. - Oxford Dictionaries.com, 2012

Modern agriculture: Also known as industrial agriculture. A form of modern farming that refers to the industrialized production of livestock, poultry, fish, and crops. The methods of industrial agriculture are techno-scientific, economic, and political. They include innovation in agricultural machinery and farming methods, genetic technology, techniques for achieving economies of scale in production, the creation of new markets for consumption, the application of patent protection to genetic information, and global trade. These methods are widespread in developed nations and increasingly prevalent worldwide. Most of the meat, dairy, eggs, fruits, and vegetables available in supermarkets are produced using these methods of industrial agriculture. - Wikipedia.com, 2012

Monocultures: The cultivation or exploitation of a single crop, or the maintenance of a single kind of animal, to the exclusion of others. - Oxford English Dictionary, 2012

Nutrient film technique: A technique used in hydroponics, where a continuous flow of nutrient solution is circulated over exposed plants roots. The plants are usually grown in channels to permit the flow of water.

Perlite: A glassy volcanic rock containing numerous concentric spheroidal cracks associated with the cooling that occurred during its formation (also called pearlstone); any volcanic glass that expands on heating to give a porous material, used in insulation, plant growth media, etc. - Oxford English Dictionary, 2012

Photovoltaics: Relating to, involving, or utilizing the generation of a voltage at the junction of two substances exposed to light. - Oxford English Dictionary, 2012

Regenerative braking: A method of breaking that involves storing the kinetic energy of a vehicle or object slowing down.

Solar aquatics: The treatment of wastewater through an engineered system that mimics the natural purification process of wetlands, streams, and meadows.

Vertical farming: The concept cultivating plant or animal life within skyscrapers, or on vertically inclined surfaces.

(Cambridge Dictionaries Online, s.v. “food miles,” 2012, <http://www.dictionary.cambridge.org>)

(Oxford Dictionaries, s.v. “aeroponics,” 2012, <http://www.oxforddictionaries.com>)

(Oxford Dictionaries, s.v. “light wells,” 2012, <http://www.oxforddictionaries.com>)

(Oxford English Dictionary, s.v. “agrochemicals,” 2012, <http://www.oed.com>)

(Oxford English Dictionary, s.v. “hydroponics,” 2012, <http://www.oed.com>)

(Oxford English Dictionary, s.v. “monocultures,” 2012, <http://www.oed.com>)

(Oxford English Dictionary, s.v. “perlite,” 2012, <http://www.oed.com>)

(Oxford English Dictionary, s.v. “photovoltaic,” 2012, <http://www.oed.com>)

(United States Geological Survey, s.v. “eutrophic,” 2012, <http://www.usgs.gov>)

(United States Geological Survey, s.v. “flood irrigation,” 2012, <http://www.usgs.gov>)

(United States Geological Survey, s.v. “hypoxia,” 2012, <http://www.usgs.gov>)

(Wikipedia, s.v. “modern agriculture,” 2012, <http://www.wikipedia.com>)

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CHAPTER 1: INTRODUCTION

Thesis Question

Does architecture have the potential to reconnect people in urban centres with food production, while also serving as a model for sustainability?

Farming Throughout History

Throughout history, farming has always been closely linked to urban centres, much more so than we care to think today. As the social historian Fernand Braudel remarked, “Town and country never separate like oil and water. They are at the same time separate yet drawn together, divided yet combined.”¹ Carolyn Steel points out that “City dwellers in the past had no choice but to acknowledge the role of food in their lives. It was present in everything they did.” Food and animal livestock used to be all around us everyday therefore there was no question of where your food was coming from. Today, however, we have forgotten where our food comes from and it seems to appear in front of us whenever we need it. We have arrived at the point where we no longer even associate food with nature. By the 19th century supplying the city with food seemed to be solved and eventually became a question of how much it would cost to feed cities rather than if they could.² Steel says: “As far as urban consumers were concerned, all the ancient fears about food – the fertility of the soil, the sun and the rain, the strength of the harvest – translated into one concern: the size of their weekly shopping bill.”³

By looking at medieval city plans, one could assume that they are irrationally laid out, but that is not the case. Carolyn Steel explains how food structured medieval city grids and patterns using London as an example: “Food shaped London ... as a way of engendering life and urban order, few things work half as well.”⁴

During the World Wars, American farms were not able to produce enough food for the country. This shortfall led the federal government to start a campaign to get Americans to start growing food on their own front lawns. During World War I and World War II, these front lawn gardens became known as “War Gardens” and “Victory Gardens” respectively.⁵ The architect Fritz Haeg writes that “by the end of World War II, over 80 percent of Amer-

ican households were growing some of their own food.”⁶ Despite this amazing power of independence the American people tapped into, they seemed to quickly forget about it after the war and missed the larger picture of what they had created. However, we can't blame them for the direction they took. Fritz Haeg continues to write that “our elders had every right to celebrate the comforts and conveniences of industrial progress. Its hidden long-term costs and a blind faith in its capacity to solve any problem created a sense that things could only get better.”⁷

Why is there a Need for Alternatives to Modern Agriculture?

In North America, food has never been more readily available in any other time in history, nor has it been cheaper. It seems to arrive here as if by magic; apples from New Zealand, oranges from California, figs from Egypt, and fish from Alaska. The fact that one can buy apples at a lower or equal price from across the world in New Zealand is indicative of how economically successful industrial farming and global trade have become. This luxury in which we participate started with the industrial revolution and continued to improve with the advent of better and more sophisticated technology and transportation. After the Industrial Revolution, the introduction of agrochemicals (pesticides, herbicides, insecticides, etc.), genetically modified organisms (GMOs), and monocultures helped to rapidly speed up food production. In combination with these new technologies, the availability of cheap oil over the last few decades has been an enormous factor on industrial agriculture, resulting in cheap, abundant food. As Carolyn Steel puts it, “We are essentially eating oil.”⁸ Each year every American consumes around four to eight barrels of oil, which has gone into producing the food they eat. In the USA, more than 20 percent of the fossil fuels burned goes to agricultural uses. Carolyn Steel describes the modern agribusiness by saying: “For every calorie of food it produces, it is burning an estimated 10 in the form of fossil fuels. Modern farming might like to call itself efficient, but with outputs like that, it is a strange kind of efficiency.”⁹ Oil prices are undoubtedly going to continue rising as the amount of remaining oil diminishes, which in turn will lead to higher food prices. A food review by the US Department of Agriculture gives a surprising statistic: Between 1985 and 2000 the retail price of fresh fruits and vegetables changed 118 percent.¹⁰

Currently, one of the main resources that we as an industrial nation are wasting is water, with global agricultural consuming 70 percent of all the available fresh water (see Appendix C: Statistics On Water Shortages, for a diagram of the world's available fresh water). This is because most farmlands are fed water through flood irrigation, which leads to huge amounts of water evaporation. As the British environmentalist Fred Pearce points out, we may get three times the yield with irrigated farming but we use twice the amount of water. In China, for example, "80 percent of water used in flood irrigation ... is lost to evaporation."¹¹

In the agribusiness, water is referred to as virtual water. Water used for agriculture has become virtual because it is no longer in the end product. For example, a bag of salad takes 300 litres of water, 1 kg of wheat takes 1000 litres, 1 kg of meat consumes 5000-10,000 litres and 1 kg of cotton uses an amazing 30,000 litres of water.¹² This virtual water is a huge problem for developing countries because in developed nations we are able to buy food from these countries for much less than if we were to grow it ourselves. In turn, developing nations use much of their ground water to feed developed nations, in order to make a living. Here is where the effects of the term "virtual water" can be seen, since a lot of these places are short on water to begin with. Steel explains the reasons cities import food that they could have grown themselves: "Foreign growers, with their year-round sunshine and low-cost labour, can deliver apples and onions to us far more cheaply and consistently than we can grow them here – until they run out of water, that is, which some already are."¹³ (See Figure C.1 in Appendix C for a breakdown of available freshwater on the planet.)

As the world was industrialized, the opportunity to waste became easier. Industrialization led to consumerism and the tendency to waste that which we have not worked hard for, with food being no exception. If we had to work hard on the land through the seasons, planting and tilling, much less food would be wasted. Carolyn Steel writes that it is estimated in Britain that one third of all the food bought is wasted (6.7 million tonnes).¹⁴ Steel continues to write, "When we waste food, we waste all the effort, labour, water, sunshine, fossil fuels – even life itself – that went into making it."¹⁵ Therefore, we see more and more evidence of modern agriculture not working every year.

In addition, we are a growing population, especially in the developing countries. According to current statistics, the population is going to reach 9 billion people by 2050.¹⁶ The amount of farm land we use today is equivalent to that of South America and when the year 2050 arrives, we are going to need another landmass the size of Brazil's to meet everyone's basic caloric needs. That much land simply does not exist.¹⁷

There are many other negative issues associated with modern agriculture which can be found in Appendix A: Disadvantages of Modern Agriculture.

Vertical Farms and What they Can Offer Us

All the negative effects described above related to modern agriculture could be alleviated with the development of the vertical farms (a list of advantages can be found in Appendix B: Advantages of Vertical Farms). According to Dickson Despommier, with vertical farming, we will be able to maximize the amount of food grown on one acre of modern farm land by up to 16 times. Despommier calculates that each floor of a vertical farm could offer four growing seasons, double the plant density, and grow two layers of plants per floor—a multiplying factor of 16 ($4 \times 2 \times 2$)¹⁸ (see Figure 1.1). One can see the potential of a vertical farm in dense urban environments where land is at a premium.

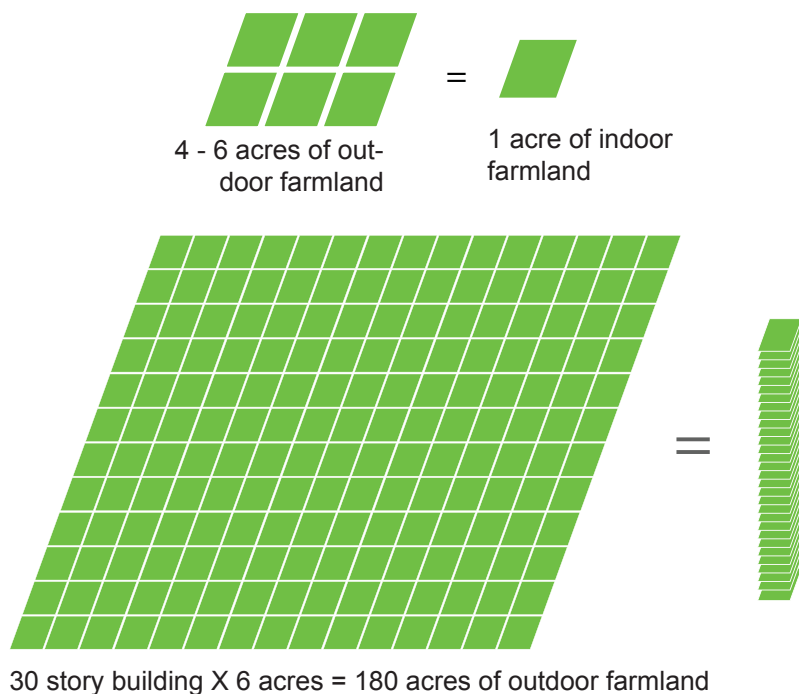


Figure 1.1: Farmland comparisons

Even if industrialized nations continue to use the modern system of agriculture with additives such as agrochemicals, fertilizers, and irrigation, we will not be able to feed the future generations indefinitely, so we need to come up with completely new methods and systems with which to grow food. Many of the major factors in the success of a vertical farm, such as hydroponics, aeroponics, photovoltaics, water purification, etc., are already well researched, and continue to improve and become more efficient through further study. Growing technologies such as hydroponics already use 70 percent less water than modern agriculture and aeroponics use 70 percent less water than hydroponics.

A vertical farm will use the systems currently found in modern hydroponic greenhouses where plants are grown in low-cost polyvinyl chloride (PVC) plastic tubing. Plants do not require soil to grow as long as a reliable source of nutrients is available. The PVC pipes serve as the delivery chamber for nutrient-rich water to run over the roots of the plants; therefore, the plants no longer have to push through heavy earth and compete for nutrients. This nutrient-water is formally known as nutrient film technology. In his book *Hydroponics for the Home Gardener*, Stewart Kenyon writes that “hydroponic plants grow faster, ripen earlier and give up to ten times the yield of soil-grown plants. These clean and pampered plants produce fruits and vegetables of great nutritive value and superior flavour.”¹⁹ The benefit of this system is that all of the water can be recovered, and water lost through transpiration can be collected by means of dehumidification. Recovering the water ultimately does not lead to agricultural runoff like modern agriculture does. Agricultural runoff today is the most destructive source of pollution to the planet. Nitrogen fertilizers used in modern agriculture are a major problem in oceans and rivers, causing hypoxia (severe depletion in oxygen levels). Eutrophic (the increase in biomass of the water) areas can develop as a result of an overload in nutrients as well. When eutrophication occurs large algae blooms can grow and again deplete oxygen levels.²⁰

With the invention of aeroponics by NASA, water conservation has reached an extreme level. Places where water is scarce could greatly benefit from this method because of the amount of water it saves. Instead of using a chamber to run nutrient water on the roots, as in hydroponics, aeroponics employs a fine mist of water laden with nutrients onto the root systems of plants. To keep the humidity at a high level around the roots, the roots are enclosed in chambers instead of piping.²¹

Why there Needs to be Food Production in Communities

By bringing food production back into cities, these urban centres can begin to in-source more of their food instead of the current practice of out-sourcing. Even though we know that one of the most basic resilient strategies for our communities is food production, processing, and consumption, we are failing to incorporate this into our design and planning professions. In the 22nd issue of the *Urban Agriculture Magazine*, Diana Lee-Smith writes, “The process of designing for food production in, and with, communities has the potential for strengthening community cohesion ... Connections between food issues and the built form have the potential to transform not only food production and distribution, but basic assumptions about the programming required in the design of buildings and urban spaces.”²² Examples of this can be seen in Chicago with Growing Home and in Milwaukee with Growing Power which are community-led urban farms.

Currently only one to two percent of the food grown in America is grown locally,²³ and locally generally means community involvement. This is quite a small number considering that about 70 percent of the world’s population lives in urban centres. It is important for urban communities to produce food themselves because their involvement makes them a part of the change. When more of the community is involved, there is a greater sense of ownership and they will work hard to see that the farm succeeds. In turn, this will help the program grow and gain the public’s acceptance of this new urban agriculture movement.

This thesis asserts that there is a dire need to start bringing the production of food back into urban centres in one form or another, whether as city plots of organic farms, hydroponics, rooftop gardens, or individual window planters. Urban farming is something that is already gaining momentum and vertical farming can play a role in this movement. A vertical farm is just one of many options, but it is the one that I would like to explore because of the need to look at it from an architectural point of view.

Choosing an Appropriate Site

Choosing an appropriate site requires the balance of several factors: accessibility, solar exposure, renewable resources, and the density of the urban area. The building must be able to integrate with the site, while also involving the community and giving back to the residents. One of the main reasons I chose Manhattan, New York, is because Manhattan (see Figure 1.2) is one of the most populous metropolitan areas in the world. (NYC 2010 United States Census put the population at 1,585,873.) I will show how building within Manhattan's density is appropriate and how it is possible to incorporate the community. By building here I will also be improving the urban condition that exists. As Rem Koolhaas wrote in his book *Delirious New York*, in Manhattan, a building can be experimental and iconic.²⁴ He continues by writing about the Manhattan grid and how "each of these sites is to meet its own programmatic destiny – the skyscraper is the instrument of a new form of unknowable urbanism."²⁵ What Koolhaas writes is true because, in essence, I will be creating a prototype for a new form of urban program that has yet to be seen.

The site I have chosen on Manhattan is in District 6, specifically in the neighbourhood of Murray Hill, along 1st Avenue between E 38 Street and E 41 Street (see Figure 1.3 and 1.4 for aerial photographs of the site). The advantages of designing this new urban program in this location have become apparent after analyzing the site. These advantages take the form of alternative energies, accessibility, renewable resources, the opportunity to address the poor urban site conditions, and the ability to connect to the existing food network of Manhattan. The building will have the ability to integrate itself within the community by directly involving and educating the residents. Fritz Haeg, who wrote a section in *On Farming*, argues that the role of the architect should also include the farmer. Haeg writes that one of the five essentials for a building that farms is that it pays attention: "It understands what is uniquely possible and available in a particular location and figures out how to sustainably transform it into something useful."²⁶ He writes that a second essential is "the building that farms welcomes a new era of active participation."²⁷ These two points - analyzing the site for potential renewable resources to aid in the production of food; and the direct involvement of the community - are the key issues that this thesis aims to address, and will set the framework in which to place the building programs.²⁸

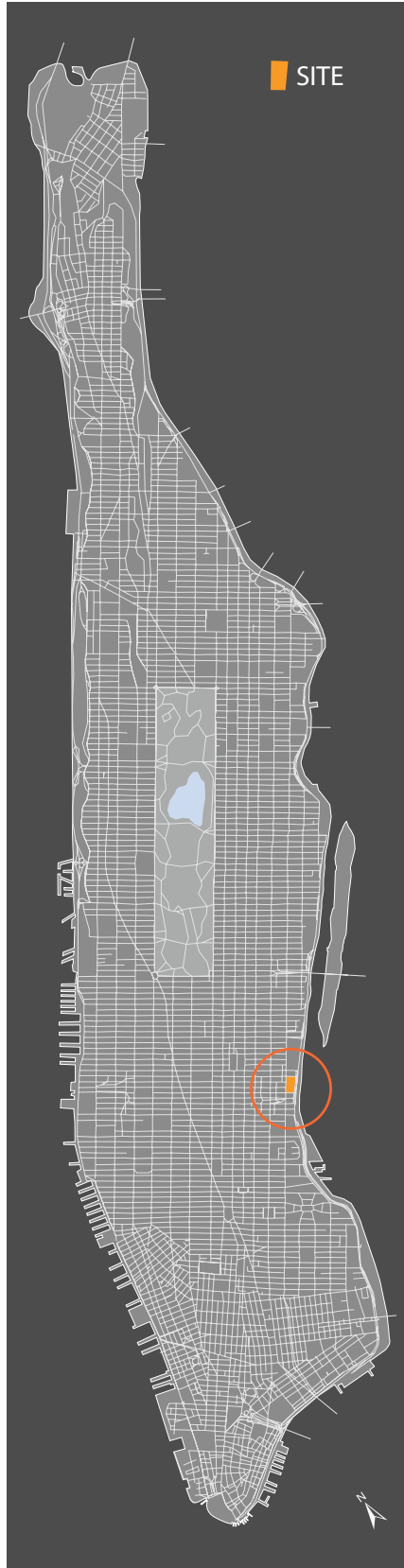


Figure 1.2: Map of Manhattan with the proposed site in orange.



Figure 1.3: Manhattan, NYC. From Bing Maps

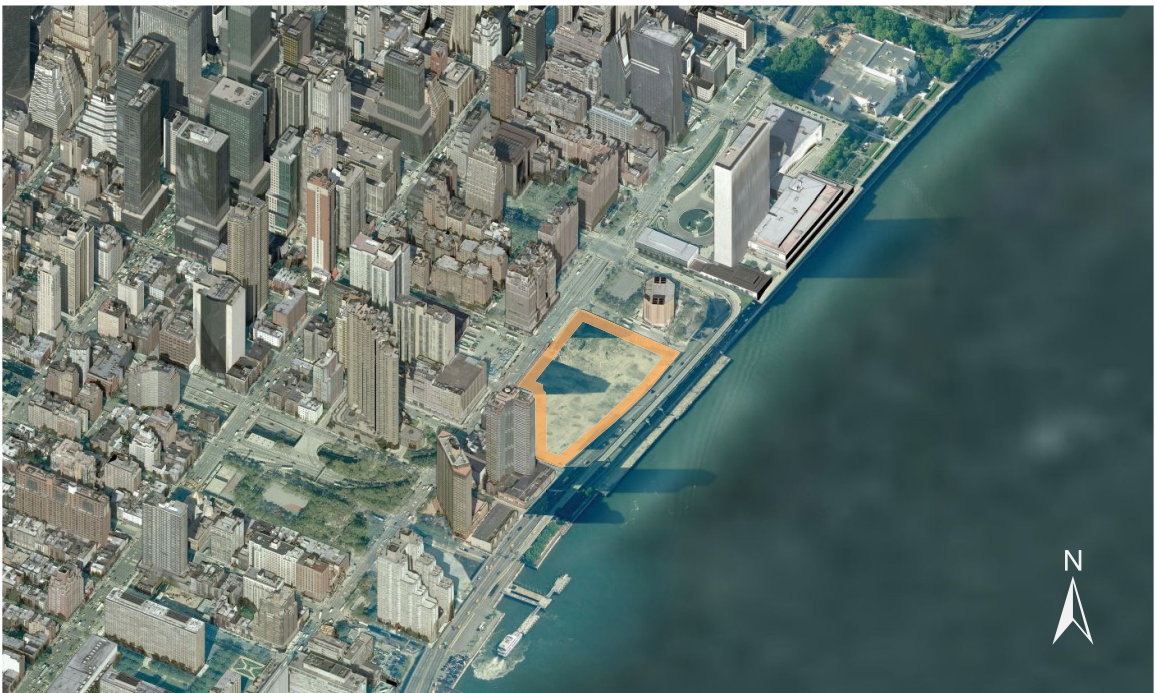


Figure 1.4: Manhattan, NYC. From Bing Maps

Considerations

Currently there have been a handful of proposals for Vertical Farms, and these farms are different than the one this thesis proposes. Some of the proposals that have surfaced so far are more of a straight-up building design that only has one goal in mind: to produce food. These buildings have little regard to the surrounding community and should be seen as more industrial than anything. They also seem to be only designed from an aesthetic point of view, which is counterproductive to the goal of producing food. Building designs advocating the use of sun, photovoltaics, light-wells, complete atomization, etc. do not appear to have truly taken these design issues into account. Sticking giant wind turbines on top of a skyscraper to generate electricity is probably not practical or possible. Even something as simple as designing the building around the solar orientation and the angle of the sun is not apparent in a lot of these concepts. The façades are straight, with a moderate amount of windows, and some of the buildings are rectangular, a bad shape for maximum sun penetration. The design developed in this thesis builds upon what has already been proposed. Rather than designing an industrial and mechanized growing system, which already exists as modern agriculture, this thesis will attempt to humanize the process of food production again by factoring people into the design.

CHAPTER 2: DESIGN

Thesis

The design of this thesis is conceived as a hybrid between urban indoor vertical farming that uses hydroponics and urban outdoor community food gardens. This will be a combination of high-tech and low-tech methods for producing food. The vision for the thesis is to use the idea of exposure and transparency as the driving design factor (aside from solar orientation, which is integral to the design).

Studying the overall food network of Manhattan, as seen in Figure 2.1, has shown how the prototype will be able to better integrate into this network. Also, an analysis of the immediate site for alternative energy resources in order to develop the project in a sustainable manner has been done. The development of an agricultural hub within the city will give an opportunity for the community to grow their own food, be educated, and provide the city with an alternative source of food production.

