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**ADDIS ABABA UNIVERSITY**  
**ETHIOPIAN INSTITUTE OF ARCHITECTURE, BUILDING**  
**CONSTRUCTION AND CITY DEVELOPMENT (EIABC)**

**HARMONY IN VERTICAL LIVING: INNOVATIVE SOLUTIONS FOR**  
**INTEGRATING APARTMENT BUILDINGS AND VERTICAL FARMING IN**  
**ADDIS ABABA**

**BY:**  
**MELAT KEBEDE**

**MAY, 2024**  
**ADDIS ABABA, ETHIOPIA**



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**Addis Ababa University**  
**Ethiopian Institute Of Architecture, Building Construction and City**  
**Development (EiABC)**

**Harmony in Vertical Living: Innovative Solutions for Integrating Apartment**  
**Buildings and Vertical Farming in Addis Ababa**

**By:**

**Melat Kebede**

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University, Ethiopian Institute of Architecture, Building Construction and City Development, in Partial Fulfillment of the Requirements for the Award of Master of Science Degree in Architectural Engineering.

**Advisor:**

**Tesfaye Hailu**

**MAY, 2024**  
**ADDIS ABABA, ETHIOPIA**

## **Declaration**

I Melat Kebede, hereby declare that the work presented in this thesis work entitled “Harmony in Vertical Living: Innovative Solution for Integrating Apartment Building and Vertical Farming in Addis Ababa” is my own work and was conducted under the supervision of Mr.Tesfaye Hailu. I confirm that the content of this study is original and has not been submitted for any other degree or qualification at any other university/institution.

Except where explicitly stated otherwise in the text, all data, figures, and ideas obtained from other sources are cited appropriately in the reference. I take full responsibility for any errors or shortcomings in this paper.

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## Approval

As a member of the Examiners board of the final Master's thesis open defense of Melat Kebede, we have read and evaluated the thesis prepared by Melat Kebede entitled “**Harmony in Vertical Living: Innovative Solutions for Integrating Apartment Buildings and Vertical Farming in Addis Ababa**” and recommended to Ethiopian Institute of Architecture, Building Construction and City Development, Addis Ababa University to accept the Thesis for the Fulfillment of Requirements for the award of Degree of Master of Science in Architectural Engineering.

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Lastly, I am deeply grateful to my friend, Yasmin Tofik, for your generous assistance with questionnaire distribution and site visits. Your willingness to help significantly eased my workload and made this journey more manageable."

## **Abstract**

*Rapid urbanization has led to an increase in demand for fresh agricultural goods and affordable housing, which has put Addis Ababa in a difficult urban position. In order to improve food security and sustainability, this study, "Harmony in Vertical Living: Innovative Solutions for Integrating Apartment Buildings and Vertical Farming in Addis Ababa," investigates the viability of incorporating vertical farming into residential complexes. The research assesses the technical, economic, social, and environmental issues of retrofitting new and existing apartment buildings with vertical farms through a combination of surveys, literature reviews, and design concepts. According to the research, this kind of integration can potentially save costs and promote sustainability while also optimizing land usage, lowering reliance on food imports, and improving air quality. In order to promote eco-friendly surroundings, reduce waste, and encourage urban agriculture, the study suggests implementing vertical farming techniques in residential areas. The information offered aids citizens, decision-makers, and governmental organizations in advancing sustainable urban development and enhancing Addis Ababa's food accessibility.*

**Key Words:** Urbanization, Vertical Living (VL), Vertical Farming (VF), Integration of Vertical Living, Sustainable Solutions

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## **Acronyms/ Abbreviations**

VF	Vertical Farming
VL	Vertical Living
BFS	Bio Facades
VGS	Vertical Greenery System
VFS	Vertical Farming System
UN-Habitat	United Nations Human Settlements Programme
FAO	Food and Agriculture Organization
UNICEF	United Nations International Children's Emergency Fund
APA	American Psychological Association
BIA	Building- Integrated Agriculture
SDG	Sustainable Development Goals
CSA	Central Statistical Agency
USDA	United States Department of Agriculture
CO2	Carbon Dioxide
ECL-AA	Emerging City Lab – Addis Ababa

## **CHAPTER ONE: INTRODUCTION**

### **1.1 Background of the Study**

Urbanization is a widespread global trend that impacts cities worldwide, often leading to significant challenges related to infrastructure and resource management (UN-Habitat, 2020). Rapid urban expansion necessitates an increase in housing and food supply, as well as sustainable development solutions (Cohen, 2006). Addis Ababa, the capital of Ethiopia, exemplifies these global challenges, with a population exceeding 5 million and continued urban growth (World Bank, 2023). This expansion has heightened the need for affordable housing and intensified the imbalance between the demand and supply of agricultural products (Taye, 2019).

In response, vertical living characterized by high-rise buildings—emerges as a strategy to address these challenges. This approach enhances urban density, reduces land use, and improves access to amenities (Glaeser et al., 2001). Additionally, vertical farming, which involves cultivating crops in stacked layers within controlled environments, presents a viable solution to urban food security and sustainability issues. This method supports year-round food production and reduces land use and minimizes resource consumption, making it an attractive solution for cities facing land scarcity and food security challenges. It also decreases dependency on imported food, addressing critical concerns in rapidly urbanizing areas (Despommier, 2013).

Vertical farming shows potential benefits in urban environments, such as improving air quality, reducing noise pollution, and contributing to aesthetic and sustainability goals (Banerjee & Adenaeuer, 2014). Integrating vertical farms into residential buildings could be particularly advantageous for cities like Addis Ababa, where internal migration from rural areas is prevalent and urban sustainability is essential (Fentaw, 2022).

The study "Harmony in Vertical Living: Innovative Solutions for Integrating Apartment Buildings and Vertical Farming in Addis Ababa" explores the feasibility and advantages of incorporating vertical farms into apartment complexes. It evaluates the technical, economic, social, and environmental impacts of such integration. The study provides recommendations for sustainable practices, including wastewater recycling and design guidelines, to support the

effective incorporation of vertical farms into residential buildings, thereby enhancing Addis Ababa's urban sustainability and food security (Kozai et al., 2015).

## **1.2 Problem Statement**

The core problem statement of this thesis is; the rapid urbanization of Addis Ababa has led to worsening living standards, an unrelenting housing shortage, and growing food insecurity, largely due to the limited availability of agricultural land and high dependence on food imports. Despite substantial infrastructure investments, the gap between food supply and demand continues to grow, straining foreign exchange reserves and deepening economic challenges. This study explores the potential of integrating vertical farming within high-rise residential buildings to improve food accessibility and address urban land limitations, examining the feasibility, technical barriers, and socioeconomic impacts of this approach in Addis Ababa.

Integrating vertical farming into high-rise residential structures presents a potential solution to these problems. Vertical farming, which involves growing crops in stacked layers within controlled environments, offers the opportunity to produce fresh, affordable food within urban areas. This approach could reduce dependence on imported food and make more efficient use of limited urban land (Despommier, 2013). However, implementing vertical farms in residential buildings may encounter technical, economic, and social challenges that need to be addressed (Banerjee & Adenaauer, 2014).

This study examines how integrating vertical farming into high-rise residential buildings can address the interconnected issues of housing and food security in Addis Ababa. By assessing the feasibility and impacts of this integration, the research aims to identify practical solutions for overcoming the technical, economic, and social barriers associated with vertical farming in a rapidly urbanizing city.

## **1.3 Research Questions:**

1. What are the current practices of vertical farming in Addis Ababa?
2. What are the advantages and disadvantages of integrating vertical living and vertical farming?

3. How do vertical farms contribute to food security, reduce food imports, and promote a healthy lifestyle for residents in Addis Ababa?

#### **1.4 General Objective of the Study**

The general objective of this study is to explore innovative solutions for integrating vertical farming with vertical living in Addis Ababa, to address challenges related to food security and sustainable urban development.

#### **1.5 Specific Objective of the Study**

1. To analyze the feasibility of integrating vertical farms within apartment buildings in Addis Ababa.
2. To explore innovative technological solutions for optimizing vertical farming within residential settings.
3. To develop design and policy recommendations for the seamless integration of vertical farming and living, considering economic, social, and environmental aspects.
4. To assess the potential impact of such integration on urban food security, environmental sustainability, and community well-being.

#### **1.6 Scope of the Study**

This study is centered on the integration of vertical farming technology within existing apartment buildings in Bole Sub-city, one of the most rapidly urbanizing areas of Addis Ababa, Ethiopia. The choice of Bole Sub-city as the focus of this research is deliberate, given its dense population, modern infrastructure, and ongoing urban development projects, which make it an ideal case study for exploring innovative urban agriculture solutions. The study seeks to understand how vertical farming can be practically and effectively implemented within the constraints of existing residential structures, considering the unique environmental, spatial, and infrastructural characteristics of the area. By concentrating on a specific sub-city, the study aims to provide detailed insights that can be extrapolated to other similar urban settings within Addis Ababa and potentially other cities in Ethiopia.

The study systematically evaluates the feasibility of integrating vertical farming into residential high-rise buildings by investigating the technical requirements, economic considerations, and social acceptability of such an initiative. Technical aspects include the suitability of existing building designs for retrofitting with vertical farming systems, the availability and management of necessary resources such as water and energy, and the potential need for modifications to support these systems. Economic analysis involves

assessing the costs associated with the installation, maintenance, and operation of vertical farms, as well as their economic viability in terms of return on investment and long-term sustainability. Social dimensions are also critically examined, focusing on the attitudes and perceptions of residents towards incorporating agriculture into their living spaces and how these attitudes might influence the success or failure of such projects.

Furthermore, the study places a strong emphasis on the potential impact of vertical farming on urban food security and sustainability in Addis Ababa. It explores how integrating agriculture within urban residential areas can contribute to reducing the city's reliance on imported food, decreasing food prices, and providing year-round access to fresh produce. The environmental benefits, such as reduced carbon footprints due to localized food production and the recycling of greywater, are also considered as part of the sustainability analysis. Ultimately, the study aims to offer actionable recommendations for policymakers, urban planners, and developers, providing a roadmap for the successful implementation of vertical farming in urban settings, with a particular focus on enhancing food security and promoting sustainable urban development in Addis Ababa.

### **1.7 Significance of the Study**

This study provides valuable insights for residents, government officials, urban planners, and policymakers in Ethiopia. By demonstrating the benefits of integrating vertical farms within urban residential buildings, the study aims to encourage the adoption of sustainable urban agriculture practices. The findings offer practical recommendations for the design and implementation of vertical farming projects in Addis Ababa, contributing to the city's efforts to achieve food security, reduce environmental impact, and improve the quality of life for its residents.

The study also has broader implications for other rapidly urbanizing cities in developing countries, where similar challenges related to housing, food security, and sustainability are prevalent. By providing a model for the integration of vertical farming and living, the study contributes to the global discourse on sustainable urban development and offers a potential solution to the pressing challenges of urbanization.

### **1.8 Limitations of the Study**

One of the primary limitations of this study is the lack of existing data on the integration of vertical farming within apartment buildings in Addis Ababa. The absence of dedicated projects or case studies in this area poses a challenge to data collection and analysis.

However, this limitation also highlights the novelty and importance of the research, as it seeks to fill a critical gap in the literature on urban agriculture and sustainable development in Ethiopia.

Another limitation is the potential resistance from residents and policymakers to the idea of integrating farming practices within residential buildings. Cultural attitudes towards agriculture and urban living may influence the acceptance and success of vertical farming initiatives. The study addresses these concerns by including surveys and interviews to gauge the perceptions and attitudes of stakeholders, providing a comprehensive understanding of the social feasibility of the proposed integration.

Finally, the study acknowledges the challenges associated with scaling up vertical farming projects in a resource-constrained environment like Addis Ababa. The economic and technical barriers to implementing large-scale vertical farming in high-rise buildings are significant and require careful consideration. The study provides recommendations for overcoming these challenges and highlights the importance of policy support, public awareness, and investment in sustainable technologies to ensure the successful integration of vertical farming in the city's urban landscape.

## **1.9 Organization of the Study**

The study organized into six chapters: Chapter One introduces the study's context and objectives. Chapter Two reviews relevant theories, concepts, and case studies. Chapter Three outlines the research design and methodology used. Chapter Four presents and analyzes the research findings. Chapter Five translated these findings into actionable design proposals. Finally, Chapter Six concludes the study by summarizing key insights and offering recommendations for future action.

## **CHAPTER TWO: - LITERATURE REVIEW**

### **2.1 Introduction**

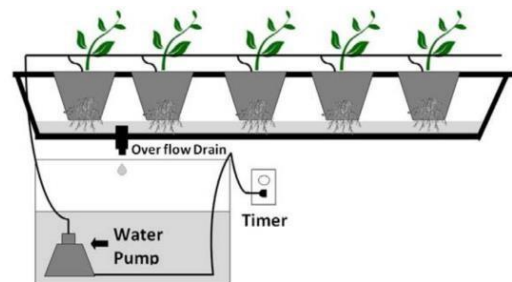
Ethiopia's urban population is projected to reach 42 million by 2037 due to its rapid growth (World Bank, 2020). Over the next ten years, as the nation strives for middle-income status, it becomes crucial to determine how to transform cities into economically productive environments. Vertical farming, in particular, offers a viable solution to this challenge in urban agriculture. This innovative method maximizes available space by cultivating food on rooftops, building facades, and in apartment hallways (Despommere, 2010). By adapting this approach, vertical farming supports local ecosystems and reduces the carbon footprint associated with food transportation, while providing urban residents with fresh, nutritious fruits, vegetables, herbs, and spices.

Vertical farming represents a contemporary approach to agriculture, involving the cultivation of crops in controlled settings in stacked layers. These farms frequently employ hydroponic or aeroponic systems in place of conventional soil, enabling plants to flourish with less water and no pesticides (Beacham et al., 2019). The advantage is obvious: vertical farms have faster growing cycles, use less water, are shelters from harsh weather, and make efficient use of available space (Oh & Lu, 2022). Furthermore, they enable local food production, thereby reducing supply chains and ensuring fresh, nutrient-dense produce year-round, as they can be installed in various locations, including underground (Eldridge et al., 2020; Shamshiri et al., 2018).

Despite the numerous advantages, there are controversies about the efficiency of vertical farming due to the high initial costs and high maintenance requirements in urban areas (Oh & Lu, 2022). However, by removing the seasonality of growing fresh vegetables, it would be possible to increase yield and profits in vertical farming (Beacham et al., 2019; Oh & Lu, 2022). According to Kozai et al. (2015), indoor vertical farming shows 100 times higher productivity in leafy lettuce compared to conventional cultivation and 15 times higher than glasshouse cultivation (Oh & Lu, 2022).

