KARIAKOO MARKET DESIGN: SMART FOOD SYSTEMS

SOHINI BHATIA

ACKNOWLEGEMENTS

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ABSTRACT

As of 2020, Eastern Africa has faced a food insecurity crisis affecting millions of people due to factors such as economic instability, high food prices, and climate change. Tanzania, in particular, has a large population that depends on smallholder farming, which faces challenges due to stagnant production, climate change, and limited access to food by marginalized families. The recent fire that destroyed the Kariakoo Market, the largest and busiest market - and one of the biggest retail spaces for fresh produce - in Dar es Salaam, has highlighted the need for innovative approaches to urban agriculture that can ensure food security and sustainability.

This project reimagines the Kariakoo marketplace as an urban farming and distrbution center that integrates hydroponics and circular food economy principles, using HARVEST, a plugin for urban food production simulations. The aim is to explore viable options for controlled environment agriculture in urban spaces in Tanzania, explore the practicality of climate-smart agriculture and ensure food and nutrition security while reducing emissions and improving economic viability. The study builds on the growing trend of urban agricultural systems that have made a difference in how food systems are approached globally, including highly technical installations that are environmentally friendly and result in a high yield (Benis, and Ferrão).

This thought project aims to contribute to the creation of more resilient and sustainable food systems in Tanzania and potentially beyond. The imagined scenario presents an opportunity for urban agriculture initiatives to help bridge the gap and improve food security in the city. It is possible that there have been changes to these numbers since then, and more up-to-date information would require further research.

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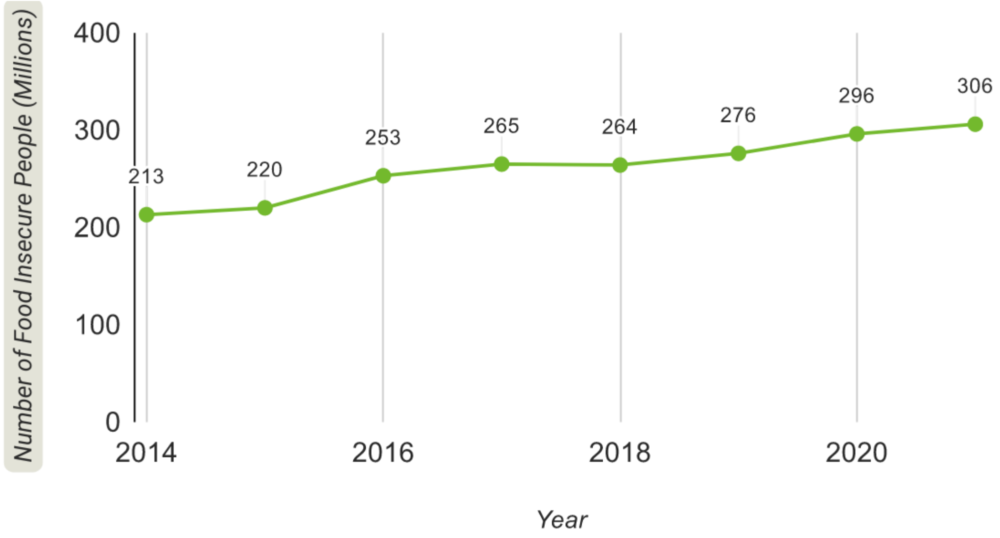
INTRODUCTION & BACKGROUND

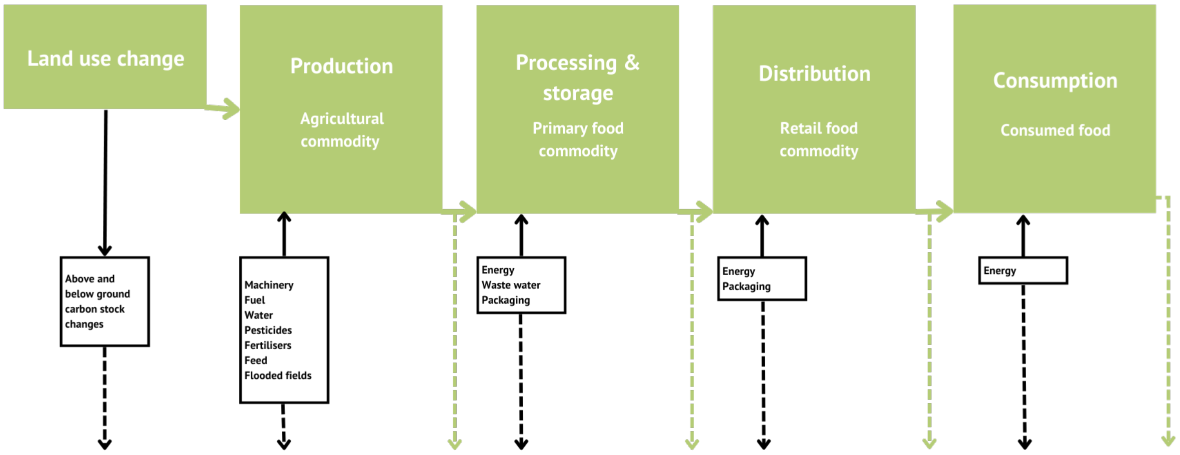
OUR FOOD SYSTEM

Currently about 56% of the world's population, 4.4 billion people - live in cities (World Bank, n.d.). As of 2021, about 28.1% of the population in the Eastern African region, 125 million people were victims of food insecurity (Food and Agriculture Organization of the United Nations, n.d.) as a consequence of the economic crisis, high food prices, prolonged drought, economic instability, and market access disruptions. This means that nearly one in three people in the region are undernourished.



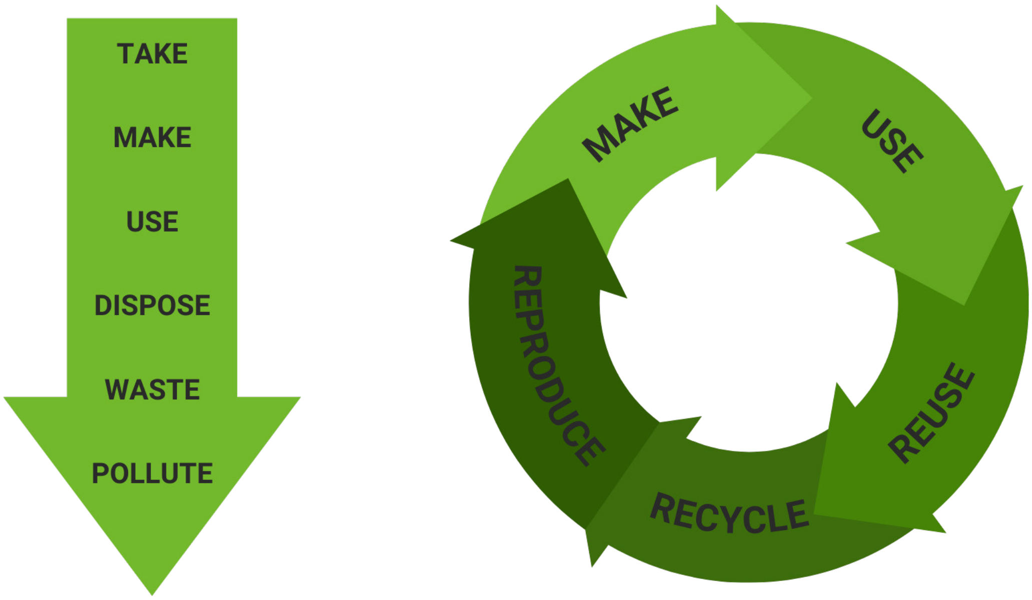
Source: Figure based on Food and Agriculture Organization of the United Nations data

Furthermore, there is a projected reduction of 40% yield across all crop types and subregions in Africa by 2050 (Knox et al, 2012). Increasing urbanization, population growth, and extreme climate events put pressure on global food security, while a third of the global population suffers from malnutrition, through either obesity, food insufficiency, or nutrient deficiency.). Additionally, the current food system contributes heavily to our global environmental challenges including biodiversity loss, climate change, freshwater pollution, deforestation, and excess nutrient accumulation.



A visualization of the current food system. Source: Figure based on Modeling Land-Use Change in Complex Urban Environments" by Brian Deal, Haozhi Pan, and Youshan Zhuang

Producing food within urban boundaries is a possible way to simultaneously tackle a breadth of environmental, social, and human health issues. As is noted in Urban agriculture of the future, “It (zero-acreage farming) promises environmental advantages such as reducing the environmental impact of architecture, reducing food miles, and improving resource and energy efficiency. Social advantages include improving community food security, providing educational facilities, linking consumers to food production, and serving as a design inspiration” (Specht et al, 2013).

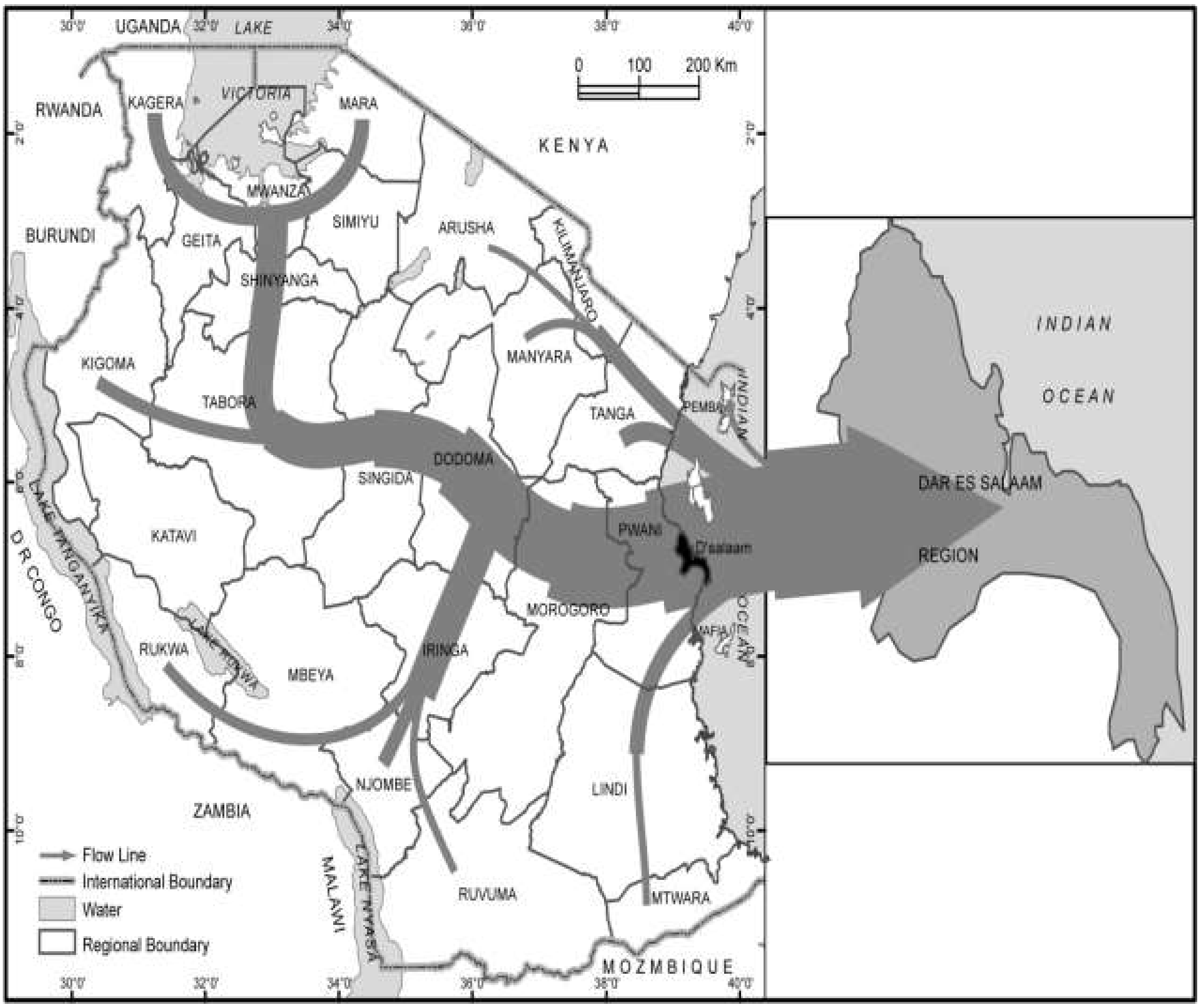


Source: Figure based on A Circular Economy Handbook for Business and Supply Chains by Catherine Weetman.

The growing urban population makes developing farmable land more difficult. An efficient method of production would be creating vertical farming spaces where more environmentally efficient methods can be used in the growing process. Vertical farming is a process in which crops are grown in levels on top of each of other with controlled environmental conditions. Food is usually grown organically without herbicides or pesticides, and black and greywater is collected and recycled. The growing urban population increases the need for land for residential, commercial, and industrial purposes. It also increases the demand for stable food sources. Almost 50% of the land mass in East Africa is used for agriculture (F.A.O - Stats (n.d.))

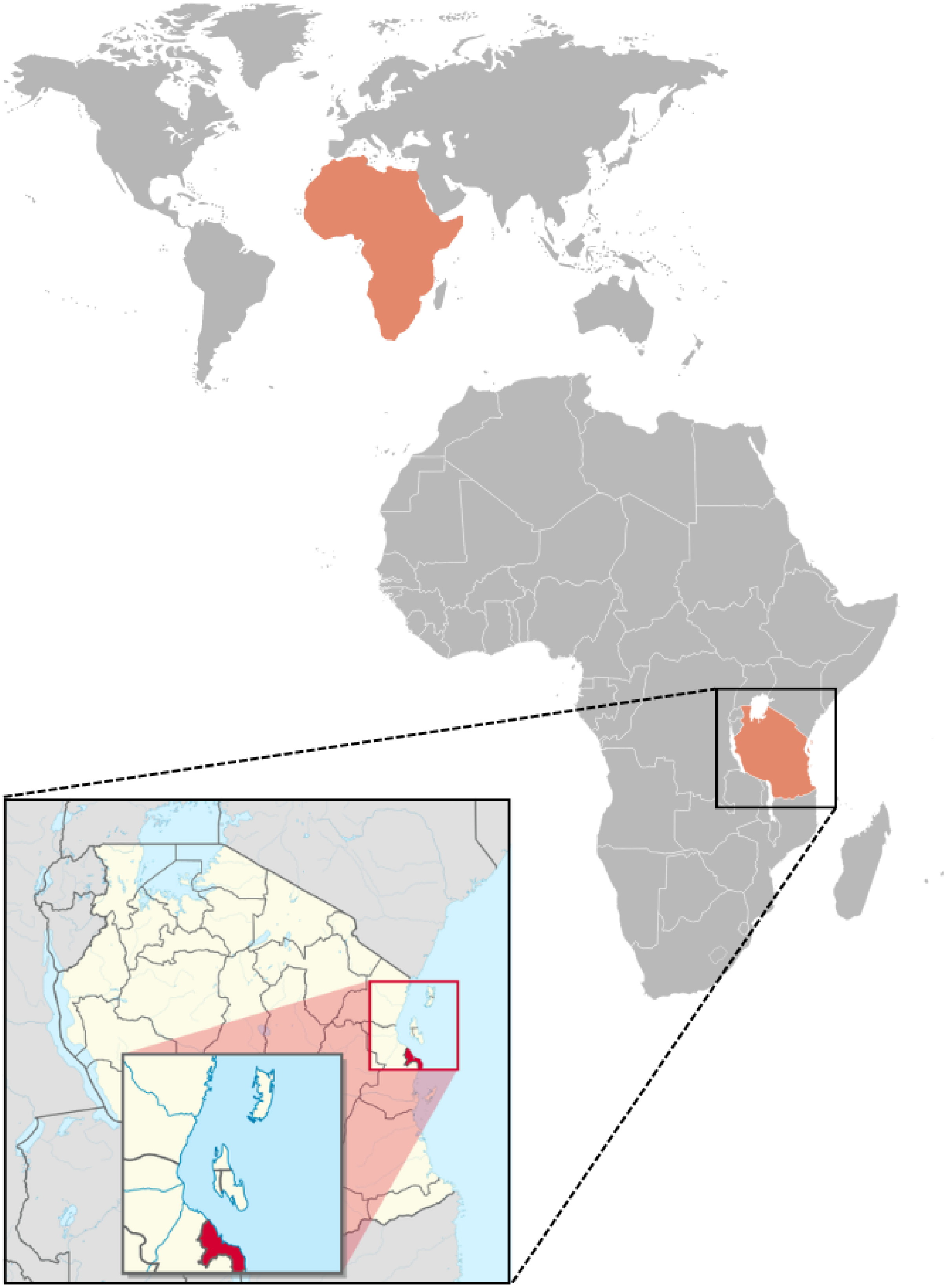
Source: Figure based on Food and Agriculture Organization: Food Security Information for Action

Over 50% of the global population now lives in cities. In Tanzania, roughly half of the population has outmigrated from rural districts since 1991 (de Weerdt and Hirvonen 2013). A whopping 85% of the population in Tanzania is engaged in traditional agricultural activities. Farmers often move temporarily to other rural locations that are more fertile during severe climatic occurrences (Paavola 2008). However, for most rural migrants, the major destination is Dar es Salaam (World Bank 2015; URT 2015a; Wenban-Smith et al. 2016). Migration to search for jobs (in cities like Dar es Salaam) is more likely to happen in disadvantaged regions (Dodoma) stressing the importance of food insecurity as a root cause of migration (FAO 2016a, b). The growth of urban population and therefore cities leads us to the question of where consumers get their food from. Is it not more sustainable and efficient to grow food within our urban spaces?

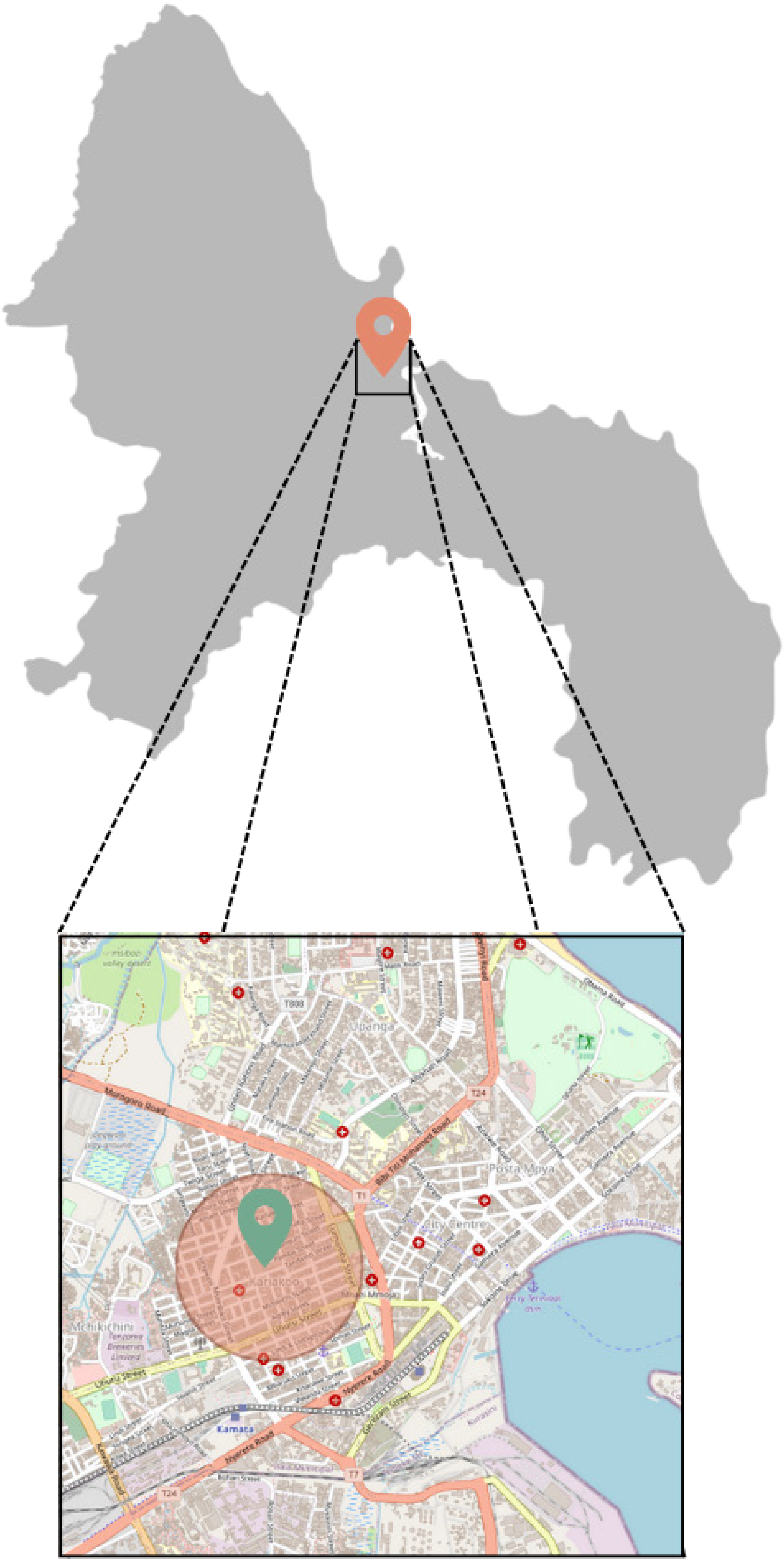


Source: Map from Migration and Urbanization Report - National Bureau of Statistics, Tanzania

For Dar es Salaam's fast-growing population, food, trade, and mitumba (second-hand clothing) are the main source of income for the typical inhabitant. With food stalls, office complexes with mirrored glass facades, and street hawkers all being seen along the same road, the urban explosion can be experienced throughout the city. Space seamlessly integrates African, Indian, and Arab influences, with mosques and churches no more than a few feet apart, along with residential, commercial, and social hubs without clear boundaries. Any space can be a meeting space.



Locating Kariakoo market at a global scale.



Locating Kariakoo market at a global scale.

Kariakoo is one of the most dynamic areas of Dar-es-Salaam, a city of more than 6 million inhabitants on the Tanzanian coast. Kariakoo is a ward in the Ilala District of Dar es Salaam, Tanzania. It sits to the south of Dar es Salaam's city center and has an area of 1.96 km^2. It has an overnight resident population of approximately 50,000 people; the day population is estimated at 210,000. Kariakoo is one of the busiest and most expansive marketplaces in Eastern Africa.

I grew up right next to Kariakoo, living in the city center, and would spend many weekends in the market with my father who has a shop in the market area. The concrete roof edifice that sits at the commercial center of the market brings just as much awe today as it did when I was a 5-year-old accompanying my father inside the market to browse the produce.

It, therefore, came to me as a shock when on the night of July 10, 2021, the building caught fire. The cause of the fire is speculated to have been an electrical fault which didn't come as a surprise considering the facilities had not been updated since the structure was first built. There were no fire detectors or extinguishers to stop the fire. The fire persisted for hours before it was put out.

There were no fire detectors or extinguishers to stop the fire. The fire persisted for hours before it was put out. There were no reported deaths, however, upwards of 1500 vendors lost their goods and the building was reported to be unsafe for use until repairs were made. The traders relocated to various other markets but this is not a long-term solution. The city's economic and population growth calls for a redesign of the market to update its infrastructure; both physically & systematically. The market is a focal point in Kariakoo, and it is the soul of the area. Currently, the market is undergoing repairs while the adjacent secondary market has been shut down to create a new market complex.

With this study, I aim to study the history of the market, and its impact within the context of the site and use comparative studies of markets, commercial agricultural systems & urban farming systems to develop a new design that addresses the needs of the people. This design will implement controlled environment agricultural systems to create climate smart agriculture that works towards greater sustainability and reduced emissions while also keeping in mind economic viability.