Generally food production is not undertaken within an urban setting and it is typically run by a few individuals without community involvement. This lack of involvement is because the urban community and the industrialization of food have alienated the process of growing food to the countryside. The city is just as dependent on the country today as it was before the Industrial Revolution. As the population continues to rise alongside climate change, a city's outsourcing of food becomes more environmentally destructive, in turn leading to increased food insecurities such as droughts, floods and so on. These insecurities are the reason reintegrating localized food production is important. The combination of indoor hydroponics and outdoor urban agricultural land will be able to provide a secure food source during increased climate change and population growth, while also re-associating people within the city to where their food originates.

The ambition to re-associate people with food production will be done within a model of holistic sustainability, education, social involvement and health (humans and environment). By involving the community through this process, the hub will be able to take a stronger foothold within the urban centre.

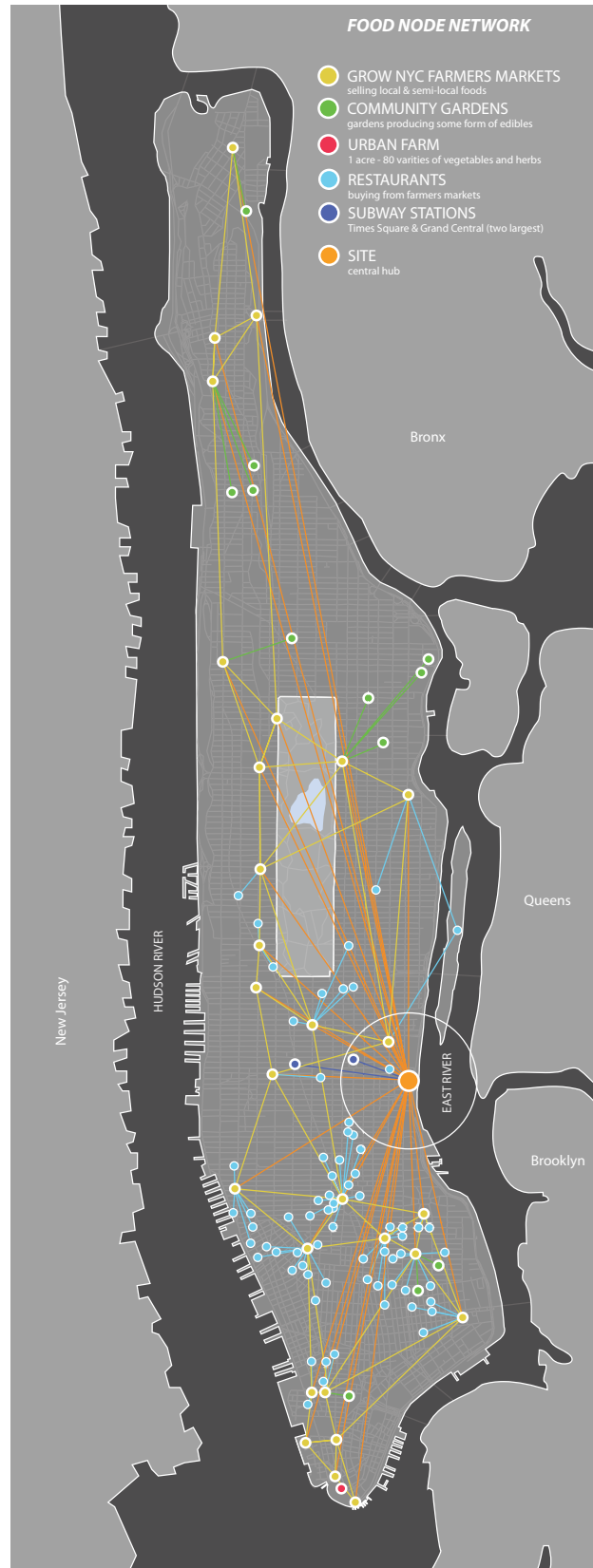


Figure 2.1: Map displaying the site as a central node within the local food network of Manhattan.

Site Analysis

Site

The site is located in Manhattan, New York, specifically in the neighbourhood of Murray Hill along 1st Avenue between E 38 Street and E 41 Street. FDR East River Drive is set between the site and the East River. Immediately surrounding the site are mostly multi-family towers and mixed-use residential and commercial towers. Other buildings include the transportation and utility building; two commercial and office buildings (one being the NYU Medical Centre); Queens Midtown Tunnel Ventilation Shaft (in the form of a building); a parking lot for the now demolished Con Edison Steam Power Plant, which will continue to be used for public parking; and the United Nations International Headquarters (see Figures 2.2 and 2.3 for photographs of the site). Therefore, the area is quite unique but it is mostly residential with an average of 83,740 housing units within the district.²⁹ Nearly 25 percent of the district is multi-family residential units and the district's age group is fairly young as well; 42.6 percent of the population is between the ages of 25 to 44 and 16.1 percent below the age of 25. There is a great potential to educate this younger generation. Unfortunately, within District 6 there is a lack of school seats; as written in the "District Needs Statement For Fiscal Year 2011," "There is a substantial shortfall in school seats for children as well as for after school and support services for children within Community District 6."³⁰ This shortfall could be taken up by the thesis project, offering additional education such as science, greater environmental awareness and attitudes, and better nutritional knowledge.

Looking at how the site currently connects to the rest of the city, it is apparent that it doesn't conform to the overall Manhattan grid of 13 x 156 city blocks (see Figure 2.4). The demolished Con Edison Steam Power Plant, which once dominated the site, spanned 6.5 acres (26,000 square metres), covering three Manhattan blocks. Now that the plant is gone, people on E 38 Street to E 41 Street can see the waterfront of the East River once more. The thesis design intentions will be to keep the lines of sight open to the waterfront to give the appearance of two 3-acre blocks once more.

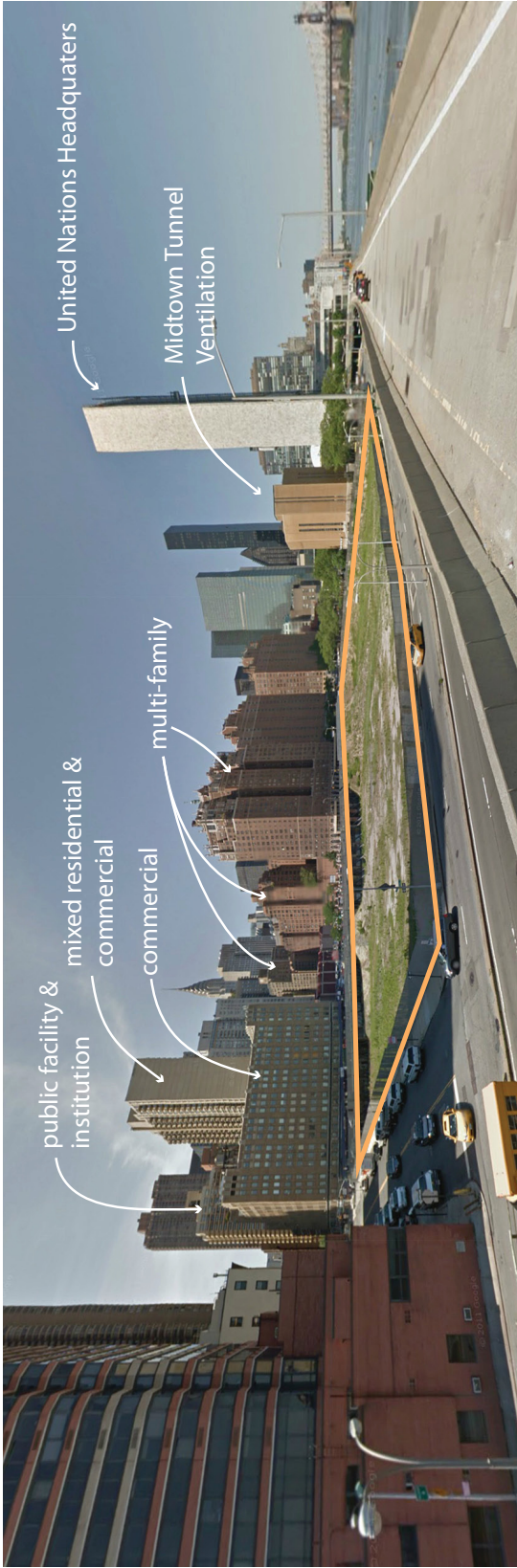


Figure 2.2: Manhattan, NYC. From Google Maps



Figure 2.3: Manhattan, NYC. From Google Maps

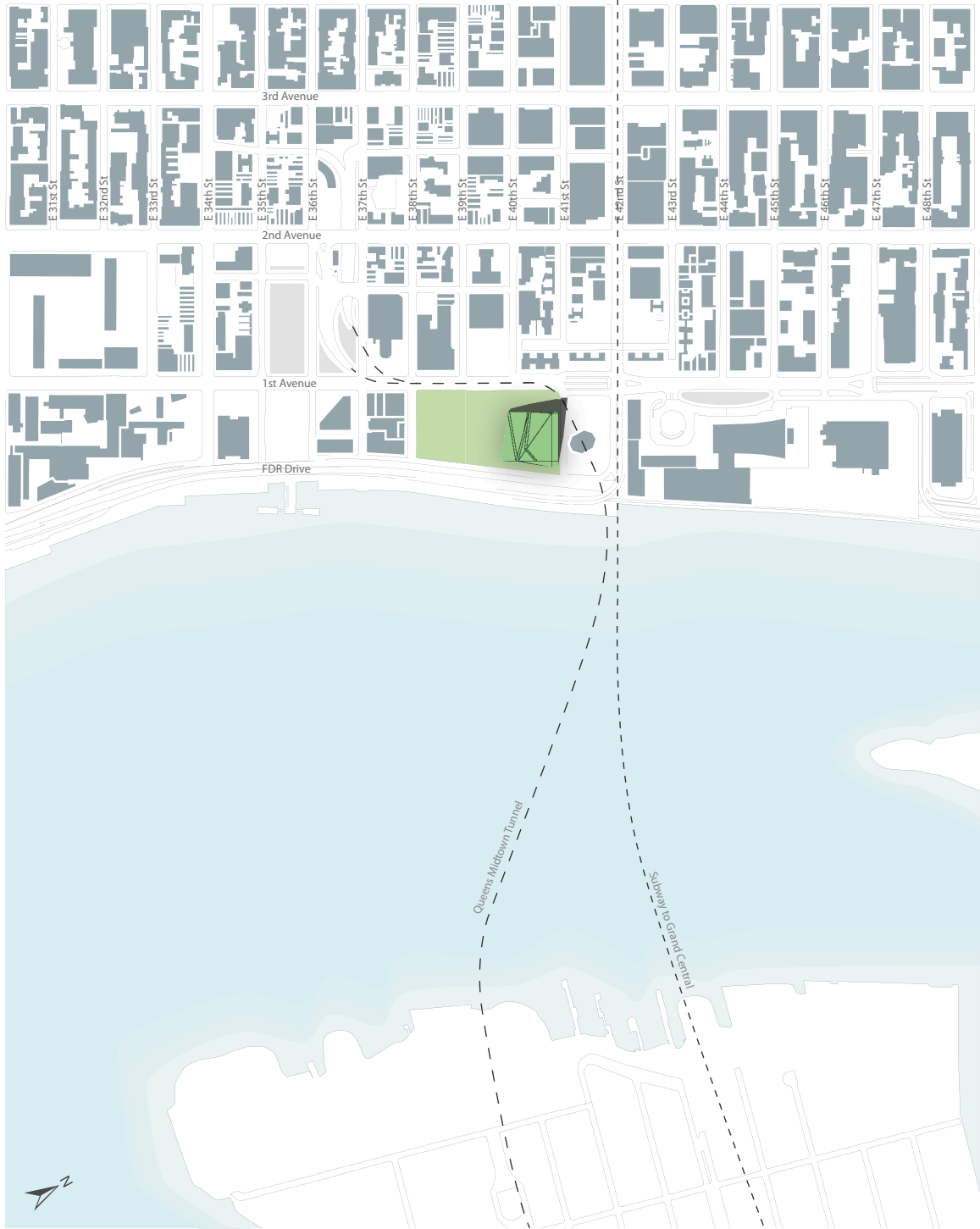


Figure 2.4: Partial plan of Manhattan with the 6.5 acre site in green.

Manhattan has an enormous transportation system (see Figure 2.8) and the site is located within blocks of major transportation routes such as cycling routes, highways, ferries, subways and tunnels. This close proximity to transportation will allow for large amounts of people commuting to Manhattan to visit the site with ease and purchase food.

Waterfront Access

Presently, FDR Drive and the off-ramp along the East River cut off direct access and views to the waterfront from the site (see Figure 2.5). Waterfront access is an extremely important issue for District 6 residents, with the community board stating in their “District Needs Statement”: “The need for a continuous waterfront esplanade, which requires building connections between segments of the existing East River waterfront esplanade and improving access to the waterfront by building pedestrian bridges over the FDR Drive.”³¹ Even though this is beyond the project’s immediate limits, it is something that will need to be addressed if a successful integration of the community is to be had. Addressing the district’s needs is also an opportunity for the project to reach out farther into the community and strengthen its roots there. As shown in Figure 2.6, one can see the existing traffic flow conditions along FDR Drive, and Figure 2.7 diagrams a possible solution to views and waterfront access. I propose decreasing the size of the site along FDR Drive to allow for repositioning of the off-ramp farther north and to increase sightlines to the East River. Extending the esplanade to E 42nd Street allows for a pedestrian ramp to follow the new off-ramp up to 1st Avenue. The new pedestrian ramp creates increased access to the waterfront and ferry terminal in the district that has the highest density of persons per acre of open space in Manhattan.



Figure 2.5: Manhattan, NYC. From Google Maps

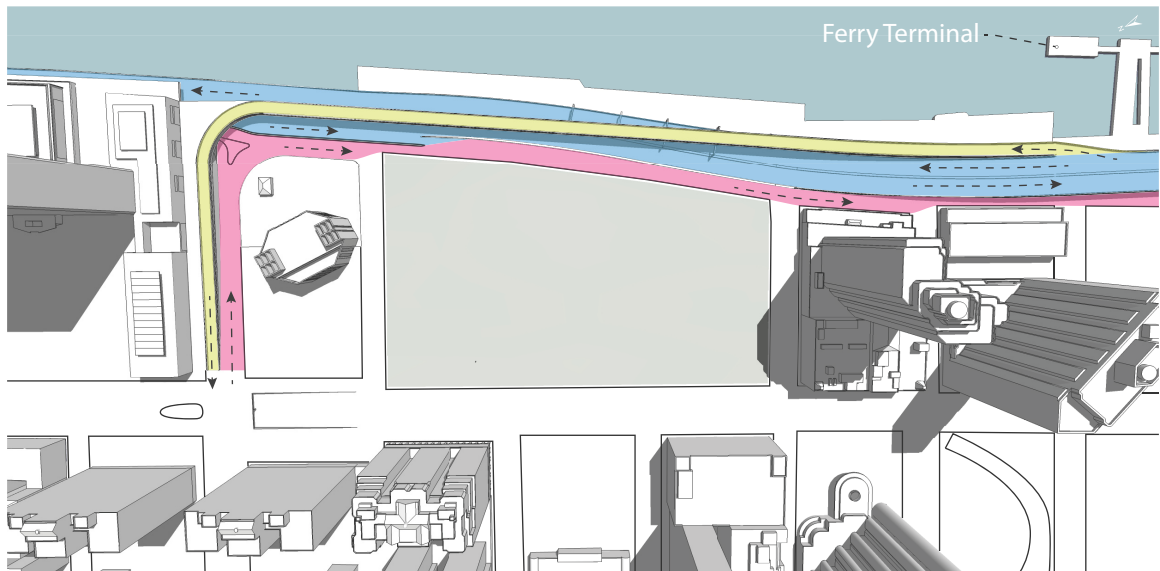


Figure 2.6: Current flow of traffic and conditions of FDR Drive and off-ramp around the site.

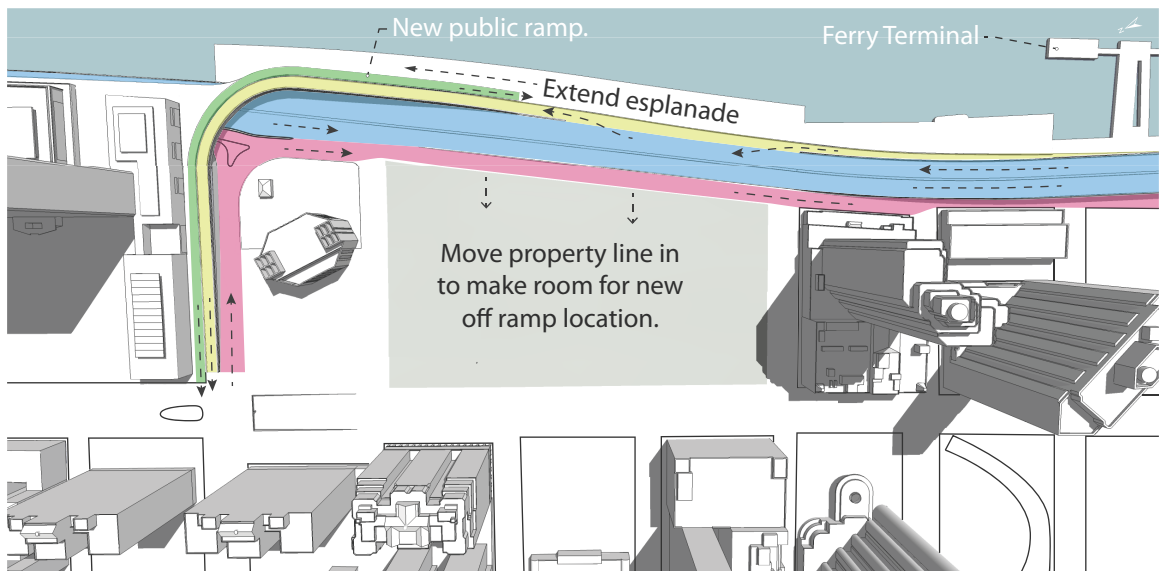


Figure 2.7: The proposed design of traffic flow and conditions of FDR Drive and off-ramp around the site, with the addition of a public ramp.

Renewable Resources

The goal of approaching the project in a sustainable manner has led to an in-depth site analysis of surrounding renewable resources. Through this analysis, I have determined that there are many physical and natural systems that I can draw upon for heat, electricity, and water reuse and recycling (see Figure 2.8). For example, the East River has the second strongest tides in the world, with enough embodied energy to power the whole project. Pilot studies have already been successfully concluded in the East River, proving its potential to generate electricity, and there will be a fully operational system running by 2012. (Ontario, Canada, has also started implementing this system as well.)³²

Water is integral to growing food, and even though hydroponics will use recycled water, the process will still require a large volume, with the outdoor agriculture using a lot as well. For sustainability purposes finding alternative methods of obtaining water is an important design issue. An alternative source of water can come from purifying harvested rain collected from the nearby residential and commercial buildings. Massive amounts of water that are consistently lost from the area could be used on-site, recycled, and cleaned through solar aquatics, before entering the harbour. The amount of rooftop area in Manhattan is enormous and can provide a substantial amount of harvested rainwater. Water collection and reuse is a major design concern for the project.

An average of 834,000 commuters (average does not include buses) pass close to the site every day by subway, car, bicycle, or ferry (see Figure 2.8). Looking at these transportation modes individually shows the potential for using them as renewable energy resources. For example, subway cars can be used to generate electricity through a method called regenerative braking which stores energy when the trains brake. Another example is the neighbouring Queens Midtown Tunnel ventilation shaft, which could be used during winter as a heat source. Additionally, organic food waste could be collected from some of the 11,000 restaurants in Manhattan and used to produce methane for fuel. This organic waste can also be used as composting soil for the outdoor urban farm.

City Greens: The Hub

Public Engagement and Circulation

The public's view will be a major driving factor in the success of the project. By integrating the public into the operation of the project, they become a part of the food hub. In turn, this integration will help the program grow and gain the public's acceptance of this new urban agricultural movement. This acceptance will be the catalyst to engendering new life and bringing back the urban order cities once had as a result of food systems.

Second to sunlight exposure, visibility of operations (see Figure 2.9 for view of operations from the exterior) within the building will be of high importance because the design and circulation of the hub will be seen from the public perspective. I propose that the landscape becomes a part of the building by sloping up to meet the façade on the third floor. This slope (as seen in Figures 2.10, and 2.11) creates a public space where the residents of Manhattan can sit and observe the operations of outdoor farming. This sloping hill will also serve as the transitional space between the farmland and the interior of the building, while also tying into the main circulation routes for the public.

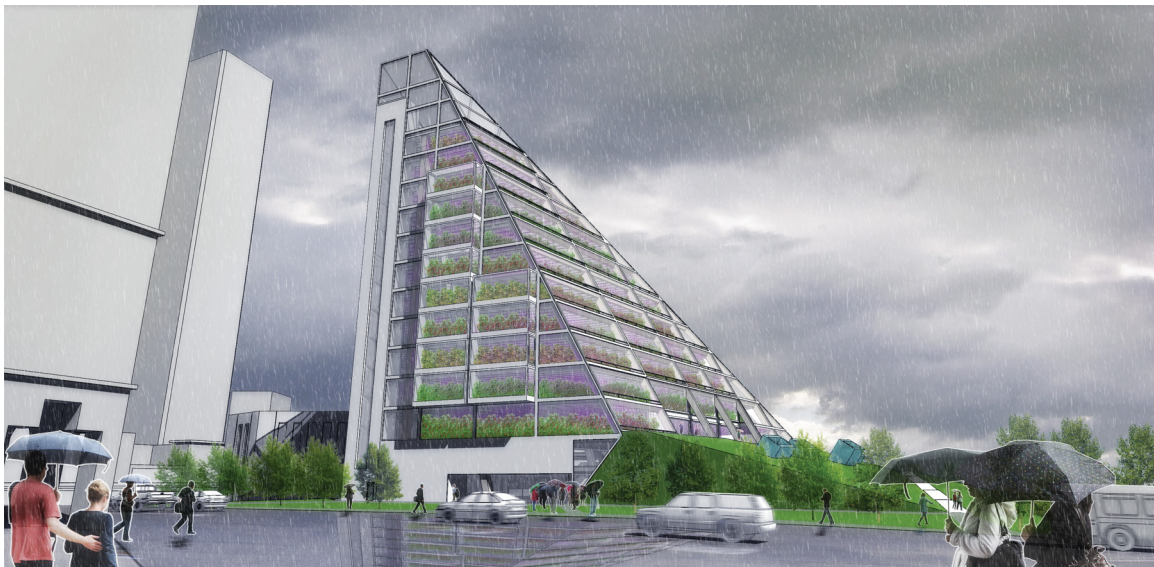


Figure 2.9: A view from E 40th St. showing the visibility of operations inside the building.



Figure 2.10: A view over the public and private farmland towards the public hill.