## 2.2 Types of Vertical Farming

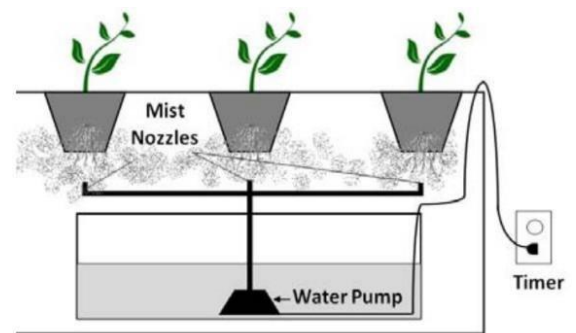
2.2.1 **Hydroponics** – is the system of growing plants in nutrient-rich fluids without soil. The plant roots are immersed in the nutrient solution, which is constantly checked and circulated to ensure the proper chemicals composition is maintained. (Birkby, 2016; “Vertical Farming: A Novel Farming Technology,” 2016).



Hydroponic graphic. Illustration: NCAT

Figure 2.1 Hydroponics

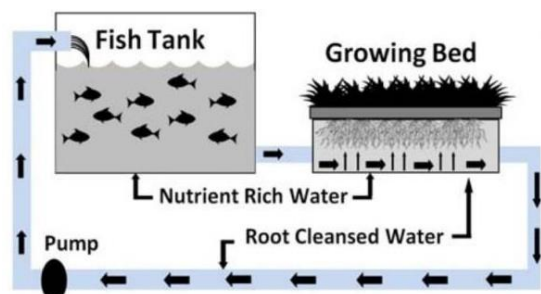
2.2.2 **Aeroponics** –refers to “growing plants in an air/mist environment without soil and very little water.” Plants are grown. Mist allows for optimal root growth and nutrient uptake. However, this approach necessitates exact control of humidity and temperature, making it more challenging to manage (Garg, 2014).



Aeroponic graphic. Illustration: NCAT

Figure 2.2 Aeroponics

2.2.3 **Aquaponics** - refers to a system that extends hydroponics by integrating plants and fish in the same environment. Fish are kept in indoor ponds, producing nutrient-rich excrement that feeds the plants in the vertical farm. In turn, the plants filter and purify the wastewater, which is then recycled into the fish ponds (Beacham et al., 2019; Birkby, 2016) 2016).



Aquaponic graphic. Illustration: NCAT

Figure 2.3 Aquaponics

### 2.3 Alternative Ways of Vertical Growth Surfaces

Existing research has largely focused on rooftop agriculture, overlooking the potential for balconies and corridors. Studies indicate that making use of these spaces can greatly improve food security in crowded cities (Tablada & Kosoric, 2022). Residents can grow a range of crops from the comfort of their own homes by maximizing space efficiency through the integration of vertically stacked layers (Song et al., 2018). Given their potential to boost architectural aesthetics and thermal performance, the effects of living walls and green facades are also worth discussing (Li & Lio, 2023). Incorporating these elements into urban planning promotes overall urban sustainability in addition to food production.

**Rooftops and balconies** - rooftops and balconies can also be used for simplified or complex versions of vertical farming. The surface of these areas can be utilized to maximize agricultural production. This method can produce different fruits, vegetables and various herbs. Rooftop agriculture can be integrated into both new and existing buildings (Caputo et al., 2017). Green roofs have been shown to store rainwater, reduce the urban heat island effect, and improve air quality and the quality of life (Song et al., 2022). When it comes to growing food in urban spaces, green roofs have been extensively studied compared to other ways of gardening vertically at home. Researcher suggest that using intensive soilless farming techniques on rooftops could potentially provide sufficient food to meet the dietary needs of approximately 77% of the local population (Orsini et al., 2014).

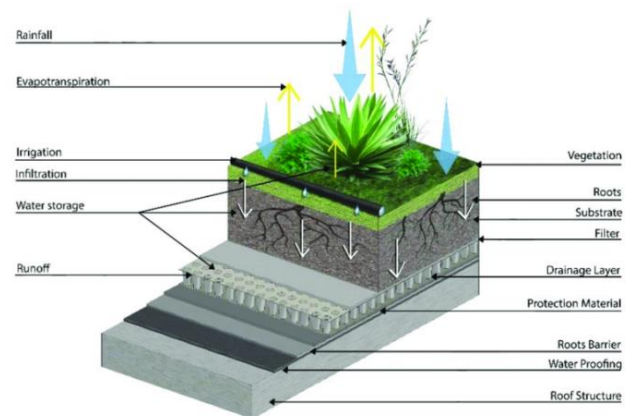


Figure 2.4 Typical green roof & cross-sectional layer

Square foot gardening is a preferred method for container gardening due to its efficiency in water use, soil management, and maintenance compared to other gardening techniques. This method not only reduces the weight load on existing or new apartment rooftops but also maximizes vegetable yield per square foot, optimizing the use of available rooftop space (Odum, 2007).

To implement this method, the rooftop garden is designed with beds measuring 120 cm by 120 cm and a depth of 30 cm. The beds are spaced 1 meter apart to create walking aisles. In a rooftop garden, dedicating each grid to a single type of plant proves advantageous. Depending on the spacing, each grid can accommodate 1, 4, 9, or 16 plants. For instance, with a spacing of 6 inches between each plant, a grid can fit 4 plants (Suite 101, 2022).

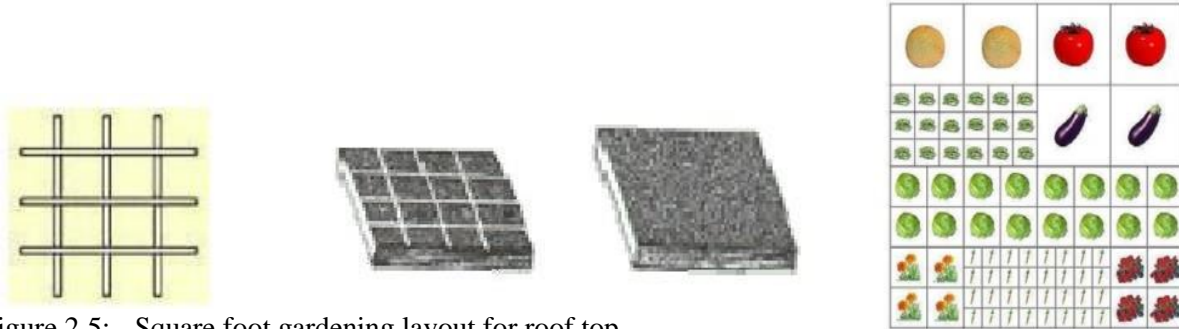


Figure 2.5: - Square foot gardening layout for roof top

**Corridors and Balconies** - Balconies serve as a key structural element for developing vertical farming on a macro scale. According to Tablada and Kosorić (2022), a survey of residents in public housing apartment buildings in Singapore shows that more than half of the respondents cultivate vegetables and herbs at home, with corridors and windows being the most popular locations for these gardens (37.3%).

Vertical farming techniques are effectively utilized in the spaces around corridors and balconies. By employing vertically stacked layers, these areas maximize horizontal space and enhance production rates (Song, Kim, & Choi, 2018). This method allows for efficient space utilization by installing hanging frames on hooks or mounting them permanently, along with incorporating automated drip irrigation systems. Additionally, this approach can also be applied to façades and other unused spaces throughout the building structure.

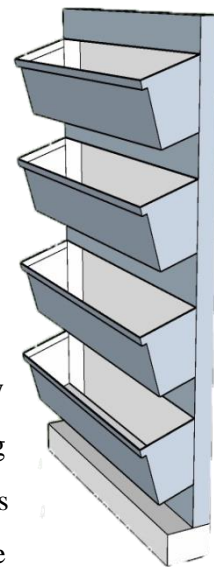


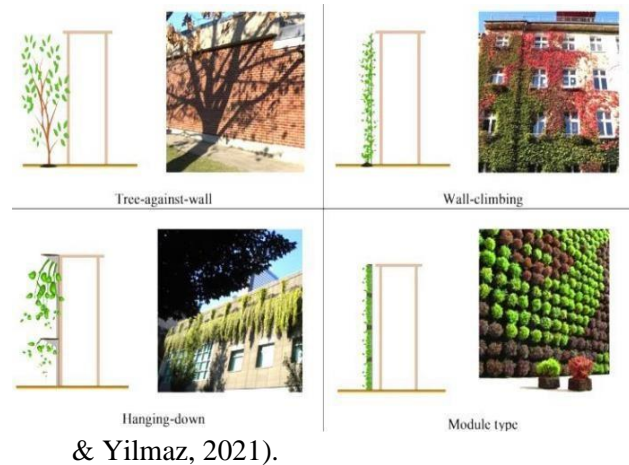
Figure 2.6:-Vertical Farming Illustration for Balcony and Corridor areas L=1m, W=10cm & H=12cm

**Façade** –Vertical or slanted growing platforms are installed on exterior walls or façades of buildings (Köhler, 2008). These vertical gardens, also known as living walls, transform building facades into green spaces, enhancing building insulation and air quality. Mir (2011)

defines green façades as consisting of vines and climbing plants that are rooted in soil or containers and growing upwards or cascading down. These plants need a supporting structure to maintain their position, support growth, and withstand seasonal changes.

Both green façades and living wall systems have distinct impacts on thermal performance. Basher, Mullen, and Ahmed (2022) note that green façades influence ventilation by interacting with the vegetation, whereas living walls use substrate covers for insulation and shading properties. According to Li and Liao (2023), green façades and living walls also significantly affect building energy consumption and microclimate regulation, contributing to the overall sustainability of

urban environments (Li & Liao, 2023; Ozturk



& Yilmaz, 2021).

Figure 2.7:- Types of vertical farming on wall

## 2.4 Problems and Consequence of Vertical Farms

Despite the environmental and social benefits associated with vertical farming challenges remain. Notably, hydroponic systems significant energy usage poses sustainability questions (Webar & Matthews, 2008). It is still crucial to assess crop output in connection to energy efficiency in order to calculate the total ecological impact of vertical farming.

Dickson Despommier, in his book *The Vertical Farm: Feeding the World in the 21st Century*, listed a number of environmental and social benefits of vertical farming (Despommier, 2011). The following is an adaptation of Despommier’s major points on Pros and cons of vertical farming (Despommier, 2011):

No.	Cons	Pros
1	Continuous Crop Production	Land and Building Costs
2	Elimination of Herbicides and Pesticides	Pollination Needs
3	Protection from Weather-Related Variations in Crop Production	Energy Use
4	Water Conservation and Recycling	Limited Number of Crop Species
5	Climate Friendly	Controversy over USDA Organic Certification
6	People Friendly	

Table 2.1 on adaptation of Despommier’s major points (Despommier, 2011)

## **2.5 Benefit of Integrating Apartment Buildings with Vertical Farming**

There are several advantages to integrating vertical farming systems inside apartment complexes, such as increased food security, cost savings, and a higher standard of living. Green areas have a good effect on mental health and well-being, according to research (Jim & He, 2011), “Nature heals” is one of the oldest therapeutic dicta, wrote Theodore Roszak in 1996 (p.22). The vertical greenery system provides numerous economic, social, and environmental benefits to building residents. According to (Jim & He, 2011), this technique has the potential to benefit those living in densely populated cities. In these dense areas, the walls of multi-story buildings cover a large proportion of the total surface area, while the ground area available for planting shade trees is limited. The most important benefits gained from using the vertical greenery system includes thermal insulation, solar protection, energy savings, acoustic insulation, aesthetics, wind protection, rain protection, increased crop production, water sustainability, conservation of natural resources, organic crops, reduction of fuel consumption, and mainly producing resource from waste (Pan & Chu, 2016).

**2.5.1 Economic Perspective** – By increasing crop production and water sustainability, as well as reducing energy costs through insulation and energy-efficient techniques, vertical farming makes urban living more economically feasible. In addition to saving fuel, this creative method increases property values and preserves natural resources, all of which lower energy costs. Additionally, by lowering indoor temperatures, vertical farming reduces the need for electricity for heating and cooling, which eventually lowers operating expenses and energy usage. Beyond these advantages, vertical farming provides a variety of non-food and non-market products that have a favorable effect on urban settings, encouraging recycling, resource conservation, and a notable decrease in food miles (Specht et al., 2013; Specht et al., 2016).

**2.5.2 Social Benefits** – Initiatives for urban gardening increase local food security and offer educational possibilities, encouraging community involvement and giving locals more authority (Specht et al., 2013). Furthermore, the installation of vertical vegetation systems – especially bio façades – benefits building occupants by lowering stress levels, increasing productivity, and giving cityscapes a distinctive and eye-catching feature. By using vertical edible landscapes to solve food security concerns, these vertical greenery systems fulfill an important social function. Urban environments might optimize their potential for food production by applying bio facades to transitional or buffer spaces, like balconies, in high rise

buildings (Taib & Prihatmanti, 2018). All things considered, urban farming produces commodities outputs and public benefits such as increased local food security, educational possibilities, links between food producers and customers, and motivating design (Specht et al., 2013).

**2.5.3 Environmental Benefits** - the integration of vertical greenery system (VGS) on multi-story buildings plays a crucial role in mitigating the urban heat island effect and enhancing urban biodiversity. By expanding surfaces areas for photosynthesis, these technologies not only help lower CO<sub>2</sub> emissions but also solve a number of environmental, made possible by vertical farming system (VFS), uses less water and fertilizer and fewer crop protection chemicals. Furthermore, when located close to metropolitan areas, VFS reduces post-farm-gate emissions and the use of outdoor places for farmers. Cities can reduce waste and transportation expenses while also increasing the quality of the final product by integrating VGS into urban supply chains (de Carbonnel et al., 2022; Pan & Chu, 2016).