HISTORY & BACKGROUND OF KARIAKOO

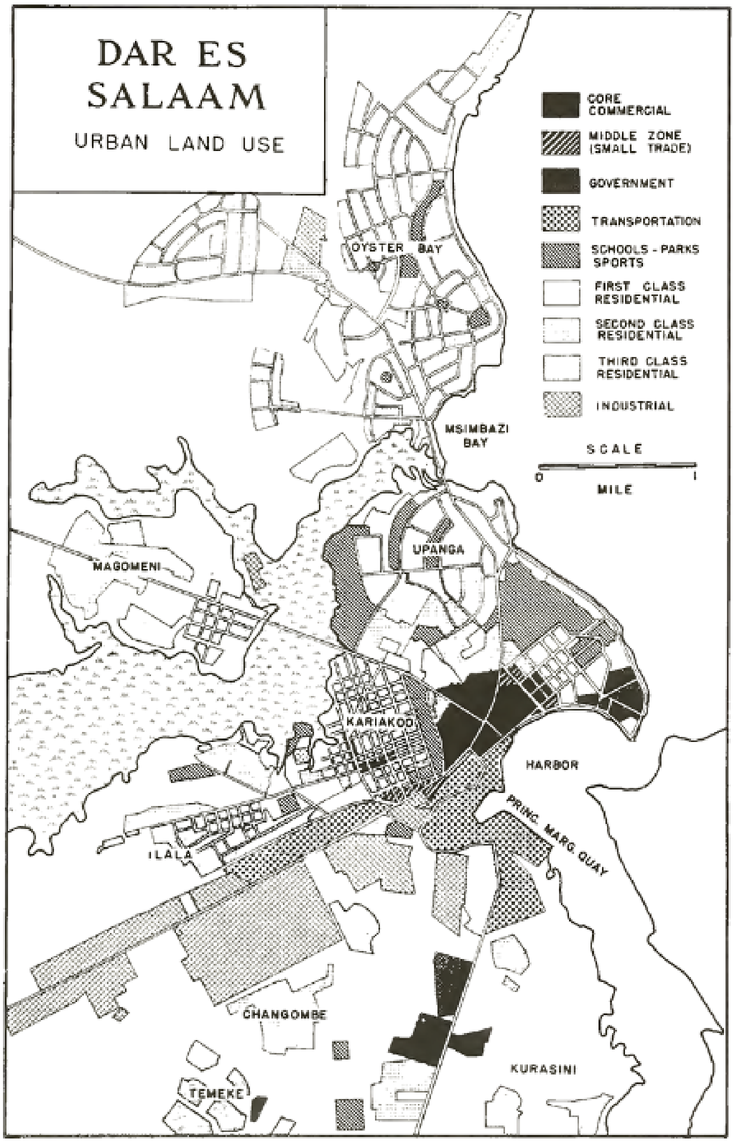
PRE-COLONIAL AND COLONIAL PERIODS

Before the German colonists took over Tanganyika (present-day Tanzania) in 1891, Kariakoo was a coconut plantation owned by Sayyid Majid bin Saïd, first Sultan of Zanzibar – who was also responsible for founding and developing Dar es Salaam between 1862 and 1866 in what was the port and fishing town Mzizima (present-day Dar es Salaam). After the death of Majid bin Saïd, his successor abandoned the city and conceded it to the German East Africa Company, which established a trading station in the city in 1887. In 1914 the German state declared the city was to be split, racially, into three zones. The first was for Europeans, zone II was for Asians (and commercial activity), and zone III was for native Africans.

Between zone II and zone III was a large steel structure that eventually became the site of the Kariakoo market. However, in 1916 this site became a military storage space for the British army after they claimed the colonized land from German East Africa. It was picked strategically to be the British Carrier Corps base as it was mostly inhabited by African people. After the disestablishment of German East Africa in 1919, the steel structure slowly started being used by locals as a market building. It was referred to as "Kariakoo", the closest to "Carrier Corps" that the non-English speakers could pronounce.

As a prominent neighborhood for native Africans, it became a lively cultural center and began growing in the 1950s as the trading scene expanded to street vendors, retail outlets, and wholesale shops. This attracted the attention of Indians and Arabs, and this is when the maduka (plural for duka – meaning; shop) were resumed by the Indians as they had been shut down by the colonists when they first arrived. The market and the area around it steadily thrived and became the commercial hub of the city.

Photo of the new central market in Kariakoo (Zone III) in the former Exhibition Building or Carrier Corps Depot, 1960



Map of urban land use in Dar es Salaam, showing the relative location of the city's major functional zones

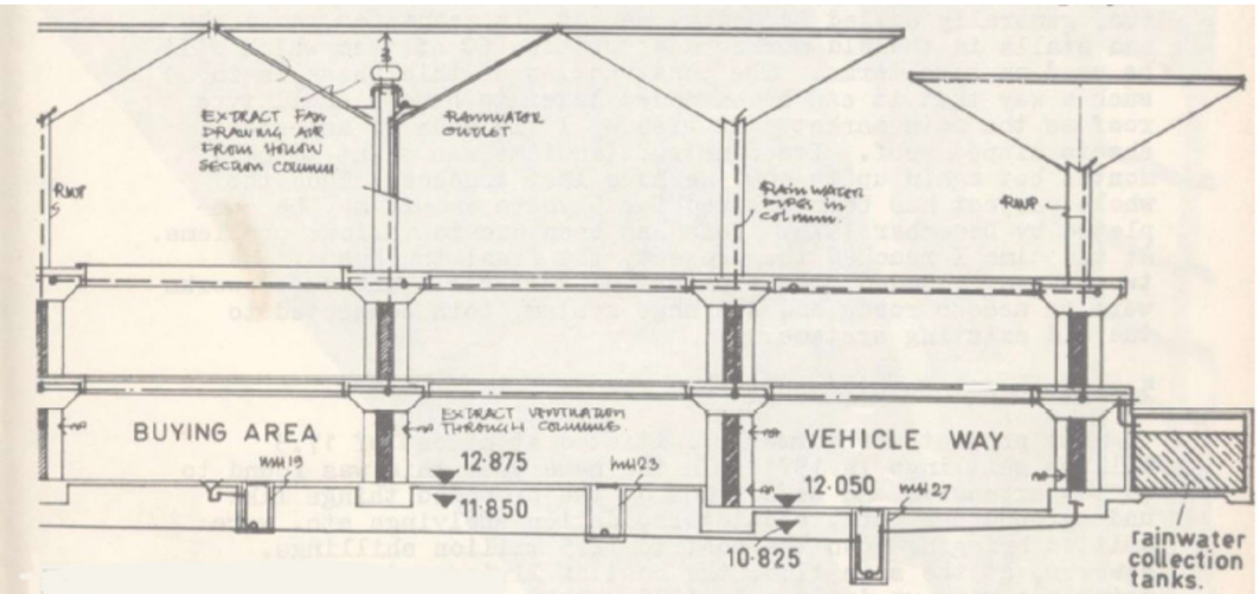
POST INDEPENDENCE

After Tanzania gained independence in 1961, there emerged a new economic era marked by the Dar es Salaam city council's search for an architect to renovate the run-down market building. However, it wasn't until 1970 that Beda Amuli, one of the first Black Africans, established his architectural practice in the city, which played a decisive role in the council's decision to entrust him with the task of designing the new market building. The construction commenced in 1972, and by 1974, the three-story building was completed, situated at the heart of the socialist movement and becoming the hub for both wholesale trade and daily commerce.

Most of the shops were owned and managed by publicly owned marketing entities, and the new Kariakoo Market came to represent socialist modernity. It was thus befitting that Amuli opted for brutalist architecture, a style associated with socialist values, characterized by the use of exposed, unpainted concrete or brick, angular geometric shapes, and a predominantly monochrome color palette, which the building exemplifies. The building took into account air circulation and has a series of hyperbolic paraboloid funnels that were meant to harvest rainwater and store it in underground collection tanks. An underground tunnel passes through the basement and had hydraulic lifts that were meant to transport goods to the different floors (Mpembeni, 1975).

Photo of the interior of the new market building in Kariakoo on the day of its inauguration, 1975. Photo from the private archive of Beda Amuli.

However, the primary market building failed to capture the vibrancy of its hustling and bustling surroundings. In stark contrast to the lively atmosphere outside, the interior of the market was relatively subdued, largely due to its perceived image as a modern shopping complex rather than a wholesale market. This resulted in an increase in window shoppers rather than actual buyers, and the escalating costs of goods further compounded the issue. To counter this, a more traditional, simplistic market was set up adjacent to the primary building where African and Asian traders thrived in the retail food market. Despite this, the primary market building still held an authoritarian presence over the rest of the market, and many of the dukas (shops) remained in Swahili houses. However, with Nyerere's retirement from office and the shift away from socialist policies, Kariakoo began to flourish. The primary market building was dwarfed by taller buildings that emerged in its vicinity, but it still remained a significant landmark.



General Arrangement of Rainwater, Drainage and Ventilation - Kariakoo Market, 1971

PRESENT DAY

In the almost five decades since the current Kariakoo structure was built, it became the definitive commercial center of the city and a hub of socio-economic life. However, the physical structure of the market alone could not accommodate the market's growth and now it continues to expand spilling out throughout the area. The primary market building itself contained a small portion of the actual program of the market. Despite this, the socio-spatial history of the area continues to influence the decisions that are made to date. It remains a place where rural and urban, formal and informal, and modern and traditional mingle but many times clash with one another as the dichotomies have yet to reconcile even 60 years post-independence.

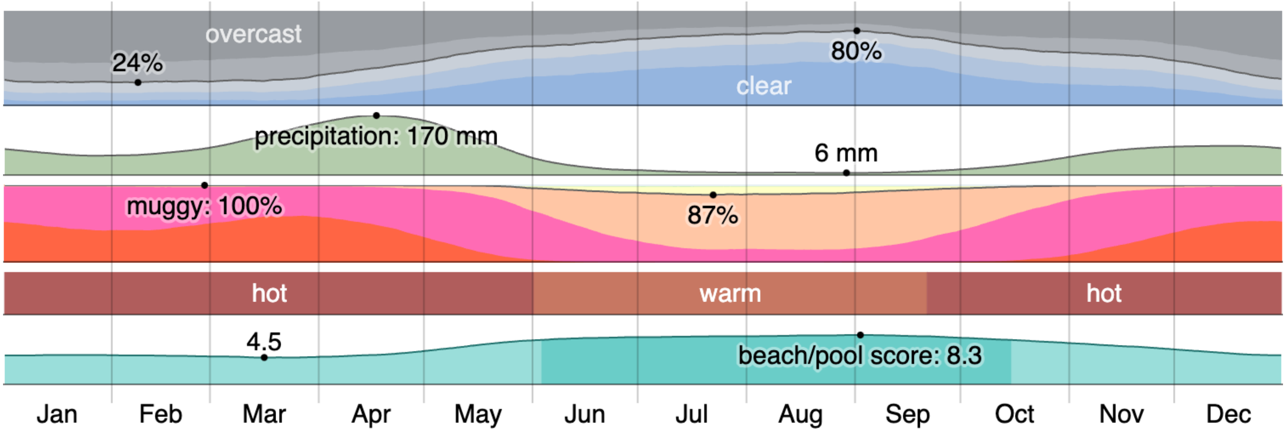
SITE ANALYSIS & CASE STUDIES

Markets are vital to the economy and culture of Africa, playing an indispensable role in facilitating daily commerce. For small-scale businesses, these bustling marketplaces are a lifeline for economic survival.

In this section, we will perform a site analysis including climatic analysis, land use, examine the organization of Kariakoo's marketplace and evaluate the accessibility of both the structure and the surrounding space. Furthermore, we will explore 3 different markets in Africa, examining their size and structure, while also exploring their cultural significance and spatial configuration within the context of the city.

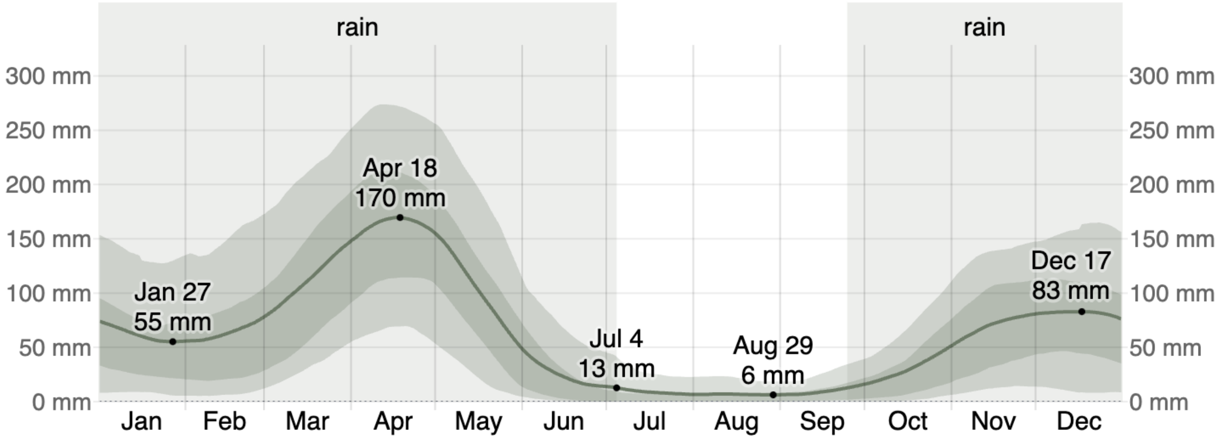
CLIMATE ANALYSIS

Dar es Salaam is a coastal city located at a latitude of 6 degrees south of the equator, within the tropics. The city's proximity to the equator means that it experiences a tropical climate characterized by high temperatures and humidity throughout the year. The city experiences a tropical wet and dry climate with distinct wet and dry seasons.

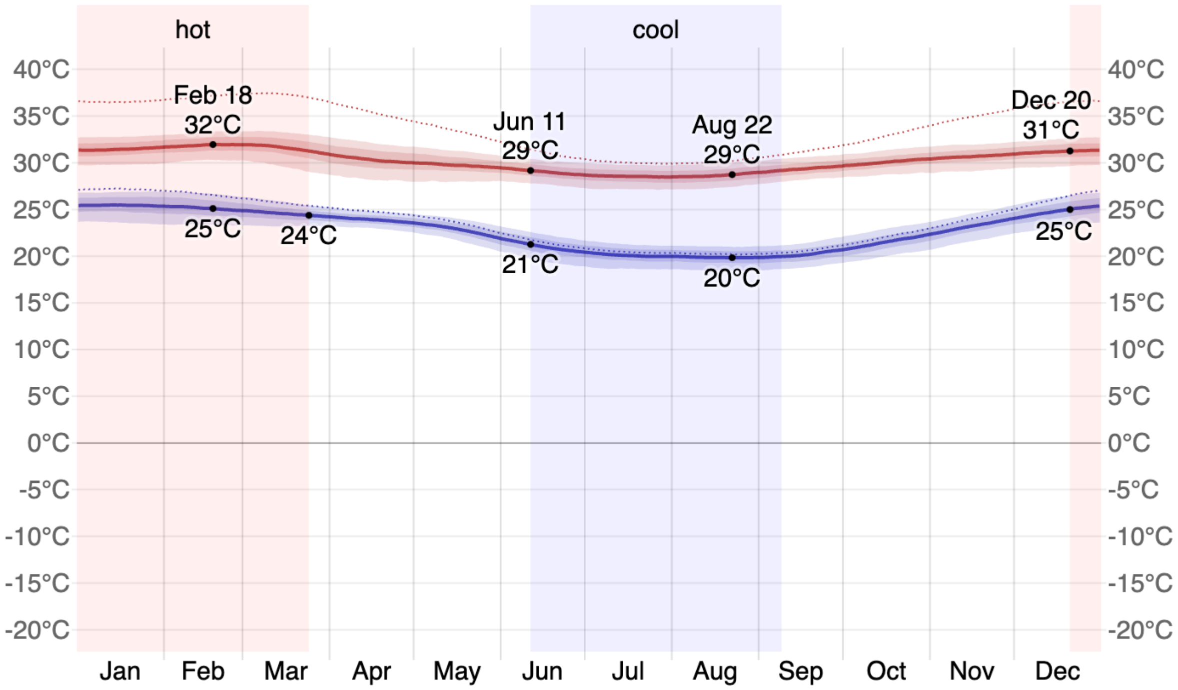


Dar es Salaam weather by month

The average annual temperature in Kariakoo is around 28 degrees Celsius, with the hottest months being January and February, and the coolest month being July. The wet season typically runs from March to May and from October to December. The average annual rainfall in Dar es Salaam is around 1100mm, with the heaviest rainfall occurring from April to May. During this time, the city experiences high levels of precipitation, which can cause flooding in low-lying areas. The wet season is also characterized by high humidity, which can make the heat feel more intense.

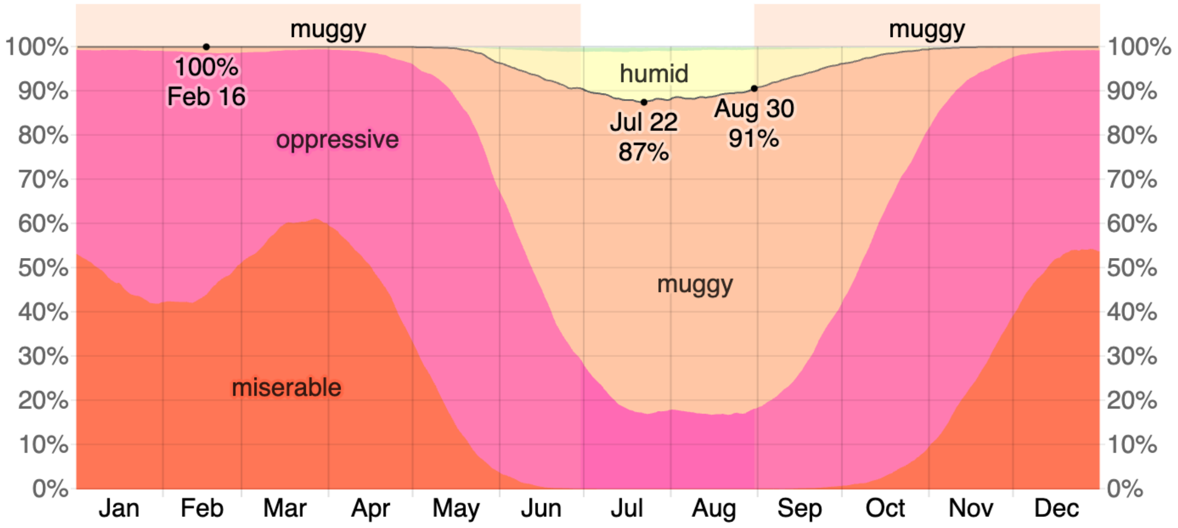


Average Monthly Rainfall in Dar es Salaam



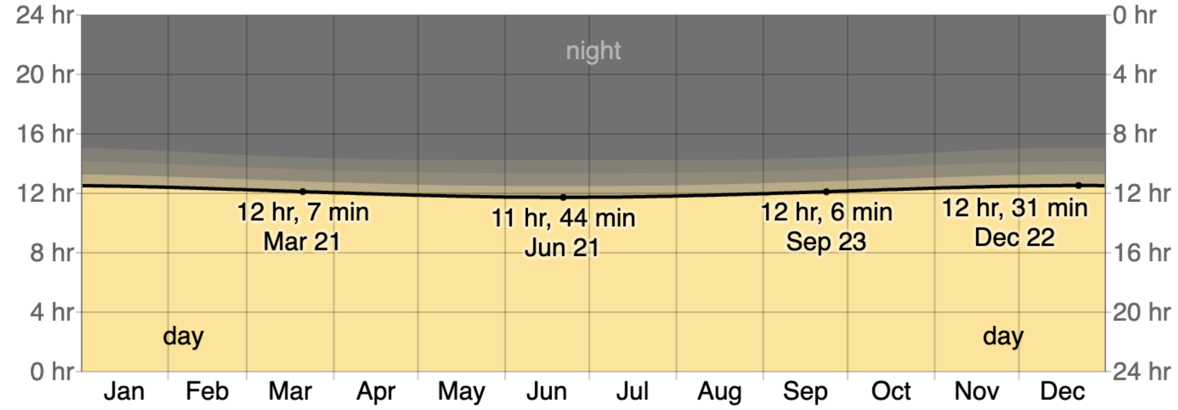
Average High and Low Temperature in Dar es Salaam

The dry season runs from June to September and from January to February. During this time, the city experiences lower levels of precipitation and cooler temperatures. However, the high humidity persists, making the climate still feel hot and humid.

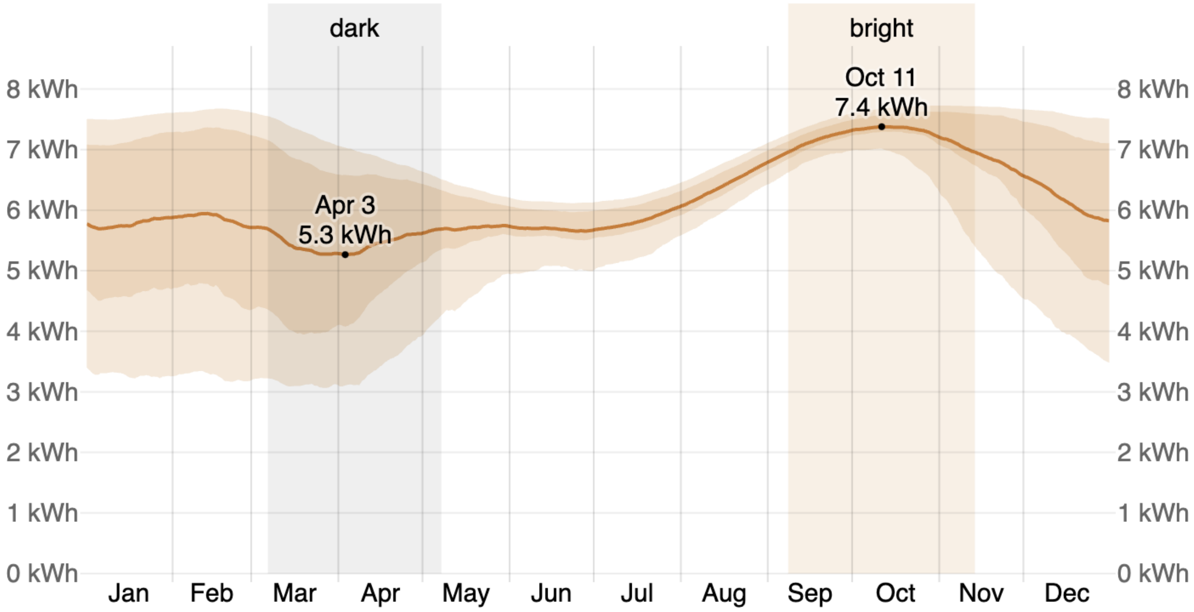


Humidity Comfort Levels in Dar es Salaam

The length of the day in Dar es Salaam does not vary substantially over the course of the year. The average daily incident shortwave solar energy experiences some variation over the course of the year, taking into account the elevation of the Sun above the horizon, and absorption by clouds and other atmospheric constituents. The brighter period of the year is from September to November, with an average daily incident shortwave energy per square meter above 7.0 kWh. The darker period of the year is from March to May, with an average daily incident shortwave energy per square meter below 5.7 kWh.



