ADDIS ABABA UNIVERSITY

ETHIOPIAN INSTITUTE OF ARCHITECTURE, BUILDING CONSTRUCTION AND CITY DEVELOPMENT

REGAINING LOST AGRICULTURAL YIELDS: VERTICAL FAÇADE FARMING ON AYAT 1 CONDOMINIUM BUILDINGS IN ADDIS ABABA, ETHIOPIA.

Endale Amdemariame Yirga

A Thesis Submitted to graduate studies of Ethiopian Institute of Architecture, Building Construction and City Development, Addis Ababa University presented in partial fulfillment of the requirement for the degree of Masters of Science in Urban Design and Development

Addis Ababa University

Addis Ababa, Ethiopia

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This is certifying that the thesis prepared by Endale Amdemariame Yirga, entitled *Regaining Lost Agricultural yields: Vertical façade Farming on Ayat 1 Condominium Buildings in Addis Ababa, Ethiopia*., and submitted to graduate studies of Addis Ababa University in partial fulfillment of the requirement for the degree of Master of Science in Urban Design and Development Compiles with the regulation of the University and meets the accepted standards for originality and quality.

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Declaration

I declare that this thesis entitled “**Regaining Lost Agricultural yields: Vertical façade Farming on Ayat 1 Condominium Buildings in Addis Ababa, Ethiopia.”** Is my work and has not been submitted to any university for a similar purpose. The references used in this thesis are duly recognized by proper citation.

Endale Amdemariame ____________________ June, 2024

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Confirmation

This thesis can be submitted for examination with my approval as a university advisor.

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Tibebu Assefa (PhD)

June, 2024

Abstract

Due to the city's rapid urbanization, agricultural and non-agricultural areas have been transformed into built-up urban areas. The Integrated Housing Development Plan (IHDP) of Addis Ababa is the main sector for the conversion of agricultural land to housing development-built areas without the provision of any option for farming products. This study aims to demonstrate vertical vegetable farming as a means to regain agricultural yields that has been taken over by condominium buildings. The study focused on Addis Ababa in Ayat 1 site 1, 2, and 3 condominium buildings and their resident as a population. A stratified sampling method based on their family size strata was used to find the population's vegetable demand, and 362 families were sampled. Purposive sampling is selected to find the potential surface area of the buildings based on their building typology and orientation. The data was gathered from the residents and farmers by questioner and key informant interview and observation from the existing building. The household's vegetable consumption amount, the buildings' potential surface area, the land's previous productivity, and the vertical farming productivity of the façade were analyzed and described statistically. Based on the literature and resident preference 10 vegetables were selected for the demonstration. The result shows that the total annual vegetable consumption of the residents in the study area is 3,632,473.4kg/year or 1,204,169,438 calories/year. The potential surface area for vegetable façade farming with 6 hours and 4 hours of daylight exposure is 297,270m2 from both, B+G+8 and B+G+10 building typologies. The 31 hectares of the study area land has been producing 46.5 tons of teff, which is 155,775,000 kcal/year. Vertical façade vegetable farming can produce 5,333,418.11kg/year or 2,309,169,276.366kcal/year. As a result of the vertical façade vegetable farming, 191.76% of the vegetable consumption of the residents can be fulfilled and 1,482.56% of the lost agricultural land produces can be regained. Using vertical façade farming on the condominium building is the key recommendation for the government, researchers, urban designers, and the community.

Key Words – vertical farming, façade vegetable farming, condominium housing, food security

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Acronyms

ADLI	Agriculture Development led to Industry
CSA	Central Statistics Agency
DLI	Day Light Integral
GF	Green Façade
GW	Green Wall
IHDP	Integrated Housing Development Plan
LW	Living Wall
PAR	photo synthetical Active Radiation
PPFD	Photosynthetic Photon Flux Density
UA	Urban Agriculture
UHI	Urban Heat Island
UN DESA	United Nations Department of Economic and Social Affairs
UN-Habitat	United Nations Habitat
UNPD	United Nations Population Division
WEF	World Economic Forum
WPR	World Population Review

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Urbanization is a major issue in the world. In Ethiopia, urbanization has been increasing rapidly, especially in the last several decades. It is one of the demographic mega-trends that has significantly influenced the physical environment (UN DESA, 2019; UN-Habitat, 2020). In 2018, 55.2% of the global population lived in urban areas. By 2050, cities are projected to house 80% of the world's people, up from 55% today (WEF 2022).

According to the United Nations Population Division (2014), the level of urbanization in Ethiopia riches to 16% in 2007 and grew to 20% in 2017. Since Addis Ababa is the capital city of Ethiopia, the city occupies the highest number of population relative to the other cities in the country. According to the 2007 census, it had a total population of 3,384,569, making it the largest metropolis in the nation by population. However, it is thought that this figure, which understated the population of the city when it was documented, was incorrect. The city has experienced strong annual population development in recent years, and as of 2017, the population is getting closer to 4 million (World Population Review, 2017). Recently, in 2023 Addis Ababa’s population is around 5 million with a growth rate of 4.45, and in 2035 this number will increase to 8.9 million with a growth rate of 3.85 (World Population Review, Addis Ababa Population 2023).

Due to population increase the urban expansion of the city is also increasing. The rapid rise in population in Ethiopia's capital city, Addis Ababa City, led to an urban agglomeration. (Terfa et al. 2019). Addis Ababa City frequently sees the peri-urban expansion of built-up areas into cultivation and grassland areas (Kassa et al. 2015). Addis Ababa has a total area of 527 km2 and a population density of 5,165.1/km2(CSA, 2007). The primary economic activity in Addis Ababa's urban fringe regions is agriculture; however, due to the city's rapid urbanization, agricultural and non-agricultural areas have been transformed into built-up urban areas (Deribew and Dalacho 2019). From 2006 to 2016 the total built portion of Addis Ababa were expanded from 24,942 ha or 48% of the area within the city's boundary to 35,050ha or 67% of the area within city's boundary (Larsen et al. 2019). According to Larsen (2019), in six-surrounding sub-cities of Addis Ababa, 10,115 ha of agricultural and vegetation areas changed in to residential housing, manufacturing and storage, mineral and gravel pits and retail and business.

In Ethiopia the main food source is Agriculture is Agriculture development led to industrialization (ADLI) is the main leading policy in the country. But The peri-urban areas that surround urban areas are considered to be among the geographical areas that are most susceptible to the rapid shifting of a significant quantity of land used for agriculture to urban areas, which causes farmers to lose their means of livelihood. The most fertile land is typically reduced when land is used for other purposes, so the effect on agricultural production and food security is frequently greater than the actual amount of land involved (Weldearegay, et, al,. 2021).

1.2. Statement of Problem

Because of rapid urbanization in Addis Ababa, the urban area coverage of the city is expanding throughout the previous years. Because of the expansion, the agricultural lands are converted into built-up areas. The problem of providing the urban poor with enough food that meets nutritional standards is one of the issues associated with the wave of urbanization in developing countries, including Ethiopia. The food insecurity issue regarding the loss of agricultural land around city of Addis Ababa is getting worse. Since 2005 Addis Ababa government initiated an integrated housing development plan (IHDP). This development plan was to accommodate low-income residents with around 400,000 housing units throughout the consecutive project sessions. The project sites include inner city redevelopment and pre-urban expansion to the peripheries of Addis Ababa.

The condominium housing development covers large concrete built-up areas. The residents of the built area mostly are, low-income and middle-income with high levels of food insecurity. The community in the condominium development sites doesn’t experience any other means of food source. Most peripheral areas’ owners of the land, were farmers who based their lives on traditional agriculture. Traditional agriculture experienced in Ethiopia requires a large area of agricultural land. Also, the trend is dependent on the rainy season, which makes one or two production yields annually. Rather than the seasonal production traditional agriculture takes a high amount of water. Traditional agriculture also requires fertilizers and pesticides that have an impact on the well-being of human health.

Building typologies implemented in condominium housing are similar including their façade treatment. The buildings have maximum blind surface areas. These blind walls don’t serve as a source of food. The climate of Addis Ababa is comfortable for Agriculture. But except for recent urban Agriculture initiatives, the residents of Addis Ababa and the government didn’t take advantage of the building's blind wall and the city’s weather and climate.

1.3. Objectives of the Study

- General objective

To demonstrate the use of vertical façade vegetable farming as a means to regain agricultural yields that has been taken over by condominium buildings.

- Specific objectives:
  - ✓ To Assess the vegetable demands of individual households living in the condominium housing.
  - ✓ To identify a potential surface area of a condominium building for vertical farming.
  - ✓ To Assess the productivity of the land when it was used for agriculture.
  - ✓ To develop compatible vertical farming planting technology.

1.4. Research Questions

How can the lost agricultural yields that has been taken over by condominium buildings be regained through vertical façade farming?

1. What is the vegetable demand of the household in condominium housing?
2. What is the potential surface area of the condominium building for vertical farming?
3. How much was the productivity of the condominium land when it was agricultural land?
4. What type of vegetable planter technology will be compatible for the existing building surface?

1.5. Scope of the Study

The spatial scope of the study was delimited to Addis Ababa city. The Addis Ababa condominium housing sites were the main setting of the study. From all the more than

150 sites of Addis Ababa housing projects, the Ayat 1 project and the three sites, site 1, site 2, and site 3 were selected for the study.

Thematic scope of the study focuses on demonstrate food security through vertical farming on the face of the buildings. There are different methods of food production in urban areas but this study concentrated on building facade food production on the condominium buildings of Addis Ababa.

1.6. Significance of the Study

The study attempts to address the problem of loss of agricultural land produces by condominium buildings based on vegetable demand of the condominium housing residents, potential of the building surface for the production of the vegetable. It can be an input for the city administration to reconsider the policy of the buildings with wide blind walls as a means of food production. It also helps to identify façade food production technics to address food security. It is also eye-opening for the resident to solve their food problem by using the building façade as a means of food source for the community. The study can also encourage researchers, and academicians to conduct more research on the related issues based on the provided knowledge.

1.7. Research Limitations

From 4008 housing units 163 housing units are abandoned. These abandoned housing units are out of the analysis. The study uses weekly bases preference to vegetables consumption amount, so some other vegetables are not included. To measure the potential surface area, only the surface area of the building, orientation of the building, and daylight exposure are used as a variable.

1.8. Organization of the Document

The whole document has five different chapters. The first chapter is the introduction part, which includes the background study, the statement of the problem, the objective, the research question, the scope and limitation, and the significance of the study. The second chapter of the document reviews literature from books, journals, publications, pictures, and images. The third chapter of the document is the research method and materials. This part explains how the study was conducted, the type and source of data, data collection and analysis, and the interpretation method. The fourth chapter is the analysis of the attained data from different source and method based on the objective and research question. The fifth and the final chapter of the document is the summary of the conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1. Theoretical Review

2.1.1. History of Vertical Farming

Arched terraces built one on top of the other, the Hanging Gardens of Babylon were created over 2,500 years ago by King Nebuchadnezzar II and housed a diverse range of trees and flowers, making them possibly the first known example of a "vertical farm." The gardens were probably irrigated by a chain pump, another early technological marvel, since they were at a height of twenty meters. At the base of the garden flowed the Euphrates River, and these pumps might have used a system of buckets and pulleys to move water to a pool at the top. Approximately a millennium ago, the Aztecs used a hydroponic method called "chinampas" to grow crops in marshy areas near lakes. The swampy ground here was not suited for farming, so the Aztecs instead constructed rafts out of reeds, stalks, and roots, covering them with mud and clay from the lake bottom. These rafts were then abandoned in the lakes. Crops were able to grow taller and yet have their roots reach into the water because to the structural support provided by the rafts. It was common practice to connect these rafts to form floating "fields" (NAAS, 2019)

The term "vertical farming" was initially coined by American geologist Gilbert Ellis Bailey in his book of the same name. It's noteworthy to observe that Bailey prioritized "down" farming above "up." Stated differently, he studied a form of subterranean farming where farmers dug deeper with explosives to increase their total cultivable area, allowing crops to be grown over a larger area (Rees 1981). William F. Gericke, an agronomist at the University of California, Berkeley, is credited with developing modern hydroponics. The process of growing plants in sand, gravel, or liquid without soil was initially explained by Gericke in his December 1929 paper "Aquaculture: A Means of Crop Production." This process makes use of extra nutrients (Gericke, W. 2010).

Architect and ecologist Kenneth Yeang created a vision of mixed-use buildings that are harmoniously connected to green spaces, allowing for the indoor gardening of plants. Yeang described this as "vegetated architecture." Unlike many other vertical farming systems, his idea was based on personal and communal use rather than large-scale production and sale (yeang K. 2008) The concept of the modern vertical farm originated with a 2011 presentation by Columbia University environmental health sciences professor Drs. Despommier and Carter. The idea of a contemporary vertical farming tower, or multi-story structure with layers of crops grown on each floor to feed New York's population using only urban rooftop agriculture, was developed by Despommier and his pupils. Ever since Despommier has made a name for himself as the foremost expert and proponent of ecological agriculture. Rather than expanding horizontally on the ground, he described the ideas and practices of modern vertical farming inside buildings and around cities in his 2010 book The Vertical Farm: Feeding the World in the 21st Century (Despommier 2010). Regretfully, not everyone still uses his approach extensively. However, in addition to hydroponic fodder, mushrooms, and poultry, India began growing lettuce, a few leafy vegetables, strawberries, and herbs on a small scale in the 20th century (NAAS, 2019).

2.1.2. Urban Agriculture and Vertical Farming

Urban agriculture includes growing plants and raising livestock as well as turning raw materials into consumable forms and marketing them, whether it is done inside city limits (intra-urban agriculture) or outside of them (peri-urban agriculture) (Chatterjee, Debnath, and Pal 2020). In urban areas like cities and towns, this type of agriculture entails the production, distribution, and processing of food crops as well as other products for the local populace (Michelle Glowa 2019). According to Kalantari et al. (Kalantari et al. 2018), it places a strong emphasis on the economical use of urban resources through closed-loop systems, cyclical processes, and astute integration with existing structures, infrastructure, and open areas.

Urban agriculture, which includes growing crops in urban areas in a variety of ways to increase resilience by supplying locally grown food, diversifying the food supply, and giving residents additional income opportunities, includes vertical farming (Aragon, Stuhlmacher, Smith, Clinton, & Georgescu, 2019). According to an Allegaert study (2020), vertical farms are frequently larger in scale and managed by businesses with multiple employees, in contrast to the majority of urban farming techniques, which include rooftop gardens, community greenhouses, and street landscaping, which are typically small-scale and managed by individuals or small groups. According to Despommier (2013), a well-known proponent of contemporary vertical farming, a vertical farm is any structure taller than one story used for indoor food production.

This definition is extremely broad even as it covers all vertical farms. Vertical farms are essentially towers with several stories that are used to raise crops on a little amount of ground. Referred to as "vertical indoor greenhouses" or "Plant Factories" in this sense, vertical farms are usually low-rise structures with plants placed on stacked growing racks (Wildeman 2020).

Urban agriculture can take many different shapes, including vertical farms, street landscaping, tactical gardens, rooftop and backyard gardens, and vertical greenery systems. Crops are grown vertically in layers utilizing soil, hydroponic, or aeroponic techniques in vertical farming. This novel technique is used in difficult circumstances such as densely populated urban areas and areas with little arable land. Advanced technology, such as automated systems for monitoring and managing variables like illumination, fertilization, and irrigation, are used by vertical farms to provide the best growing conditions for plants (Ghazal, Mansour, and Davidová, 2023).

2.1.3. Vertical Farming and Food Security

Vertical farming, as discussed in various scholarly works, including those by Corvalan et al. (2005) and Healy and Rosenberg (2013), aims to proactively address food security concerns in rapidly urbanizing areas, thereby ensuring the long-term sustainability of our cities. The concept is simple: instead of expanding outward, farming is brought indoors. Scholars such as Despommier (2010, 2013, 2014) have identified three main types of vertical farming approaches.

The first type involves constructing tall buildings with multiple levels of growing beds, often supplemented with artificial lighting. This model has seen implementation worldwide, with urban farms springing up in both new and repurposed structures, including warehouses retrofitted for agricultural use (Despommier, 2014).

The second approach entails utilizing rooftops of various buildings, both old and new, spanning industrial, commercial, residential, and even retail and dining establishments (Despommier, 2014; Touliatos et al., 2016).

The third type represents a more ambitious concept: the construction of multi-story buildings dedicated entirely to farming. While numerous visionary proposals have surfaced in the past decade, none have been realized. However, the success of smaller-scale vertical farming projects and ongoing technological advancements may pave the way for the development of skyscraper farms. It's crucial to acknowledge the interconnection between these three types, as the evolution of smaller projects may contribute to the feasibility and realization of larger-scale vertical farming ventures (Despommier, 2014).

Environmentalists, urban farmers, architects, agronomists, and public health experts have been welcoming this mini-revolution with other professions as they work together to discover a solution for an ultra-urban, food-scarce future. The concept of vertical farming has brought together experts in robotics, hydroponics, aquaponics, and aeroponics to further these fields. The concept of a vertical farm is backed by nonprofit organizations that work to promote environmental consciousness and local economic development. Similarly, this idea has been supported by for-profit companies who aim to meet the need for local produce. To improve local food security, governments have also begun sponsoring similar programs. Countries from Korea, Japan, China, Germany, the United Arab Emirates, China, France, India, Sweden, Singapore, and the United States have gathered to discuss vertical farming. They firmly believe that the concept is necessary for the long-term viability of their own cities (Despomeir, 2014).

2.1.4. Purpose of Vertical Farming

Food security

Food security is a pressing subject that is getting worse. According to demographers, the number of people living in cities will increase dramatically in the ensuing decades. Meanwhile, specialists in the subject of land (including ecologists, geologists, and agronomists) have cautioned about an increasing scarcity of agricultural land (Corvalan et al., 2005; Healy, 2013; Thomaire, 2015). A worldwide famine could result from these causes if food demand increases dramatically faster than supply. UN estimates indicate that there will be more than 9 billion people on the planet by 2050 (UN 2017). The UN estimates that by this time, 80% of people on Earth would reside in cities. Furthermore, it predicts that in order to feed the additional 3 billion people on the earth by 2050, we will need 70% more food (UN, 2017). Farmers predict that when oil prices rise and the availability of water, energy, and agricultural resources declines, food prices will increase even more (Despommier, 2013, 2014, Touliatos et al., 2016). In recent decades, food prices have already increased. Agriculture is still being swept up by the suburban sprawl that is spreading outward. On the other hand, high costs and a lack of usable land have made urban agriculture difficult. We desperately need creative solutions to deal with this massive worldwide issue. (Despommier, 2014, Muller et al., 2017; Touliatos et al., 2016).

The fundamental idea behind vertical farming is to produce more food on a smaller amount of land (Touliatos et al. 2016, Muller et al. 2017). The same logic that we use to cram residences and commercial establishments onto pricey and limited property, such in Manhattan or Hong Kong, may also be applied to farming. Supporters of the vertical farm claim that it would create small, self-sufficient ecosystems for food production and waste management, among other uses. Vertical farming has the ability to boost the economy, lessen pollution, provide new job opportunities, restore ecosystems, and expand access to healthful meals in addition to facilitating efficient and environmentally friendly food production.

In a regulated setting, crops are less vulnerable to dust, pesticides, contaminated water runoff, crop rotation, weather fluctuations, and insect infestation (UN, 2017). Consequently, growing food indoors may offer a healthier environment (Healy 2013). Because indoor farming is year-round and weather-independent, it has the potential to deliver better yields and provide a lifetime of income. Furthermore, indoor farming offers a low-impact method that can significantly reduce travel costs and greenhouse gas emissions by cutting the distances between distant farms and the local market. Additionally, by providing metropolitan regions with the much-needed "green collar" jobs, vertical farming could strengthen regional economies.

Significantly, vertical farms may be able to assist in addressing the problem of scarce farmland (Corvalan et al., 2005; Healy et al., 2013). According to estimates from the UN Food and Agriculture Organization, each person on Earth in 1961 had access to 0.42 hectares (1 acre) of arable land. By 2002, that amount had dropped by more than 50% to 0.23 hectares (0.5 ac) due to urbanization and population growth (Healy et al., 2013). Twenty-five percent of all arable land is badly degraded, according to a 2011 UN assessment of the world's land resources. Furthermore, since 1960, one million American farmers have given up on their farms. The U.S. Department of Agriculture (USDA) estimates that there are 23 million "food deserts" in the country as of 2014; these are metropolitan areas and rural communities that are difficult to reach for healthful, reasonably priced, and fresh food. Dickson Despommier predicts that the current agricultural supply will eventually run out significantly. Put another way, the average person requires 1500 calories a day, so by 2050, the amount of agricultural land currently in use will need to be increased by an area the size of Brazil in order to meet this need (Despommier, 2010).

Climate Change

Climate change is causing the loss of arable land. The significant loss of significant agricultural land brought on by storms, hurricanes, flooding, and drought has hurt the global economy (Despommier, 2010, Muller, et al., 2017, UN, 2017). For instance, a protracted drought in 2011 caused the United States to lose a grain crop valued at $110 billion (Muller et al., 2017, USDA, 2016). Scientists predict that both the rate of climate change and the unfavorable weather it causes will continue to rise. These incidents will desecrate large tracts of agricultural land, rendering them unfit for farming. Through programs like crop insurance against natural catastrophes, governments usually provide substantial support to traditional farming (Thomaier et al., 2015, Padmavathy and Poyyamoli, 2016, Padmavathy, A.; Poyyamoli et al., 2013). Furthermore, the nation's supply of petrol and diesel fuel more than 20% is largely derived from traditional farming, which uses it for agricultural activities like planting, weeding, harvesting, and fertilizer application. As the name implies, food miles are the distances that crops have to travel in order to reach inhabitants in key cities.

From the farm to the table, food frequently travels 1500 miles (Despommier, 2013, Astee et al., 2010). In certain situations, such as cold weather, food miles can rise dramatically when stores, restaurants, and healthcare facilities fly in product from overseas to meet demand. Over 90% of the food in large American cities is usually brought in from outside. A 2008 study from Carnegie Mellon estimated that the annual carbon dioxide emissions from dinner delivery to each household is around 0.4 tons (Blaustein-Rejto, 2011, FOA, 2015). This is especially important because of the increasing distance that urbanization and globalization are creating between farmers and cities. Climate change has unfortunately accelerated due to growing greenhouse gas emissions from agriculture and food transportation.

Urban density

Vertical farming provides advantages over "horizontal" urban farming since it creates space for more urban activities, such as more housing, services, and amenities (Despommier, 2010). Research indicates that longer commutes and a decrease in population density are the outcomes of turning urban territory into farming. If America converted just 7.9% of its massive one billion acres of crop and pastureland to urban farms, metropolitan area densities would be cut in half (Despommier, et al., 2005). Living in a less densely populated place uses more energy and pollutes the air and water more. The National Highway Travel Survey (NHTS) estimates that a 50% reduction in urban density would need households to purchase an additional 100 gallons of petrol annually. The conversion of a very tiny section of agricultural into cities would result in increased gas consumption and the annual production of 1.77 tons of carbon dioxide by each home (Blaustein-Rejto, 2011). Despommier explains the efficient use of space in vertical farms. He claimed that a 30 story (about 100 meter high) skyscraper with a basal area of 2.02 ha (5 acres) could produce an amount of agricultural yield equivalent to 971.2 ha (2400 acres) of conventional horizontal farming. As a result, one high-rise farm could generate the same amount of food as 480 normal horizontal farms (FOA, 2015, Cho, 2011).

Health

Conventional agricultural practices sometimes prioritize profit and economic gain at the expense of the harm they cause to the environment and public health. (2010), (2013), Touliatos et al. (2016), Despommier. These practices routinely create excessive water waste, contaminate the land, and cause erosion. More than half of farms still use raw animal excrement as fertilizer, which can attract flies and contain weed seeds that can infect plants or spread illness, according to the World Health Organization (Al-Kodmany, 2018). As a result, eating this kind of food is bad for people's health.

The misuse of pesticides and herbicides, which leads to contaminated agricultural runoff, would also be reduced if crops were grown indoors (Blaustein-Rejto, 2011). According to Renee Cho (Blaustein-Rejto, 2011), "Pests, pathogens, and weeds have a much harder time infiltrating and destroying crops in a contained environment" When too much fertiliser is washed into water bodies (such as rivers, streams, and oceans), it can break the natural equilibrium and cause eutrophication, or a high concentration of nutrients. For example, eutrophication may accelerate the growth of algae. Bacteria consume dead algae when it dies, creating oxygen-free aquatic zones (Despommier, 2013). As of 2008, there were 405 dead zones on Earth, according to (Blaustein-Rejto, 2011).

Furthermore, by providing precise irrigation and effective scheduling, indoor vertical farming uses cutting-edge growth techniques that consume a little amount of water—roughly one-tenth of what is used in traditional farming (Blaustein-Rejto, 2011, Wood, 2011). Given that as the population of cities increases, so will the needs for water, this might have a major mitigating effect. Over two-thirds of the freshwater on Earth is used for agricultural purposes, and as metropolitan areas grow and demand more water, farmers are losing their supply of crop water. Warmer temperatures brought on by climate change and an increase in droughts mean that the water situation will probably get worse (Blaustein-Rejto, 2011)

The ecosystem

Natural areas have been invaded by traditional agriculture since ancient times. Dickson Despommier claims that farming is the most destructive activity on the planet (Despommier, 2010). More ecological processes have been disturbed by it than by anything else. roughly the past 50 years, agricultural encroachment has severely damaged the Brazilian rainforest, resulting in the removal of roughly 1,812,992 km2 (700,000 mi2) of hardwood forest for farming (Despommier, 2010).

Despommier claims that the deterioration of these ancient ecosystems is hastening the process of climate change. The impact of agriculture on the planet's ecosystems can be reduced by indoor vertical farming through the restoration of biodiversity and the mitigation of the negative consequences of climate change. If cities used vertical farms to produce even 10% of the ground area they consume, they might be able to reduce their CO_2 emissions sufficiently to lead to improved technological developments for the long-term betterment of the biosphere. Wild fish populations may increase and river and coastal water quality may be enhanced by lowering fertilizer discharge. According to Wood et al. (Wood, et.al, 2001), the greatest justification for considering converting the majority of food production to vertical farming is the promise of restoring the services and activities [of ecosystems].

Ecosystem

Supporters of the vertical farm also assert that the cost of food will be reasonable. The gap is shrinking quickly as a result of the rising costs of traditional farming. For example, if vertical farms were placed strategically in metropolitan areas, it might sell produce directly to consumers. By doing away with the intermediary, which can account for as much as 60% of costs, shipping costs would be reduced (Al-Kodmany, 2018). Vertical farms also use intensive farming practices and advanced farming technology to significantly increase output. Researchers have been able to maximize indoor farming by calibrating, adjusting, and changing a number of variables, including as light intensity, light color, space temperature, crop and root, CO_2 levels, soil, water, and air humidity (Al-Kodmany, 2018, Harris, 1992, Munoz, and Joseph, 2010). Furthermore, vertical farming presents an opportunity to strengthen the local economy. Abandoned buildings can be converted into vertical farms to provide people with healthful food in metropolitan locations when fresh produce is scarce. Furthermore, farming indoors in a modern setting can be fun. This has drawn a younger, tech-savvy generation to the discipline, creating a new breed of farmers. Furthermore, vertical farming encourages the development of innovative agricultural technologies. Ultimately, farming could help to restore the relationship between city dwellers and the natural world (Al-Kodmany 2018).

2.1.5. Vertical Greenery System

Other names for Vertical Greening Systems (VGS) include bio walls, vertical gardens, and green-wall technology. They are made up of vertical devices that disperse plants that could be affixed to an internal wall or the facade of a building. There are several green-wall typologies that cater to varying degrees of intricacy, spanning from the most basic arrangement to the most intricate and advanced design.

Another material that can be used to improve the functionality of facades or structures is vegetation. A "vertical garden," or vertical green, is a vertical surface that is made greener by plants that are either anchored in the ground, incorporated into the wall material, or fastened to the facade in the form of modular panels (Perini et al., 2014). Vertical greening systems, often known as green walls, are constructions that allow plants to grow vertically on a wall surface, negating the need for a large amount of ground-level area. Typically, VGSs cover a section of a building's face with growth media and supporting structures for the plants. Any type of vegetated wall surface is referred to as a "vertical greening system" in this sense.

2.1.6. Method and Classification of Vertical Greenery System (VGS)

Vertical greenery systems (VGS) are categorized into two main groups: living walls (LWS) and green facades (GFS), which range from simpler arrangements to more complex and contemporary designs. The classification is determined by the type of vegetation and construction method used. These systems can help lower surface temperatures, improve air quality, and reduce heat flux (Morsi and Elian, 2021). The selection of growth substrates or construction systems is influenced by the characteristics and growth requirements of the plants (Virtudes and Manso, 2016; Pérez et al., 2011; Manso and Castro-Gomes, 2015a).