The farmland, as seen in Figures 2.10 and 2.11, is broken up into two main categories: public plots of land and private plots of land. The public plots are where the general public can come volunteer their time and learn about traditional farming methods. During their volunteer time, people will be guided by permanent workers on the urban farm. After they have fulfilled their time, those who volunteered will be able to take home produce from the fields. The private plots of land are an option for people who wish to rent a small portion of farmland to tend themselves. All food produced here is property of the renter. Interspersed throughout the farmlands are tool sheds, greenhouses and resting pavilions. Refer to Figure 2.11 to see the layout of the farmland and how it transitions from the exterior to the interior of the building. Figure 2.12 shows the relation of the programs to the immediate surroundings of the city, while Figure 2.13 and 2.14 show the building within the greater context of Manhattan.

Other publicly accessible programs mixed in with the farmlands are park spaces, a chicken yard, two small orchards, and a farmland centre (which would provide information on how the farmland operates, and how one is able to volunteer and rent land).

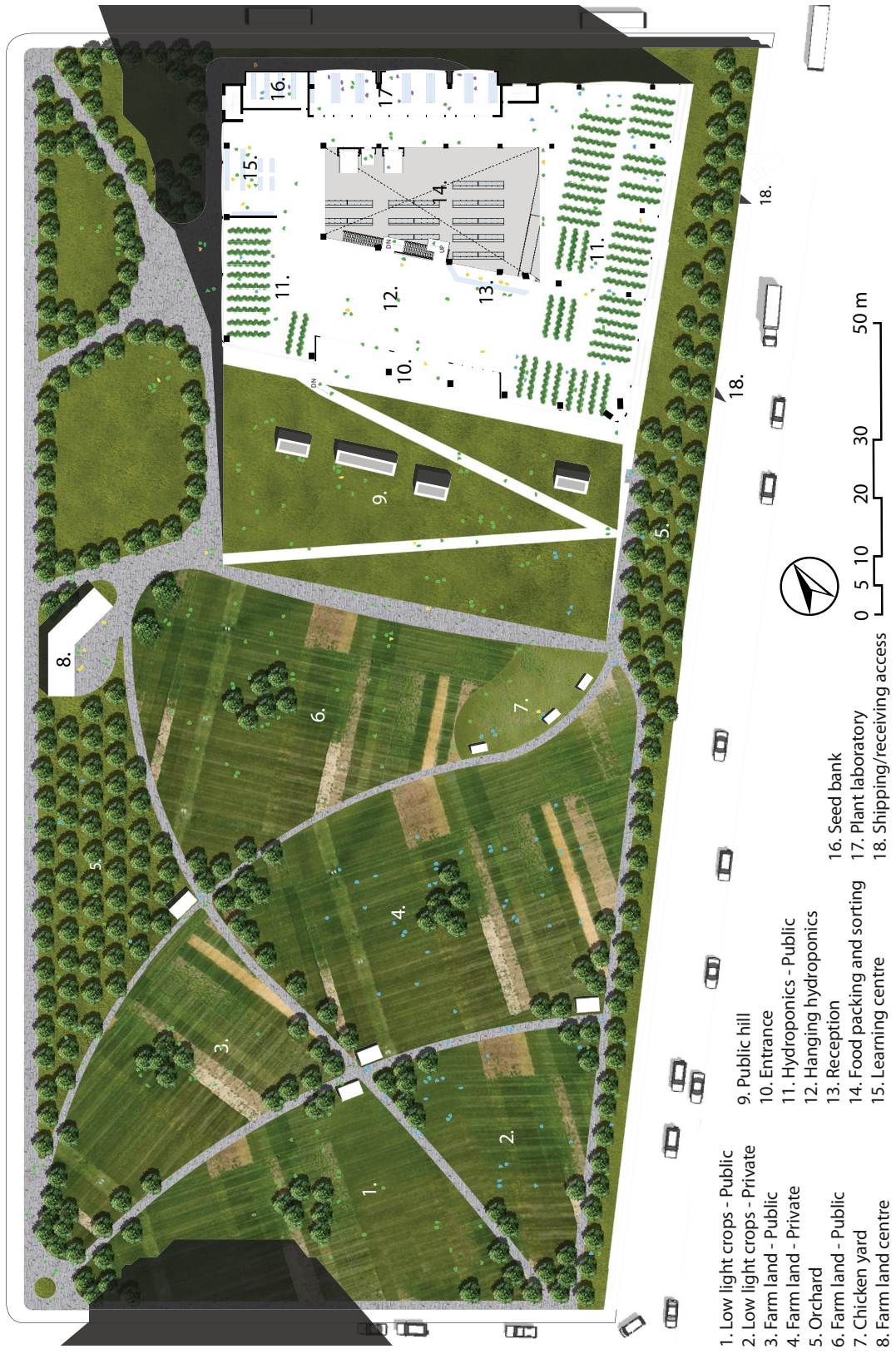


Figure 2.11: Site plan showing the organization of programs.



Figure 2.12: Overall site plan showing the extended waterfront esplanade with the new pedestrian ramp.

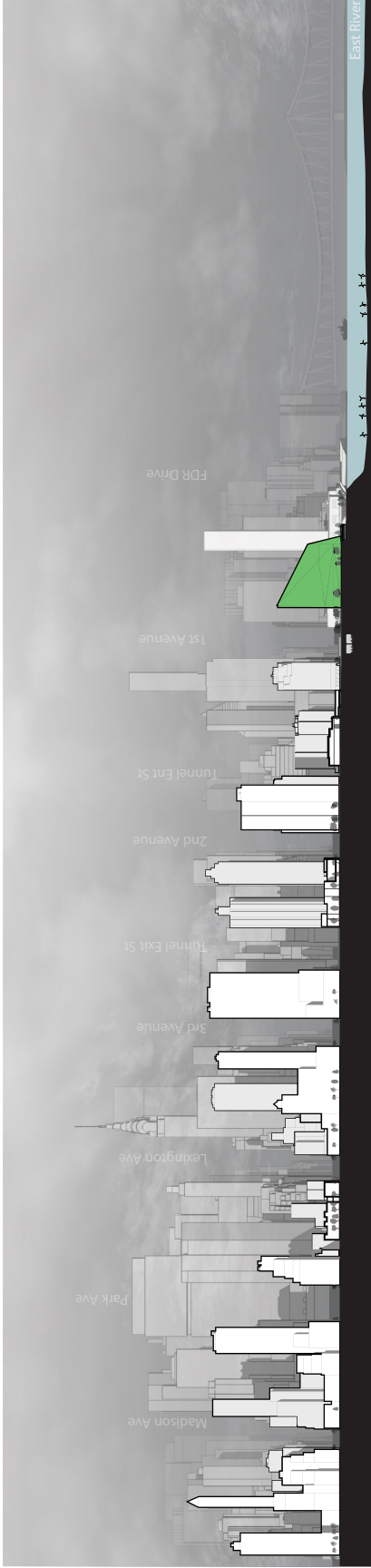


Figure 2.13: Section through Manhattan, looking north. The building in green is shown within the context of the city.

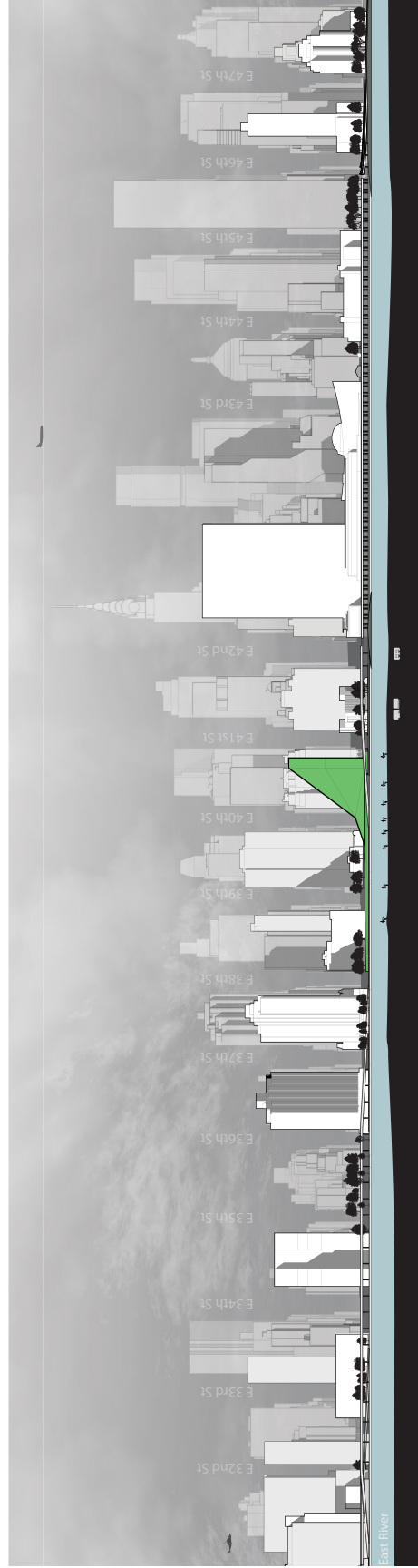


Figure 2.14: Section through Manhattan East River, looking west. The building in green is shown within the context of the city.

The main circulation within the building will be oriented around a central atrium (see Figure 2.15). This atrium allows for the visible mixing of the public circulation with the workers' or food's circulation. There are five main paths of circulation entering the building, which include transportation for shipping and receiving, bicycles for small deliveries, the field farming and the public through either the ground floor or hill entrance (see Figure 2.18 sectional drawing of the hill entrance). These main circulations routes can be seen in Figure 2.16 and 2.17.



Figure 2.15: A view of the central atrium. Food packing and sorting can be seen on the ground floor.

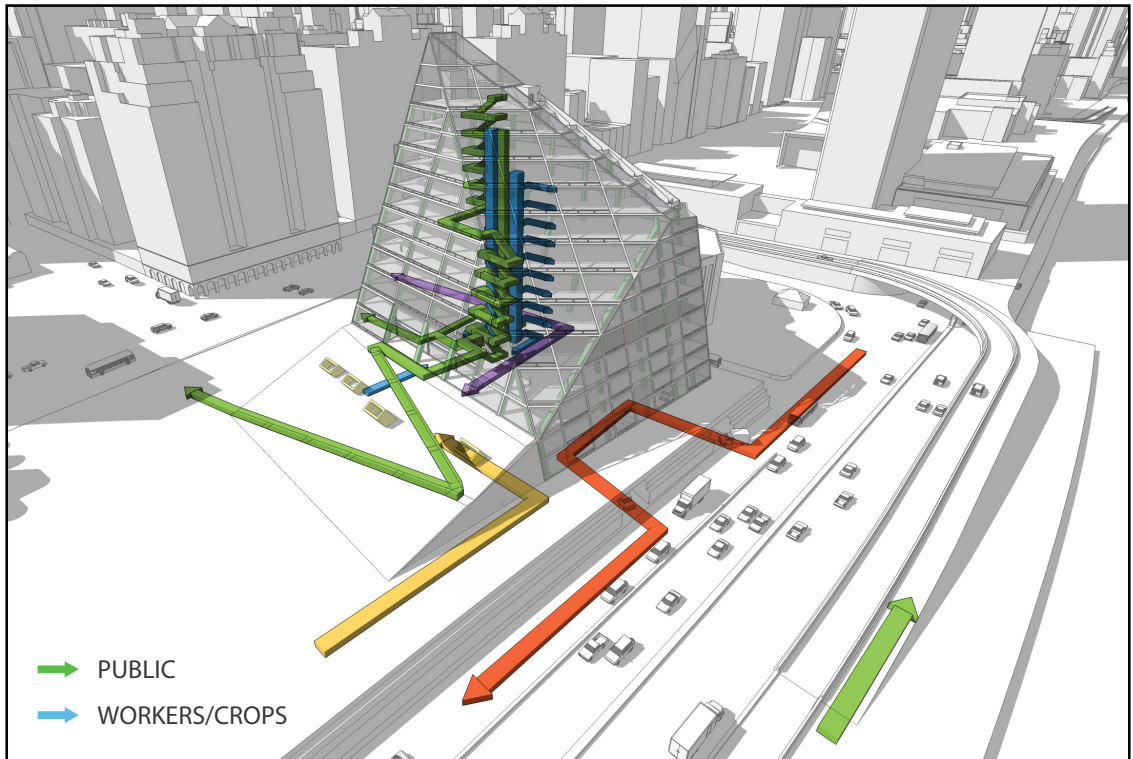


Figure 2.16: This diagram shows the main circulation routes entering and passing throughout the building.

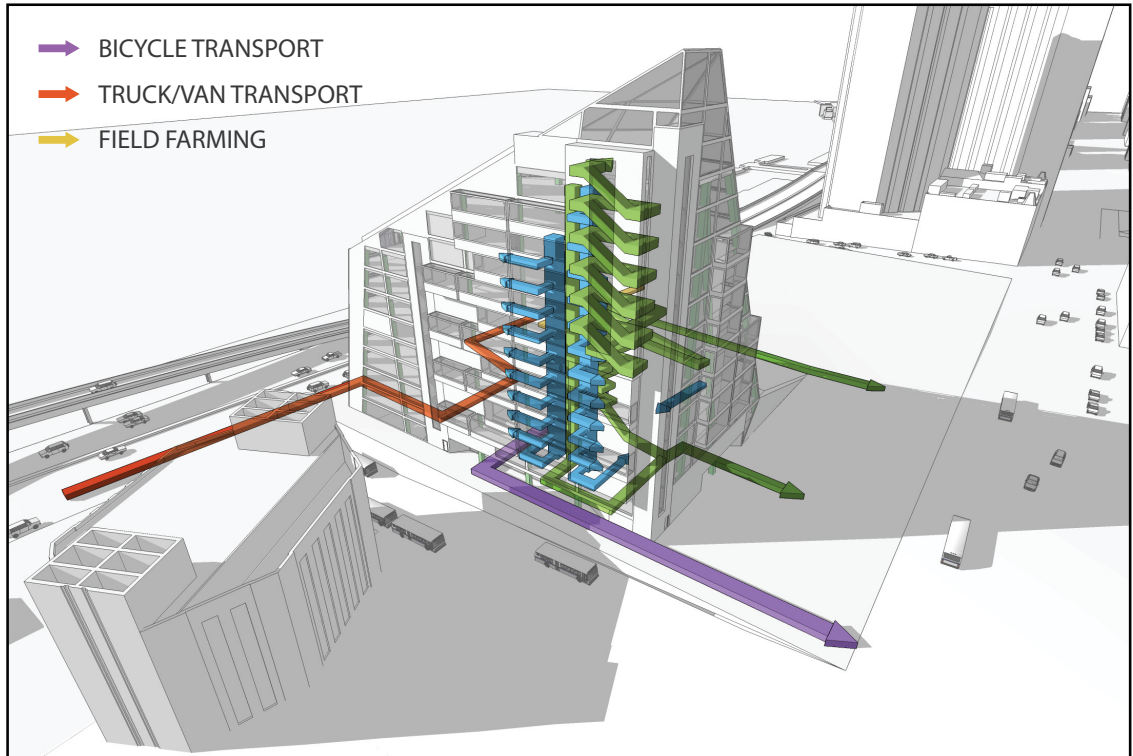


Figure 2.17: This diagram shows the main circulation routes entering and passing throughout the building.

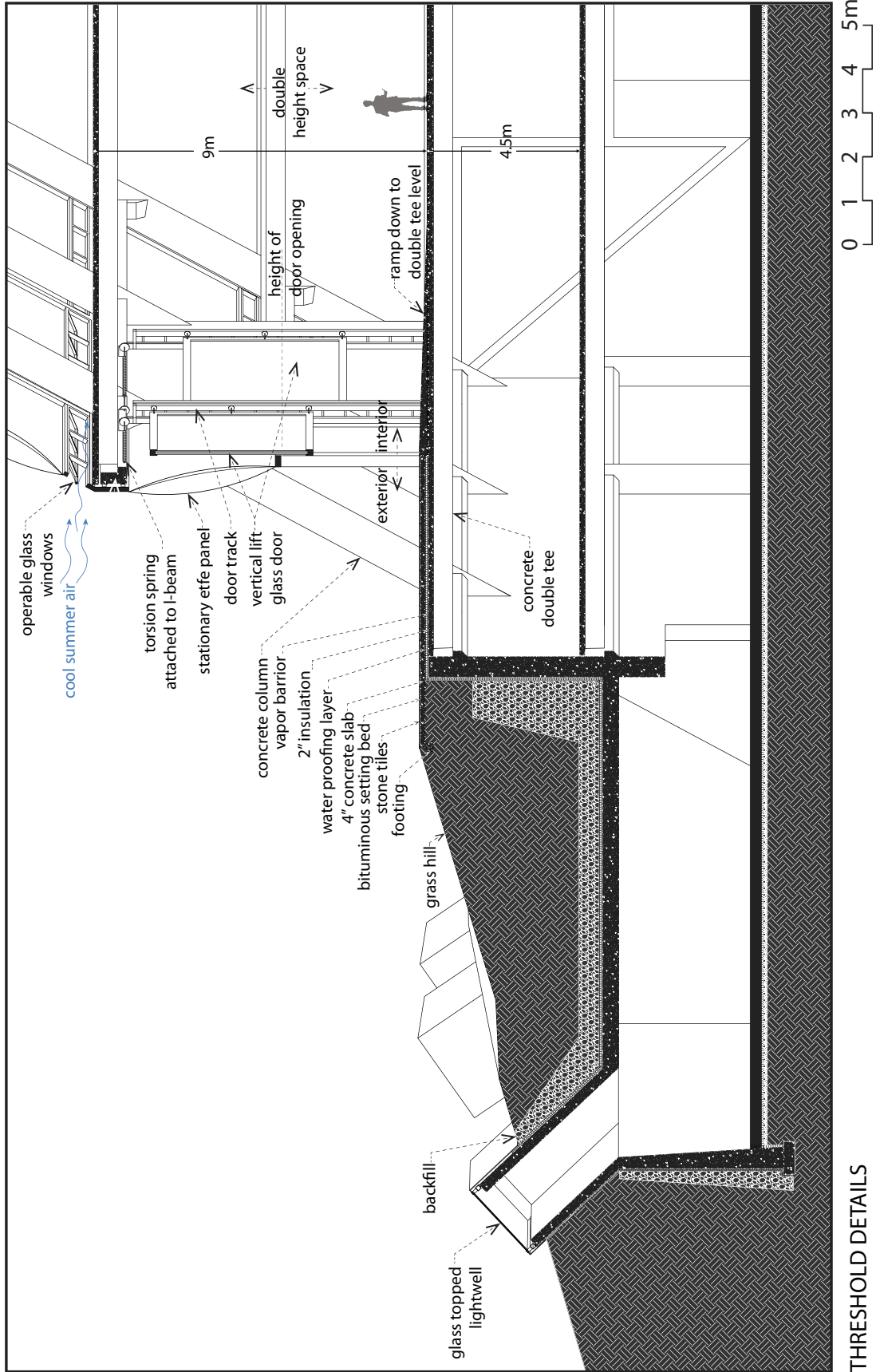


Figure 2.18: Section through the main barn door entrance up the public hill.

Growing

The central hub will produce food; however, the project is not trying to feed all of Manhattan. Instead, it will serve as an example of an optimal method of growing localized food within a dense urban area, offering a precedent that could be replicated throughout the city.

Within the building there will be two main hydroponic systems: the nutrient film technique (NFT) channel system and the bato bucket system. The NFT system is ideal for growing leaf crops (lettuce, spinach, swiss chard, etc.) and herbs, while the bato bucket system is ideal for growing vine crops (tomatoes, cucumbers, peppers, etc.). By adapting and modifying the “Food Matrix” (designed by Craig England in Toronto) to suit the uses of hydroponic food production (see Figure 2.19), the requirements and yields of hydroponic vegetables can be shown with ease. These hydroponic systems will directly influence the circulation within the building for a few reasons. Firstly (unless under complete LED lighting), hydroponics require direct access to sunlight, so the plants must be placed along the exterior walls of the building, thereby placing the circulation towards the interior. Secondly, harvesting and moving the plants to distribution requires space, so most space directly adjacent to growing areas is designated as circulation, as shown in Figure 2.20. Furthermore, the public needs close access in order to observe how these systems work and to participate in designated areas such as the hydroponics showroom. For a detailed look at the design and space requirements of these hydroponic systems, see Figures D.1 - D.8 in Appendix D.

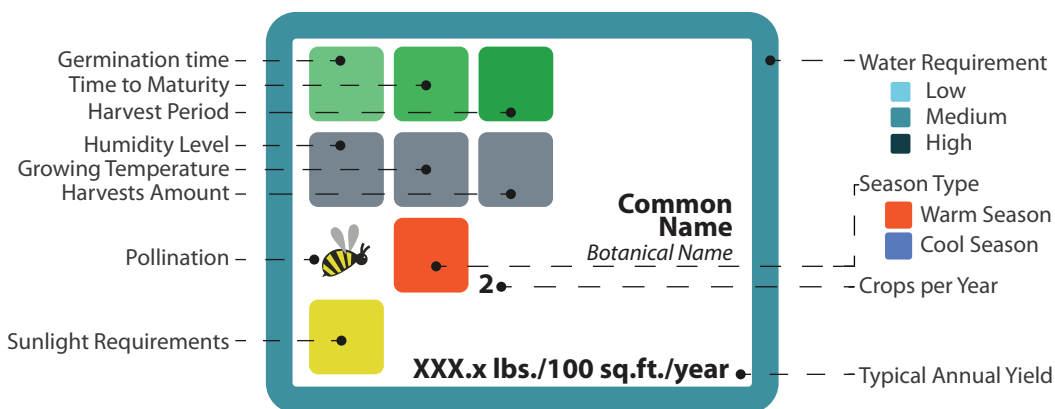


Figure 2.19: Hydroponic Food Matrix



Figure 2.20: Hydroponic tomatoes being grown under LED lights. Circulation is oriented to the interior of the building while plants are situated to the exterior of the building for maximum solar gain.

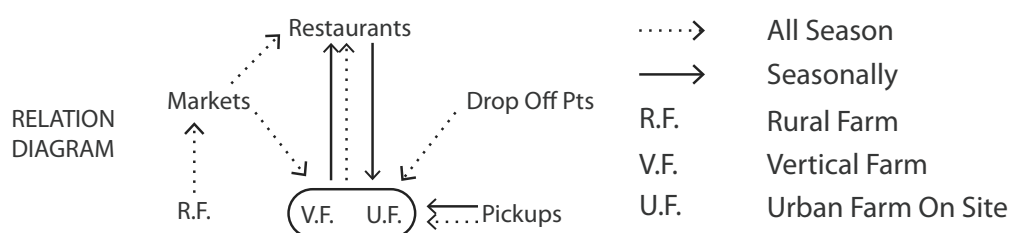
Within the building, plant health will be monitored and checked within the plant lab. The plant lab will test seeds for diseases and periodically test the health of the hydroponic plants growing. The plant lab will also continuously experiment on making the plants more nutritious and tasteful so as to produce the best food possible. Figure 2.21 below gives an idea of what a plant lab might look like.



Figure 2.21: A view of the plant lab where plant testing occurs. Testing is done for diseases and to improve the crop's yields, taste and nutritional value.