Hours of Daylight and Twilight in Dar es Salaam



Average Daily Incident Shortwave Solar Energy in Dar es Salaam

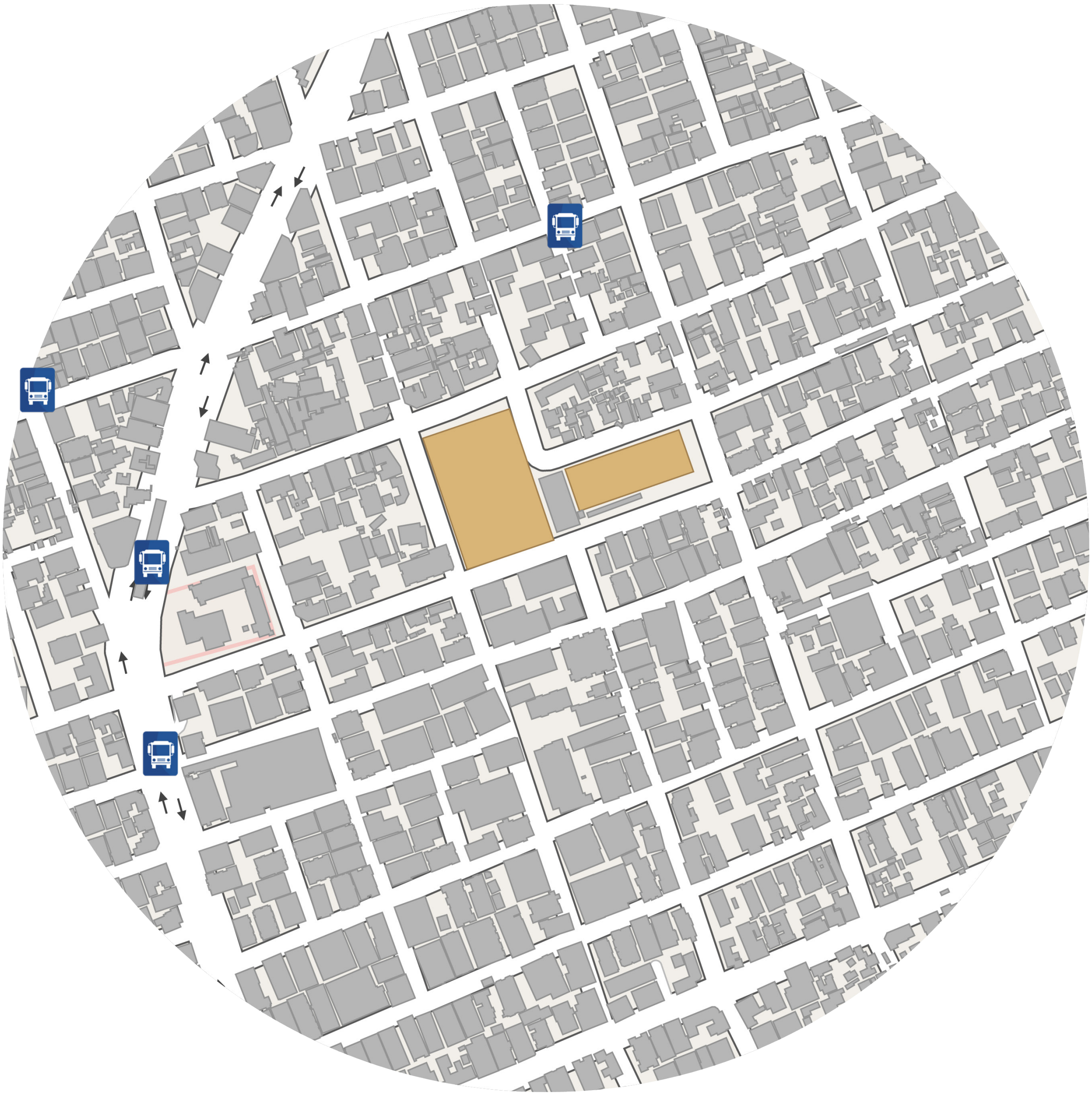
SPATIAL ANALYSIS

The location of a market plays a crucial role in shaping the level of activity it experiences. The Kariakoo market, located at the heart of its neighborhood, has grown to become the commercial hub of the city. However, the original building could not accommodate the growing population of the city, which has multiplied over 16 times since its establishment. As a result, the market has expanded beyond the confines of the primary building and now largely exists in an informal, mobile capacity.

The maps below provide insight into the density of activity in the market's vicinity, though it's important to note that they do not capture the majority of trade which occurs outside of permanent structures.

Analysis of Retail Spaces by type of commodity/service.

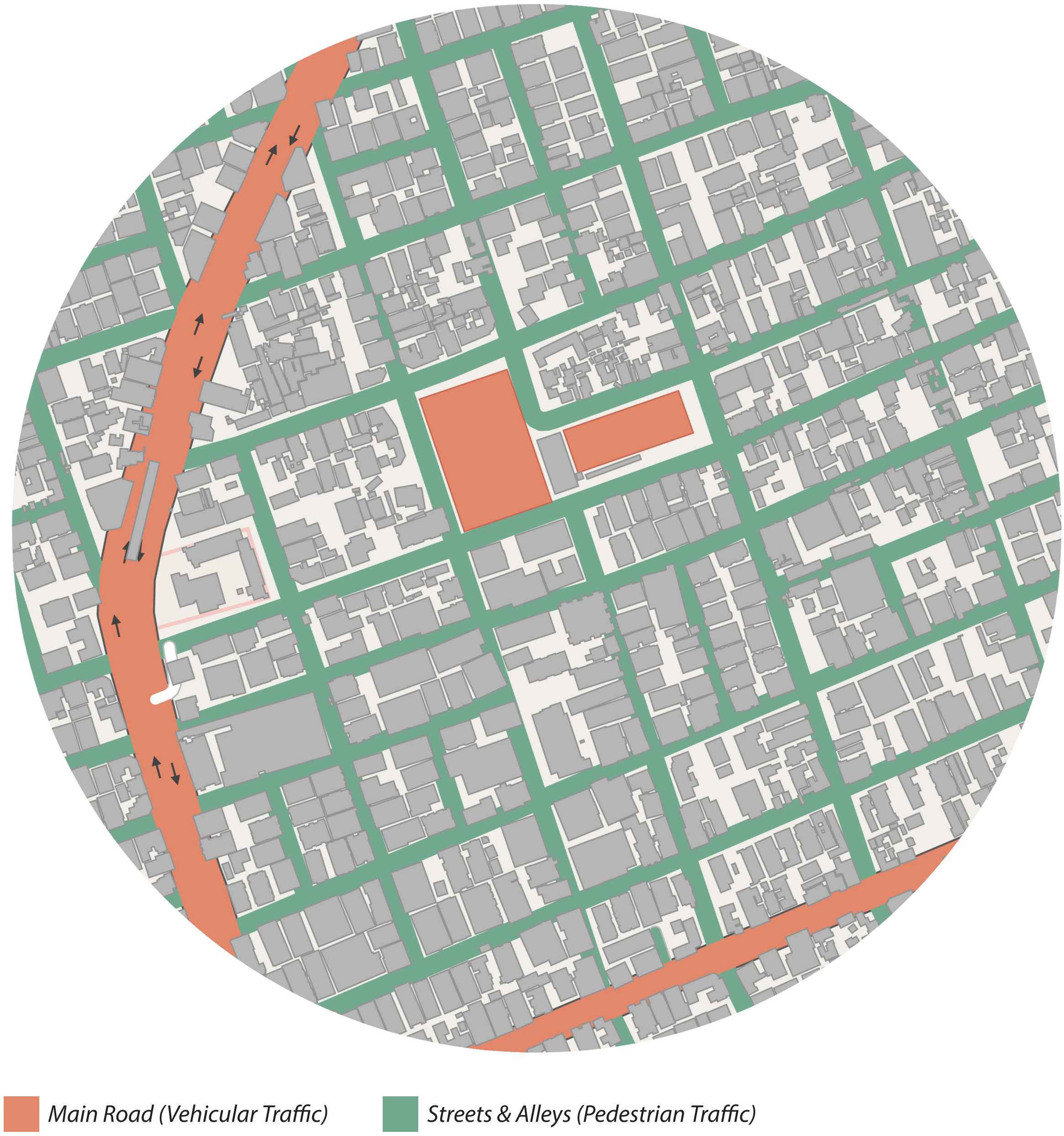
The spatial distribution of the market is characterized by a maze of narrow alleys and streets that connect different sections of the market. The retail sector of Kariakoo Market is organized according to product categories. For instance, the produce section is located in the northern part of the market, while the electronics section is located in the southern part. The market also has designated areas for wholesale and retail sales, which are separated to prevent competition between vendors. The spatial organization of the market ensures that vendors are clustered together, making it easier for buyers to compare prices and quality.



Nodes of Transportation at the Site

Transportation is a critical component of the Kariakoo Market's functioning, with access to various modes of transport contributing significantly to the influx of people. Daladalas, buses that carry both passengers and cargo, are widely used for transportation, and there is a station located right next to the market, with a couple of others about two to three blocks away. In recent years, the bus rapid transit (BRT) has also been introduced, with a station located just two blocks away from the market building and outside where the market neighborhood borders.

However, due to the narrow streets and alleys in the central business district of Dar es Salaam where the market is located, larger vehicles such as trucks have restricted access to the market. This has resulted in vendors relying on smaller vehicles to transport their goods in and out of the market.



Vehicular & Pedestrian Traffic Circulation

Despite the challenges posed by the limited access to larger vehicles, pedestrian traffic in the market remains extremely high, with thousands of people visiting the market every day. The narrow streets and alleys can get congested, particularly during peak hours, which has prompted the market management to implement measures to ease pedestrian traffic. These measures include creating wider walkways and installing signs to guide visitors through the market.

The urban design of Kariakoo Market is a reflection of the city's colonial past. Over the years, the market has undergone several renovations and expansions, but the basic layout has remained the same. The market is characterized by a mix of modern and traditional architecture, with vendors selling their goods in small stalls or open-air shops.

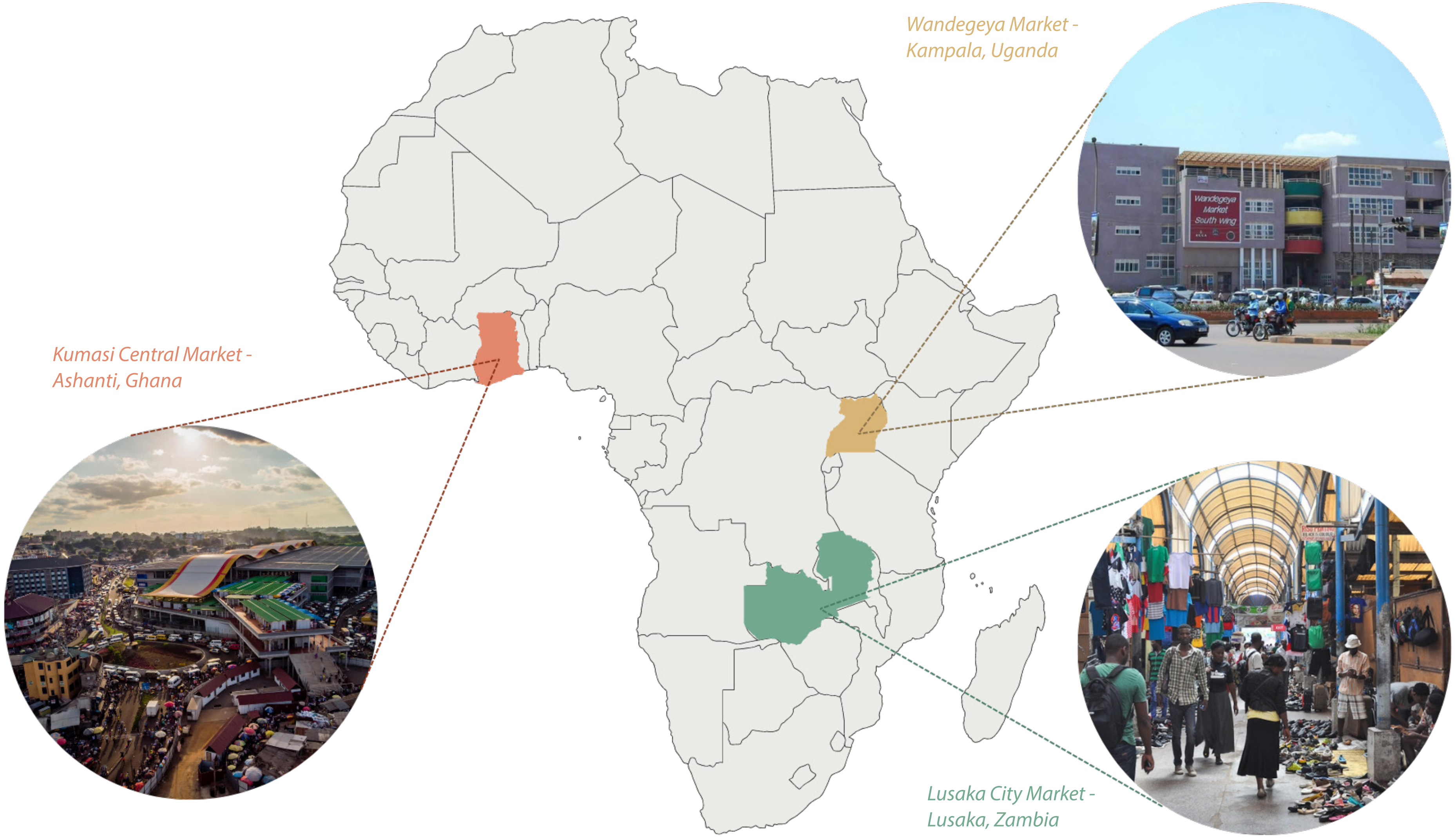
The architecture of Kariakoo Market is also influenced by the local climate. The market is located in a tropical region with high temperatures and humidity levels. Therefore, the buildings are designed to provide natural ventilation and shade. The market's buildings feature large windows and open-air spaces to allow for air circulation, and the roofs are designed to provide shade for vendors and shoppers.

The spatial distribution of Kariakoo Market has also influenced the local economy. The market is a major employer in the city, providing jobs for thousands of people. Moreover, the market has stimulated the growth of other businesses in the area, such as restaurants, cafes, and hotels.

The market's spatial distribution has also impacted the social fabric of the community. The market serves as a meeting place for people from different backgrounds and cultures, and it has become a symbol of the city's diversity and resilience.

PRECEDENTS

To deepen my knowledge and understanding of marketplaces beyond the Kariakoo Market, I conducted research on three additional marketplaces situated in diverse regions across the African continent. By studying the Kumasi Central Market in Ashanti, Ghana, the Wandegeya Market in Kampala, Uganda, and the Lusaka City Market in Lusaka, Zambia, I gained valuable insights into the similarities and differences between these markets and the Kariakoo Market.

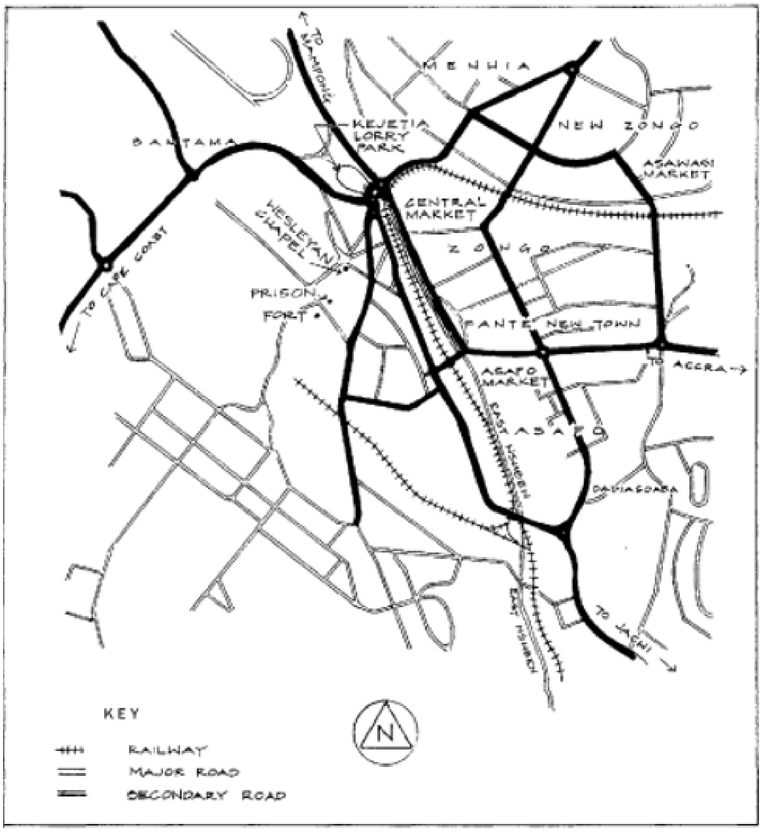

Wandegeya Market -
Kampala, Uganda
Kumasi Central Market -
Ashanti, Ghana
Lusaka City Market -
Lusaka, Zambia
Wandegeya Market South Wing

SITE 1:
KUMASI CENTRAL MARKET – ASHANTI, GHANA

Datanomics. (2022). [Photograph of Ariel View of Kejetia Market]. Twitter.

Deutsche Bank. (n.d.). Market makeover: Transforming trade finance [Photograph].

Kejetia or Kumasi Central Market is the largest of all Ghanaian markets. It is made up of several other markets and is the largest single open-air market in continental Africa, covering an area of over 170,000 square meters. It is located both in the city's center and in the geographical center of the country, with easy access to major transportation routes. The current location of the market was founded in 1925. A central transport terminal was built on the western side of the market in 1927. An estimated 300,000 people visit the market daily.



Location of Kejetia Market in urban context and major transportation routes

The spatial configuration of Kumasi Market is such that it is organized around a central axis, with smaller paths branching out to create smaller sections. This arrangement makes it easy for both traders and customers to navigate the market and locate specific products. They are organized by commodity type and further divided by wholesale or retail. Each of the locations targets a specific set of consumers according to their specific needs. There are three main divisions: bulk commodity wholesale, specialized commodity retail, and mixed commodity retail. Despite the size of the market, there is a sense of orderliness and structure in the layout, with designated areas for loading and offloading goods, as well as designated parking areas for vehicles.

In February 2015, the Kejetia market underwent reconstruction to better the transportation and movement in the area as productivity had reduced and there was a decline in microeconomic growth along with fire hazard concerns. The Parliament of Ghana approved a US$270M financing for the redevelopment. The total construction area is over 170,000 square meters. The main structure of the building is a pre-manufactured steel structure. There are a little over 8400 shops in the current facility and it is designed to accommodate 300,000 people when it is full to capacity. By the end of 2018, this first stage was near completion and the scene was set for the second and third phases – the actual redevelopment of the market.

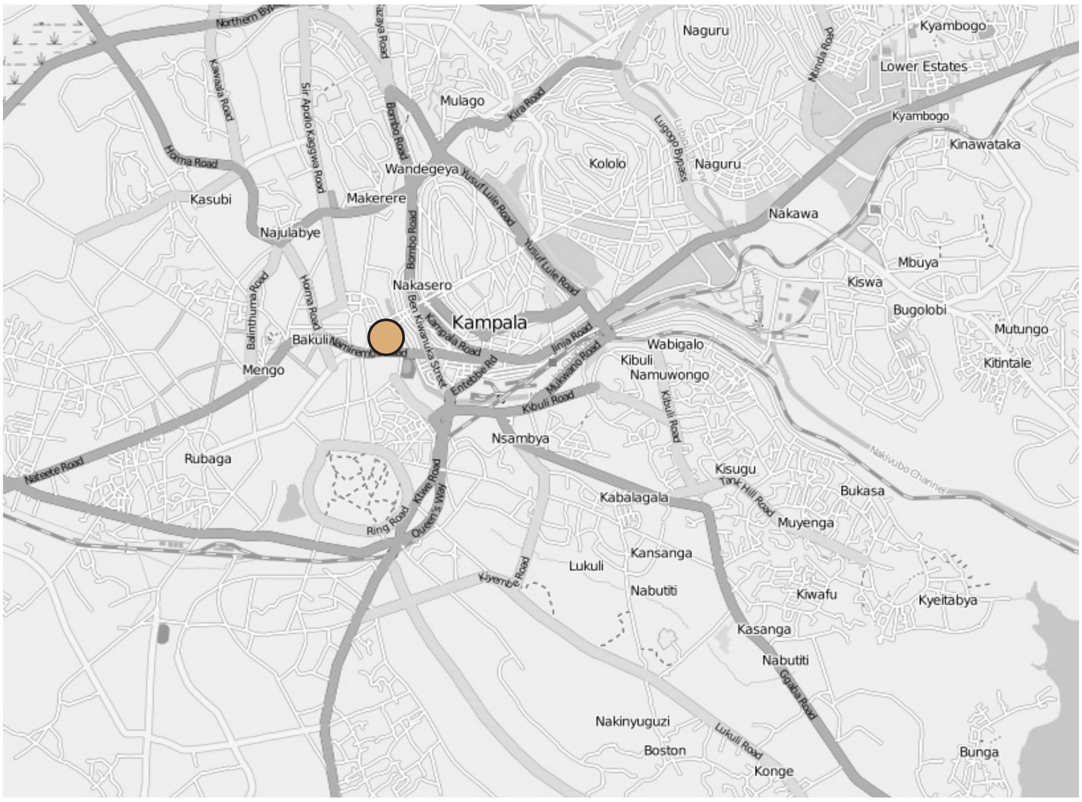
Like the Kariakoo Market, it is a major hub for commercial activity, attracting thousands of visitors each day. However, unlike Kariakoo, the Kumasi market has a more organized and structured layout, with designated sections for specific goods and services, making it easier for shoppers to navigate.

SITE 2:
WANDEGEYA MARKET - KAMPALA, UGANDA

Kampala Capital City Authority. (2015). [Photograph of Kampala city center]. Twitter.

Sebamala, J. (2021, May 6). President wants local authorities to manage public markets, returns Market Bill 2021 to Parliament for reconsideration [Photograph].

Wandegeya Market, located in Kampala, Uganda, is a bustling hub of commercial activity situated in the Kawempe division, adjacent to Makerere University. Established in 1934, the market has undergone significant redevelopment, resulting in a modern, well-organized structure that covers an impressive 16,700 square meters and boasts over 1000 stalls. The redevelopment began in 2011 and was completed in 2013, resulting in a market that is divided into north and south wings, with each floor dedicated to selling specific types of products and managed by specialized supervisors.



Location of Wandegeya Market in urban context and major transportation routes

The market is laid out in trade zones, with each floor dedicated to selling a particular commodity. Vendors are restricted to selling only the products within their zone and are supervised by specialized managers who report to the top management. Despite its modernization, Wandegeya Market retains its unique character, with informal traders and street vendors adding to the lively atmosphere. The structure of Wandegeya Market is somewhat chaotic, with numerous narrow alleys and pathways crisscrossing the site. The market is divided into different sections based on the types of goods sold, with each section being a hive of activity in its own right. The market is also home to a number of informal traders who operate outside the designated stalls and shops, adding to the overall frenetic energy of the space.

Wandegeya Market's location next to Makerere University and its proximity to Kampala's central business district make it an important node in the city's commercial network. Its history and continued evolution reflect the changing nature of urban life in Kampala and the ongoing importance of markets as centers of trade and exchange. As a bustling, modern marketplace, Wandegeya Market represents an essential component of Uganda's economy and a vibrant expression of urban life in the region.

One of the primary differences between Wandegeya and Kariakoo is that the former market is located on a much smaller plot of land, which has resulted in vendors having to use more creative and space-efficient methods of displaying their wares.

SITE 3:
LUSAKA CITY MARKET - LUSAKA, ZAMBIA

Google Earth. (2022). View of Lusaka City Market [Google Earth snapshot].

Shunya. (n.d.). Lusaka city market street scenes [Photograph].

Lusaka City Market is an open-air market in the city of Lusaka, the capital of Zambia. It is composed of structures of repetitive modular boxes, which are made from a range of materials including wood, corrugated iron, and plastic sheeting and is spread out over about 70,000 m2. The layout of the market is somewhat haphazard, with narrow alleyways and crowded spaces creating a maze-like environment that can be difficult to navigate. Despite this, the market is generally well-organized, with different sections dedicated to specific types of goods, such as fruits and vegetables, clothing, electronics, and handicrafts. Given that it is located in the central business district it is always busy and is accessible by multiple transport routes. The market features a central area where buses and taxis pick up and drop off passengers, adding to the overall chaotic but bustling atmosphere of the site.

Location of Lusaka City Market in urban context and major transportation routes

The market also serves as a vital source of affordable goods for local residents, particularly those on low incomes, who may not have access to formal retail outlets. However, the market also faces challenges, including poor infrastructure, inadequate sanitation facilities, and limited security, which can affect the safety and well-being of traders and customers alike. Multiple fires have broken out over the years for various reasons, including arson. It is not made of very sturdy & permanent structures and the only thing that keeps it running is the well-established social organization of the market location to maintain its presence.

Despite its size and organization, the Lusaka market shares similarities with Kariakoo in terms of the informal, mobile nature of some of its vendors and the challenges posed by narrow streets and alleys.

URBAN FARMING

Urban agriculture, which involves growing crops in cities, has become increasingly important in recent years due to its potential to increase access to fresh produce, reduce transportation costs and carbon emissions, and promote local food production.

Vertical farms have gained attention in recent years as a promising solution to meet the increasing demand for fresh produce in urban areas while reducing the environmental impact of food production. They can be very diverse both structurally and technologically. These farms use space-efficient techniques to grow crops in a controlled environment, allowing for year-round production and the use of fewer resources than traditional farming methods.

Some vertical farms rely solely on artificial lighting to provide the necessary light for plant growth, while others use a combination of natural and artificial light. In addition, plants can be grown using soil-based methods or hydroponic systems, with the latter being more commonly used due to its efficiency in resource usage. Hydroponic systems can recirculate nutrient solutions, allowing for the reuse of water, and the transpired water from the plants can be collected and recycled for irrigation. This means that vertical farms can use up to 90% less water than traditional farming methods (Grewal et al., 2020).