## 2.6 Conceptual Frame Work

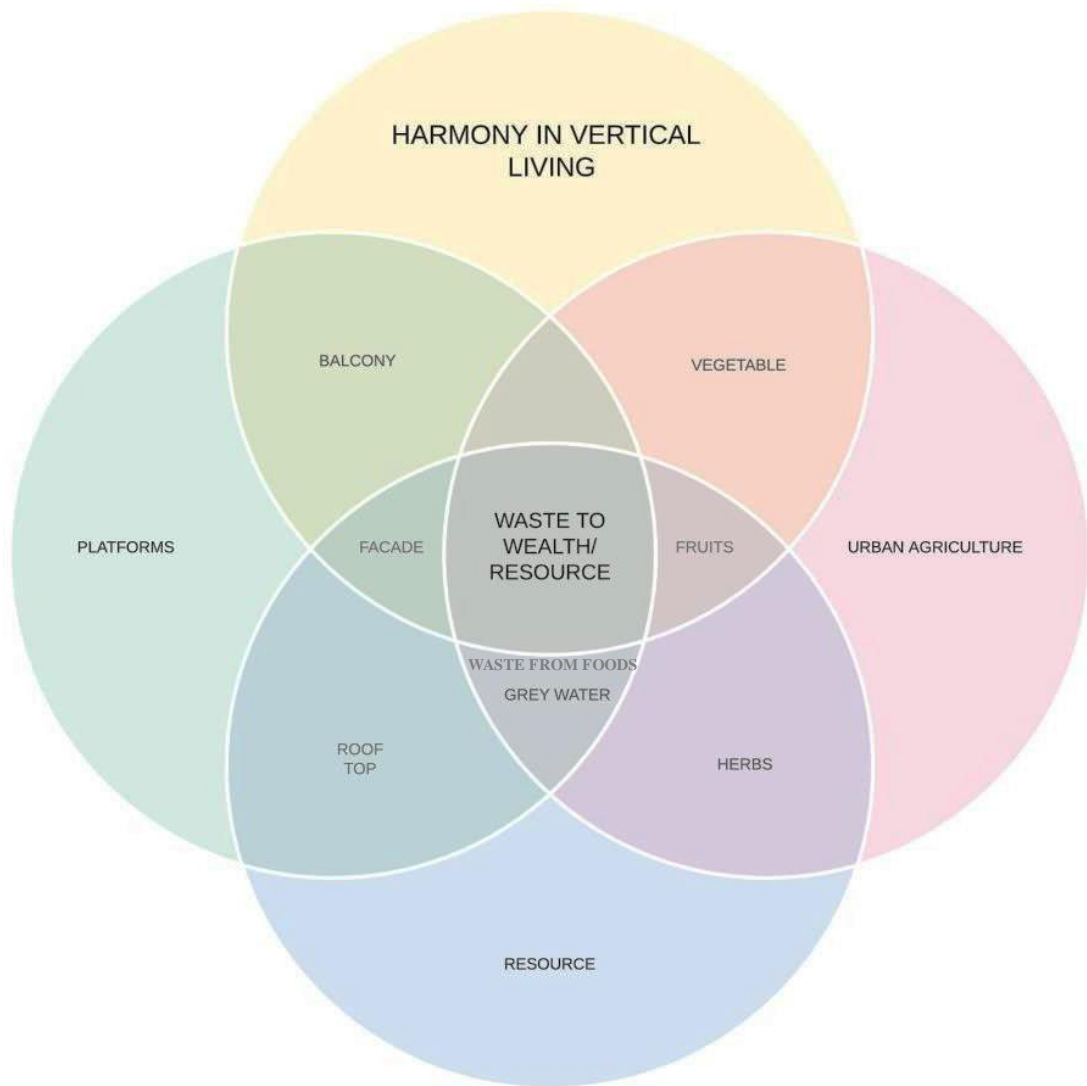


Figure 2.8 Illustration of Conceptual Frame Work

## **2.7 Considerations For Vertical Farming**

One of the primary considerations for vertical farming is the lack of comprehensive scientific research. Currently, there is insufficient data on crucial aspects such as food production capacity, crop quality, energy consumption, and other key factors (Al-Chalabi, 2015; Eigenbrod & Gruda, 2015; Mok et al., 2014; Pinstrup-Andersen, 2018). This significant gap in knowledge makes it challenging to accurately evaluate the effectiveness and potential of vertical farms. Therefore, there is a pressing need for more in-depth research in several key areas such as

**Crop choice** - Crop range in VF systems is currently limited, with most producers predominantly favoring salad leaves and other small leafy vegetables (Agrilyst, 2017).

**Economics** – Money is a big hurdle for vertical farming. Setting it up is expensive and choosing the right location is crucial (Benke & Tomkins, 2017). For example, putting a greenhouse on a rooftop can cost three times more than building one on the ground because it needs to modify the building to handle the weight (Brinet et al., 2016).

**Environmental effects** – Vertical farming is often touted as a more eco-friendly way to grow food because it cuts down on transportation by placing farms in cities. However studies shows that growing the food itself actually creates most of the greenhouse gas emissions in our food system (83%), with transportation being a much smaller contributor only (11%) (Weber & Matthews 2008).

**Energy requirements** – Compared to traditional farms, hydroponic greenhouses can produce 10 times more food while using 10 times less water. However the energy cost is a whopping 80 times higher. This highlights the need to find ways to make vertical farms more energy-efficient. The good news is that hydroponics, a common method in vertical farming, can still boost yields up to 10 times compared to growing in soil (Burrage, 2014; Savvas et., 2013).

## 2.8 Criteria for Selection of Crops

The choice of plants for vertical farms fulfills several functions, such as supplying food, medicine, and aesthetic benefits. This selection becomes increasingly crucial as land becomes more limited in our rapidly urbanizing world (Abdoellah et al., 2020; Mellisse et al., 2018; Woldeamanual et al., 2018). Choosing crops creatively is essential, especially as home gardens shrink compared to the desire to exercise.

Maximizing small vegetable containers allows us to achieve significant food yields, even in confined spaces. Fast-maturing crops such as tomatoes, peppers, fenugreek, green onions, lettuce, radishes, and coriander are pivotal to these efforts (Duggan & Zha, 2019). These plants flourish in urban environments, where there is a persistent demand for fresh vegetables despite the reduction in available garden spaces.

Moreover, selecting adaptable plant species that thrive in particular climates, such as those in Addis Ababa – facilitates more effective gardening techniques (Duggan & Zha, 2019). Adequate sunlight enhances the growth and yield of various crops, particularly in locations facing south or west.

Ultimately, transforming constrained urban areas into fruitful gardens tapping into inner horticulturists. By embracing fast-maturing greens and herbs, it's possible to turn even modest pieces of land into thriving vertical farms, contributing to sustainability and self-sufficiency one radish at a time.

## 2.9 Climate of Addis Ababa

Addis Ababa's climate is very consistent and predictable, making it an ideal place for vegetable and crop production. The city has warm weather, with an average daytime temperature of 16.6°C and a nighttime average of 8.5°C (World Bank, 2022). The average annual rainfall is 1,280 mm, with the bulk falling between March to October (National Meteorological Agency of Ethiopia, 2023). This climatic stability promotes the growth of a wide variety of crops and considerably increases local food production, strengthening the city's food security initiatives. Some examples of vegetables and crops that grow in Addis Ababa's climate include:

- Vegetables: Cabbage, lettuce, tomatoes, peppers, beans, eggplants, onions, spinach and carrots.

- **Crops:** Cereals (wheat, maize, rice), legumes (beans, Peas, lentils), and oilseeds (soybeans, sesame, sunflower seeds)

## 2.10 Waste Water Treatment

Greywater recycling systems, along with vertical farming, provide an effective alternative for addressing water constraint while promoting sustainable practices in urban settings. Encouraging inhabitants to utilize water responsibly promotes a conservation culture, which results to significant cost savings (Memon et al., 2005). Reusing greywater on-site or in the surrounding area effectively reduces the demand for fresh water, lowers energy consumption, and addresses various social and economic needs. The use of treated greywater alleviates pressure on the main water supply and provides significant environmental benefits (Memon et al., 2005).

Internationally, several countries have implemented successful greywater reuse systems. For instance, Australia has established guidelines for greywater recycling, allowing households to use treated greywater for irrigation and toilet flushing, which has significantly reduced their reliance on potable water (Lant, 2012). Similarly, in Israel, a robust system for treated wastewater reuse in agricultural applications has made significant strides in water conservation, where approximately 85% of treated wastewater is reused (The World Bank, 2016).

Purifying and reusing greywater in apartment buildings emerges as an effective strategy for conserving valuable resources, minimizing environmental impact, and potentially lowering water bills. The following strategies are recommended for integrating greywater reuse in apartment buildings with vertical farms:

### 2.10.1 Greywater Reuse:

- **Harvesting and Filtration:** Capture greywater from sinks, showers, and washing machines through a separate plumbing system. Treat the water through filtration and disinfection for non-potable uses. In Australia, for instance, greywater systems are widely used in residential settings to reduce water demand and enhance sustainability (Rogers et al., 2012).
- **Irrigation:** Utilize treated greywater to irrigate landscaping, rooftop gardens, or vertical farming systems. This approach can significantly decrease reliance on municipal water for these purposes. In Israel, greywater reuse systems are integrated into agricultural practices,

demonstrating substantial reductions in water consumption for irrigation (Shelef & Sorek, 2015).

### **2.10.2 Rainwater Harvesting:**

- **Collection and Storage:** Rainwater harvesting systems are installed on rooftops or balconies to capture rainwater. The water is stored tanks for later use. In Germany, these systems commonly supplement potable water supplies and assist in managing storm water. The country's practices involve sophisticated filtration systems to ensure the harvested rainwater is safe for non-potable uses, such as irrigation and toilet flushing (Eichhorn et al., 2017).

- **Irrigation and Other Uses:** Collected rainwater is used for various purposes similar to treated greywater, such as irrigation. In Japan, rainwater harvesting is implemented for both residential and commercial purposes, effectively reducing dependency on conventional water sources. Additionally, in urban settings like Tokyo, local governments encourage the installation of rainwater tanks to mitigate flooding during heavy rainfall while providing water for gardens and landscaping (Ishikawa & Yamamoto, 2014).

Countries like Australia and the United States also adopt rainwater harvesting extensively. In Australia, especially drought-prone regions, rainwater collection systems are mandated for new housing developments. Residents use the harvested water for various applications, including washing clothes and watering plants, demonstrating a commitment to sustainability water conservation (Australian Government, 2022). In the U.S., cities like San Diego have initiated programs to incentivize residents to install rainwater tanks, highlighting the importance of localized water management in urban areas (City of San Diego, 2020).

By employing a combination of these strategies and promoting responsible water use among residents, apartment buildings significantly reduce their water consumption and contribute to a more sustainable future. Every drop saved has a positively impacts our precious water resources.

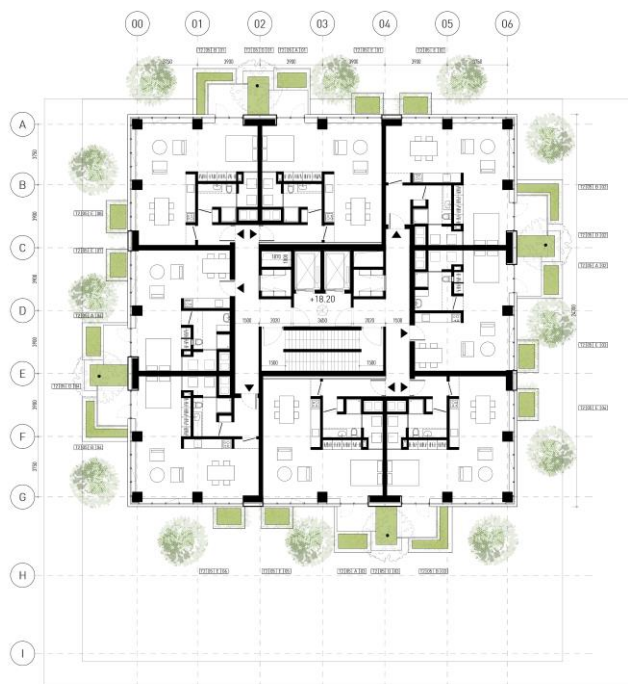
## 2.11 International Case Studies

### 2.11.1 Trudo Tower - the first vertical forest in social housing

The 19-storey residential tower in Eindhoven, Netherlands, features hundreds of different plant species on each of its four facades, as well as 125 affordable apartments for low-income residents. The miniseries comprises of three episodes that investigate how "living in contact with trees and greenery - and enjoying their benefits - is not the privilege of the wealthy but could well become a viable option for millions of citizens around the world (20 Dec 2021).



Figure 2.9 Trudo Tower



Call Out of one bedroom Layout.

Figure 2.10 Floor plan and call out of Trudo Tower

Although the flats are less than 50 square meters each, but they offer great spatial extension by terraces of more than 4 square meters.

*“The Trudo Tower in Eindhoven represents the achievement of a great goal for all of us, namely that of making the Vertical Forest typology of building (something which we are experimenting with in different parts of the world) accessible even for tenants with low incomes; this is to show that living in contact with trees and greenery - and enjoying their advantages - is not the prerogative of rich people but could well become a possible choice for millions of citizens around the world. Stefano Boeri” (trudo.nl/ trudo-toren).*



Figure 2.11 3D view of Trudo Tower Building

Architect Stefano Boeri’s experience gained during the construction of the first Vertical Forest in Milan, combined with the latest construction technologies, resources optimization, and the prefabrication of the building’s main parts, all contributed to the reduction of construction costs (trudo.nl/trudo-toren).



Figure 2.12 Balcony view of Trudo Tower

In terms of the design of the organic component, 135 trees of various species were planted on each of the four facades, along with 10,000 shrubs and plants of smaller dimensions.

### 2.11.2 Bosco Verticale / Boeri Studio - The World's First Vertical Forest-Eco Home.



Figure 2.13 Bosco Vertical Building

The Bosco Vertical, or Vertical Forest, is a ground-breaking architectural project designed by Stefano Boeri situated in Milan, Italy. Incorporating nature into high crowded regions, this project was finished in 2014, comprises of two residential structures covers with trees, shrubs, and other vegetation. It provides a new viewpoint on urban life (Boeri et al., 2020).

The experience gained by architect during the construction of very first Vertical Forest in Milan, together with the latest construction technologies, resource optimization, and the prefabrication of the building's main components, contributes to the opening of the first Vertical Forest (Il Bosco Verticale) in October 2014.

The taller of the two towers reaches 110 meters and is adorned with over 9,000 trees, 20,000 plants and 100,000 shrubs. Each balcony transforms into a mini-garden, contributing to the building's greenery (Boeri, 2014). This design is not just about aesthetics: it represents to merging nature with urban life. By integrating various plant species, the Vertical Forest fosters biodiversity and creates a refuge for urban wildlife, reminding us that even amidst concrete, life can flourish (Boeri, 2013).



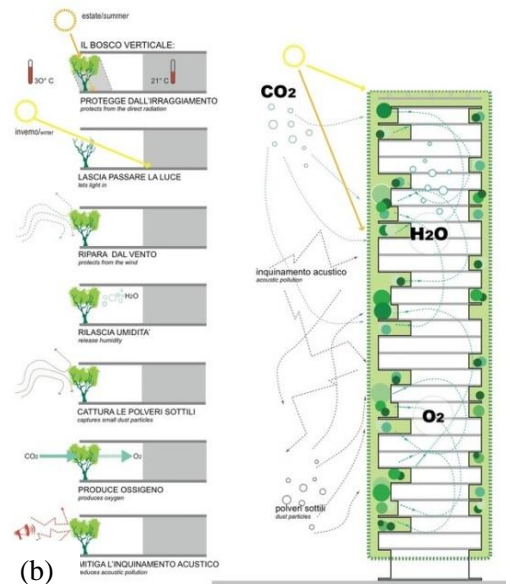
Figure 2.14 Bosco Vertical Building

**A Breath of Fresh Air for the city** - Bosco vertical has a significant effect on the environment. By collecting carbon dioxide and releasing oxygen, trees and plants contribute to air purification in a world where air pollution is a major issue. Additionally, they lesson the urban heat island effect, which can cause uncomfortable temperatures in cities. Studies show that the greenery on the building helps insulate apartments, reducing the need for air conditioning and heating and promoting energy efficiency (Boeri et al., 2020).



