# BUILDING OUR FOOD SAFETY THROUGH TECHNOLOGICAL INNOVATIONS

Ahmad Addeen Syah Bin Shahar
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft

***ABSTRACT***

*This thesis explores the critical issue of global food insecurity and its impact on Doha, Qatar. The increasing unpredictability of climate change and the imposition of food export bans due to extreme weather events have heightened the urgency to achieve self-sufficiency in food production. This thesis delves into the impacts of climate change on food production and availability and the efforts to achieve food sustainability within urban areas. It discusses the challenges faced by Qatar, a country traditionally reliant on food imports due to its harsh desert environment and the shift towards self-sufficiency through innovative agricultural methods such as vertical farming. The research highlights the importance of prioritizing locally grown food; it looks at common vertical farm strategies and what are the best approaches to not only produce food in arid regions but to increase production yield and deploy automated vertical farms en masse in multiple areas simultaneously, inspiring a new era of sustainable food production.*

## I. INTRODUCTION

Global food insecurity is not just a pressing issue, it is a ticking time bomb, especially for nations with challenging natural environments that heavily rely on imported produce. With the increasing unpredictability of climate change and the imposition of food export bans due to droughts in various countries, the urgency to achieve self-sufficiency in food production has become paramount (Flavelle, 2019). Food self-sufficiency is not just a goal, it is necessary to mitigate the risk of hunger and famine and ensure the availability of accessible and affordable food, a challenge faced by approximately 800 million people worldwide. Establishing food sustainability within urban areas offers benefits such as reduced transportation time, fuel consumption, and helps to control urban expansion, as evidenced by the experiences of Doha, Qatar, in the early 2000s. Their aim is to achieve food self-sufficiency by 2030 (Ibrahim, 2022).

This thesis undertakes two primary causes of global food insecurity and their impact on Doha, Qatar, a city that serves as a microcosm of the global food security challenge. Doha has experienced a population boom four times in the early 2000s, 2.2 million out of 2.6 million are expats, and has increased steadily ever since.

### 1.1. Cause 1 – Global Climate Change

The global climate is rapidly changing, increasing the risk of hunger and famine across countries. Frequent extreme weather events, such as hurricanes, typhoons, cyclones, prolonged droughts, and devastating floods, create food shortages that are a significant concern for many nations. Climate change has also led to the spread of new pests and diseases that affect crops and livestock, further impacting food production and availability (Gupta et al., 2015). By 2050, the global temperature will increase by 1.5 degrees Celsius, altering precipitation and the suitable climate for certain foods. In recent years, we have witnessed the devastating impact of climate change and through more frequent and intense wildfires in parts of Europe, North America, and Australia. These wildfires have destroyed vast land areas and disrupted ecosystems and agriculture, leading to significant food supply disruptions (Flavelle, 2019). Additionally, droughts in regions like India have halted rice production, leading the government to ban rice exports to ensure domestic food security. The warming of our oceans has caused the extinction of local marine species and forced others to migrate to more hospitable environments. Climate change has resulted in lower fish yields and higher prices for seafood, making it harder for the masses to afford nutritious food (Gupta et al., 2015).

Furthermore, severe climate changes have displaced millions, creating inhospitable environments that make survival even more challenging. As the world climate spirals out of control and limits our food sources, locally grown food is not sustainable in the long run. There is a growing need to prioritize locally grown food, even in harsh environments like deserts. Some nations are slowly evolving to self-sufficiency through vertical farming within the urban landscape, providing much larger food yields in a small timeframe than traditional agricultural methods. Although vertical farming requires huge amounts of energy to produce food around the clock, some farms are self-sustainable through passive energy harvesting technologies and are even more productive in scorching heat countries like Qatar and the UAE (Brears, 2024).

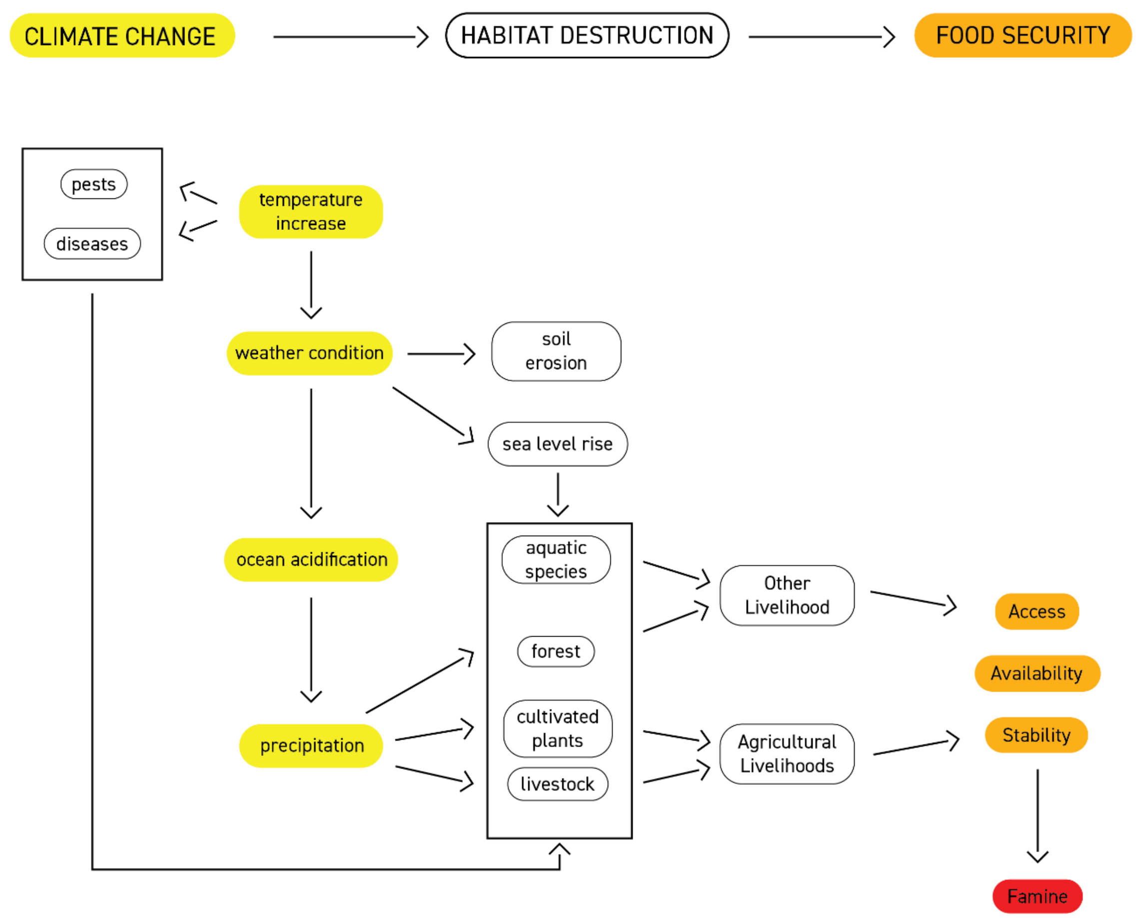


Figure 1 (own image). Climate change and its effects on global food security

## 1.2. Cause 2 – Food Dependent

Qatar, a small, flat desert land country surrounded mainly by water in the Persian Sea, traditionally relied on neighboring countries for food and water in exchange for pearls and oysters harvested on its coastline and horses bred in the desert. Their long historical trade imports for centuries provided them with food, now known as their natural dishes, from rice in India and Pakistan, spices in Iran, fruits in Oman, and freshwater from Saudi Arabia (National Museum of Qatar, N/A). As Qatar began to flourish in the 1950s in terms of oil exports, it still imported 95% of its food. Unlike countries like Oman, Saudi Arabia, and UAE, which has some agricultural advantages to produce food locally, Qatar is a flat desert land with no agricultural possibilities. Although they have become highly affluent due to the abundant oil deposits within their borders, they are still reliant on other countries for food. 20% of food imports come from Southeast Asia, the Americas, and Europe, and 80% of major food imports come from Middle Eastern countries, as shown in Figure 3.

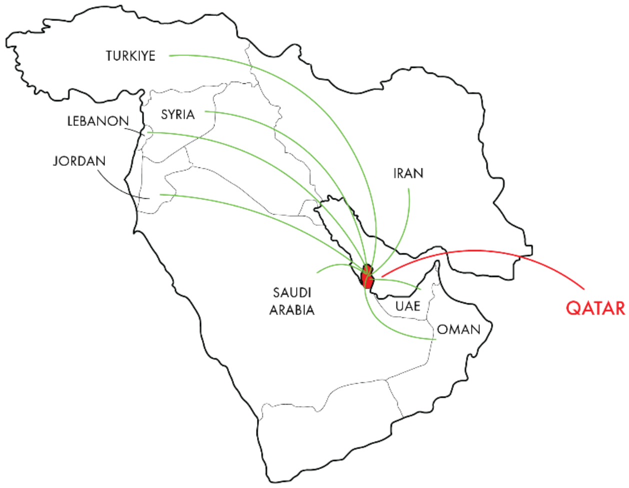


Figure 2 (own image). 80% of Qatar's food imports is in the Middle East

## II. Aquaponics Vertical Farm

The two diagrams below highlight the stark contrasts between conventional and vertical agricultural methods, emphasizing vertical farms' numerous advantages. For instance, the advanced vertical farm method abstains from using soil, leading to a significantly higher production yield of up to 50 times. Moreover, it operates with a 90% to 95% reduction in water usage, eliminates the need for pesticides and weed control, and can be implemented in various settings, including arid regions (Dupuis, 2023). This boosts agricultural productivity and contributes to a greener, more sustainable future.