Usually, commercial vertical farms use warehouse-like structures that are thermally insulated, with ventilation being kept at a minimum. This allows for precise control of the environmental conditions inside the farm, regardless of the weather conditions outside. Artificial light is used as the sole light source for plant growth in these farms, which can be adjusted according to the needs of different plant species. This enables farmers to optimize crop growth and yields (Jovicich et al., 2018). In addition to the recirculating nutrient solution in a hydroponic or aeroponic system, the water transpired by plants can be condensed and collected at the cooling panel of the air conditioners and then recycled for irrigation.

PRECEDENTS

In my pursuit to broaden my understanding of various forms of controlled environment agriculture, I took a comprehensive approach to exploring established farms. By studying the technologies they employ and the types of crops they grow, I aimed to gain a deeper understanding of the methods used to maintain optimal growing conditions across different farming settings, including greenhouses, hydroponic farms, and vertical farms. Additionally, I conducted case studies of currently existing commercial and residential urban farming setups, with a particular focus on identifying an urban agricultural system that is economically viable and sustainable specifically for East African Countries. This involved identifying problem areas and exploring emerging technologies that combine hydroponics with circular food economy models such as using digeponics, building wastes, insect rearing, and more. Through this process, I sought to gain a comprehensive understanding of the various approaches to controlled environment agriculture and their potential for sustainable food production in urban areas.

SITE 1:
LA CITÉ MARAÎCHÈRE - ROMAINVILLE, FRANCE

"La Cité Maraîchère in Romainville / Ilimelgo" 03 Dec 2021. ArchDaily. [Photograph - Birds eye view]

"La Cité Maraîchère in Romainville / Ilimelgo" 03 Dec 2021. ArchDaily. [Photograph - Side elevation view]

La Cité Maraîchère is an urban farming project located in Romainville, France that has gained significant attention for its innovative approach to sustainable agriculture. The project was initiated in 2017 by the city council of Romainville, in collaboration with the landscape design firm, Atelier Georges. It was finally realized and kicked off production and sales in 2021. According to Atelier Georges, the project aims to "create a virtuous circle of food production, waste treatment, and energy production." To achieve this, the project incorporates a range of innovative technologies, including aquaponics, which involves growing crops in water that is fertilized by fish waste. The project also incorporates vertical farming, where crops are grown in vertically stacked layers, maximizing space and reducing water consumption.

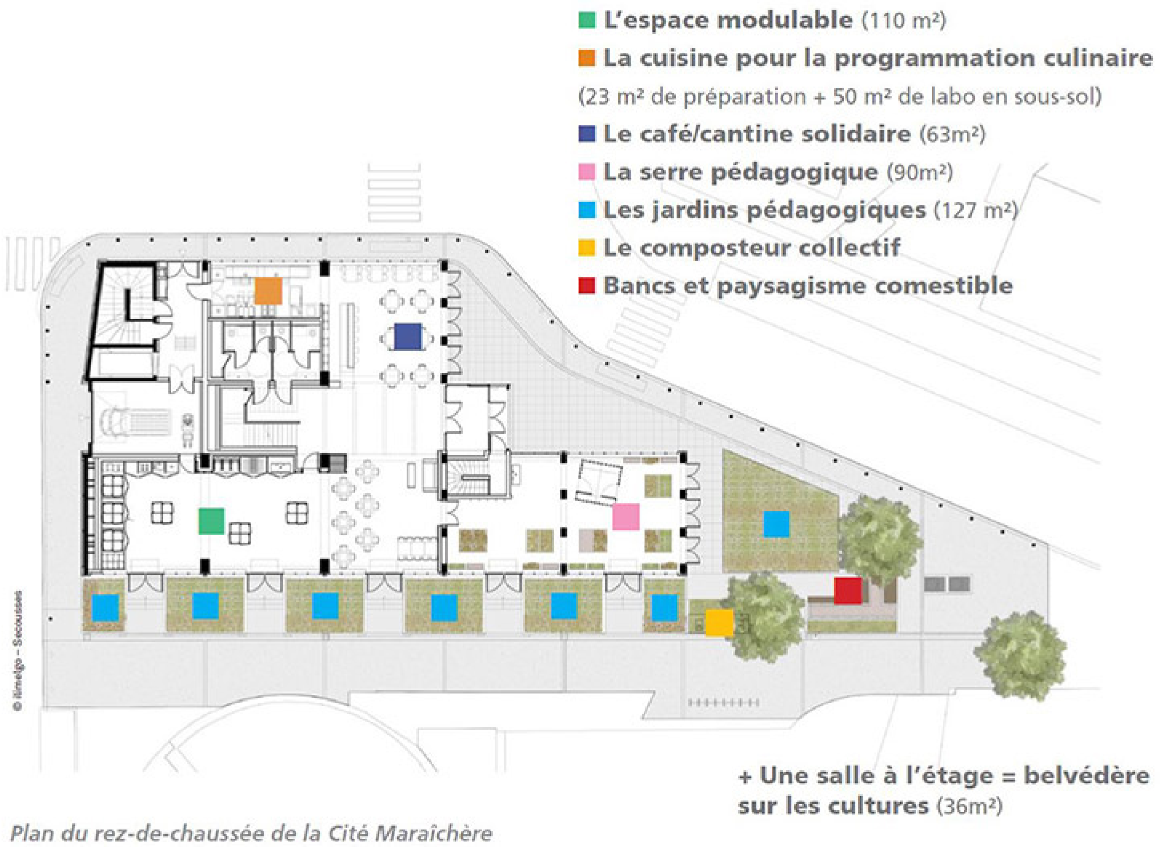
Located in the heart of the Marcel Cachin priority district, the objectives of the project included: promoting short supply chains, creating jobs, guaranteeing residents quality food, developing a social community economy and raising awareness among residents for the management of energy resources. Former " Cité ", the Marcel Cachin district, made up of large HLM complexes from the 1960s, was the subject of a requalification operation as part of the first ANRU. In order to promote greater social diversity throughout the city, 80% of the 563 housing units demolished were rebuilt in the old city centre in mixed-use residences.

Top: "La Cité Maraîchère in Romainville / Ilimelgo" 03 Dec 2021. ArchDaily. [Diagram - Front Section]

Left: "La Cité Maraîchère in Romainville / Ilimelgo" 03 Dec 2021. ArchDaily. [Diagram - Right Section]

The Cité Maraîchère is a building consisting of a vertical greenhouse spread over two towers of three and six floors, a ground floor with a coffee-canteen and educational areas, outdoor spaces and a basement for mushroom growing.It is designed as a "controlled" environment agricultural structure that combines both ventilation systems and daylight within high-performance thermal envelopes.

It employs the use of many ecologically friendly techniques such as the use of rainwater for crop watering, the adoption of substrates from composted urban waste, avoidance of synthetic chemical inputs, use of certified organic seeds and plants, fostering of natural light, heat and ventilation in the production floors, intelligent bio-climatic management of the growing areas backed by a mini weather station to optimize settings, sorting of organic waste and installation of a neighborhood composter.



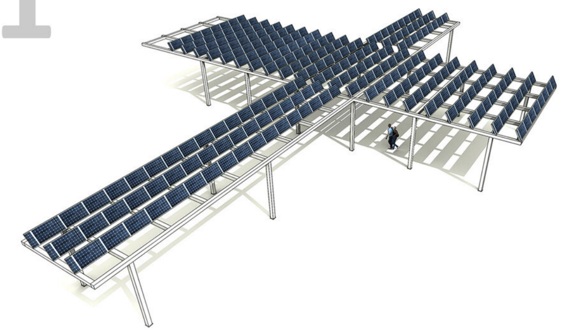
🟩 *Modular Space*
🟧 *Culinary SPace*
🟦 *Cafe/Canteen*
🟪 *Educational Greenhouse*
🟦 *Educational Space*
🟨 *Composter*
🟥 *Benches & Landscaping*

Source: La Cité Maraîchère. (n.d.). Multiplicité des espaces à la Cité Maraîchère [Plan of spaces at La Cité Maraîchère]

The reception of La Cité Maraîchère has been generally positive, with many people applauding the project for its innovative approach to urban agriculture and its potential to address issues related to food security, environmental sustainability, and community development.

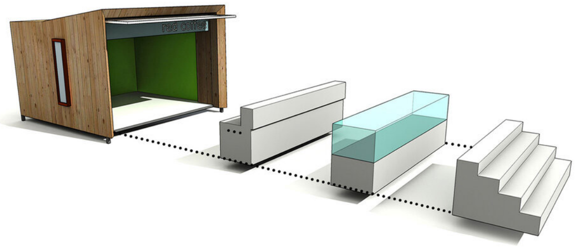
SITE 2:
MOYO URBAN FARM & RESTAURANT – CAPE TOWN, SOUTH AFRICA

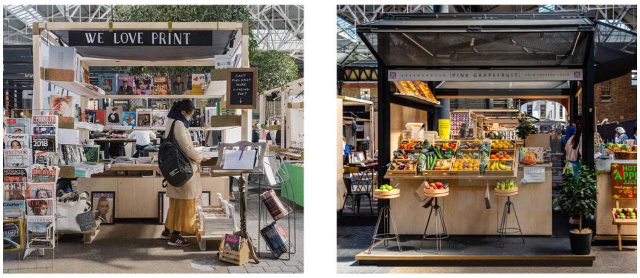
1



Market Arcade - Inspired by African Souks, covered with solar panels that provide power to the stalls while also acting as a shading device for the area underneath.

2

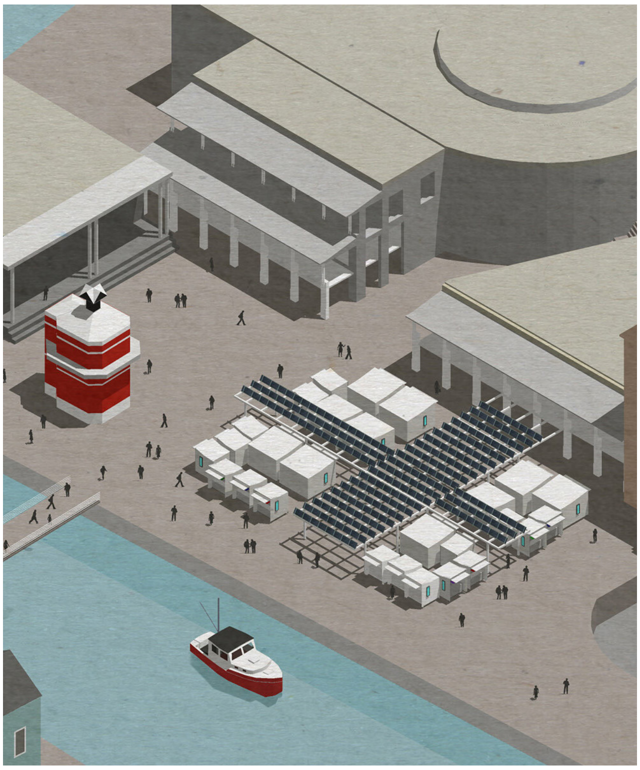




Market Stalls - Made up of a cluster of pre-fabricated modular units that can be adapted to meet the tenants' needs.

3

Urban Farm - An Aquaponic farm that offers fresh produce and fish to supplement the restaurant and the market.



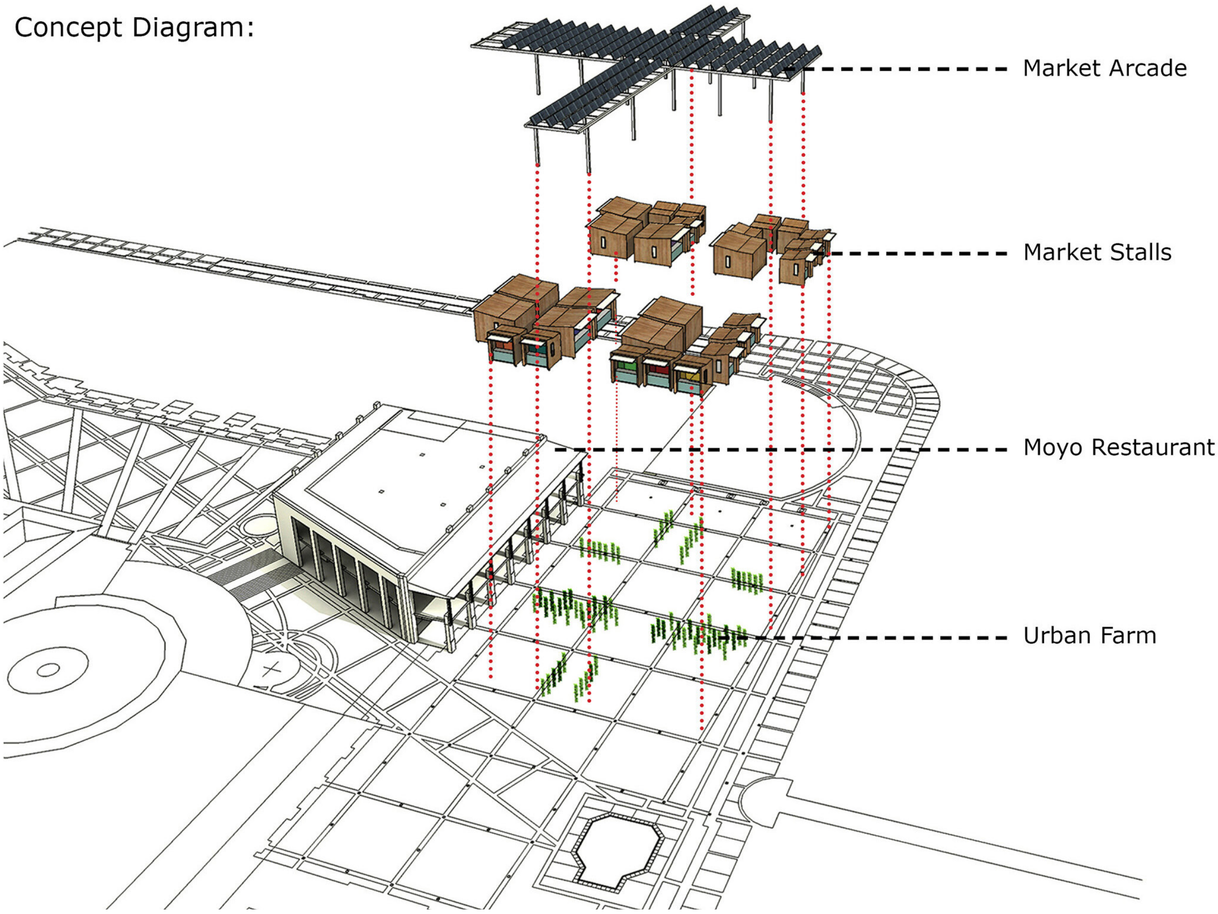
Images Sourced from Tsai Design Studio

Moyo Urban Farm & Restaurant is a sustainable food project located in Cape Town, South Africa. The project was initiated in 2015 by the founders of Moyo Restaurant, a popular eatery in the city. It features a two storey restaurant and open air market. located at the V&A waterfront on Cape Town's historic working harbor, the site is a major tourist destination with over 23 million visitors per year. The aim of the project was to create a sustainable food system that would provide fresh, organic produce to the restaurant, while also educating the community about sustainable agriculture. It tells a story through food and the full cycle it goes through, from preparation to plate.

The farm spans over 3500 square meters of land and features a range of sustainable agriculture practices, including aquaponics, vermiculture, and composting. The project also incorporates a range of renewable energy technologies, such as solar panels, to reduce energy consumption and promote sustainability.

This combination of a market and a restaurant that shows the food in its full cycle, that focuses on food security, urban farming and sustainable technologies. The market portion of this structure is inspired by a traditional African market structure. It is a semi covered structure with the narrow, long strip as the main market route, while the wide strip is populated with seats as a public lounge. There are solar panels on top of this area that provide energy to the market and restaurant while also acting as a shading device. The stalls are made up of a cluster of pre-fabricated modular units that can be adapted to meet the tenants' needs.

Concept Diagram:



Source: Tsai Design Studio

Moyo Urban Farm's usage of innovative techniques such as hydroponics and aquaponics suggests that it is able to grow a variety of crops in a relatively small space. This approach not only maximizes the farm's production capacity but also reduces its water usage and waste output.

While specific figures on Moyo's food production are not readily available, the farm's focus on high-yield farming suggests that it is capable of producing a significant amount of fresh produce and eggs. This is particularly noteworthy given Moyo's location in Cape Town, a city that has experienced significant food insecurity and unequal access to healthy food. By providing fresh, locally grown food to its restaurant and local customers, Moyo is contributing to a more sustainable and equitable food system in Cape Town.

SITE 3:
FERME DE VIE – SOUTH AFRICA

Source: Stellenbosch. NEO Architects. (2016, February 22) [Photographs]

Ferme de Vie urban farming center was envisioned as a research facility to educate local, unskilled laborers from the community in the Winelands of South Africa. The purpose of the development is to transform an existing old structure into a multifunctional space that includes exhibition space, hydroponic farming, and research. This project was a conceptual project and has not been implemented.

The farm spans around 250000 square meters and features a range of sustainable agriculture practices, including aquaponics, permaculture, and regenerative farming. The urban farming component makes the bulk of the project which consists of 28 upcycled containers for hydroponic usage. The fresh crops are grown and sold to the local community.

One of the unique aspects of Ferme De Vie is its focus on community engagement and education. The farm hosts regular workshops and training sessions on sustainable agriculture, with a focus on empowering local communities to develop their own sustainable food systems. The aim is to create a network of sustainable farmers who can work together to promote a more sustainable food system in South Africa.

DESIGN PROPOSAL

The proposed marketplace is more than just a retail space. It is a response to the growing food insecurity problem and aims to provide a platform for the public to engage with the production of food. By including a vertical farming setup, the public can better understand and connect with the growing process of food. This approach also aligns with the global trend of urban agriculture, which has been gaining traction due to the benefits of reduced food miles and carbon emissions.

The commercial space in the vertical marketplace is designed to cater to both long and short-term opportunities. This promotes small traders and provides a home for existing businesses to thrive. The education of the general public on issues related to food and its production is also a key aspect of the proposed vertical marketplace. It can help improve lifestyles and consumption patterns while creating awareness around climate change and its impact on food security. With labs and research rooms, there is an opportunity for the public to learn about the process of agriculture, empowering them to make more informed choices about the food they consume.

The proposed vertical marketplace with its focus on food production, education, and commercial opportunities, is a novel approach to tackling food insecurity. By engaging the public in the production process, the marketplace can help foster a sense of community, encourage sustainable practices, and promote local food systems. Through this integrated approach, the vertical marketplace has the potential to revolutionize the food retail industry and lead the way in sustainable urban development.

Throughout the design process, my proposal for integrating urban farming into a retail space took a number of different paths. What began as a simple idea evolved into a complete reimagining of the Kariakoo marketplace as an urban farming and distribution center. As I worked through the project, it became apparent that there was a significant need for locally sourced fresh produce in the area, and I became increasingly motivated to develop a design that would address this need.

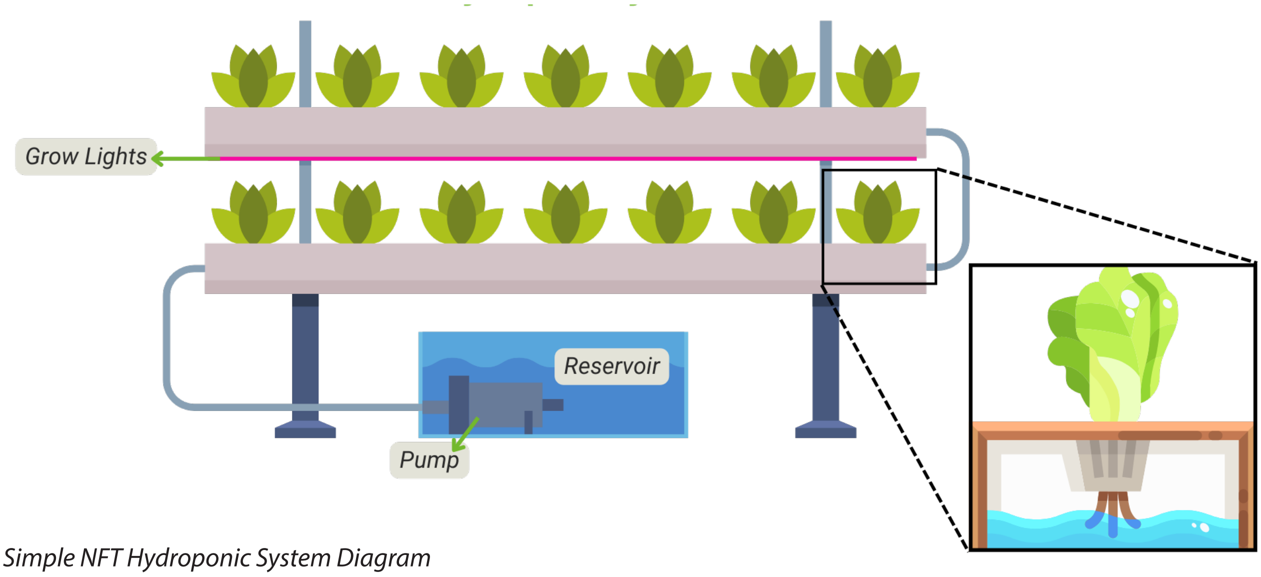
As the design process progressed, I explored various design options and programmatic requirements to create an optimal solution. I considered different spatial configurations, farming techniques, and the integration of technology to enhance the farm’s efficiency and productivity. Throughout the design process, I relied heavily on data and simulations to evaluate the feasibility of different scenarios and to fine-tune the design to optimize food production.

In addition to the technical challenges, I also had to consider the cultural and social implications of the project. I sought to develop a design that would be not only sustainable but also culturally sensitive and relevant to the community.

As I delved into the meaning and aesthetic choices of the original structure, I began to develop my own vision for the space. From there, I mapped out the program within the existing footprint and used HARVEST, a Rhino plugin, to run simulations based on collected data to assess food production.

NUTRIENT FILM TECHNIQUE (NFT)

NFT hydroponic systems are gaining popularity in urban agriculture, providing a sustainable and efficient way to grow crops in limited spaces. In the Nutrient Film Technique (NFT), a thin film of water continuously flows through the pipe/gutter, so it is always in contact with the roots. This ensures constant availability of nutrients to the plants. NFT also supplies ample oxygen to the plants, since the roots are exposed above the thin film. This system requires the nutrient solution to be continuously in circulation, which results in no stagnant water in any point of the system.



Simple NFT Hydroponic System Diagram

According to a study by Grewal et al. (2020), NFT hydroponic systems have several advantages for urban agriculture, including their ability to utilize minimal space, require less water than traditional farming methods, and produce higher yields in a shorter amount of time (p. 87).

One example of the use of NFT hydroponic systems in urban agriculture can be seen in Singapore, where vertical farms using this technology have been established in response to the city-state's limited land resources. Vertical farms using NFT hydroponic systems are able to produce high-quality crops such as lettuce, kale, and herbs, while using up to 90% less water than traditional farming methods (Goh & Lee, 2020).

In addition to their sustainable and efficient nature, NFT hydroponic systems also have the potential to be linked to blockchain technology through the use of NFTs, or non-fungible tokens. This would enable growers to track and verify the origin and quality of their produce, as well as provide a new market for urban agriculture produce (Salmi & Bock, 2020).

Overall, NFT hydroponic systems offer a promising solution for sustainable urban agriculture, providing a way to grow crops efficiently and effectively in limited spaces. As the world's population continues to grow and cities become increasingly crowded, the need for innovative and sustainable solutions like NFT hydroponic systems will only become more important.