Distribution

A key component of providing access to localized food is distribution. By adding to existing distribution systems such as the Basket System of Lufa Farms in Montreal,³³ I have been able to design a new system to integrate with the farmer's market and restaurant community of Manhattan. The new "Bin System" will combine hydroponic foods with that of the local food collected at the farmer's markets (see Figure 2.24 for detailed diagram of foods available from markets). For marketing purposes, I have given the hub the recognizable name of City Greens. Individuals can place orders to pick up their bin of food from City Greens or various drop-off locations, or they can choose to have their bin delivered. The reason for adding market food to the bin service is because certain foods cannot be economically grown with hydroponics. Restaurants that already purchase their food seasonally from Manhattan farmer's markets will be able to continue buying their produce from City Greens during the winter. (see Figure 2.23 for a more detailed description of the Bin System.) The relations diagram below (Figure 2.22) describes how the vertical farm and urban farm would interact with the public, markets, and restaurants based on the new Bin System. Each crossover between the V.F. & U.F. bubble in the diagram and the other food nodes serves as a point of interface or opportunity to expose people. These interfaces will serve as the base for designing the building.

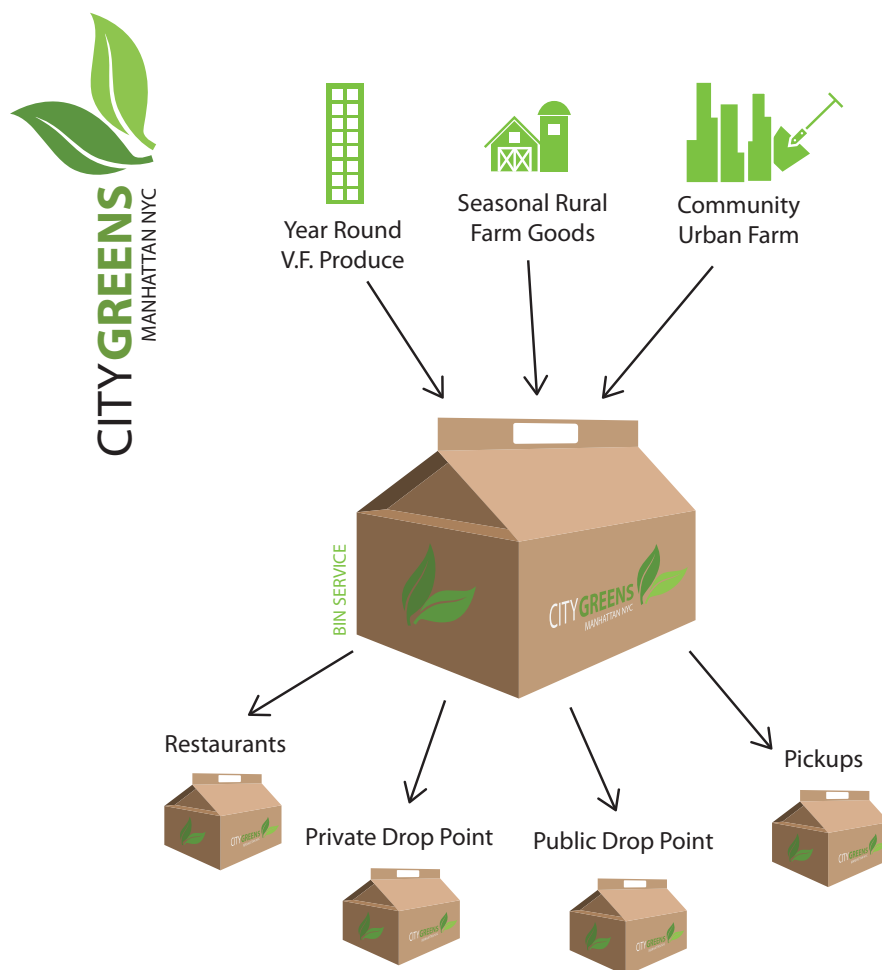


Drop Off Points: Public & Private

Private includes employers, churches, charities, places with sufficient subscribers, etc.

Public includes YMCAs, cafes, health facilities, gyms, kiosks, etc.

Figure 2.22: Relations diagram between different food nodes within Manhattan.



THE CITY GREENS BIN SERVICE

A service that gathers and combines year-round fresh hydroponic vegetables with different fruits, vegetables, and goods from local farmers based on your order, ready for delivery or pickup.

Why City Greens provides products from local farmers:

Certain vegetables currently cannot be grown hydroponically in a greenhouse economically, therefore in order to give our customers access to a wide variety of local seasonal goods we offer this additional service.

Restaurant Owners:

Restaurant owners who normally cannot purchase their produce at the GrowNYC farmer's markets during the off-season will still be able to buy a variety of produce from City Greens hydroponic farm. We can even collect other goods you normally buy from the markets and add them to your basket as well.

Because we also have a outdoor urban farm we will also take your organics to be used as compost.

Figure 2.23: A diagram and write-up describing the Bin service in more detail.

GOODS SOLD AT GROW NYC FARMERS MARKETS



















	Vegetables		Fish
	Fruits		Beef, Pork & Lamb
	Berries		Poultry
	Jams & Preserves		Eggs
	Honey		Cheese
	Grains & Flour		Milk & Yogurts
	Legumes		Bread & Baked Goods
	Mushrooms		Ice Cream
	Wine		Pastries & Desserts

Figure 2.24: A table of the types of foods one can purchase at Manhattan Farmer's Markets.

Program Development

City Greens is to be a visible agricultural operation, observed by the public throughout the food production cycle of seed, growth, harvest, packaging, and distribution. This cycle of growth determines the layout of the program within the building. An observer will be able to circulate their way through the building and witness the cycle from either seed to distribution or from distribution to seed. The circulation, accompanied by the growing cycle, dictates that the programs are to be layered in a hierarchical manner from beginning to end. The importance of this layering is to make a comprehensive and linear food cycle, much like in modern agriculture, except people will no longer be removed from the process. People usually witness only the appearance phase as they enter a grocery store, seeing nothing between seed and delivery. The public will circulate in the centre of the building, while the programs used for growing will occupy the south side, and research-office spaces will be located on the northern side. See Figure 2.25 for a layout of the programs.

Within the set programs of City Greens, there are four main teams which can be seen already in the example of Lufa Farms in Montreal.³⁴ The teams include a Growing Team, Research Team, Consumer Team, and Community Team. Figure 2.25 gives an idea of where these teams would be located based on their colour.

Programs that will involve the public more directly are necessary for involving the community with the operation. Within City Greens, there is the opportunity to teach about nutrition, cooking, environmental issues, alternative energies, traditional farming methods, and hydroponic farming. Programs that strengthen the experience of the user include a market, a hydroponics showroom/learning centre, an educational outdoor urban farm, and spaces for members of the community to tend their own plot. Figures 2.26 - 2.29 show the floor plans of three different levels within the building, and these, accompanied with the plan of Figure 2.11, show most of the major programs within the City Greens project. Figure 2.30 shows the entire group of programs spread out over the whole site.

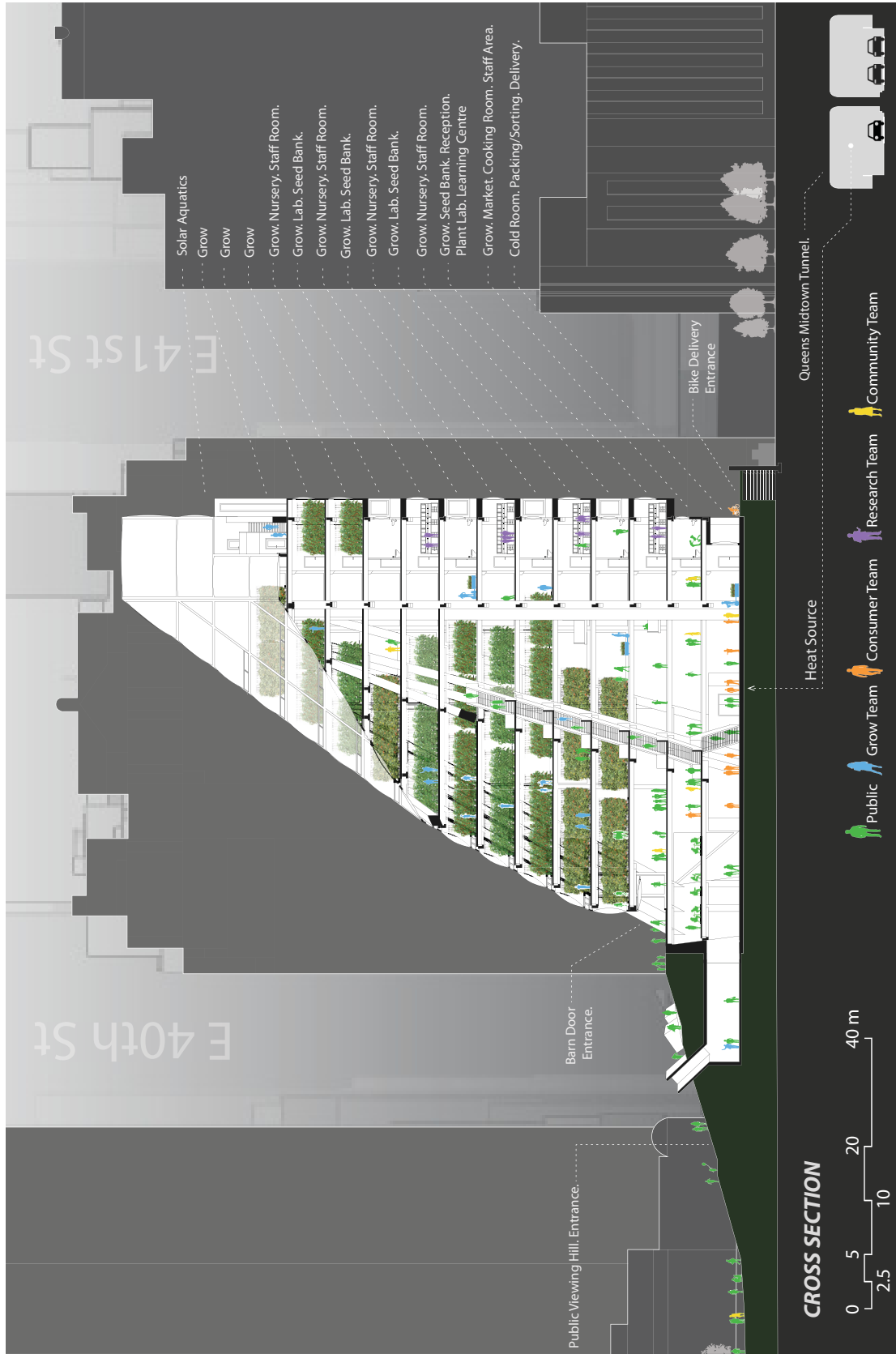
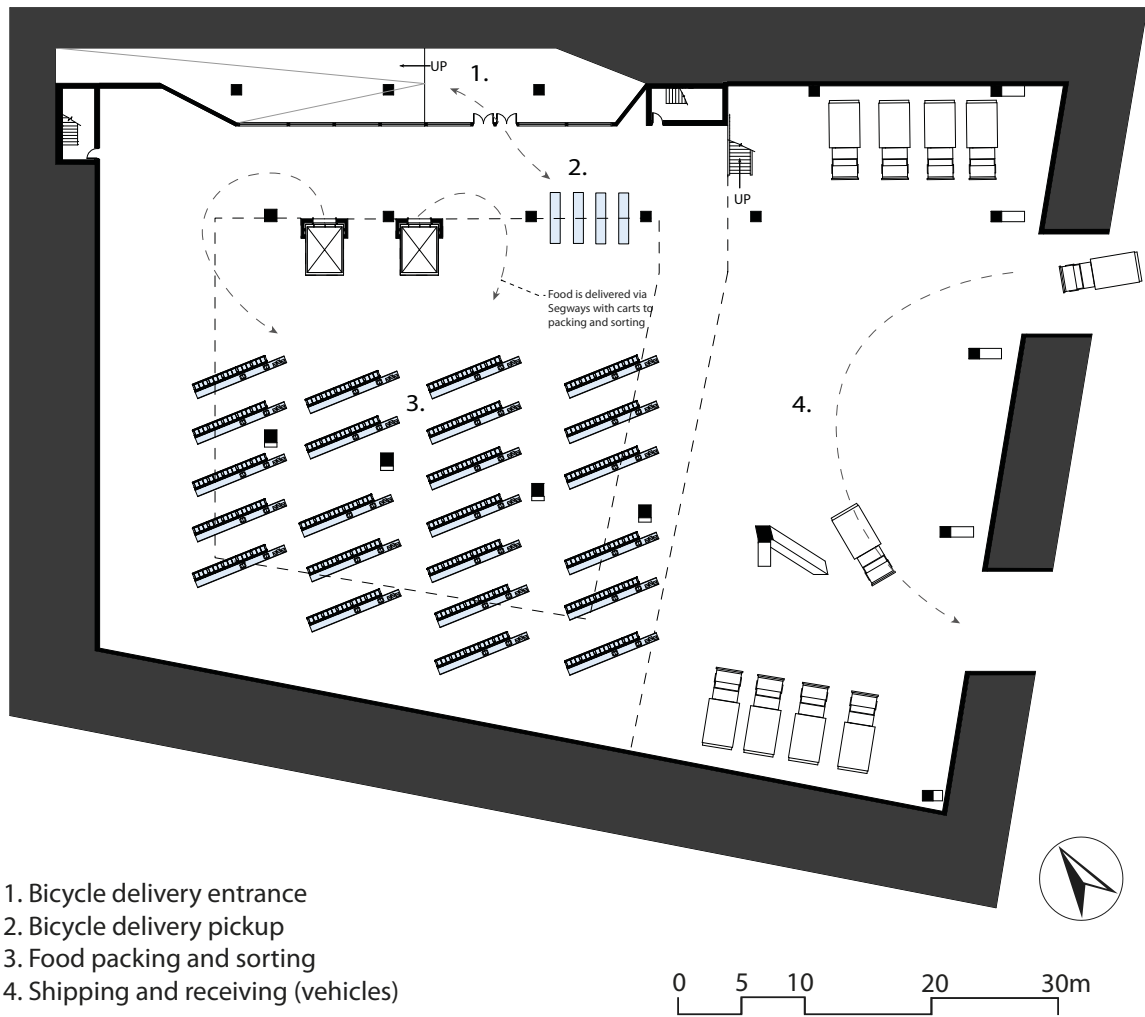


Figure 2.25: Section through Manhattan East River, looking west. The building in green is shown within the context of the city.



1. Bicycle delivery entrance
2. Bicycle delivery pickup
3. Food packing and sorting
4. Shipping and receiving (vehicles)

Figure 2.26: Lower level showing the food packing and sorting area, as well as shipping and receiving area.

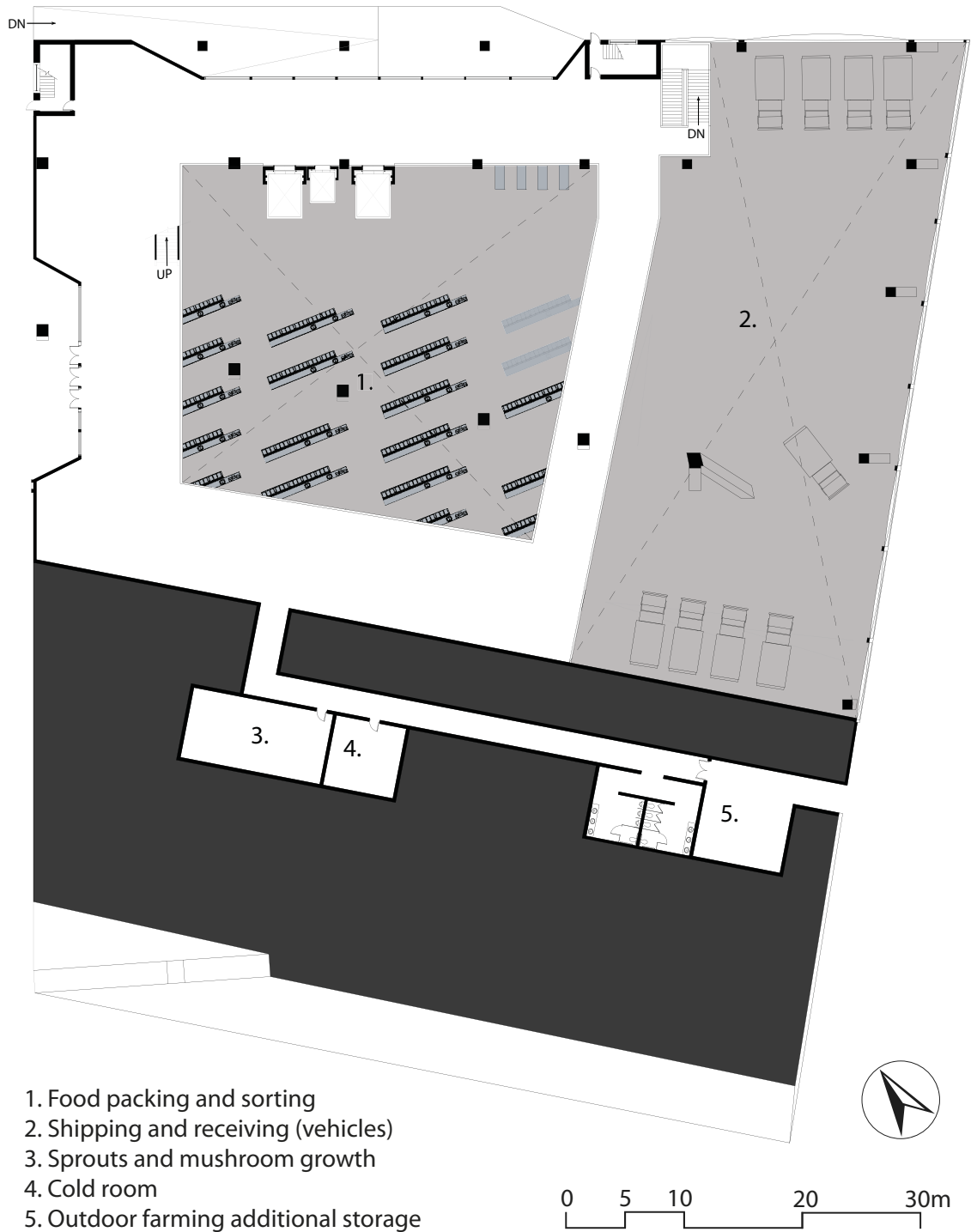


Figure 2.27: Ground floor plan overlooking the shipping and receiving area, as well as the shipping and receiving area.

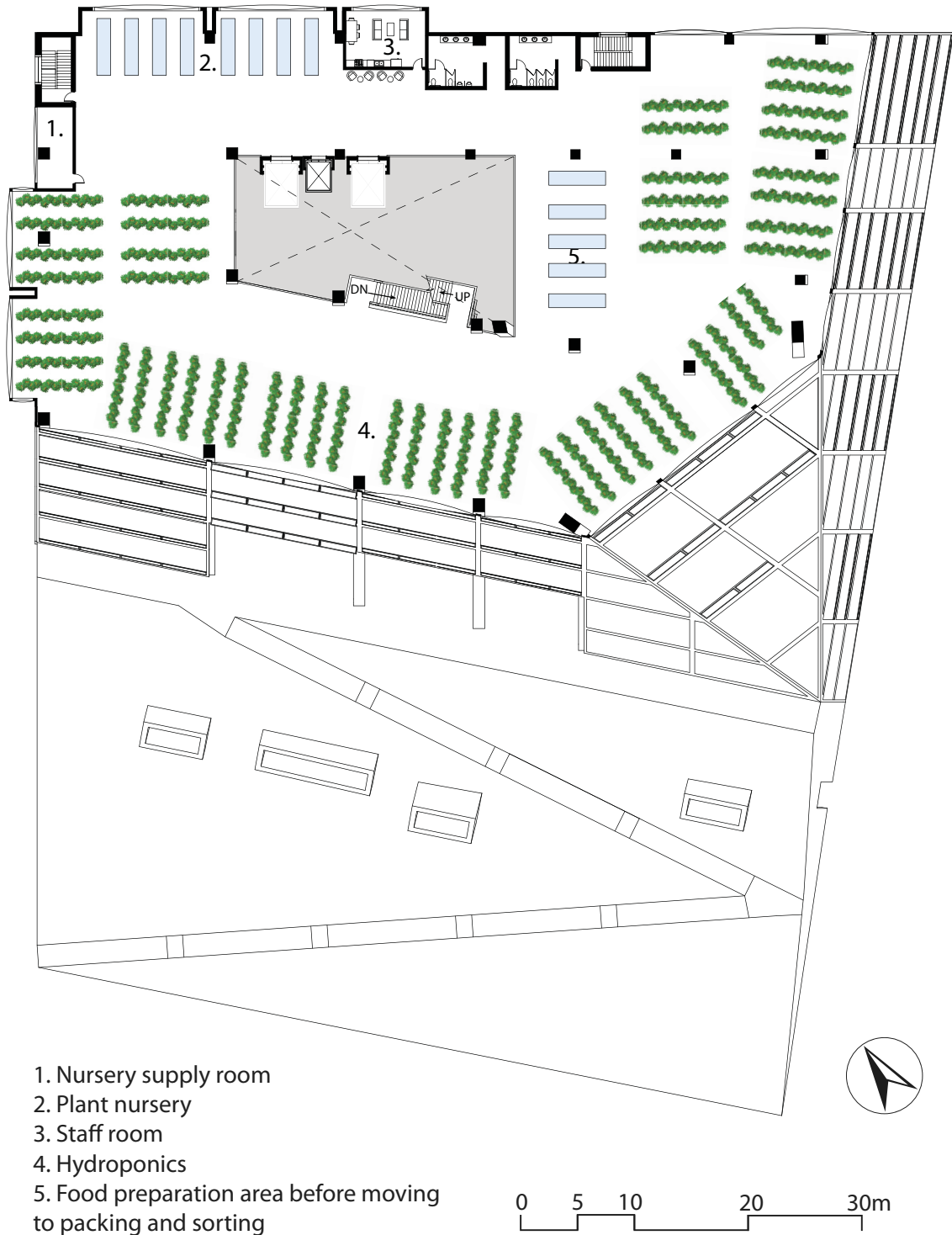


Figure 2.28: 8th floor plan.