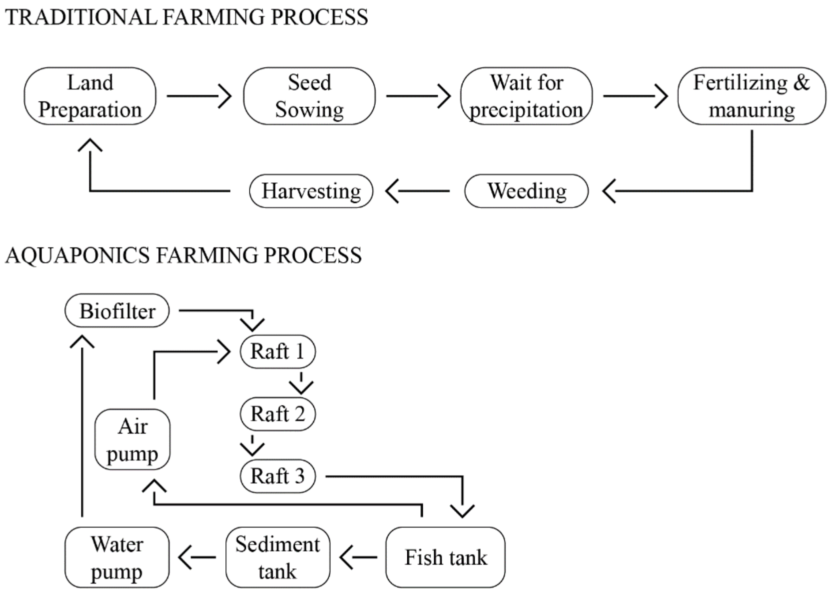


Figure 3 (own image). Traditional Farming Process vs. Aquaponics Farming Process

There are three types of advanced vertical farms: Hydroponics, Aeroponics, and Aquaponics. All the farm types are built without soil and protection from outdoor environments. They rely on nutrient-rich water solutions through mist or water channeling. In aeroponics, seeds are planted in pieces of foam into tiny pots; one end is exposed to constant light in the form of LED lights, and the other absorbs nutrient mist (Barth, 2018). Its advantage is that it can be built vertically and exist anywhere. Hydroponics are best for short-rooted crops; they rely on nutrient-rich water channeling from one grow tank to another (Brahlek, 2023). Aquaponics is an advanced method of Hydroponics. The fish tank is added to the existing hydroponics system, creating a plant-to-fish symbiosis, each depending on the other for nutrients and food (Go Green Aquaponics, 2023). More information on the different types of Aquaponics is explained in Appendix A, which illustrates why the Aquaponics Raft System is the best option for a vertical stack farm. Aquaponics is the best option in a desert country as it meets the people's dietary requirements as they most often consume dishes containing rice, fish or meat. In a country that does not have fresh water and vertical farms often require vast amounts of energy, there are technologies that have been used in vertical farms capable of harvesting the surroundings to generate electricity from solar and water from passive wind. This adaptability of vertical farming methods gives hope for their potential worldwide application (Dupuis, 2023).

To provide a practical understanding of the fundamental parameters of vertical farming, such as energy and water requirements, this chapter will delve into the Bustanica vertical farm in Dubai. As the largest vertical farm in an arid region, it serves as a tangible example, offering valuable insights into the minimum size requirements of each farming component, resources intake, and expected production yield. The only parameter that requires further research is the size of the fish tank, which can be acquired in Chapter III, section 3.1.

Table 1. Parameters of the Bustanica vertical farm in Dubai.

| **Parameters** | **Outcome** |
|---|---|
| Food | Lettuce, Berries, Parsley, Kale, |
| Farm Type | Hydroponics |
| Total Floor Area | 31,000 sqm |
| Daily Yields | 3,000 kilograms |
| Annual Yields | 1,100,000 kilograms |
| Electricity | 573 J per sqm per hour |
| Water | 62,620,000 L (2,020 L per 1000sqm)<br>*95% less water than traditional farm |
| Grow Stacks | 27 |
| Vertical Stacks | 3 |
| Vertical Stack Height | 6 meters |
| Labor | In-house team: agronomy experts, engineers, horticulturists, and plant scientists. |
| Investment | USD 40 million |
| Technology | Artificial Intelligence |

**Formula:** Every 1,000 sqm floor area of crops requires 573,000 Joules of electricity. One solar panel in Qatar produce 5kWh or 1,800,000 Joules on average throughout the year which could power 3,000 sqm of crops. A 1,000 sqm crop will require 2,020 L of water, 95% of which can be recycled. 1,000 sqm of crops would produce approximately 100 kilograms of food a day.

# III. Research Method 1 - Case Study Analysis

There are four case studies in this section; two case studies investigate integrating the human aspect, and the other two investigate only integrating technology. Each offers a unique perspective on integrating vertical farms within the urban fabric but also investigates mass production of food to not only be grown for those living closest to but to the entire neighborhood. The structure of grow racks is essential to understanding the farm components and which structure is the best for growing as tall as possible.

## 3.1. Tampines Blk 146 Rice Vertical Farm, Singapore

A small modular vertical farm attached to an existing social housing apartment in Singapore is made from used scaffolding, can be placed in small spaces, and vertically. It has demonstrated a sustainable life cycle analysis from growing rice to composting waste foods. Although the farm could grow as high as the scaffolding structure allows and in tight spaces, volunteers must participate in every phase, from supervising to growing to packaging food. Circulation could only allow one person at a time to ascend or descend the stairs. It may allow up to two people per level, making the seedling, supervising, and harvesting long and challenging. As it may be a suitable private farm for each apartment block, mass production with ease is only possible if it is technological and A.I. assisted. To understand more about Tampines Blk 146, go to Appendix B.

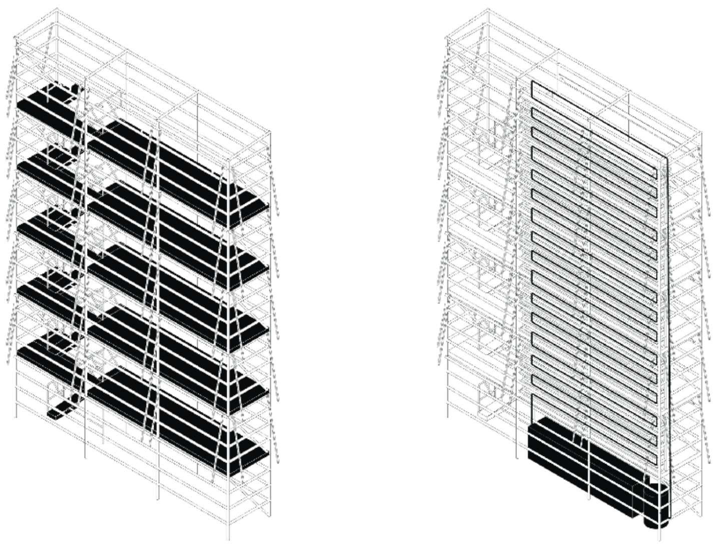

Figure 4 (own image).  Tampines Blk 146 Circulation (left) and Aquaponics Flow (right)

## 3.2. Nest We Grow, Japan

A similar approach to Tampines Blk 146 Rice Vertical Farm, Nest We Grow by Kengo Kuma Associates used Japanese joinery on wood structures as it is known to be structural and could last for many decades with minimal supervision. It has all the facilities to make life cycle analysis more efficient. It utilizes the environment to intake daylight for the plants and harvests rainwater on the roof without causing discomfort for the users. In addition to participating in the vertical farm as a community, there are facilities where food can be prepared. However, it has the same circulation problem as Tampines Blk 146, making growing and harvesting food long and challenging. The only attractive outcome in Tampines Blk 146 and Nest We Grow is the structural aspect, as long-lasting and structurally sound vertical farms used by the materials from the existing environment could be quickly set up. To understand the structural modular elements of Nest We Grow in depth, go to Appendix C.

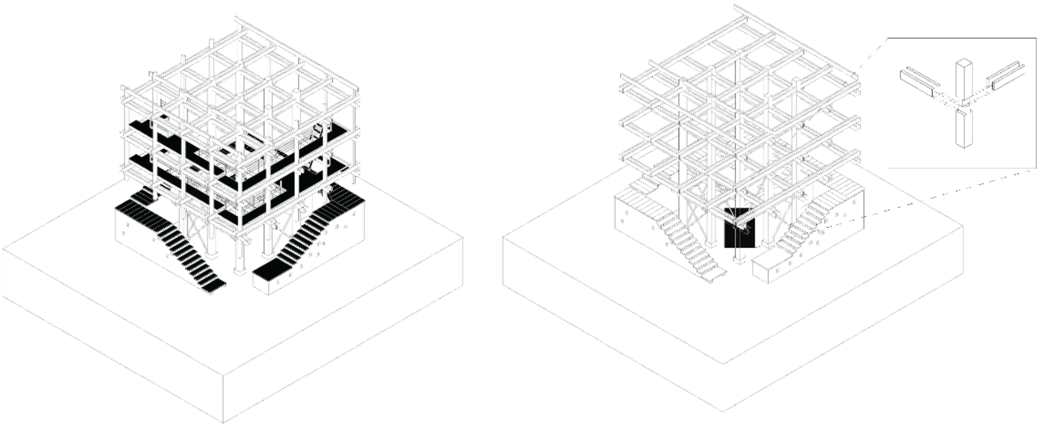

Figure 5 (own image).  Nest We Grow Circulation (left) and Main Structures Interlock Method (right)

### 3.3. Unmanned vertical skyscraper, China

China has rushed to stabilize its food security through population growth in major cities and its fear of dwindling future-generation farmers in the countryside. They have recently built a 26-story pig farm in the middle of the city, lobsters and oysters farms on the edge of the desert, and have now attempted to grow crops in a controlled indoor environment that requires little human intervention through the use of Artificial Intelligence or A.I. to monitor every seedling growth, adjust temperature and lighting to maximize food growth, improve nutrient-rich water, supervise bacterial level, and all aspects that previously requires constant human supervision cutting down time and labor during food production. Although still in development within an agricultural university, they have hoped to use this model in creating vertical farm skyscrapers like the 26-story pig farm that now exists in their city landscape, creating affordable and accessible food for city inhabitants. Currently, it stands at 10 meters with 20 stacks of crops using a simple truss structure. China's experimentation on growing in any region has been proven successful and aims to feed its population through this method.