HANDS ON RESEARCH – BUILDING AN NFT HYDROPONIC SYSTEM

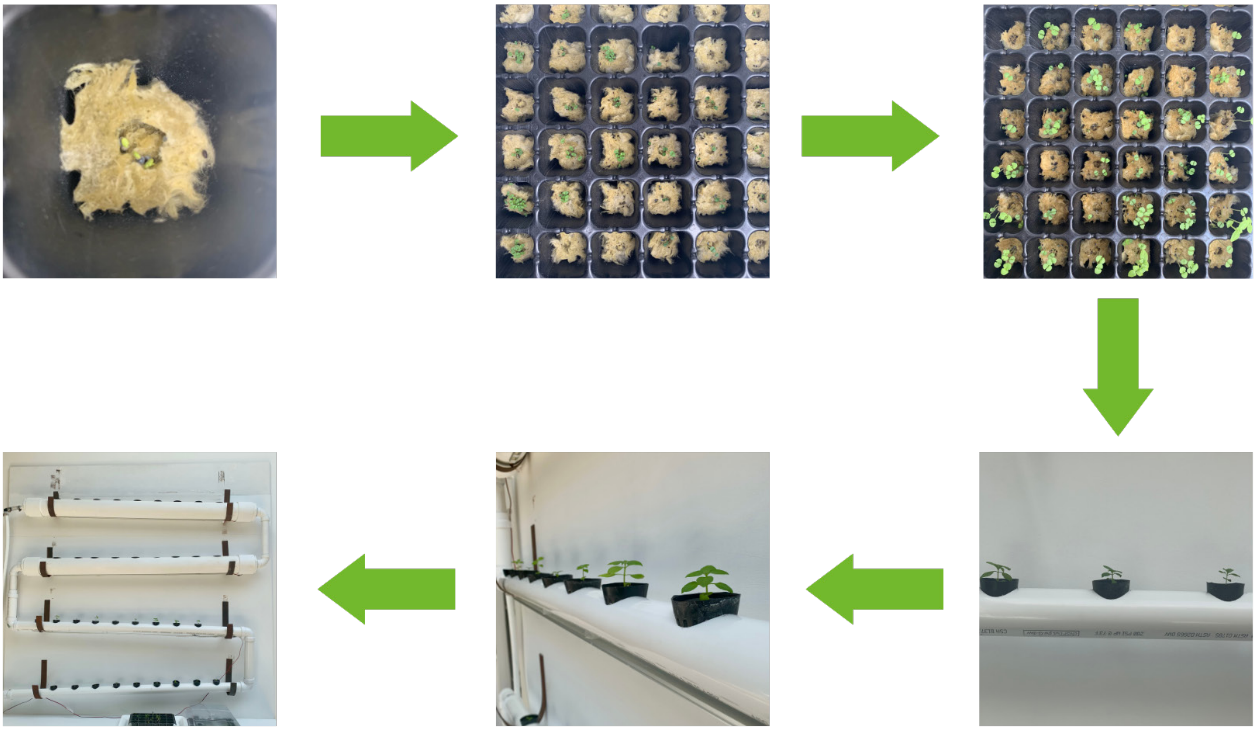
In this particular case, the process of planting in a hydroponic system began by filling a grow tray with 48 rockwool pods. These pods, made from spun volcanic rock, provide an ideal growing environment for plants, allowing for proper drainage and aeration while retaining moisture.

Basil seeds were then carefully placed into each pod, with a focus on ensuring that the seeds were properly spaced and not overcrowded. The grow tray was then placed in a location where it would receive ample sunlight and the necessary environmental conditions for germination.

Over the next two weeks, the rockwool pods were consistently sprayed down with water to ensure that they remained damp and the seeds had the necessary moisture to germinate. This process is critical in the early stages of plant growth, as dehydration can quickly lead to stunted growth or even plant death.

At the two-week mark, the basil plants had grown to a point where they were ready to be transplanted into the NFT (Nutrient Film Technique) hydroponic system. NFT is a type of hydroponic system where a shallow stream of nutrient-rich water is constantly circulated over the roots of the plants. This method allows for optimal nutrient uptake and oxygenation, resulting in faster and healthier plant growth.

Approximately 20 of the strongest and healthiest basil plants, which had grown to around 3 inches in length and had at least two sets of leaves, were carefully removed from their rockwool pods and transplanted into the NFT system. The remaining plants were left in the grow tray to continue growing until they reached the desired size for transplanting.



Once transplanted, the basil plants in the NFT system were carefully monitored and maintained, with a focus on ensuring that the water levels and nutrient concentrations remained optimal for growth.

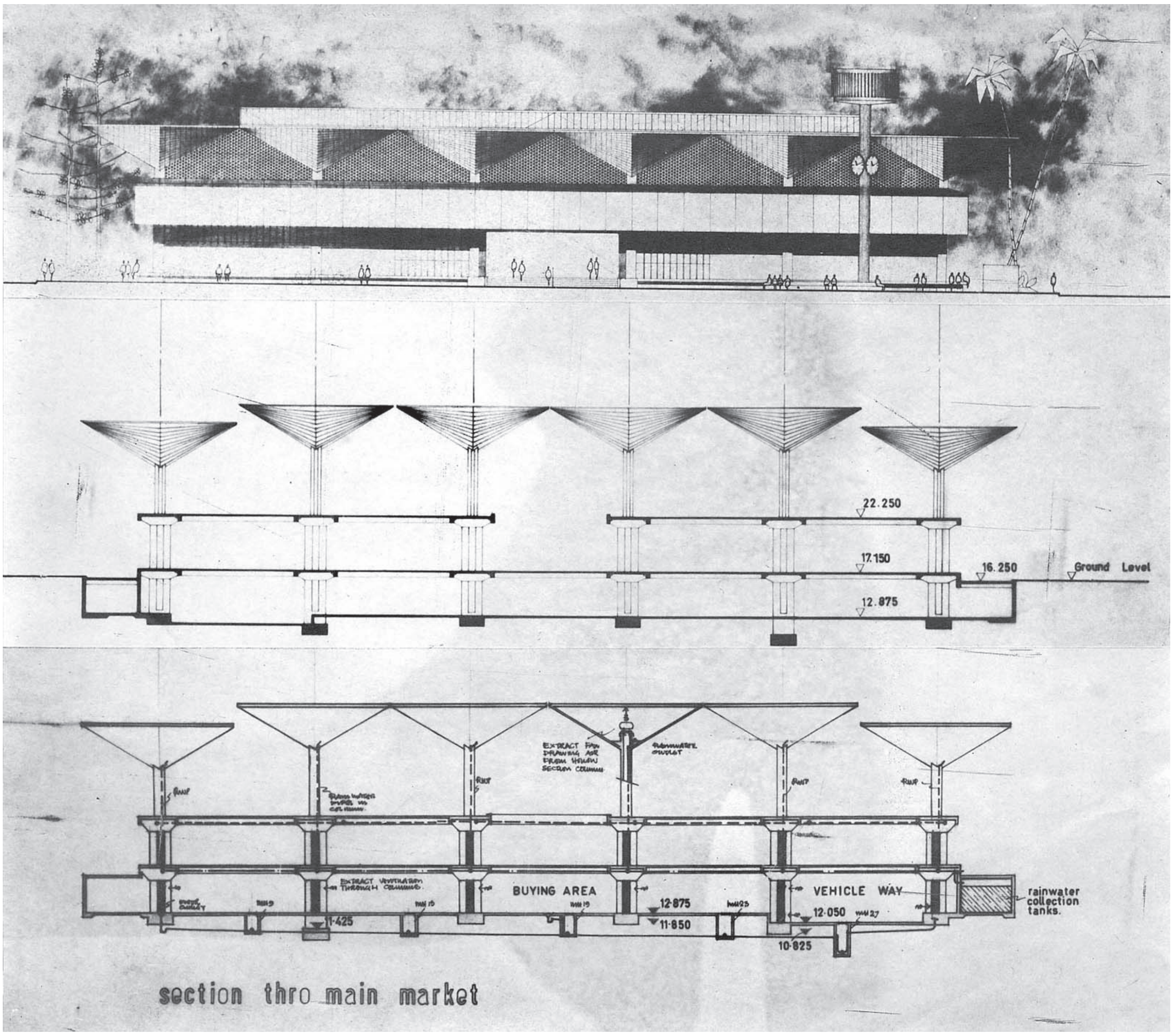
The hydroponic system was built using pipes and connectors, which were carefully chosen to provide the necessary support and stability for the growing plants. These pipes were connected to a reservoir tank that held water and nutrients, which could be added to the tank to provide the necessary nutrients for plant growth.

To prevent algae growth, which can quickly take over a hydroponic system and harm the plants, the reservoir tank was kept away from light. Additionally, the holes in the pipes were covered completely with black cups to ensure that no light could penetrate the system and cause algae to grow.

The pump in the tank played a critical role in the operation of the hydroponic system, as it was responsible for pumping water through the system and allowing the water to recycle through the system. This continuous flow of water ensured that the plants had a constant supply of water and nutrients, which is essential for optimal growth and health.

Maintaining the hydroponic system required regular monitoring and attention, as any issues or imbalances in the system could quickly lead to problems for the plants. Careful adjustments were made to the water and nutrient levels as needed, and the system was regularly checked for any signs of disease or pest infestations.

PRELIMINARY DESIGN CONCEPT



Existing Structure Perspectival & Sectional view. Source: Gerkan, Marg and Partners (GMP) Engineers. (n.d.)

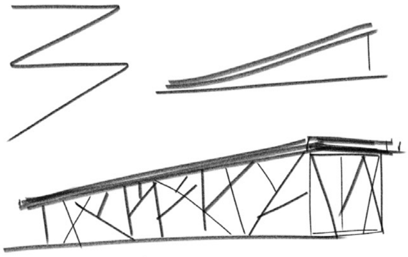
Amuli's design for the Kariakoo Market was inspired by the traditional African marketplace, which typically consists of a series of interconnected stalls and small shops arranged in a grid pattern. Amuli aimed to create a design that was both functional and aesthetically pleasing, while also reflecting the local culture and traditions.

In an interview with "Africa is a Country", Amuli explained that his design for the Kariakoo Market was informed by his own experiences growing up in a small village in Tanzania. He observed how people in his community would set up stalls and sell their goods in the marketplace, and he wanted to recreate that sense of community and connection in the design of the Kariakoo Market.

In order to develop my own unique design concept, I drew upon a variety of sources for inspiration. Taking into account Beda Amuli's vision and design process for the Kariakoo Market, I explored new ways to portray a columnar form. I was drawn to the innovative work of renowned Japanese architect, Shigeru Ban, who is known for his use of laminated timber columns in his structures. Ban's approach to architecture is inspired by biomimicry, where he looks to the natural world for design solutions. This led me to draw inspiration from the tree-like form of Ban's columns and incorporate it into my own design.

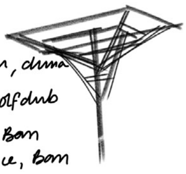
In my design, I aimed to capture the organic, flowing quality of a tree trunk, while also incorporating the strength and stability of a traditional column. To achieve this, I chose to use cross laminated timber (CLT). This material allowed me to create a more sustainable and environmentally-friendly structure, while also providing the necessary load-bearing capacity.

Fortunately, Tanzania has an abundant supply of timber and forest resources, making it an ideal location for the production and use of CLT. The country's government has also been promoting sustainable forestry practices. This makes it even more feasible to implement the use of CLT in the construction of the Kariakoo market, allowing for a sustainable structure that also highlights the beauty of nature.



wilderness Restaurant

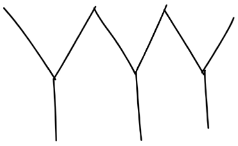
- Bamboo garden, chengdu, china
- Shigeru Ban South korea Golfclub
- Japan Pavilion, Shigeru Ban
- Centre Pompidou, France, Ban

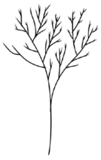


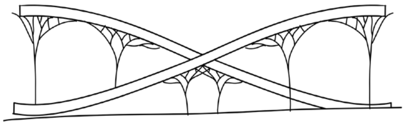
meerstad market, netherlands

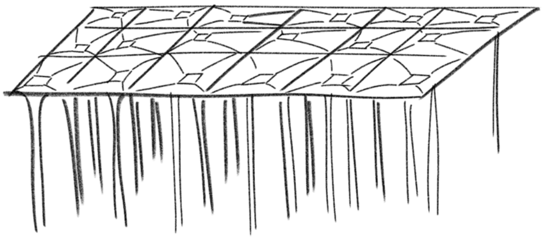
Cambridge central mosque

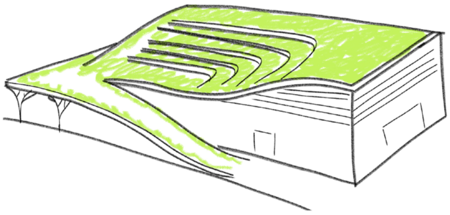
Singapore Botanic garden



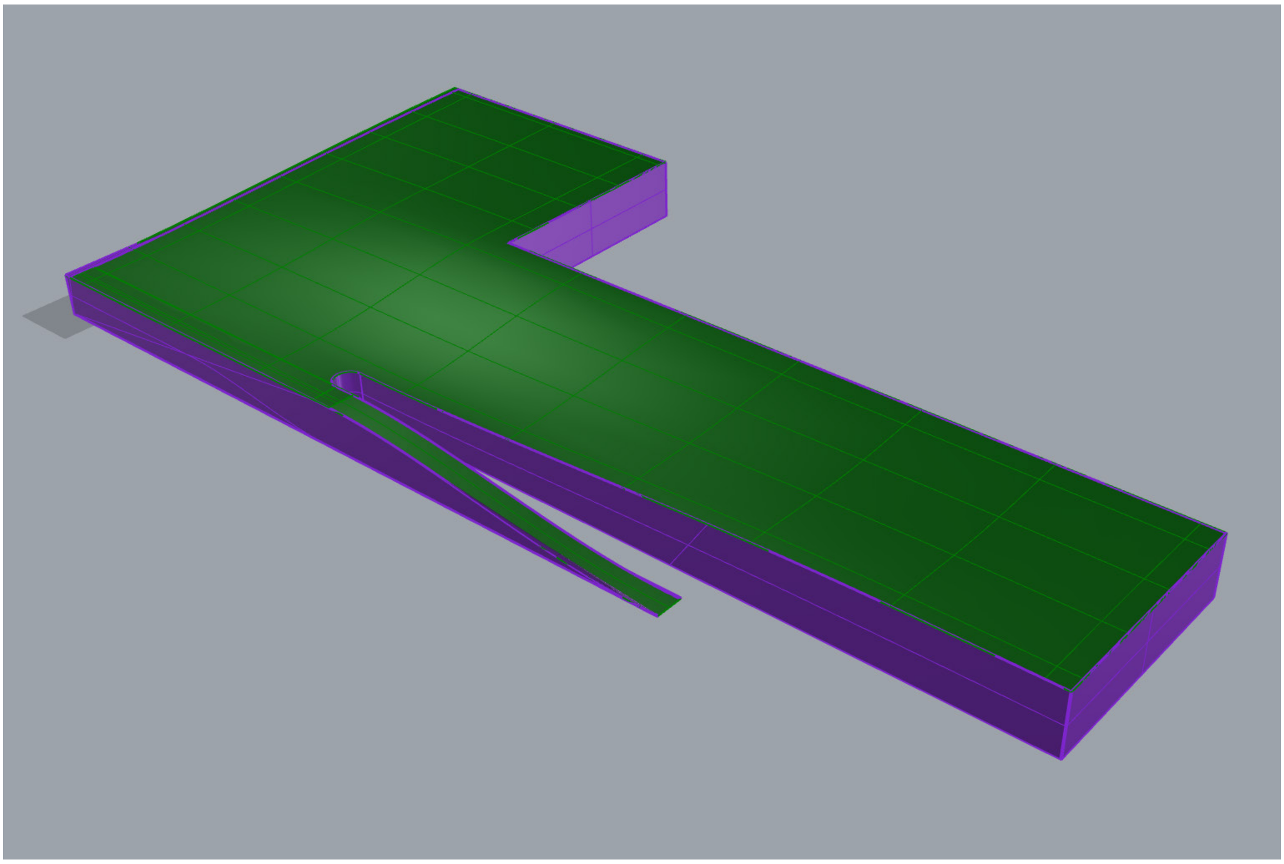








As part of my design concept, I was interested in highlighting the importance of farming and sustainable agriculture. In order to achieve this goal, I planned to incorporate a rooftop community growing space within my proposed structure. This would not only serve as an educational space, but also as a practical area for growing fresh produce in an urban environment. By showcasing the benefits of sustainable agriculture in this way, I aimed to create a space that would inspire and educate visitors, while also providing a practical solution for cultivating fresh produce in a dense, urban environment.



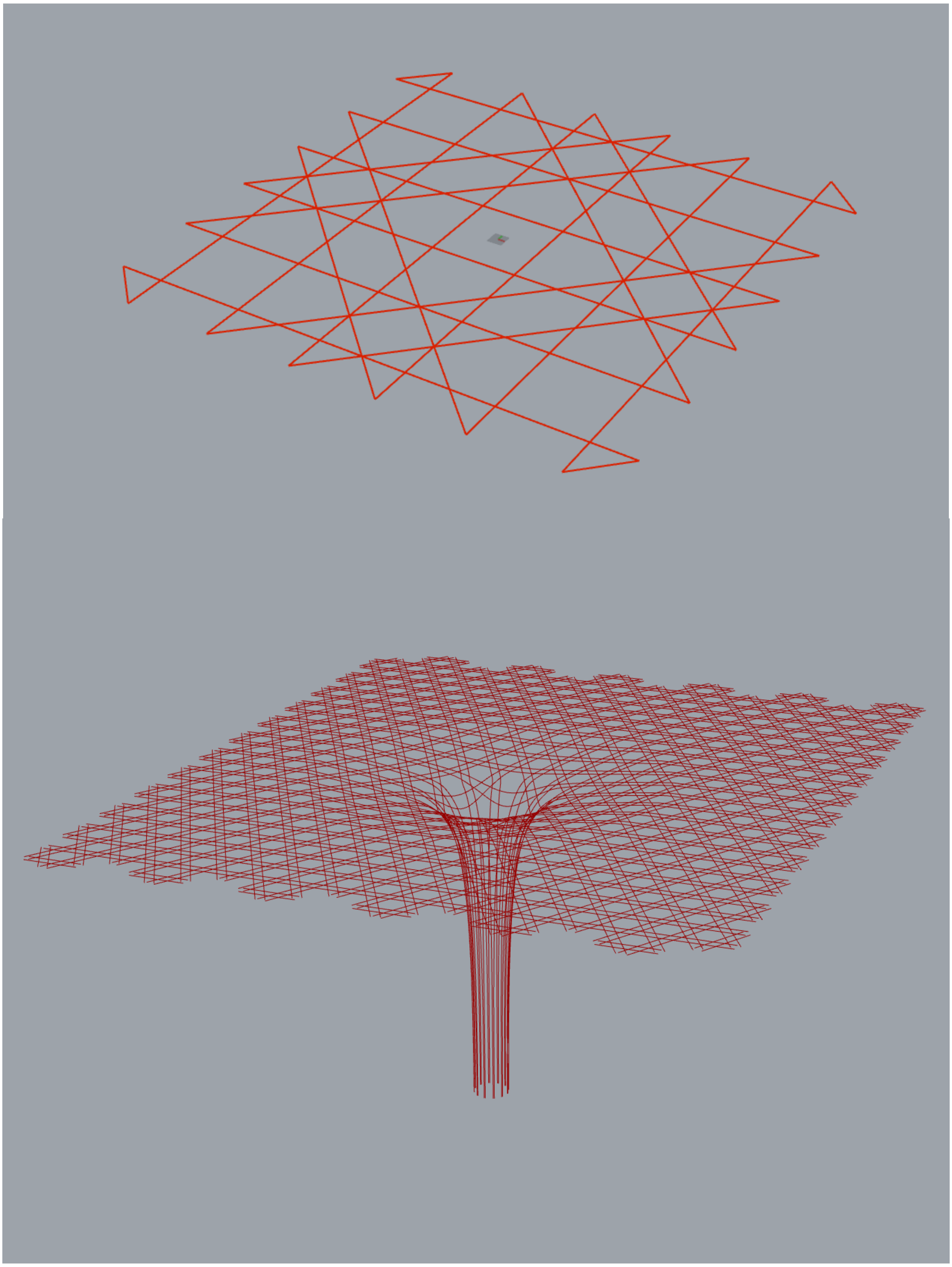
Conceptual 3D Rhino Modeling

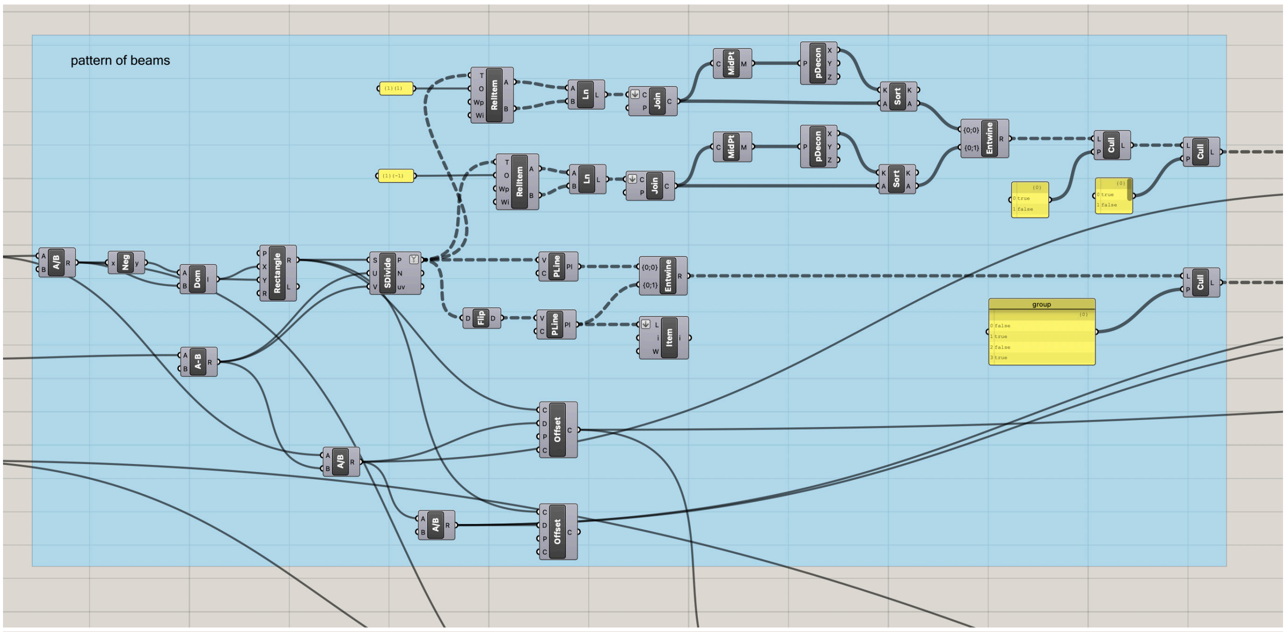
Following the mid-review, I made the decision to modify my building concept in response to the feedback provided by the reviewers. Some of the suggestions I received included exploring alternative construction materials instead of relying solely on concrete. Additionally, I was advised to simplify the program by focusing on a few key ideas, rather than overcomplicating the design. Furthermore, I was encouraged to place greater emphasis on site context when developing my proposal.

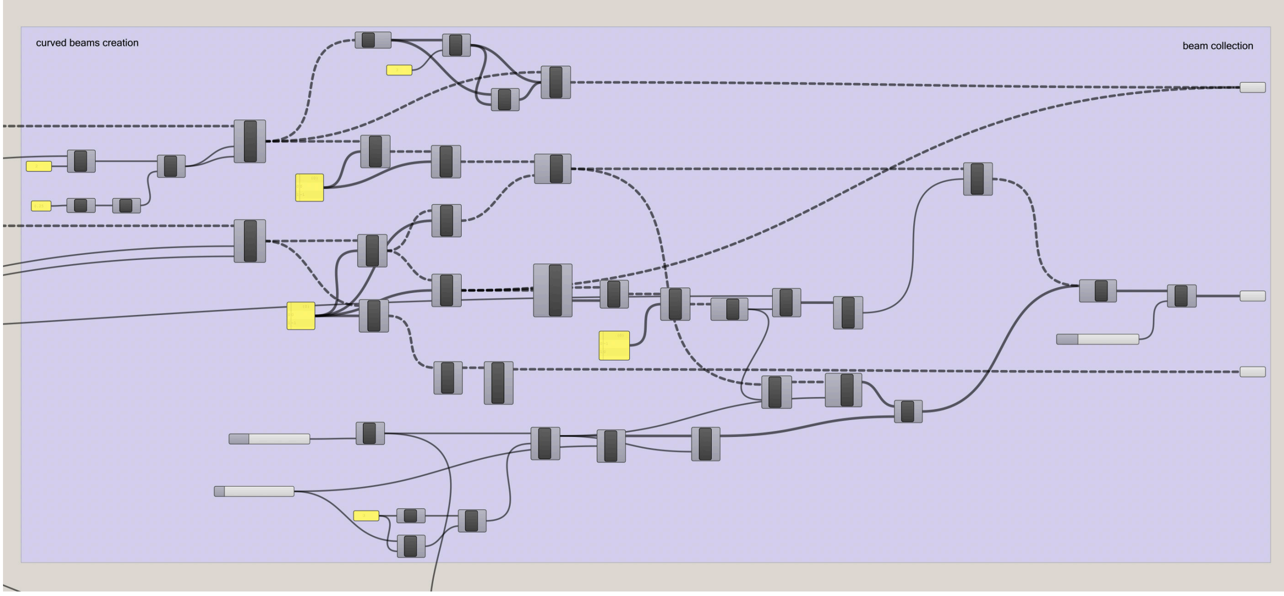
After receiving feedback from the reviewers and making modifications to my building concept, I was able to simplify my ideas and create a more practical and functional design. By utilizing the existing footprint, I was able to develop a structure that takes into account the unique characteristics of the site, including its topography and dynamic surroundings.