(a)

Figure 2.15 Balcony area (a) and picture Illustration of Bosco Vertical Building (b)



## 2.12 Lessons for Addis Ababa

Bosco Vericale's Creative concepts are pertinent to cities like Addis Ababa, which face issues with food security and fast urbanization. Imagine establishing self-sufficient

communities that offer fresh produce delivered directly outside residents' doors in addition to housing by incorporating vertical farms inside high-rise residential structures, The future of urban living in Addis Ababa may be shaped by such ideas, which provide solutions that put sustainability and welfare of the community first.



Figure 2.16 Sectional illustration and Planter detail of Bosco Vertical Building

## 2.11 Literature Gap

Despite the increased interest in vertical farming and greywater reuse, there is a considerable gap in the literature on their practical use in urban settings, particularly in developing countries like Ethiopia. Current research focuses primarily on the technological benefits and environmental impact of vertical farming and greywater systems, but it frequently overlooks key elements such as economic feasibility, community acceptability, and the unique socio-cultural dynamics of urban areas in Ethiopian. While many studies focus on rooftop agriculture suggests that vertical farming can also be integrated into apartment building balconies and corridors of apartment buildings (Tablada & Kosorić, 2022). This oversight limits our understanding of how vertical farming can be tailored to various urban environments. Furthermore, while existing literature recognizes difficulties such as high energy consumption in hydroponic systems (Weber & Matthews, 2008), it frequently lacks comprehensive evaluation methodologies to quantify energy efficiency in relation to crop yields. Addressing these gaps through targeted research is essential to fully realize the benefits of vertical farming and greywater reuse in improving food security and sustainability in Ethiopia urban communities.

## **2.14 Conclusion**

In rapidly urbanizing cities like Addis Ababa, vertical farming integrated inside apartment buildings offers a promising approach for tackling food security and sustainable urban environment. Vertical farming makes the most of scarce urban space and encourages effective resource use by employing cutting-edge agricultural methods including hydroponics, aeroponics, and aquaponics (Beacham et al., 2019). The potential advantages including enhanced food security, lower energy expenses, and better mental health – highlight how crucial it is to incorporate green areas into urban designs (Specht et al., 2013; Jim & He, 2011). Additionally, vertical farming systems combined with greywater systems combined with greywater recycling help to reduce water scarcity and promote people's responsible use of water (Memon et al., 2005).

However, further study is needed to fill the existing gaps in the literature regarding the economic, social, and technological elements of these systems in Ethiopian urban settings if their full potential is to be realized. We can build resilient and self-sufficient urban landscapes that improve food security and promote sustainable development by encouraging cooperation among stakeholders, including community members, architects, and urban planners. Adopting cutting-edge strategies like vertical farming and greywater reuse will open the door for further cities that are more resource-efficient and promote sustainability and community involvement as urban populations continue to rise.

## **CHAPTER THREE: METHODOLOGY**

### **3.1 Introduction**

This research adopts a mixed-method approach, integrating both qualitative and quantitative data collection techniques to provide a comprehensive analysis of the feasibility and impact of integrating vertical farming within residential high-rise buildings in Addis Ababa. Purposive sampling was employed to specifically target individuals living in high-rise buildings, as their insights are most relevant to the study. Key stakeholders, including residents, professionals (such as architects, urban planners, and engineers), and policymakers in Addis Ababa, were identified and invited to participate in surveys and interviews.

An in-depth literature review was conducted to gather existing knowledge on vertical farming, urban agriculture, and sustainable development. The review explores the current state of vertical farming technologies, their application in urban environments, and the challenges and opportunities associated with their implementation. Additionally, the literature review examines case studies from cities around the world that successfully integrate vertical farming, providing valuable insights and best practices applicable to Addis Ababa's context.

To capture a wide range of perspectives, surveys are designed to quantify attitudes, preferences, and concerns related to vertical farming and high-rise living. These surveys are complemented by semi-structured interviews with residents, professionals, and policymakers to gain deeper qualitative insights. The interviews provided a platform for participants to express detailed opinions and experiences, helping to identify potential barriers to implementation and the broader social implications of integrating vertical farming into Addis Ababa's urban landscape.

Finally, a proposal design illustrates the potential impact of vertical farming in Addis Ababa, considering space optimization, energy efficiency, and the use of sustainable materials. This design, coupled with an evaluation of economic, social, and environmental feasibility, aims to provide a practical framework for the integration of vertical farming within existing apartment buildings. The feasibility evaluation draws on data from the surveys, interviews, literature review, and global case studies, resulting in recommendations for policymakers, urban planners, and developers to guide the successful implementation of vertical farming in the city's high-rise residential buildings.

**Assessing the feasibility of integrating VF into apartment buildings in Addis Ababa (Bole sub-city):**

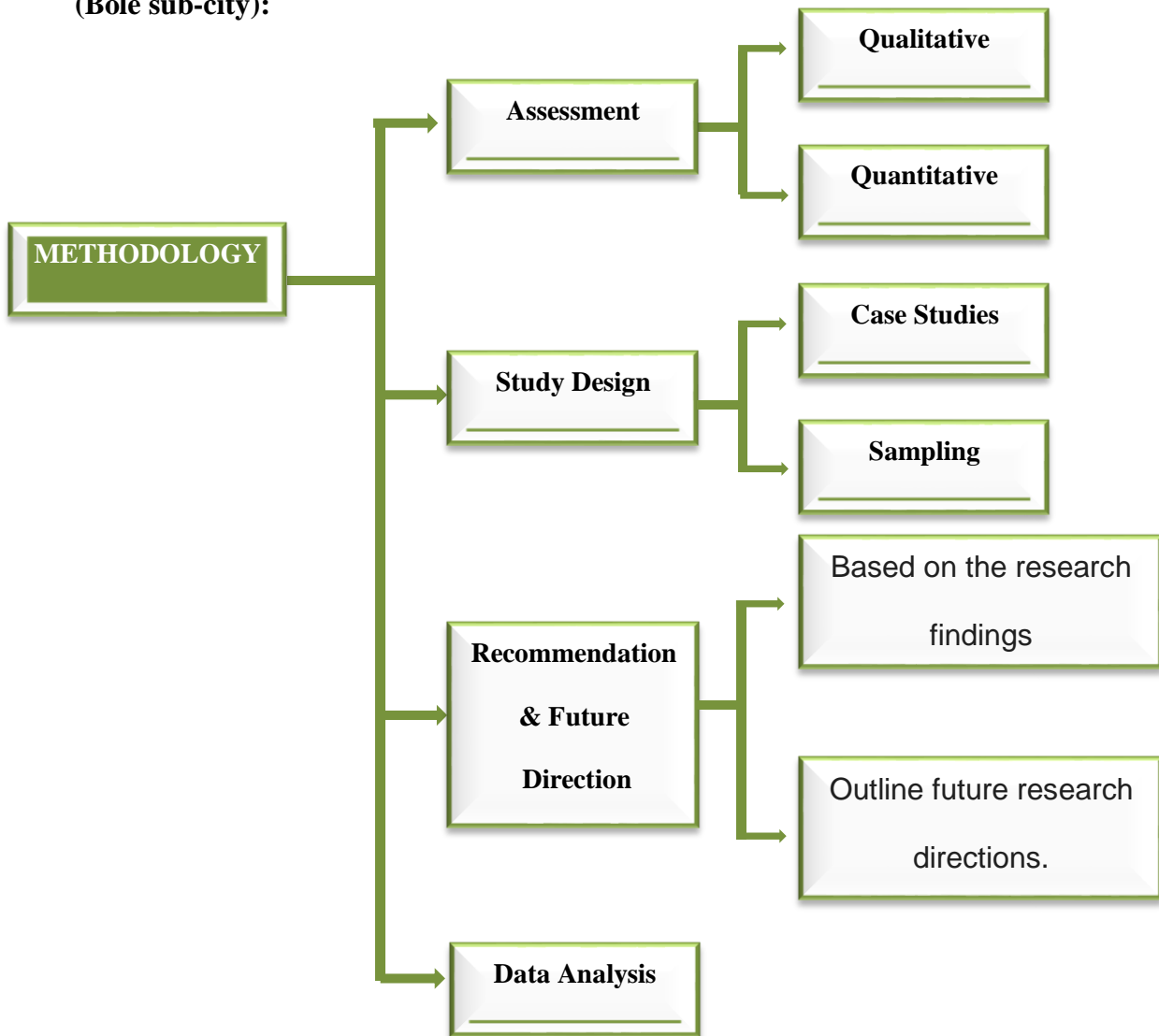


Figure 3.2 Research Method Outline

### 3.2 Study Area

Addis Ababa, the capital of Ethiopia, is facing rapid population growth, which leads to a scarcity of land for cultivation. The city is divided in eleven sub-cities and among these, the researcher selected Bole sub-city, which is the fourth largest city in terms of population size (Ethiopian Statistics Service, n.d.). According to data from the Addis Ababa Building Permit and Approval Authority, there are 2,386 /Two thousand three hundred eighty six/ buildings with eight and above story buildings in Bole sub city.

The research focuses on Addis Ababa city as massive developmental and transformational projects has been undergoing in the construction sector for the past few decades. Among

many developments, the rise of vertical living buildings like apartments, mixed use and real states were well observed. Several apartment buildings are in Bole sub city. The area is well known for its modern high-rise apartment buildings with suitable structures for the implementation of vertical farming. Having a relatively modern population, residents tend to be more willing to accept new technologies and innovative solutions like adopting vertical farming compared to other sub cities. Thus, the researcher targeted Bole sub city as a prime location to study the integration of vertical farming in apartment buildings.

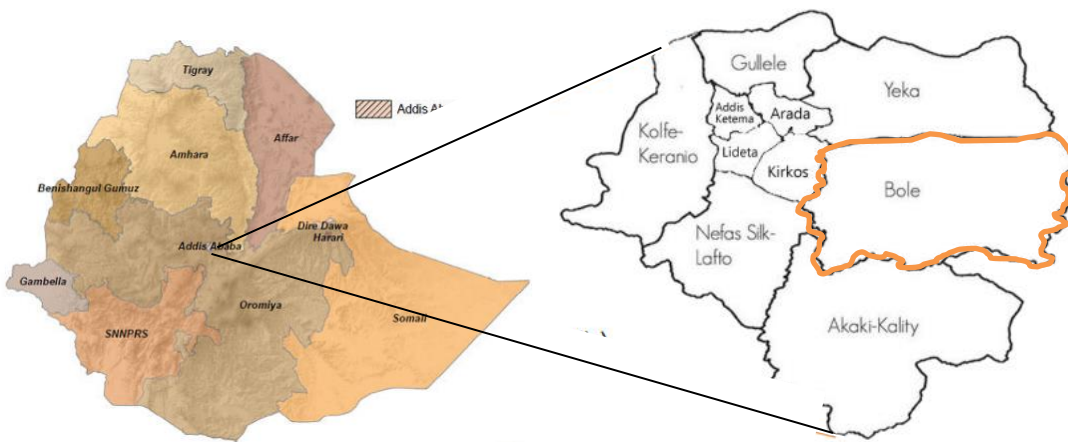


Figure 3.2 Study Area Location Map

Figures 3.2 Maps of Addis Ababa

Source: [addisababa.gov.et](http://addisababa.gov.et)

### 3.3 Study Design

This study employs a mixed-methods approach that integrates both qualitative and quantitative data collection techniques. A purposive sampling strategy is used to select participants for surveys and interviews. The study design includes the following components:

- Surveys: To quantify residents’ opinions and assess the feasibility of integrating vertical farming.
- Interviews: To gain in-depth insights from key stakeholders, such as residents, architects, urban planners, and policymakers.

- Case Studies: To assess the physical characteristics of selected apartment buildings in Bole sub-city, particularly their suitability for vertical farming.

The study examines both the advantages and challenges of integrating vertical farming systems into apartment buildings in Bole sub-city. It also evaluates the potential impact on food security and sustainable urban development.

By employing a mixed-method approach with purposive sampling, the study gathers data through surveys, interviews, and case studies to evaluate the viability and benefits of integrating vertical farming systems into apartment buildings in Bole sub-city, Addis Ababa. It further addresses potential obstacles and measures both quantitative and qualitative outcomes to support food security and promote sustainable urban development.

### **3.4 Study Population**

The study population for this research consists of residents living in apartment buildings in Bole sub-city, Addis Ababa. The sample represents a diverse group of individuals in terms of age, gender, economic status, and interest in urban agriculture, with a particular focus on vertical farming. By considering these demographic factors, the research aims to capture a comprehensive understanding of residents' viewpoints and experiences with the integration of vertical farming systems into their living environments.

### **3.5 Sampling**

In order to select participants, this researcher employs a purposive sampling approach, ensures that a sufficient number of representative samples are covered among all residents. Stratified random sampling allows researchers to collect a representative sample of the population and obtain a deeper understanding of the residents' opinions regarding the integration of vertical farming into their apartment buildings. In the first stage of sampling, Woredas within Bole sub city, Addis Ababa purposively chosen. In the second stage, the researcher randomly selects apartment building from each chosen Woreda. Finally, residents within each selected building are randomly selected to participate in the study, marking the last stage of the sampling process.

#### **3.5.1 Sampling Criteria**

Considering the vast number of potential population relevant to be a candidate to give response to the research question, defining sampling criteria is crucial to narrow the number of candidates down for focused investigation.

In this specific case, the student researcher focuses on ‘‘ case buildings’’ in Bole sub city, Addis Ababa, chosen based on the following criteria’s: -

1. **Building Type:** The **apartment building must be** aligned with the goal of integrating vertical farming within the context of vertical living.
2. **Physical Space:** The apartment building must have accessible rooftops and balconies to accommodate the potential installation and operation of vertical farming systems.

### 3.5.2 Sample Size

The sample size for this study is determined by the criteria mentioned above. Based on field visits and assessments, a selection of apartment buildings meeting the criteria for vertical farming integration was identified.

### 3.5.3 Selected Case Buildings

A systematic approach is used to identify apartment buildings in Addis Ababa with accessible rooftops and balconies as potential case studies. This selection process involves extensive field visits across various sub-cities. The apartment buildings listed below are chosen because they meet the pre-established sampling criteria and are located in Bole sub-city, Addis Ababa. Two apartment buildings in Bole sub-city are selected as case studies for this research:

- ✓ Grand View Addis Apartment
- ✓ Bimer Apartment

Both buildings meet the sampling criteria of having accessible rooftops and balconies suitable for the integration of vertical farming systems. These apartment buildings have different exterior and interior spaces. Details regarding their location, orientation, height, roof type, balconies, and layout are provided.