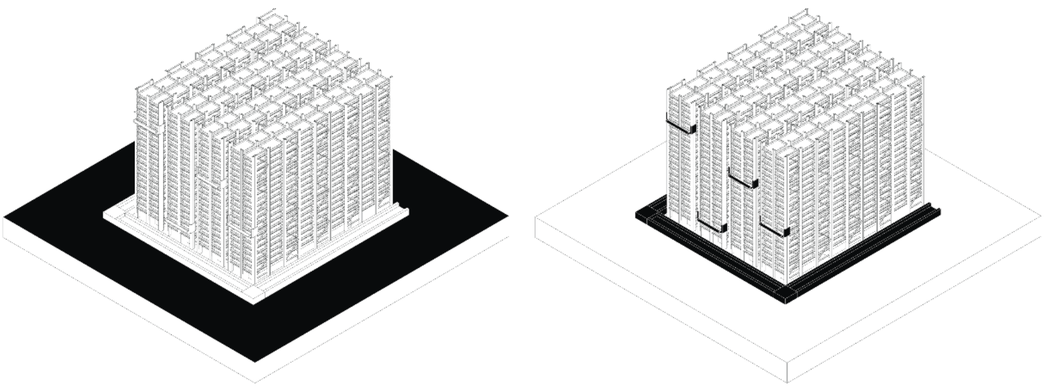

Figure 6 (own image).  Unmanned vertical skyscraper Circulation (left) and Automation (right)

### 3.4. Nordic Harvest, Copenhagen

A model similar to the vertical skyscraper in China is a running agricultural facility that uses robots to transport grow stacks from the racks to the harvest area. Other vertical farm models could only grow up to 50 times more than traditional agriculture. However, Nordic Harvest uses robotic technology to successfully grow 200 times more per square meter and has found innovative ways to recycle water up to 250% nutrients, and fertilizers that contribute to its high production yield. Currently, it feeds 5% of the population in Copenhagen and has a land area of 7,000 sqm including production areas and administration. For reference, Copenhagen has a population of 600,000. These two vertical farms case studies; the unmanned vertical skyscraper in China and the Nordic Harvest in Copenhagen, are helpful to understanding that the only way to mass produce food is through cutting down human intervention as much as possible in its growth stage and implementing advanced technologies like A.I. to supervise every aspect of the production, lift technology and robots to transport the finished grow products from the shelves to the kitchen.

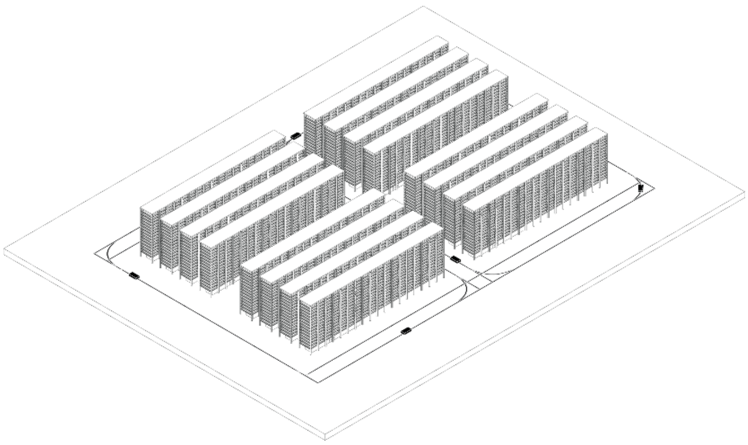

Figure 7 (own image). Nordic Harvest Automation

## IV. Research Method II – Technologies & Construction Method

This chapter delves into the crucial role of specific strategies in the mass production of self-sustainable vertical farms. These strategies, namely sustainable technologies, automation, and a prefabricated construction approach, are not just options but necessities for the future of food affordability and accessibility.

### 4.1. Sustainability Technologies

Despite its high energy requirements, a vertical farm holds the potential to be a global solution, particularly in desert countries endowed with a steady source of solar energy throughout the year. By implementing small-scale portable technologies, we can produce food and water through various methods, from passive wind to solar to food waste, reducing our dependence on traditional agriculture and its associated environmental costs.

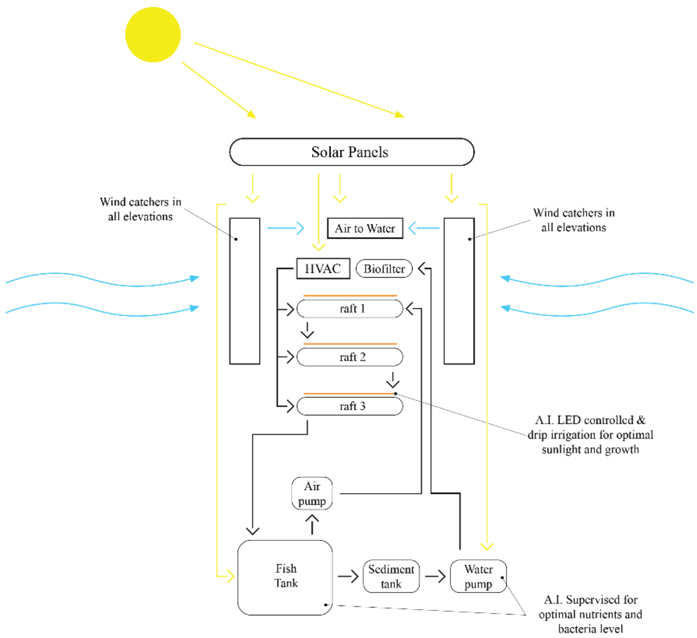


Figure 8 (own image). Sustainable Technologies and Aquaponics Raft System

### 4.2. Automation

In establishing vertical farms outside of urban centers, there must be in-house professionals during operating hours. In contrast, if it has automation and A.I. integrated, it will be able to not only cut operating costs but will perform the same tasks more efficiently, from monitoring food growth through energy-efficient artificial lighting emulating natural conditions to optimal nutrient levels. Chapter III's first two case studies rely on volunteers to participate in all stages, from planting to harvesting. In comparison, the final two case studies use only automation to plant, sort, and grow, exponentially increasing production yield. Bustanica recycles 9% of water, whereas Nordic Harvest, through the help of A.I. and automation, was able to recycle 250% of water, proving that A.I. assistance and automation integration is the only way forward to mass production and higher production yields all year round.

### 4.3. Prefabricated Construction Approach

Going back to Bustanica vertical farm, another important aspect is their prefabricated modular building systems that eliminate the disadvantages of vertical farms, which are high cost, high technical knowledge, and lengthy construction time. This section will investigate how a prefabricated modular approach could be beneficial in deploying aquaponics vertical farms throughout Doha, Qatar, in a relatively shorter amount of time than pre-existing vertical farm models and land deforestation to make way for traditional agriculture.

Bustanica's use of offsite and modular construction methods is a testament to the efficiency of the prefabricated construction approach. This approach ensures completion within budget, maintains compliance with quality and safe standards, and results in significant cost and resource savings, including staffing and equipment. It accelerates project progress and contributes to a more favorable budget outcome, demonstrating its effectiveness and potential for widespread adoption in the vertical farming industry.

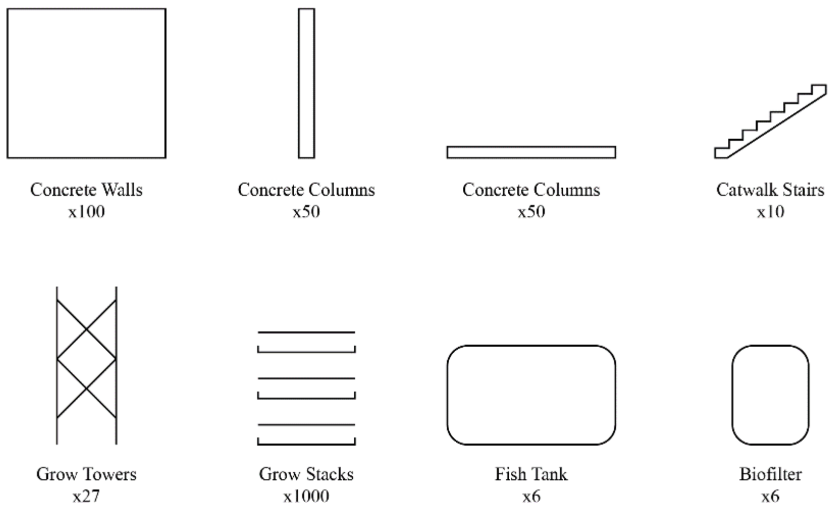


Figure 9 (own image). Conventional Prefabricated Construction Approach

## V. Potential Outcomes

This section delves into three pivotal scenarios each with its unique implications. It assumes uniformity in labor, time, land area, electricity, and water usage across all three scenarios, based on the average conditions in the respective regions. However, the focus shifts to the crucial aspects of transportation time and carbon emissions from the vertical farm to Doha, Qatar. The first scenario explores rice cultivation in the Netherlands, the second involves food import from China, and the third scenario envisions local food production within the urban landscape of Doha, Qatar.

For reference, 1 acre will feed a person annually; 0.5 acres of that 1 acre will be used to grow vegetables and fruits and the other half will grow rice. If grown on one floor, 2,300,000 acres or 9,300,000,000 sqm is needed to feed 2,300,000 people. One acre of produce is roughly 1,750 kg which makes 2,300,000 acres weigh 4 billion kg. Weight for transport in all three scenarios will be in tonnes: 1000 kg is 1 ton, and 4 billion kg is 4,400,000 tons. 4,400,000 tons is not food to be delivered daily but annually.

### 5.1. Hypothetical Outcome #1 - Sourced Only in the Netherlands

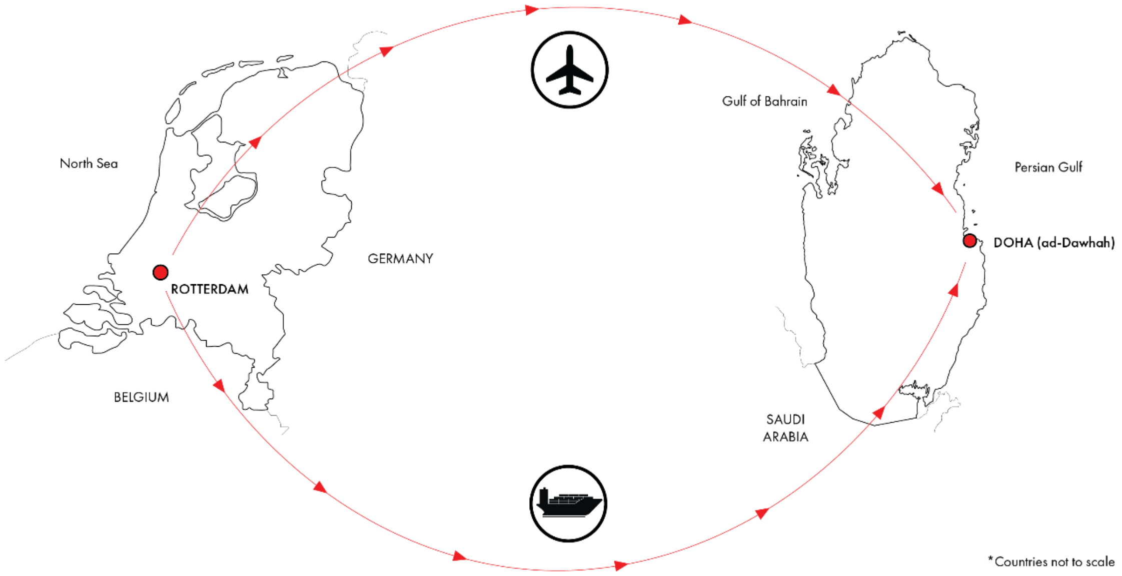


Figure 10 (own image).  Rotterdam, Netherlands, to Doha, Qatar

For reference, the Netherlands has a land are of 41,850 square kilometers, and Qatar has a land area of 11,571 square kilometers, almost four times smaller than the Netherlands.