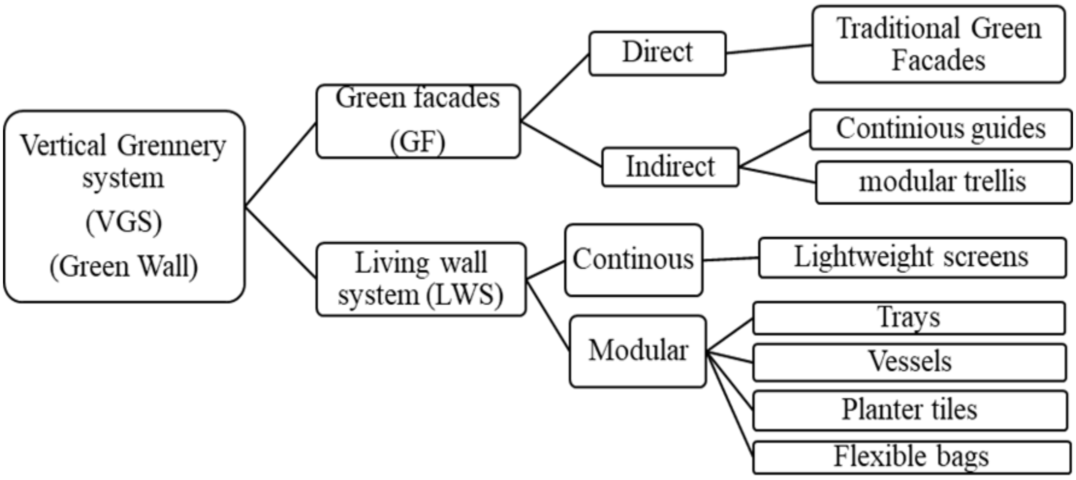


Figure 2. 1 classification of green walls, according to their construction characteristics (source: Manso and Castro-Gomes, 2015)

Green Façade (GF)

The use of hanging or climbing evergreen or deciduous plants along the wall is the foundation of green facades (GFS). These plants can either grow downward on the wall or upwards along the vertical surface, as shown in several well-known cases, when they are connected at specific heights (Morsi and Elian, 2021; Manso and Castro-Gomes, 2015a). The plants used in green facades are usually rooted in the ground, and it takes a while for them to cover the entire surface (Tarboush, 2020).

Direct system green façade

A cheap way to green a building's facade is by using climbing plants that are typically placed in the ground at the base of the structure (Rakhshandehroo, Mohd Yusof, and Deghati Najd, 2015). Without the need for further structural systems, direct green facades attach plants directly to the wall (Manso and Castro-Gomes, 2015a; Morsi and Elian, 2021). The plant roots are either in the ground or in planters (El Menshawy, Mohamed, and Fathy, 2022). Sucker root structures on self-clinging plants, which are widely used, allow them to stick directly to walls and cover the whole vertical surface (Rakhshandehroo, Mohd Yusof, and Deghati Najd, 2015).

Indirect system of green façade

Plants are supported by wires or meshes to keep them away from surfaces such as building walls. According to Rahkshandehroo, Mohd Yusof, and Deghati Najd (2015), planter boxes at different heights on the facade can be incorporated into the indirect greening strategy. An element common to contemporary green façade designs is indirect green facades, which include a framework for vegetation to support and form a double facade that separates the building wall from the greenery (Tarboush, 2020; Morsi and Elian, 2021).

Modular and continuous methods are the two methodologies that make up indirect green systems. Continuous guides direct plant growth over the whole surface by using a single support structure. Comparably, assembling several modules along the surface creates the modular trellises found in green facades. Modular trellises with plant rooting vessels and a specific support structure to guide the growth of vegetation are the major differentiator (Morsi and Elian, 2021; Manso and Castro-Gomes, 2015).

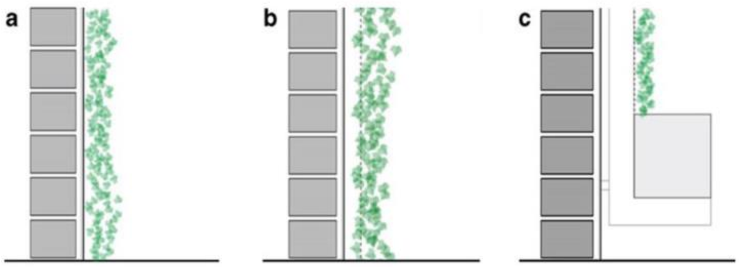


Figure 2. 2. (a) direct system   (b) indirect system   (c) indirect system with planter box (source: Manso and Castro-Gomes, 2015)

Figure 2. 3. Modular trellis panel system, (source: Rakhshandehroo, Mohd Yusof, and Deghati Najd 2015)

Living Wall System

The living walls system is a modern way to clothe building facades. It allows large areas to be covered quickly and encourages steady plant growth along vertical surfaces, which makes it easier to integrate green walls around tall buildings. Living walls are appropriate for a variety of building styles and can support a wide variety of plant species (Tarboush, 2020; Manso and Castro-Gomes, 2015a). Utilizing hydroponic techniques with balanced nutrient solutions, these walls are made of modular panels that are each outfitted with its own soil or alternative growing media including foam, felt, perlite, and mineral wool to suit the hydration and nutritional needs of the plants

(Perini et al., 2011). To support a diverse range of plants and provide consistent surface growth, cutting-edge technologies and materials are needed (Hefnawy, 2022).

Continues system

Two layers of synthetic fabric with pockets filled with plants and growing medium make up this arrangement. To protect the structure from excessive moisture, a waterproof membrane is placed between the fabric walls and the facade, supporting the walls. Typically, vegetated mats operate as hydroponic systems, supplying water and nutrients to plant roots via an irrigation system located at the top of the wall. Comparably, a hanging pocket living wall has fabric containers in the shape of pockets that are attached to a strong backing layer. These planting medium-filled felt or plastic containers act as the roots of the plants (El Menshawy, Mohamed, and Fathy, 2022). Permeable screens that are lightweight and can hold individual plants are the foundation of Continuous Living Wall Systems (Morsi and Elian, 2021; Manso and Castro-Gomes, 2015).

Modular system

The composition, weight, and structure of modular living walls vary. They are made out of interchangeable modular containers that can be planter tiles, wire cages, framed boxes, solid planter boxes with pre-cut holes, flexible bags, trays, or panels. These containers are sometimes divided into smaller individual compartments and placed either at an angle or perpendicular to the back wall. As an alternative, they could be made out of several vertically stacked horizontal mini-planters or troughs. The growing media needed to maintain the plant material is kept in these containers (Manso and Castro-Gomes, 2015). They usually arrive pre-vegetated, providing an instantaneous aesthetic effect after installation. Using gravity to distribute water and nutrients throughout the growing media, the system requires consistent watering and fertilization at different levels along the wall (El Menshawy, Mohamed, and Fathy, 2022; Morsi and Elian, 2021).

In general, trays are sturdy, connectable containers that can hold the weight of substrate and plants. A variant on the typical plant support, vessels can be fastened vertically to one another or to a vertical structure. Planter tiles, which are used as design components for the exterior or interior cladding of buildings, highlight the unique shape of modular elements. They function as modular cladding with planting gaps, extending beyond merely adding a layer of greenery. Plants can be applied to surfaces with different geometries, such curved or slanted surfaces, thanks to flexible bags made of lightweight materials and a growing media (Manso and Castro-Gomes, 2015).

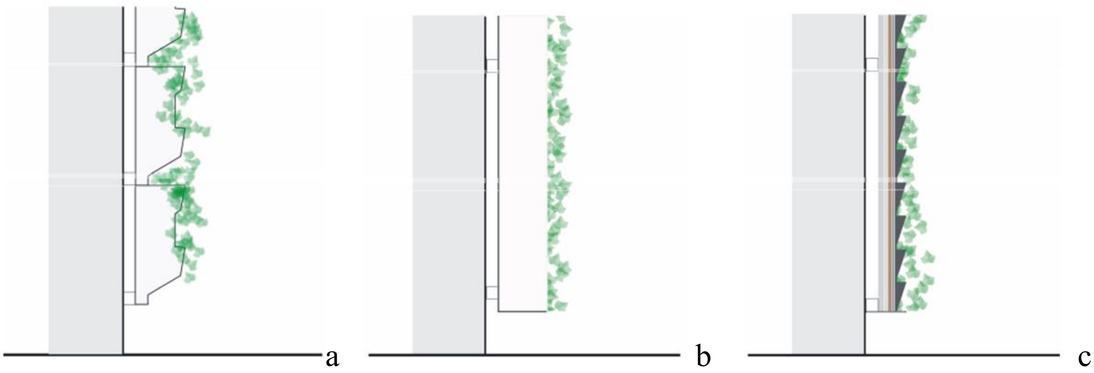


Figure 2. 4 (a) LWS based on planter box (b) LWS based on foam substrate (c) LWS based on the felt layer (source: Manso and Castro-Gomes, 2015)

Hydroponic System

From the Greek terms "hydro," which means water, and "ponos," which means work, the phrase "hydroponics" was born, meaning "working with water." With this type of cultivation, plant roots are grown in nutrient-enriched water as opposed to conventional soil. Hydroponics is a versatile farming method that may be used both indoors and outdoors, including on roofs and green walls. It has several benefits over traditional soil-based growth methods. Because roots in hydroponic systems do not have to go deep into the soil to obtain nutrients, they can grow roots more quickly and in smaller spaces because they have direct access to oxygenated nutrient solutions in their planting containers. As a result, hydroponic crops can be grown almost anywhere, year-round, under the right circumstances. Furthermore, compared to conventional approaches, using a covered water tray for fertilizer distribution is a cleaner harvesting technique that can save up to 90% of water and produce up to 80% more crops in 30% less time (Ghazal, Mansour, and Davidová, 2023). In a hydroponic system, certain growing parameters must be followed in order to successfully grow lucrative and healthy plants. These conditions can vary depending on the variety of plant. Typically, the main drivers of growth consist of:

1. Carbon dioxide (CO_2) and oxygen (O_2): Although plants, like all living things, depend on airborne oxygen to survive, the presence of oxygen in water facilitates the uptake of nutrients. Moreover, carbon dioxide is required for photosynthesis to occur. Both gases are naturally present at concentrations that are conducive to plant growth in ordinary breathing air.
2. Water (H_2O): Water is essential to metabolic processes because it acts as a solvent for nutrients and oxygen. PH levels between 5.00 and 7.00 are usually required for the best plant growth.
3. Nutrients: As a source of nourishment, plants need nutrients. Phosphorus (P), potassium (K), and nitrogen (N) are the three most important elements. These can be bought commercially in a range of formulas.
4. Temperature: A key factor in hydroponic systems, temperature affects both the water's oxygen content and the metabolic activities of the plants. For the best

plant growth and development, the water and surrounding temperature should be kept between 18 and 25°C.

5. Light: Among the most important variables are light's intensity, spectrum, and duration; they will be covered in detail in the section that follows.

Since light is easier to control than other growing factors, light is the primary factor influencing crop development. For photosynthesis to occur, each crop needs a minimum amount of light, which might come from either artificial or natural sources. It is advised to provide light for eight to ten hours every day. Furthermore, light intensity and spectrum are important factors to take into account; words like PAR, PPFD, and DLI are explained below.

PAR:

The term PAR, or photosynthetically active radiation, refers to the range of visible light that is essential for photosynthesis in plants and lies between 400 and 700 nanometers (nm) in the light spectrum.

PPED:

The Photosynthetic Photon Flux Density (PPFD), or $\mu mol\ m^{-2}\ s^{-1}$ (micromoles per meter squared per second), is a measurement of the amount of PAR photons (measured in micromoles) that reach the plant surface every second. For plants to grow efficiently, the ideal range is usually 500–1500 $\mu mol\ m^{-2}\ s^{-1}$, whereas sunshine usually provides 900–1500 $\mu mol\ m^{-2}\ s^{-1}$.

DLI:

The quantity of active photons that are received in a particular location throughout the course of the day is measured by the Daylight Integral (DLI). It is a useful tool for farmers to use when choosing plants based on available light levels or whether additional illumination is required. DLI is measured in moles/m2/day and is calculated using the formula μmol m^{-2} s^{-1} (or PPFD) multiplied by (3600 multiplied by photoperiod) divided by 1,000,000.

2.1.7. Vertical Greenery System Food Production

Areas with ideal characteristics for successful facade and roof farming projects are prioritized. Taller residential and commercial structures are a common feature of these neighborhoods since they provide more space for farming. Furthermore, locations with an abundance of low-quality or unimpressive architectural designs are given priority since these structures frequently offer options for roof farming and facades without detracting from the overall aesthetic appeal of the neighborhood. Because they are easier to reach for distribution and have higher demand for locally grown produce, neighborhoods near city centers are given more consideration. Additionally, residential areas close to schools and universities are given preference in order to make it simpler for researchers working on facade and roof farming techniques to access these areas. Additionally, locations with difficult terrain, like hilly regions, are given priority since facade and roof farming can provide a workable alternative for agricultural production in these harsh settings (Ghazal, Mansour, and Davidová, 2023).

Possible crops for vertical farming:

The majority of crops can theoretically be grown hydroponically, given that the right circumstances are fulfilled for growth. Practically speaking, though, some crops are naturally better suited for hydroponic farming than others. Suggested herbs and vegetables for hydroponic gardening are listed in Tables 2.2 and 2.3, together with the favored means of production (from seeds or cuttings) (dengarden, 2023).

Table 2. 1 Suitable herbs for hydroponic, (source dengarden, 2023).

Common Name	Latin Name
Tarragon	*Artemisia dracunculus* L.
Peppermint	*Mentha x piperita* L.
Green Mint	*Mentha L.* [such as*:*
	Mentha x piperita L.
	Mentha spicata L.
	Mentha pulegium L.]
Oregano	*Origanum vulgare* L.
Basil	*Ocimum basilicum* L.
Sage	*Salvia officinalis* L.
Stevia	*Stevia rebaudiana (Bertoni) Hemsl.*
Lemon Balm	*Melissa officinalis* L.
Rosemary	*Rosmarinus officinalis* L.

Table 2. 2 Suitable vegetables for hydroponic, (source dengarden, 2023)

Common Name	Latin Name
Lettuce	*Lactuca sativa* L.
Spinach	*Spinacia oleracea* L.
Bok Choy	*Brassica chinensis* L.
Tomatoes	*Solanum lycopersicum* L.
Peppers	*Capsicum annuum* L.
Cucumber	*Cucumis sativus* L.
Celery	*Apium graveolens* L.

Crops Selection Criteria

The right crop selection must be carefully considered in order to attain the best agricultural results on façade. The factors for crop selection applied in the particular studies described in the literature review were examined in this inquiry (Tablada et al., 2018). Important elements noted are as follows:

- Hydroponic farming possibility:

The crops that are selected should be compatible with the given planting space, require little upkeep from building occupants especially inexperienced ones and be acceptable for hydroponic cultivation on building facades and rooftops.

- Available natural DLI:

While adding LED supplemental lighting units is an option that will be covered later, it is imperative that the necessary Daylight Integral (DLI) match the available DLI at the agricultural area in order to maximize crop growth and profitability. Nevertheless, going above and beyond the required DLI is acceptable because every extra DLI unit can increase production by 1% at most, but this will vary depending on the plant. In other words, since every facade and roof have a unique DLI, the crops chosen should reflect that. Respecting this factor can save energy consumption by reducing the need for LED supplemental lighting.

- Acceptable Plant growing conditions:

Since the plants will be grown above residents' roofs and in front of their windows, it is imperative that the growing conditions required for the selected plants meet human comfort criteria. As a result, between 22 and 27°C should be the ideal growing temperature for a few chosen crops, and between 40 and 60% relative humidity should be maintained (ASHREA, 2015). Assuring compliance with these requirements will improve the facade and roof farming concept's appeal.

Local consideration:

In order to effectively use urban farming to meet local food needs, it is imperative to give priority to crops that both meet the nutritional needs of the community and are able to flourish in the existing environmental circumstances. This strategy not only increases the likelihood of successful crop production but also promotes the idea of locally produced food, which may reduce the amount of energy needed to provide ideal growing conditions. Additionally, choosing crops that have a large market demand can help the urban farming effort make money and reduce the amount of money the community has to spend on these specific crops.

2.1.8. Advantages and Disadvantages of Vertical Greenery System.

Two different scales show the benefits of Green Walls (GWS): the building scale and the urban scale (Hefnawy 2022). The benefits of Vertical Green Spaces (VGS) have been apparent in response to ecological issues brought on by urbanization, underscoring its potential to improve the quality of urban life. Global warming mitigation, energy conservation, noise abatement, carbon sequestration, oxygen production, reduction of rainwater effects, creation of wildlife habitats, particle filtration, urban agriculture, substantial health benefits, and aesthetically pleasing environments are just a few of the environmental, and economic, and social implications of vertical garden systems (VGS) (Morsi and Elian 2021; Perini and Rosasco 2013).

Table 2. 3 Advantages and disadvantages of Vertical greenery system (VGS) source (Manso and Castro-Gomes 2015b)

System	Classification	Subcategory	Advantage	Disadvantage
Green facades (GFS)	Direct GFS	Traditional GF	Low cost Not any contributing materials (growing media, support, irrigation) Low environmental problem	Spontaneous development of vegetation. Limited variety of plant species climate adaptation Dispersed growth on the facade. Slow facade coverage. Maintenance difficulties
	Indirect GFS	Continuous guides	Lower consumption, enhancement guidance for vegetation.	Limited variety of plant species/ climate adaptation Slow facade coverage. Dispersed growth on the facade. Some materials have a high environmental burden.

		Modular trellis	Managed Drainage /irrigation Light support. Capacity to build and dismantle for repair purposes.	Limited variety of plant species/ climate adaptation High cost.
Living walls (LWS)	Continues LWS	Felt pockets	Flexible and lightweight Regular growth An increased plant selection. Regular water and nutrient distribution.	High water and nutrient consumption. Complex in implementation Lack of space for root growth. Regular maintenance. High cost.
	Modular LWS	Trays	Managed Drainage /irrigation Capacity to build and dismantle for repair purposes. An increased plant selection	Complex in implementation High cost. Heavier methods Surface types are restricted to trays' measurements. Large environmental load of some used materials.

	Flexible bags	Adaptable to sloped surfaces An increased plant selection aesthetic value	Complex in implementation. Heavier methods due to growing media High cost.
	Planter tiles	An increased plant selection aesthetic value attractive design	Complex in implementation Lack of space for root growth. Surface types restricted to trays measurements. High cost.

2.1.9. Case Study

case study (1): Proposed productive facade in Singapore:

A 2018 study carried out in Singapore investigated the use of vertical greenery systems (VGS) for productive reasons, despite a lack of research in this area. The study first described the general issues related to this field in Singapore, emphasizing the country's heavy need on imported resources for the production of power (which makes up 95% of resources) and food consumed indoors (more than 90%). The report also highlighted as a significant factor Singapore's high population density of 7796 people per square kilometer, with 94.6% of them living in multistory buildings.

The study included planters for food cultivation together with solar panels for shade and electricity generation in its proposal for a productive facade. For each of the four elevations, two choices were taken into consideration: a facade with windows or a balcony, creating eight possible permutations. The researchers developed five main criteria; food production capabilities, energy generation, thermal performance, indoor daylighting, and view angle potential in order to maximize these alternatives. Grasshopper software was used to evaluate these criteria, and the VIKOR multi-criteria optimization method was then used to identify the best design.

The results showed that most of the solar panels on the facades needed to be angled steeply, and that the eastern and western facades needed more solar protection. To maximize efficiency, the study also suggested placing two planters somewhat below the windows. This means that a 20 square meter facade might produce 35–66 kg of leafy greens, or 55–103% of what a medium-sized household in Singapore would typically consume. Ultimately, the Tropical Technologies Laboratory (T2 Lab) in Singapore received a prototype of the ideal facade design (Tablada et al., 2018).

case study (2): 3D city models for urban farming site identification in buildings.

The paper "3D city models for urban farming site identification in buildings" investigates the feasibility of urban farming on facades in Singapore against the paucity of existing research on the topic. The study examines the use of three-dimensional (3D) city models for evaluating photosynthetically active radiation (PAR) on residential building facades, windows, and outdoor corridors against conventional field trips and labor-intensive measurements. The study demonstrates a strong association (correlation coefficients more than 0.5 in most cases) between field data collecting and simulations generated from 3D city models.

In addition, the study examines the spatiotemporal distribution of PAR inside buildings and examines the effects of shadows and different weather on it. It comes to the conclusion that using 3D city models to locate appropriate farming places on an urban scale is a workable option. Nevertheless, the study ignores important factors like the best crop selection for each location, crop consumption patterns in urban areas, potential crop yields, fulfilment percentage (production versus consumption), and installation costs related to such farming systems for particular neighborhoods, even though high-resolution PAR measurements were conducted at an urban scale in Singapore.

To provide a more thorough understanding of the potential for facade farming on an urban scale in a different location with similar conditions, the author's research, on the other hand, aims to use a different tool (Rhino Grasshopper) to conduct a similar analysis of Daily Light Integral (DLI) and address the aforementioned gaps (Palliwal et al., 2021).

2.2. Vertical Farming and the Context of Addis Ababa

In Addis Ababa and the surrounding areas, agriculture in its broadest sense has been practiced for a very long time, even before the settlements were founded. Alongside the city's development, it has persisted and has been crucial to some socioeconomic circumstances, including the provision of food and raw materials, jobs, and money for the impoverished living in metropolitan areas. The industry has made a significant contribution to the area's urban families' access to food security and employment opportunities. However, several unfavorable factors severely limit UA in Addis Ababa and the surrounding area. These include the competitive demands for land, a lack of awareness on the part of city administrators and planners, an inappropriate market channel between producers and consumers, improper management of wastewater and urban solid waste, improper use of vacant spaces and parts of buildings, an inability to enforce the current bylaws, and the absence of a well-thought-out and contextualized UA policy or strategy.

Urban agriculture can improve local ecosystems and green areas, and Farm Africa's Addis Ababa pilot project has demonstrated how growing food in a city may be a potent and realistic way to combat poverty and hunger (Farm Africa, 2021).

Sida, the Swedish International Development Cooperation Agency, provides funds to Farm Africa, which in turn helps low-income urban populations raise fish and poultry as well as veggies. Despite their lack of farming or gardening knowledge, the majority of project participants were eager women who contributed a feeling of communal spirit. A few were neighbors from the low-income neighborhoods nearby. Since the plot site was created on the property of the Ministry of Planning and Development, some of the other workers were low-paid government employees. Structures that climb vertically have been built to make the most of the limited urban area. University groups and other individuals with an interest in urban agriculture can now learn more about the location.

The project's main objectives were to provide access to markets and encourage the growth and consumption of nutrient-dense, market-oriented vegetables, herbs, and spices. The outcomes have been remarkable. In addition to raising fish and poultry, the volunteers have raised a variety of vegetables, such as lettuce, carrots, beets, and cabbages. The program has surpassed its goal in just a single year, and participants have seen a 50% rise in household income.

Figure 2. 5 urban agriculture pilot project in Addis Ababa (source: farm Africa)

The vertical farming sample project in the new Ethiopian Standard Authority compound serves as an example for other organizations and homes looking to employ urban agriculture to improve food security. The vertical farming project was developed in 2021 in the compound of the Ethiopian Standard Authority. The vegetation found in the ESA vertical farming sample includes cabbage, spinach, tomato, pepper, garlic, onion, and other plants that are essential to the production of traditional medicines (ESA, 2021).

Figure 2. 6 Vertical farming project in ESA compound (source: ESA social media)

The administration of Addis Ketema Sub-City also started vertical farming initiatives in the Administration compound in 2022. Within the compound, vertically stacked structures are constructed with discarded plastic containers, and soil is used as a growing medium for the development of vegetables and leafy greens. Additionally, vegetable planters were hung from the majority of the compound fences' external and interior faces. The goal of the project was to demonstrate to the sub city's citizens that, given a small amount of space, anyone could grow their own vegetables for food. Additionally, the project shows how the vertical farming method uses little water. The initiative goes to the almost every sub city administration compound at least on the face of the compound fence.

Figure 2. 7 Vertical farming in the compound of Addis Ketema Sub-city

2.3.Conclusion

In addition to the physical components of urban development, urbanization also refers to the people who live there and interact with, affect, and are influenced by these components. A major obstacle encountered by city dwellers is the availability and accessibility of food. As a result, urban agriculture especially vertical farming emerges as a crucial remedy. Urban agriculture includes vertical farming techniques that are practiced both indoors and outdoors. One effective method of growing food on the outside of urban buildings particularly those with a lot of blind facades is the vertical greenery system.

Although vertical farming has been the subject of many studies, this literature review focuses mostly on food production. But there isn't much research on façade food production in particular, especially in developing nations. There is a great chance for more research and advancement in the field of urban agriculture because of this knowledge gap.

CHAPTER THREE

MATERIALS AND METHODS

3.1.Study Area

The study was conducted in Addis Ababa city. The wave of condominium housing development and construction in the city is one of the greatest tasks of the government to Achieve the lack of housing for the residents of the city, due to the high amount of migration to urban areas, especially to Addis Ababa city. Therefore, there is a high value of land surfaces that have been converted from agricultural land to housing residential land.

From the Addis Ababa city, condominium sites were the focus area of the study. The Addis Ababa Grand Housing Plan has implemented hundreds of thousands of housing units in more than 150 sites. From these sites, the Ayat 1 project was selected. The project contains four sites site 1, site 2, site 3 and site 4. Based on their current residence occupation and level of completion the site is selected for the study. The site is located on the east side of Addis Ababa. It is also in the east Lemi Kura Sub-city. Centrally located at Latitude and Longitude coordinates of: 9.012220°, 38.894047° and covers an area of 31 hectares. The three sites of Ayat 1 are near the Ayat 49 taxi station. These sites are part of the 2007 E.C. 40/60 project. There are 14, 38, and 41 blocks in site 1, site 2, and site 3 respectively. Which is a total of 93 blocks (Figures 3.1 and 3.2).

These condominium sites are selected because of various reasons. The first reason was the housing sites were previously farming lands. Owner individuals of the land have been producing crops mostly Teff. But after the land has been converted to residential land the government relocates the farmers. The second reason is these sites contain B+G+8 and B+G+10 building typologies. Other condominium sites have more than B+G+10, even if they are transferred to the residents, because of their incompletion residents are not living there yet because of their completion level. As much as possible the most high-rise building sites are selected for the study.

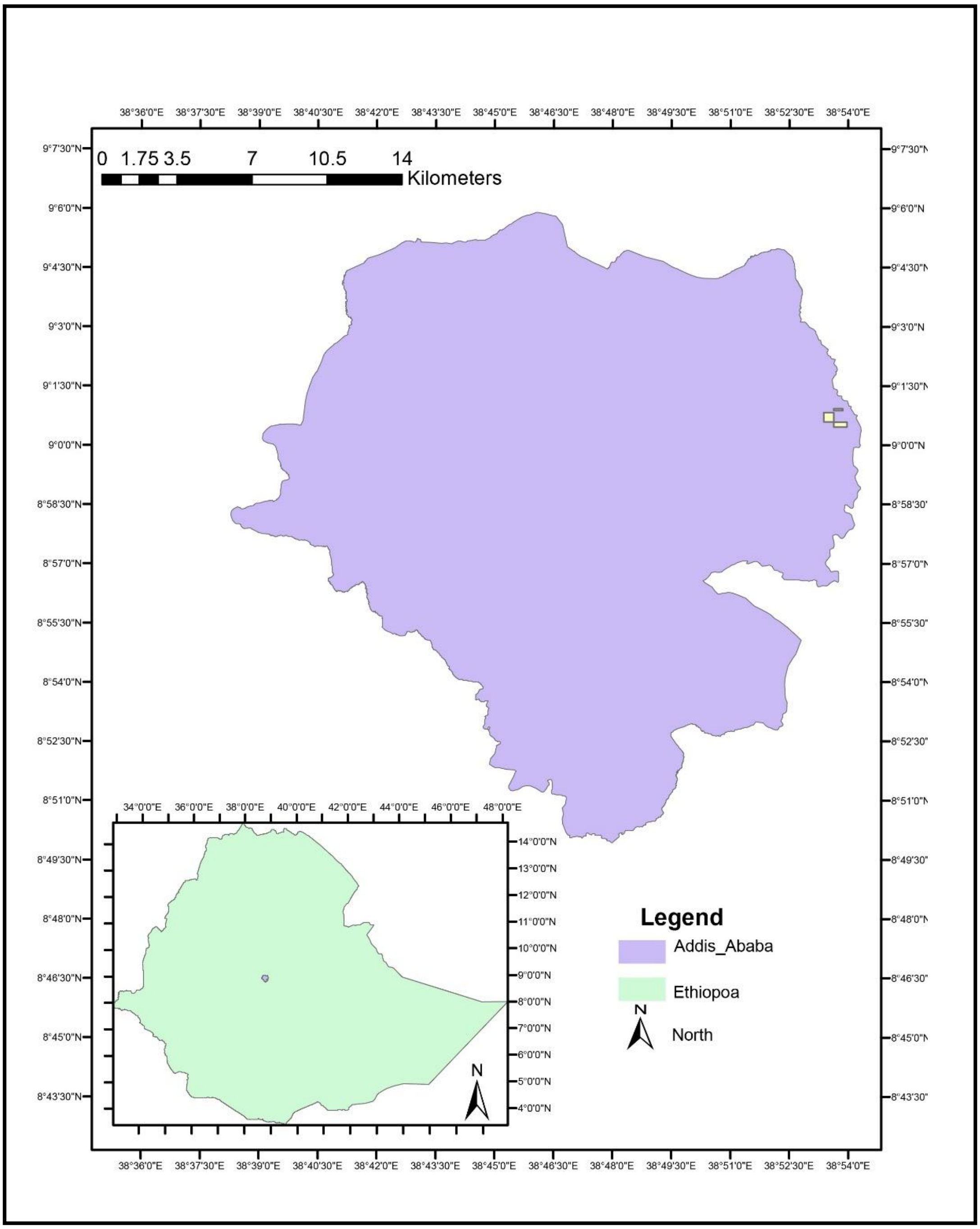


Figure 3. 1 Study Area

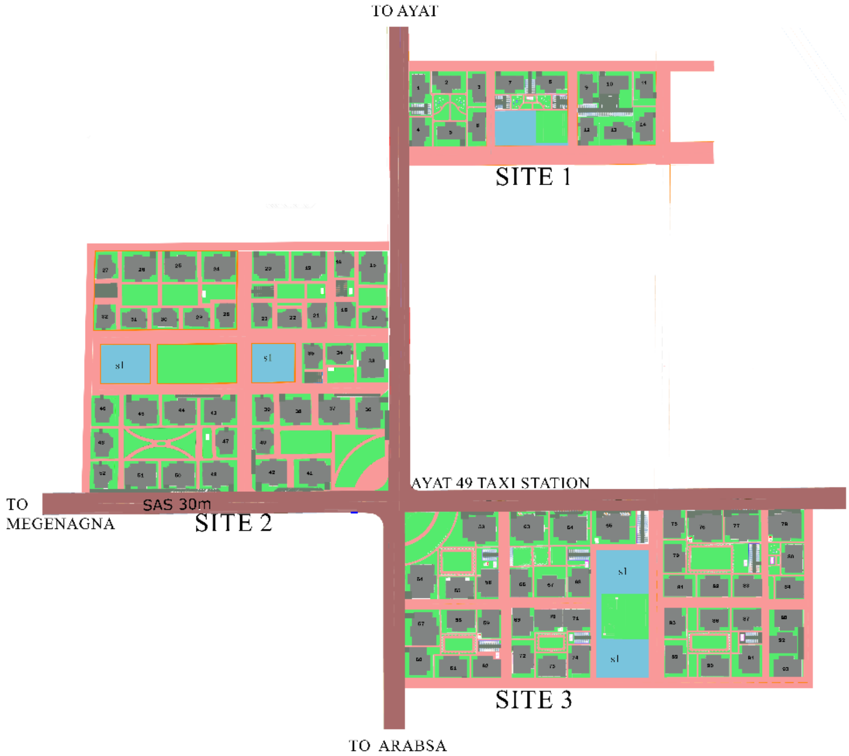


Figure 3. 2 Ayat 1 Site 1, 2 and 3

3.2.Research Design

Based on the objectives and questions of the research, data were collected and analyzed to reach a conclusion and recommendation.