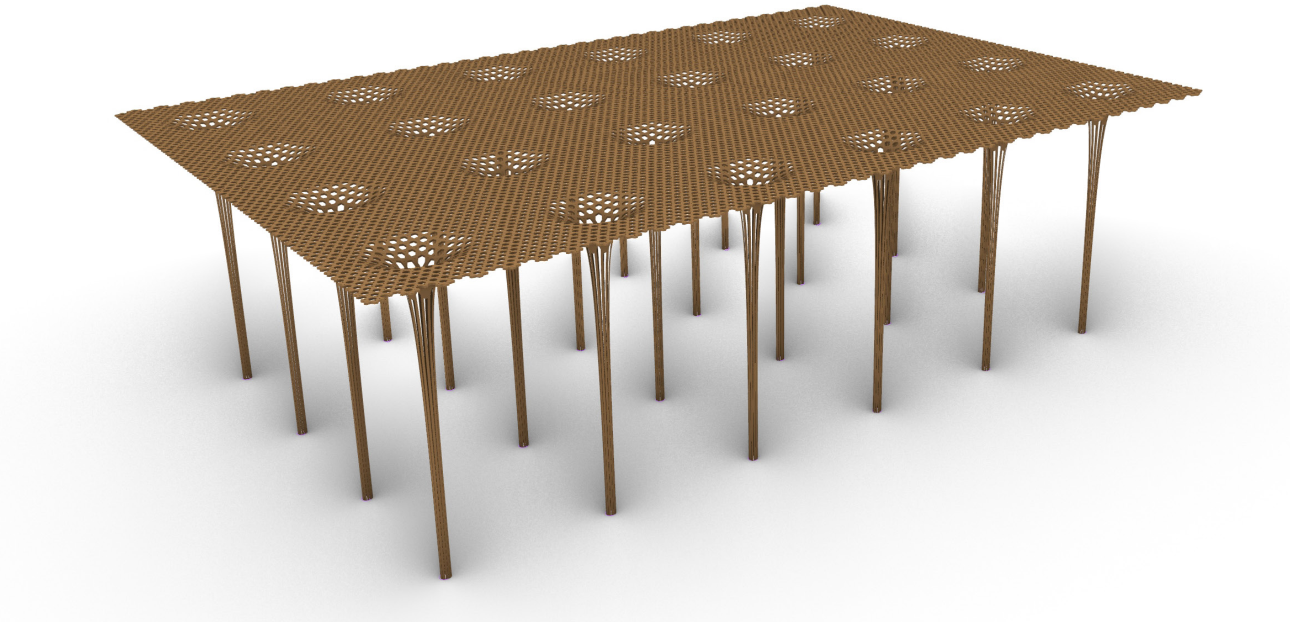
CONCEPT DEVELOPMENT

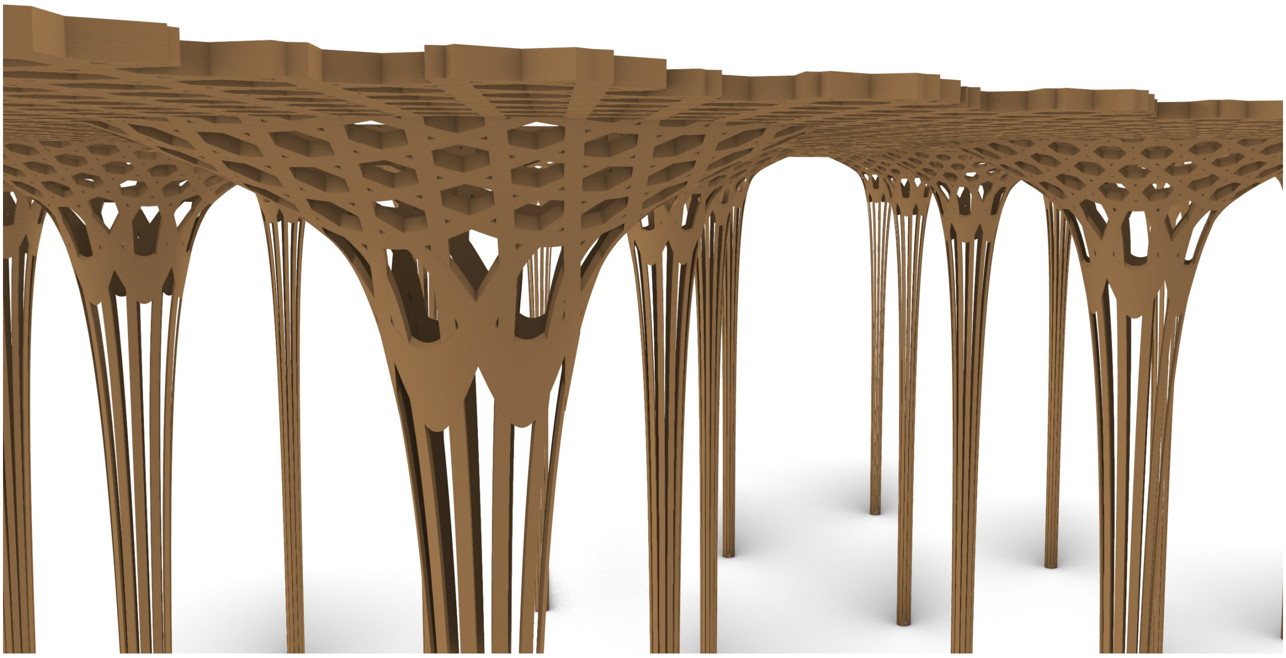
I used Grasshopper, a visual programming language and plugin for Rhino, to create a highly efficient and customizable parametric design of the columns. This allowed me to develop a precise and intricate framework for the columns, which could be adjusted and modified based on specific design requirements and site conditions.

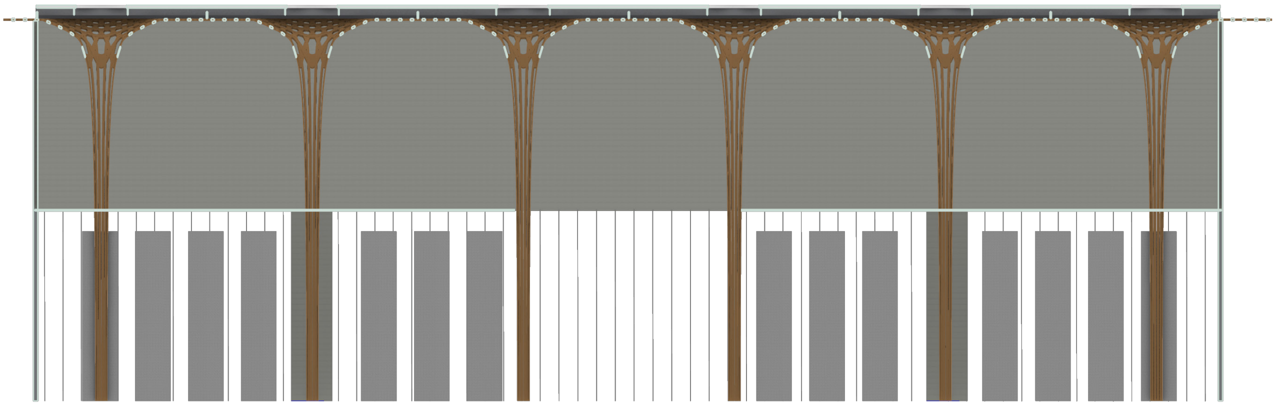


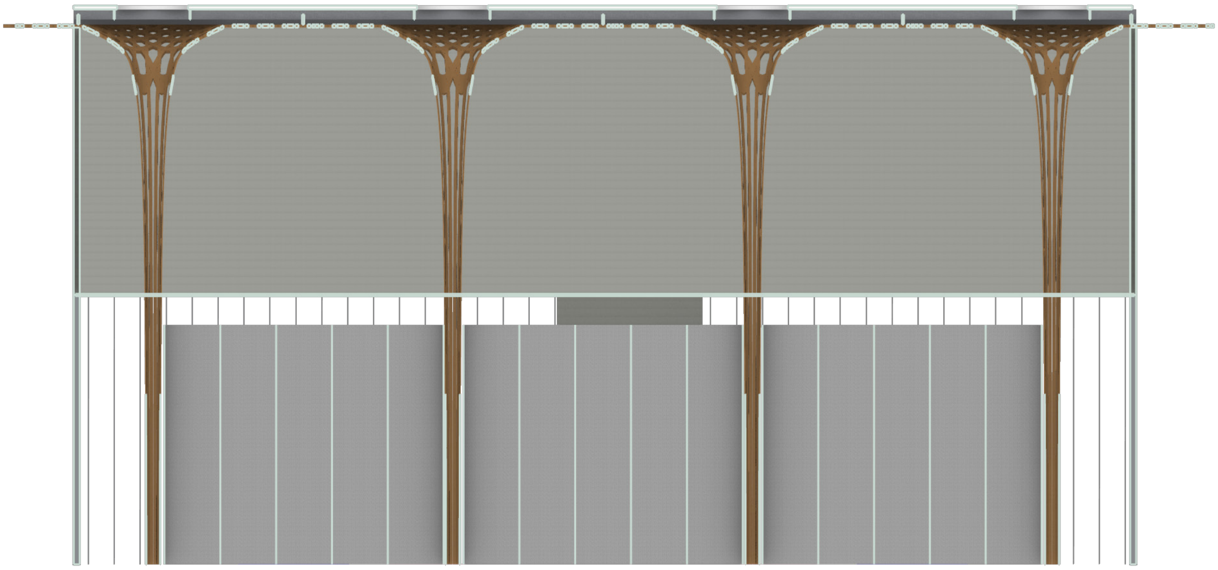

pattern of beams
{1;1;1}
{1;1;-1}
RelItem
Ln
Join
MidPt
pDecon
Sort
Entwine
Cull
A/B
Neg
Dom
Rectangle
SDivide
PLine
Flip
Item
Offset
A-B
group
0 true
1 false
0 false
1 true
2 false
3 true


curved beams creation
beam collection









ADJACENCY

As I begin to think about specific pieces of the project I wanted to keep the following things in mind when I placed the different components next to each other:

1. Space planning: By understanding the relationships between different spaces, I would be able to better plan the layout and flow of the space, ensuring that it is arranged in a logical and efficient way.

2. Functionality: Ensure that components are placed in a way that supports their intended functions. For example, if a laboratory needs to be located near a storage room, the matrix can help ensure that these spaces are located adjacent to each other.

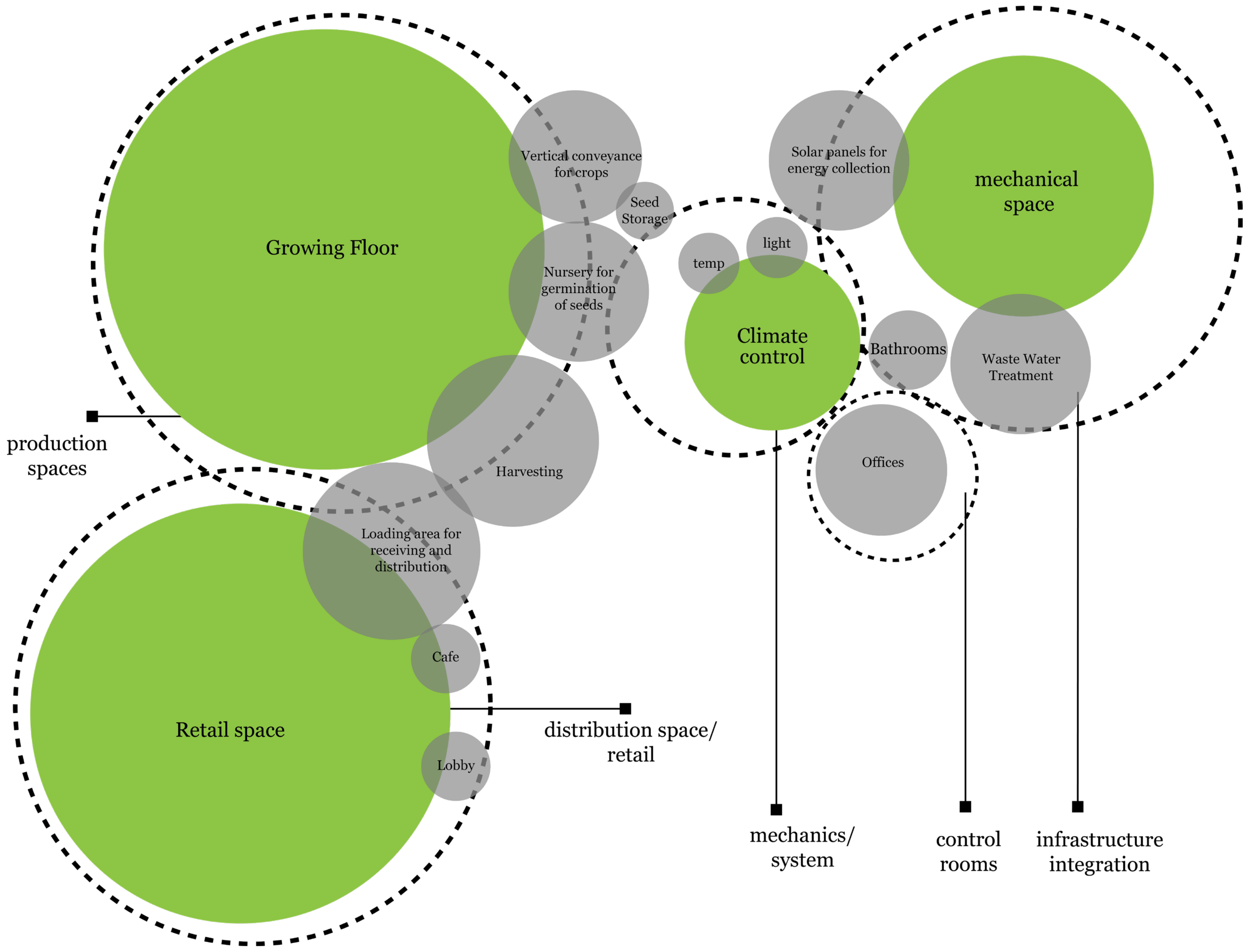
3. Communication: Communicate my design ideas to other people and provide a clear and concise way to convey the relationships between different spaces and how they will be used.

Therefore I developed an Adjacency Matrix and an Adjacency Diagram to begin to map out my plan.

An Adjacency Matrix is a table that lists the connections or relationships between different spaces in a building, usually represented as rows and columns. The cells in the matrix indicate whether or not there is a connection or adjacency between the spaces, and may include additional information such as the type of connection, the distance between spaces, or the frequency of interaction between them.

	Production area	Facilities	Vertical Circulation	Administration	Pickup/ Drop off	Retail	Community Spaces
Production area		Most	Most	Less	Most	Less	Least
Facilities	Most		Most	Most	Less	Least	Least
Vertical Circulation	Most	Most		Less	Less	Less	Less
Administration	Less	Most	Less		Least	Less	Least
Pickup/drop off	Most	Less	Less	Least		Most	Least
Retail	Less	Least	Less	Less	Most		Most
Community Spaces	Least	Least	Less	Least	Least	Most	

An Adjacency Diagram, on the other hand, is a visual representation of the adjacency matrix. It often takes the form of a bubble diagram, where each space is represented by a circle or bubble, and the connections between them are shown by lines or arrows. The size and position of the bubbles can also indicate the relative size or importance of the spaces.


Growing Floor
Vertical conveyance for crops
Seed Storage
Nursery for germination of seeds
Harvesting
Loading area for receiving and distribution
production spaces
Retail space
Cafe
Lobby
distribution space/ retail
temp
light
Climate control
Solar panels for energy collection
mechanical space
Bathrooms
Waste Water Treatment
Offices
mechanics/ system
control rooms
infrastructure integration

PROGRAM BREAKDOWN

	Quantity	Area/Unit	Total Area (square meters)
FARM			
Farming Pods	350	7	2450
Controls	1	2	2
Community farming space	25	2	50
Research area	1	45	45
Processing	2	30	60
Germination area	2	20	40
Nursery	2	12	24
Packaging area	2	22	44
Storage	1	60	60
Offices	4	15	60
Bathrooms			45
Circulation	-	400	400
		Farm Total	3280
RETAIL			
Retail Space			
Big stalls	200	9	1800
Small stalls	145	4	580
Cafe	1		420
Offices	4	15	60
Bathrooms			45
Circulation	-	435	435
		Retail Total	3340
FACILITY			
Mechanical	2	150	300
Water Filtration	1	75	75
Electrical	2	40	80
Bathrooms			45
Storage	2	10	20
Circulation	-	78	78
		Facilities Total	598
GENERAL			
Lobby	1	150	150
Loading/Unloading	1	100	100
Storage	1	25	25
Information	1	10	10
Staff Bike Room	1	10	10
Circulation	-	45	45
		General Total	340

CIRCULATION			
Stairs	3	20	60
Elevator (Passenger)	2	13.2	26.4
Elevator (Freight)	1	16	16
Equipment	2	10	10
		Circulation Total	112.4
		Total Area	7670.4

Using the Adjacency Matrix and Diagram as an aid to understand the relationships between different spaces, I was able to develop a Program Breakdown that begin to reflects the needs of the project and list out the spaces and functional pieces of the project.

Farm/ Production Area:

1. Farming Pods: These are the are essentially self-contained growing chambers that allow for precise control of environmental conditions such as temperature, humidity, and lighting. They are particularly useful in urban farming, as they can be used in small spaces and allow for year-round crop production.

Controls: Controls are a critical aspect of farming pods, as they allow for the precise management of environmental conditions. This includes things like temperature control, humidity control, and lighting control. Effective controls can help ensure that crops grow optimally and are of high quality.

Community Farming Space: An area of the urban farm where the community can come together to participate in farming activities. It allows for people to engage with the growing process and learn more about it.

Research Area: This area is dedicated to the development of new agricultural practices and technologies. This can include things like experimentation with new crops or growing techniques, as well as testing of new equipment or controls.

Processing: This is the area of the urban farm where harvested crops are washed, sorted, and prepared for distribution. This can include things like washing stations, sorting tables, and packaging equipment.

Germination Area/Nursery: This is an area of the urban farm where seeds are germinated and seedlings are started and are grown until they are ready to be transplanted into the farming pods. Germination areas can include things like seed trays, grow lights, and heating mats. Nursery areas can include things like plant shelves, watering systems, and grow lights.

Packaging Area: This is where harvested crops are packaged for distribution. Packaging areas can include things like scales, bags, and labeling equipment.

Storage: Here the harvested crops are stored before they are distributed. Storage areas can include things like refrigeration units, shelving, and temperature controls.

Other spaces:

1. Mechanical spaces: These house the mechanical systems and equipment that are required to support the operation of the farm. These systems can include things like heating, ventilation, and air conditioning (HVAC), water supply and irrigation systems, and electrical systems.

2. Administrative/Office Spaces: These are the areas where administrative tasks are carried out, such as record-keeping, financial management, and customer service. Administrative/office spaces can include offices, conference rooms, and storage areas.

3. Support Areas: These can include maintenance areas, restrooms, and equipment storage. Support areas are important for ensuring that the urban farm is well-maintained and equipped to handle the demands of production and processing.

HARVEST – RUNNING SIMULATIONS

(Information pulled from UMI - Harvest Documentation)

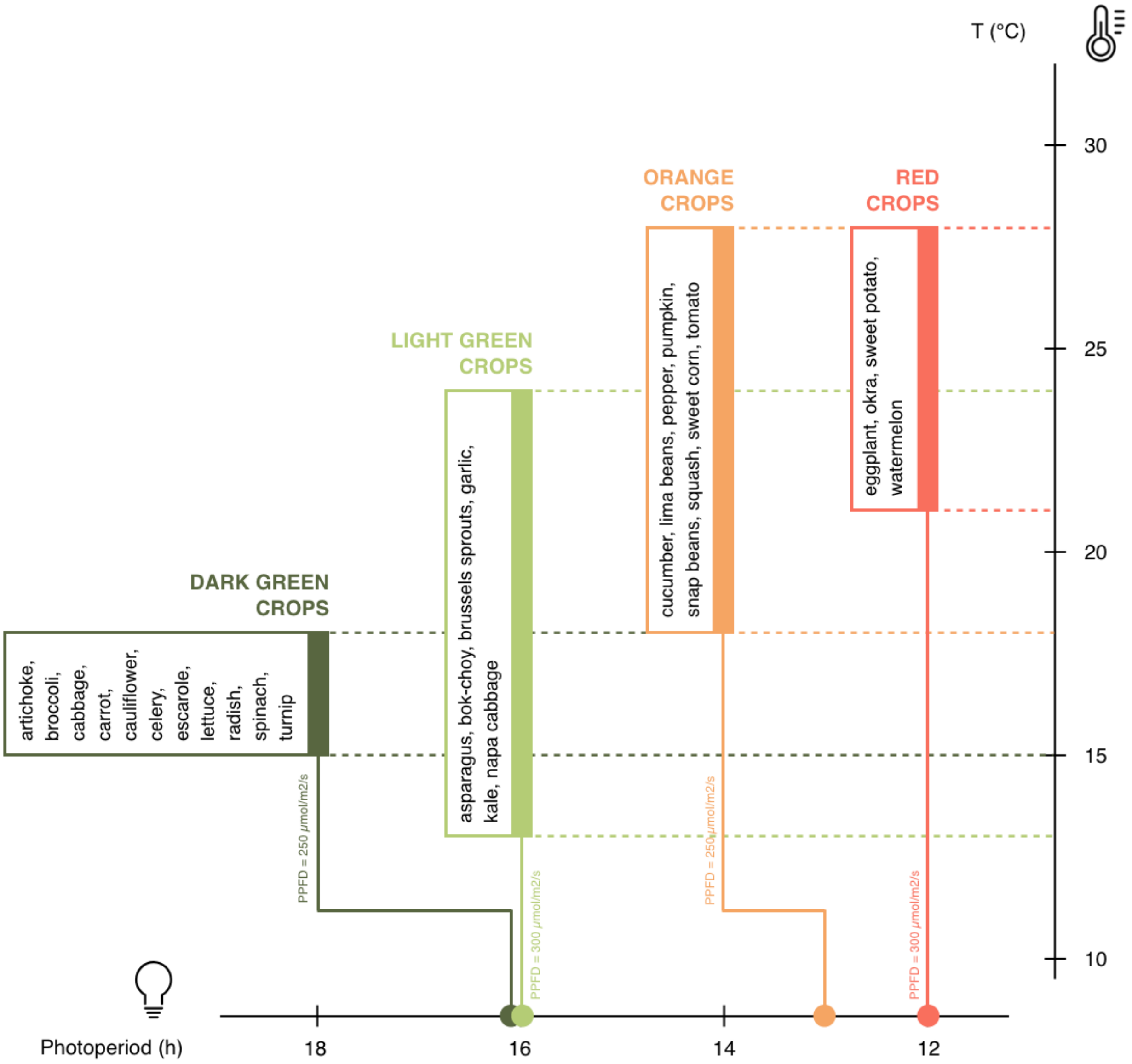
HARVEST – the urban food production simulation plugin – estimates food yields of indoor farms and their associated operational building energy use, water use, and carbon emissions. It also provides insights into the economic performance of the farms through metrics such as operational costs and jobs created locally.