There are two transportation options to transport food from the port city of Rotterdam, Netherlands, to the coastal city of Doha, Qatar. The longest method is by container ship, and although it takes 36 days and 19 hours to travel 12,294 km, it can carry as much as 300,000 tons or 300,000,000 kg per shipment. To transport 4,400,000 tons of food annually, 15 trips in one year will have to be made which will take 566 days and 61 hours. The carbon emissions are for every 10,000 tons a container ship transports it will emit 11.1 g $CO_2$ per km. If container ships need to carry 4,400,000 tons of food in a 12,294 km journey, it will produce 60,000,000 g of $CO_2$. To understand the scale, 70 acres of forest are needed to remove 60,000,000 g of $CO_2$ annually.

The shorter transportation will be by air freight, which takes 13 hours and 25 minutes to travel 4,863 km to Doha, Qatar, cutting time by 66% compared to container ships. Unlike container ships, the maximum weight it can carry is 150,000 kg per shipment but produces 500 g $CO_2$ per ton per km. There will need to be 30 trips which will take 397 hours and 5 minutes annually to transport 4,400,000 tons of food for 2,300,000 people. The staggering carbon emissions from this transport method leads to an astounding 10,700,000,000,000 g of $CO_2$ annually.

## 5.2. Hypothetical Outcome #2 - China Pakistan Belt Road to Qatar

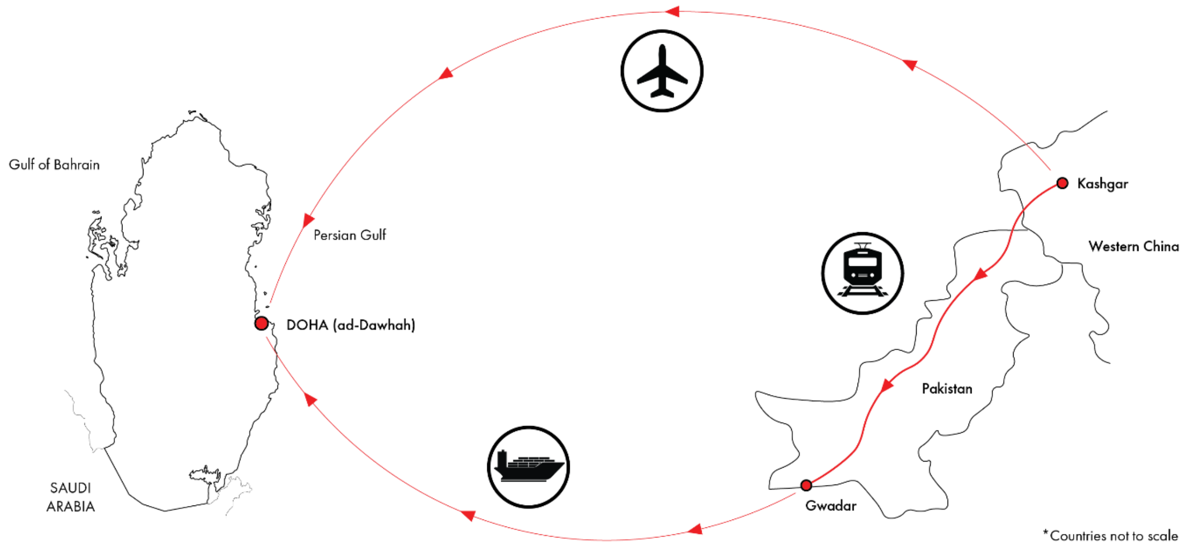


Figure 11 (own image). Kashgar, Western China, to Doha, Qatar

For reference, China's land area is 9,597,000 square kilometers, in Western China it is 6,860,000 square kilometers, and Qatar has a land area of 11,571 square kilometers making it 592 times smaller than the land area in Western China.

A second scenario will be growing food in Kashgar in Western China. The first transport option will be to use the China-Pakistan Belt and Road Corridor, a 3,000 km highway, that links Kashgar in Western China to the coastal city of Gwadar in Pakistan by freight train that has a cargo capacity of up to 12,500 tons per trip and emits 35.1 g $CO_2$ per tonne per km. It will take 352 trips and will emit 462,000,000,000 g $CO_2$ for transporting 4,400,000 tons of food from Kashgar to Gwadar. From Gwadar port, food will then be transported to Doha by container ship which has a maximum capacity of 300,000 tons per shipment. For every 10,000 tons of cargo transported it emits 11.1 g $CO_2$ per km. It is a 3-day journey traversing 1,354 km and 15 trips annually to transport 4,400,000 tons of food. It has a carbon emission of 6,612,760 g $CO_2$. Total carbon emissions for the first transport option by freight train and container ship is 462,006,612,760 g $CO_2$. To understand the negative environmental outcomes, 539 acres of forest will need to be grown to eliminate the total carbon emissions for one year.

The second transport option is by air freight which will take 6 hours from Kashgar to Doha and will travel 2,796 km. It has a cargo capacity of 150,000 kg per shipment and produces 500 g $CO_2$ per ton per km. It will take 30 trips annually, approximately 180 hours total, and emits an annual carbon emission of 6,151,200,000,000 g $CO_2$.

## 5.3. Hypothetical Outcome #3 - Grown in Qatar


Figure 12 (own image). Grown within the cityscape of Doha, Qatar

There are two options for this hypothetical outcome. The left image is of a centralized facility south of Doha, which is currently empty, to house all the vertical farms and transport food daily to all the supermarkets in the city. This centralized facility will require many laborers and time to load and transport food to all its destinations. The second option, right image, is to have small-scale vertical farms occupying currently empty plots of land scattered throughout the city and situated within a 15-minute walk from the vertical farm to any residential. It will have to be inviting rather than having a factory exterior by creating social environments within the vertical farms to attract nearby residents to buy the food.

Additional diagrams of this outcome is available in Appendix F.

# VI. CONCLUSIONS

Increasingly unprecedented environmental conditions, such as droughts and tsunamis, that negatively impact the agricultural industry have prompted governments to issue an export-on-food ban to ensure food safety within their population. This shows a need for a different construction approach to the vertical farm to deploy en masse, as its common construction approach has been known for its high energy intake, high startup costs, lengthy construction time, and high technical knowledge requirements. This research paper has outlined the strategies required to mass produce food in any environmental conditions by analyzing the case studies, learning from what has been done, what has worked, and what other strategies could improve its performance. Although the majority of vertical farms take away the human aspect and even though some do require volunteers to participate in all stages of vertical farming, the only method to drastically increase food production yield around the clock is through automation and A.I. as our modern technologies will use data to reduce resources, energy, and waste as much as possible while producing crops and vegetables at never-before-seen rates. The prefabricated construction approach is the best way forward and has been demonstrated in some aspects of all the case studies but used entirely to construct Bustanica. After analyzing the hypothetical outcomes of carbon emissions, time, and fuel consumption to transport foods in one location from the vertical farms to the destination, the best outcome is to attract nearby residents within a 15-minute walk window to the vertical farm. However, the vertical farm environment has to be attractive for the residents to want to come over. This is where the architect plays a crucial role. They are responsible for designing the vertical farm's layout, aesthetics, and functionality, ensuring that it is a welcoming and appealing space for residents to visit.

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## GLOSSARY

***KEYWORDS:*** *Climate Change, Self-Reliant, Vertical Farms, Urban Transformation, Affordability,*

### *DEFINITIONS*

Climate Change: Weather patterns undergo significant and long-lasting alterations primarily caused by human activities such as greenhouse gas emissions. Climate change has substantial effects on the environment and human health.

Self-Reliant/Sustainable: Capability to function independently without relying on external help for energy or resources, achieved through passive energy harvesting technologies and sustainable materials.

Vertical Farms: Agricultural facilities in urban areas that utilize vertical space to grow crops in a controlled environment, aiming to maximize food production and minimize environmental impact.

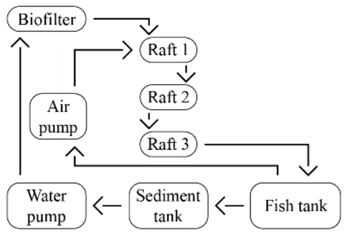
Urban Transformation: Process of change, redevelopment, and revitalization within urban areas, driven by population growth, technological advancements, and changing lifestyles. It aims to improve the quality of life and enhance the city's functionality.

Affordability: The ability of individuals or households to cover basic needs without experiencing financial hardship, including access to essential urban services.

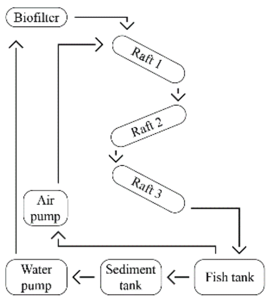
## APPENDIX A. (AQUAPONICS)

The concept of growing plants and fish together has existed for thousands of years in Asia and first came into existence in controlled indoor environments in the 1970s. In Asia, rice and fish farming systems were often used and practiced in paddy rice fields. The wastewater from fish was used as fertilizer for the crops while the crops provided nutrients and shelter from predators creating a self-sustainable system.

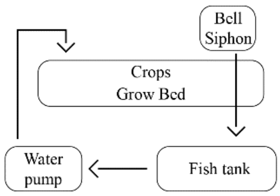
In modern aquaponics the process is subdivided into steps that are explained in depth in chapter V sub-topic 5.2 that investigates how each component of the aquaponics farm in one step of that process. Specifically, this research paper investigates the Raft System, it is one of the three types of aquaponics system. The other two are Media Based Aquaponics System and Nutrient Film Technique (NFT).