- Vegetable demands of household

A questionnaire was conducted among household members to gather information on their family size, vegetable consumption amount, dietary preference, and frequency of vegetable consumption. Vegetable consumption demand has been assessed based on the information gathered from the household. These data were used to calculate the total vegetable demand of the household.

- Potential surface area

The feasibility study identifies the potential surface area of the building that is functional for vertical farming. The survey was conducted among 93 blocks in the existing condominium housing buildings in Addis Ababa city Ayat 1 site 1, site 2, and site 3. The data includes measurement of the surface area of the building, window-to-wall ratio, cardinal orientation of the buildings, and wall system directly from observation and information from the housing project agency project office. Based on the data analyzed the potential surface area of the of the building for vertical vegetable production was identified.

- Productivity of the land

The productivity of agricultural land is assessed by analyzing the current use of land and the previous production yield based on the information gathered from the current landowners near the site. The data enabled to realize the amount of production of Teff per year.

- Suitable vertical farming technology

After collecting data for the previous objectives and conclusion sample design was conducted. The design demonstrates a technology that can be used on the surface of the building to produce selected vegetables.

Vegetable demands of the household tell the amount of vegetables consumed and required by the resident. The vegetable demand of the residents was converted to calories to compare with the amount of calories produced from the land in traditional agriculture before the land was converted to a condominium site. Finally, after the potential surface area identified and demonstrated the amount of vegetable calories produced in vertical farming technology, the regained lost agricultural produce was defined. The figure 3.3 below shows the whole research design and the workflow of the study

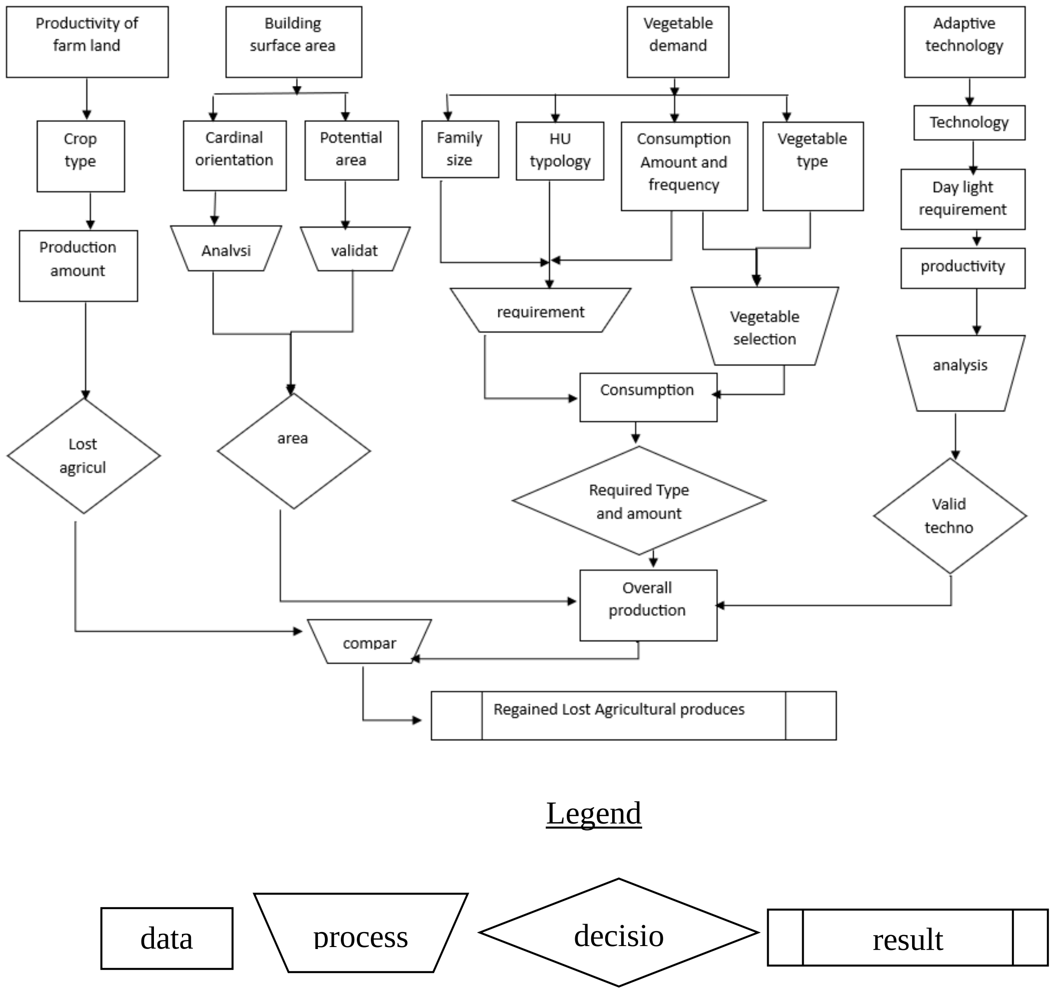


Figure 3. 3 Research design process and workflow

3.3.Data Type and Source

- Vegetable demands of household

The data gathered directly from the household to assess the vegetable demand of the household was, family size, vegetable dietary preference, and vegetable consumption amount. The main source of data was the households who lives in the study area.

- Potential surface area

To identify the potential surface area of the study area, building typologies, the number of blocks, perimeter and surface area of the building, blind wall surface area, and cardinal orientation of the buildings were gathered. The main source of the data was the existing buildings and housing development project office.

- Productivity of the land

To assess the productivity of the land, the area of the land that the site occupies, the crop type, and the amount of production when the land was agricultural were gathered. The main source of the data was the farmers who farm near the site in the traditional method.

- Suitable vertical farming technology

To demonstrate the vertical farming technology the literature review and case study analysis was conducted. The physical and natural characteristic analysis of vegetables was the main data used for the design of the technology. The data sources were researches, published journals, and agricultural professionals.

3.4.Sampling Design

The Ayat 1 site 1, 2, and 3 has 4008 housing units in the 66 blocks of B+G+8 and 27 blocks of B+G+10 building typologies. The building typology of B+G+8 has 4 housing units with two housing unit typologies per floor on 7 typical floors except for the ground and first floors. The building typology of B+G+10 has 10 housing units with three housing unit typologies per floor on 8 typical floors except for ground and first floors. The housing unit and typologies are explained in table (Table 3.1) below.

Table 3. 1 The building block and housing unit typology

Site	**building typology**	**Number of blocks**	**Residential**				**shops**
			1 bed room	2 bed room	3 bed room	**Total**	
Site 1	B+G+8	14	0	98	294	**392**	168
	B+G+10	0	0	0	0	**0**	0
	Total	**14**	**0**	**98**	**294**	**392**	168
Site 2	B+G+8	20	0	140	420	**560**	240
	B+G+10	18	288	864	288	**1440**	558
	Total	**38**	**288**	**1004**	**708**	**2000**	798
Site 3	B+G+8	32	0	224	672	**896**	384
	B+G+10	9	144	432	144	**720**	248
	Total	**41**	**144**	**656**	**816**	**1616**	632
Grand total	B+G+8	66	0	462	1386	**1848**	1598
	B+G+10	27	432	1296	432	**2160**	
	Grand Total	**93**	**432**	**1758**	**1818**	**4008**	**1598**
Percentage			10.7%	44%	45.35	100%	

3.4.1. Sampling Technique

- Vegetable demands of households

After buildings are grouped by their block, floor, flat, and family size using stratified sampling each stratum was represented by the dominant and majority of family size group.

- Potential surface area

Similarly to the first objective after grouping the building typologies which are B+G+8 and B+G+10 building typologies, as representative of the whole building blocks one B+G+8 and one B+G+10 building block were selected based on their characteristics. But based on their cardinal orientation, blocks with similar orientations were grouped and represented. Then after that individual data was multiplied for the total similar orientation and building typologies.

- Productivity of the land

After identifying sites that were agricultural land, since the land productivity properties are the same around the site the information gathered from the three farmers around the site was used for the study.

3.4.2. Sampling Size

All 93 blocks' resident were grouped according to their family size. The family size group with more than 10 family size, of the whole building blocks are taken as the representative samples. The table below (Table 3.2.) shows how each block grouped with their family size group count.

The sample size of this study is determined by a precision level of 5%. The level of precision is the range in which the true value of the population is estimated. Therefore, the sample size was calculated by a 95% confidence level and precision level of ±5%.

According to Yemane (1967) the formula to determine and calculate the sample size

$$\text{n}= N\ 1+N(e)2$$

Where **n** = sample size, **N** = total study area population **e** = level of precision

The total population of the study area is 4,008-163=3,845 and the level of precision is 0.05.

$$n = 3,845/1+3,845(0.05)2$$

$$n = 362.3 \approx 362$$

Table 3. 2 Family size count of each block

Block	**Count of Family size**										
	1	2	3	4	5	6	7	8	9	abandon	Grand Total
1				1	14	5	1	5		2	28
2				4	14	7	1			2	28
3			1	4	12	6	1	2		2	28
4			2	6	12	6				2	28
5			2	4	11	5	2	2		2	28
6				5	12	4	2	3		2	28
7			3	7	9	7				2	28
8			2	6	6	12				2	28
9				4	14	5	3	1		1	28
10			3	2	10	9	2			2	28
11			2	4	13	6	1			2	28
12			2	6	15	4				1	28
13			2	5	10	8	1	1		1	28
14		1	2	6	8	7	2	1		1	28
15	3	9	11	14	18	10	7	5		3	80
16			1	4	15	7				1	28
17				7	15	4				2	28
18				8	13	5				2	28
19	1	10	4	16	24	11	8	3		3	80

20	1	15	8	11	26	11	4	1	3	80
21				2	14	10			2	28
22				10	15	2			1	28
23				6	15	6			1	28
24		11	9	14	27	14	3		2	80
25		3	13	19	25	14	3	1	2	80
26		3	6	22	31	13	3		2	80
27			1	5	11	5	4	1	1	28
28			3	2	13	8			2	28
29			3	3	12	8	1		1	28
30				4	14	5	3		2	28
31			1	7	12	6	1		1	28
32			1	5	13	6	1	1	1	28
33	1	6	11	14	26	16	2		4	80
34				6	13	8			1	28
35				4	15	6		1	2	28
36		3	15	12	30	13	5		2	80
37		4	10	16	30	15		2	3	80
38		6	8	20	28	16			2	80
39				7	17	2		1	1	28
40				7	17	3			1	28
41	1	8	13	14	26	15	1	1	1	80
42		5	6	21	29	17			2	80
43		5	7	19	28	16	3		2	80
44		5	7	16	33	14	3		2	80
45		4	5	16	29	14	6	4	2	80
46				5	16	4	1		2	28
47				6	15	5		1	1	28
48			1	6	15	5			1	28
49		2	10	20	31	11	1	1	4	80

50	1	6	21	32	10	6	1	3	80
51	2	5	19	32	15	3	1	3	80
52		1	3	13	5	2	3	1	28
53	3	5	18	34	12	5	1	2	80
54	1	4	21	32	13	3	3	3	80
55			4	13	10			1	28
56			3	17	6			2	28
57	8	5	23	26	16			2	80
58			5	15	6		1	1	28
59			9	13	2	1	1	2	28
60			14	10	2			2	28
61			13	13	1			1	28
62			3	15	7	1		2	28
63	3	6	17	34	16		1	3	80
64	2	6	18	33	17	1		3	80
65	4	9	18	27	20			2	80
66		2	7	11	7			1	28
67	1	1	6	11	7	1		1	28
68			5	14	5	2		2	28
69		1	4	15	6	1		1	28
70		2	3	13	8	1		1	28
71		2	8	13	4			1	28
72			4	13	9	1		1	28
73		2	2	12	4	6		2	28
74			4	15	6	1		2	28
75			6	12	8			2	28
76	7	3	17	32	18	1		2	80
77	4	5	18	31	15	2	3	2	80
78	4	7	21	25	13	4	4	2	80
79	1	2	5	12	5	1		2	28

80		1	1	8	10	7				1	28
81			2	3	14	7	1			1	28
82		1	2	2	11	7	3			2	28
83			1	4	15	4	3			1	28
84			1	4	13	5	4			1	28
85			2	3	10	9	1	1		2	28
86				4	11	12				1	28
87				11	11	5				1	28
88				6	15	5				2	28
89			4	3	10	8	1			2	28
90			2	6	9	9	1			1	28
91			2	4	11	5	2	1	2	1	28
92			2	6	13	6				1	28
93				4	14	7	1			2	28
Grand Total	7	143	268	819	1626	785	136	59	2	163	4008

To find the proportion of each family size strata for the sample size calculated (see the Table 3.3 below) below. Each family size group has different proportion from the total sample of 362.

Table 3. 3 Proportion of each family size group for the sample

	family size group										
	1	2	3	4	5	6	7	8	9	abandoned	Grand Total
Count of family size	7	143	268	819	1626	785	136	59	2	163	4008
samples	1	13	25	77	153	74	13	5	1		362

3.5.Method of data collection

The details of data collection method to achieve each specific objectives are listed under table 3.4

Table 3. 4 Data collection method and tools

No.	Specific objectives	Types of data	Source of data	Tools
1	To Assess the vegetable demands of individual households living in the condominium housing.	family size, vegetable dietary preference, and vegetable consumption amount.	Households	Questionnaire
2	To identify a potential surface area of a condominium building for vertical farming.	the number of blocks, perimeter and surface area of the building, blind wall surface area, and cardinal orientation of the buildings	Building analysis, Housing development project office	Observation and Measurement
3	To Asses the productivity of the land when it was used for agriculture.	the area of the land that the site occupies, the crop type and the amount of production	Farmers	Key informant interview

4	To develop compatible vertical farming planting technology.	physical and natural characteristic analysis of vegetable	Literature and agriculture professionals

The main data were obtained through observation, questionnaires, and interviews. The other data were collected from books, journals, previously undertaken research papers, government policies and strategy papers, satellite images, photographs, and housing agency publications.

i. Observation

Observation was necessary to collect reliable data. Observation creates a direct opportunity to assess the necessary data. Especially for the second and third objective observation of the building and the site that was a farm land gives a better insight. Through observation buildings and previous agricultural land that has been converted to built-up areas on site were measured.

ii. Questionnaire

A mix of open-ended and closed-ended questionnaires was used. The questionnaires were prepared in English translated to Amharic and distributed to the residents. Through questionnaires, the vegetable demand of the household was collected.

iii. Key Informant Interview (KII)

The three farmers, who has farmland near the study area, was interviewed directly in Amharic after the questions were prepared in English and translated into Amharic. This interview is used to attain the productivity of the land while it was agricultural land.

3.6. Method of Data Analysis

- The data, found for the first objective were analyzed using descriptive statics such as the average consumption amount of each vegetable preference in each respondent household, frequency of vegetable purchase, and frequency of vegetable preference across the respondents to calculate the total vegetable demand of the household. The correlation was used to identify the relationship between family size and vegetable consumption amount. Regression analysis and ANOVA, were used to describe the significant impact of the family size on the consumption amount of each vegetable.
- The second objective also used statical description by calculating the potential area of the building surface area of the study area. Based on the building typology and cardinal orientation of each building, hours of daylight availability in two seasons of the year were explained.

  From the total of 93 blocks on the site 66 blocks are B+G+8 building typology with eight orientation categories because all the four sides are different. 27 blocks are B+G+10 building typologies with four orientation categories because two sides of the buildings are mirrors. Each orientation category of both, building blocks and the number of blocks in each category is explained in Figures 3.4 and 3.5 below. Also, each building's orientation has two main different sun rotation, paths, when the sun rises from the east through the north and the south. In October, November, December, January, February, and March, the sun rises and sets through North. In April, May, June, July, August, and September the sun rises and sets through the south.

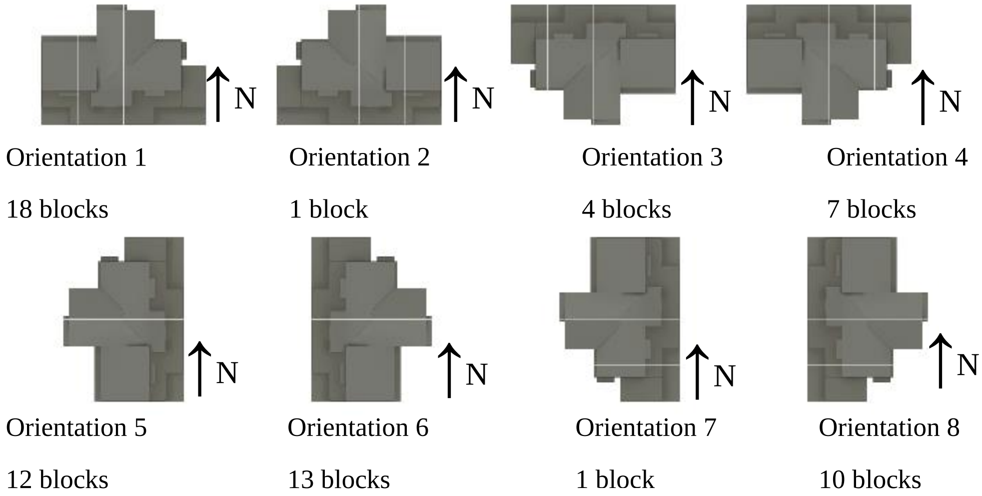


Figure 3. 4 B+G+8 building typology orientation category

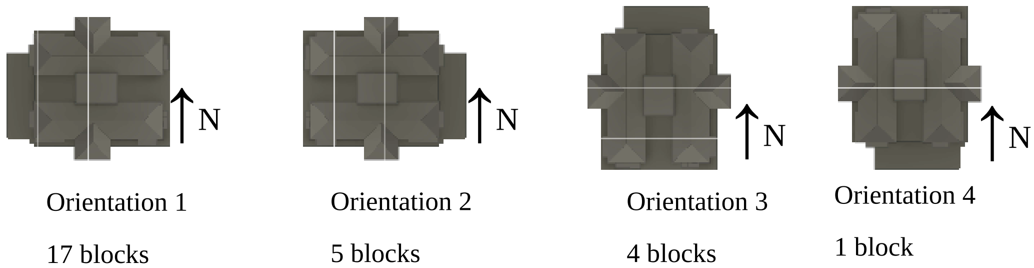


Figure 3. 5 B+G+10 Building typology orientation category

- The productivity of previous farming crops on the site before the site became a condominium construction and residence area, were identified and the yearly productivity of the land was described statically.
- The fourth objective was to demonstrate productive façade technology on the building based on the findings of the earlier three objectives to develop suitable façade vegetable production technology. Physical and natural characteristics like daylight requirement, planting spacing, cultivation days, and productivity of each vegetable are explained to develop the plantation module and calculate the total annual production and productivity of selected vegetables on the vertical façade technology.

3.7.Method of Data Interpretation

The analyzed data was interpreted as tables, charts, graphs, and maps. Software like AutoCAD, Autodesk Revit, GIS, SPSS, and Excel were used to interpret the data in different ways.

AutoCAD was used to measure and calculate the perimeter and surface area of the building. Revit was used to observe the building's orientation and potential surface area exposed to the sun, for 4 hours and 6 hours a day. GIS was used to locate the geographical location of the site. SPSS was used to calculate, preference, purchase frequency, consumption amount, correlation, regression, and ANOVA analysis. Excel was used to generate graphs.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1.Household Vegetable Consumption of the Respondents

Based on the respondents' weekly consumption, a selection of ten species of vegetables is presented for analysis. These vegetables are selected as the most commonly consumed vegetables by the residents. These vegetables are Onion, Tomato, Potato, Carrot, Cabbage, kale, Lettuce, Swizz chard, Leek and Green paper.

4.1.1. Reliability of Factors

The reliability of the factors (family size, vegetable preference, purchase frequency, and consumption amount) used in a structured questionnaire was calculated with Cronbach's alpha for all the respondents. The Cronbach's alpha indicates good (>80) as shown below in table 4.1.

Table 4. 1 Cronbach's alpha value of the reliability test

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.880	.900	29

4.1.2. Vegetable preference

Vegetable Preference of respondents collected based on their weekly consumption.

Onion Preference

Onion and Tomato, are preferred by all the respondent households. Potato is preferred by 358 respondent households. Carrot is preferred by 347 respondent households. cabbage is preferred by 294 respondent households. Kale is preferred by 334 respondent households. Lettuce is preferred by 283 respondent households. Swiss chard is preferred by 252 respondent households. Leek is preferred by 166 respondent households. Green Pepper is preferred by 341 respondent households. The preference of every vegetable in every family size category is shown in Table 4.2 below.

Table 4. 2 Onion preference

		Preference									
		onion	tomato	potato	carrot	cabbage	kale	lettuce	Swiss chard	leek	Green paper
Family size	One	1	1	1	1	0	1	1	1	1	1
	Two	13	13	12	12	10	4	9	3	13	13
	Three	25	25	25	21	25	25	19	25	19	25
	Four	77	77	77	77	28	77	49	32	28	68
	Five	153	153	153	153	146	140	130	114	41	144
	Six	74	74	71	68	70	71	62	63	53	71
	Seven	13	13	13	9	10	13	8	12	9	13
	Eight	5	5	5	5	4	3	4	2	1	5
	Nine	1	1	1	1	1	0	1	0	1	1
Total		362	362	358	347	294	334	283	252	166	341

The figure 4.1 below summarizes the preference frequency of each vegetable type across the sample households.

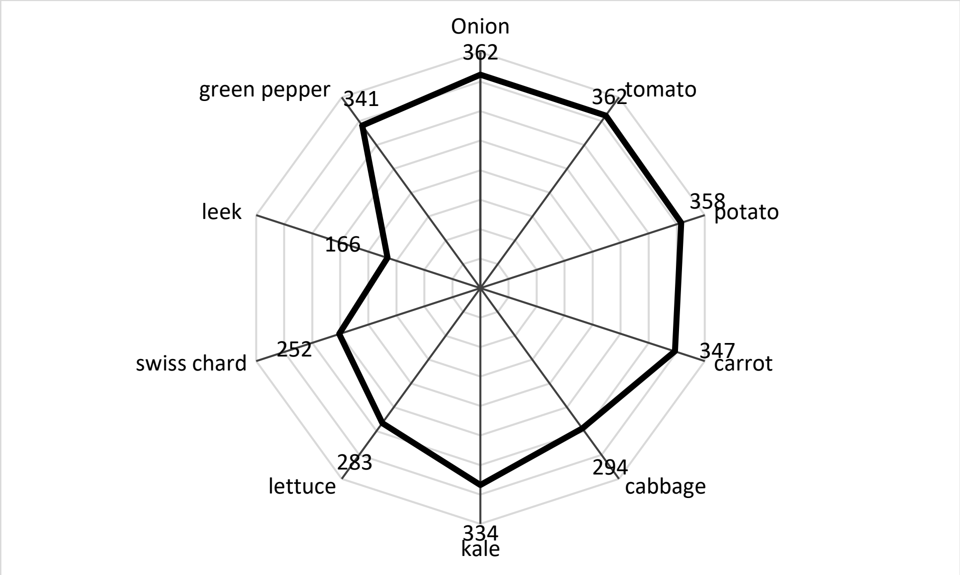


Figure 4. 1 Summary of vegetable preference

4.1.3. Vegetable Purchase Frequency

The vegetable purchase frequency of respondents was collected based on their weekly consumption.

Onion Purchase Frequency

Onion is purchased only 1 day per week by 202 respondent households. The remaining 160 respondent households' purchases are 2, 3, and 4 days per week. The onion purchase frequency of every family size category of respondent households is shown in Table 4.3 below.

Table 4. 3 Onion purchase frequency

	Onion purchase frequency day/week				
	1	2	3	4	Total

Famil y size	one family size	0	1	0	0	1
	two family size	7	6	0	0	13
	three family size	14	3	0	8	25
	four family size	40	21	16	0	77
	five family size	97	23	25	8	153
	six family size	34	37	3	0	74
	seven family size	8	2	3	0	13
	eight family size	2	3	0	0	5
	nine family size	0	1	0	0	1
Total		202	97	47	16	362

Tomato Purchase Frequency

Tomato is purchased one day per week by 202 respondent households. The remaining 160 respondent households' purchases are 2, 3, and 4 days per week. The Tomato purchase frequency of every family size category of respondent households is shown in Table 4.4 below.

Table 4. 4 Tomato purchase frequency

		Tomato purchase frequency day/week				
		1	2	3	4	Total
Famil y size	one family size	0	1	0	0	1
	two family size	3	10	0	0	13
	three family size	14	7	4	0	25
	four family size	47	21	9	0	77
	five family size	99	36	16	2	153

	six family size	32	31	11	0	74
	seven family size	4	4	5	0	13
	eight family size	3	1	1	0	5
	nine family size	0	1	0	0	1
Total		202	112	46	2	362

Potato Purchase Frequency

Potato is never purchased by 4 respondent households based on their weekly preference. The remaining 358 respondent households' purchases are 1, 2, 3, 4, and 5 days per week. The Potato purchase frequency of every family size category of respondent households is shown in Table 4.5 below.

Table 4. 5 Potato purchase frequency

		Potato purchase frequency day/week						
		0	1	2	3	4	5	Total
Family size	one family size	0	0	1	0	0	0	1
	two family size	1	7	5	0	0	0	13
	three family size	0	17	4	4	0	0	25
	four family size	0	25	35	17	0	0	77
	five family size	0	114	17	11	8	3	153
	six family size	3	63	8	0	0	0	74
	seven family size	0	9	4	0	0	0	13
	eight family size	0	2	3	0	0	0	5
	nine family size	0	1	0	0	0	0	1
Total		4	238	77	32	8	3	362

Carrot Purchase Frequency

Carrot is never purchased by 15 respondent households based on their weekly preference. The remaining 347 respondent households' purchases are 1, 2, 3, 4, and 5 days per week. The carrot purchase frequency of every family size category of respondent households is shown in Table 4.6 below.

Table 4. 6 Carrot purchase frequency

		Carrot purchase frequency day/week					
		0	1	2	3	4	Total
Family size	one family size	0	0	1	0	0	1
	two family size	1	5	7	0	0	13
	three family size	4	18	3	0	0	25
	four family size	0	56	21	0	0	77
	five family size	0	116	19	17	1	153
	six family size	6	68	0	0	0	74
	seven family size	4	9	0	0	0	13
	eight family size	0	5	0	0	0	5
	nine family size	0	0	1	0	0	1
Total		15	277	52	17	1	362

Cabbage Purchase Frequency

Cabbage is never purchased by 68 respondent households based on their weekly preference. The remaining 294 respondent households' purchases are 1, 2, 3, and 5 days per week. The cabbage purchase frequency of every family size category of respondent households is shown in Table 4.7 below.