Additionally, it compares simulation outputs to existing urban supply chains and provides a carbon balance as well as a site premium. The following sections describe the simulation inputs, the structure of the tool and its underlying models, and the simulation outputs.It is being developed by Khadija Benis at MIT. Last summer, I had the opportunity to work in her lab as a research assistant The following sections present an overview of the inputs, structure, and outputs of the module.

MODELING CROP GROWTH

Photosynthesis is fundamental to plant growth and has been shown to be affected by environmental factors such as light and temperature (Kozai et al., 2016). Crop growth models consist of mathematical equations that represent these reactions occurring between plants and their environment, predicting the growth rate and final state of total biomass and harvestable yield (Jame and Cutforth, 1996). HARVEST food production calculations use the gathered data on optimal growth conditions of crops and apply these models as described in the sections below.

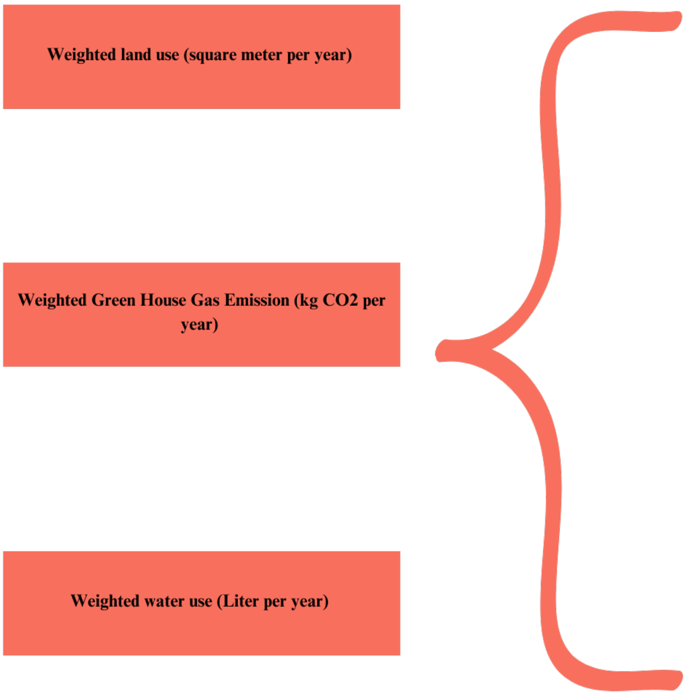
Thermo-classification of vegetables was one of the earliest attempts to group plants and remains widely used today (Welbaum, 2015). Based on their light and temperature requirements for optimal growth, HARVEST clusters crops into four groups – red, orange, light green, and dark green crops (see Fig. 2). Red and orange are warm season crops. Red crops prefer temperatures above 21°C (with optimal max going upto 29°C), whereas orange crops are adapted to temperatures ranging from 18.3°C to 29.4°C. Light green and dark green are cool-season crops. Light green crops are adapted to temperatures ranging from 12.8°C to 23.9°C, whereas dark green crops prefer average monthly temperatures of 15.6°C to 18.3°C.



Source: UMI Docs. (n.d.). Classification of crops based on light and temperature requirements [Diagram]

CEA FARM TEMPLATES

Simulating indoor crop growth requires the definition of specific templates for the “farm” building type, which are based on the optimal indoor conditions required by the plants. A default crop template library is embedded in HARVEST. In order to build these templates, a database of optimal growth conditions for a set of crops was developed through a literature review of scientific articles describing the settings and outcomes of controlled-environment cultivation experiments conducted in growth chambers equipped with hydroponic systems. The UMI Template Editor can be used to edit and/or add templates.



Food Subgroup	Food Group
Whole and refined grains	Grains
Dark green Red and orange Dry beans, lentils and peas Starchy vegetables Other vegetables	Vegetables
All fruit	Fruits
Cow's milk products Fluid milk and yogurt Cheese and other dairy	Dairy
Soy Milk	Dairy Substitute
Nuts Tofu	Plant Protein
Beef Pork Chicken Turkey Eggs Fish	Animal Protein

ZONE INFORMATION

The user has the ability to tailor the building envelope to fit the specific requirements of their project since indoor farms can be installed in any building. For example, to model a shipping container growing unit, the user can set the envelope and adjust its dimensions according to the envelope properties and dimensions of standard shipping containers.

To ensure that farms operate efficiently, it is important to define the loads for occupancy, equipment, and lighting based on their specific requirements. For occupancy, the number of farmers per square meter and a schedule for when the farm is occupied were established by looking at existing practices in commercial hydroponic farms. Similarly, the power density of the equipment and its operating schedule was set based on the specifics of hydroponic farms. To determine the lighting power density, the number of vertically stacked growing racks for a particular crop and the specifications of the lighting fixtures were taken into consideration. A lighting schedule was allocated based on the crop's photoperiod requirements, and an illuminance target in lux was set according to the photosynthetic photon flux density (PPFD).

In addition, the heating and cooling set points were defined according to the thermal needs of each crop, as documented in the literature. By taking all of these factors into account, it is possible to optimize the operation of the farm and ensure that the crops grow as efficiently as possible while also minimizing energy usage and costs.

SCHEDULES

Depending on how the work is divided on a farm, people might have different schedules. When it comes to lighting, changing the timing can make a big difference in how well plants grow. We know that the amount of light plants get affects their growth, and if we control the light, we can control how they grow. Scientists have found that increasing the amount of light in a controlled environment helps plants grow more, and there's a linear relationship between the amount of light they get and how much they grow (e.g., Cockshull et al., 1992). By using this information, we can choose the right type of lights and decide when to turn them on and off to make sure plants get the right amount of light each day. This can help save money on lighting and energy costs.

URBAN FOOD PROFILES

A fundamental preliminary step in the sustainability assessment of urban food production consists of collecting and integrating data on the existing supply chain for the crops to be assessed. The Urban Foodprints method consists of getting snapshots of the existing food system for a given urban area, using metrics related to food demand, resource use intensity of production, and food miles, to estimate the overall environmental impacts caused by the supply of a given crop to the city (Benis et al., 2018). In addition to this environmental sustainability component, HARVEST integrates a cost analysis component. A site-specific input file is therefore needed to run simulations: the Urban Food Profile (UFP), which contains crop-specific data related to the existing supply chain for the assessed crops. Specifically, the UFP file is a JSON file containing the list of simulated vegetables for which the following data inputs must be provided:

FOOD PROFILES INPUTS

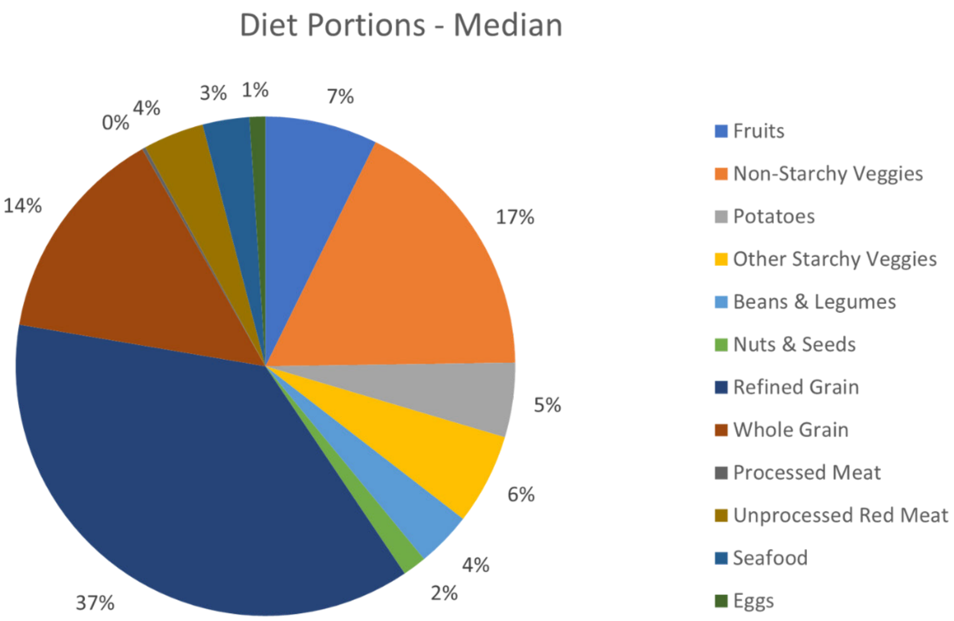
Input name	Type	Unit	Description
Name	(string)	n/a	Crop name
Color	(string)	n/a	Color code of the crop group
TemplateGroupCode	(string)	n/a	R = Red; O = Orange; LG = Light Green; DG = Dark Green
PerCapitaSupply	(double)	kg/cap/year	Yearly per capita food supplied to the population
FoodMiles	(double)	km	Average distance traveled by the crop to reach the city
PerKgEnergyUse	(double)	kWh/kg	Embedded energy use per unit weight of imported produce
EFEnergyOrigin	(double)	kgCO2eq/kWh	Emission factor of energy at origin of produce
WaterUseImported	(double)	L/kg	Embedded water use per unit weight of imported produce
EFWaterOrigin	(double)	kgCO2eq/L	Emission factor of water at origin of produce
FoodWaste	(double)	n/a	Share of conventional agricultural output that is wasted
AverageRetailPrice	(double)	$/kg	Yearly average selling price of the produce
LightUseEfficiency	(double)	kg/mol/m2	Ratio of gross yield to the absorbed Photosynthetically Active Radiation (PAR)
WaterUseEfficiency	(double)	kg/L	Ratio of biomass produced to the rate of transpiration
OccupancyCoefficient	(double)	n/a	Ratio of area occupied by the plants to the total floor area of the farm
RootDepth	(double)	m	Maximum depth of the roots
ShootHeight	(double)	m	Maximum height of the plant before harvest
TrayInterval	(double)	n/a	Interval to keep plant canopies at optimal distance from lighting fixtures
HarvestIndex	(double)	n/a	Ratio of harvested edible yield to total gross yield
CropLosses	(double)	n/a	Share of yield lost at farm gate
EFWater	(double)	kgCO2eq/m3	Emission factor of water
WaterRate	(double)	$/m3	Water rate in the city

SIMULATION OUTPUTS

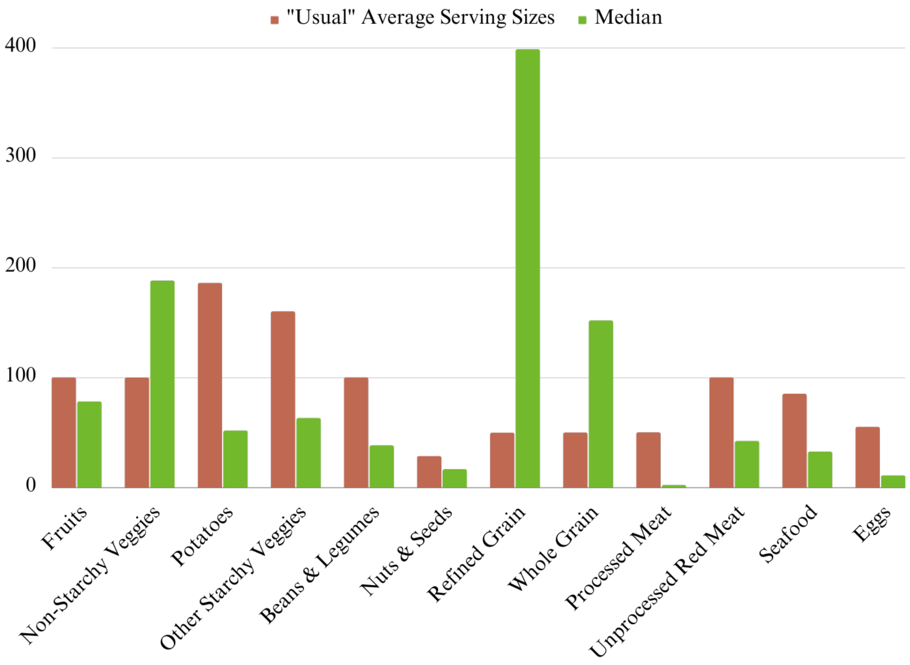
Site metrics provide an overview on (1) local food consumption; (2) food expenditure; and (3) farming area needed for 100% self-sufficiency.

DIETARY DATA

In Tanzania, dietary data has shown that the country faces a significant challenge in meeting the food needs of its population, particularly in terms of providing a diverse and nutrient-dense diet. According to the 2018 Tanzania National Nutrition Survey, only 10% of Tanzanian households consume the recommended minimum dietary diversity, which includes foods from at least five different food groups. This is a major concern, as a lack of dietary diversity can lead to micronutrient deficiencies and other health issues.



Source: Figure based on Global Dietary Database data



Source: Figure based on Global Dietary Database data

The Tanzanian diet relies heavily on starchy staples. The most commonly consumed refined grains in Tanzania are maize (corn) flour, rice, and wheat flour. Other refined grains that are consumed in Tanzania include sorghum flour, cassava flour, and millet flour. Maize is a major staple food throughout mainland Tanzania, providing over 40 percent of household calories. Tanzania faces challenges in meeting the demand for staple foods such as maize and rice, which are critical components of the country's diet. The production of these crops has been hampered by a range of factors, including climate change, pests, and diseases, and low levels of agricultural productivity.

According to the Tanzania National Bureau of Statistics, Tanzania imported 7.03 trillion Tanzanian shillings worth of agricultural products in 2020, which is equivalent to approximately 3.1 billion US dollars. This represents an increase of 1.9% compared to the previous year.

Among the top agricultural products that Tanzania imported in 2020 were rice, wheat, sugar, maize, and palm oil. These products were imported mainly from countries such as India, China, Brazil, and the United Arab Emirates.

The following table provides a comprehensive breakdown of crop production in Tanzania, highlighting the loss of crops, the supply per capita, and the gross value of the products. This also includes the crops that are produced for export. However, in the context of supply only that which is consumed locally is considered.

Subsequently, the next table provides a detailed analysis of the quantity of crop imports, as well as the country or countries from which they are sourced.

With this information at hand, I was able to collect and analyze data on various crops, categorizing them based on their temperature requirements as HARVEST classifies them. This allowed me to determine the average distance that different crop groups travel and to estimate the production and import costs accordingly.

Item	Production (1000 tonnes)	Loss (1000 tonnes)	Supply (kg/ capita/yr)	Gross Product Value (1000 $USD)
Wheat and products	63.388	15	17.22	15012
Rice and products	3474.766	53	48.24	1358875
Barley and products	20.019	1	0	
Maize and products	63.388	697	55.87	1134538
Millet and products	3474.766	48	2.77	115826
Sorghum and products	20.019	90	5.04	158986
Cassava and products	63.388	569	91.69	1189012
Potatoes and products	3474.766	76	11.82	253625
Sweet potatoes	20.019	295	53.81	810500
Sugar cane	63.388	51	8.58	161111
Beans	3474.766	56	16.49	912774
Peas	20.019	2	0.27	10440
Groundnuts	63.388	51	6.08	492162
Coconuts - Incl Copra	3474.766	32	4.46	68534
Tomatoes and products	20.019	53	10.33	219708
Onions	63.388	23	4.24	82860
Oranges, Mandarines	3474.766	45	8.42	176635
Lemons, Limes and products	20.019	1	0.15	5790
Bananas	63.388	733	40.15	1211489
Pineapples and products	3474.766	38	7.17	149385

Annual Production Quantity of crops (2019) Source: FAOSTAT

Country of Import	Item	Value (tonnes)
Italy	Apples	21
Mozambique	Apples	0
South Africa	Apples	2092
United Arab Emirates	Apples	0
Zambia	Apples	311
Burundi	Bananas	567
Mozambique	Bananas	0
Belgium	Beans, dry	0
Burundi	Beans, dry	15
India	Beans, dry	27
Italy	Beans, dry	4
Malawi	Beans, dry	20
Netherlands	Beans, dry	15
Poland	Beans, dry	1
Türkiye	Beans, dry	1
Uganda	Beans, dry	4100
United Arab Emirates	Beans, dry	5
United States of America	Beans, dry	1060
Burundi	Beans, green	10
Kenya	Beans, green	508
Uganda	Beans, green	2500
United Arab Emirates	Beans, green	6
India	Coconuts	0

Country of Import	Item	Value (tonnes)
Nigeria	Coconuts	
United Arab Emirates	Coconuts	0
Indonesia	Groundnuts, prepared	0
South Africa	Groundnuts, prepared	1
United Arab Emirates	Groundnuts, prepared	19
Malawi	Groundnuts, shelled	18586
Zambia	Groundnuts, shelled	30
Kenya	Lemons and limes	200
South Africa	Lemons and limes	14
Argentina	Maize	595
Bulgaria	Maize	2010
India	Maize	235
Kenya	Maize	430
South Africa	Maize	60082
Thailand	Maize	0
Uganda	Maize	38683
United Arab Emirates	Maize	519
United States of America	Maize	26
Zambia	Maize	10262
India	Millet	1
Malawi	Millet	1
Burundi	Onions, dry	4
India	Onions, dry	58

Country of Import	Item	Value (tonnes)
Malawi	Onions, dry	78
South Africa	Onions, dry	28
United Arab Emirates	Onions, dry	0
Egypt	Oranges	41
Mozambique	Oranges	2
South Africa	Oranges	45
India	Peas, dry	0
Kenya	Peas, dry	2506
South Africa	Peas, dry	0
United Arab Emirates	Peas, dry	54
United States of America	Peas, dry	6498
Kenya	Peas, green	1360
Malaysia	Peas, green	26
United Arab Emirates	Peas, green	5
Burundi	Pineapples	1
United Arab Emirates	Pineapples	0
Netherlands	Potatoes	79
South Africa	Potatoes	12
India	Rice, broken	132
Pakistan	Rice, broken	685
United Arab Emirates	Rice, broken	9
Myanmar	Rice, husked	3040
United Arab Emirates	Rice, husked	1
China, mainland	Rice, milled	260
Denmark	Rice, milled	0
India	Rice, milled	7496
Italy	Rice, milled	0
Pakistan	Rice, milled	145759
South Africa	Rice, milled	0
Spain	Rice, milled	0
Thailand	Rice, milled	12956
United Arab Emirates	Rice, milled	227
Viet Nam	Rice, milled	20434
Burundi	Sorghum	56
India	Sorghum	3
Uganda	Sorghum	8700
Burundi	Sweet potatoes	0
South Africa	Sweet potatoes	1
Burundi	Tomatoes	0
Mozambique	Tomatoes	0
South Africa	Tomatoes	5
Australia	Wheat	1005
Canada	Wheat	48699
Germany	Wheat	91137
India	Wheat	13
Latvia	Wheat	38400

Country of Import	Item	Value (tonnes)
Poland	Wheat	35000
Russian Federation	Wheat	516097
United States of America	Wheat	102735

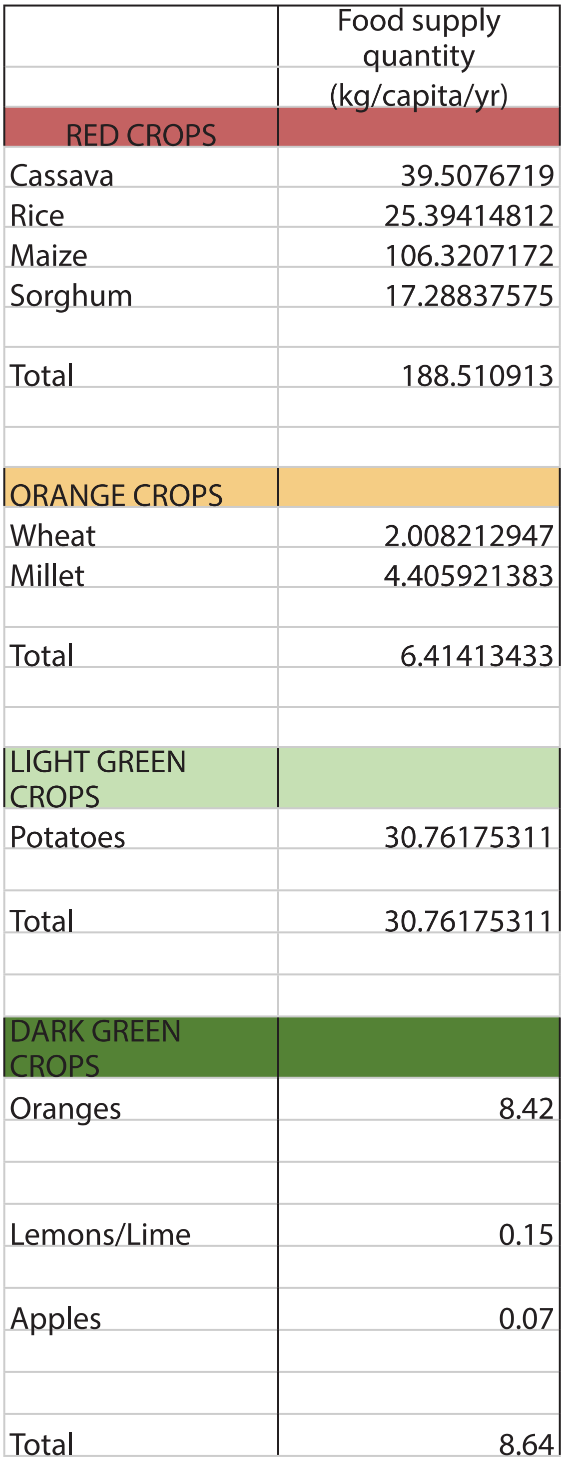
Annual Import Quantity of crops (2019) Source: FAOSTAT

	Food supply quantity (kg/capita/yr)	Partner Countries	Quantity (kg)	Distance (km)	Losses (kg)	% Loss	Gross Value ($)	Average value ($/kg)
RED CROPS								
Cassava	91.69				569000000	10.69854857	1189012000	0.2235624364
Sweet Potato	53.81	South Africa	1000	4000	295000000	9.451344487	810500000	0.259671685
Sugarcane	8.58				51000000	10.24748891	161111000	0.3237221934
Groundnuts	6.08	South Africa	1000	4000	51000000	14.46109455	492162000	1.39552965
		United Arab Emirates	19000	9127				
Coconut	4.46				32000000	12.36943004	68534000	0.2649145369
Rice	48.24	India	132000	5301	53000000	1.894101026	1358875000	0.4856314211
		Pakistan	685000	5231				
		United Arab Emirates	9000	9127				
		Myanmar	3040000	6789				
		United Arab Emirates	1000	9127				
Maize	55.87	Argentina	595000	10634	697000000	21.5074378	1134538000	0.3500861617
		Bulgaria	2010000	8345				
		India	235000	5301				
		Kenya	430000	1070				
		South Africa	60082000	4000				
		Uganda	38683000	1590				
		United Arab Emirates	519000	9127				
		United States of America	26000	14400				
		Zambia	10262000	1904				
Sorghum	5.04	Burundi	56000	1162	90000000	30.78552342	158986000	0.5438296917
		India	3000	5301				
		Uganda	8700000	1590				
Total	273.77			5856.3		13.9268711		0.4808684721

	Food supply quantity (kg/capita/yr)	Partner Countries	Quantity (kg)	Distance (km)	Losses (kg)	% Loss	Gross Value ($)	Average value ($/kg)
ORANGE CROPS								
Wheat	17.22	Australia	1005000	10135	15000000	1.50173285	15012000	0.01502934236
		Canada	48699000	13744				
		Germany	91137000	10180				
		India	13000	5301				
		Latvia	38400000	10781				
		Poland	35000000	10054				
		Russian Federation	516097000	9442				
		United States of America	102735000	14400				
Beans	16.49	Burundi	15000	1162	56000000	5.854663519	914485000	0.9560717801
		India	27000	5301				
		Italy	4000	9900				
		Malawi	20000	1438				
		Netherlands	15000	10612				
		Poland	1000	10054				
		Türkiye	1000	7317				
		Uganda	4100000	1590				
		United Arab Emirates	5000	9127				
		United States of America	1060000	14400				
		Burundi	10000	1162				
		Kenya	508000	1070				
		Uganda	2500000	1590				
		United Arab Emirates	6000	9127				
Tomatoes	10.33	South Africa	5000	4000	53000000	8.845250097	219708000	0.3666740015
Pineapple	7.17	Burundi	1000	1162	38000000	9.136902905	149385000	0.3591884843
Millet	2.77	India	1000	5301	48000000	29.87418301	115826000	0.7208764836
		Malawi	1000	1438				
Total	53.98			6914.923077		11.04254648		0.365442078

	Food supply quantity (kg/capita/yr)	Partner Countries	Quantity (kg)	(km)	Losses (kg)	% Loss	Gross Value ($)	Average value ($/kg)
LIGHT GREEN CROPS								
Potatoes	11.82	Netherlands	79000	10612	76000000	11.08487205	253625000	0.3699211413
		South Africa	12000	4000				
Peas	0.27	Kenya	1360000	1070	2000000	12.77029119	16250000	1.03758616
		Malaysia	26000	7069				
		United Arab Emirates	5000	9127				
Onions	4.24	Burundi	4000	1162	23000000	9.351828811	82860000	0.336909798
		India	58000	5301				
		Malawi	78000	1438				
		South Africa	28000	4000				
Bananas	40.15	Burundi	567000	1162	56000000	2.404567906	1211489000	0.52019778
Total	56.48			4494.1		8.902889991		0.5661537197

	Food supply quantity (kg/capita/yr)	Partner Countries	Quantity (kg)	Distance (km)	Losses (kg)	% Loss	Gross Value ($)	Average value ($/kg)
DARK GREEN CROPS								
Oranges	8.42	Egypt	41	3843	45000000	9.213719597	176635000	0.3616589691
		Mozambique	2	1378				
		South Africa	45	4000				
Lemons/ Lime	0.15	Kenya	200	1070	1000000	11.49326208	5790000	0.6654598741
		South Africa	14	4000				
Apples	0.07	Italy	21	9900	0	0		2
		South Africa	2092	4000				
		Zambia	311	1904				
Total	8.64			3761.875		6.902327224		1.009039614



	Food supply quantity (kg/capita/yr)
RED CROPS	
Cassava	39.5076719
Rice	25.39414812
Maize	106.3207172
Sorghum	17.28837575
Total	188.510913
ORANGE CROPS	
Wheat	2.008212947
Millet	4.405921383
Total	6.41413433
LIGHT GREEN CROPS	
Potatoes	30.76175311
Total	30.76175311
DARK GREEN CROPS	
Oranges	8.42
Lemons/Lime	0.15
Apples	0.07
Total	8.64

Food Supply Quantity by Crop Type

ENERGY & CARBON EQUIVALENCE

Tanzania has a large renewable energy potential. Of the country's total generation capacity, close to 55% of Tanzania's electricity comes from renewable energy, with natural gas contributing 892.72MW and Hydroelectric power 573.70MW of the total 1,601.84 megawatts, as of April 2020.