The Raft System (image above) also known as Floating System has nutrient rich water circulating through long canals, usually at a depth of 20cm, while rafts for the crops float on top. Plant roots hang down in the rafts absorbing nutrient rich water filled with nutrients to thrive. The nutrient filled water flows from the fish tank through the filtration process to the raft tanks and back to the fish tank. The rafts light weight makes it easier to vertically stack increasing yields that are not achievable in a Media Based Aquaponics System.




Similar to the Raft System, the Nutrient Film Technique or NFT (image above) positions the raft tanks in an angle allowing water to channel down from one raft to another.




Media Based Aquaponics System (image above) is the most common system that uses a Flood and Drain technique. A media based uses a grow bed filled with grow media typically gravel, lava rock, or clay pebbles to plant the crops. It is frequently flooded with water from the fish tank through a bell siphon for the plants to access the nutrients. The water drains back into the fish tank where the cycle restarts. All waste is broken down in the grow bed and it has no additional filtration making it easy to operate. However, although it is an effective system the weight of the grow media can make it limited to one level rather than being able to stack grow beds onto one another.

# APPENDIX B. (TAMPINES BLK 146 RICE VERTICAL FARM, SINGAPORE)

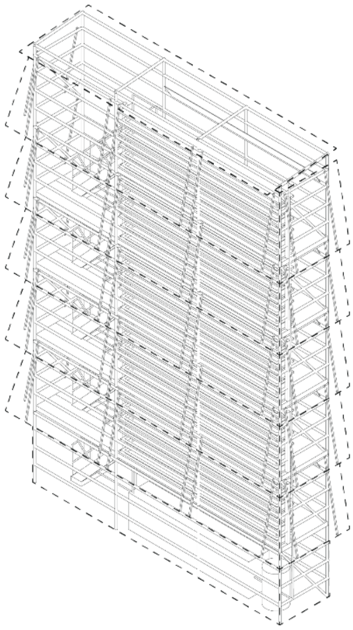


Diagram 1 (own image). Tampines BLK 146 Rice Vertical Farm behind the curtain wall