Table 4. 7 Cabbage purchase frequency

		Cabbage purchase frequency day/week					
		0	1	2	3	5	Total
Family size	one family size	1	0	0	0	0	1
	two family size	3	10	0	0	0	13
	three family size	0	25	0	0	0	25
	four family size	49	5	23	0	0	77
	five family size	7	119	14	8	5	153
	six family size	4	48	22	0	0	74
	seven family size	3	8	2	0	0	13
	eight family size	1	4	0	0	0	5
	nine family size	0	1	0	0	0	1
Total		68	220	61	8	5	362

Kale Purchase Frequency

Kale is never purchased by 30 respondent households based on their weekly preference. The remaining 332 respondent households' purchases are 1, 2, 3, and 4 days per week. The kale purchase frequency of every family size category of respondent households is shown in Table 4.17 below.

Table 4. 8 Kale purchase frequency

		Kale purchase frequency day/week					
		0	1	2	3	4	Total
Family size	one family size	0	1	0	0	0	1
	two family size	9	4	0	0	0	13
	three family size	0	17	8	0	0	25
	four family size	0	37	23	0	17	77

	five family size	13	101	14	25	0	153
	six family size	5	41	0	0	28	74
	seven family size	0	11	0	0	2	13
	eight family size	2	3	0	0	0	5
	nine family size	1	0	0	0	0	1
Total		30	215	45	25	47	362

Lettuce Purchase Frequency

Lettuce is never purchased by 76 respondent households based on their weekly preference. The remaining 286 respondent households' purchases are 1, 2, and 3 days per week. The Lettuce purchase frequency of every family size category of respondent households is shown in Table 4.9 below.

Table 4. 9 Lettuce purchase frequency

		Lettuce purchase frequency day/week				
		0	1	2	3	Total
Family size	one family size	0	1	0	0	1
	two family size	4	9	0	0	13
	three family size	3	14	8	0	25
	four family size	28	40	7	2	77
	five family size	23	99	26	5	153
	six family size	12	40	0	22	74
	seven family size	5	6	0	2	13
	eight family size	1	3	1	0	5
	nine family size	0	1	0	0	1

Total		76	213	42	31	362

Swiss Chard Purchase Frequency

Swiss chard is never purchased by 125 respondent households based on their weekly preference. The remaining 237 respondent households' purchases are 1, 2, and 3 days per week. The Swiss chard purchase frequency of every family size category of respondent households is shown in Table 4.10 below.

Table 4. 10 Swiss Chard purchase frequency

		Swiss chard purchase frequency day/week				
		0	1	2	3	Total
Family size	one family size	0	1	0	0	1
	two family size	10	3	0	0	13
	three family size	6	15	4	0	25
	four family size	54	21	2	0	77
	five family size	39	110	3	1	153
	six family size	11	35	28	0	74
	seven family size	1	10	2	0	13
	eight family size	3	1	1	0	5
	nine family size	1	0	0	0	1
Total		125	196	40	1	362

Leek Purchase Frequency

Leek is never purchased by 194 respondent households based on their weekly preference. The remaining 168 respondent households' purchases are 1, 2, and 5 days per week. The leek purchase frequency of every family size category of respondent households is shown in Table 4.11 below.

Table 4. 11 Leek Purchase frequency

		Leek purchase frequency day/week				
		0	1	2	5	Total
Family size	one family size	0	1	0	0	1
	two family size	0	13	0	0	13
	three family size	4	21	0	0	25
	four family size	49	28	0	0	77
	five family size	112	17	23	1	153
	six family size	21	53	0	0	74
	seven family size	4	9	0	0	13
	eight family size	4	1	0	0	5
	nine family size	0	1	0	0	1
Total		194	144	23	1	362

Green Pepper Purchase Frequency

Green pepper was never purchased by 21 respondent households based on their weekly preference. The remaining 341 respondent households' purchases are 1, 2, 3, and 4 days per week. The Green pepper purchase frequency of every family size category of respondent households is shown in Table 4.12 below.

Table 4. 12 Green pepper purchase frequency

		Green pepper frequency day/week					
		0	1	2	3	4	Total
Family size	one family size	0	1	0	0	0	1
	two family size	0	13	0	0	0	13
	three family size	0	25	0	0	0	25
	four family size	9	51	0	0	17	77
	five family size	9	109	4	31	0	153
	six family size	3	68	3	0	0	74
	seven family size	0	13	0	0	0	13
	eight family size	0	0	5	0	0	5
	nine family size	0	0	1	0	0	1
Total		21	280	13	31	17	362

The Figure 4.2 below, presents the summary of the total weekly purchase frequency of each vegetable.

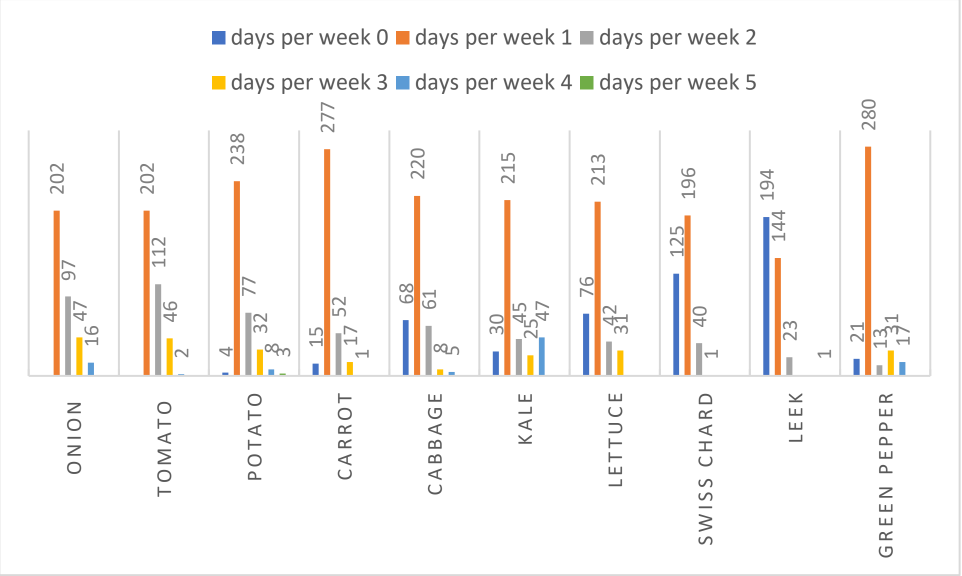


Figure 4. 2 Summary of weekly Vegetable purchase frequency

4.1.4. Vegetable Consumption Amount

Onion Consumption Amount

Table 4.13 shows that from the total 362 respondent households, the consumption amount of onion is 0.3% 1kg/week, 2.5% 2kg/week, 11% 3kg/week, 30.4% 4kg/week, 32.3% 5kg/week,10.8% 6kg/week, 11% 7kg/week and 1.7% 8kg/week.

Table 4. 13 Onion consumption amount

		Onion consumption amount kg/week								
		1	2	3	4	5	6	7	8	Total
Family size	one family size	1	0	0	0	0	0	0	0	1
	two family size	0	6	7	0	0	0	0	0	13
	three family size	0	3	5	10	7	0	0	0	25
	four family size	0	0	25	30	22	0	0	0	77
	five family size	0	0	3	55	65	9	21	0	153
	six family size	0	0	0	15	23	28	7	1	74
	seven family size	0	0	0	0	0	0	9	4	13
	eight family size	0	0	0	0	0	2	3	0	5
	nine family size	0	0	0	0	0	0	0	1	1
Total		1	9	40	110	117	39	40	6	362
Percent of total (%)		**0.3**	**2.5**	**11**	**30.4**	**32.3**	**10.8**	**11**	**1.7**	**100**

Tomato Consumption Amount

Table 4.14 shows from the total 362 respondent households the consumption amount of tomato is 5% consume 1kg/week, 18.5% 2kg/week, 41.7% 3kg/week, 14.1% 4kg/week, 11.6% 5kg/week, 6.1% 6kg/week and 3% 7kg/week.

Table 4. 14 Tomato consumption amount

		Tomato consumption amount kg/week							
		1	2	3	4	5	6	7	Total
Family size	one family size	1	0	0	0	0	0	0	1
	two family size	0	13	0	0	0	0	0	13
	three family size	0	3	16	6	0	0	0	25
	four family size	14	28	16	2	17	0	0	77
	five family size	1	20	85	24	7	5	11	153
	six family size	2	3	34	18	10	7	0	74
	seven family size	0	0	0	1	4	8	0	13
	eight family size	0	0	0	0	4	1	0	5
	nine family size	0	0	0	0	0	1	0	1
Total		18	67	151	51	42	22	11	362
Percent of total (%)		**5**	**18.5**	**41.7**	**14.1**	**11.6**	**6.1**	**3.0**	**100**

Potato Consumption Amount

Table 4.15 shows from the total 362 respondent households the consumption amount of potatoes is 1.1% don't consume every week, 15.5% consume 1kg/week, 1.4%1.5kg/week, 22.7% 2kg/week, 38.1% 3kg/week, 8.3% 4kg/week, 12.7% 5kg/week and 0.3% 6kg/week.

Table 4. 15 Potato consumption amount

		Potato consumption amount kg/week								
		0	1	1.5	2	3	4	5	6	Total
Family size	one family size	0	1	0	0	0	0	0	0	1
	two family size	1	2	5	5	0	0	0	0	13
	three family size	0	0	0	7	8	6	4	0	25

	four family size	0	32	0	26	17	0	2	0	77
	five family size	0	16	0	24	63	14	36	0	153
	six family size	3	5	0	16	43	6	1	0	74
	seven family size	0	0	0	4	2	3	3	1	13
	eight family size	0	0	0	0	4	1	0	0	5
	nine family size	0	0	0	0	1	0	0	0	1
Total		4	56	5	82	138	30	46	1	362
Percent of total (%)		**1.1**	**15.5**	**1.4**	**22.7**	**38.1**	**8.3**	**12.7**	**0.3**	**100**

Carrot Consumption Amount

Table 4.16 shows from the total 362 respondent households the consumption amount of carrots is 4.1% don't consume every week, 0.3% consume 0.5kg/week, 25.3% 1kg/week, 38.7% 2kg/week, 29% 3kg/week, 3.3% 4kg/week, and 0.3% 5kg/week.

Table 4. 16 Carrot consumption amount

		Carrot consumption amount kg/week							
		0	0.5	1	2	3	4	5	Total
Family size	one family size	0	1	0	0	0	0	0	1
	two family size	1	0	9	3	0	0	0	13
	three family size	4	0	0	14	7	0	0	25
	four family size	0	0	37	40	0	0	0	77
	five family size	0	0	25	27	89	11	1	153
	six family size	6	0	17	48	3	0	0	74
	seven family size	4	0	0	6	2	1	0	13
	eight family size	0	0	0	2	3	0	0	5
	nine family size	0	0	0	0	1	0	0	1
Total		15	1	88	140	105	12	1	362

Percent of total (%)	**4.1**	**0.3**	**25.3**	**38.7**	**29.0**	**3.3**	**0.3**	**100**

Cabbage Consumption Amount

Table 4.17 shows, that from the total 362 respondent households, the consumption amount of cabbage is 18.8% don't consume every week, 22.9% consume 1kg/week, 42% 2kg/week, 5.2% 3kg/week, and 11% 4kg/week.

Table 4. 17 Cabbage consumption amount

		Cabbage consumption amount kg/week					
		0	1	2	3	4	Total
Family size	one family size	1	0	0	0	0	1
	two family size	3	9	1	0	0	13
	three family size	0	15	10	0	0	25
	four family size	49	5	23	0	0	77
	five family size	7	22	69	15	40	153
	six family size	4	27	40	3	0	74
	seven family size	3	4	6	0	0	13
	eight family size	1	1	3	0	0	5
	nine family size	0	0	0	1	0	1
Total		68	83	152	19	40	362
Percent of total (%)		**18.8**	**22.9**	**42**	**5.2**	**11**	**100**

Kale Consumption Amount

Table 4.18 shows from the total 362 respondent households the consumption amount of kale is 8% don't consume every week, 0.3% consume 0.25kg/week, 8.3% 0.5kg/week, 55.5% 1kg/week, 21.8% 2kg/week, and 6.1% 3kg/week.

Table 4. 18 Kale consumption amount

		Kale consumption amount kg/week						
		0	0.25	0.5	1	2	3	Total
Family size	one family size	0	1	0	0	0	0	1
	two family size	9	0	3	1	0	0	13
	three family size	0	0	10	15	0	0	25
	four family size	0	0	15	57	5	0	77
	five family size	13	0	2	83	34	21	153
	six family size	3	0	0	38	32	1	74
	seven family size	2	0	0	5	6	0	13
	eight family size	2	0	0	2	1	0	5
	nine family size	0	0	0	0	1	0	1
Total		9	1	30	201	79	22	362
Percent of total (%)		**8**	**0.3**	**8.3**	**55.5**	**21.8**	**6.1**	**100**

Lettuce Consumption Amount

Table 4.19 shows from the total 362 respondent households the consumption amount of lettuce is 20.7% don't consume every week, 9.7% consume 0.25kg/week, 7.5% 0.5kg/week, 44.5% 1kg/week, 16.3% 2kg/week, and 1.4% 3kg/week.

Table 4. 19 Lettuce consumption amount

		Lettuce consumption mount kg/week						
		0	0.25	0.5	1	2	3	Total
Family size	one family size	0	1	0	0	0	0	1
	two family size	4	0	9	0	0	0	13
	three family size	3	0	3	11	8	0	25
	four family size	28	0	1	41	7	0	77
	five family size	23	34	14	43	34	5	153
	six family size	12	0	0	57	5	0	74
	seven family size	4	0	0	6	3	0	13
	eight family size	1	0	0	3	1	0	5
	nine family size	0	0	0	0	1	0	1
Total		75	35	27	161	59	5	362
Percent of total (%)		**20.7**	**9.7**	**7.5**	**44.5**	**16.3**	**1.4**	**100**

Swiss Chard Consumption Amount

Table 4.20 shows from the total 362 respondent households the consumption amount of Swiss chard 32% don’t consume every week, 2.5% consume 0.25kg/week, 27.6% 0.5kg/week, 24.9% 1kg/week, and 13% 2kg/week.

Table 4. 20 Swiss chard consumption amount

		Swiss chard consumption amount kg/week					
		0	0.25	0.5	1	2	Total
Family size	one family size	0	1	0	0	0	1
	two family size	10	0	3	0	0	13
	three family size	6	0	15	4	0	25

	four family size	45	0	20	12	0	77
	five family size	39	0	48	43	23	153
	six family size	11	8	14	19	22	74
	seven family size	1	0	0	10	2	13
	eight family size	3	0	0	2	0	5
	nine family size	1	0	0	0	0	1
Total		116	9	100	90	47	362
Percent of total (%)		**32**	**2.5**	**27.6**	**24.9**	**13**	**100**

Leek Consumption Amount

Table 4.21 shows from the total 362 respondent households the consumption amount of leek is 55.5% don't consume every week, 3% consume 0.25kg/week, 22.9% 0.5kg/week, 12.2% 1kg/week, and 6.4% 2kg/week.

Table 4. 21 Leek consumption amount

		Leek consumption amount kg/week					
		0	0.25	0.5	1	2	Total
Family size	one family size	0	1	0	0	0	1
	two family size	0	4	7	2	0	13
	three family size	10	4	11	0	0	25
	four family size	49	0	28	0	0	77
	five family size	112	2	0	16	23	153
	six family size	21	0	31	22	0	74
	seven family size	4	0	5	4	0	13
	eight family size	4	0	1	0	0	5
	nine family size	1	0	0	0	0	1

Total	201	11	83	44	23	362
Percent of total (%)	**55.5**	**3**	**22.9**	**12.2**	**6.4**	**100**

Green Pepper Consumption Amount

Table 4.22 shows from the total 362 respondent households the consumption amount of green pepper is 5.8% don't consume every week, 34.5% consume 0.25kg/week, 49.4% 0.5kg/week, and 10.2% 1kg/week.

Table 4. 22 Green pepper consumption amount

		Green pepper consumption amount kg/week				
		0	0.25	0.5	1	Total
Family size	one family size	0	1	0	0	1
	two family size	0	13	0	0	13
	three family size	0	25	0	0	25
	four family size	9	38	30	0	77
	five family size	9	37	70	37	153
	six family size	3	10	61	0	74
	seven family size	0	1	12	0	13
	eight family size	0	0	5	0	5
	nine family size	0	0	1	0	1
Total		21	125	179	37	362
Percent of total (%)		**5.8**	**34.5**	**49.4**	**10.2**	**100**

4.1.5. The Correlation Results

Pearson's *r* varies between +1 and -1. The strength of the relationship between variables is strong if the value is 0.7 and above, moderate if the value is 0.4-0.69, weak 0.1-0.39, and no relationship if the value is 0 to 0.1. In the below table, the relationship under their variable category is highlighted. The maximum value under the dependent variable except for identical factors is 0.733 which is between the Onion amount and the Tomato amount. The minimum value, under the dependent variable except for identical factors is 0.102, which is between the Onion amount and the Leek amount. Since there is only one independent variable the correlation result is identical. The correlation between Leek amount and potato amount, and Swiss chard amount and tomato amount isn't significant. which means family size doesn't have significant impact on leak amount, and Swiss chard amount and potato amount doesn't impact each other (See table 4.23).

Table 4. 23 The correlation result

Correlations

		Family size	Onion amount	Tomato amount	Potato amount	Carrot amount	Cabbage amount	Kale amount	Lettuce amount	Swiss chard amount	Leek amount	Green paper amount
Family size	Pearson Correlation	1	.671**	.424**	.226**	.150**	.228**	.324**	.108*	.328**	.102	.292**
	Sig. (2-tailed)		.000	.000	.000	.004	.000	.000	.040	.000	.053	.000
	N	362	362	362	362	362	362	362	362	362	362	362

Onion amount	Pearson Correlation	.671**	1	.733**	.518**	.229**	.316**	.424**	.145**	.245**	.410**	.381**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.006	.000	.000	.000
	N	362	362	362	362	362	362	362	362	362	362	362
Tomato amount	Pearson Correlation	.424**	.733**	1	.580**	.272**	.190**	.400**	.144**	.140**	.403**	.281**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.006	.008	.000	.000
	N	362	362	362	362	362	362	362	362	362	362	362
Potato amount	Pearson Correlation	.226**	.518**	.580**	1	.540**	.410**	.250**	.165**	-.021	.332**	.421**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.002	.693	.000	.000
	N	362	362	362	362	362	362	362	362	362	362	362
Carrot amount	Pearson Correlation	.150**	.229**	.272**	.540**	1	.619**	.310**	.198**	.161**	.120*	.393**
	Sig. (2-tailed)	.004	.000	.000	.000		.000	.000	.000	.002	.022	.000
	N	362	362	362	362	362	362	362	362	362	362	362

Cabbage amount	Pearson Correlation	.228**	.316**	.190**	.410**	.619**	1	.357**	.146**	.228**	.274**	.486**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.005	.000	.000	.000
	N	362	362	362	362	362	362	362	362	362	362	362
Kale amount	Pearson Correlation	.324**	.424**	.400**	.250**	.310**	.357**	1	.535**	.619**	.622**	.388**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000
	N	362	362	362	362	362	362	362	362	362	362	362
Lettuce amount	Pearson Correlation	.108*	.145**	.144**	.165**	.198**	.146**	.535**	1	.266**	.421**	.354**
	Sig. (2-tailed)	.040	.006	.006	.002	.000	.005	.000		.000	.000	.000
	N	362	362	362	362	362	362	362	362	362	362	362
Swiss chard amount	Pearson Correlation	.328**	.245**	.140**	-.021	.161**	.228**	.619**	.266**	1	.343**	.152**
	Sig. (2-tailed)	.000	.000	.008	.693	.002	.000	.000	.000		.000	.004
	N	362	362	362	362	362	362	362	362	362	362	362

Leek amount	Pearson Correlation	.102	.410**	.403**	.332**	.120*	.274**	.622**	.421**	.343**	1	.535**
	Sig. (2-tailed)	.053	.000	.000	.000	.022	.000	.000	.000	.000		.000
	N	362	362	362	362	362	362	362	362	362	362	362
Green paper amount	Pearson Correlation	.292**	.381**	.281**	.421**	.393**	.486**	.388**	.354**	.152**	.535**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.004	.000	
	N	362	362	362	362	362	362	362	362	362	362	362

****. Correlation is significant at the 0.01 level (2-tailed).**

***. Correlation is significant at the 0.05 level (2-tailed).**

4.1.6. Cause and Effect Result

Onion

The table below presents the statistical description of the mean onion consumption amount. Which is 4.768 and the mean of family size, which is 4.86 across 362 sample respondents (see table 4.24).

Table 4. 24 Onion amount of descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Onion amount	4.7680	1.28975	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of onion consumption amount.

In the table below, the R square of the model summary is the measure of the amount of variance in the dependent variable that is caused by the independent variable (predictor). R2=0.451, the predictor (independent variable) family size is responsible for 45.1% of the variance in onion consumption amount (see table 4.25).

Table 4. 25 Regression predicting Onion amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.671[a]	.451	.449	.95708	.451	295.577	1	360	.000

a. Predictors: (Constant), family size

The ANOVA table below, is a test of where the above R2 is significantly greater than zero. The overall regression model was significant, F (1,360) =295.577, $p<0.05$, R2=0.451 (see table 4.26).

Table 4. 26 ANOVA test for onion amount

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	270.749	1	270.749	295.577	.000[b]
	Residual	329.760	360	.916		
	Total	**600.508**	**361**			

a. Dependent Variable: onion amount

b. Predictors: (Constant), family size

In the coefficients displayed in Table 4.27, the regression model for family size is significant (B=.743, t=17.192, $p<0.05$), tested at Alpha 0.05, which indicates that family size has a significantly positive impact on onion consumption amount. When the family size increases by one person the onion consumption amount increases by 0.743kg.

Table 4. 27 Beta Coefficient of onion amount

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.155	.216		5.347	.000
	Family size	.743	.043	.671	17.192	.000

a. Dependent Variable: onion amount

Tomato

The table below presents the statical description of the mean Tomato consumption amount, which is 3.3923, and the mean family size, which is 4.86 across 362 sample respondents (see table 4.28).

Table 4. 28 Tomato amount descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Tomato amount	3.3923	1.36872	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of tomato consumption amount.

In the table below, the R square of the model summary is the measure of the amount of variance in the dependent variable that is caused by the independent variable (predictor). R2=0.18, the predictor (independent variable) family size is responsible for 18% of the variance in tomato consumption amount (see table 4.29).

Table 4. 29 Regression predicting Tomato amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.424[a]	.180	.177	1.24135	.180	78.882	1	360	.000

a. Predictors: (Constant), family size

The ANOVA table below is a test of where the above R2 is significantly greater than zero. The overall regression model was significant, F (1,360) =78.882, $p<0.05$, $R^2=0.18$ (see table 4.30).

Table 4. 30 ANOVA test for tomato amount

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	121.553	1	121.553	78.882	.000[b]
	Residual	554.745	360	1.541		
	Total	676.298	361			

a. Dependent Variable: tomato amount

b. Predictors: (Constant), family size

In the coefficients displayed in Table 4.31, the regression model for family size is significant (B=.498, t=8.882, $p<0.05$), tested at Alpha 0.05, which indicates that family size has a significant positive impact on tomato consumption amount. When the family size increases by one person the tomato consumption amount increases by 0.498kg.

Table 4. 31 Beta coefficient of tomato amount

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.972	.280		3.467	.001
	Family size	.498	.056	.424	8.882	.000

a. Dependent Variable: tomato amount

Potato

The table below presents the statistical description of the mean of potato consumption amount, which is 2.755 and the mean of family size, which is 4.86 across 362 sample respondents (see table 4.32).

Table 4. 32 Potato amounts descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Potato amount	2.7555	1.23949	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of potato consumption amount.

In the table below, the R square of the model summary is the measure of the amount of variance in the dependent variable that is caused by the independent variable (predictor). R2=0.051, the predictor (independent variable) family size is responsible for 5.1% of the variance in potato consumption amount (see table 4.33).

Table 4. 33 Regression predicting potato amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df 1	df2	Sig. F Change
1	.226[a]	.051	.049	1.20896	.051	19.460	1	360	.000

a. Predictors: (Constant), family size

The ANOVA table below is a test of where the above R2 is significantly greater than zero. The overall regression model was significant, F (1,360) =19.460, $p<0.05$, $R^2=0.051$ (see table 4.34).

Table 4. 34 ANOVA test for potato amount

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	28.442	1	28.442	19.460	.000[b]
	Residual	526.172	360	1.462		
	Total	554.614	361			

a. Dependent Variable: potato amount

b. Predictors: (Constant), family size

In the coefficients displayed in table 4.35, the regression model for family size is significant (B=.241, t=4.411, $p<0.05$), tested at Alpha 0.05, which indicates that family size has a significant positive impact in potato consumption amount. When the family size increases by one person the potato consumption amount increases by 0.241kg.

Table 4. 35 The beta coefficient of onion amount

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.585	.273		5.806	.000
	Family size	.241	.055	.226	4.411	.000

a. Dependent Variable: potato amount

Carrot

The table below presents the statistical description of the mean carrot consumption amount, which is 2.034, and the mean family size, which is 4.86 across 362 sample respondents (see table 4.36).

Table 4. 36 Carrot amounts descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Carrot amount	2.0345	.92939	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of carrot consumption amount.

In the table below, the R square of the model summary is the measure of the amount of variance in the dependent variable that is caused by the independent variable (predictor). R2=0.023, the predictor (independent variable) family size is responsible for 2.3% of the variance in carrot consumption amount (see table 4.37).

Table 4. 37 Regression predicting carrot amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.150[a]	.023	.020	.92010	.023	8.327	1	360	.004

a. Predictors: (Constant), family size

The ANOVA table below is a test of where the above R2 is significantly greater than zero. The overall regression model was significant, $F(1,360) = 8.327$, $p<0.05$, $R^2=0.023$ (see table 4.38).

Table 4. 38 ANOVA test for carrot amount

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.049	1	7.049	8.327	.004[b]
	Residual	304.769	360	.847		
	Total	311.818	361			

a. Dependent Variable: carrot amount

b. Predictors: (Constant), family size

In the coefficients displayed in Table 4.39, the regression model for family size is significant ($B=.12$, $t=2.886$, $p<0.05$), tested at Alpha 0.05, which indicates that family size has a significant positive impact in carrot consumption amount. When the family size increases by one person the carrot consumption amount increases by 0.12kg.

Table 4. 39 The beta coefficient of carrot amount

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.452	.208		6.988	.000
	Family size	.120	.042	.150	2.886	.004

a. Dependent Variable: carrot amount

Cabbage

The table below presents the statistical description of the mean cabbage consumption amount. Which is 1.668 and the mean of family size, which is 4.86 across 362 sample respondents (see table 4.40).

Table 4. 40 Cabbage amount descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Cabbage amount	1.6685	1.17006	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of cabbage consumption amount.

In the table below, the R square of the model summary is the measure of the amount of variance in the dependent variable that is caused by the independent variable (predictor). R2=0.052, the predictor (independent variable) family size is responsible for 5.2% of the variance in cabbage consumption amount (see table 4.41).

Table 4. 41 Regression predicting cabbage amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.228[a]	.052	.049	1.14087	.052	19.709	1	360	.000

a. Predictors: (Constant), family size

The ANOVA table below is a test of where the above R2 is significantly greater than zero. The overall regression model was significant, F (1,360) =19.709, $p<0.05$, $R^2=0.052$ (see table 4.42).

Table 4. 42 ANOVA test for onion amount

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	25.653	1	25.653	19.709	.000[b]
	Residual	468.568	360	1.302		
	Total	494.221	361			

a. Dependent Variable: cabbage amount

b. Predictors: (Constant), family size

In the coefficients displayed in Table 4.43, the regression model for family size is significant (B=.229, t=4.436, $p<0.05$), tested at Alpha 0.05, which indicates that family size has significant positive impact in cabbage consumption amount. When the family size increases by one person the cabbage consumption amount increases by 0.229kg.

Table 4. 43 The beta coefficient of cabbage amount

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.557	.258		2.161	.031
	Family size	.229	.052	.228	4.439	.000

a. Dependent Variable: cabbage amount

Kale

The table below presents the statistical description of the mean kale consumption amount, which is 1.216, and the mean family size, which is 4.86 across 362 sample respondents (see table 4.44).

Table 4. 44 A kale amount of descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Kale amount	1.2162	.72001	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of kale consumption amount.

In the table below, the R square of the model summary is the measure of the amount of variance in the dependent variable that is caused by the independent variable (predictor). R2=0.105, the predictor (independent variable) family size is responsible for 10.5% of the variance in kale consumption amount (see table 4.45).

Table 4. 45 Regression predicting kale amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df 1	df2	Sig. F Change
1	.324[a]	.105	.102	.68218	.105	42.154	1	360	.000

a. Predictors: (Constant), family size

The ANOVA table below is a test of where the above R2 is significantly greater than zero. The overall regression model was significant, F (1,360) =42.154, $p<0.05$, $R^2=0.105$ (see table 4.46).