## **GRANDVIEW ADDIS APARTMENT**

Grandview Addis is an International Property Award winning architectural design, is a landmark mixed-use development located in Bole Rwanda, a prime area in the heart of Addis Ababa. It is a monumental masterpiece that is set to deliver Addis's most prestigious address.



Figure 3.2 Grand View Addis Apartment

The apartment consists of three iconic towers, each with 6 floors. The project is being carried out by MDM developers, a subsidiary of CP power E.A, a market leader in real estate construction and management in Eastern Africa.

A series of intricately designed three residential towers which are separately, yet intrinsically linked and rising to 15 floors are offering 1, 2 and 3-bed apartments featuring open-plan layouts and balconies with panoramic views and overlooking the grand infinity pool.

Figure 3.25 Existing 3 Bedroom Layouts at Grand View Addis Apartment



Figure 3.26 Proposed layout for 3 Bedroom at Grand View Addis Apartment



Figure 3.5 and 3.6 displays the layouts of existing three bedroom apartments alongside proposed layouts. These figures clearly demonstrate how space can be better utilized. Rather than leaving the wide balcony area open and unused, repurposing it productive functions would be a strategic enhancement.

Figure 3.27 Layout for 2 Bed room at Grand View Addis Apartment (A, B, C, D)

(A) Existing Two Bed Room Layout



(B) Proposal of Two Bed Room



(C) Existing Two Bed Room Layout



(D) Proposal for One Bed Room



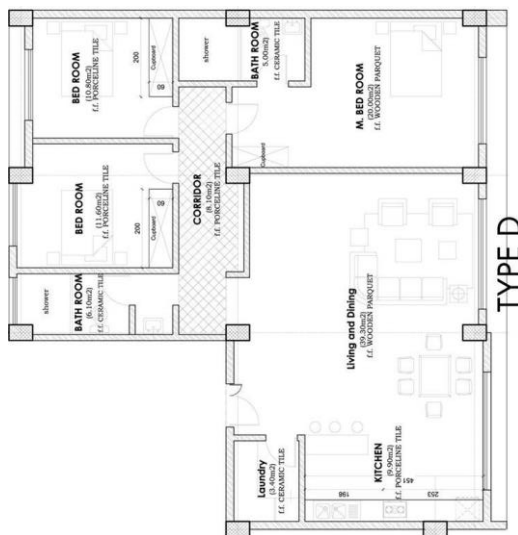
Figure 3.7 (a, b, c & d) presents the layouts of existing two and one bedroom apartments alongside proposed layouts. These figures provide insight into how space can be optimized. Instead of leaving the wide balcony area open and unused, a functional transformation to incorporate productive uses would be a strategic improvement.

## BIMER APARTMENT

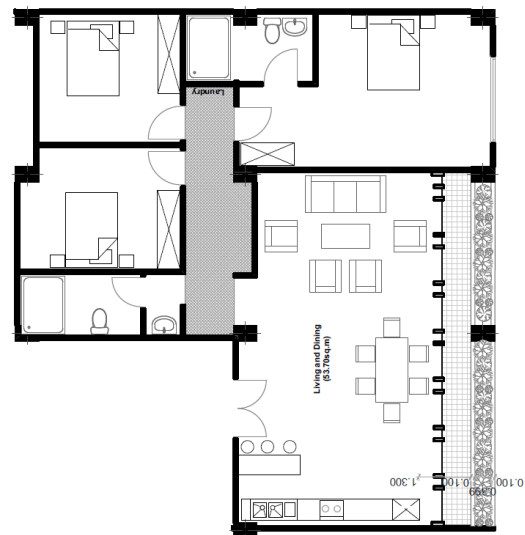


Figure 3.28 Bimer Apartment

Bimer Apartment Complex is a 10-story building located between the 22 (Haya Hulet) Square and St. Uraiel Church. The complex is beautifully designed to provide a spacious and functional living space filled with natural light. It offers a range of amenities, including a gym and underground parking space, which give the property a class of its own.



(A) Existing Two Bed Room Layout



(B) Proposal of Two Bed Room

Figure 3.2 Layout of Two Bed room at Bimer Apartment

The researcher, using Figure 3.5.3.6 as an example, highlights the possibility of incorporating a vertical farm on apartment balconies with minimal space adjustments.

### 3.6 Analysis Plan

The analysis plan is an essential tool that enables researchers to conduct **more efficient and transparent** research, ultimately leading to **more reliable and impactful findings**. This analysis plan outlines the general approach for analyzing data collected in a research project investigating the integration of vertical farms into new and existing infrastructure. The data analysis plan specifies the methods used to process both quantitative and qualitative data gathered during the study.

#### 3.6.1. Method of Data Analysis

To gain a general understanding of the potential for integrating vertical farming in apartment buildings, both case building measurements and resident questionnaire data will be quantitatively analyzed. This analysis will involve organizing and tabulating the data, followed by a comprehensive examination of trends and relationships within the context of the research question. By integrating quantitative results with the real-world context provided by the case building measurements, the research aims to arrive at a valid and practical conclusion on the feasibility and impact of vertical farming in Addis Ababa's apartment buildings.

#### 1. Quantitative Data Collection Methods

Quantitative data will be analyzed to assess the feasibility and impacts of building-integrated VF. Focus on measuring collecting and analyzing numeric data.

- **Building Infrastructure and Rooftop Space:** Analyze existing building structures and available rooftop space in different types of apartment buildings across Addis Ababa.
- **Resident Survey (Questionnaires):** Conduct a survey with residents of existing apartment buildings to assess their attitudes, needs, and preferences regarding vertical farming (VF) integration.
- **Resource Availability:** Assess the availability of resources like water and solar energy necessary for VF.
- **Cost-Benefit Analysis:** Conduct a cost-benefit analysis to evaluate the economic viability of integrating VF into apartment buildings.

## 2. Qualitative Data Collection Methods

- **In-depth interviews:** Conduct in-depth interviews with architects, urban planners, relevant government officials and other stakeholders to understand existing policies and regulations regarding VF and rooftop utilization.
- **Focus group discussions:** Organize focus group discussions with residents of apartment buildings to evaluate their interest and potential concerns regarding building-integrated VF.

The findings from both quantitative and qualitative data will be triangulated to provide a richer picture and comprehensive understanding of the research topic.

### 3.7 Data Collection Methods

To effectively address the research objectives, a strategic combination of data collection methods was deemed necessary. Questionnaires will be used to gather a large volume of data; local prior observations will provide real-world context. This combination of methods ensures a multifaceted understanding of the research question.

1. **Questionnaires:** Questionnaires are prepared for apartment residents of the selected case buildings. They relate to integration of vertical living/ apartment buildings with vertical farming. They include questions categorized in 2 Sections. (See Appendix 2).
2. **Building Measurements:** Following a predefined sample selection criterion, buildings related to this research were chosen. To analyze their impact on integration of vertical farming in vertical living, key measurements were taken, including location, orientation, height, and layout. Details and pictures of these selected case buildings are already provided in the 'Selected Case Buildings' section for reference.

## **CHAPTER FOUR: - ANALYSIS AND INTERPRETATION OF RESULTS**

### **Introduction**

This chapter investigates prior research and pilot projects focused on vertical farming initiatives in Addis Ababa. Through an in-depth examination of various case studies conducted at different times, the chapter evaluates the feasibility of vertical farming in the unique climate of Addis Ababa, identifies the most effective implementation strategies, and highlights areas where further research is required. This analysis sheds light on the evolution of vertical farming initiatives in the city and the potential pathways for their development.

In addition to local case studies, the paper examines international examples of apartment buildings that incorporate vertical farming into their design. Analyzing these examples provides insights into the prevalence and success of vertical farming in urban residential buildings globally. The chapter also explores design strategies that enable effective integration of vertical farming systems, offering a comparative perspective that can inform similar efforts in Addis Ababa. This combined analysis aims to clarify the design approaches best suited for urban vertical farming in Addis Ababa and assesses the viability of integrating vertical farming into the city's residential structures.

### **4.1. Prior Studies / pilot projects**

Vertical farming is gaining significant attention in Addis Ababa as a promising method for urban agriculture, as illustrated in Figure X. This approach offers several benefits, including optimal space utilization, the ability to grow both ornamental and edible plants in confined spaces, and simplified plant management. However, challenges remain, including limited public awareness and potential water supply issues.

In May 2021, Prime Minister Abiy Ahmed acknowledged a vertical farming pilot project by the Ethiopian Standards Authority (ESA) in their new compound, which aims to promote urban agriculture (Reliable News Source [RNS], 2021). Prime Minister Abiy emphasized the importance of urban areas developing food self-sufficiency, stating, "Our cities need to be able to at least partially feed themselves" (ENA, 2021). This statement underscores the potential of vertical farming to contribute to food security in Addis Ababa.



Figure 4.1 Gulele Sub city vertical gardening trials in Addis Ababa city.



Figure 4.2 Vertical gardening systems in Addis Ababa city Bole Roundabout.

#### **4.1.1 Local Observations and Current Practices**

Local case studies in Ethiopia reveal promising developments in urban agriculture and vertical farming, particularly in cities like Mekelle and Addis Ababa. In Mekelle, UNICEF launched a hydroponic vegetable farming pilot project aimed at addressing child malnutrition and strengthening local food systems (UNICEF USA, 2024). According to UNICEF Deputy Executive Director Ted Chaiban explains, "This initiative will not only help prevent child malnutrition but will also enable families to grow vegetables at a low cost" (UNICEF USA, 2024).

In Addis Ababa, Farm Africa’s urban agriculture pilot projects highlight the potential for urban agriculture to support food security, nutrition, and improved livelihoods. Teshome Nega, Urban Agriculture Project Coordinator at Farm Africa, emphasizes that growing food within city limits can be an effective way to alleviate poverty and hunger while enhancing urban ecosystems and green spaces. Collaborating with the Ministry of Planning and Development as part of the Sida-funded Growth for the Future (G4F) program, Farm Africa focuses on improving household incomes and

food security for low-income households and youth through horticulture and other forms of urban agriculture (Farming First, 2023).



Figure 4.3 Farm Africa’s projects in Addis Ababa

The pilot projects demonstrate the effectiveness of urban agriculture in enhancing food security, environmental sustainability, and poverty reduction. With cities now housing over half of the global population, Farm Africa’s projects in Addis Ababa are positioned as models that could inspire similar initiatives in other metropolitan areas facing urban food security challenges (Farm Africa, 2023). Vertical farming practices are expanding, with applications in various spaces, including gardens, community areas, balconies, and rooftops (Nega, 2023).

The researcher’s observations underscore the growing popularity of vertical farming in Addis Ababa. This approach provides several advantages, including efficient space utilization, the cultivation of both ornamental and edible plants in limited spaces, and convenient plant management. Figure 28 illustrates the pilot vertical gardening projects in Addis Ababa, showcasing the city's strides toward sustainable urban agriculture. The researcher observed that the current Practice of vertical farming in Addis Ababa is increasingly popular. This method offers numerous benefits, including maximizing space utilization, allowing for both ornamental and edible plants in confined areas, and facilitating convenient plant management.

#### **4.1.2 Challenges and Gaps in Vertical Farming Practices**

Despite its advantages, vertical farming faces obstacles in Addis Ababa, limiting its effectiveness and scalability. Key issues include:

- **Low public awareness** of vertical farming benefits.
- **Inconsistent project commitment** and early project abandonment.
- **Inadequate watering and fertilization practices** leading to plant stress.
- **Poor planning** around space allocation, soil preparation, and regular maintenance.

Addressing these gaps is essential to maximizing the benefits of vertical farming in dense urban areas.

#### **4.2. Resident Survey Results on Vertical Farming in Apartment Buildings**

To assess resident attitudes toward integrating vertical farming (VF) systems within apartment buildings in Addis Ababa, a survey was conducted across three apartment complexes, involving a total of 60 residents. Using purposive sampling, this questionnaire aimed to gather insights into residents' interest and perspectives on incorporating VF in their living spaces. Key focus areas included general awareness, interest levels, perceived benefits, and concerns, preferred locations for VF within apartments, willingness to contribute financially, and additional feedback. This data collection offers valuable insights into the feasibility and potential acceptance of vertical farming within Addis Ababa's apartment buildings (See Appendix B).

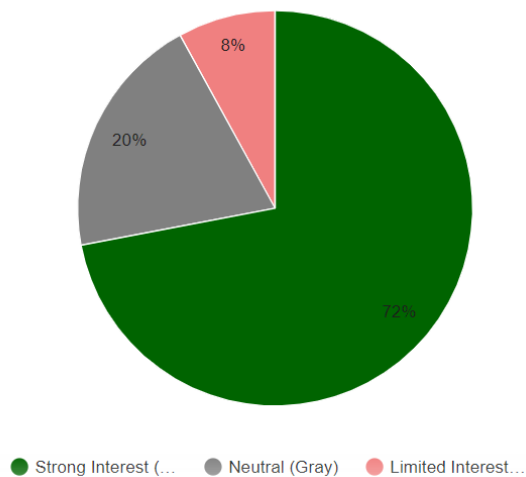
## Case Building Survey Summary

Table 5.2 Survey results on selected case buildings

Question	Grand View Addis Apartment	Bimer Apartment Complex
Awareness	37%	22%
Interest in VF	Strongly Interested: 34%, Neutral: 6%, Not Interested: 0%	Strongly Interested: 16%, Neutral: 7%, Not Interested: 4%
Level of Benefits	High: 36%, Medium: 2%, Low: 2%	High: 16%, Medium: 6%, Low: 5%
Understanding		
Potential Concerns	Water Scarcity: 15%, Maintenance: 22%	Space: 15%, Water Scarcity: 17%

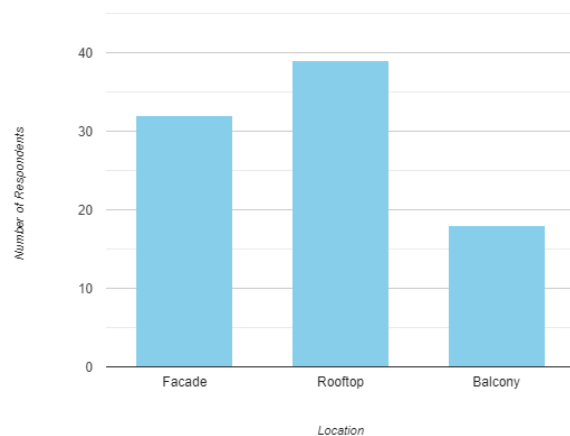
The results indicate general acceptance and optimism towards integrating vertical farming in apartment buildings, though challenges like water scarcity need addressing.