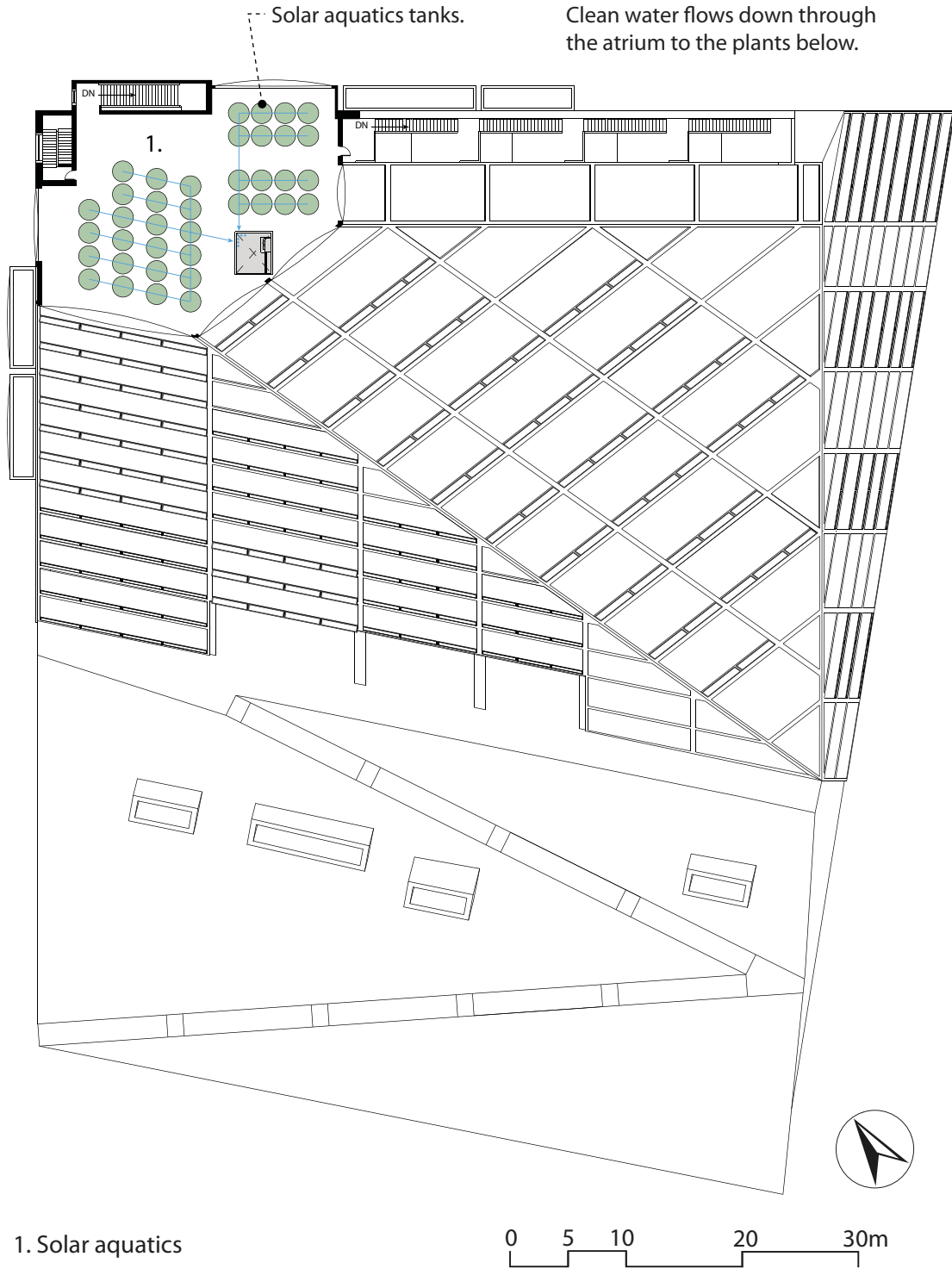


Figure 2.29: 15th floor plan: solar aquatics.

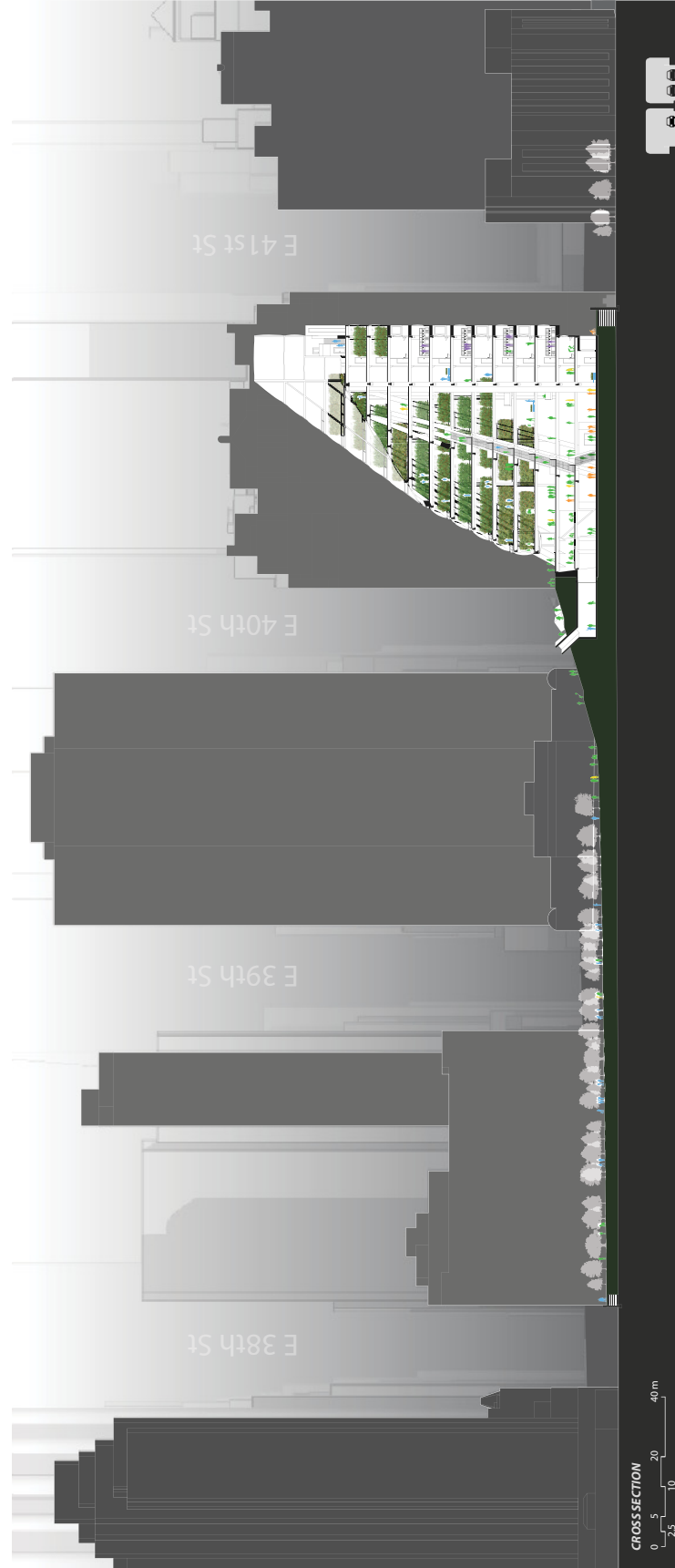


Figure 2.30: Section through Manhattan East River, looking west. The building in green is shown within the context of the city.

Building Façade

A 6.5-acre site in Manhattan is rare, leaving a lot of open space and potential for southern sun exposure, which is key for growing food indoors. Through shadow studies, seen in Figure 2.31 - 2.33, I have determined that the optimal location to build City Greens is the northeast corner of the site, where the maximum solar gain can be found throughout the year. The building is shaped and angled in such a way to follow the path of the sun throughout the day.

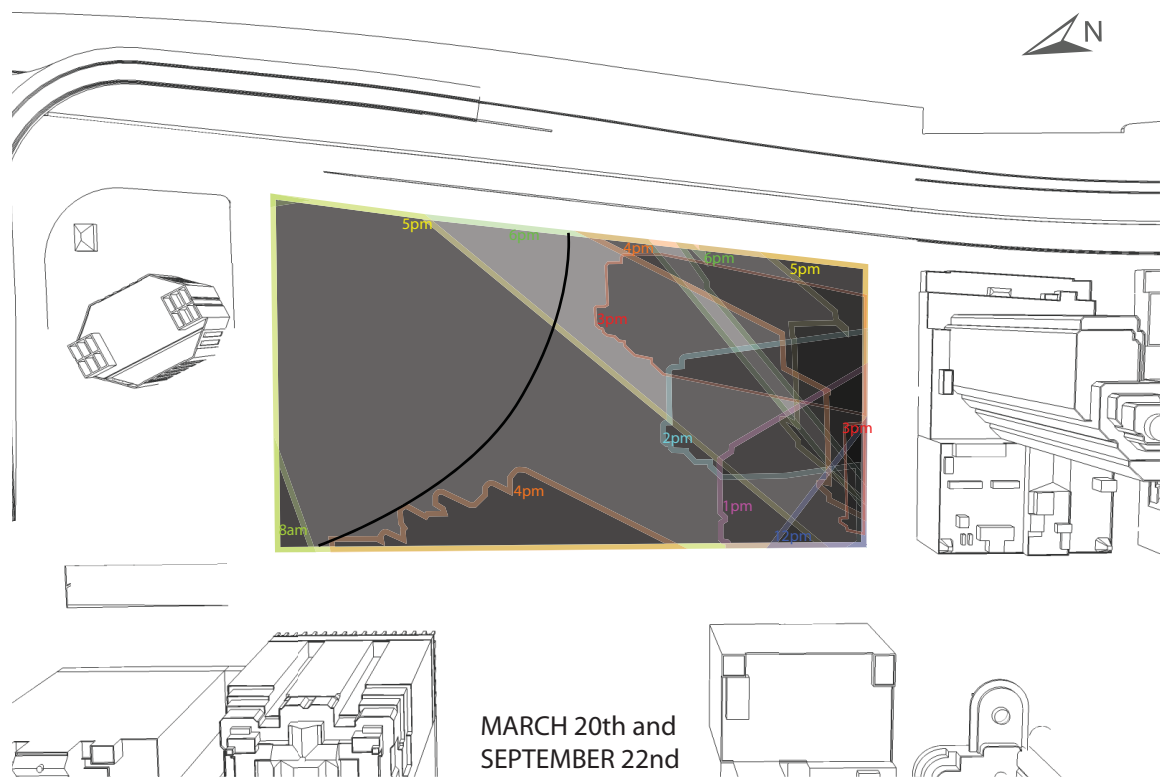
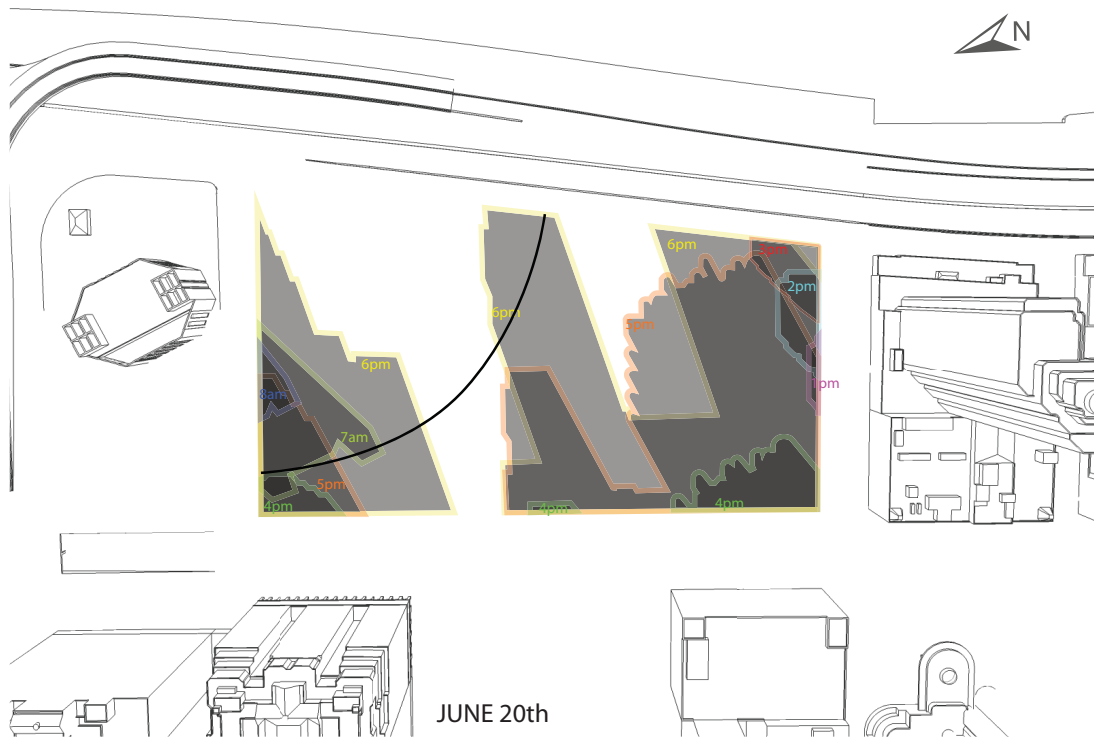
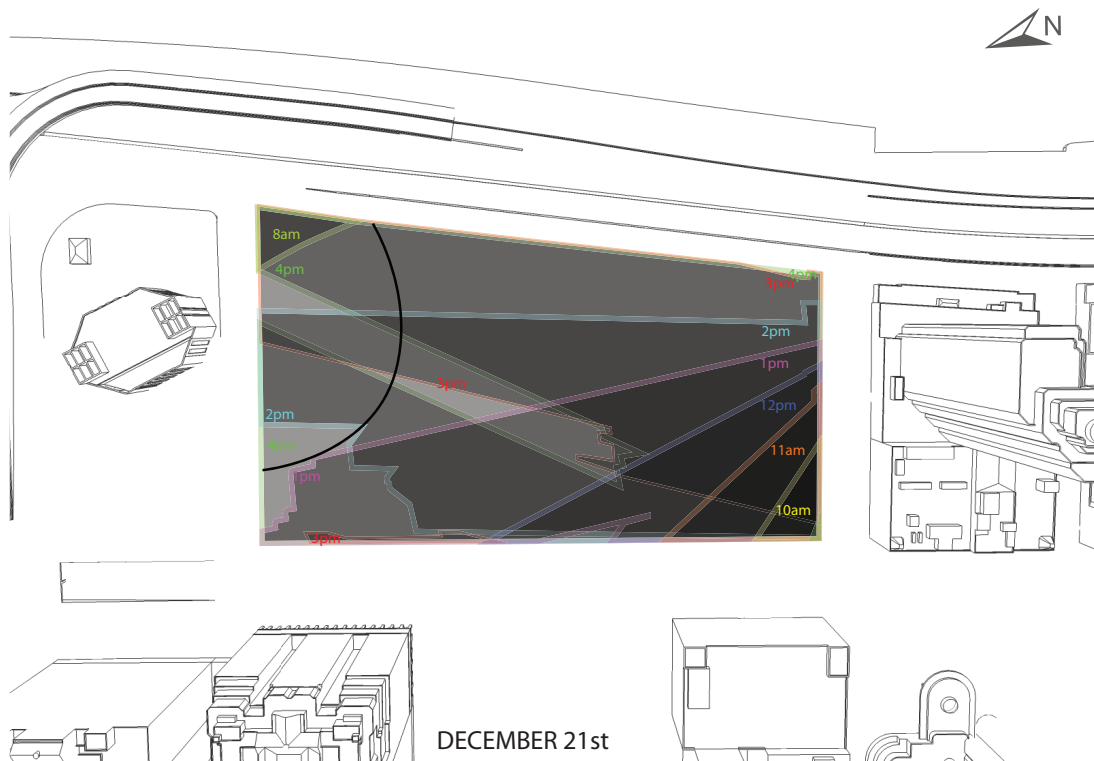


Figure 2.31: Shadow study on site during the spring equinox. The outlines represent shadow lines of adjacent building throughout different times of the day. The black line shows where the least hours of shadows occur.



JUNE 20th

Figure 2.32: Shadow study on site during the summer solstice. The outlines represent shadow lines of adjacent building throughout the day. The black line shows where the least hours of shadows occur.



DECEMBER 21st

Figure 2.33: Shadow study on site during the winter solstice. The outlines represent shadow lines of adjacent building throughout the day. The black line shows where the least hours of shadows occur.

To increase the amount of sunlight that enters the building, a material with great transparency and thermal value is needed. Ethylene-tetra-fluoro-ethylene (ETFE) is one such material, allowing for 95 percent light transmission while weighing only 1 percent of an equal-sized piece of glass. Using ETFE usually requires a system of inflated walls, which can be seen in the Beijing National Aquatics Centre. The pressurized walls lend themselves to a shading system, where screens are printed directly onto the ETFE sheets. The pressure difference between the ETFE layers allows for screens to open and close to adjust the sunlight transmission. This shading is shown in the diagram of Figure 2.34. A model study of the basic operation of this inflated wall system was done in order to aid in conceptualization, which can be seen in Figures 2.35 and 2.36. For more properties on ETFE, refer to Appendix H: ETFE (ethylene-tetra-fluoro-ethylene) Design and Benefits.

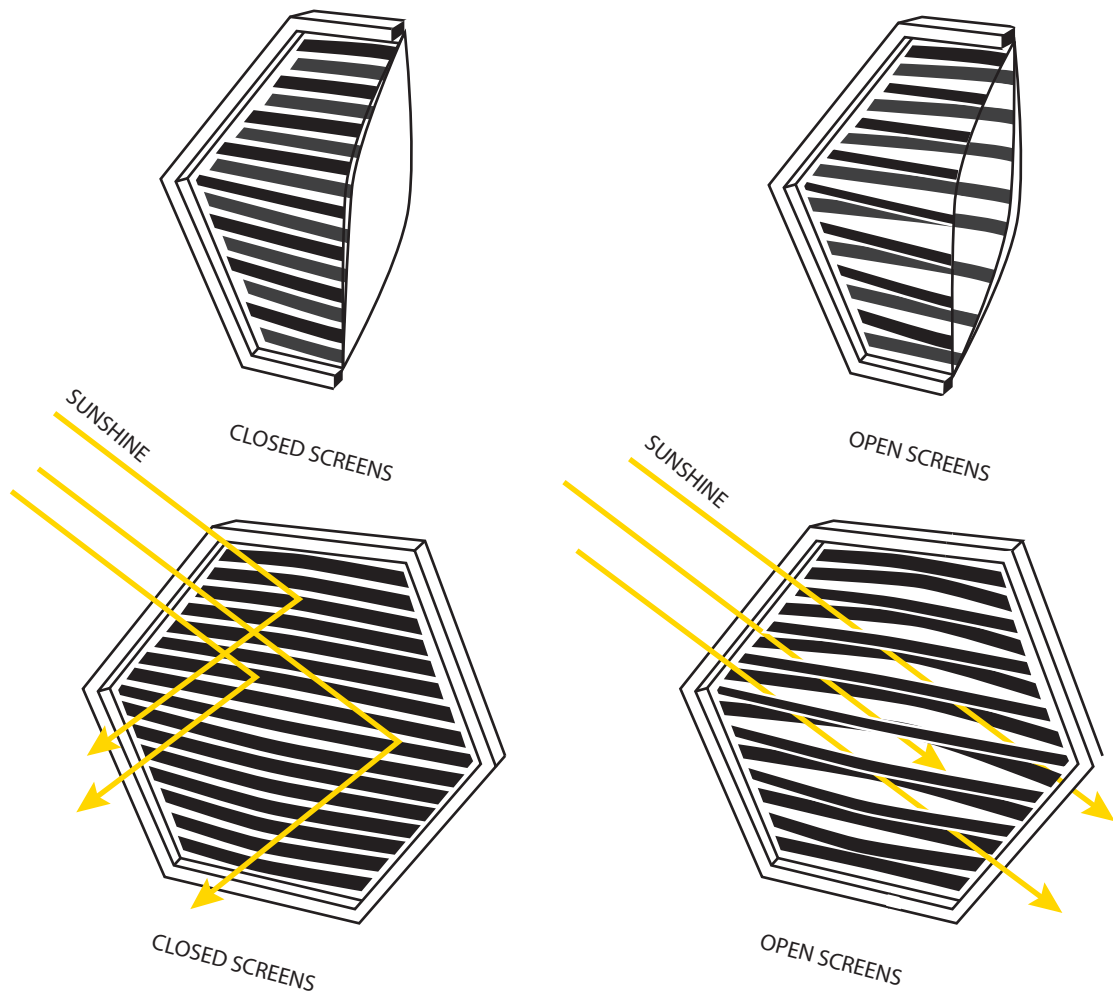


Figure 2.34: A simple diagram showing the operation of printed screening on ETFE in one node of the façade. In this case the node design is a hexagon, but can take almost any shape.

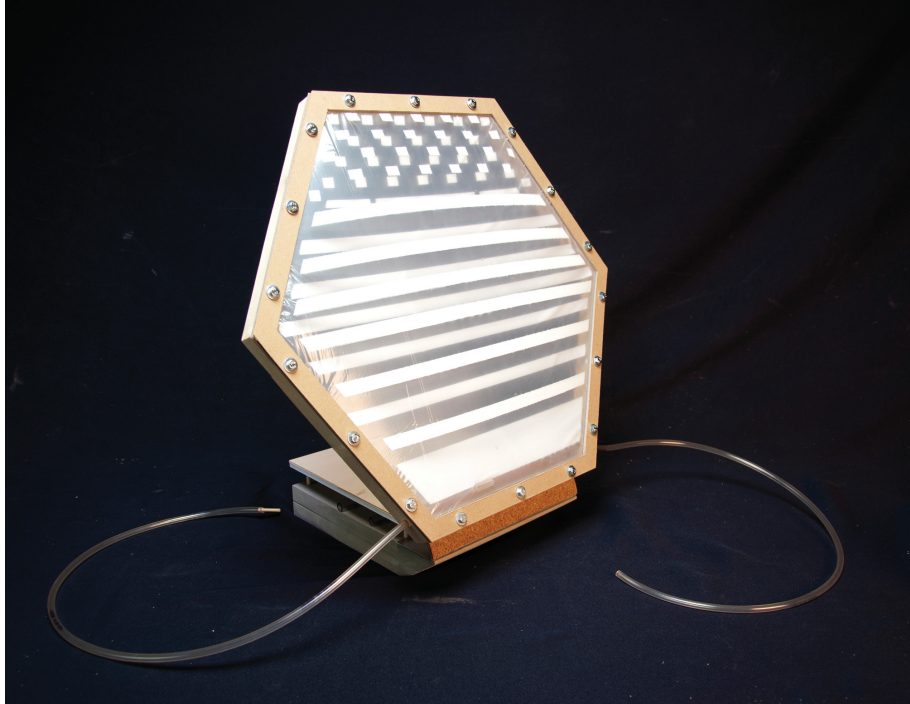


Figure 2.35: A model of one node of an ETFE inflated wall system. Screens printed on the ETFE shown in white are used as a shading system by changing the pressure between the three layers of ETFE. This image shows the screens open.