Table 4. 46 ANOVA test for kale amount

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19.617	1	19.617	42.154	.000[b]
	Residual	167.531	360	.465		
	Total	187.148	361			

a. Dependent Variable: kale amount
b. Predictors: (Constant), family size

In the coefficients displayed in Table 4.47, the regression model for family size is significant (B=.200, t=6.493, $p<0.05$), tested at Alpha 0.05, which indicates that family size has a significant positive impact on kale consumption amount. When the family size increases by one person the kale consumption amount increases by 0.2kg.

Table 4. 47 The beta coefficient of kale amount

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.244	.154		1.583	.114
	Family size	.200	.031	.324	6.493	.000

a. Dependent Variable: kale amount

Lettuce

The table below presents the statistical description of the mean lettuce consumption amount, which is 0.873, and the mean family size, which is 4.86 across 362 sample respondents (see table 4.48).

Table 4. 48 Lettuce amounts of descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Lettuce amount	.8736	.69556	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of lettuce consumption amount.

In the table below, the R square of the model summary is the measure of the amount of variance in the dependent variable that is caused by the independent variable (predictor). R2=0.012, the predictor (independent variable) family size is responsible for 1.2% of the variance in lettuce consumption amount (see table 4.49).

Table 4. 49 Regression predicting lettuce amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df 1	df2	Sig. F Change
1	.108[a]	.012	.009	.69246	.012	4.239	1	360	.040

a. Predictors: (Constant), family size

The ANOVA table below is a test of where the above R2 is significantly greater than zero. The overall regression model was significant, F (1,360) =4.239, $p<0.05$, $R^2=0.012$ (see table 4.50).

Table 4. 50 ANOVA test for lettuce amount

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.033	1	2.033	4.239	.040[b]
	Residual	172.623	360	.480		
	Total	174.656	361			

a. Dependent Variable: lettuce amount

b. Predictors: (Constant), family size

In the coefficients displayed in Table 4.51, the regression model for family size is significant (B=.064, t=2.059, $p<0.05$), tested at Alpha 0.05, which indicates that family size has a significantly positive impact on lettuce consumption amount. When the family size increases by one person the lettuce consumption amount increases by 0.064kg.

Table 4. 51 The beta coefficient of lettuce amount

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.561	.156		3.586	.000
	Family size	.064	.031	.108	2.059	.040

a. Dependent Variable: lettuce amount

Swiss chard

The table below presents the statistical description of the mean of Swiss chard consumption amount, which is 0.652, and the mean of family size, which is 4.86 across 362 sample respondents (see table 4.52).

Table 4. 52 Swiss Chard descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Swiss chard amount	.6526	.64327	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of Swiss chard consumption amount.

In the table below, the R square of the model summary is the measure of the amount of variance in the dependent variable that is caused by the independent variable (predictor). R2=0.108, the predictor (independent variable) family size is responsible for 10.8% of the variance in Swiss chard consumption amount (see table 4.53).

Table 4. 53 Regression predicting Swiss chard amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df 1	df2	Sig. F Change
1	.328[a]	.108	.105	.60847	.108	43.466	1	360	.000

a. Predictors: (Constant), family size

The ANOVA table below is a test of where the above R2 is significantly greater than zero. The overall regression model was significant, F (1,360) =43.466, $p<0.05$, $R^2=0.108$ (see table 4.54).

Table 4. 54 ANOVA test for Swiss chard amount

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16.093	1	16.093	43.466	.000[b]
	Residual	133.287	360	.370		
	Total	149.380	361			

a. Dependent Variable: Swiss chard amount

b. Predictors: (Constant), family size

In the coefficients displayed in Table 4.55, the regression model for family size is significant (B=.181, t=6.593, $p<0.05$), tested at Alpha 0.05, which indicates that family size has a significant positive impact on Swiss chard consumption amount. When the family size increases by one person the Swiss chard consumption amount increases by 0.181kg.

Table 4. 55 The beta coefficient of Swiss chard amount

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.228	.137		-1.661	.098
	Family size	.181	.027	.328	6.593	.000

a. Dependent Variable: Swiss chard amount

Leek

The table below presents the statistical description of the mean of leek consumption amount, which is 0.3709, and the mean of family size, which is 4.86 across 362 sample respondents (see table 4.56)

Table 4. 56 A leek amount of descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Leek amount	.3709	.54608	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of leek consumption amount.

In the table below, the significance value is greater than 0.05, which means the family size doesn't significantly impact the leek consumption amount (see table 4.57).

Table 4. 57 Regression predicts leek amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.102[a]	.010	.008	.54398	.010	3.782	1	360	.053

a. Predictors: (Constant), family size

Green Pepper

The table below presents the statistical description of the mean of leek consumption amount, which is 0.435, and the mean of family size, which is 4.86 across 362 sample respondents (see table 4.58)

Table 4. 58 Green pepper amount descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Green paper amount	.4358	.24015	362
Family size	4.86	1.165	362

The result of the criterion (dependent) variable is presented below. The analysis is to test the independent variable (predictor) family size account for the variance of green pepper consumption amount.

In the table below, the R square of the model summary is the measure of the amount of variance in the dependent variable that is caused by the independent variable (predictor). R2=0.085, the predictor (independent variable) family size is responsible for 8.5% of the variance in green pepper consumption amount (see table 4.59).

Table 4. 59 Regression predicting green pepper amount

Model Summary									
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.292[a]	.085	.083	.23001	.085	33.525	1	360	.000

a. Predictors: (Constant), family size

The ANOVA table below is a test of where the above R2 is significantly greater than zero. The overall regression model was significant, F (1,360) =33.525, $p<0.05$, $R^2=0.085$ (see table 4.60).

Table 4. 60 ANOVA test for green pepper amount

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.774	1	1.774	33.525	.000[b]
	Residual	19.046	360	.053		
	Total	20.819	361			

a. Dependent Variable: green paper amount
b. Predictors: (Constant), family size

In the coefficients displayed in Table 4.61, the regression model for family size is significant (B=0.060, t=5.790, $p<0.05$), tested at Alpha 0.05, which indicates that family size has a significantly positive impact on green pepper consumption amount. When the family size increases by one person the green pepper consumption amount increases by 0.06kg.

Table 4. 61 The beta coefficient of green pepper amount

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.143	.052		2.761	.006
	Family size	.060	.010	.292	5.790	.000

a. Dependent Variable: green paper amount

4.1.7. Summary of Vegetable Consumption of Households

Based on the respondent household's information and the above analysis result the average vegetable consumption amount is summarized in table 4.62 below. Each vegetable has a different weekly average consumption amount in kg (Figure 4.3)

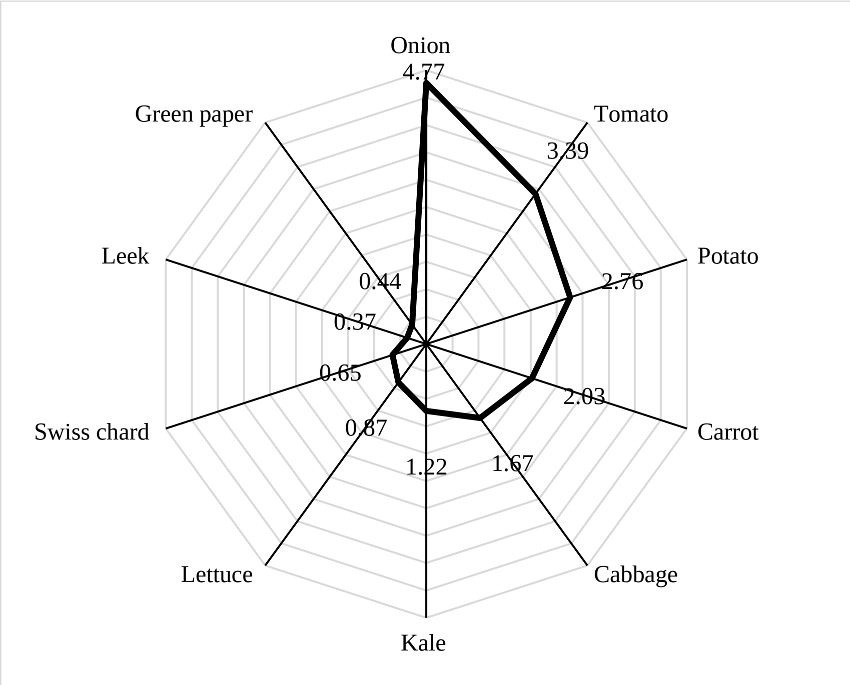


Figure 4. 3 weekly average consumption of each vegetable in kg

Table 4. 62 Summary of vegetable consumption amount

	Weekly consumption of HH		**Annual consumption of HH**		**Annual consumption of a population**	
Values	In kg	In calories	In kg	In calories	In kg	In calories
Onion	4.77	1,431	247.93	74,412	953,305.1	286,114,140
Tomato	3.39	734.5	176.40	38,194	678,249.5	146,855,930
Potato	2.76	3,382.2	143.29	175,874.4	550,939.6	676,237,068

Carrot	2.03	441.3	105.80	22,947.6	406,784	88,233,522
Cabbage	1.67	208.7	86.76	10,852.4	333,601.5	41,727,478
Kale	1.22	536.8	63.24	27,913.6	243,159	107,327,792
Lettuce	0.87	121.8	45.43	6,333.6	174,671.3	24,352,692
Swiss chard	0.65	137.4	33.94	7,144.8	130,485.7	27,471,756
Leek	0.37	113.4	19.28	5,896.8	74,149	22,673,196
Green paper	0.44	176	22.66	9,152	87,128.5	35,189,440
Total	**18.17**	**4,949.7**	**944.73**	**313,180**	**3,632,473.4**	**1,204,169,438**

The average family size of a household in the study area is 4.86. The total vegetable consumption of the household weekly is 18.7kg or 4,949.7kcalories and annually is 944.73kg or 313,180kcalories. The total vegetable consumption of the population annually is 3,632,473.4kg (3,632.4 ton) or 1,204,169,438kcalories.

4.2.Potential Vertical Surface Area of the Building

4.2.1. Surface Area of B+G+8 Building Typology

In all the three sites there are two typology of building blocks, the B+G+8 and the B+G+10. The total building footprint area of the B+G+8 building block typology is 986.75m^2 and the total vertical wall surface area of the building is 3,337.31m^2 (figure 4.4). The building has a 3.3m room height with a basement floor. The opening area is 884.63m^2 which is 26.39% of the overall. The remaining surface area which is a blind wall that can serve for a vegetable plantation is 2,456.68m^2 which is 73.61% of the overall (see table 4.63 below).

Figure 4. 4 B+G+8 Building typology elevations a) front b) right c) left d) rear

Table 4. 63 Surface area of B+G+8 building typology

Building elevation	Total wall area of selected wall (m2)	Window area of selected wall (m2)	Bare wall area (m2)	% of Bare wall compared to selected wall total area	% of a bare wall compared to the total building footprint	Total building footprint (m2)
Front elevation	1010.45	402.75	607.7	60.14	61.58	986.75
Rear elevation	974.23	156.3	817.93	83.95	82.89	

Right side elevation	654.97	167.20	487.77	74.4	49.43
Left side elevation	697.66	158.38	539.28	77.29	54.65
Total	**3,337.31**	**884.63**	**2,456.68**	**73.61**	**248.56**

4.2.2. Surface Area of B+G+10 Building Typology

The total building footprint area of the B+G+10 block typology is 1,508.22m^2 and the vertical surface area of the wall is 6,612.94m^2 (figure 4.5). The building has a 3.0m room height with a basement floor. The opening area is 1,768.05m^2 which is 26.74% of the overall. The remaining surface area which is a blind wall that can serve for vegetable plantation is 4,844.89 which is 73.26% of the overall (see table 4.64 below)

a b c d

Figure 4. 5 B+G+10 Building typology elevations a) front b) right c) left d) rear

Table 4. 64 surface area of B+G+10 Building typology

Building elevation	Total wall area of selected wall (m^2)	Window area of selected wall (m^2)	Bare wall area (m^2)	% of Bare wall compared to selected wall total area	% of a bare wall compared to the total building footprint	Total building footprint (m^2)
Front elevation	1236.75	444.01	792.74	64.09	52.56	1508.22
Rear elevation	1262.11	442.51	819.6	64.9	54.34	
Right side elevation	1450	461.43	988.57	68.17	65.54	
Left side elevation	1356.1	229.54	1126.56	83.07	74.69	
Courtyard	1308	190.56	1117.44	85.43	74.08	
Total	**6612.94**	**1768.05**	**4844.89**	**73.26**	**321.23**	

There are three sites in the study area. Site 1 has 14 blocks of B+G+8 building typology. So, the total blind surface area available in the site 1 is 34,393.52m^2 (3.4393ha). Site 2 has 20 blocks of B+G+8 building typology and 18 blocks of B+G+10 typology. The total blind surface area in the site 2 is 136,342.61m^2(13.6342ha). Site 3 has 32 blocks of B+G+8 building typology and 9 blocks of B+G+10 building typology. The total blind surface area in the site 3 is 122,217.77m^2(12.2217ha). The total potential vertical surface area of the building is 292,953.9m2(29.2953ha).

4.2.3. Potential Blind Surface Area Based on the Building Blocks Orientation and Day Light Exposure

Figure 4.6 below shows the annual sun orientation path and Figure 4.7 below presents the potential surface area of each building typology and their orientation within the season variation and daylight exposure hour length.

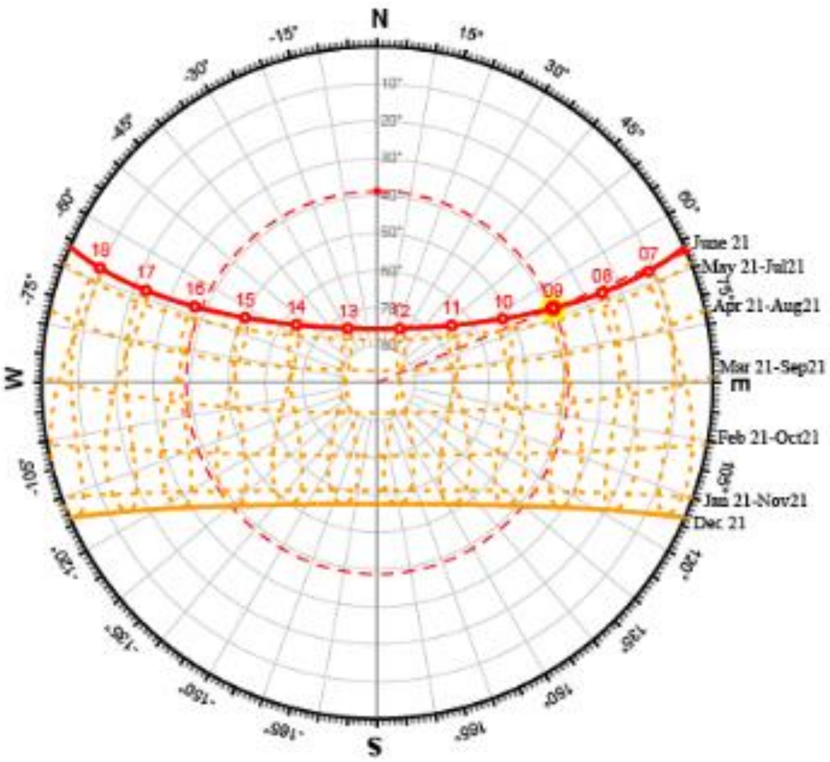


Figure 4. 6 Annual sun path diagram

B+G+8 Orientation 1

Dec 21 | Jun 21

9:00 AM 3:00 pm | 9:00 AM 3:00 pm

6 Hours/day - 607.7m^2 * 18 = 10,938.6m^2
4 Hours/day - 957.99m^2 * 18 = 17,243m^2

6 Hours/day - 496.52m^2 * 18=8,937.36m^2
4 Hours/day - 1,310.33m^2 * 18=23,585.94m^2

B+G+8 Orientation 2

Dec 21 | Jun 21

9:00 AM 3:00 pm | 9:00 AM 3:00 pm

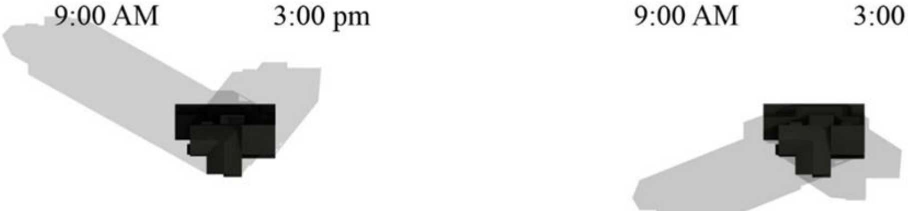
6 Hours/day - 607.7m^2 * 1= 607.7m^2
4 Hours/day - 957.99m^2 * 1 = 957.99m^2

6 Hours/day - 496.52m^2* 1= 496.52m^2
4 Hours/day - 1,310.33m^2 * 1= 1,310.33m^2

B+G+8 Orientation 3

Dec 21 | Jun 21

9:00 AM 3:00 pm | 9:00 AM 3:00 pm



6 Hours/day - 496.52m^2 *4 = 1,986.08m^2
4 Hours/day - 1,310.33m^2 *4= 5,241.32m^2

6 Hours/day - 607.7m^2 *4 = 2,430.8m^2
4 Hours/day - 957.99m^2 *4 = 3,831.96m^2

B+G+8 Orientation 4

Dec 21 | Jun 21

9:00 AM 3:00 pm | 9:00 AM 3:00 pm

6 Hours/day - 496.52m^2*7 = 3,475.64m^2
4 Hours/day - 1,310.33m^2 *7 = 9,172.31m^2

6 Hours/day - 607.7m^2 *7 = 4,253.9m^2
4 Hours/day - 957.99m^2*7 = 6,705.93m^2

G+8 Orientation 5

Dec 21

9:00 AM 3:00 pm

6 Hours/day - 249.15m² *12 = 2,989.8m²
4 Hours/day - 726.78m² *12 = 8,721.36m²

Jun 21

9:00 AM 3:00 pm

6 Hours/day - 192.3m²*12 = 2,307.6m²
4 Hours/day - 868.27m²*12 = 10,419.24m²

B+G+8 Orientation 6

Dec 21

9:00 AM 3:00 pm

6 Hours/day - 249.15m²*13 = 3,238.95m²
4 Hours/day - 726.78m² *13 = 9,448.14m²

Jun 21

9:00 AM 3:00 pm

6 Hours/day - 192.3m² *13 = 2,499.9m²
4 Hours/day - 868.27m² *13 = 11,287.51m²

B+G+8 Orientation 7

Dec 21

9:00 AM 3:00 pm

6 Hours/day - 192.3m²*1=192.3m²
4 Hours/day - 868.27m²*1=868.27m²

Jun 21

9:00 AM 3:00 pm

6 Hours/day - 249.15m²*1=249.15m²
4 Hours/day - 726.78m² *1=726.78m²

B+G+8 Orientation 8

Dec 21

9:00 AM 3:00 pm

6 Hours/day - 192.3m²*10=1,923m²
4 Hours/day - 868.27m² *10 =8,682.7m²

Jun 21

9:00 AM 3:00 pm

6 Hours/day - 249.15m²*10=2,491.5m²
4 Hours/day - 726.78m²*10=7,267.8m²

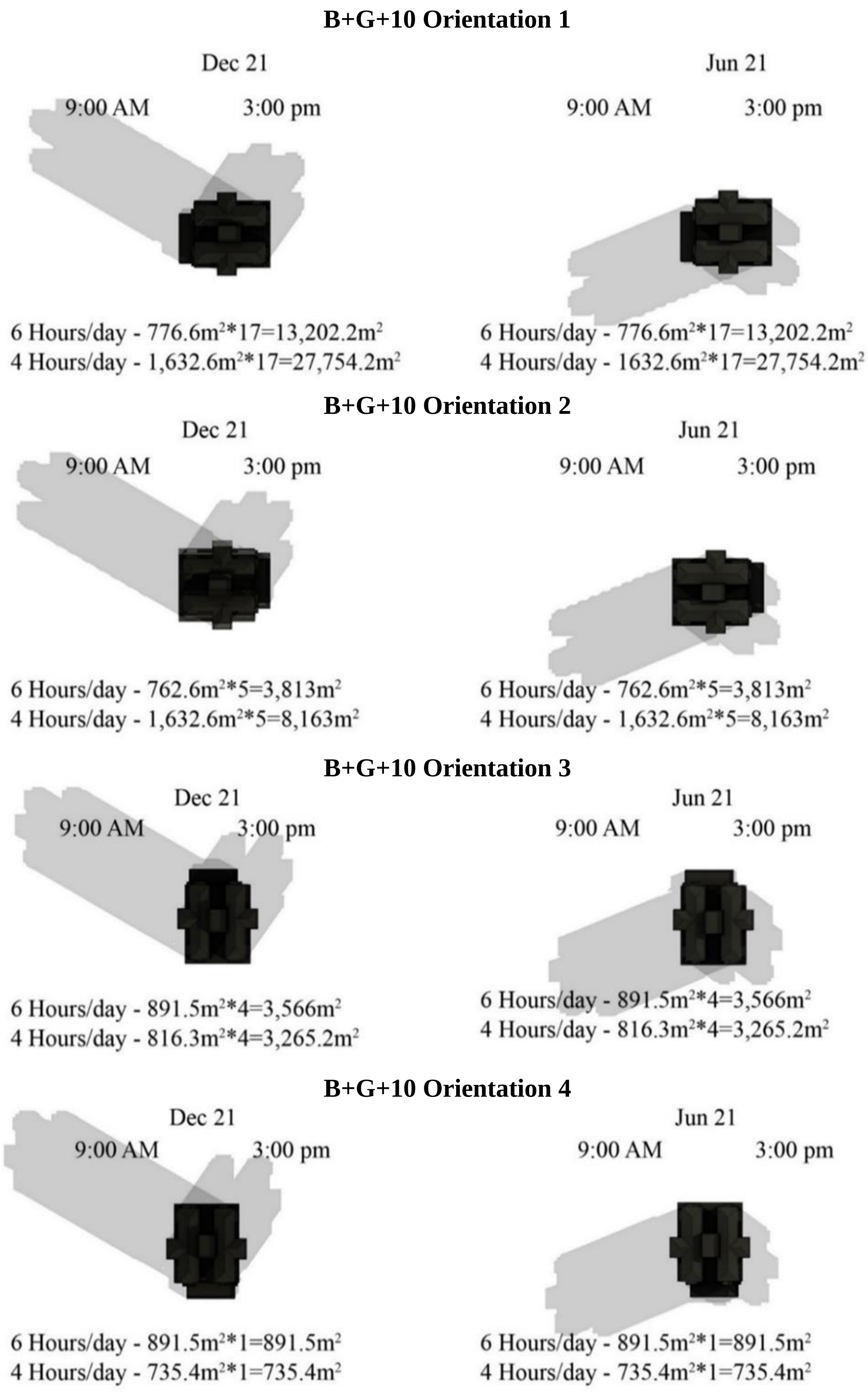


Figure 4. 7 six hour and four hour exposed surface area of each building orientation

The table 4.65 below shows the total available and potential surface area for the vegetable farming technology for every group of buildings based on their corresponding orientation throughout the year.

Table 4. 65 Potential surface area of each building typologies

		potential areas in m^2			
	NO. Of blocks	Oct, Nov, Dec, Jan, Feb, Mar		Apr, May, Jun, Jul, Aug, Sep	
		6 hours/day	4 hours/day	6 hours/day	4 hours/day
		B+G+8			
Orientation 1	18	10,938.60	17,243	8,937.36	23,585.94
Orientation 2	1	607.7	957.99	496.52	1,310.33
Orientation 3	4	1,986.08	5,241.32	2,430.80	3,831.96
Orientation 4	7	3,475.64	9,172.31	4,253.90	6,705.93
Orientation 5	12	2,989.80	8,721.36	2,307.60	10,419.24
Orientation 6	13	3,238.95	9,448.14	2,499.90	11,287.51
Orientation 7	1	192.3	868.27	249.15	726.78
Orientation 8	10	1,923	8,682.70	2,491.50	7,267.80
		B+G+10			
Orientation 1	17	13,202.20	27,754.20	13,202.20	27,754.20
Orientation 2	5	3,813	8,163	3,813	8,163
Orientation 3	4	3,566	3,265.20	3,566	3,265.20
Orientation 4	1	891.5	735.4	891.5	735.4
Total		46,824.77	100,252.89	45,139.43	105,053.29

The Figure 4.8 below shows the total potential surface area of each building typologies with respect to their orientation, sun orientation season and day light exposure hour length.

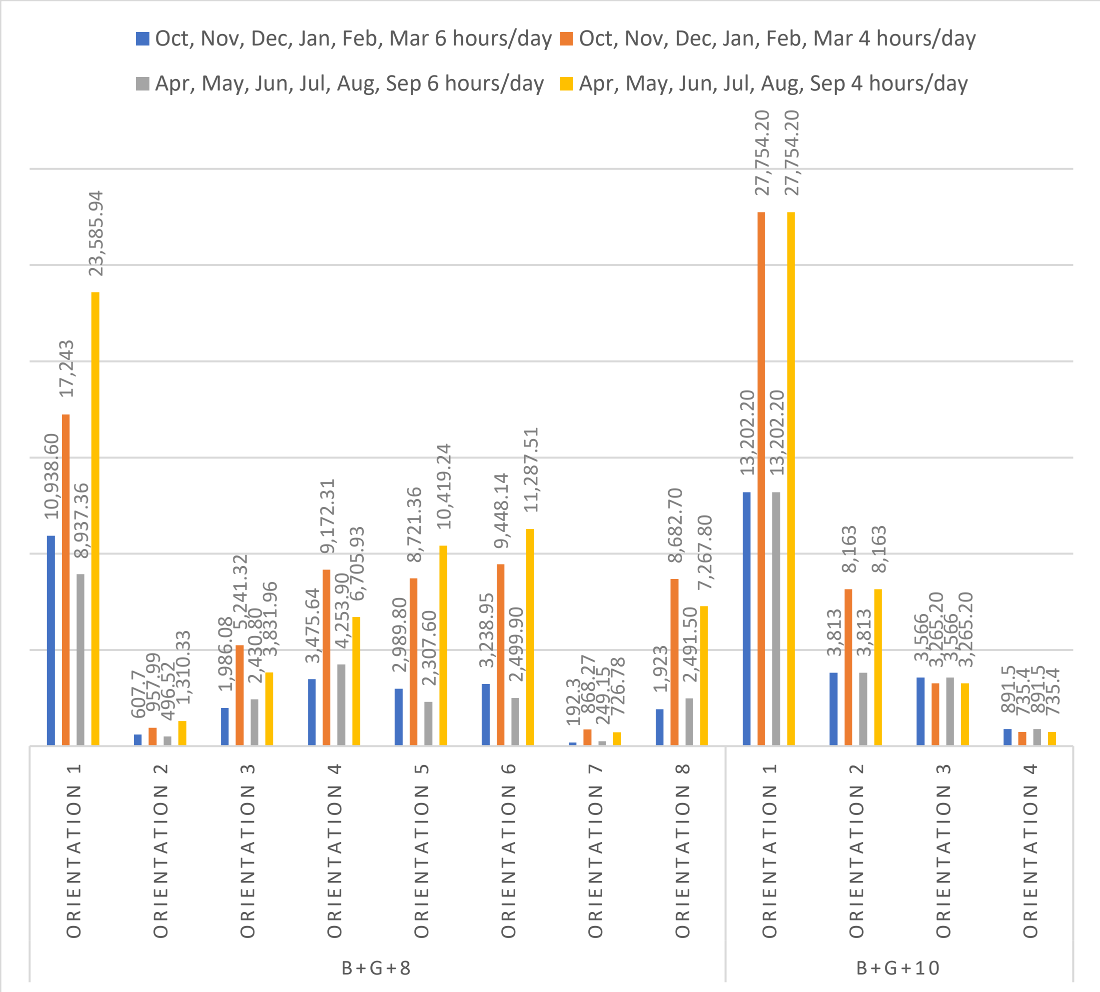


Figure 4. 8 total surface area of each building typologies and their orientation

4.3.Productivity of the Land

The main crop produced from the land in traditional agriculture in the area is Teff. As of the most peripheral areas of Addis Ababa city, the farmers who farms the agricultural land traditionally produces teff as a main crop to supply for the city. Based on the response of the interviewed three farmers around the site, they harvest average of 1.5ton of Teff annually per hectare. Since the Calorie amount of 1 kg Teff is 3,350kcal, 1.5ton (1,500kg) of tef can have 5,025,000kcal/year. The total site area is 31 hectares. The three residential sites would produce 46.5ton (46,500kg) of teff. This is 155,775,000kcal/year.

4.4.Compatible Vertical Farming Technology

4.4.1. Characteristics of Vegetables.

Vegetable requirement of day light or direct sun light differs from vegetable to vegetable. In general, there are three categories, full sun, partial sun and shade.

Full sun – Full sun daylight requirement means vegetables have to get from six hours to eight hours and more of direct sun light throughout the day.