Interest Level in Vertical Farming



(a)

Location Preference for Vertical Farming



(b)

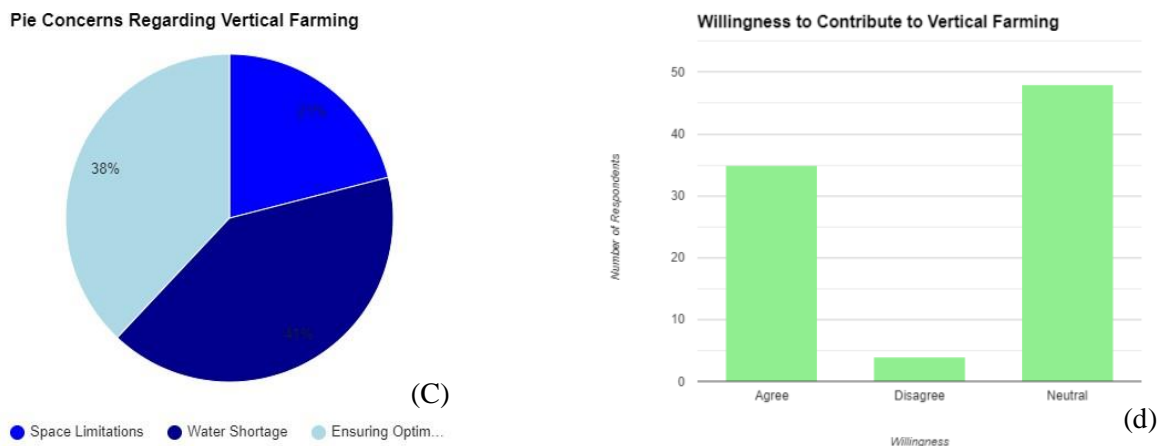


Figure 4.4 Integration of Vertical Farming on Apartment Building Survey results on selected case buildings (a), (b), (c), (d).

### Key Findings

- **Interest Levels:** Over 72% of residents expressed strong interest in vertical farming, with rooftop spaces being the most preferred location, followed by facades and balconies.
- **Concerns:** The most cited concerns included water scarcity (41%), optimal growing conditions (38%), and space limitations (21%).
- **Financial Contribution:** More than 70% of residents were willing to contribute financially to support vertical farming initiatives.

### 4.3. Secondary Data: Urban Agriculture and Vertical Farming in Addis Ababa

In Ethiopia, research on integrating vertical farming into apartment buildings remains limited, although the concepts of vertical farming and urban agriculture, particularly in Addis Ababa, have been examined in the literature. Data from the Addis Ababa City Administration Trade and Industry Bureau (AACATIDB) indicate that urban agriculture has become significant in the city. For example, in 2011/12, 11,716 registered households in Addis Ababa collectively produced over 153,662 quintals of cereals and vegetables (AACATIDB, 2012).

Studies reveal that children from low-income, urban-farming families are as healthy as those from wealthier families and generally healthier than their non-farming, low-income counterparts (Smit et al., 1996; (Teferi et al., 2003; Tacio et al., 2007; Messay et al., 2010). Urban and peri-urban agriculture has emerged as a critical part of urban economies, supporting food security and offering economic benefits to both low- and high-income communities worldwide. Compared to other urban-based economic activities, urban farming

provides substantial economic support to household economies (Falvey, 1999; Sawio, 2004; Smit et al., 1996; Tinker, 1994; Messay et al., 2010)

Urban food insecurity is an escalating concern due to the rising costs associated with food imports and urban distribution systems (Maxwell, 1994; Smit et al., 1996; Teferi, 2003; Tacio, 2007; Messay, 2010; Zezza & Tasciotti, 2010). In Addis Ababa, food prices have surged significantly over the past five years, increasing the financial burden on urban consumers (AACATIDB, 2012). During the 2010-11 agricultural season, urban farmers in the city supplied approximately 170,618 quintals of grain, 23,520 quintals of pulses, 100 quintals of oilseeds, and 16,081 quintals of vegetables to local markets (AACATIDB, 2012).

Despite urban agriculture's role in alleviating food insecurity and supporting urban economies, Ethiopia has yet to formally integrate urban and peri-urban agriculture (UPA) into its national urban planning policies. Several researchers advocate for incorporating UPA into national strategies to enhance food security and economic resilience in cities (Teferi, 2003; Messay, 2010; Zenebe, 2010). Vertical farming provides a promising approach to improve food security and promote sustainable land use in urban settings. However, its successful implementation in Addis Ababa depends on overcoming challenges such as limited resources, infrastructure constraints, and a lack of public awareness. High-tech farming methods may not be feasible due to their high costs and limited accessibility. Instead, low-tech alternatives present a more practical solution.

Incorporating simple vertical farming methods, such as utilizing balconies and façades in apartment buildings—could prove both cost-effective and accessible, encouraging greater community engagement. Emphasizing less complex methods and making use of existing building spaces like balconies and façades may allow vertical farming to thrive in Addis Ababa, given the city's resource limitations. This approach could mitigate issues associated with high-tech dependency, restricted crop variety, and high costs, aligning well with local conditions to enhance food security and create a scalable, sustainable model for urban agriculture in Addis Ababa.

Table 5.3 UPA Types in Addis Ababa City.

UPA types	Male-headed	Female-headed	Total
Peri-urban on-plot farmers	2736	600	3336
On-plot vegetable producers	1378	678	2056
Home gardeners	1759	2639	4398
Mushroom producers	116	78	194
Dairy farmers	548	263	811
Poultry producers	232	232	464
Fatteners	132	225	357
Apiarian	100	0	100
<b>Total</b>	<b>7001</b>	<b>4715</b>	<b>11716</b>

**Source: Addis Ababa City Administration** -Trade and Industrial Development Bureau Urban Agriculture Extension Service Core Business Process (Data obtained on June 15, 2012).

#### 4.4. Techniques for Planting Edible Vegetables in Vertical Farms

This research identifies two primary gardening methods for rooftop integration:

- **Container garden system** - is an ideal way to grow vegetation on a roof top because it's more light weight and cost effective than traditional green roof systems. It also allows for easier distribution of weight on the roof to ensure that it does not exceed the structural load capacity of the building (Alternatives and the rooftop Garden Project, 2008).
- **Square foot Gardening** - is a popular gardening system that maximizes space efficiency by dividing the garden into square foot sections. This technique is particularly advantageous for rooftop gardens due to limited space available.

By combining these two methods, residents can optimize space, enhance soil quality, manage pests effectively, conserve water, and improve the aesthetic appeal of rooftop gardens.

**GROW MORE FOOD WITH LESS SPACE!**



(a)



(b)

Figure 4.5 Combination of (a) Container system with (b) Square foot gardening

#### 4.4.1. Water Efficiency and Conservation Strategies

When gardening on rooftop, water usage and efficiency are crucial considerations due to the unique challenges of limited space, exposure to elements, and potential water runoff issues. Key strategies include:

**Drip irrigation or soaker hoses** - to deliver water directly to the plant roots, minimizing evaporation and runoff. These methods help conserve water by ensuring that it reaches the plants where it is needed most.

**Rain Water Harvesting** – Installation of rain water harvesting system to collect or capture the runoff from the roof and gutters and store rain water for watering for sustainable water source.

**Grey Water Treatment** – considering treatment methods to improve water quality and reduce potential risks this may include filtering debris, using natural cleaning products includes vinegar, baking soda, and citrus – based cleaners by this users can minimize the impact of contaminants in greywater on plant health, soil quality and water resources.

**Enhance Soil Health With Organic Matter Integration** – By integrating compost and organic matter into the soil, user can boost its water retention capacity and enrich its nutrient profile. Soil that is rich in organic content and well-structures can efficiently hold moisture, decreasing the necessity for frequent watering and subsequent maintenance.

**Efficient Irrigation Technology** – utilize advanced irrigation systems equipped with timers, sensors, or moisture meters to automate watering processes and adapt based on current weather conditions and plant requirements. These innovative systems are designed to enhance water efficiency, minimize the risk of overwatering, and ensure optimal irrigation practice.

#### **4.4.2. Soil Preparation Techniques**

- **Adding organic matter;** incorporate organic matter such as compost, well-rotted manure, or leaf mold to enrich the soil with essential nutrients as organic matter helps improve soil structure, fertility and water retention.
- **Mulching;** Apply a layer of organic mulch such as straw, shredded leaves, or grass clippings around the plants once they are established. Mulch helps retain soil moisture, suppress weeds, and regulate soil temperature.
- **Companion Planting;** considering companion planting to maximize space and enhance plant growth. For example, planting onions and garlic together can help deter pests, while legumes like beans can fix nitrogen in the soil.
- **Watering;** Ensure the soil is adequately moist but not waterlogged before planting. After planting the garden beds thoroughly to help settle the soil around the roots of the plants.





#### **4.4.3. Organic Waste Management**

Residents can compost food scraps such as vegetable peels, fruit cores, eggshells and coffee grounds can be composted to create nutrient – rich fertilizer. This locally generated resource can serve as a valuable input for a vertical farming system in apartment buildings, promoting a more sustainable and closed-loop urban agriculture system.

#### 4.4.4. Representatives Plant Types (Local Produce)

In alignment with the researcher’s original concept, a specific set of crops has been chosen for detailed examination. These crops include tomatoes, Potatoes, Onions (referred to as “TOP”) due to their status as some of the most widely grown and consumed vegetables globally. Legumes have also been included because of their high protein content, which enhances the nutritional diversity of the selected crops. Thus, the chosen crops for this study—tomatoes, potatoes, onions, and legumes—were selected based on their nutritional value, growth requirements, and suitability for local conditions.

Table 5.4 Representative Crops / Plant Types

Plant Types	Space Requirement	Planting pattern	Water Requirement	Estimated outcome
1 <b>Legume (Aba Choma)</b> 	Legumes are like beans can be planted closely together in rows. 30-45cm between rows.	Can be planted in Rows, mounds or trellised for vertical growth depending on the variety.	Requires regular watering to keep the soil consistent. 1-1.5 inches per week.	Typically mature in 60-90days, depending on the variety. Each plant can produce multiple beans.
2 <b>Tomato</b> 	Require adequate space 1-4 square feet.	Can be planted in rows, or clusters with spacing of 18-36inches between plants allowing for good air circulation.	Requires consistent moisture especially during bulb formation. 1-2 inch of water per week.	Take 60-85days to mature. A single tomato plant can yield 10-20pounds of fruit during the growing season.
3 <b>Onion</b> 	Can be planted closely together in rows or raised beds. Needs 15-30cm.	Usually planted in rows with spacing adjusted. Closer spacing for smaller bulbs, wider spacing for larger bulbs.	Requires consistent moisture especially during bulb formation. 1 inch of water per week.	Takes 90-120days to rich maturity. With each plant producing 1-2 bulbs.
4 <b>Potato</b> 	Standard spacing of Potato is 0.5m between plants in rows and 0.75m between rows.	To maximize potato yield, using hilling method (planting in trench) to protect the developing potatoes from sunlight for abundant harvest.	Requires consistent moisture 1-2 times a week. Avoid overwatering.	The early season varieties can be ready to harvest in 60-80days after planting.

#### 4.4.5. Food Production Estimates for Vertical Farming in a 40sq.m Area

Predicting the exact amount of food production may vary by several factors such as variety of species selection, planting density, growing conditions, factors in potential losses like pest and disease pressure, consistent watering and fertilization, sunlight and pollination and many more. But it's possible to get a good estimate of the potential amount of production by assuming 40sq.m rooftop garden. Acknowledging the limitations mentioned earlier;

#### 4.4.6. Calculations

##### A. Tomato Plant

1. Calculate the number of Tomato plants:
  - Assuming a standard spacing of 1 square foot per tomato plant, on a 40sq.m rooftop garden, the area can support the growth of up to 43 tomato plants ( $40\text{sq.m} = 430.56\text{sq.ft}$ )
2. Estimate the yield per plant;
  - Assuming an average yield of 7kg per tomato plant over the growing season.
3. Calculate Total Yield:
  - Total Yield = Number of plants x yield per plant
  - Total Yield = 43 plants x 7kg / plant

Total Yield = 293kg of tomatoes per growing season.

4. Estimate yearly production:
  - Assuming three harvests per year, the yearly tomato production can be calculated as follows:
    - Yearly production = Total yield per harvest x Number of harvests per year
    - Yearly production = 293kg /harvest x 3 harvest
    - Yearly production = 878 kg of tomatoes per year.

Therefore, in a 40sq.m area, with an estimated yield of 7kg per plant, the yearly production of Tomatoes can be approximately 878kg.

##### B. Onion

1. Estimate Yield per plant;
  - Assume the average yield of Onion per plant is 1.5kg.
2. Calculate Total yields

- Assuming in a 40sq.m area considering standard spacing 15cm between plant in rows and 30cm between rows.

- Number of plants =  $40\text{sq.m} / 0.045\text{sq.m/plant} = 889\text{plants}$

- Number of yield per plant =  $1.5\text{kg/plant} * 889\text{plants} = 1333.5\text{kg}$

3. Estimate yearly production:

- Yearly production = Total yield  $1333.5\text{kg} * 2\text{yearly production} = 2667\text{kg}$

Therefore, based on our assumptions, planting Onion in a 40sq.m area could potentially yield approximately 2667kg.

### **C. Potato**

1. Estimate the Yield per plant;

- Assuming the average yield of Potato per plant is 2.25kg.

2. Calculate Total Yields

- Assuming in a 40sq.m area considering standard spacing 0.5 in rows & 0.75m between rows 1066plants per square meter space.

- Number of plants  $40\text{sq.m} = 40\text{sq.m} * 1066\text{plants/ sq.m} = 2401.5\text{kg}$

3. Estimate yearly production:

- In Addis Ababa, depending on the specific elevation and microclimate possible to have two potato growing seasons.

- Yearly production = Total yield  $2401.5\text{kg} * 2\text{yearly production} = 4803\text{kg}$

Therefore, based on our assumptions, planting potatoes in a 40sq.m area could potentially yield approximately 4803kg.

### **D. Legume (Aba Choma)**

1. Estimate the Yield per plant;

- Assuming the average yield of Legumes per plant is 0.5kg.

2. Calculate Total Yields

- Assuming in a 40sq.m area, the researcher need to calculate the number of plants that can be accommodated in 10plants per square meter space.

- Number of plants in  $40\text{sq.m} = 40\text{sq.m} * 10\text{ plants/ Sq.m} = 400\text{plants}$

- Number of plants total yield =  $0.5\text{ kg/plant} * 400\text{ plants} = 200\text{kg}$

3. Estimate yearly production :

- Assuming three harvests per year

- Yearly Production = Total Yield 200kg \* 3yearly production = 600kg

Therefore, in a 40sq.m area, with an estimated yield of 0.5kg per plant, the yearly production of legumes can be approximately 600kg.