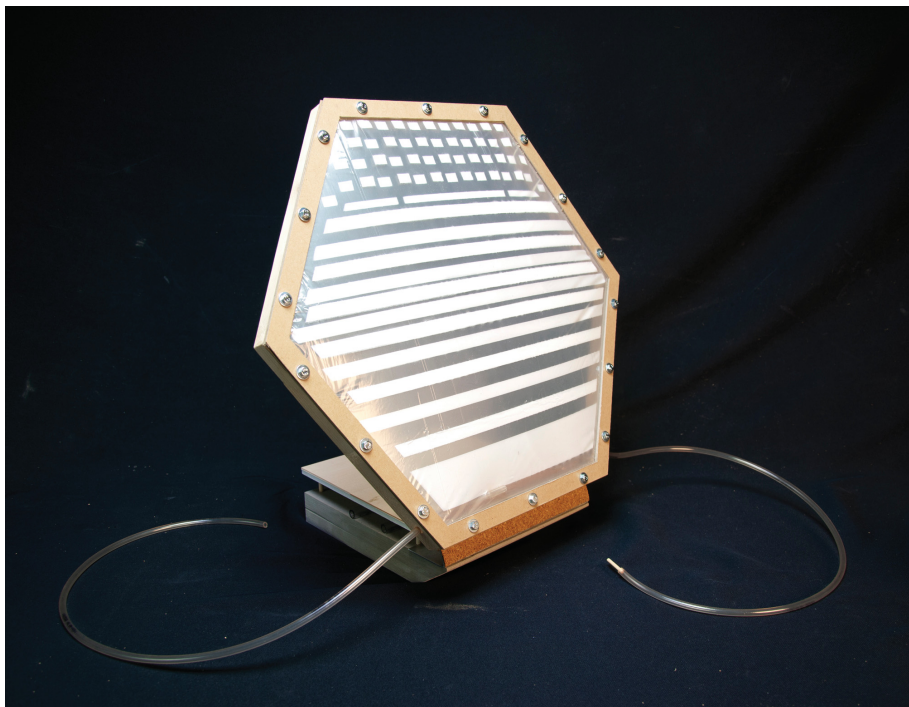
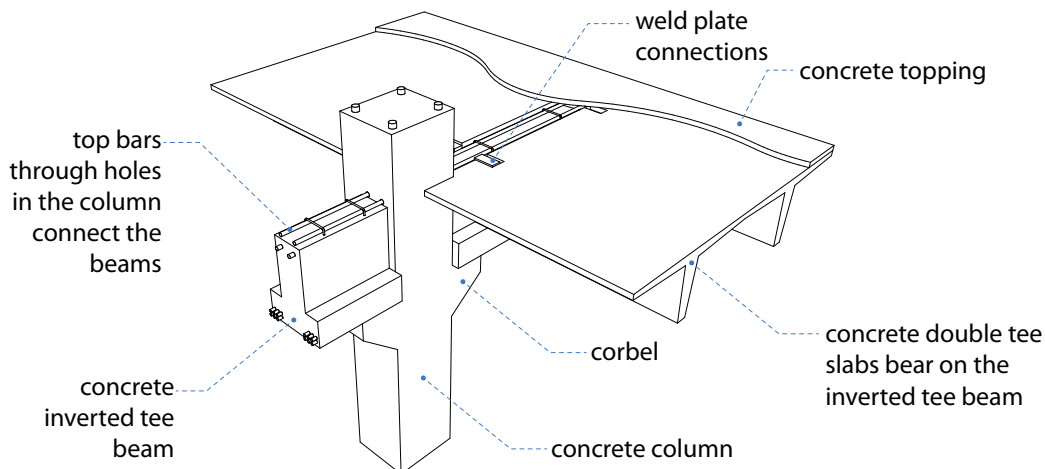


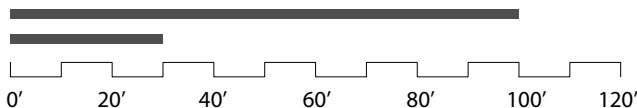
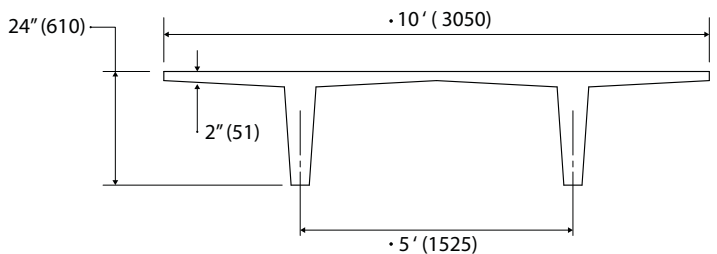
Figure 2.36: This image show the screens closed for shading.

Building Structure

Due to the nature of the building, large spans of open space are required. In order to achieve these large spans, while minimizing the amount of columns within, a system of double tees is used. Double tees have the ability to span nine to thirty metres. The reduction in vertical structure allows for more space to grow plants, as well as improving solar gain. A breakdown of the structural system and elements used can be seen in Figures 2.37 - 2.39.

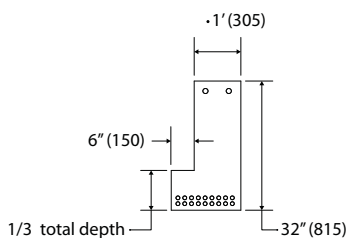


DOUBLE TEES

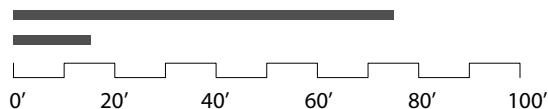
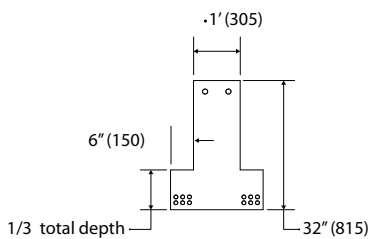


- 30' to 100' (9 to 30m) span range
- Rule of thumb for depth: span/28

L-SHAPED BEAMS

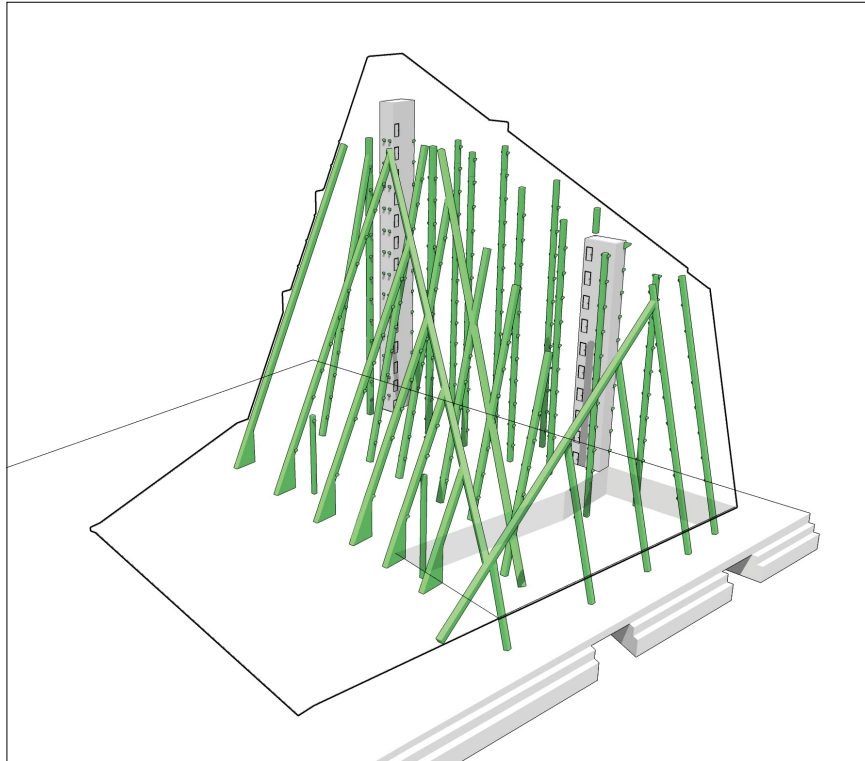


INVERTED TEE BEAMS

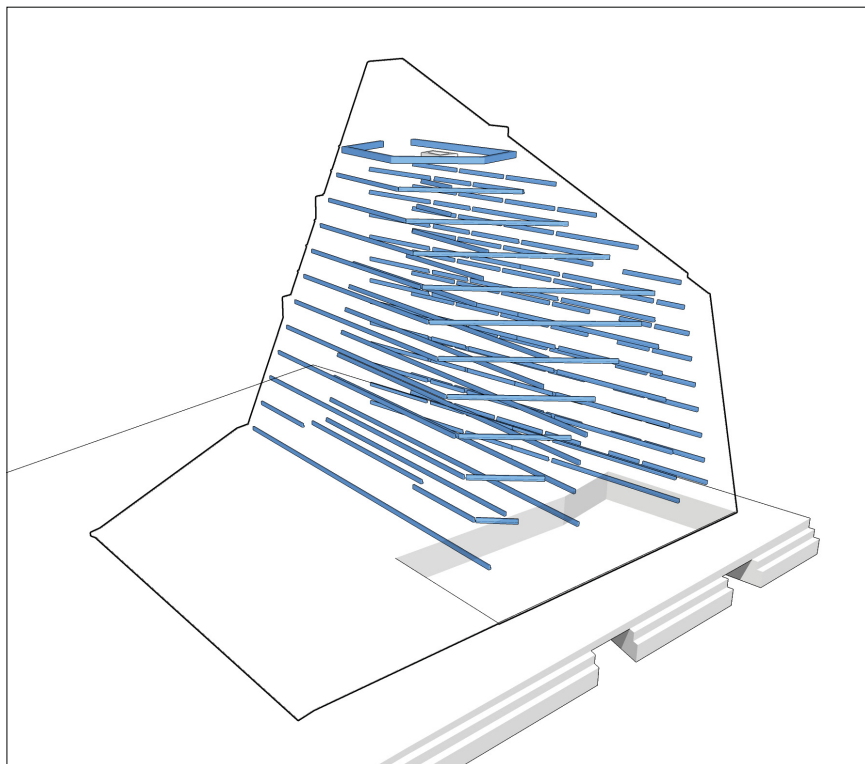


- 15' to 75' (4.5 to 22m) span range
- Rule of thumb for depth: span/15

Figure 2.37: A description of the main structural systems used.

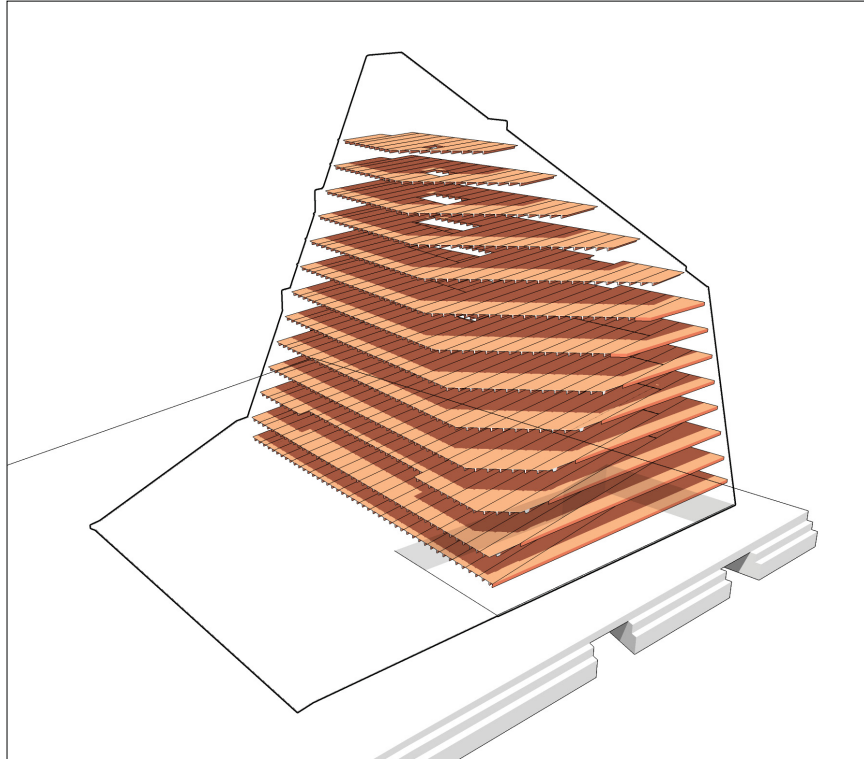


Columns & Structural Stairwells

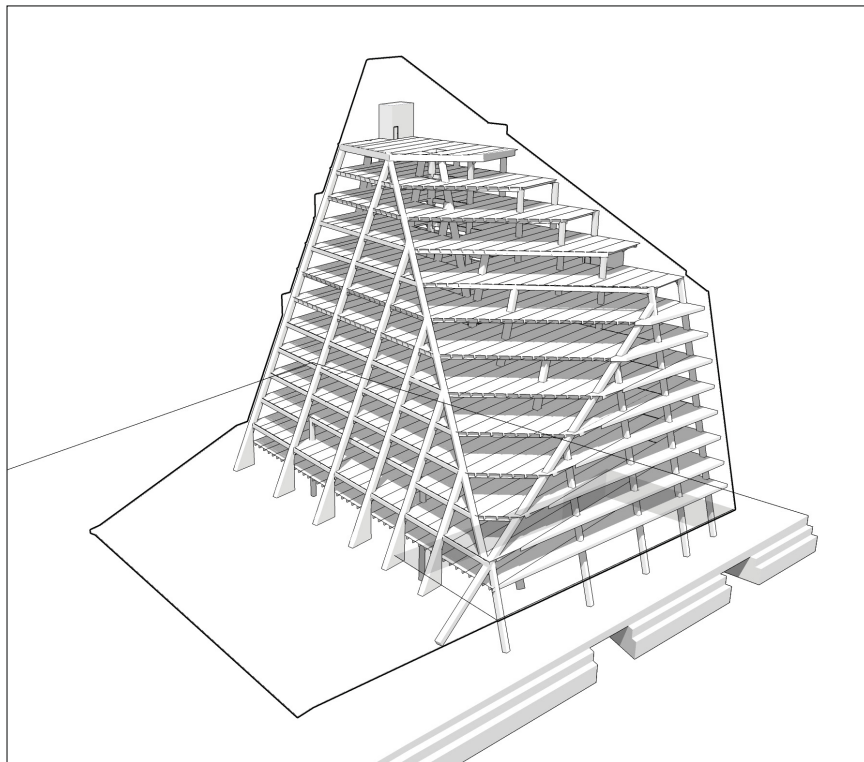


L-Shaped & Inverted Tee Beams

Figure 2.38: Diagrams isolating the different structural elements within the building.



Double Tees



Entire Structure

Figure 2.39: Diagrams isolating the different structural elements within the building.

CHAPTER 3: SUMMARY

The thesis focuses on methods of integrating the public into the operation of food production in an urban centre. Using architecture as a tool to engage the public with this production proves possible, and within an urban setting, results in a more educational operation than that of traditional farming in the countryside. Not only does architecture allow a more transparent operation of producing food, but it also creates the opportunity for new programmatic combinations such as hydroponic and traditional farming. The combination also allows for the regrouping of traditional ideas such as sustainability and food, and the feeders and the fed. Now, within the city, farmers and customers can be seen together as one entity instead of two disconnected dependencies. The reintegration of food production into the city can be seen as a re-alliance of the country and the city.

Further studies are possible in a wide area of study, depending on one's profession. For myself, further studies could be done on technical issues such as mechanical systems involved in hydroponics, energy requirements required by LED lighting and the ETFE inflated wall system. Other beneficial areas of study include horticulture, solar aquatics, and how to store electrical energy (collected from tidal turbines, regenerative braking, and photovoltaics).

City Greens was designed to become the first hybrid prototype growing food within an urban centre. As a proposal for a prototype, one needs to come up with a viable economic plan. Further studies from externals should be done to determine what would be the most economical foods to grow. Also, if vertical farms are to start feeding developing nations, more studies are needed in growing staple foods hydroponically. Foods that feed the world are crops such as grains, millet, and rice.

A concern for many people, when they discover vertical farm proposals, is the notion that these farms will be hyper-modern, computer controlled systems. Joyce Hwang writes about this in *On Farming*: "Unlike the community garden or the family farm models, vertical farm prototypes propagate imaginations laden with hyper-efficiency and current technology."³⁵ She continues by saying that no matter how mechanized it could become, there will still be the need for intensive manual labour.

In the foreword to *The Vertical Farm*, Majora Carter even writes that when vertical farms actually become a reality they will be much different than what Dickson Despommier imagines:

In the time between now and the realization of Dickson Despommier's vision for our food system, there are many opportunities for innovation and entrepreneurship. If the skyscraper farm is like a 747 jetliner, we are now at the stage of the Wright Brothers. [...] There will be many failures as a legion of tinkerers and engineers all struggle to take off with the right combination of profitability, sustainability, and quality food.³⁶

Majora Carter's foreword shows that in the beginning, vertical farms are not going to be perfect, just as with any new vision or design ambitions. Farming itself took thousands of years to perfect and even now we continually try to push it to the next level of resilience and productivity. As with my thesis, it is not proposing a solution but rather building upon the proposals that already exist. The difference with my proposal, however, is seeing the need for a more holistic and engaging approach to urban agriculture. My thesis will serve as a vision for designing a more complete prototype which can hopefully add to the growing field of urban agriculture.

APPENDIX A: DISADVANTAGES OF MODERN AGRICULTURE

- Uses up to 70 percent of the available fresh water on Earth. It is estimated in China, for example, that 80 percent of water used in flood irrigation is lost to evaporation.
- Agricultural run-off: one of the most destructive sources of pollution on Earth.
- The clearing of rainforests to produce farmland.
- Fossil fuels consumption: within the United States, more than 20 percent is used in agricultural production.
- The use of agrochemicals promotes the development weeds that are increasingly resistant to these exact .
- Crops are susceptible to weather conditions such as droughts, floods, and pests.
- Generally only one to two harvests per year.
- More prone to bacterial infections transferable to humans (E.coli, salmonella, etc.)
- If a crop fails the farmer must wait until next year to replant.
- This method of food production will not be able to keep up with expected population growth.

APPENDIX B: ADVANTAGES OF VERTICAL FARMS

- No weather-related crop failures due to droughts, floods, or pests.
- All vertical farming food is grown organically without the use of herbicides, pesticides, or fertilizers.
- No agricultural run-off because all water used within the building is recycled.
- Reduced fossil fuel consumption through the elimination of transportation and machinery on the land.
- Existing farmland can start to return to functioning ecosystems.
- The vertical farm will be able to produce much of its own energy through solar, wind, methane, etc.
- If a crop has become contaminated, the crops can be destroyed and a new harvest can be started shortly after. There is no need to wait until next season.
- Hydroponics uses up to 70 percent less water than modern agriculture. Aeroponics uses up to 70 percent less water than hydroponics.
- Much higher crop yields per acre. One acre of vertical farmland is equivalent to 4-6 acres of modern agricultural farmland.

APPENDIX C: STATISTICS ON WATER SHORTAGES

The statistics below³⁷ in the Figure C.1 pie chart do not take into account the amount used by the industrial and chemical industries. By the year 2025, two-thirds of the world will be facing water scarcity and agriculture will be a major factor in this depletion.³⁸

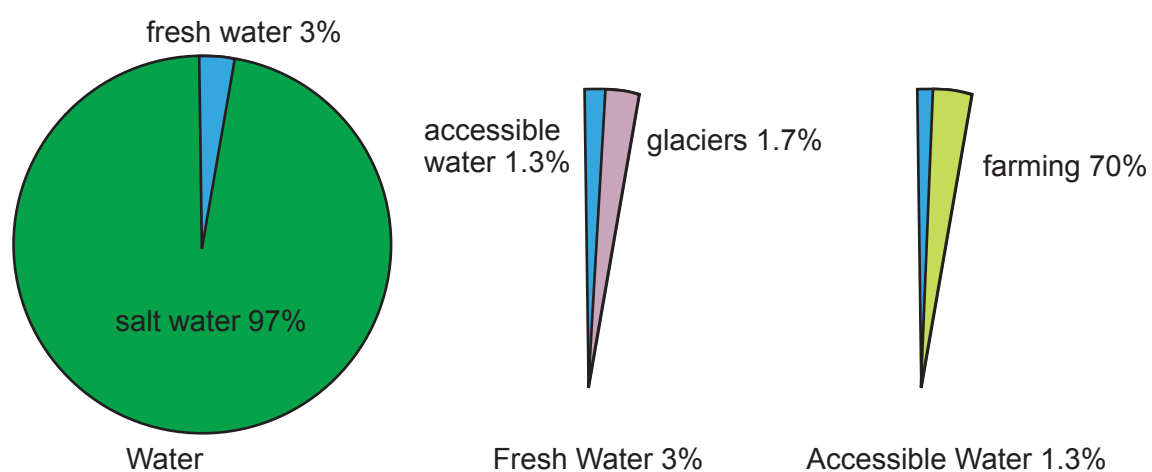


Figure C.1: Percentages of the world's available fresh water.

APPENDIX D: HYDROPONIC SYSTEMS

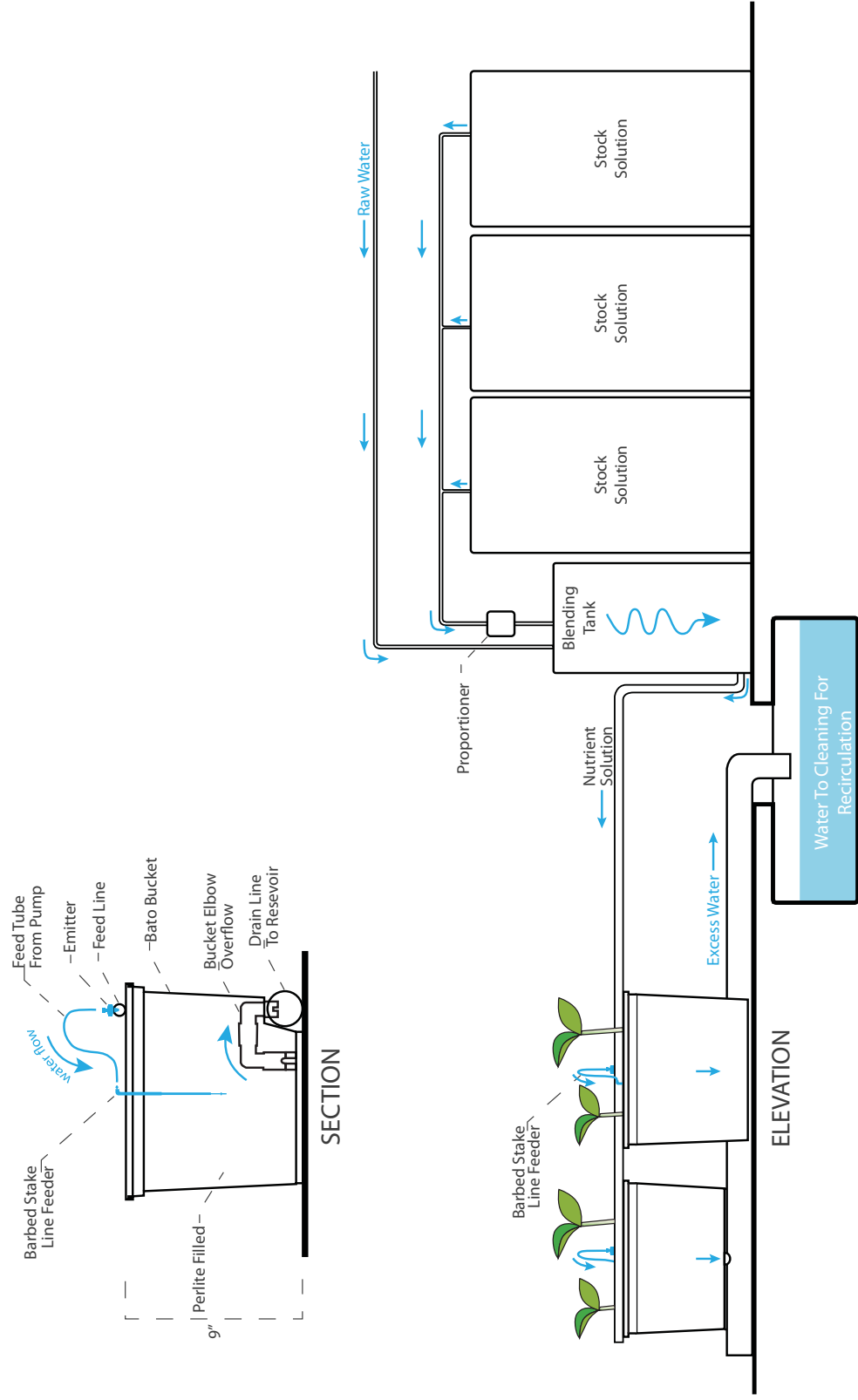


Figure D.1: A brief look at how the Bato Bucket system works and the key components.