Partial sun- partial sun day light requirement refers to vegetables needs access of four to six hours of a day typically either in the morning or the afternoon.

Partial shade or Full shade- Partial shade or full shade means access of two to four hours a day or no direct sunlight at all.

The table 4.66 below explains the characteristics of each vegetable. These characteristics includes, day light requirement, spacing requirement, cultivation days and harvesting yield. Vegetable with the longest root depth is carrot, which is average of 25 cm.

Table 4. 66 Vegetables characteristics

vegetables	Day light hour/day	Spacing in cm	Cultivation days	Round per year	Harvest yield kg/m^2
Onion	6	10	85-120	4	5.2
Tomato	6	60	65-90	4	8.9
Potato	4	20	80-100	4	4.4

Carrot	6	5	65-75	4	2
Cabbage	6	30	60-90	4	5.2
Kale	4	20	40-80	5	2.8
Lettuce	4	15	40-80	5	2.7
Swiss chard	4	10	50-70	5	3.5
Leek	6	10	70-120	4	2.2
Green pepper	6	30	70-85	4	2.3

The vegetable preference and consumption number of households in study area analyzed and interpreted above. The interpreted data shows ten most commonly used vegetables. Based on the study area building typology, their cardinal orientation, and their respective potential day light exposure the potential blind surface for vertical vegetable farming identified in different season. Also based on their day light requirement vegetables are classified in to two groups full sun and partial shade/ partial sun vegetables.

4.4.2. Design and Development

Based the literature and data analysis, modular living wall is preferable for vegetable production on the façade of the building. The modular living wall using planter box and soil growing medium was adopted for the design. The design used steel structures to connect with the building structures and plastic as growing medium and vegetable container. Soil is the growing medium (figure 4.9).

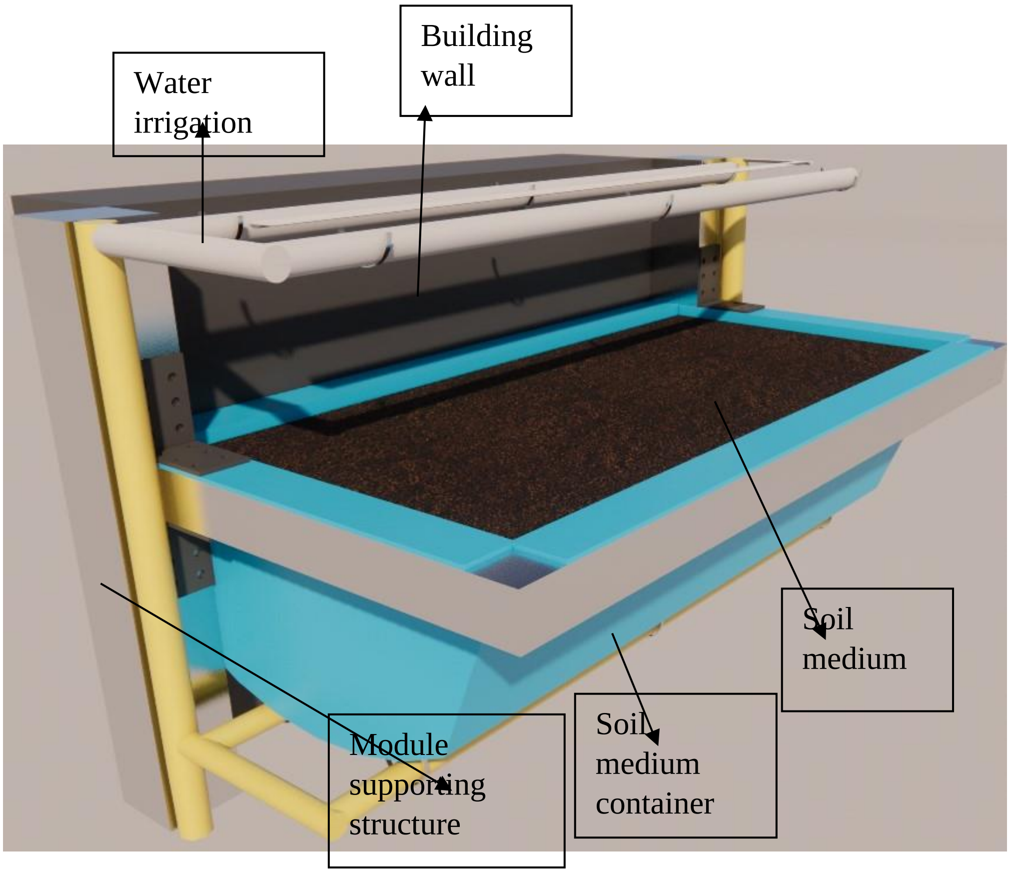


Figure 4. 9 Vegetable planter module design

Physical Properties

The module has overall dimension of 104cm x 504cm x 31cm. The soil media overall dimension is 100cm x 500cm x 25cm and volume of $0.125m^3$. The supporting structure is 2cmx2cm steel bar. The soil medium container is a light weight plastic material. There are pipelines for water irrigation (figure 4.10).

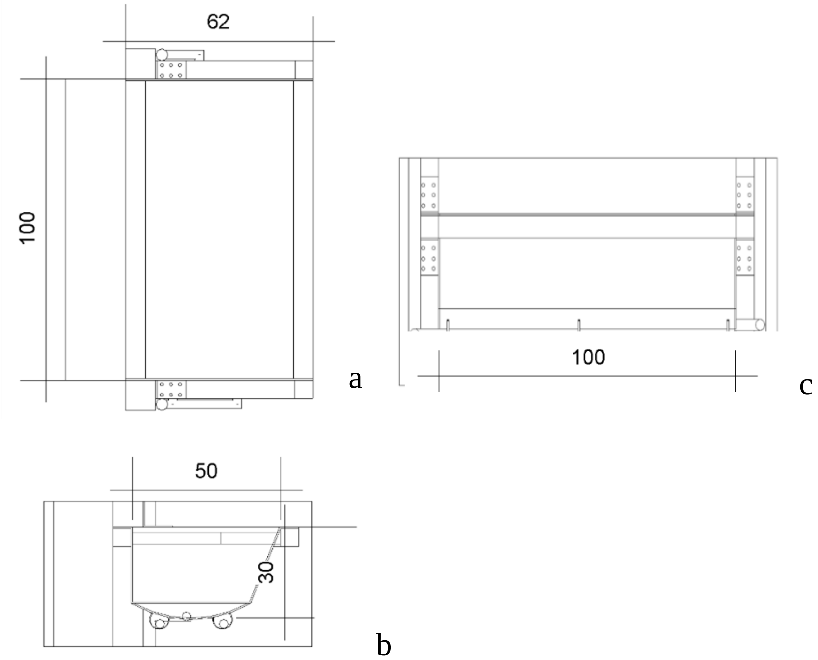


Figure 4. 10 Views of the module a) Plan b) Elevation c) Section

The single module has occupied 0.5 m^2 from the wall surface and has 0.5m^2 area of production. The areas lost for the module structure placement on the surface of the wall and production area from the module are equivalent.

4.4.3. Vegetable Production

The selected ten vegetables are grouped under six hour per day daylight requirement and 4 hours per day daylight requirement. Onion, tomato, carrot, cabbage, leek and green pepper requires six hours per day daylight. Also based on the building cardinal orientation and potential production surface area, the surface area that are exposed for minimum of six hours per day daylight in both seasons are dedicated for the six vegetables mentioned above. The remaining vegetables, potato, kale, lettuce and Swiss chard requires four hours per day daylight. And the remaining potential production surface area that are exposed for minimum four hours per day daylight in both seasons are dedicated for the four vegetables mentioned.

Space Proportion

The total potential surface area available for six per day daylight required vegetables is 91,637.77m^2 and four hour per day daylight required vegetables is 205,306.18m^2. From the available surface area, based on respondent consumption proportion each vegetables have different proportions (see table 4.67 below).

Table 4. 67 Space proportion and annual production round of each vegetable

Vegetables	Proportion (%)	Dedicated area (m^2)	Production round
	6 hours per day daylight		
Onion	37.64	34,642.75	4
Tomato	26.75	24,600.31	4
Carrot	16.02	14,732.59	4
Cabbage	13.18	12,120.82	4
Leek	2.92	2,685.34	4
Green pepper	3.49	3,209.53	4
Total	100	91,963.77	
	4 hours per day daylight		
Potato	50.18	103,022.64	4
Kale	22.18	45,536.91	5
Lettuce	15.81	32,458.90	5
Swiss chard	11.83	24,287.72	5
Total	100	205,306.18	

Depending on the vegetable's daylight requirement and available potential surface area of the building, onion, Tomato, carrot, cabbage, leek and green pepper are dedicated to be planted on the surface which gets at least 6 hours per day daylight. All the vegetables grouped in this category can be harvested four rounds per year. Potato, kale, lettuce and

Swiss chard are dedicated to be planted on the surface which gets at least 4 hours per day daylight (see Figure 4.11). Except for potato, the remaining vegetables grouped under this category can be harvested five rounds per year, but potato can be harvested four round per year.

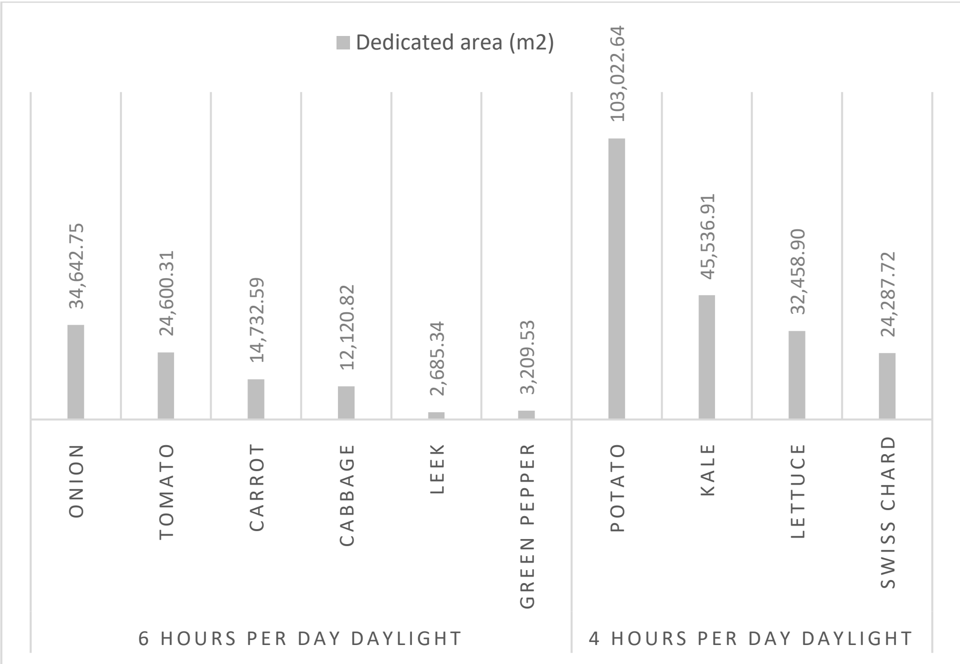


Figure 4. 11 space proportion of vegetables

Onion Production

Based on the respondent's consumption amount proportion and grouping depending on daylight requirement, onion takes 37.64% of six hour per day daylight exposed surface, which is 34,642.75m^2. Onion's yield is 5.2kg/m^2, therefore: -

$$34{,}642.75m^2 * 5.2kg/m^2 = 180{,}142.3kg$$

$$180{,}142.3kg * 4 \text{ (round/year)} = 720{,}569.2kg/year$$

$$720{,}569.2kg * 300kcalories = \mathbf{216{,}170{,}760kcalories/year}$$

Tomato Production

Tomato takes 26.75% of six hour per day daylight exposed surface, which is 24,600.31m^2. Tomato's yield is 3kg/m^2, therefore: -

$$24{,}600.31m^2 * 8.9kg/m^2 = 218{,}942.759kg$$

$$218{,}942.759kg * 4\ (round/year) = 875{,}771.03\ kg/year$$

875,771.03 kg * 216kcalories = **189,166,543.776kcalories/year**

Carrot Production

Carrot takes 16.02% of six hour per day daylight exposed surface, which is 14,732.59m^2. Carrot's yield is 2kg/m^2, therefore: -

$$14{,}732.59m^2 * 2kg/m^2 = 29{,}465.18kg$$

$$29{,}465.18kg * 4\ (round/year) = 117{,}860.72kg/year$$

117,860.72kg * 217kcalories = **25,575,782.75kcalories/year**

Cabbage Production

Cabbage takes 13.18% of six hour per day daylight exposed surface, which is 12,120.82m^2. Cabbage's yield is 5.2kg/m^2, therefore; -

$$12{,}120.82m^2 * 5.2kg/m^2 = 63{,}028.264kg$$

$$63{,}028.264kg * 4\ (round/year) = 252{,}113.05kg/year$$

252,113.05kg * 125kcalories = **31,514,132kcalories/year**

Leek Production

Leak takes 2.92% of six hour per day daylight exposed surface, which is 2,685.34m^2. Leek's yield is 2.2kg/m^2, therefore; -

$$2,685.34m^2 * 2.2kg/m^2 = 5,907.748kg$$

$$5,907.748kg * 4 \text{ (round/year)} = 23,630.99kg/year$$

23,630.99kg * 306kcalories = **7,231,082.94kcalories/year**

Green pepper Production

Green pepper takes 3.49% of six hour per day daylight exposed surface, which is 3,209.53m^2. Green pepper's yield is 2.3kg/m^2, therefore: -

$$3,209.53m^2 * 2.3kg/m^2 = 7,381.91kg$$

$$7,381.91kg * 4 \text{ (round/year)} = 29,527.67 kg$$

29,527.67kg * 400kcalories = **11,811,068kcalories**

Potato Production

Potato takes 50.18% of four hour per day daylight exposed surface, which is 103,022.64m^2. Potato's yield is 4.4kg/m^2, therefore: -

$$103,022.64m^2 * 4.4kg/m^2 = 453,299.61kg$$

$$453,299.61kg * 4 \text{ (round/year)} = 1,813,198.46kg/year$$

1,813,198.46kg * 770kcalories = **1,396,162,814.2kcalories/year**

Kale Production

Kale takes 22.18% of four hour per day daylight exposed surface, which is 45,536.91m^2. Kale's yield is 2.8kg/m^2, therefore: -

$$45,536.91m^2 * 2.8kg/m^2 = 127,503.34kg$$

$$127,503.34kg * 5 \text{ (round/year)} = 637,516.74kg/year$$

637,516.74kg * 440kcslories = **280,507,365.6kcalories/year**

Lettuce Production

Lettuce takes 15.81% of four hour per day daylight exposed surface, which is 32,458.90m^2. Lettuce's yield is 2.7kg/m^2, therefore; -

$$32,458.90m^2 * 2.7kg/m^2 = 87,639.03kg$$

$$87,639.03kg * 5 \text{ (round/year)} = 438,195.15kg/year$$

438,195.15kg * 140kcalories = **61,347,321kcalories**

Swiss chard Production

Swiss chard takes 11.83% of four hour per day daylight exposed surface, which is 24,287.72m^2. Swiss chard's yield is 3.5kg/m^2, therefore; -

$$24,287.72m^2 * 3.5kg/m^2 = 85,007.02kg$$

$$85,007.02kg * 5 \text{ (round/year)} = 425,035.1kg/year$$

425,035.1kg * 211kcalories = **89,682,406.1kcalories**

The Table 4.77 below presents the summery of annual vegetable production using vertical façade technology in kg and calories of each vegetable.

Table 4. 68 The capacity of vegetable production of vertical façade vegetable farming

	Annual production of the potential surface	
Vegetables	In kg	In calories
Onion	720,569.2	216,170,760
Tomato	875,771.03	189,166,543.776

Potato	1,813,198.46	1,396,162,814.2
Carrot	117,860.72	25,575,782.75
Cabbage	252,113.05	31,514,132
Kale	637,516.74	280,507,365.6
Lettuce	438,195.15	61,347,321
Swiss chard	425,035.1	89,682,406.1
Leek	23,630.99	7,231,082.94
Green paper	29,527.67	11,811,068
Total	**5,333,418.11**	**2,309,169,276.366**

The figure 4.12 below presents the production capacity of vertical façade vegetable farming technology using the potential surface area of the existing building.

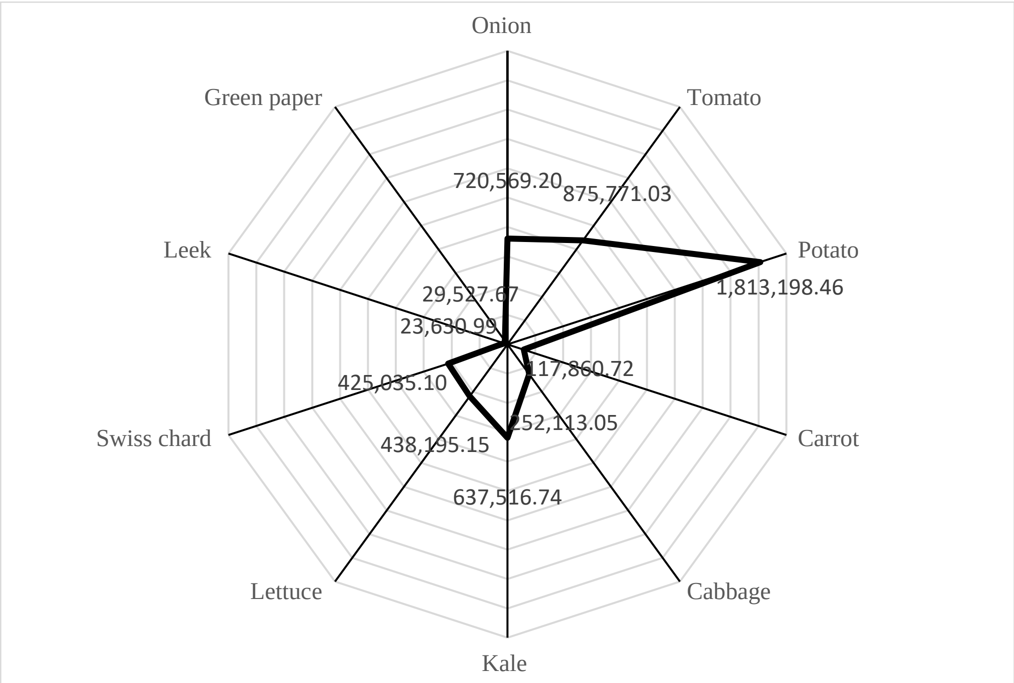


Figure 4. 12 Vertical façade vegetable farming production capacity of the potential surface area of the buildings

4.5. Discussion

To identify the vegetable consumption of the condominium housing residents, Ayat 1, sites 1, 2, and 3 were selected. From all three sites, the family size of each 3,845 households was asked, and found that the average family size is 4.8. The overall household is grouped in 1 up to 9 family size. Based on each family size group and their respective proportion, 362 households were taken as a sample and answered their vegetable consumption preference, purchase frequency, and consumption amount on their weekly basis.

The mostly consumed ten vegetables selected for the study. These vegetables are onion preferred by 362(100%) respondents, tomato preferred by 362(100%) respondents, potato preferred by 358(99%) respondents, carrot preferred by 347(96%), cabbage preferred by 294(81%), kale preferred by 334(92%), lettuce prefeed by 283(78%), Swiss chard preferred by 252(70%), leek preferred by 166(46%) and green pepper preferred by 341(94%) respondents. The weekly average purchase frequency of each vegetable shows that most of the residents purchase vegetables one day per week. The resident who purchases a vegetable once a week is, onion and tomato 202 each, potato 238, carrot 227, cabbage 220, kale 215, lettuce 213, Swiss chard 196, leek 144, green pepper 280. The weekly average vegetable consumption of the respondents also shows that; onion 4.77kg, tomato 3.39kg, potato 2.75kg, carrot, 2.03kg, cabbage 1.67kg, kale 1.21kg, lettuce 0.87kg, Swiss chard 0.65kg, leek 0.37kg, and green pepper 0.43kg.

Based on the correlation analysis and Pearsons's correlation value the relationship between family size and vegetable consumption amount was analyzed and the result shows that onion and tomato have a moderate relationship with family size and potato, carrot, cabbage, kale, lettuce, Swiss chard, and green pepper have week relationship with family size. Leak doesn't have a significant relationship with family size.

The cause-and-effect analysis of family size and each vegetable shows that except for leek family size has a positive impact on the consumption amount of every vegetable included in the study. The regression analysis shows that; the impact of family size on the consumption amount of onion is 45.1%, tomato is 18%, potato is 5.1%, carrot is 2.3%, cabbage is 5.2%, kale is 10.5%, lettuce is 1.2%, Swiss chard is 10.8% and green pepper is 8.5%. Since family size and leek consumption amount don't correlate, family size doesn't have impact on the consumption amount of leek. For every family increase by one person, vegetable consumption increases by, 0.743kg of onion, 0.498kg of tomato, 0.241kg of potato, 0.12kg of carrot, 0.229kg of cabbage, 0.2kg of kale, 0.064kg of lettuce, 0.181kg for Swiss chard and 0.06kg for green pepper. The total weekly vegetable consumption amount of a single household is 4,949.7 kcalories. The total annual vegetable consumption amount of a single household is 313,180kcalories. The total annual vegetable consumption amount of all household is 3,632,473.4kg or 1,204,169,438 kcalories.

To identify the potential vertical surface area of the building in the study area, blind wall measurement, cardinal orientation and daylight availability of the building have been used. Based on the analysis, the B+G+8 building typology has 8 orientations and two sun rotation direction seasons and the B+G+10 building typology has 4 orientations and two sun rotation directions. The sun's rotation direction is from east to west through north and east to west through south. In both sun rotation directions, there is either a 6-hour daylight exposed surface area per day or a 4-hour daylight exposed surface per day. The 4-hour daylight per day and 6-hour daylight per day is obtained from the characteristics of vegetables. B+G+8 building typology in all orientations has 49,019m2 of 6 hours per day daylight exposed and 125,470m2 of 4 hours per day daylight exposed potential surface area, which is a total of 174,489m2 potential surface area for vegetable farming. B+G+10 building typology in all orientations has 42,945.4m2 of 6 hours per day daylight exposed and 79,835.6m2 of 4 hours per day daylight exposed potential surface area, which is a total of 122,781m2 potential surface area for vegetable farming. Totally

The total land area of the study area is 31 hectares which was agricultural land before it became a residential area. Based on the farmer respondents near the site the farmers who were farming the land have been harvesting teff with an annual production yield of 46.5ton, which is 155,775,000kcal/year. In 2017/18 the Agricultural sample survey shows that the Teff yield was 1.748to/ha as Ethiopia and 1.788 ton/ha as Oromia region (CSA, 2018). This shows that the result 1.5ton/ha is less than the CSA survey.

Based on the physical characteristics of the vegetables, a modular living wall using a planter box with soil as a growing medium was adopted and designed. The module has a 0.5m2 production area and occupies 0.5m2 of the surface of the wall. Using the module on the potential blind surface of the wall vegetables can be produced.

The analysis explains that the integration of the module on the blind surface of the wall can produce the 10 most preferred vegetables. Onion production can be 720,569.2kg or 216,170,760 of calories, which is 75.58% of the annual onion consumption. Tomato production can be 875,771.03kg or 189,166,543.776 of calories, which is 128.8% of the annual tomato consumption. Potato production can be 1,813,198.46kg or 1,396,162,814.2 of calories, which is 206.46% of the annual potato consumption. Carrot production can be 117,860.72kg or 25,575,782.75 of calories, which is 28.98% of the annual carrot consumption. Cabbage production can be 252,113.05kg or 31,514,132 of calories, which is 75.52% of the annual cabbage consumption. Kale production can be 637,516.74kg or 280,507,365.6 of calories, which is 261.35% of the annual kale consumption. Lettuce production can be 438,195.15kg or 61,347,321 of calories, which is 251.91% of the annual lettuce consumption. Swiss Chard production can be 425,035.1kg or 89,682,406.1 of calories, which is 326.45% of the annual Swiss chard consumption. Leek production can be 23,630.99kg or 7,231,082.94 of calories, which is 31.89% of the annual leek consumption. Green pepper production can be 29,527.67kg or 11,811,068 of calories, which is 33.56% of the annual lettuce consumption.

In General, around 20kg of vegetables can be produced in a square meter. This result is almost similar with study in Singapore (Tablada et al. 2018). The Singapore study shows in 2om^2 façade 33-66kg of leafy greens might be produced. This shows the façade vegetable production is efficient.

From the total annual consumption of the study population, 191.76% of the required vegetables can be produced. Relative to the productivity of the land in traditional agriculture which is 155,775,000kcal/year, 2,309,169,276.366kcal/year can be regained on vertical farming technology which covers 1,482.56% of the previous production. The potential of the blind surface to produce vegetables is way more than the amount of the population requires. The required amount (100%) can be used for the resident and the remaining 91.76% can be delivered to market for the surrounding community.

4.5.1. Comparison of Annual Consumption Amount of Total Population Versus the Production of Vertical Farming Technology

The table 4.69 below presents the comparison between the annual consumption amount of the study area population and the annual production of the potential vertical surface area of the building. It shows most vegetables like tomato, potato, kale, lettuce, and

Swiss chard can be produced more than the required amount. Around 75% of Onion and cabbage requirements can be fulfilled. The remaining vegetables like carrot, leek, and green pepper, can produce almost 30% of the required amount. In general, 191.76% of the total annual required vegetables can be produced by modular living wall vertical farming technology using the building's potential vertical surface area.

The land that has been agricultural land and becomes a condominium building site and residential area could produce 155,775,000 kcal/year. Using vertical farming technology, 2,309,169,276.366kcal/year can be produced, which is 1,482.56% of the previous production.

Table 4. 69 Annual consumption of population vs annual production of the building

	Annual consumption of a population		**Annual production of the potential surface**		**Proportion of regained vs required**
Values	In kg	In calories	In kg	In calories	In %
Onion	953,305.1	286,114,140	720,569.2	216,170,760	75.58
Tomato	678,249.5	146,855,930	875,771.03	189,166,543.776	128.8
Potato	550,939.6	676,237,068	1,813,198.46	1,396,162,814.2	206.46
Carrot	406,784	88,233,522	117,860.72	25,575,782.75	28.98
Cabbage	333,601.5	41,727,478	252,113.05	31,514,132	75.52
Kale	243,159	107,327,792	637,516.74	280,507,365.6	261.35
Lettuce	174,671.3	24,352,692	438,195.15	61,347,321	251.91
Swiss chard	130,485.7	27,471,756	425,035.1	89,682,406.1	326.45
Leek	74,149	22,673,196	23,630.99	7,231,082.94	31.89

Green paper	87,128.5	35,189,440	29,527.67	11,811,068	33.56
Total	**3,632,473.4**	**1,204,169,438**	**5,333,418.11**	**2,309,169,276.366**	**191.76**

The Figure 4.13 below shows the comparison between the annual consumption of the population in calories and the annual production of the potential surface area of the study area.

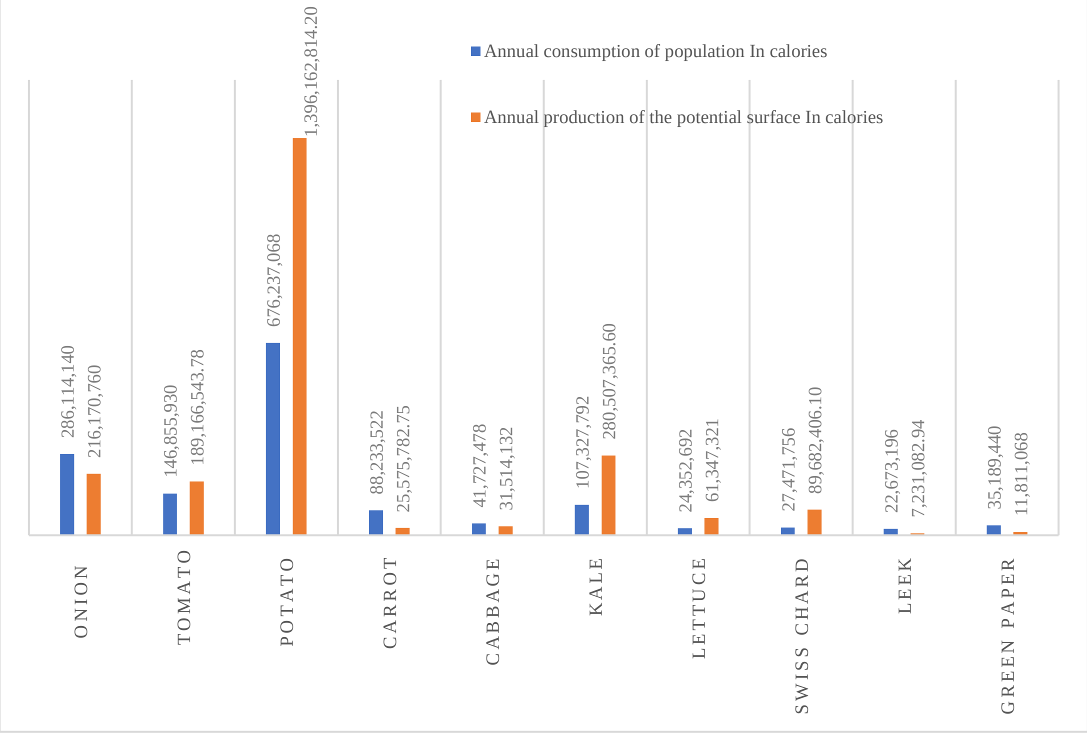


Figure 4. 13 Comparison between annual vegetable consumption and annual production

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1.Conclusion

This study was conducted to demonstrate the use of vertical façade vegetable farming as a means to reclaim agricultural land produces that has been taken over by condominium housing. By examining the vegetable consumption of the resident households, the potential surface area of the building, the previous agricultural productivity of the land and the production capacity of the modular living wall vertical farming technology on Ayat 1 sites 1, 2, and 3 condominium housing buildings the following conclusion has been made; -

- 4008 housing units are available on the site and 163 of them are empty and the remaining 3845 housing units have an average of 4.8 family-sized households. From the total household, 362 households were selected in a stratified method based on their family size for the study.
- Onion, tomato, potato, carrot, cabbage, kale, lettuce, Swiss chard, leek, and green pepper are the most ten vegetables preferred by the residents based on their weekly bases. Each vegetable is preferred in a family size based on their interest and has a different purchase frequency.
- Family size and each vegetable consumption amount of the households have a positive relationship except leek. Leak doesn’t have a relationship with family size. This means the vegetable consumption amount is impacted by family size with different levels of impact for each vegetable. The total annual vegetable consumption amount of all households is 1,204,169,438kcalories.