#### **4.5. Challenges of Integrating vertical farming on Apartment Buildings**

- **Structural Considerations** –Vertical gardens and rooftop farms need to consider the weight load capacity of the building structure. Additionally, waterproofing needs to be addressed to prevent leaks and damage.
- **Environmental factors** – Require careful consideration of sunlight availability and wind exposure. Plants may need shade protection from strong sunlight or wind protection from strong winds.
- **Access and Maintenance** - might be challenging to access for maintenance tasks such as watering, weeding, and pest control. Planning for safe and convenient access is important.

Vertical farming for edible crops requires careful planning, substantial investment in infrastructure, and consistent management to address various challenges. However, the potential benefits—such as local food production, reduced environmental impact, and enhanced community engagement—make this approach a valuable endeavor for those committed to investing the necessary time and resources. Despite these challenges, the advantages of supporting local food systems, promoting environmental sustainability, and fostering community engagement underscore vertical farming’s promise in urban areas.

#### **4.6. Reflection on Findings**

According to the assessment above, vertical farming offers promising benefits, including increased food security and sustainable land use practices. However, its success in Addis Ababa depends on overcoming challenges related to limited resources and infrastructure. Factors such as land availability, demographics, and housing type significantly impact the viability of these projects.

Integrating vertical farming within apartment buildings presents unique hurdles, including high energy demands for artificial lighting and the need for extensive rooftop renovations. Existing high-tech methods reveal challenges in maximizing space utilization for efficient

production. Given these limitations, a focus on low-tech alternatives is more suitable for Addis Ababa's context. The high costs and limited access to advanced technologies highlight the need for simpler approaches. Utilizing existing building elements like balconies and façades, along with less complex growing methods, could offer a feasible and sustainable solution for integrating vertical farming into apartment buildings in Addis Ababa. This approach addresses concerns about high-tech dependency, limited crop variety, and excessive initial costs.

In Addis Ababa, a focus on accessible, low-tech solutions tailored to local conditions could enable vertical farming to flourish. By emphasizing simpler methods and utilizing available spaces like balconies and façades, the city can mitigate challenges associated with high-tech dependency, restricted crop options, and elevated expenses. This approach aligns with the city's resource limitations, enhances food security, and provides a scalable model for sustainable urban agriculture in Addis Ababa.

## CHAPTER FIVE: DESIGN PROPOSAL

### 5.1 Introduction

In this chapter, an apartment building integrated with vertical farming is proposed. The proposal is intended to show how vertical farming can be integrated with buildings, factors to be encountered, design considerations, details and all.

### 5.2 Site Selection

The selected site is located in Bole Sub-city around Megenagna square. This is one of the areas in Addis Ababa with a high level of crowded and urbanization. Its location, area and exposure make it a strategic choice for the theme of this research.

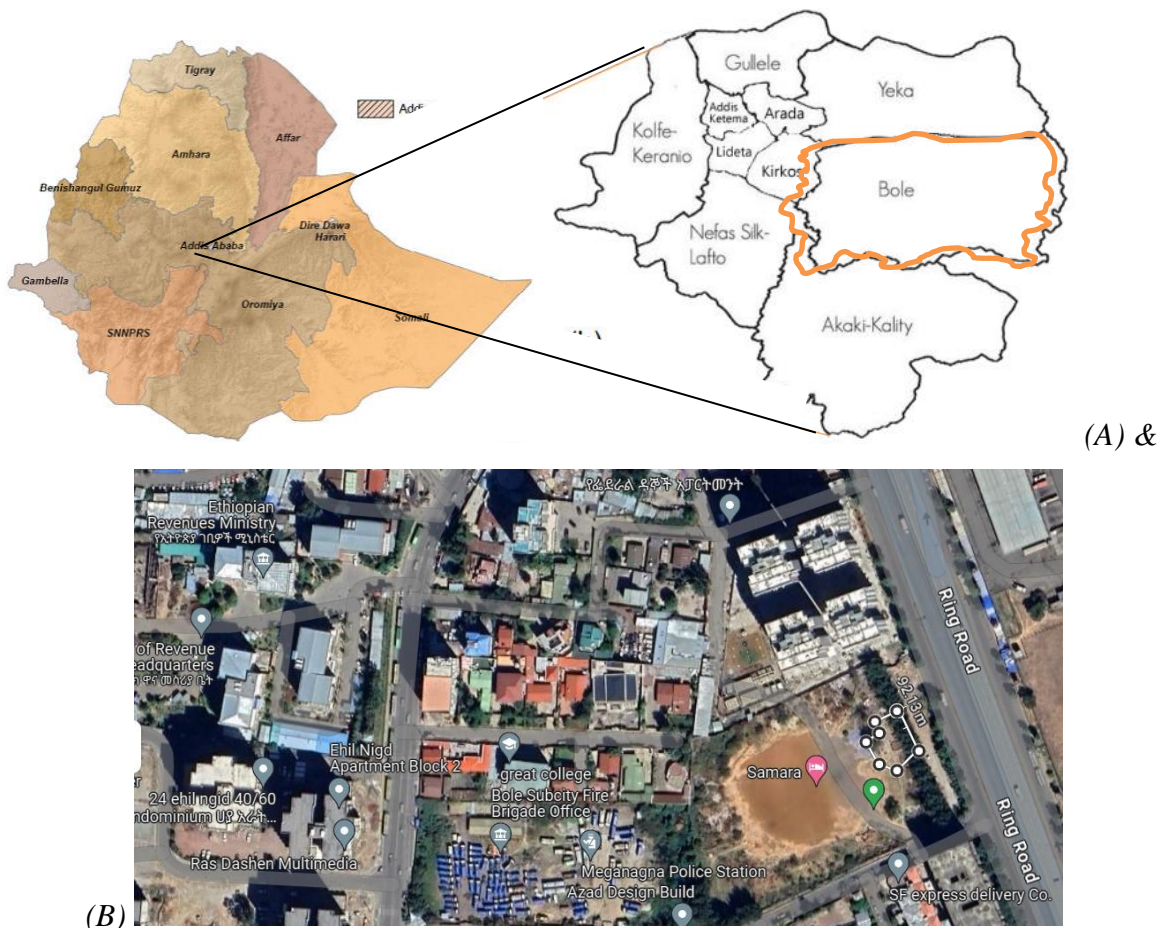


Figure 5.1 Location maps of strategic site (a) Map of Ethiopia, (B) Map of Addis Ababa, (C) Googleearth.com

### 5.3 Site and Ground Floor Plan

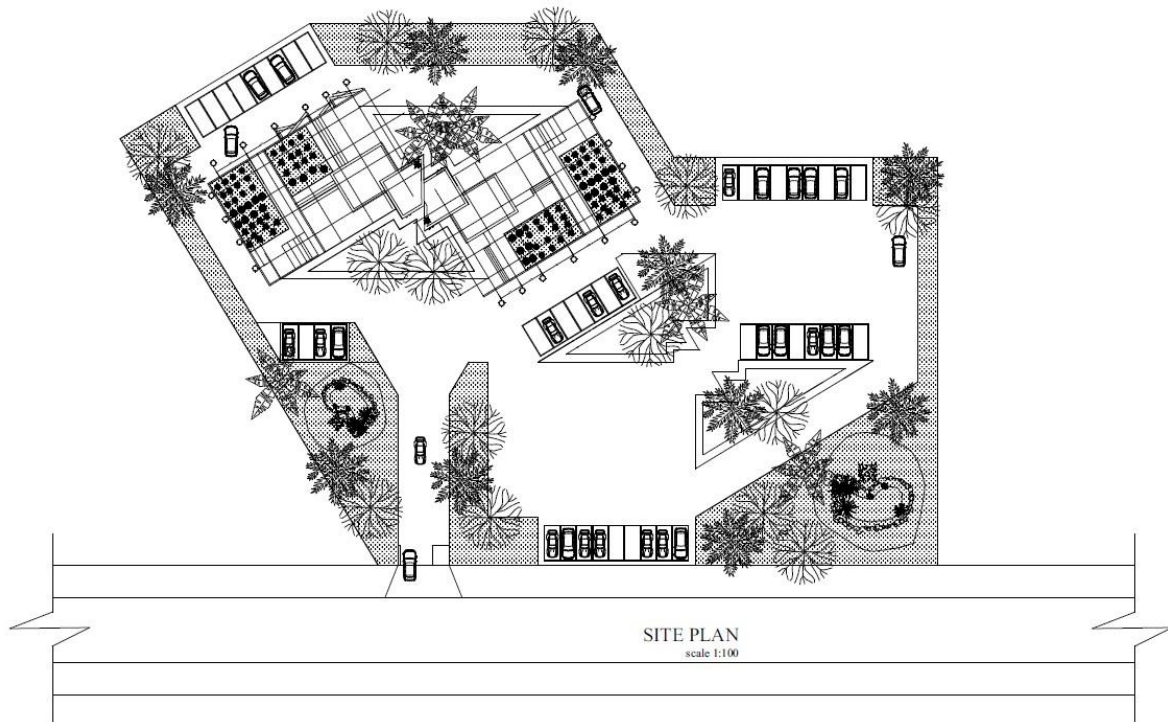


Figure 5.1 Site Plan of proposed building

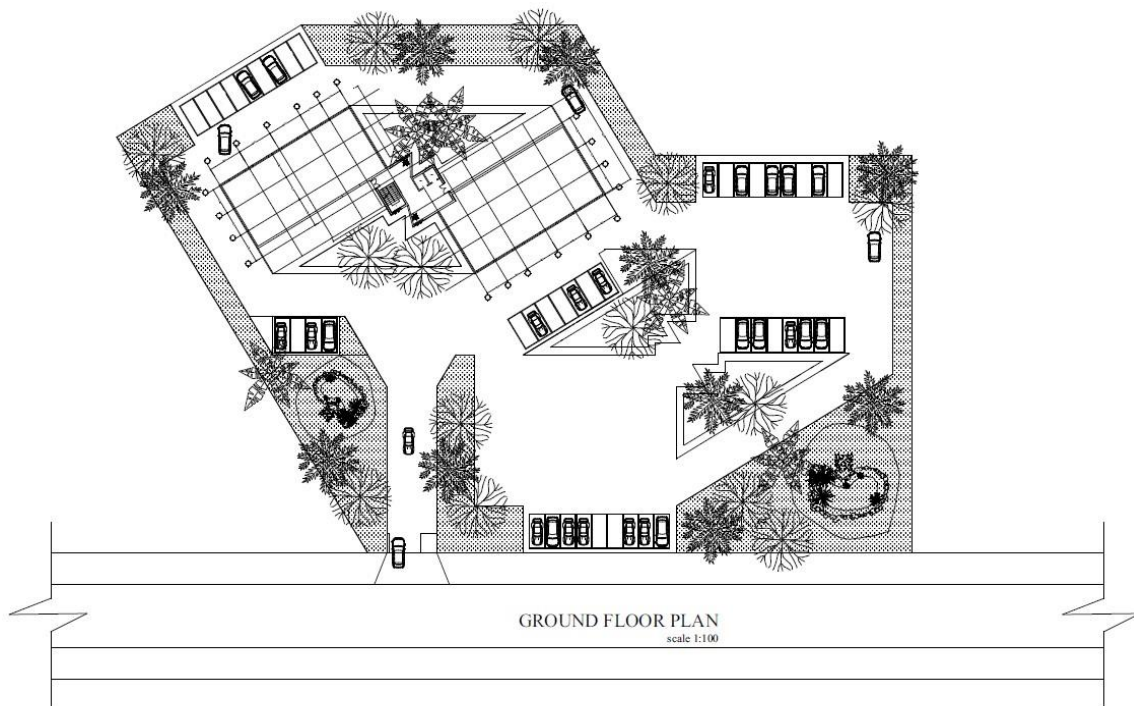
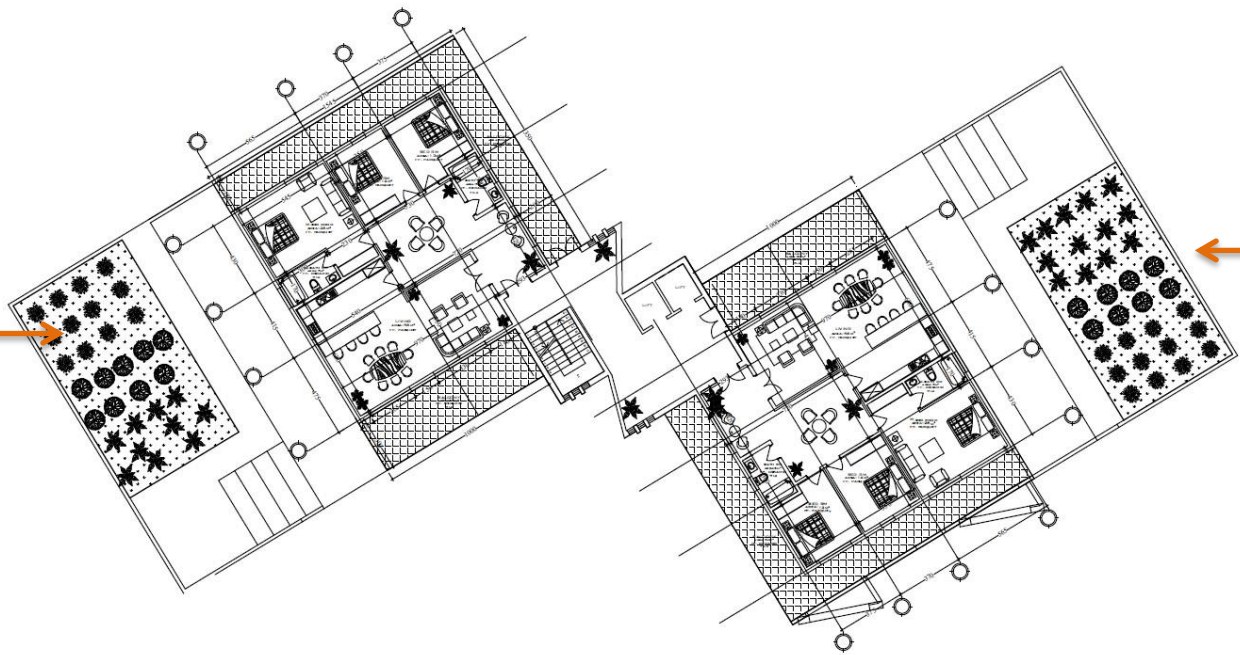


Figure 5.1 Ground floor Plan of proposed building

## 5.4 First Floor Plan



1<sup>st</sup> FLOOR PLAN  
scale 1:100

Figure 5.1 First Floor Plan of the proposed integrated vertical farming apartment building