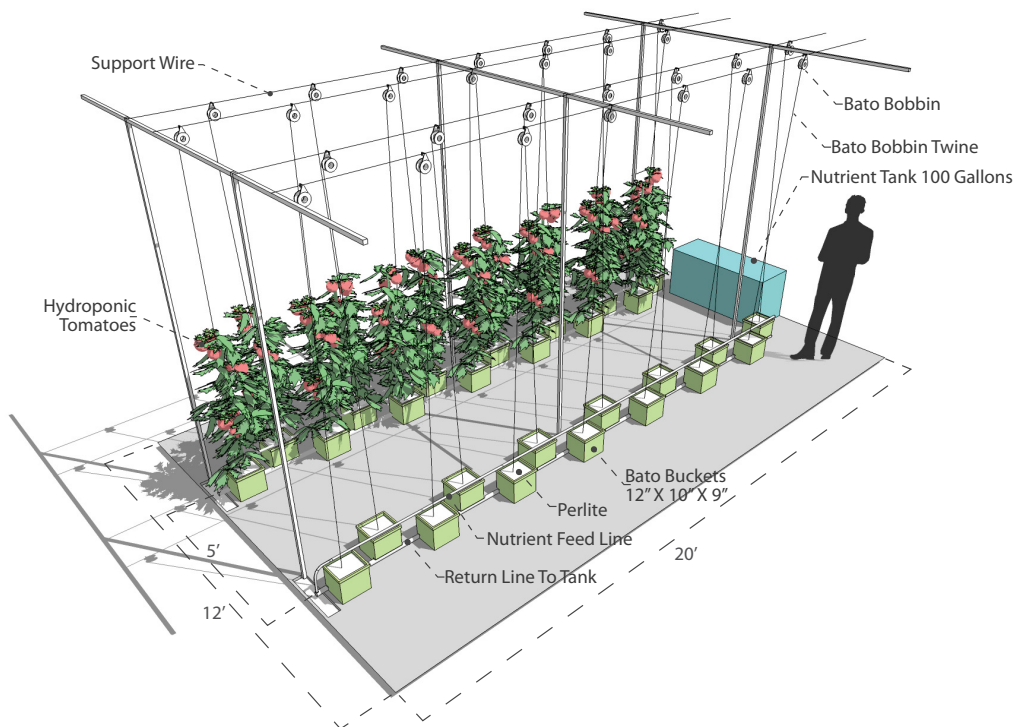


Figure D.2: Bato Bucket system operation and dimensions.

24 Bato Bucket System

Ideal for growing vine crops

- °tomato
- °cucumber
- °egg plant
- °pepper
- °etc

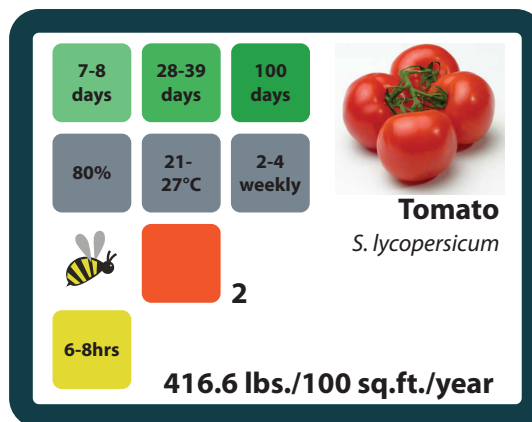


Figure D.3: Example of the adapted Food Matrix system formatted to the requirements of tomatoes.

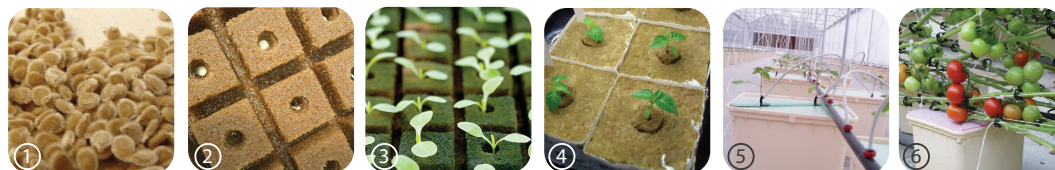


Figure D.4: Looking at the steps of lettuce growth through hydroponics: 1. Tomato seed. From Appalachian Seeds, Heirloom Tomato Seeds and Plants; 2. Seeds in rockwool. From Saipan Hydroponics, Transpacific Hydroponics Pilot Project; 3. Tiny seedlings. From Doug Oster, Post Gazette; 4. Rockwool seedling transplant. From Fatalii, Rockwool Pictures; 5. Young dutch bucket tomato 2. From Crop King, Hydroponic Growing Systems; 6. Hydroponic tomatoes over dutch bucket. From Crop King, Hydroponic Growing Systems

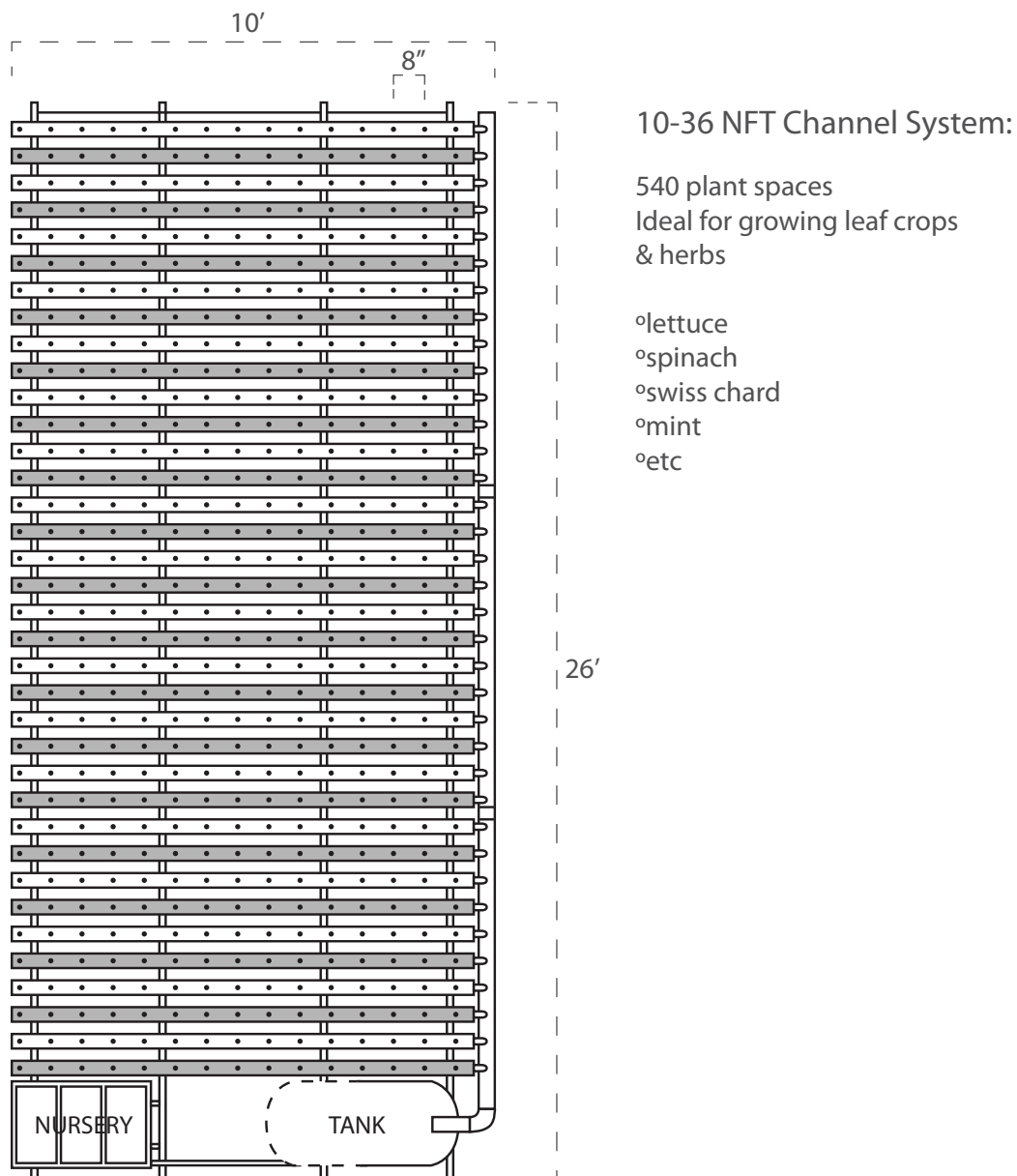


Figure D.5: Plan view of NFT channel system.



Figure D.6: Looking at the steps of lettuce growth through hydroponics: 1. Lettuce seeds. From Science Photo, Science Photo Library; 2. Seeds in rockwool. From Saipan Hydroponics, Transpacific Hydroponics Pilot Project; 3. Tiny seedlings. From Doug Oster, Post Gazette; 4. Horticubes. From David Kuack, Hort America; 5. NFT drain end. From Crop King, Hydroponic Growing Systems; 6. End view of NFT channel. From Crop King, Hydroponic Growing Systems

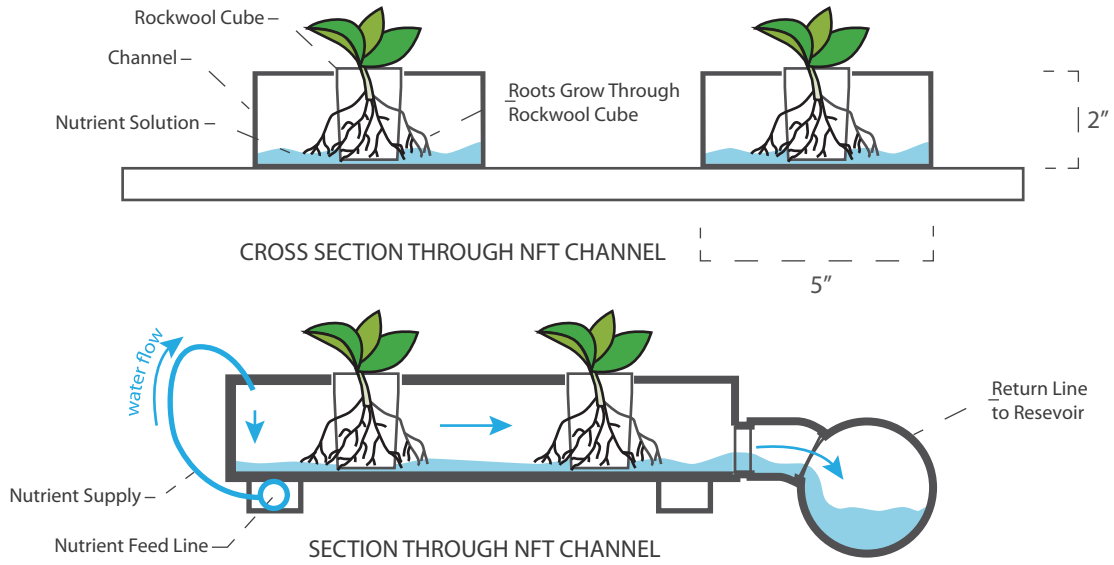


Figure D.7: Cross section and longitudinal section through the NFT channels.

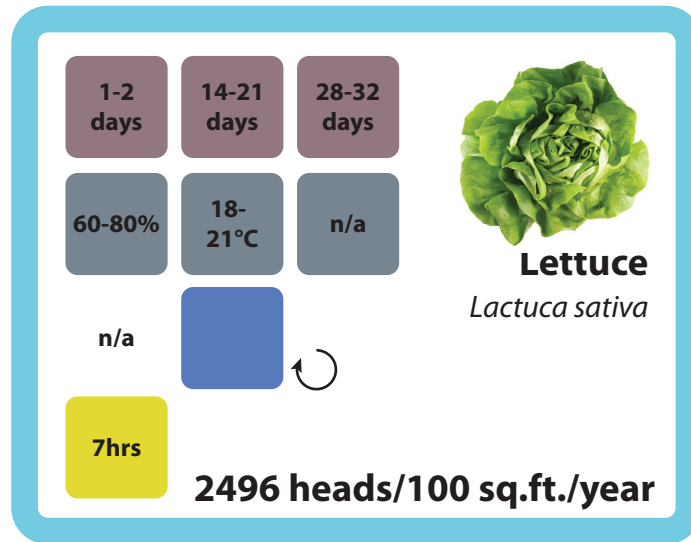


Figure D.8: Example of the adapted Food Matrix system formatted to the requirements of lettuce.

APPENDIX E: WATER

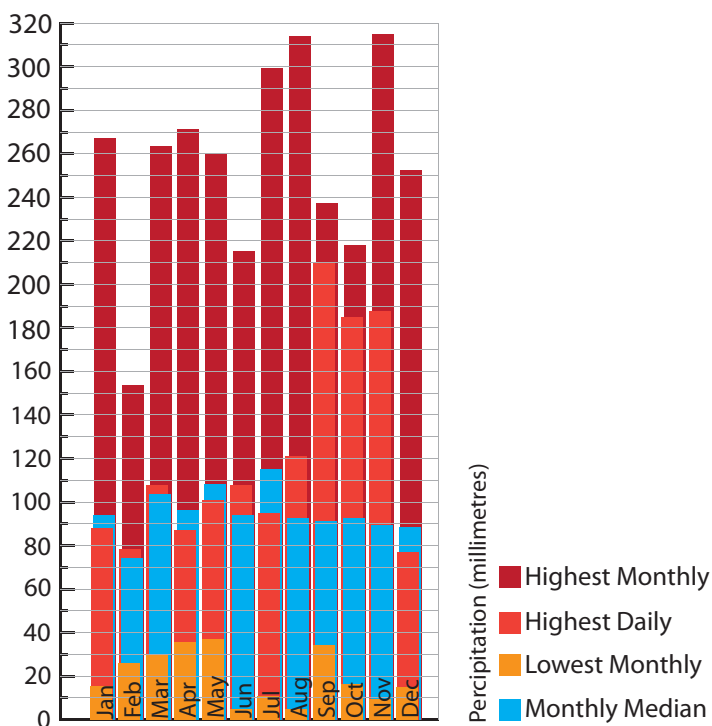
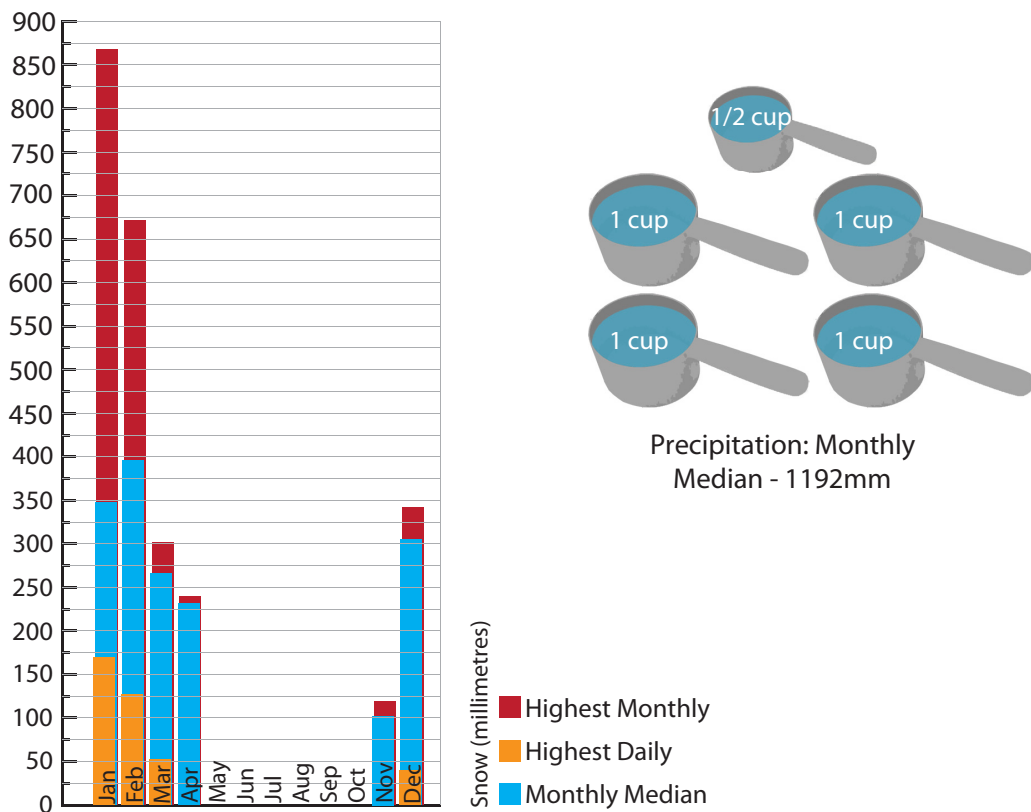


Figure E.1: Annual precipitation statistics from Central Park, Manhattan 1971-2000. (Data collected from NOAA Satellites and Information Service, Precipitation)

Annual Rainfall Yield in Gallons for Various Roof Sizes and Rainfall Amounts									
ROOF SIZE IN SQUARE FEET	RAINFALL IN INCHES								
	20	24	28	32	36	40	44	48	52
1000	11236	13483	15730	17979	20225	22472	24719	26966	29214
1100	12360	14832	17303	19775	22247	24719	27191	29663	32135
1200	13483	16180	18876	21573	24270	26966	29663	32360	35056
1300	14607	17528	20450	2371	26292	29214	32135	35056	37978
1400	15730	18876	22023	25169	28315	31461	34607	37753	40899
1500	16854	20225	23596	26966	30337	33708	37079	40450	43820
1600	17978	21573	25169	28764	32360	35955	39551	43146	46742
1700	19101	22921	26742	30562	34382	38202	42023	45843	49663
1800	20225	24270	28315	32360	36405	40450	44495	48540	52584
1900	21348	25618	29888	34157	384227	42697	46966	51326	55506
2000	22472	26966	31461	35955	40450	44944	49438	53933	58427
2100	23596	28315	33034	37753	42472	47191	51910	56629	61349
2200	24719	29663	34607	3955	44495	49438	54382	59326	64270
2300	25843	31011	36180	41348	46517	51686	56854	62023	67191
2400	26966	32360	37753	43146	48540	53933	59326	64719	70113
2500	28090	33708	39326	44944	50562	56180	61798	67416	73034
GALLONS OF WATER COLLECTED									

The capacity of rainwater to be collected on site

MONTH	AVERAGE RAINFALL
Jan	3.70
Feb	2.95
Mar	4.05
Apr	3.79
May	4.25
Jun	3.72
Jul	4.52
Aug	3.66
Sep	3.58
Oct	3.67
Nov	3.49
Dec	3.45
Annual	46.92

Figure E.2: A chart displaying the capacity of rainwater that can be collected based on roof size from Manhattan, New York. This is important to know because City Greens will be using mostly harvested rainwater. (Data collected from NOAA Satellites and Information Service, Precipitation)

APPENDIX F: SOLAR

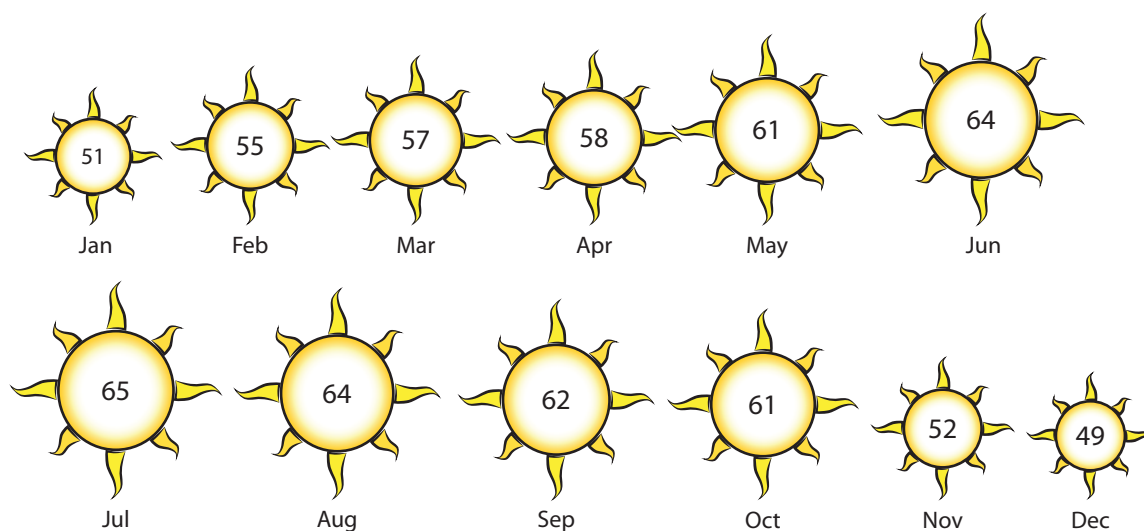


Figure F.1: Sunshine - average percent of possible (no clouds) over the past 109 years. (Data collected from NOAA Satellites and Information Service, Sunshine - Average Percent Possible)

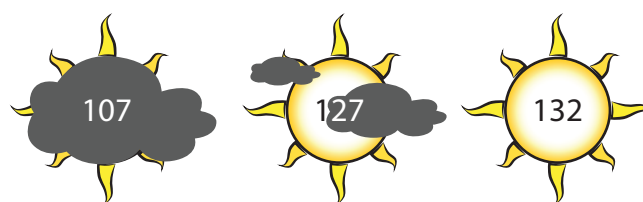


Figure F.2: Annual cloudiness - mean number of days over the past 42 years. (Data collected from NOAA Satellites and Information Service, Sunshine - Average Percent Possible)

When comparing the solar requirements of certain plants on the food matrix to annual solar statistics, one can determine the average amount of artificial light needed during the year (see Figure F.3). Lettuce, for example, requires roughly 7 hours of direct sunlight a day. In August 64 percent of the month has no clouds: $64\% \times 7 \text{ hrs} = 4.48 \text{ hrs}$ of direct sun during August. Therefore August requires an average of 2.52 hrs of artificial light per day.