- The total available surface area that is potential for vertical façade vegetable farming is 174,489m^2 from the B+G+8 building typology and 122,781m^2 from the B+G+10 building typology.

- The previous agricultural productivity of the land was teff production with an annual yield of 46.5ton, which is 155,775,000kcal/year.

- Using vertical façade vegetable farming technology, 2,309,169,276.366kcal/year from all ten vegetables can be produced. This amount can fulfill 191.76% of the required vegetable consumption amount.

- Finally, by using vertical façade vegetable farming technology on the site can be the means to regain 1,482.56% of the lost agricultural produces by condominium housing.

5.2.Recommendation

- The government needs to review the green building policy and its implementation concerning vertical food production. In a developing country like Ethiopia, food scarcity is high. Vertical vegetable farming on the façade of the building can be response for the scarcity, especially in urban areas. Addis Ababa Housing Development Agency needs to consider using the blind vertical surface of the wall for vegetable production.

- Urban planners and designers also need to plan and design urban buildings enabling them to produce food. There are a variety of vertical farming technologies compatible with vegetable production on and in the building. Space between buildings, rooftops, open spaces and other different vertical farming methods can be demonstrated and implemented.

- The community who lives in existing condominium housing buildings can use vertical façade farming technology to supply their vegetable requirement. Small-scale vertical farming like balconies and indoor planters is recommended for the community.
- This study only focuses on vertical façade vegetable farming as a means to reclaim the lost agricultural land produces that has been taken over by condominium housing buildings. However, other vertical farming technologies need further study and demonstration on different buildings.

REFERENCES

Al-Kodmany, K. (2018). The Vertical Farm: A Review of Developments and Implications for the Vertical City. *Buildings*, *8*(2), 24. https://doi.org/10.3390/buildings8020024

Al-Kodmany, K. (2018). The Vertical City: A Sustainable Development Model. *WIT Press*

Allegaert, D. (2020). The Vertical Farm Industy: Exploratory Research of a Wicked Situation. *University of Wageningen*.

Aragon, N. U., Stuhlmacher, M., Smith, J. P., Clinton, N., & Georgescu, M. (2019). Urban agriculture's bounty: contributions to Phoenix's sustainability goals. *Environmental Research Letters*.

ASHRAE. 2015 ASHRAE handbook; *ashrae*

Astee, L.Y.; Kishnani, N.T. (2010). Building integrated agriculture: Utilising rooftops for sustainable food crop cultivation in Singapore. J. *Green Build*.

Bruno Venditti. (2023). World Economic Forum https://www.weforum.org/agenda/2022/04/global-urbanization-material-consumption. (Accessed in Sep. 2023)

Blaustein-Rejto, D. (2011). Harvard Economist Claims Urban Farms Do More Harm Than Good. *Inhabitat*, Available online: http://inhabitat.com/harvard-economist-claims-urban-farms-do-more-harm-than-good/ (accessed on 12 April 2023).

Central Statistical Agency (Ethiopia), Government of Ethiopia, United Nations Population Fund (UNFPA), United Nations Development Program (UNDP)

(2008). Ethiopia Population and Housing Census. Addis Ababa, Ethiopia: Central Statistical Agency (Ethiopia); 2007. Summary and statistical report, December 2008, Addis Ababa.

Chatterjee, Anwesha, Sanjit Debnath, and Harshata Pal. (2020). Implication of Urban Agriculture and Vertical Farming for Future Sustainability. In *Urban Horticulture - Necessity of the Future*, Intech Open. https://doi.org/10.5772/intechopen.91133.

Cho, R. (2011). Vertical Farms: From Vision to Reality. State of the Planet, Blogs from the *Earth Institute*, 13 October 2011.Available online: http://blogs.ei.columbia.edu/2011/10/13/vertical-farms-from-visionto-reality/comment-page-1/ (accessed on April 2023).

Corvalan, C.; Hales, S.; McMichael, A.J. (2005). Ecosystems and Human Well-Being: *Health Synthesis*; World Health Organization

Deribew, Kiros Tsegay, and Desalegn Wana Dalacho. (2019). "Land Use and Forest Cover Dynamics in the North-Eastern Addis Ababa, Central Highlands of Ethiopia." *Environmental Systems Research* 8, no. 1: https://doi.org/10.1186/s40068-019-0137-1.

Despommier, D. (2014). Encyclopedia of Food and Agricultural Ethics (Vertical Farms in Horticulture). *Springer*

Despommier, D. (2013). Farming up the city. The rise of urban vertical farms. Trends *Biotechnol*.

Despommier, D. (2010). The Vertical Farm: Feeding the World in the 21st Century; *Thomas Dunne Books*

El Menshawy, Adel Samy, Abdelaziz Farouk Mohamed, and Nayera Mahmoud Fathy. (2022). A Comparative Study on Green Wall Construction Systems, Case Study: South Valley Campus of AASTMT. *Case Studies in Construction Materials* 16 (June): e00808. https://doi.org/10.1016/j.cscm.2021.e00808.

Ghazal, Iyad, Reema Mansour, and Marie Davidová. (2023). AGRI|gen: Analysis and Design of a Parametric Modular System for Vertical Urban Agriculture. *Sustainability* 15 (6): 5284. https://doi.org/10.3390/su15065284

Gericke, W. (2010). The Complete Guide To Soilless Gardening. *Kessinger Legacy Reprints*

Hefnawy, Noha H. (2022). The Effect of Using Green Walls in Enhancing the Imageability of Urban Spaces *IOP Conference Series: Earth and Environmental Science* 1113 (1): 012007. https://doi.org/10.1088/1755-1315/1113/1/012007.

Harris, D. (1992). Hydroponics: A Practical Guide for the Soilless Grower, 2nd ed.; *New Holland Publishing*.

Healy, R.G.; Rosenberg, J.S. (2013). Land Use and the States; *Routledge*

Kalantari, F.; Mohd tahir, O.; Joni, R.A.; Fatemi, E. (2017). Opportunities and Challenges in Sustainability of Vertical Farming. *A Review. J. Landsc. Ecol*.

Kassa L, Zeleke G, Alemu D, Hagos F and Heinimann A. (2015). Impact of urbanization of Addis Abeba city on peri-urban environment and livelihoods.

Larsen, Yeshitela, Mulatu, Seifu, and Desta. (2019). The Impact of Rapid Urbanization and Public Housing Development on Urban Form and Density in Addis Ababa, Ethiopia." *Land* 8. https://doi.org/10.3390/land8040066

Manso, Maria, and João Castro-Gomes. (2015). Green Wall Systems: A Review of Their Characteristics. *Renewable and Sustainable Energy Reviews 41*

Mary wickison, (2023). 25 of the Best Plants for Indoor Hydroponic Gardens. https://dengarden.com/gardening/indoor-hydroponic-garden

Morsi, A., & Elian, N. (2021). The Vertical Greenery Systems Significant Role in Achieving Better Architectural and Urban Thermal Performance. (Dept. A). *MEJ. Mansoura Engineering Journal*, *46*(2), 102–115. https://doi.org/10.21608/bfemu.2021.188836

Muller, A.; Ferré, M.; Engel, S.; Gattinger, A.; Holzkämper, A.; Huber, R.; Müller, M.; Six, J. (2017). Can soil-less crop production be a sustainable option for soil conservation and future agriculture? Land Use Policy.

Munoz, H.; Joseph, J. (2010). Hydroponics: Home-Based Vegetable Production System, *Inter-American Institute for Cooperation on Agriculture (IICA*).

NAAS (2019). Vertical Farming. Policy Paper No. 89, *National Academy of Agricultural Sciences.*

Padmavathy, A.; Poyyamoli, G. (2016). Enumeration of arthropods in context to Plant Diversity and Agricultural (Organic and Conventional) Management Systems. *Int. J. Agric. Res.*

Pérez, G., Rincón, L., Vila, A., González, J. M., & Cabeza, L. F. (2011). Green vertical systems for buildings as passive systems for energy savings. *Applied Energy*, *88*(12), 4854–4859. https://doi.org/10.1016/j.apenergy.2011.06.032

Perini, K.; Ottelé, M. (2014). Designing green façades and living wall systems for sustainable constructions. *Int. J. Des. Nat. Ecodynamics*

Tarboush, et al. (2020). Evaluation of perception with regards to green wall systems application in Nicosia, N. Cyprus. International Journal of ADVANCED AND APPLIED SCIENCES, 7(3), 24–36. https://doi.org/10.21833/ijaas.2020.03.004

Terfa BK, Chen N, Liu D, Zhang X, Niyogi D. (2019). Urban expansion in Ethiopia from 1987 to 2017: characteristics, spatial patterns, and driving forces. *Sustainability 11*:2973. https://doi.org/10.3390/su11102973

Thomaier, S.; Specht, K.; Henckel, D.; Dierich, A.; Siebert, R.; Freisinger, U.B.; Sawicka, M. (2015). Farming in and on Urban Buildings: Present Practice and Specific Novelties of Zero-Acreage Farming (ZFarming). *Renew. Agric. Food Syst.*

Touliatos, D.; Dodd, I.C.; McAinsh, M. (2016). Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. *Food Energy Secur.*

UNDESA (United Nations Department of Economic and Social Affairs). (2018). World urbanization prospects: *Revision, highlights. UNDESA, New York.*

UNPD (United Nations Population Division). (2014). World urbanization prospects: *Revision, New York,*

UN-Habitat. (2017). The state of Addis Ababa 2017: The Addis Ababa we want. *UN-Habitat*, Nirobi.

Virtudes, A., & Manso, M. (2016). Applications of Green Walls in Urban Design. *IOP Conference Series: Earth and Environmental Science*, *44*, 032016. https://doi.org/10.1088/1755-1315/44/3/032016

Weldearegay, S. K., Tefera, M. M., & Feleke, S. T. (2021). Impact of urban expansion to peri-urban smallholder farmers' poverty in Tigray, North Ethiopia. *Heliyon*, *7*(6), e07303. https://doi.org/10.1016/j.heliyon.2021.e07303

Wood, S.; Sebastian, K.; Scherr, S.J. (2001). Pilot Analysis of Global Ecosystems: *Agroecosystems; International Food Policy Research Institute and World Resources Institute*:

World population review https://worldpopulationreview.com/world-cities/addis-ababa-population (Accessed in Sep. 2023)

APPENDIX

Appendix A: Questioner for objective 1

የዚህ መጠይቅ ዋነኛ አላማው በአዲስ አበባ ከተማ በኮንዶሚኒየም የጋራ መኖርያ ቤቶች ውስጥ የሚኖሩ ነዋሪዎችን የቤተሰብ የጓሮ አትክልት አጠቃቅማቸውን የተመለከተ መረጃ በመሰብሰብ አሁን ካለው የተሻል አቅርቦት እና አማራጭ የጓሮ አትክልት የማምረት ሂደትን መጠቆም ነው። በመሆኑም የእርሶ ገልጽ እና ተአማኒነት ያለው ምላሽ ስኬታማ ጥናት ለማድረግ እና የተሻል አማራጭ ለመፈለግ ወሳኝነት አለው። ቀጥልው የተቀመጡትን ጥያቄዎች ጊዜዎትን ወስደው ትክክለኚውን እና ቀጥተኛውን ምላሽ እነዲሰጡ በአክብሮት እንጠይቆታልን።

ሰለትብብርዎ እና ሰለ ጊዜዎ እጅግ እናመሰግናለን።

በዚህ መጠይቅ ጀርባም ጥያቄዎች አሉ።

1. በቤት ውስጥ ያልው የቤተሰብ ብዛት ምን ያህል ነው?
   ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10
   ሌላ____

   <u>በሰንጠረዥ ውስጥ ይሚሞሉ ጥያቄዎች</u>

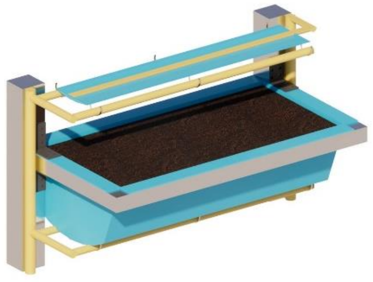
1. ቤተሰቦ የትኞቹን አይንት የጓሮ አትክልቶችን ይጠቅማሉ? (የሚጠቅሙትን ላይ ✓ ያድርጉ ከተዘረዘሩት ሌላ ካለ ከስር ባሉት ባዶ ቦታዎች ይሙሉ።)
2. ቤተሰቦ ምን ያሂል ጊዜ አትክልት ይገዛሉ? (እባክዎ በሳምንት የሚገዙበት ቀን ላይ ✓ ምልክትን ያድርጉ)
3. አንድ ጊዜ ሲገዙ ምን ያህል ይግዛሉ? (በአንድ ጊዜ የሚገዙትን ያህል ላይ ✓ ምልክትን ያድርጉ። ምላሾት ከተጠቀሰው የተለየ ከሆነ ሌላ መጠን የሚለው ቦታ ላይ መጠኑን ያስቀምጡ።)

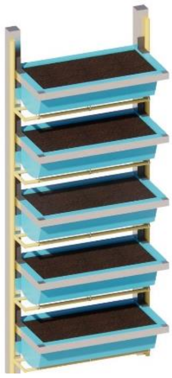
/የሚጠቀሙት የጓሮ አትክልት		በሳምንት ውስጥ የሚሸምቱበት ቀን ብዛት							በአንድ ጊዜ ይሚሽሙቱት መጠን በኪ.ግ				
		7	6	5	4	3	2	1	1kg	2kg	3kg	4kg	ሌላ መጠን
ሽንኩርት													
ቲማቲም													
ድ`ንች													
ካሮት													
ጥቅል ጎመን													
ሓብሻ ጎመን													
ሰላጣ													
ቆስጣ													
የሾርባ ቅጠል													
ቃርያ													

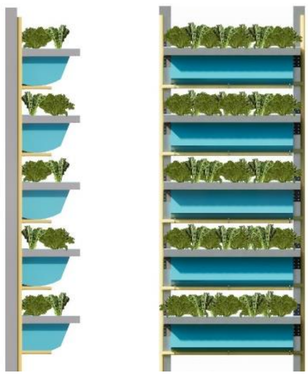
Appendix B: Interview Question for objective 3

1. በዚህ አካባቢ የሚመረተው ሰብል ምንድነው?
2. በአመት ምን ያህል ኩንታል የሰበሰባል?

Appendix C: vegetable planter module demonstration on the building façade







Single Module Connection Pants on the module

Before And After the Module constructed for B+G+10 Building Typology

Module Sample prototype

ANNEXE

REGAINING LOST AGRICULTURAL YIELDS: VERTICAL FAÇADE FARMING ON AYAT 1 CONDOMINIUM BUILDINGS IN ADDIS ABABA, ETHIOPIA.

Endale Amdemariame Yirga[1], Tibebu Assefa[2]

1&2 Addis Ababa University

The IHDP of Addis Ababa is the main sector for the conversion of the agricultural land to housing development-built areas without provision of any option for farming products. This study's aims to demonstrate vertical vegetable farming as a means to regain agricultural yields that has been taken over by condominium buildings. The study focused on Addis Ababa in Ayat 1 site 1, 2, and 3 condominium buildings and their resident as a population. Vegetable consumption amount of a household, potential surface area of the buildings, previous productivity of the land and the vertical farming productivity of the façade analyzed and described statistically. The potential surface area for the vegetable façade farming with 6 hours and 4 hours daylight exposure is 297,270m2 from both B+G+8 and B+G+10 building typologies. The vertical façade vegetable farming has the ability to produce 5,333,418.11kg/year or 2,309,169,276.366kcal/year. As a result of the vertical façade vegetable farming, 191.76% of the vegetable consumption of the resident can be fulfilled and 1,482.56% of the lost agricultural land produces can be regained.

Key Words – vertical farming, façade vegetable farming, condominium housing, food security

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INTRODUCTION

Due to population increase the urban expansion of the city is also increasing. The rapid rise in population in Ethiopia's capital city, Addis Ababa City, led to an urban agglomeration [1]. Addis Ababa City frequently sees the peri-urban expansion of built-up areas into cultivation and grassland areas [2]. The primary economic activity in Addis Ababa's urban fringe regions is agriculture; however, due to the city's rapid urbanization, agricultural and non-agricultural areas have been transformed into built-up urban areas [3]. From 2006 to 2016 the total built portion of Addis Ababa were expanded from 24,942 ha or 48% of the area within the city's boundary to 35,050ha or 67% of the area within city's boundary [4]. According to Larsen [4], in six-surrounding sub-cities of Addis Ababa, 10,115 ha of agricultural and vegetation areas changed in to residential housing, manufacturing and storage, mineral and gravel pits and retail and business. In Ethiopia the main food source is Agriculture is Agriculture development led to industrialization (ADLI) is the main leading policy in the country. But The peri-urban areas that surround urban areas are considered to be among the geographical areas that are most susceptible to the rapid shifting of a significant quantity of land used for agriculture to urban areas, which causes farmers to lose their means of livelihood. The most fertile land is typically reduced when land is used for other purposes, so the effect on agricultural production and food security is frequently greater than the actual amount of land involved [5].

Because of rapid urbanization in Addis Ababa, the urban area coverage of the city is expanding throughout the previous years. Because of the expansion the agricultural lands are converted in to built-up area. The food insecurity issue regarding the loss of agricultural land around the city of Addis Ababa is getting worse. Since 2005 Addis Ababa government initiated integrated housing development plan (IHDP). The project sites include inner city redevelopment and pre urban expansion to the peripheries of Addis Ababa. The condominium housing development covers large concrete built up areas. Building typologies implemented in condominium housing are similar including their façade treatment. The buildings have maximum blind surface areas. These blind walls don't serve as a source of food. The climate of Addis Ababa is comfortable for Agriculture. But except recent urban Agriculture initiatives, the residents of Addis Ababa and the government didn't take advantage of the buildings blind wall and the city's weather and climate.

The aim of the study is to demonstrate the use of vertical façade vegetable farming as a means to regain agricultural yields that has been taken over by condominium buildings. Spatially the study focuses on the Addis Ababa housing project Ayat 1, site 1, 2 and 3. The study focuses on the demonstration of vertical farming on the façade of the building as a means of food security. The study can be an input for, the city administration to reconsider policy of the buildings with wide blind walls as a means of food source, for the community to solve their food problem using building façade farming, also can initiate the researchers to conduct more researches.

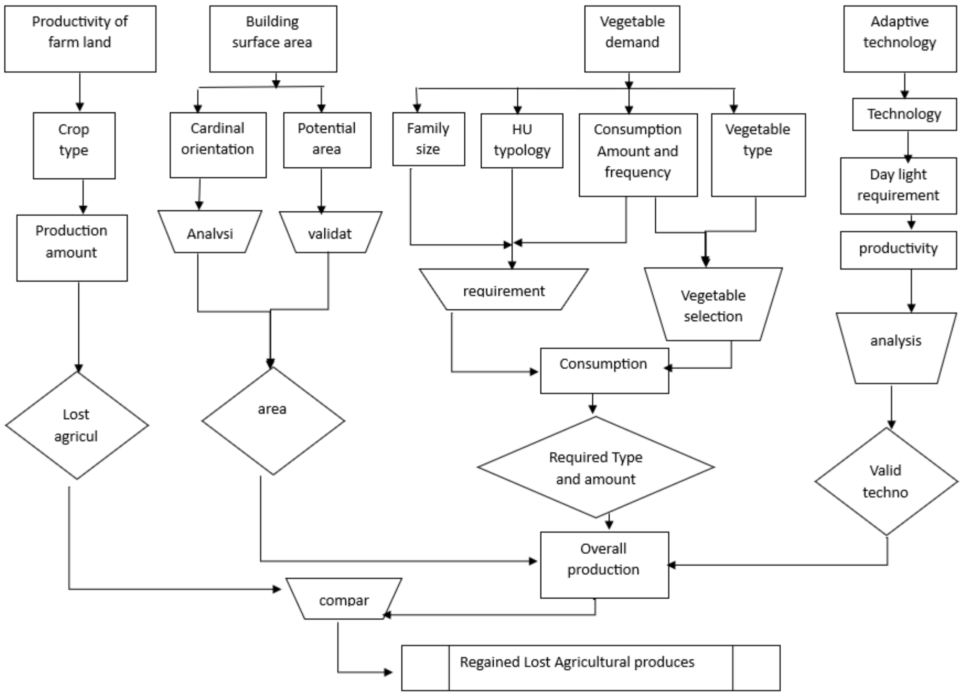
Vertical Farming

Vertical farming, as discussed in various scholarly works, including those by Corvalan et al. [6] and Healy and Rosenberg [7], aims to proactively address food security concerns in rapidly urbanizing areas, thereby ensuring the long-term sustainability of our cities. Environmentalists, urban farmers, architects, agronomists, and public health experts have been welcoming this mini-revolution with other professions as they work together to discover a solution for an ultra-urban, food-scarce future. Urban agriculture can take many different shapes, including vertical farms, street landscaping, tactical gardens, rooftop and backyard gardens, and vertical greenery systems. Crops are grown vertically in layers utilizing soil, hydroponic, or aeroponic techniques in vertical farming. This novel technique is used in difficult circumstances such as densely populated urban areas and areas with little arable land. Advanced technology, such as automated systems for monitoring and managing variables like illumination, fertilization, and irrigation, are used by vertical farms to provide the best growing conditions for plants [8].

Other names for Vertical Greening Systems (VGS) include bio walls, vertical gardens, and green-wall technology. They are made up of vertical devices that disperse plants that could be affixed to an internal wall or the facade of a building. There are several green-wall typologies that cater to varying degrees of intricacy, spanning from the most basic arrangement to the most intricate and advanced design. A "vertical garden," or vertical green, is a vertical surface that is made greener by plants that are either anchored in the ground, incorporated into the wall material, or fastened to the facade in the form of modular panels [9]. Vertical greenery systems (VGS) are categorized into two main groups: living walls (LWS) and green facades (GFS), which range from simpler arrangements to more complex and contemporary designs. These systems can help lower surface temperatures, improve air quality, and reduce heat flux [10]. The selection of growth substrates or construction systems is influenced by the characteristics and growth requirements of the plants [11,12,13]. The use of hanging or climbing evergreen or deciduous plants along the wall is the foundation of green facades (GFS). The plants used in green facades are usually rooted in the ground, and it takes a while for them to cover the entire surface [14]. The living walls system is a modern way to clothe building facades. It allows large areas to be covered quickly and encourages steady plant growth along vertical surfaces, which makes it easier to integrate green walls around tall buildings. Living walls are appropriate for a variety of building styles and can support a wide variety of plant species [14,13].

MATERISLS AND METHODS

For the study, Ayat 1 project were selected. The project contains four sites named site 1, site 2, site3 and site 4, but site 4 is not included in the study, because of its level of completion. Based on their current residence occupation and level of completion the site 1, 2 and 3 are selected for the study. The site is located in east side of Addis Ababa. There are 14, 38 and 41 blocks in site 1, site 2, and site 3 respectively. Which is total of 93 blocks with B+G+8 and B+G+10 building typologies. The overall study flowchart is [presented in Figure 1 below.



Legend

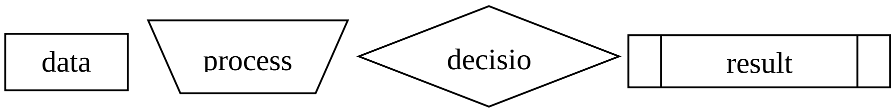


Figure 1 research design process

A questioner was conducted among household members to gather information on their family size, vegetable consumption amount, dietary preference and frequency of vegetable consumption.

To find the proportion of each family size strata for the sample size calculated. the table (Table 1) below. Each family size group has different proportion from the total sample of 362.

Table 1 proportion of each family size group for the sample

	family size group										
	1	2	3	4	5	6	7	8	9	abandoned	Grand Total
Count of family size	7	143	268	819	1626	785	136	59	2	163	4008
samples	1	13	25	77	153	74	13	5	1		362

Descriptive statistics were used like mean of consumption amount, frequency of purchase and preference across the sample. Correlation, regression and ANOVA were used to analyze the relationship between the family size and vegetable consumption amount and the significant impact of the family size on the consumption amount.

To identify the potential surface area of the study area, the building typologies, the number of blocks, perimeter and surface area of the building, blind wall surface area and cardinal orientation of the buildings were gathered (see Table 2)

Table 2 The building blocks and housing unit typologies

Site	**building typology**	**Number of blocks**	**Residential**				**shops**
			1 bed room	2 bed room	3 bed room	**Total**	
Site 1	B+G+8	14	0	98	294	**392**	168
	B+G+10	0	0	0	0	**0**	0
	Total	**14**	**0**	**98**	**294**	**392**	168
Site 2	B+G+8	20	0	140	420	**560**	240
	B+G+10	18	288	864	288	**1440**	558
	Total	**38**	**288**	**1004**	**708**	**2000**	798
Site 3	B+G+8	32	0	224	672	**896**	384
	B+G+10	9	144	432	144	**720**	248
	Total	**41**	**144**	**656**	**816**	**1616**	632
Grand total	B+G+8	66	0	462	1386	**1848**	1598
	B+G+10	27	432	1296	432	**2160**	
	Grand Total	**93**	**432**	**1758**	**1818**	**4008**	**1598**
Percentage			10.7%	44%	45.35	100%	

From the total of 93 blocks on the site 66 blocks are B+G+8 building typology with eight orientation category, because all the four sides are different. 27 blocks are B+G+10 building typologies with four orientation category, because two sides of the buildings are mirror. Each orientation category of both building block and number of blocks in each category is explained in the figure 2 and 3 below.

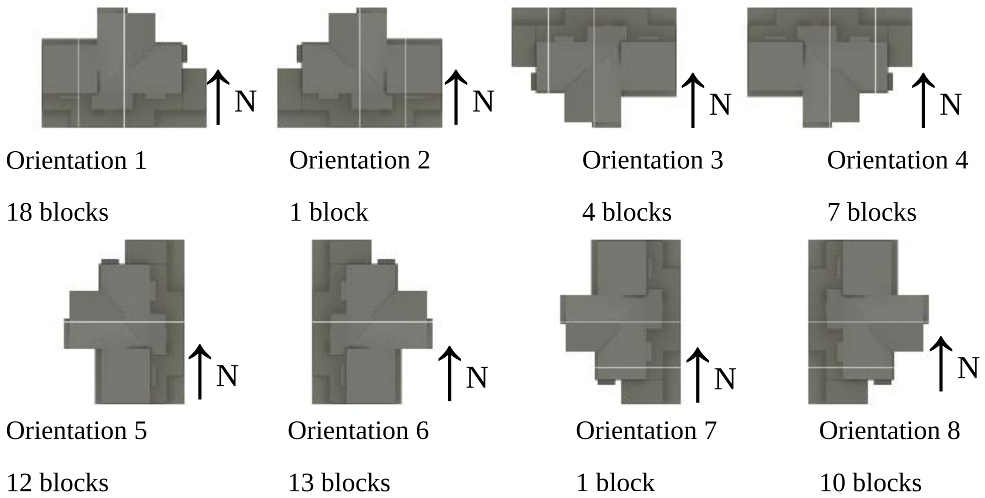


Figure 2 B+G+8 Building typology orientation category

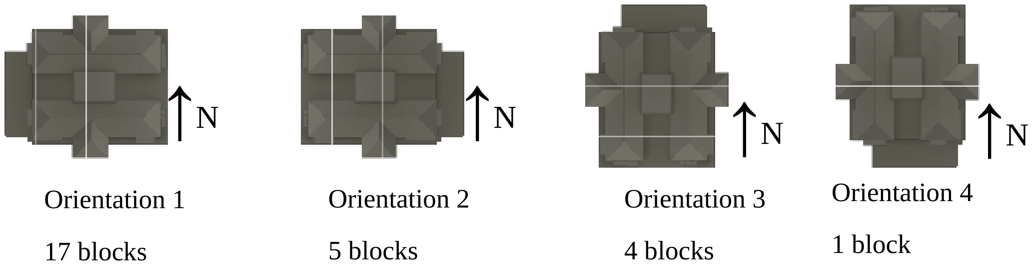


Figure 3 B+G+10 building typology orientation category

The productivity of agricultural land assessed by analyzing the current use of land and the previous crop production yield based on the information gathered from the current land owners near the site. After collecting data of vegetable consumption demand, potential surface area and the previous productivity of the land and conclusion sample design conducted. The design demonstrates a technology that can be used on the surface of the building to produce selected vegetables.