Distribution of electricity generation:

Source	Quantity (MW)	Percentage of Total
Natural Gas	892.72	55.7
Hydroelectricity	573.70	35.8
Heavy fuel oil	88.80	5.5
Biomass	10.50	0.6
Wind	0	0.0
Geothermal	0	0.0
Nuclear	0	0.0
Other	0	0.0
Total	1,601.84	100.00

According to the World Bank, Tanzania's carbon dioxide emissions in 2018 amounted to 11.9 million metric tons, with a per capita emission rate of 0.2 metric tons. Tanzania's carbon dioxide emissions in 2018 were relatively low compared to the emissions of the world's top emitters. Here are some comparisons:

- The United States emitted approximately 5.28 billion metric tons of carbon dioxide in 2018, with a per capita emission rate of 16.6 metric tons.
- China emitted approximately 10.06 billion metric tons of carbon dioxide in 2018, with a per capita emission rate of 7.2 metric tons.
- India emitted approximately 2.46 billion metric tons of carbon dioxide in 2018, with a per capita emission rate of 1.8 metric tons.
- The European Union emitted approximately 3.46 billion metric tons of carbon dioxide in 2018, with a per capita emission rate of 6.6 metric tons.

However, when looking at carbon equivalence, Tanzania's emissions increased to 115.8 million metric tons when accounting for other greenhouse gases such as methane and nitrous oxide. (World Bank, 2021)

UNSTATS Energy Statistics:

Terajoules								
	All Coal	All Oil	Natural Gas	Primary biofuels / Waste	Charcoal	Electricity	Total energy	of which: renewables
2018								
Primary production	16202	..	26049	771460	..	*8957	822668	780417
Imports	..	107317	..	..	..	425	107742	..
Exports	..	..	..	..	..	..	..	..
International marine bunkers	..	-202	..	..	..	..	-202	..
International aviation bunkers	..	-5777	..	..	..	..	-5777	..
Stock changes	..	..	..	..	..	..	..	..
Total energy supply	16202	101338	26049	771460	..	*9382	924431	780417
Statistical Difference	0	-2513	-1	-1	0	-184	-2699	8956
Transfers	..	..	..	..	..	..	..	..
Transformation	..	-15892	-19963	-147433	49088	17669	-116530	-98345
Electricity plants	..	-15892	-19963	-1297	..	17669	-19482	-1297
Charcoal plants	..	..	..	-146136	49088	..	-97048	-97048
Other transformation	..	0	0	0	..	..	0	0
Energy industries own use	..	..	..	..	..	-464	-464	..
Losses	..	..	..	..	..	-3830	-3830	..
Final consumption	16202	87960	6087	624028	49088	22939	806304	673116
Final energy consumption	16202	85588	6087	624028	49088	22939	803933	673116
Manufacturing, const., mining	16202	687	6087	58181	..	6188	87345	58181
Transport	..	77464	..	..	..	..	77464	..
Road	..	74509	..	..	..	..	74509	..
Domestic aviation	..	2955	..	..	..	..	2955	..
Domestic navigation	..	..	..	..	..	..	..	..
Other transport	..	..	..	..	..	..	..	..
Other	..	7438	..	565847	49088	16751	639124	614935
Agriculture, forestry, fishing	..	989	..	47302	..	583	48874	47302
Commerce and public services	..	..	..	..	..	5875	5875	..
Households	..	6449	..	499442	49088	9781	564760	548530
Other consumers	..	..	..	19103	..	511	19614	19103
Non-energy use	..	2372	..	..	..	..	2372	..

2019								
Primary production	18373	..	34258	772493	..	9241	834365	781734
Imports	..	104895	..	..	..	408	105303	..
Exports	..	..	..	..	..	..	..	..
International marine bunkers	..	-203	..	..	..	..	-203	..
International aviation bunkers	..	-6147	..	..	..	..	-6147	..
Stock changes	..	..	..	..	..	..	..	..
Total energy supply	18373	98545	34258	772493	..	9648	933318	781734
Statistical Difference	0	0	-1486	0	0	-38	-1523	9241
Transfers	..	..	..	..	..	..	..	..
Transformation	..	-19620	-29558	-147432	48989	19073	-128548	-98444
Electricity plants	..	-19620	-29558	-1296	..	19073	-31400	-1296
Charcoal plants	..	..	..	-146136	48989	..	-97147	-97147
Other transformation	..	0	0	0	..	..	0	0
Energy industries own use	..	..	..	..	..	-538	-538	..
Losses	..	..	..	..	..	-4183	-4183	..
Final consumption	18373	78926	6186	625061	48989	24038	801572	674049
Final energy consumption	18373	76436	6186	625061	48989	24038	799082	674049
Manufacturing, const., mining	18373	731	6186	59200	..	6068	90559	59200
Transport	..	67919	..	..	..	..	67919	..
Road	..	66866	..	..	..	..	66866	..
Domestic aviation	..	1053	..	..	..	..	1053	..
Domestic navigation	..	..	..	..	..	..	..	..
Other transport	..	..	..	..	..	..	..	..
Other	..	7785	..	565860	48989	17970	640604	614849
Agriculture, forestry, fishing	..	1034	..	47305	..	511	48850	47305
Commerce and public services	..	..	..	..	..	6569	6569	..
Households	..	6751	..	499452	48989	10443	565635	548441
Other consumers	..	..	..	19103	..	447	19550	19103
Non-energy use	..	2490	..	..	..	..	2490	..

Carbon Intensity: Carbon intensity is a measure of the amount of carbon dioxide emissions produced per unit of energy consumed. To calculate the carbon intensity of a particular fuel or energy source, the total amount of carbon dioxide emissions produced during the extraction, processing, transportation, and combustion of that fuel is divided by the total amount of energy generated or consumed.

Carbon Intensity per energy source:

Energy Source	gC02e/kwh
Oil	840
Coal	1001
Gas	486
Nuclear	13
Hydropower	21
Solar	35.5
Wind	13
Other renew.	32.33

Source: National Renewable Energy Laboratory (NREL). "Life Cycle Assessment."

Electricity Mix by Country with comparison to Tanzania (2020):

	Oil (%)	Coal (%)	Gas (%)	Nuclear (%)	Hydropower (%)	Solar (%)	Wind (%)	Other renew. (%)	Carbon Intensity (kgCO2e/kWh)
Egypt	12.64	0	77.37	0	6.49	1.9	1.44	0.16	0.48
India	0	70.56	3.88	3.32	12.18	4.4	4.5	1.16	0.73
Thailand	0.41	19.99	61.61	0	2.65	2.82	1.92	10.6	0.51
Brazil	1.38	3.6	8.62	2.17	64.58	1.25	9.36	9.04	0.11
Spain	6.03	2.39	26.01	22.11	12.1	7.87	20.91	2.58	0.21
US	0.71	19.11	40.23	19.5	7.06	3.27	8.31	1.81	0.40
Nigeria	0	0	81.03	0	18.81	0.08	0	0.08	0.40
Tanzania	5.5	0	55.7	0	35.8	1.2	1.2	0.6	0.33

Carbon Equivalence & Costs in Tanzania:

Source	Carbon Equivalence	Unit	Cost per unit	Unit
Electricity	0.32519598	kgCO2/kWh	0.098	$/kWh
Gas	0.232	kgCO2/kWh	0.05	$/kWh
Oil	0.296	kgCO2/kWh	0.08	$/kWh
Water	2.77	kgCO2/m3	0.43	$/m3

Embodied Energy: Embodied energy refers to the total amount of energy required to produce a material, product, or service throughout its entire life cycle, from extraction and processing of raw materials to manufacturing, transportation, use, and disposal. It is an important metric for measuring the environmental impact of a product or service, as it takes into account the energy required at every stage of its life cycle, rather than just the energy consumed during use.

By collecting and analyzing data on crop production, food supply, embodied energy, labor, and crop productivity, as required by HARVEST, I conducted a sustainability assessment of high-yield urban agriculture. This involved collecting and integrating data on the existing supply chain to establish a baseline scenario for the environmental performance analysis. The tables below present the collected data grouped by crop type, as highlighted in the urban food profile section of HARVEST's process.

DAR ES SALAAM FOOD PROFILES:

Red Crops:

CURRENT SUPPLY CHAIN		
	Value	Units
Per capita supply	273.77	kg/cap/year
Food miles	5856.3	km
Embodied energy	0.003282846	kWh/kg
Embodied water	0.107085515	L/kg
Food waste	13.9268711	%
Average retail price	0.480868472	$/kg
URBAN FARMING		
Labor	1500	$/year
Water rate	0.00043	$/L
EMISSION FACTORS		
Embodied energy - Emission factor	0.000397126	kgCO2eq/kWh
Embodied water - Emission factor	0.00003191148347	kgCO2eq/kWh
Water - Emission Factor	0.000298	kgCO2eq/L
CROP PRODUCTIVITY		
Occupancy coefficient	0.42	m
Root depth	0.3	kg/cap/year
Shoot height	0.6	m
Tray interval	1.5	index
Light Use Efficiency (LUE)	0.0068	kg/mol/m2
Water Use Efficiency (WUE)	0.063	kg/L/m2
Harvest index	0.33	index
Crop losses	0.05	index

Orange Crops:

CURRENT SUPPLY CHAIN		
	Value	Units
Per capita supply	53.98	kg/cap/year
Food miles	6914.923	km
Embodied energy	0.003282846	kWh/kg
Embodied water	0.107085515	L/kg
Food waste	11.04254648	%
Average retail price	0.365442078	$/kg
URBAN FARMING		
Labor	1500	$/year
Water rate	0.00043	$/L
EMISSION FACTORS		
Embodied energy - Emission factor	0.000397126	kgCO2eq/kWh
Embodied water - Emission factor	3.19E-05	kgCO2eq/kWh
Water - Emission Factor	0.000298	kgCO2eq/L
CROP PRODUCTIVITY		
Occupancy coefficient	0.42	m
Root depth	0.3	kg/cap/year
Shoot height	1.5	m
Tray interval	1.5	index
Light Use Efficiency (LUE)	0.01465	kg/mol/m2
Water Use Efficiency (WUE)	0.0796	kg/L/m2
Harvest index	0.33	index
Crop losses	0.05	index

Light Green Crops:

CURRENT SUPPLY CHAIN		
	Value	Units
Per capita supply	56.48	kg/cap/year
Food miles	4494.1	km
Embodied energy	0.003282846	kWh/kg
Embodied water	0.107085515	L/kg
Food waste	8.902889991	%
Average retail price	0.56615372	$/kg
URBAN FARMING		
Labor	1500	$/year
Water rate	0.00043	$/L
EMISSION FACTORS		
Embodied energy - Emission factor	0.000397126	kgCO2eq/kWh
Embodied water - Emission factor	3.19E-05	kgCO2eq/kWh
Water - Emission Factor	0.000298	kgCO2eq/L
CROP PRODUCTIVITY		
Occupancy coefficient	0.42	m
Root depth	0.1	kg/cap/year
Shoot height	0.3	m
Tray interval	1.5	index
Light Use Efficiency (LUE)	0.0119	kg/mol/m2
Water Use Efficiency (WUE)	0.0305	kg/L/m2
Harvest index	0.67	index
Crop losses	0.05	index

Dark Green Crops:

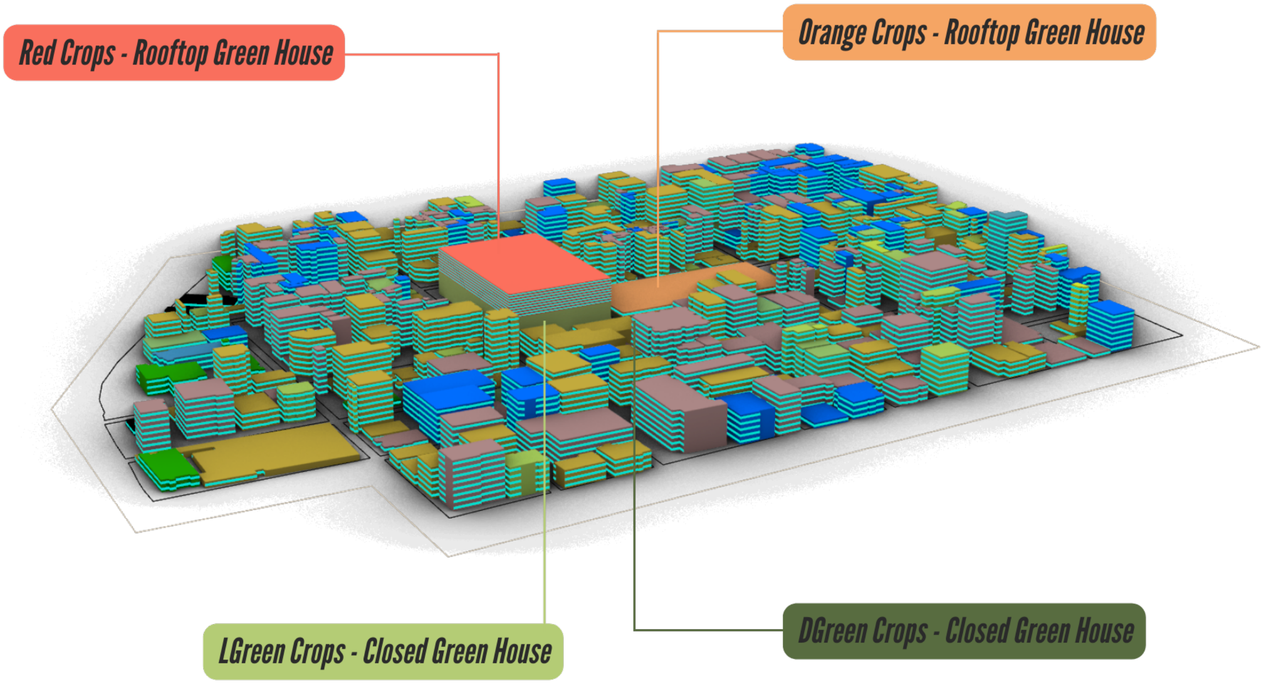
CURRENT SUPPLY CHAIN		
	Value	Units
Per capita supply	8.64	kg/cap/year
Food miles	3761.875	km
Embodied energy	0.003282846	kWh/kg
Embodied water	0.107085515	L/kg
Food waste	6.902327224	%
Average retail price	1.009039614	$/kg
URBAN FARMING		
Labor	1500	$/year
Water rate	0.00043	$/L
EMISSION FACTORS		
Embodied energy - Emission factor	0.000397126	kgCO2eq/kWh
Embodied water - Emission factor	3.19E-05	kgCO2eq/kWh
Water - Emission Factor	0.000298	kgCO2eq/L
CROP PRODUCTIVITY		
Occupancy coefficient	0.42	m
Root depth	0.6	kg/cap/year
Shoot height	0.5	m
Tray interval	1.5	index
Light Use Efficiency (LUE)	0.01048	kg/mol/m2
Water Use Efficiency (WUE)	0.0459	kg/L/m2
Harvest index	0.6	index
Crop losses	0.05	index

URBAN INTEGRATION

The first step in the design process involves importing an EnergyPlus weather file (EPW format) containing the annual climate data of the project location. This data is crucial to accurately simulate the thermal behavior of the building and its surrounding environment. The file is imported from the EnergyPlus weather database, which provides detailed weather data for locations around the world. In addition to the weather file, the 3D model of the urban area is also imported into the design software. This model can be obtained from a Geographic Information System (GIS) or Light Detection and Ranging (LiDAR) data, or it can be manually generated within the Computer-Aided Design (CAD) software. The 3D model is used to visualize the project site and analyze the surrounding context, such as the orientation of the building, the shape of the site, and the presence of neighboring buildings and natural features.

Due to the lack of available GIS data on the Kariakoo neighborhood, I resorted to a combination of OpenStreetMaps, CADMapper, and manual data collection to create a neighborhood model of Kariakoo through a manual building process.

By combining the imported weather file and the 3D model of the urban area, I was able to simulate the thermal behavior of the building and its surrounding environment. This allows for the optimization of the building's energy performance and the reduction of its environmental impact. Additionally, the 3D model was a valuable tool for visualizing the project site and analyzing its context, which helped inform various placement & design decisions.



The second step involves the selection of the geometry and crop species to be grown, which are used as inputs for subsequent steps. The farm is represented as a basic box located at a specific urban site, such as a rooftop or a building floor, and the farm builder, a function within the HARVEST plugin,then decomposes the box into various components, including the footprint and envelope. The window-to-wall ratio (WWR) of the envelope can be modified to suit the chosen farm type. For my particular case, since I was working in a tropical climate I chose a 30% WWR to minimize heat gain and reduce the energy consumption for cooling while also assuming that shading devices to mitigate heat gain while allowing more natural light into the building would be used.

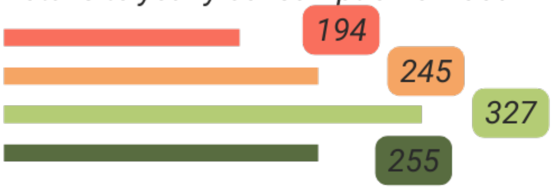
The farm builder assigns the structural characteristics and construction materials for the chosen farm type, such as greenhouses or indoor farms, which are then used in the thermal simulation in step 3. For instance, greenhouses can be built using common materials, and indoor farms use envelope materials that match the host building. The materials' properties, such as thermal conductivity and light transmissivity, are incorporated into the material selection.

For the next few steps, I used the default thermal, lighting, and plant growth models that were incorporated in the software. This then led to simulation results in three categories: (1) yearly food yield per square meter; (2) monthly water use per square meter; and (3) monthly energy use per square meter. These simulations were conducted in iterations to enhance the results based on the specific project-related performance criteria.

RESULTS & DISCUSSION

Food Consumption

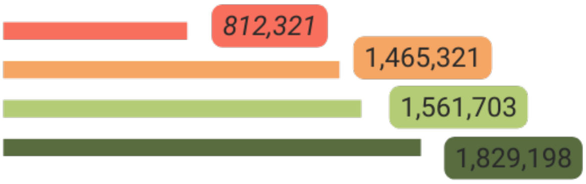
Total site yearly consumption of food



1022 tons/year

Food Expenditure

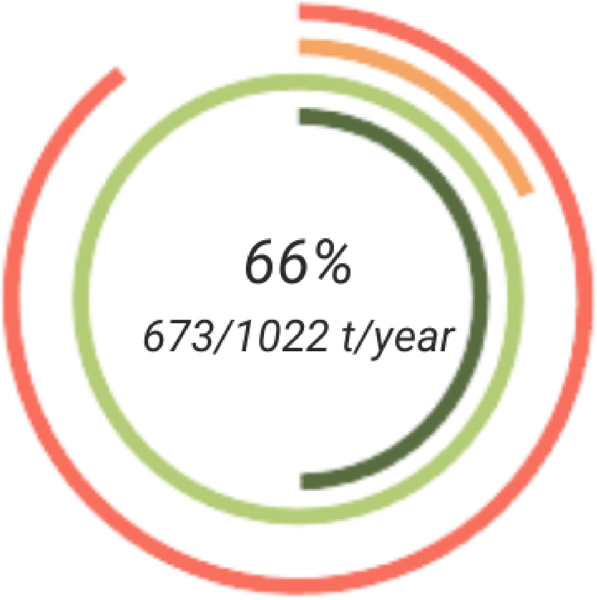
Yearly expenditure of consumers to purchase food



$5,669,000/year

Local Food Production

Ratio of total site production to total site yearly demand for vegetables.



**This has been simulated specifically for the Kariakoo Neighborhood not Dar es Salaam city*

According to the 2012 Tanzania National Census, the population of Kariakoo ward was estimated to be approximately 13,780 individuals. This number, while seemingly modest in comparison to the larger population of Dar es Salaam, actually accounts for roughly 0.32% of the entire population of the city. It is worth noting that this data is specific to the year 2012, and it is possible that the population of Kariakoo ward may have changed since then. Just to provide some perspective there was roughly about a 4% increase in the poulation of Kariakoo between 2002 - 2012 and it does not take into account the visitors. It only considers residents. According to Kariakoo Market Corporation data approximately 200,000 people visit the market daily.

For an ideal scenario I chose to model a situation where 200,000 people were consumers and the diet was modeled to meet nutrional standards (versus the current one). I chose to use current market prices for the food as my base so I could compare demand met to traditional agriculture expenditure.

According to a report by the Tanzania Horticultural Association in 2018, Dar es Salaam's food demand was projected to increase to 2.3 million tons by 2030, while only 25% of the food consumed in the city was produced locally. This indicates a significant gap between demand and local supply.

According to the projected expenditure the yearly per capita cost to purchase food is roughly $28. Compared to traditional agriculture produced food consumption expenditure in 2012 was an average of $39. (Mason-D'Croz et al., 2015)

LIMITATIONS

Due to the lack of specific data on carbon emissions, crop production, and food demand and supply in Dar es Salaam, sourcing accurate information for my project has been a challenge. Unfortunately, there are currently no GIS models or existing research that I could use as a reference. Instead, I have had to rely on data gathered from UN organizations and the National Bureau of Statistics, which I then had to manually input and simulate in the program.

This has limited my ability to experiment with different scenarios, crop placements, and energy sources due to the short time frame and the need to learn a new program. Despite these limitations, I have made the most of the available data to create a simulation that can provide insights into potential solutions for food production and energy use in the city.

NEXT STEPS

As I move forward with my project, there are several crucial next steps that I must undertake. One of these is to finalize the floor plans for the production and retail/distribution spaces of my urban agriculture venture. To achieve this, I recognize the need to run several scenario types, incorporating different variables and factors, and projecting outcomes for each. This approach will help me to identify the most effective and efficient design for my urban farm that will maximize productivity, minimize costs, and optimize the use of space.

To arrive at the best possible projections for my farm's design, I will need to consider several factors. These include the types of crops to be grown, the optimal cultivation techniques, the projected yield, and the market demand for each product. Once I have gathered and analyzed all of this data, I can then begin to finalize my floor plans and design the production and retail/distribution spaces for my urban farm. These spaces will need to be optimized for maximum efficiency and functionality, while also ensuring that they are aesthetically pleasing and inviting to customers.

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