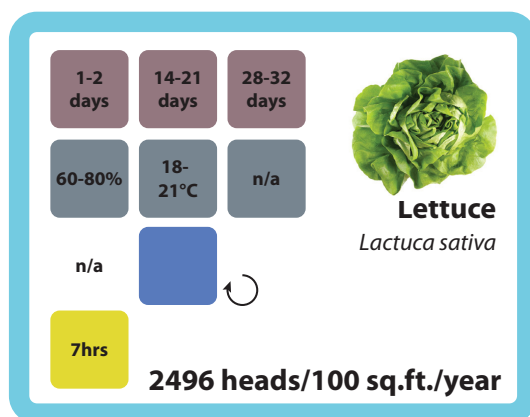


Figure F.3: An adaption of the Food Matrix to fit hydroponics.

APPENDIX G: SOLAR AQUATICS

What is solar aquatics? As written in *Greening the City: Ecological Wastewater Treatment In Halifax*, edited by Christine Macy, solar aquatics is:

an engineered system that mimics the natural purifying processes of freshwater streams, meadows, and wetlands. Using greenhouses to control the environment during cold weather, this system relies on bacteria, algae, plants and aquatic animals to metabolize the nutrients and contaminants in wastewater as it flows through a series of tanks, engineered streams, and constructed marshes.³⁹

One of the best examples of solar aquatics can be found in Bear River, Nova Scotia. The solar aquatics station in Bear River is 2400 square feet and can process 56,781 litres (15,000 gallons) of wastewater per day or 15,141,647 litres (4,000,000 gallons) of wastewater per year. Even though this centre treats wastewater in the form of sewage, it can just as easily be used to treat harvested rainwater as shown in Figure G.1.

As stated on the Newcity website, in a solar aquatics system:

- The system replicates, under controlled conditions, the natural purifying process of freshwater streams, meadows, and wetlands;
- The system recovers nutrients through the treatment of waste and wastewater;
- Sewage collected from an area flows through a series of tanks, engineered streams, and constructed marshes where contaminants are metabolized or bound up by algae, plants, bacteria, and aquatic animals that are grown in greenhouses;
- Sewage is not treated as waste but considered as food for the biological community in the greenhouses;
- Treatment typically takes two to four days.⁴⁰

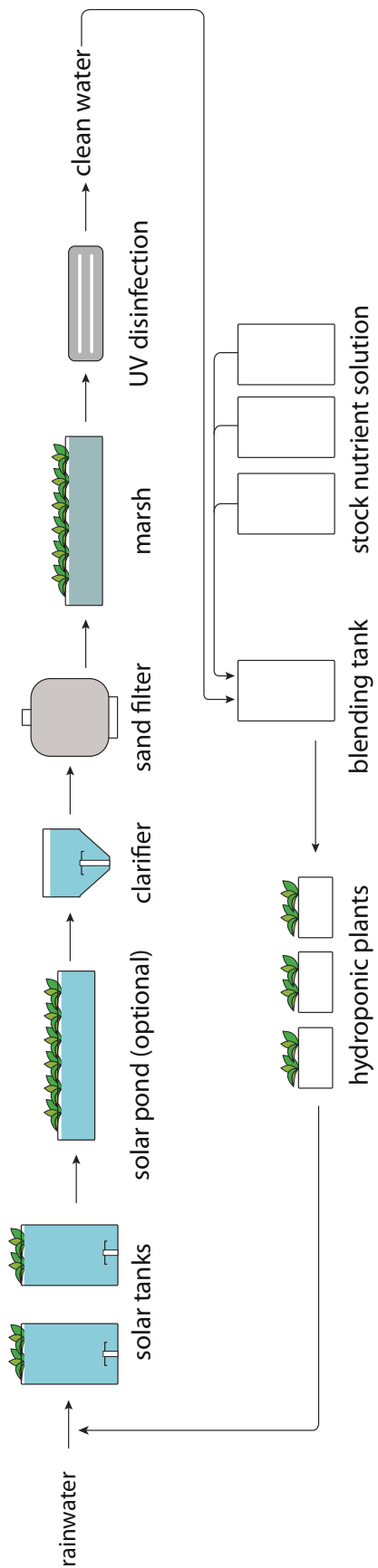
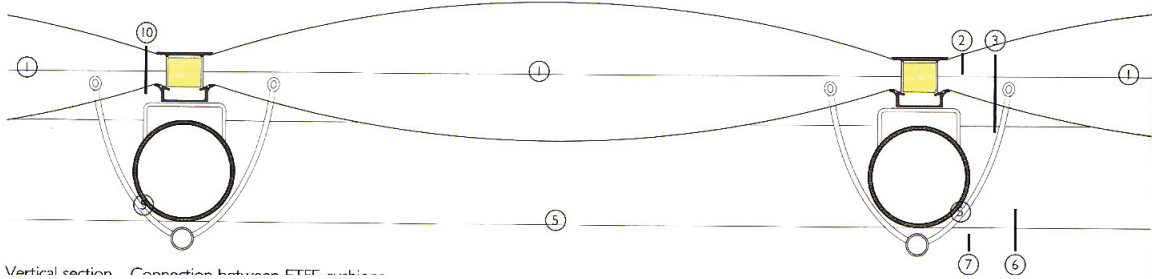


Figure G.1: Diagram showing the modified solar aquatics process linking into a hydroponic system.

APPENDIX H: ETFE (ETHYLENE-TETRA-FLUORO-ETHYLENE) DESIGN AND BENEFITS

ETFE was chosen as the material for the building façade because of its beneficial properties. ETFE is a polymer similar to Teflon (PTFE) which is extruded as a sheet material.⁴¹ The benefits of using ETFE on a building designed around transparency are clear:

- A common thickness of 0.2mm, minimal weight (around 350g/m² for 0.2mm thickness and 1000g/m² for 0.5mm thickness);
- High transparency (95% light transmission);
- High resistance to tearing;
- Life expectancy (25-35 years);
- Using ETFE in a dense urban also is a benefit because of its high resistance to pollution and chemicals;
- The inflated ETFE cushions are usually self-cleaning as well because of their low surface friction (like Teflon) and usually cleaned during rain;
- Another benefit of ETFE includes its ability to do away with separate shading systems by printing a pattern onto the ETFE surface itself, as described in Chapter 2: Building Façade.⁴²



Vertical section: Connection between ETFE cushions

Figure H.1: Watts, vertical section: connection between ETFE cushions. From Watts, *Modern Construction Handbook*

Details:

1. ETFE cushion
2. Extruded aluminum clamping plate
3. Extruded aluminum retaining profile
4. Plastic edge bead to ETFE membrane
5. Supporting structure
6. Plastic air supply tube
7. Main air supply tube
10. Thermal Insulation



3-D view of joint between ETFE cushions showing air supply pipes

Figure H.2: Watts, 3-D view of joint between ETFE cushions showing air supply pipes. From Watts, *Modern Construction Handbook*

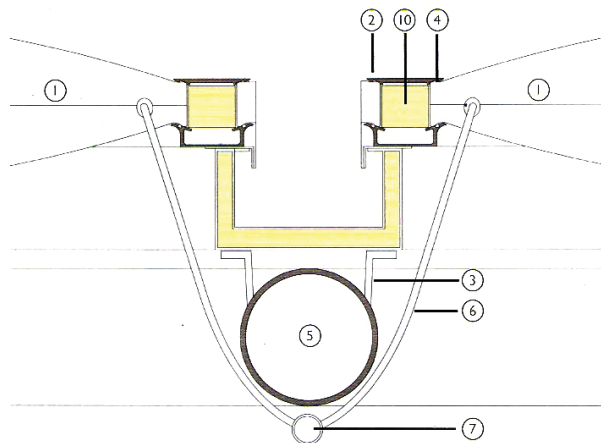


Figure H.3: Watts, vertical section: ETFE clamping detail with insulated gutter. From Watts, *Modern Construction Handbook*

APPENDIX I: CASE STUDIES

Printed shading on ETFE: Art Center for the College of Design in Pasadena, US



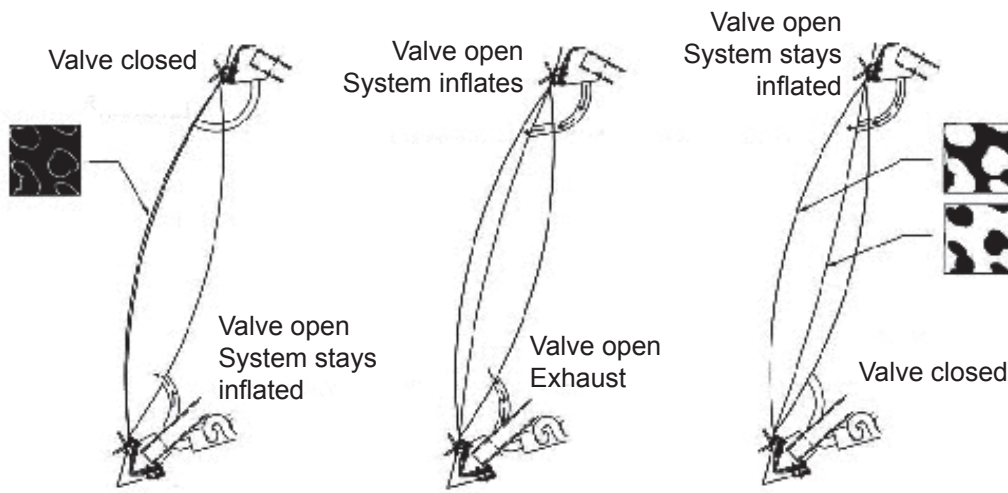
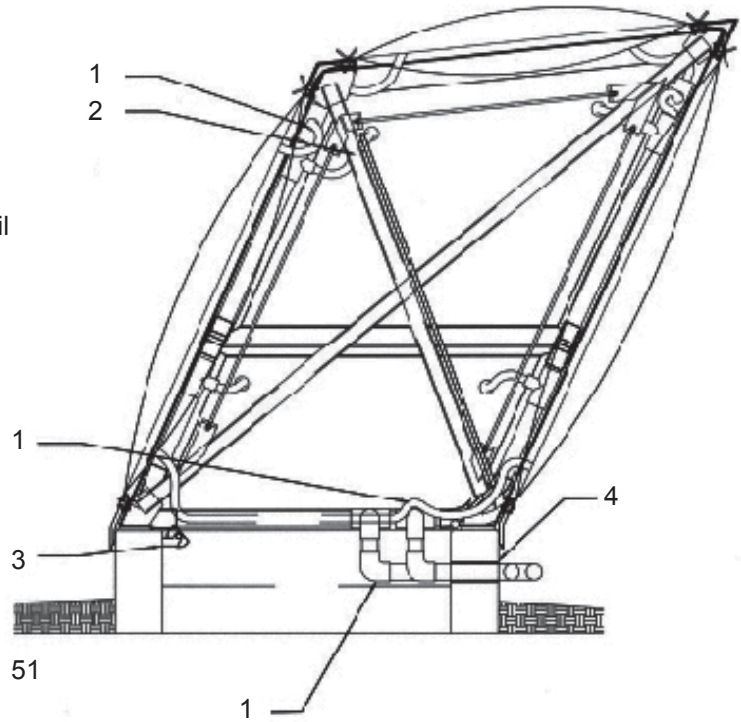
Figure I.1: Daly Genik Architects: The skylights also function as sculptures in the accessible roof landscape (built project, 2004). From LeCuyer, *ETFE: Technology and Design*



Figure I.2: Daly Genik Architects, interior view closed (built project, 2004). From LeCuyer, *ETFE: Technology and Design*

- 51: Cross section
 1. typical pneumatic supply tube
 2. skylight support structure
 3. lighting fixture
 4. concrete curb penetration

52: Variable positions of middle foil



52

+ 0 Min.
Rejects Light

- 10 Min.
Transition

+ 20 Min.
Admits light

Figure I.3: Daly Genik Architects, cross section (built project, 2004). From LeCuyer, *ETFE: Technology and Design*

The Rite Project: Roosevelt tidal energy, East River, NYC

In 2002, NYC initiated a three phase project called The Rite Project which was to test the potential of tidal power in the East River, NYC. The project went through three phases: Phase 1: The Prototype Testing and Phase 2: Demonstration and now with Phase 3: MW-Scale Build-Out nearing completion. The turbines will produce electricity through a system called Free Flow Kinetic Hydropower system. The project was able to demonstrate that this Free Flow system can be scaled down for a populous centre. Through its two year demonstration, this system proved to be an efficient source of renewable energy. It is the first grid-connected array of tidal turbines. Six turbines were installed during the demonstration phase, with the following results:

- Grid-connected power with no power quality problems;
- Fully bidirectional operation – passive yawing with high efficiency on both ebb and flood tides;
- Automatic control and continuous, unattended operation;
- No fouling or damage from debris;
- Produce 70 megawatt hours of energy;
- 9,000 turbine-hours of operation;
- Marine life mortality rates did not seem to increase.⁴³

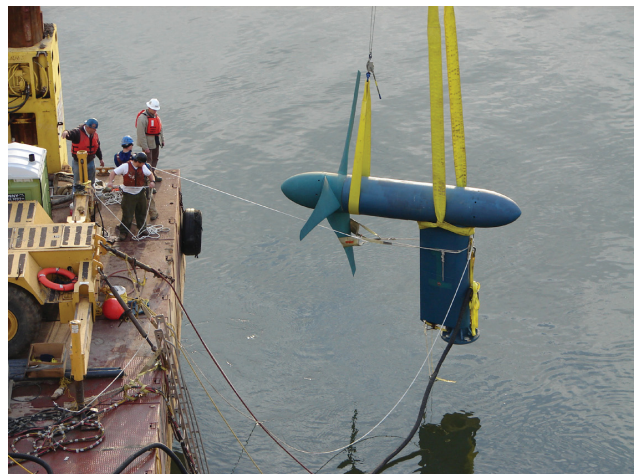


Figure I.4: Free flow system turbine being installed in East River, New York, NY. Photograph by Kris Unger, from Verdant Power Inc.

The Sun Works Centre: Manhattan School for Children

The school is the first rooftop environmental science lab in New York public city schools. New York Sun Works, which operates the facility, plans to build 100 additional classrooms like this throughout the city. It operates by hands-on learning though growing food. Students have year-round access and are educated on environmental sciences, climate change, conservation, food production, health and nutrition, and sustainable development.

- Size: 1420 square feet, seating 40 students.
- Yield: 8,000 pounds of produce a year with 400-600 plants at any given time.
- Produce: lettuce, tomatoes, cucumbers, peppers, squash, eggplants and strawberries.
- Systems: hydroponics, aquaponics, solar panels, rainwater catchment, composting station and weather station.
- Water collection: 40,000 gallons a year.
- No pesticides. The school uses ladybugs as a natural method of protection.
- Fertilizer: Through aquaponics the fish (tilapia) will provide fertilizer for the plants. Worms from the composting will feed the fish.⁴⁴



Figure I.5: Photo 6. From Flickr, Bright Farm's Photostream



Figure I.6: untitled. From NY Sun Works, The Sun Works Centre at PS333

Wayside Energy Storage Project by Viridity Energy, Philadelphia, Pennsylvania.

- The system will use a regenerative braking system to capture the energy released when subway cars are braking into the station.
- It is estimated by Southeastern Pennsylvania Transportation Authority (SEPTA) that they can save \$100,000 per year on their electricity bill.
- A 1-1.5 megawatt battery will be used to store the electricity.
- A 6-car passenger train can produce up to 3 megawatts over 15 seconds of braking.
- The stored energy will be used to power the trains leaving the station and because there will be excess, it will be sold back to the grid.⁴⁵



Figure I.7: Beijing subway development. From Railway Technology, Projects

APPENDIX J: CITY GREENS FOOD PRODUCTION PER CAPITA

In order to give a sense of the capacity of vegetables City Greens can produce I will use the example of tomatoes and lettuce. Determining the exact amount depends on which crops are being grown, as each yields varying amounts. In the United States, according to the USDA, Americans consume an average of 201.7 pounds of fresh vegetables per capita, per year.⁴⁶

For the sake of ease, assume that only tomatoes are grown on every floor, through the bato bucket method. By referring back to Appendix D: Hydroponic Systems, Figure D.2 shows that the 24 bato bucket system has a space requirement of 20' X 12' or 240 square feet, including circulation. Comparing this to the adapted food matrix for tomatoes as seen in Figure J.1 below, this method is capable of yielding 416.6 lbs./100 sq.ft./year. Therefore, a 24 bato bucket system is capable of yielding 1000 pounds of tomatoes per year $((240 \text{ sq.ft.} \div 100 \text{ sq.ft.}) \times (416.6 \text{ lbs.})) = 999.84 \text{ lbs.})$. City Greens will have 11 floors devoted to growing produce and can comfortably fit 280 bato bucket systems. This amounts to 280,000 lbs. of tomatoes per year $(280 \text{ systems} \times 1000 \text{ lbs./year})$. If an American were to eat only tomatoes as vegetables, City Greens would be able to give 1388 $(280,000 \div 201.7)$ people their yearly supply of fresh vegetables.

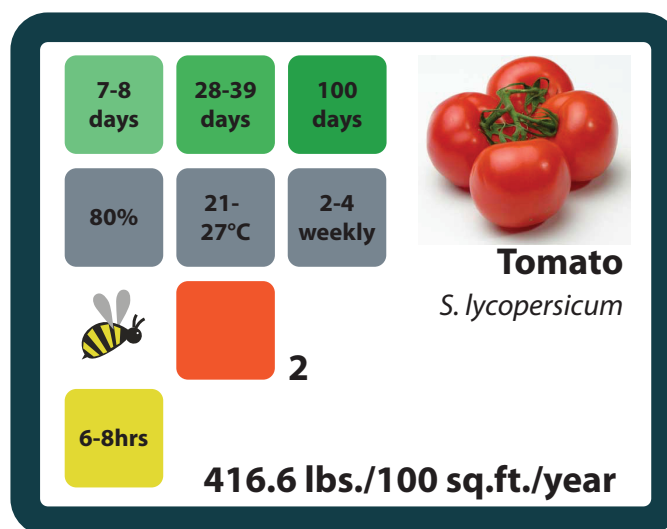


Figure J.1: Adapted Food Matrix for tomatoes.

Next, assume that City Greens only grows lettuce through the nutrient film technique. By referring back to Appendix D: Hydroponic Systems, Figure D.5 shows that the 540 plant NFT channel system has a space requirement of 10' X 26' or 260 square feet without circulation. If 5' of circulation is added to the space requirements, this would bring the total up to 390 square feet (15' X 26'). Comparing this to the adapted food matrix for lettuce as seen in Figure J.2 below, this method is capable of yielding 2496 heads/100 sq.ft./year. Therefore, a 540 NFT channel system is capable of yielding 9734 heads of lettuce per year $((390 \text{ sq.ft.} \div 100 \text{ sq.ft.}) \times (2496 \text{ heads})) = 9734$). Through this method, an average of 160 NFT channel systems will be able to fit. This amounts to 1,557,440 heads of lettuce per year $(160 \text{ systems.} \times 9734 \text{ heads/year})$. According to the University of California Vegetable Research and Information Centre iceberg lettuce is shipped in cartons weighing 50 pounds with 24 - 30 heads per carton. The number of heads per carton tells us that each head weighs between 1.67 and 2.08 pounds, or an average of 1.875 pounds each.⁴⁷ With a head of lettuce weighing an average of 1.875 pounds, the yield would be 2,920,200 lbs. $(1.875 \text{ lbs.} \times 1,557,440 \text{ heads})$ of lettuce per year. If an American were to eat only lettuce as vegetables, City Greens would be able to give 14,447 $(2,920,200 \div 201.7)$ people their yearly supply of fresh vegetables.

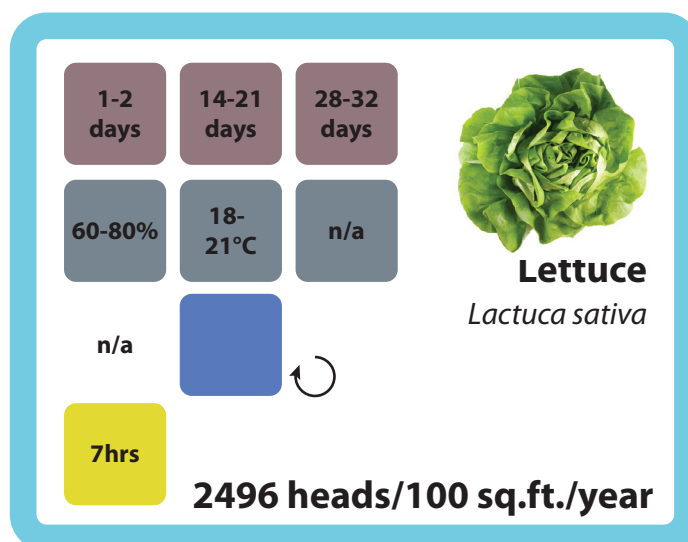


Figure J.2: Adapted Food Matrix for lettuce.

As of 2010, according to the United States Census Bureau, Manhattan had a population of 1,585,873.⁴⁸ Comparing this population to the amount of people lettuce could feed, it shows that City Greens could give 0.91 percent of the population their annual supply of fresh vegetables. This percentage amounts to requiring 109.77 City Greens buildings in order to feed the population of Manhattan.

It is important to keep in mind, however, that these figures do not include calculations from the outdoor farmland. The farmland has an area of roughly 158,846 square feet and by referring to the original food matrix by Craig England in the book *On Farming*, lettuce is capable of yielding 85.8 lbs./100 sq.ft./year.⁴⁹ This amounts to 1851 pounds (158,846 ÷ 85.8) of lettuce per year and increases the capacity of City Greens from 2,920,200 lbs. to 2,922,051 lbs.

What this shows is that even though the hydroponics systems of City Greens would only be able to give 0.91 percent of people their yearly supply of fresh vegetables, it is still far greater than the capacity of traditional farmland to yield the same.

APPENDIX K: THESIS PRESENTATION



Figure K.1: Photo of the layout for the final presentation.

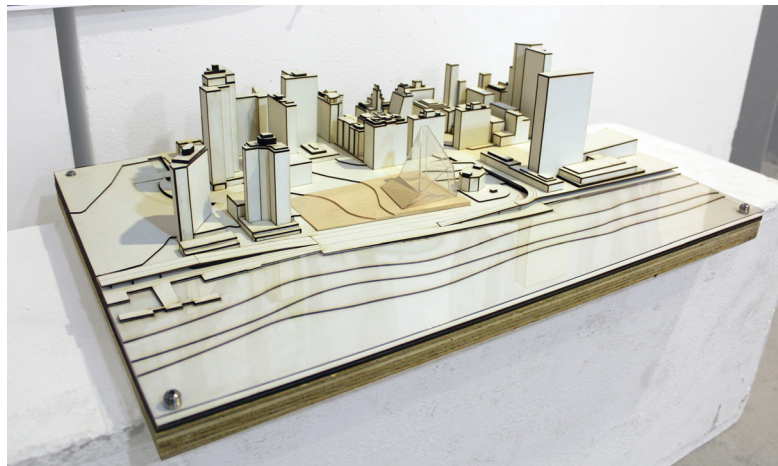


Figure K.2: City model showing the site in the context of the city.



Figure K.3: Building model. 1:200.

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