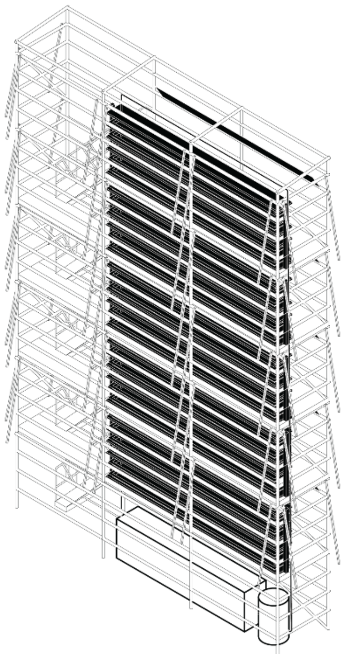


Diagram 2 (own image). Aquaponics Raft System

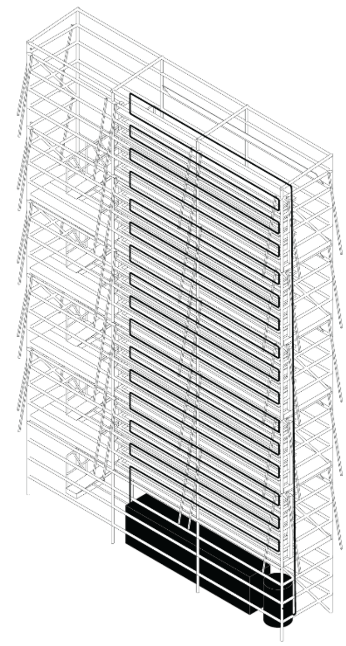


Diagram 3 (own image). Water Flow from Biofilter to grow stacks to fish tank

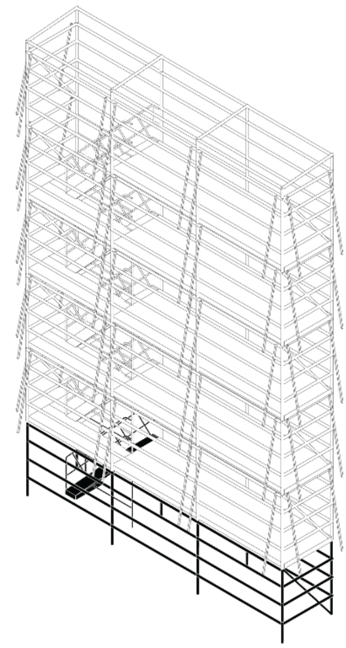


Diagram 4 (own image). Module 1 - 1 type needed

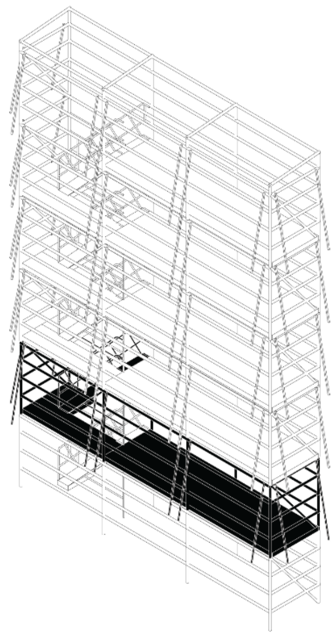


Diagram 5 (own image). Module 2 - 1 type needed for vertical expansion

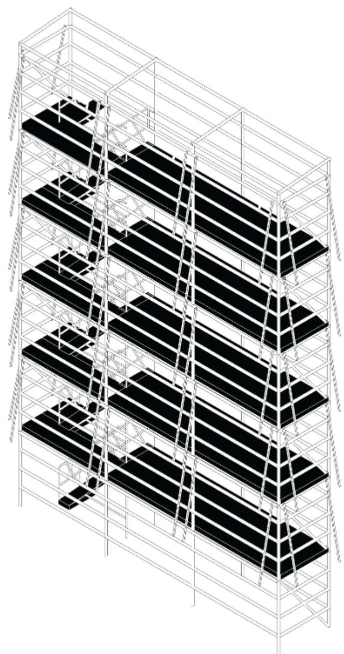


Diagram 6 (own image). Circulation within the vertical farm

## APPENDIX C. (NEST WE GROW, JAPAN)

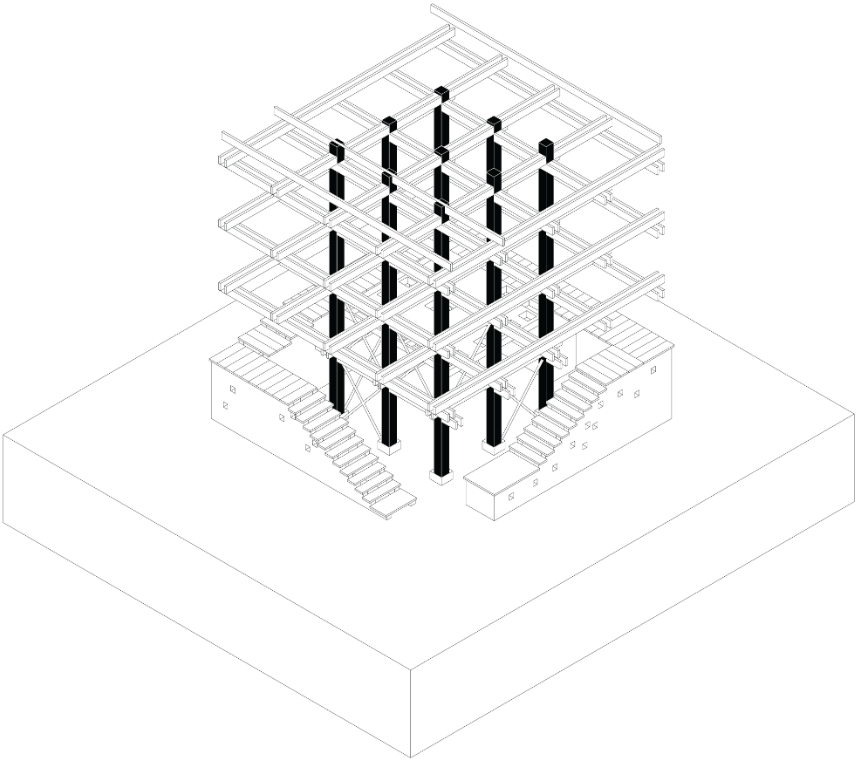