RESULT AND DISCUSSION

The mostly consumed ten vegetables selected for the study. These vegetables are onion preferred by 362(100%) respondents, tomato preferred by 362(100%) respondents, potato preferred by 358(99%) respondents, carrot preferred by 347(96%), cabbage preferred by 294(81%), kale preferred by 334(92%), lettuce prefeed by 283(78%), Swiss chard preferred by 252(70%), leek preferred by 166(46%) and green pepper preferred by 341(94%) respondents (see Figure 4).

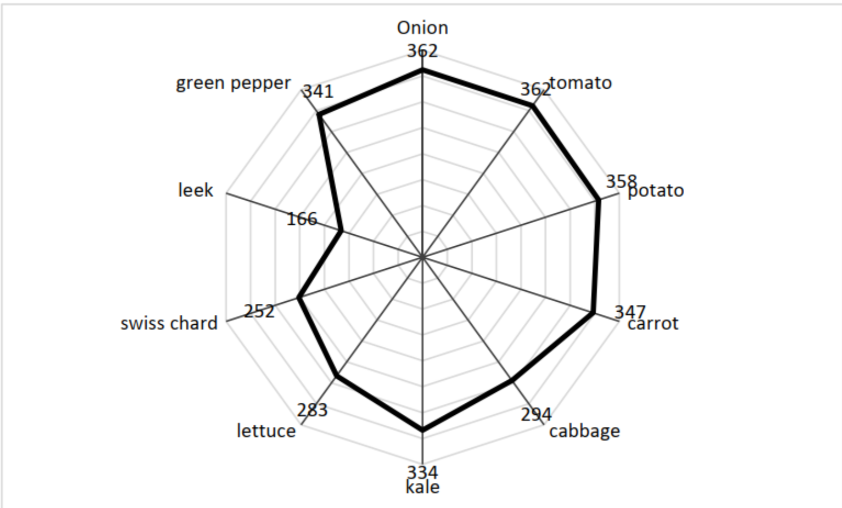


Figure 4 Total vegetable preference

The weekly average purchase frequency of each vegetable shows that most of the resident purchase vegetable one day per week. Resident who purchases a vegetable once a week are, onion and tomato 202 each, potato 238, carrot 227, cabbage 220, kale 215, lettuce 213, Swiss chard 196, leek 144, green pepper 280 (see Figure 5).

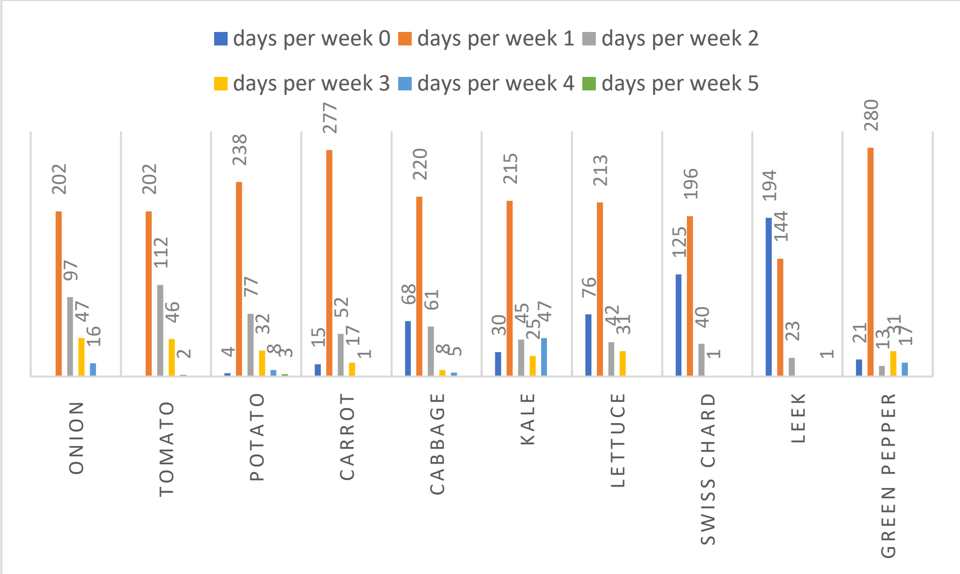


Figure 5 Summery of weekly Vegetable purchase frequency

The weekly average vegetable consumption of the respondents also shows that; onion 4.77kg, tomato 3.39kg, potato 2.75kg, carrot, 2.03kg, cabbage 1.67kg, kale 1.21kg, lettuce 0.87kg, Swiss chard 0.65kg, leek 0.37kg, and green pepper 0.43kg (see Figure 6).

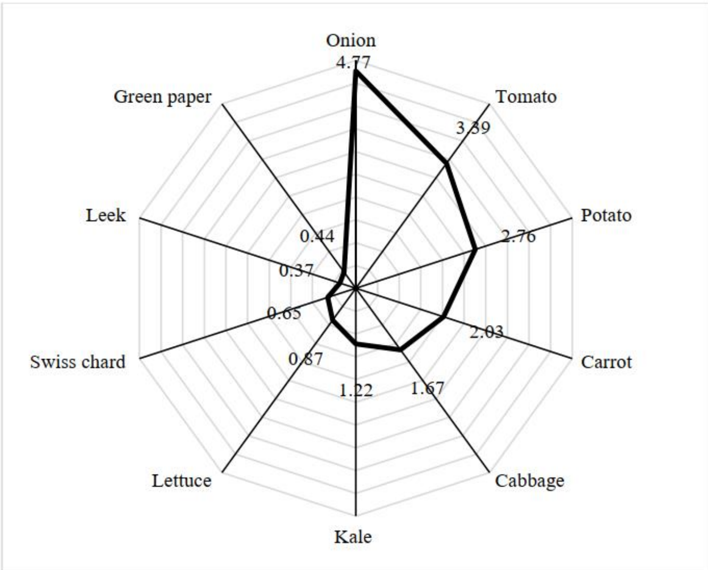


Figure 6 Weekly average consumption of each vegetable in kg

The total building foot print area of B+G+8 building block typology is 986.75m^2 and the total vertical wall surface area of the building is 3,337.31m^2 (Figure 7). The building has 3.3m room height with basement floor. The opening area is 884.63m^2 which is 26.39% of the overall. The remaining surface area which is a blind wall that can serve for vegetable plantation is 2,456.68m^2 which is 73.61% of the overall (see table 3 below).

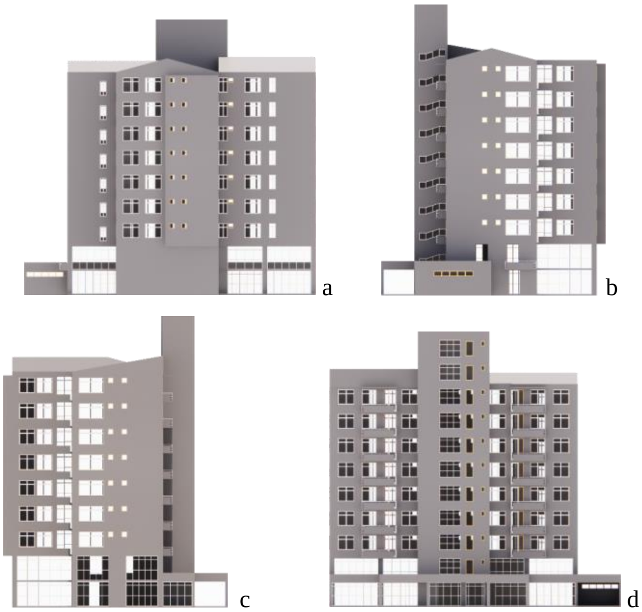


Figure 7 B+G+8 building typology elevations a) front b) right c) left d) rear

Table 3 Surface area of B+G+8 building typology

Building elevation	Total wall area of selected wall (m2)	Window area of selected wall (m2)	Bare wall area (m2)	% of Bare wall compared to selected wall total area	% of bare wall compared to the total building footprint	Total building footprint (m2)
Front elevation	1010.45	402.75	607.7	60.14	61.58	986.75
Rear elevation	974.23	156.3	817.93	83.95	82.89	
Right side elevation	654.97	167.20	487.77	74.4	49.43	
Left side elevation	697.66	158.38	539.28	77.29	54.65	
Total	**3,337.31**	**884.63**	**2,456.68**	**73.61**	**248.56**	

The total building foot print area of the B+G+10 block typology is 1,508.22m^2 and the vertical surface area of the wall 6,612.94m^2 (figure 8). The building has 3.0m room height with basement floor. Th opening area is 1,768.05m^2 which is 26.74% of the overall. The remaining surface area which is a blind wall that can serve for vegetable plantation is 4,844.89 which is 73.26% of the overall (see table 4 below)

Figure 8 B+G+10 Building typology elevations a) front b) right c) left d) rear

Table 4 Surface area of B+G+10 building typology

Building elevation	**Total wall area of selected wall (m^2)**	**Window area of selected wall (m^2)**	**Bare wall area (m^2)**	**% of Bare wall compared to selected wall total area**	**% of bare wall compared to the total building footprint**	**Total building footprint (m^2)**
Front elevation	1236.75	444.01	792.74	64.09	52.56	1508.22
Rear elevation	1262.11	442.51	819.6	64.9	54.34	
Right side elevation	1450	461.43	988.57	68.17	65.54	
Left side elevation	1356.1	229.54	1126.56	83.07	74.69	
Courtyard	1308	190.56	1117.44	85.43	74.08	
Total	**6612.94**	**1768.05**	**4844.89**	**73.26**	**321.23**	

The table 5 below shows the total available and potential surface area for the vegetable farming technology for every group of buildings based on their corresponding orientation throughout the year.

Table 5 Potential surface area of each building typologies

		potential areas in m^2			
	NO. Of blocks	Oct, Nov, Dec, Jan, Feb, Mar		Apr, May, Jun, Jul, Aug, Sep	
		6 hours/day	4 hours/day	6 hours/day	4 hours/day
			B+G+8		
Orientation 1	18	10,938.60	17,243	8,937.36	23,585.94
Orientation 2	1	607.7	957.99	496.52	1,310.33

Orientation 3	4	1,986.08	5,241.32	2,430.80	3,831.96
Orientation 4	7	3,475.64	9,172.31	4,253.90	6,705.93
Orientation 5	12	2,989.80	8,721.36	2,307.60	10,419.24
Orientation 6	13	3,238.95	9,448.14	2,499.90	11,287.51
Orientation 7	1	192.3	868.27	249.15	726.78
Orientation 8	10	1,923	8,682.70	2,491.50	7,267.80
			B+G+10		
Orientation 1	17	13,202.20	27,754.20	13,202.20	27,754.20
Orientation 2	5	3,813	8,163	3,813	8,163
Orientation 3	4	3,566	3,265.20	3,566	3,265.20
Orientation 4	1	891.5	735.4	891.5	735.4
Total		46,824.77	100,252.89	45,139.43	105,053.29

The Figure 9 below shows the total potential surface area of each building typologies with respect to their orientation, sun orientation season and day light exposure hour length.

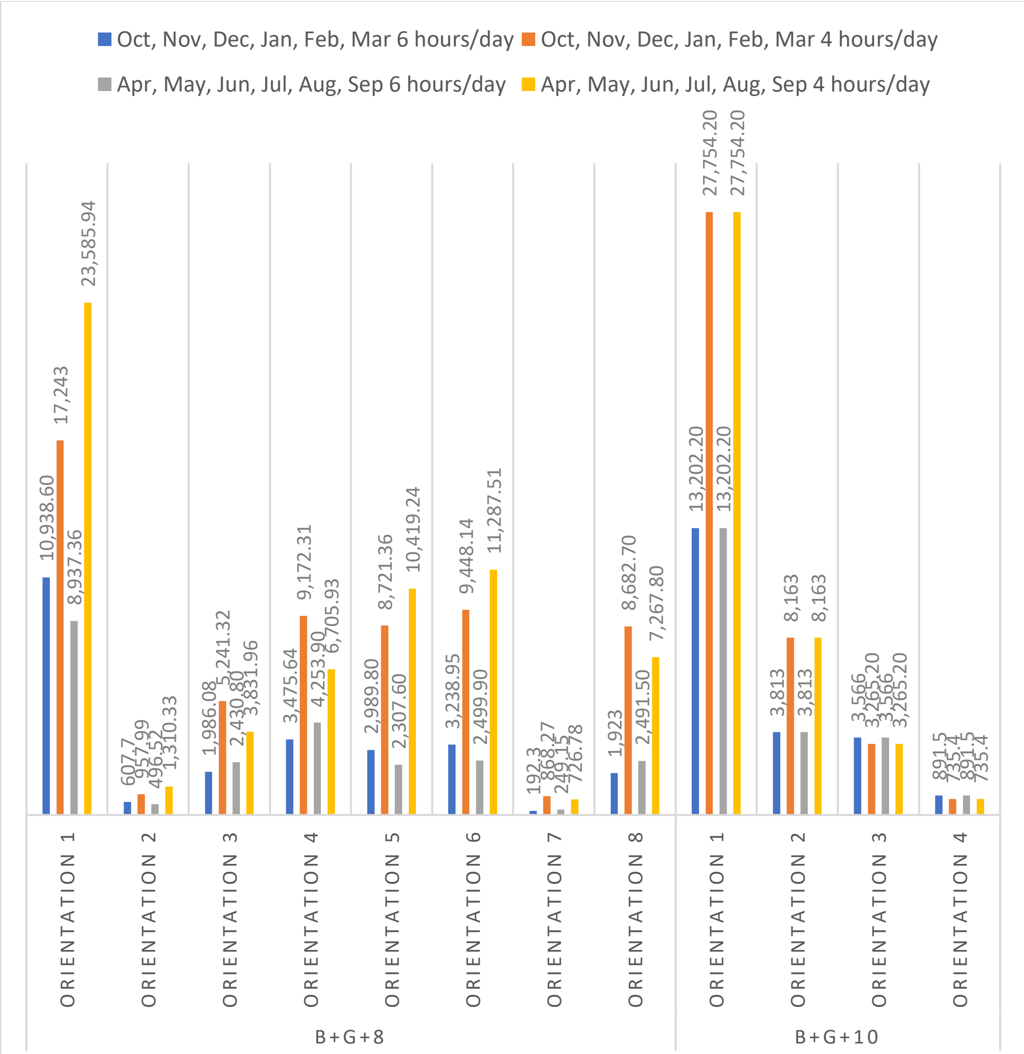


Figure 9 Total surface area of each building typologies and their orientation

The main crop produced from the land in traditional agriculture in the area is Teff. As of the most peripheral areas of Addis Ababa city, the farmers who farms the agricultural land traditionally produces teff as a main crop to supply for the city. Based on the response of the farmers around the site, they harvest average of 1.5ton of Teff annually per hectare. Since the Calorie amount of 1 kg Teff is 3,350kcal, 1.5ton (1,500kg) of tef can have 5,025,000kcal/year. The total site area is 31 hectares. The three residential sites would produce 46.5ton (46,500kg) of teff. This is 155,775,000kcal/year.

The table 6 below explains the characteristics of each vegetable. These characteristics includes, day light requirement, spacing requirement, cultivation days and harvesting yield. Vegetable with the longest root depth is carrot, which is average of 25 cm.

Table 6 Vegetable characteristics

vegetables	Day light hour/day	Spacing in cm	Cultivation days	Round per year	Harvest yield kg/m^2
Onion	6	10	85-120	4	5.2
Tomato	6	60	65-90	4	8.9
Potato	4	20	80-100	4	4.4
Carrot	6	5	65-75	4	2
Cabbage	6	30	60-90	4	5.2
Kale	4	20	40-80	5	2.8
Lettuce	4	15	40-80	5	2.7
Swiss chard	4	10	50-70	5	3.5
Leek	6	10	70-120	4	2.2
Green pepper	6	30	70-85	4	2.3

Based on the literature and data analysis, a modular living wall is preferable for vegetable production on the façade of the building. The modular living wall using a planter box and soil growing medium was adopted for the design. The design used steel structures to connect with the building structures and plastic as a growing medium and vegetable container. Soil is the growing medium (figure 10).

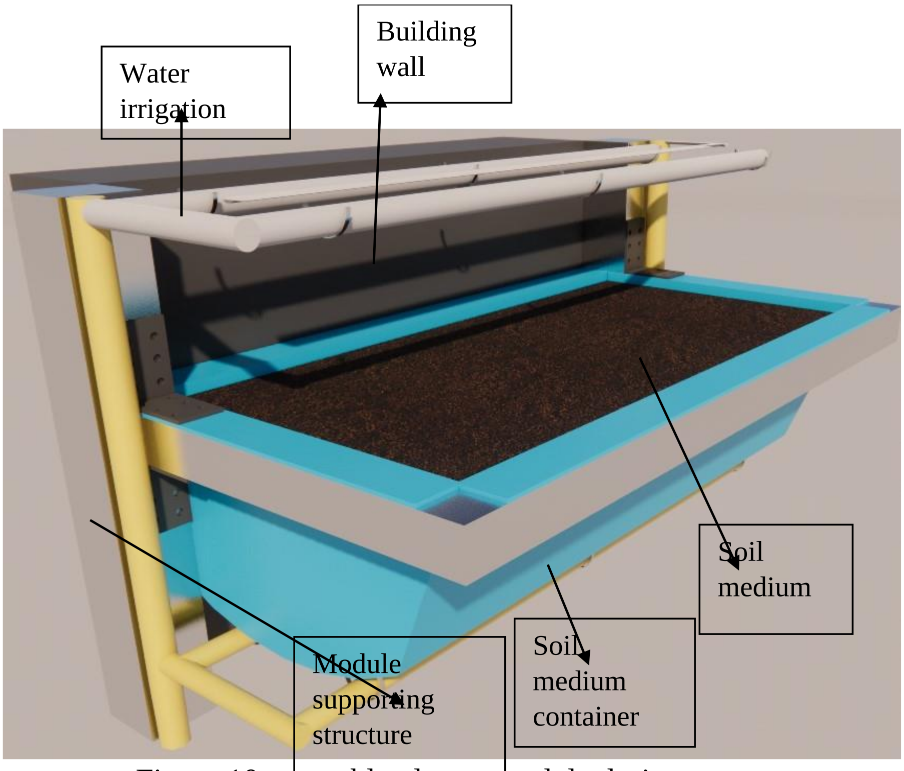


Figure 10 vegetable planter module design

The module has overall dimension of 104cm x 504cm x 31cm. The soil media overall dimension is 100cm x 500cm x 25cm and volume of 0.125m3. The supporting structure is 2cmx2cm steel bar. The soil medium container is a light weight plastic material. There are pipelines for water irrigation (Figure 11).

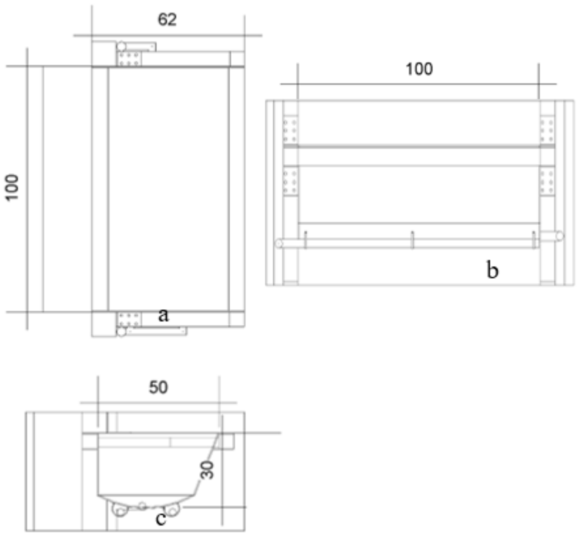


Figure 11 Views of the module a) Plan b) elevation c) section

The total potential surface area available for six per day daylight required vegetables is 91,637.77m^2 and four hour per day daylight required vegetables is 205,306.18m^2. From the available surface area, based on respondent consumption proportion each vegetables have different proportions (Figure 12 below).

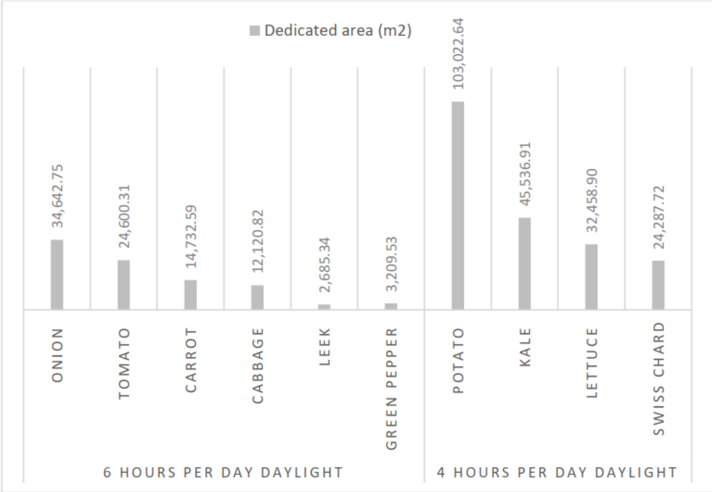


Figure 12 Space proportion of vegetables

The analysis explains that the integration of the module on the blind surface of the wall can produce 10 most preferred vegetables. Onion production can be 720,569.2kg, Tomato production can be 875,771.03kg. Potato production can be 1,813,198.46kg. Carrot production can be 117,860. Cabbage production can be 252,113.05kg. Kale production can be 637,516.74kg. Lettuce production can be 438,195.15kg. Swiss Chard production can be 425,035.1kg. Leek production can be 23,630.99kg. Green pepper production can be 29,527.67kg (Figure 13).

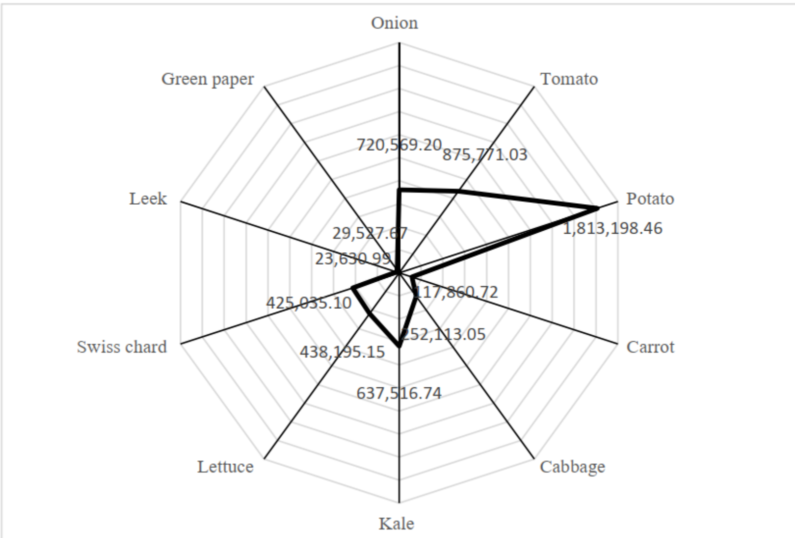


Figure 13 Vertical façade vegetable farming production capacity of the potential surface area of the building

From the total annual consumption of the study population, 191.76% of required vegetable can be produced. Relative to the productivity of the land in traditional agriculture which is 155,775,000kcal/year, 2,309,169,276.366kcal/year can be regained on vertical farming technology which covers 1,482.56% of the previous production. The potential of the blind surface to produce vegetable is way more than the amount of the population requires (Figure 14).

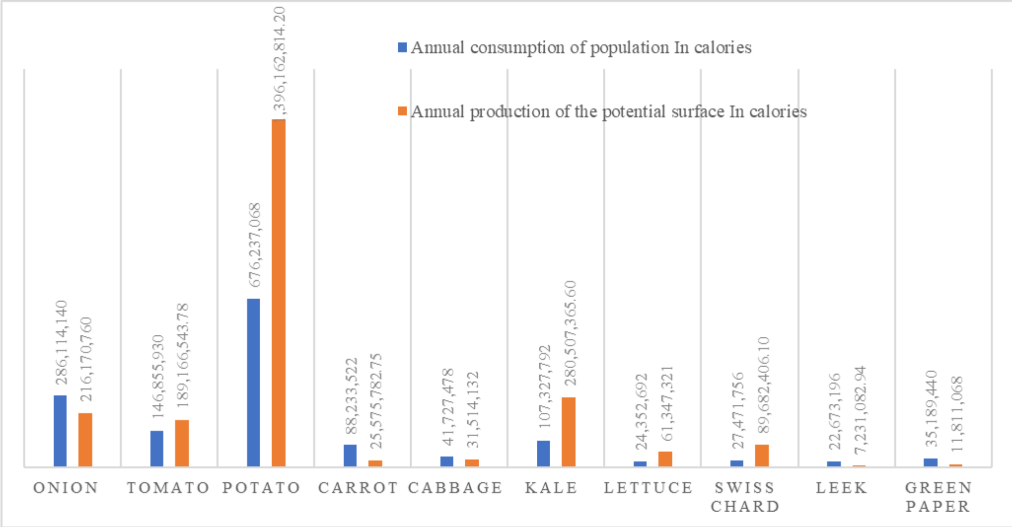


Figure 14 Comparison between annual vegetable consumption and annual production

Conclusion

The study concluded that the blind vertical façade of the Ayat 1 project site 1, 2 and 3 condominium housing buildings has the potential to regain 191.76% of the resident's vegetable demand. Also 1,482.56% of the land produces when it was farmland can be regained. This amount of production can support the resident food requirement. It is recommended to the government to develop policies and strategies regarding the vertical façade vegetable production. the community also has the opportunity to provide themselves with enough vegetable and income from market of extra production. There is also wide research gap to be conducted.

Reference

1. Terfa BK, Chen N, Liu D, Zhang X, Niyogi D. (2019). Urban expansion in Ethiopia from 1987 to 2017: characteristics, spatial patterns, and driving forces. Sustainability 11:2973. https://doi.org/10.3390/su11102973
2. Deribew, Kiros Tsegay, and Desalegn Wana Dalacho. (2019). "Land Use and Forest Cover Dynamics in the North-Eastern Addis Ababa, Central Highlands of Ethiopia." Environmental Systems Research 8, no. 1: https://doi.org/10.1186/s40068-019-0137-1
3. Kassa L, Zeleke G, Alemu D, Hagos F and Heinimann A. (2015). Impact of urbanization of Addis Abeba city on peri-urban environment and livelihoods
4. Larsen, Yeshitela, Mulatu, Seifu, and Desta. (2019). The Impact of Rapid Urbanization and Public Housing Development on Urban Form and Density in Addis Ababa, Ethiopia." Land 8. https://doi.org/10.3390/land8040066
5. Weldearegay, S. K., Tefera, M. M., & Feleke, S. T. (2021). Impact of urban expansion to peri-urban smallholder farmers' poverty in Tigray, North Ethiopia. Heliyon, 7(6), e07303. https://doi.org/10.1016/j.heliyon.2021.e07303
6. Corvalan, C.; Hales, S.; McMichael, A.J. (2005). Ecosystems and Human Well-Being: Health Synthesis; World Health Organization
7. Healy, R.G.; Rosenberg, J.S. (2013). Land Use and the States; Routledge
8. Ghazal, Iyad, Reema Mansour, and Marie Davidová. (2023). AGRI|gen: Analysis and Design of a Parametric Modular System for Vertical Urban Agriculture. Sustainability 15 (6): 5284. https://doi.org/10.3390/su15065284

9. Perini, K.; Ottelé, M. (2014). Designing green façades and living wall systems for sustainable constructions. Int. J. Des. Nat. Ecodynamics
10. Morsi, A., & Elian, N. (2021). The Vertical Greenery Systems Significant Role in Achieving Better Architectural and Urban Thermal Performance. (Dept. A). MEJ. Mansoura Engineering Journal, 46(2), 102–115. https://doi.org/10.21608/bfemu.2021.188836
11. Virtudes, A., & Manso, M. (2016). Applications of Green Walls in Urban Design. IOP Conference Series: Earth and Environmental Science, 44, 032016. https://doi.org/10.1088/1755-1315/44/3/032016
12. Pérez, G., Rincón, L., Vila, A., González, J. M., & Cabeza, L. F. (2011). Green vertical systems for buildings as passive systems for energy savings. Applied Energy, 88(12), 4854–4859. https://doi.org/10.1016/j.apenergy.2011.06.032
13. Manso, Maria, and João Castro-Gomes. (2015). Green Wall Systems: A Review of Their Characteristics. Renewable and Sustainable Energy Reviews 41
14. Tarboush, et al. (2020). Evaluation of perception with regards to green wall systems application in Nicosia, N. Cyprus. International Journal of ADVANCED AND APPLIED SCIENCES, 7(3), 24–36. https://doi.org/10.21833/ijaas.2020.03.004