Diagram 7 (own image). Main Structure

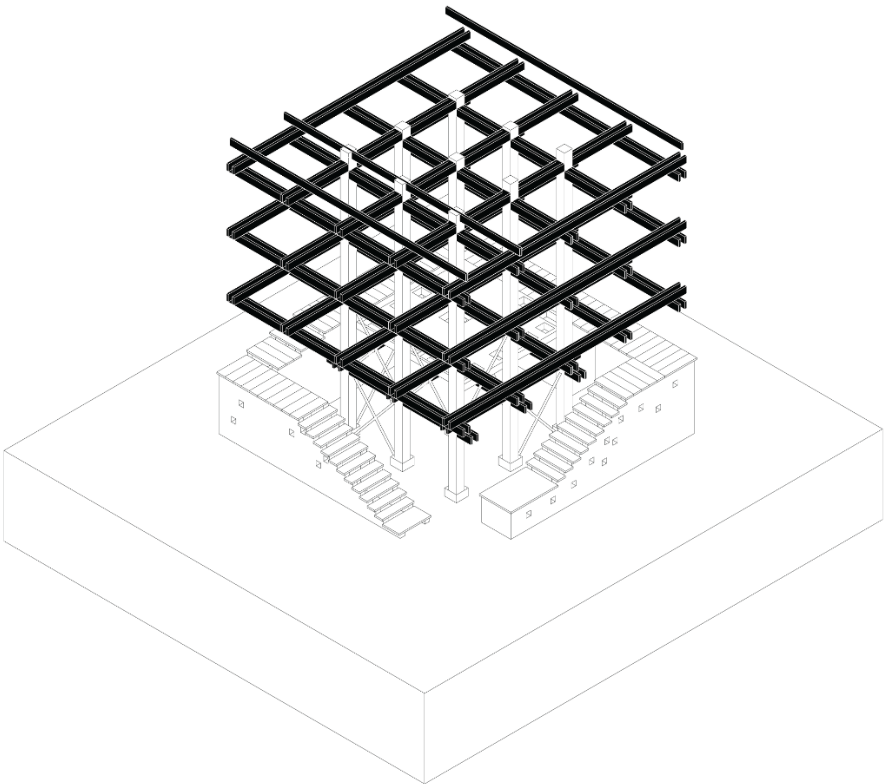


Diagram 8 (own image). Secondary Structure

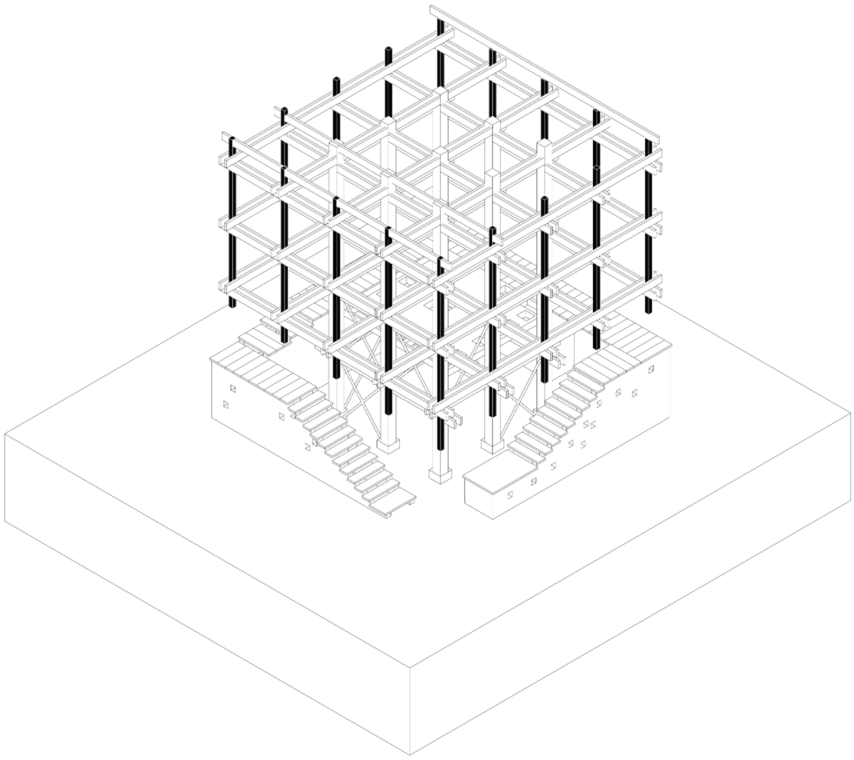


Diagram 9 (own image). Tertiary Structure

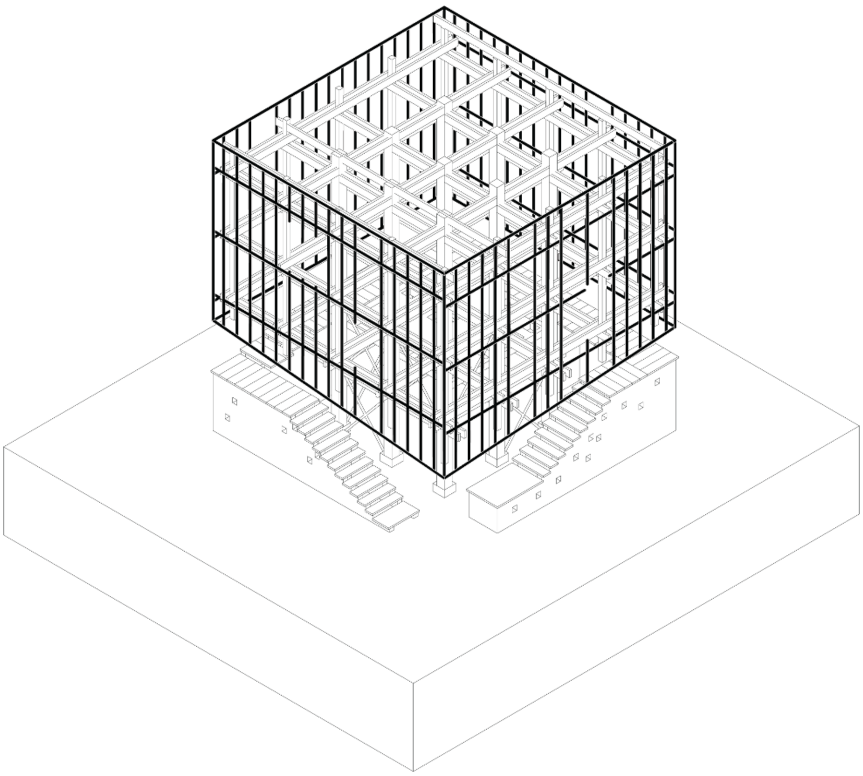


Diagram 10 (own image). Curtain Wall Structure

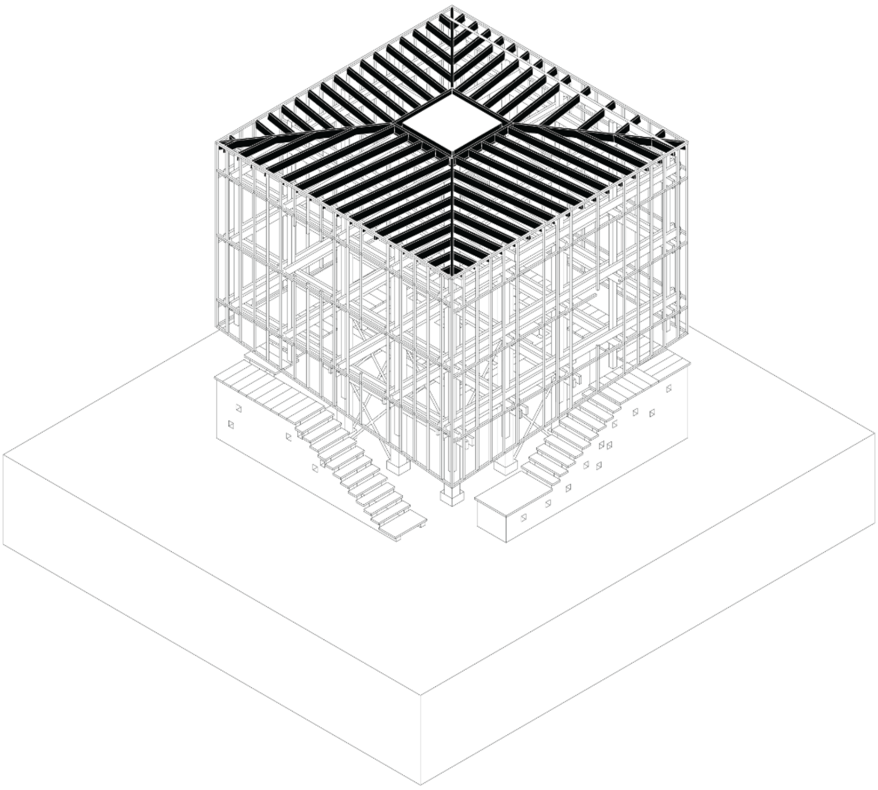


Diagram 11 (own image). Roof Structure

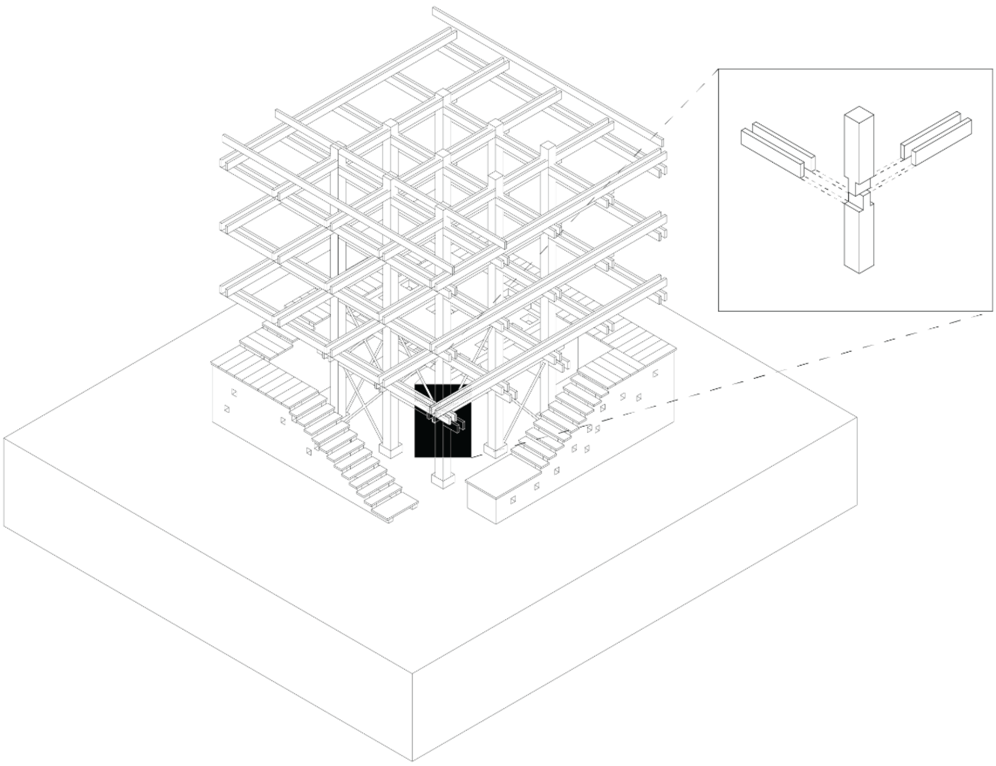


Diagram 12 (own image). Interlocking method for all structure layers

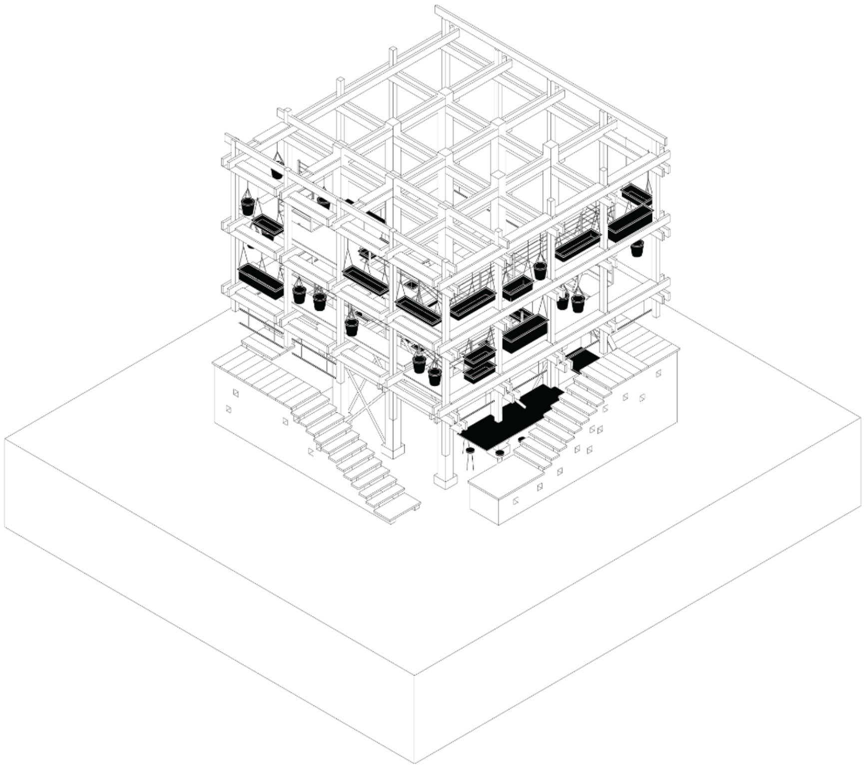


Diagram 13 (own image). Life Cycle - compositing, growing, harvesting, storing, eating

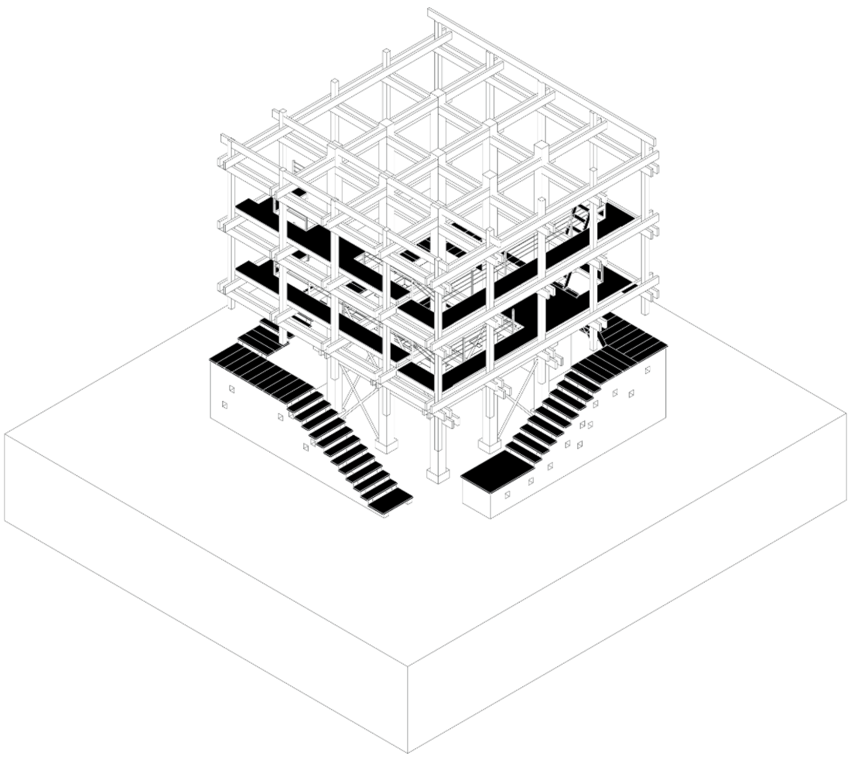


Diagram 14 (own image). Circulation

## APPENDIX D. (UNMANNED VERTICAL SKYSCRAPER, CHINA)

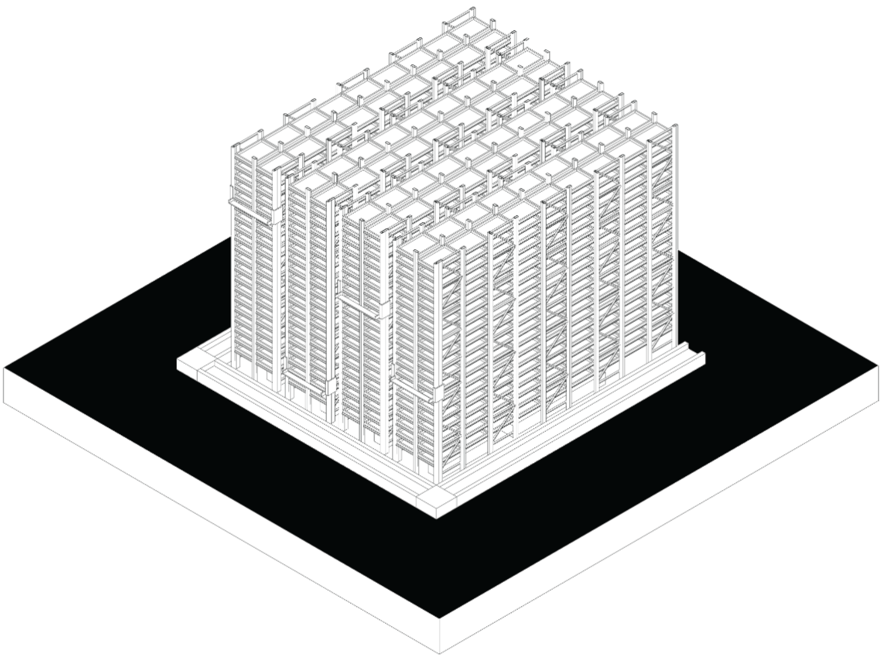


Diagram 15 (own image). Human Circulation

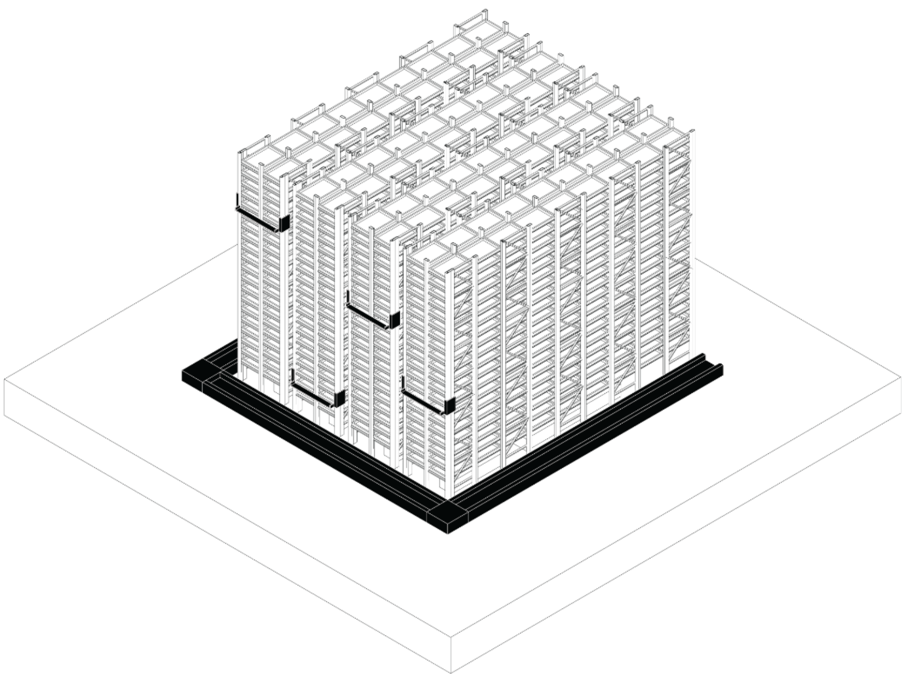


Diagram 16 (own image). Unmanned Lift and Conveyor Technology

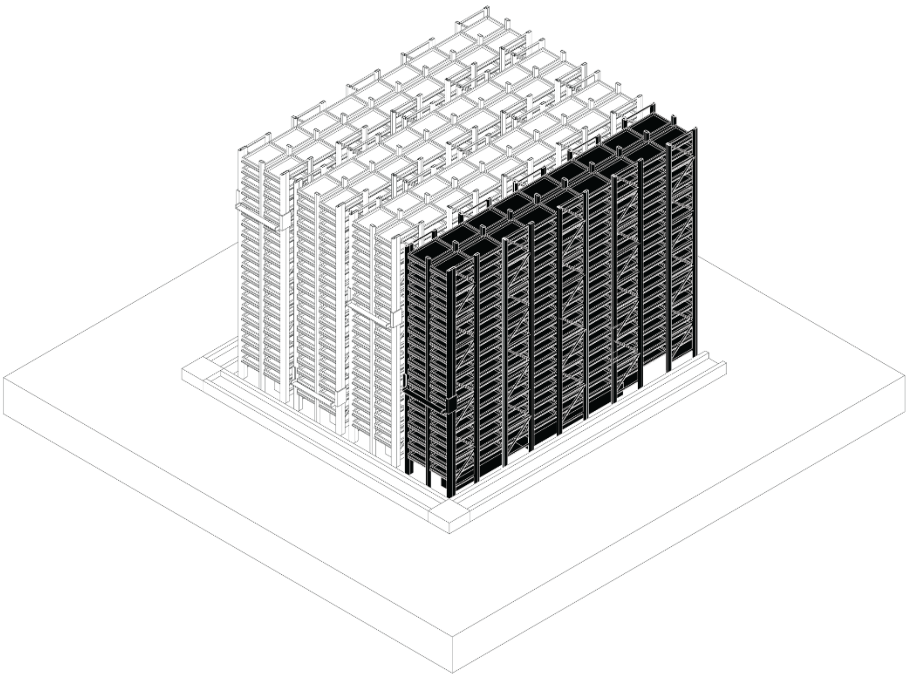


Diagram 17 (own image).  Vertical Farm

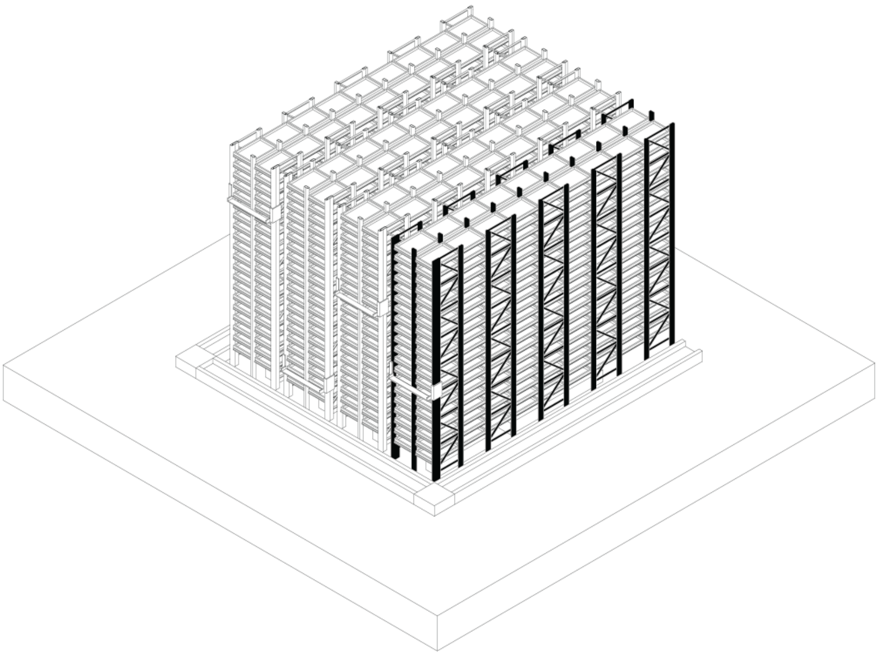


Diagram 18 (own image).  Structure

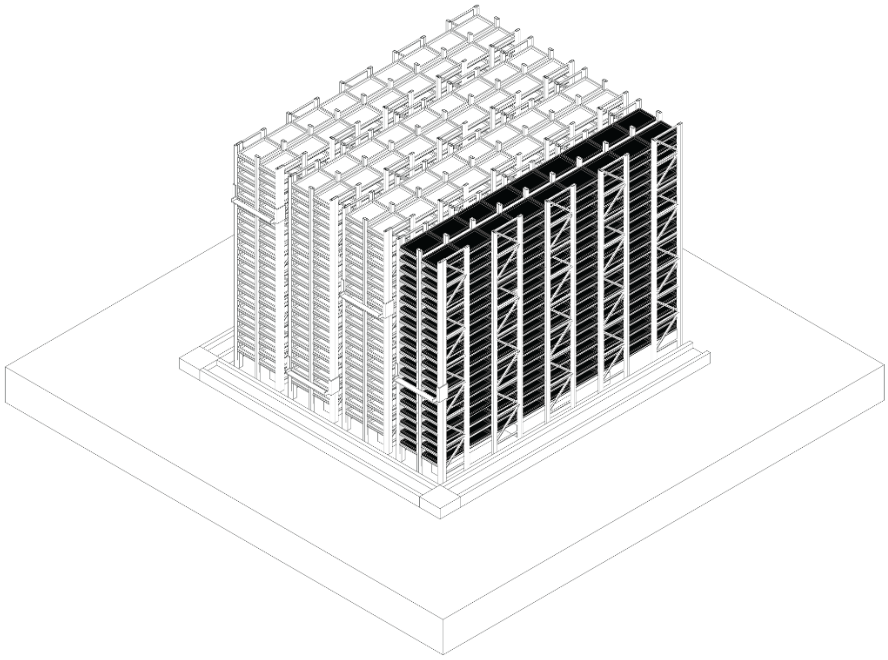


Diagram 19 (own image). Grow stacks in between structure

# APPENDIX E. (NORDIC HARVEST, COPENHAGEN)

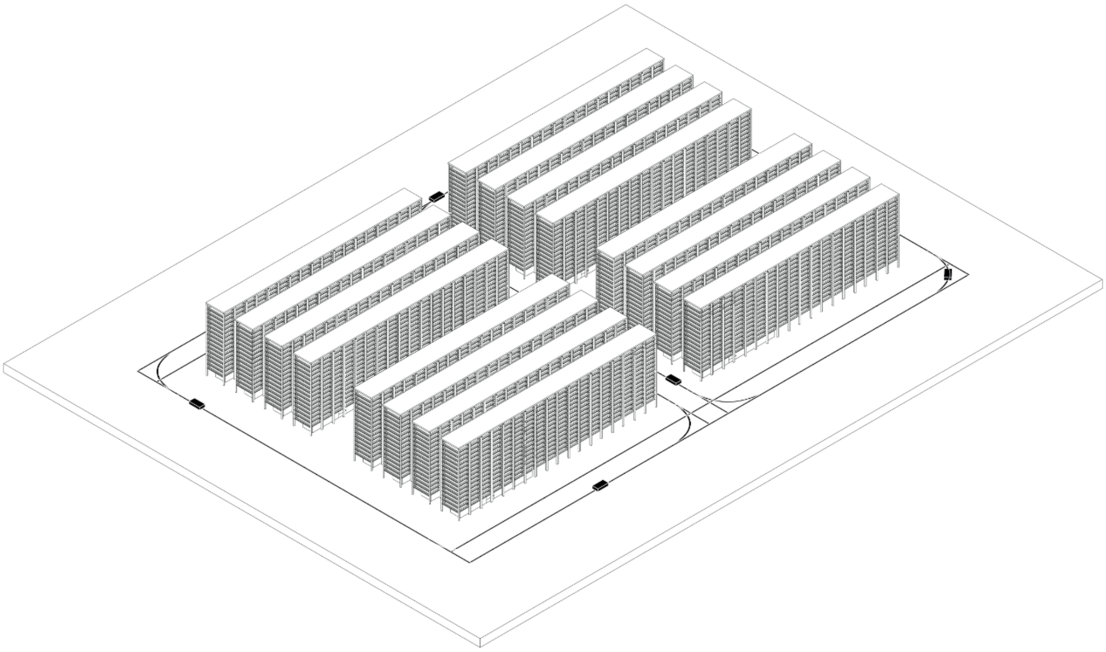


Diagram 20 (own image). Robots Grow Stacks Transportation

# APPENDIX F. (GROWN IN QATAR)


Diagram 21 (own image). Map of Doha

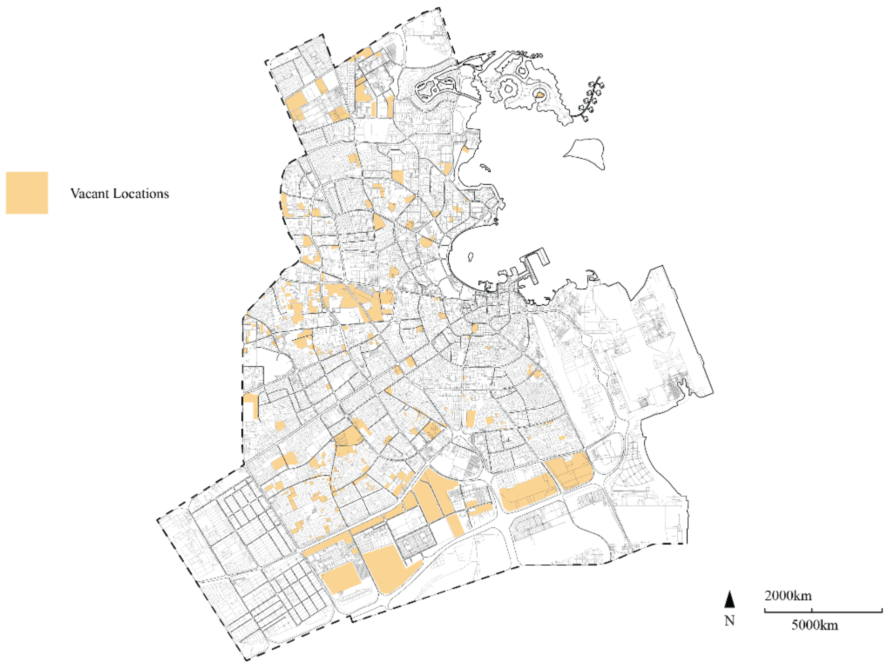



Diagram 22 (own image). Vacant Locations

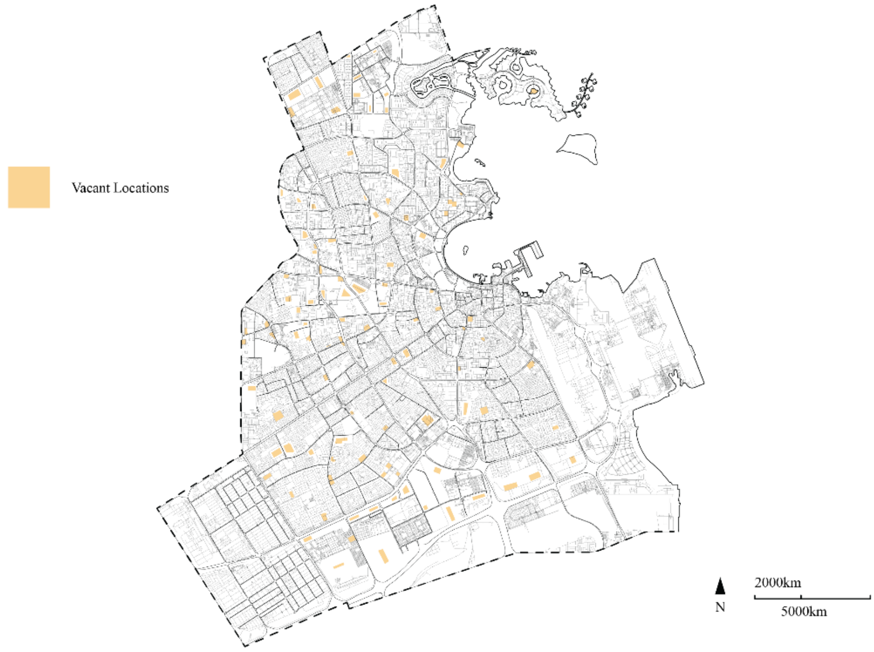



Diagram 23 (own image).  Suitable Locations for Vertical Farms


Diagram 24 (own image).  Suitable Locations & Mobility