Figure 5.1 3d illustration of first floor farming area

### 5.5 Floor Plan of 4th, 7th, 10th, 13th, 16th, and 17th Floors

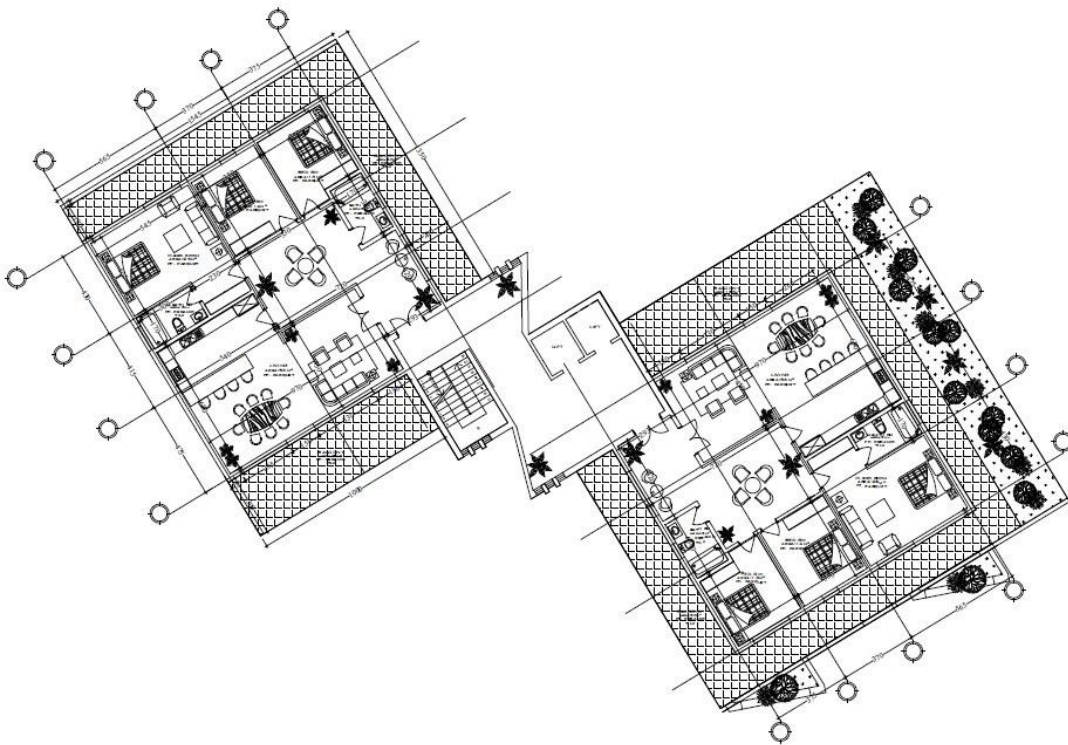


Figure 5.1 Floor Plan of 4th, 7th, 10th, 13th, 16th, and 17th of the proposed integrated vertical farming apartment building



Figure 5.1 Front Elevation

### 5.6 Floor Plan of 2nd, 3rd 5th, 6th, 9th, 11th, 12th 14th 15th Floors

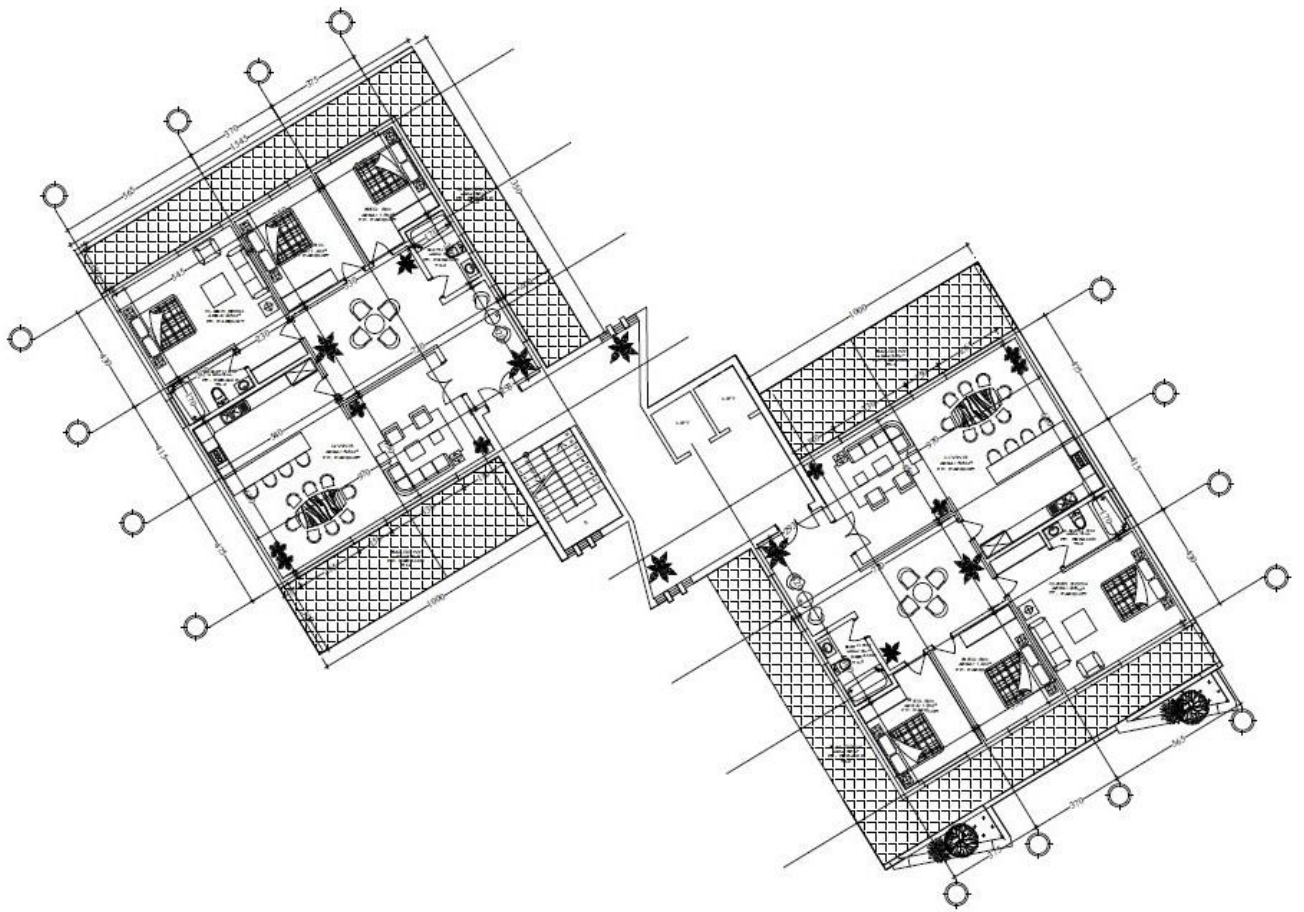


Figure 5.1 Floor Plan of 2nd, 3rd 5th, 6th, 9th, 11th, 12th 14th 15th of the proposed integrated vertical farming apartment building



Figure 5.1 3d view

## 5.7 Details and illustrations



Figure 5.10 Schematic diagrams of green wall system

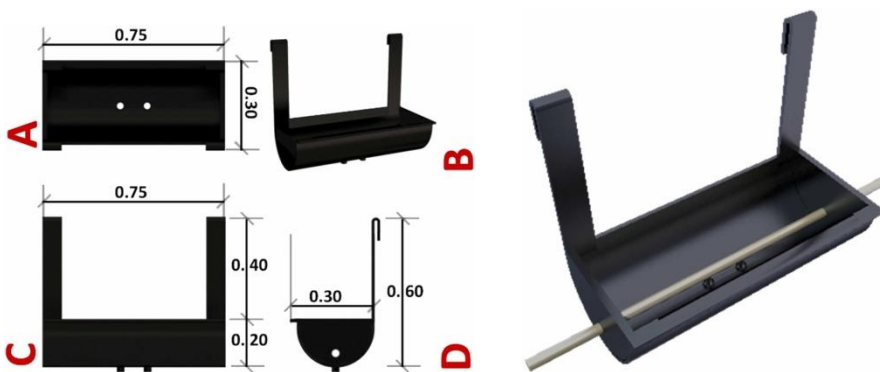
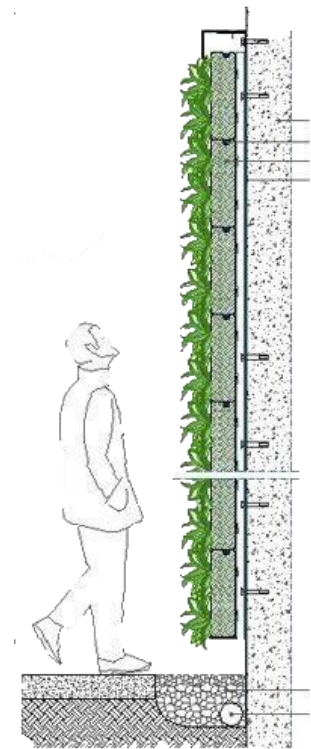


Figure 5.11 Modular planter box detail showing its size and dimension

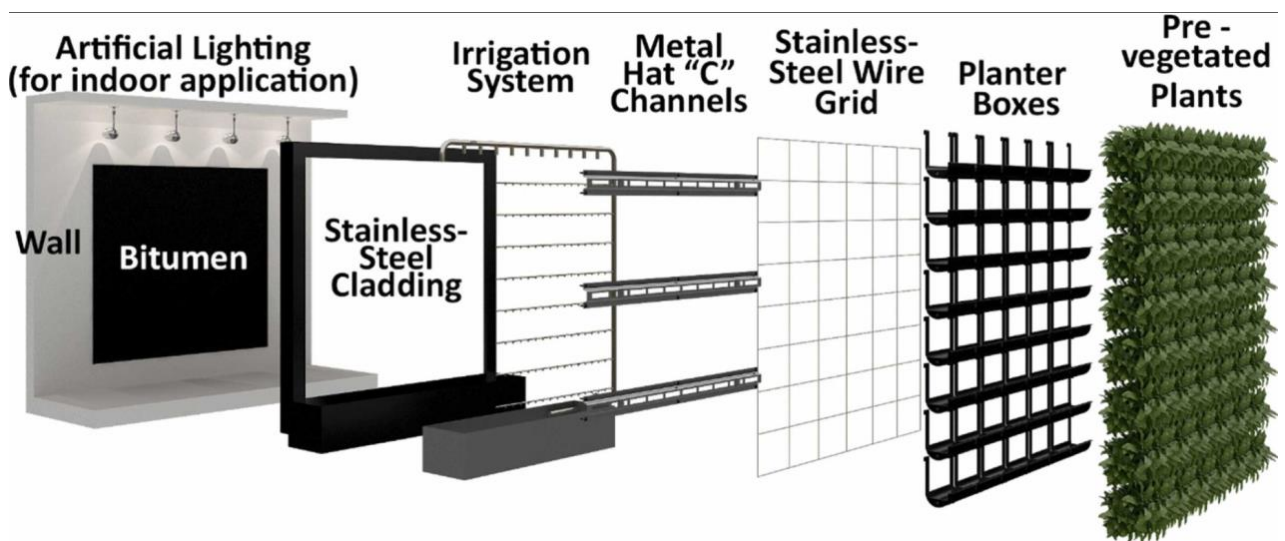


Figure 5.12 Conceptual diagram of planter box system showing its main components.

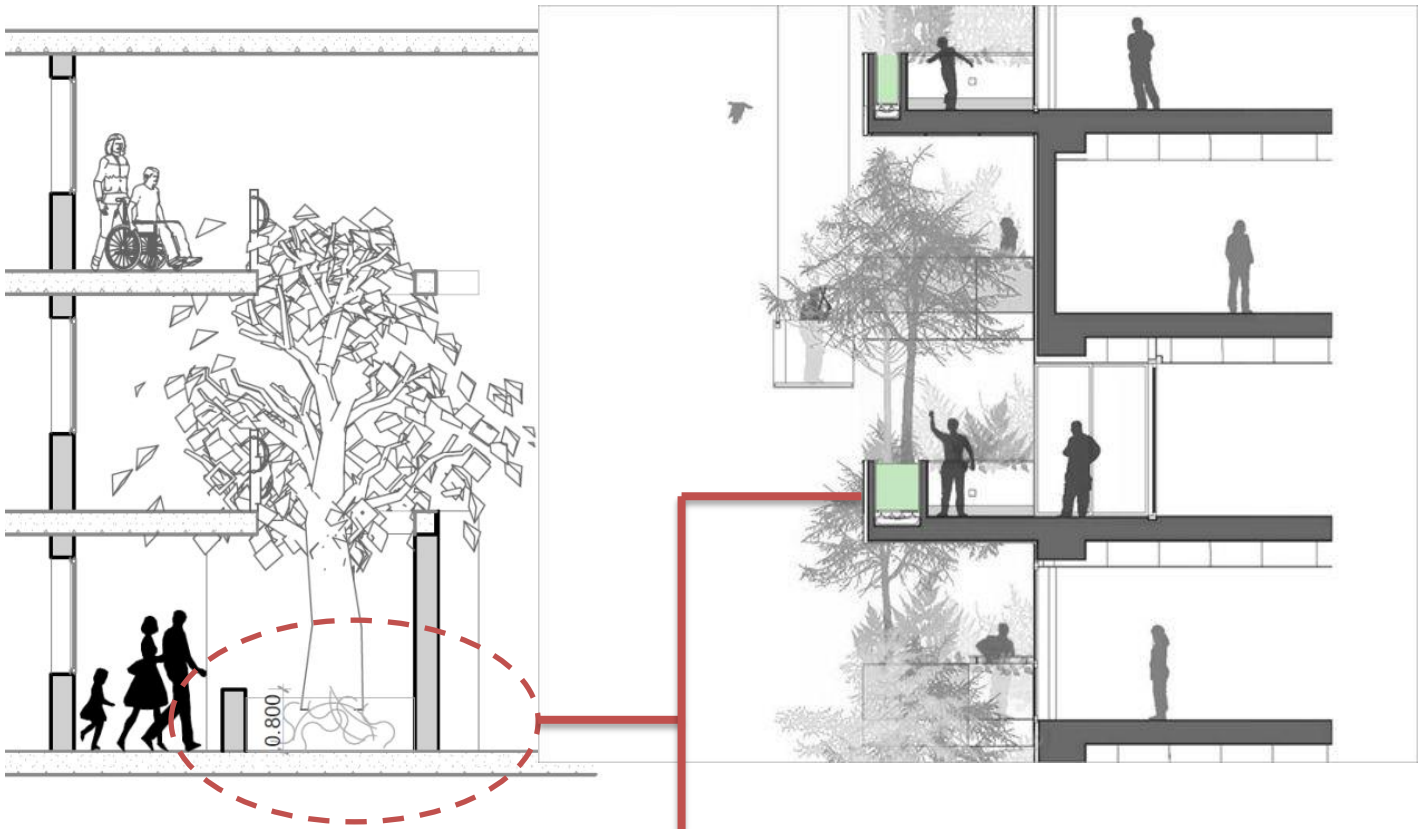


Figure 5.13 Sectional Detail of Building Balcony Area

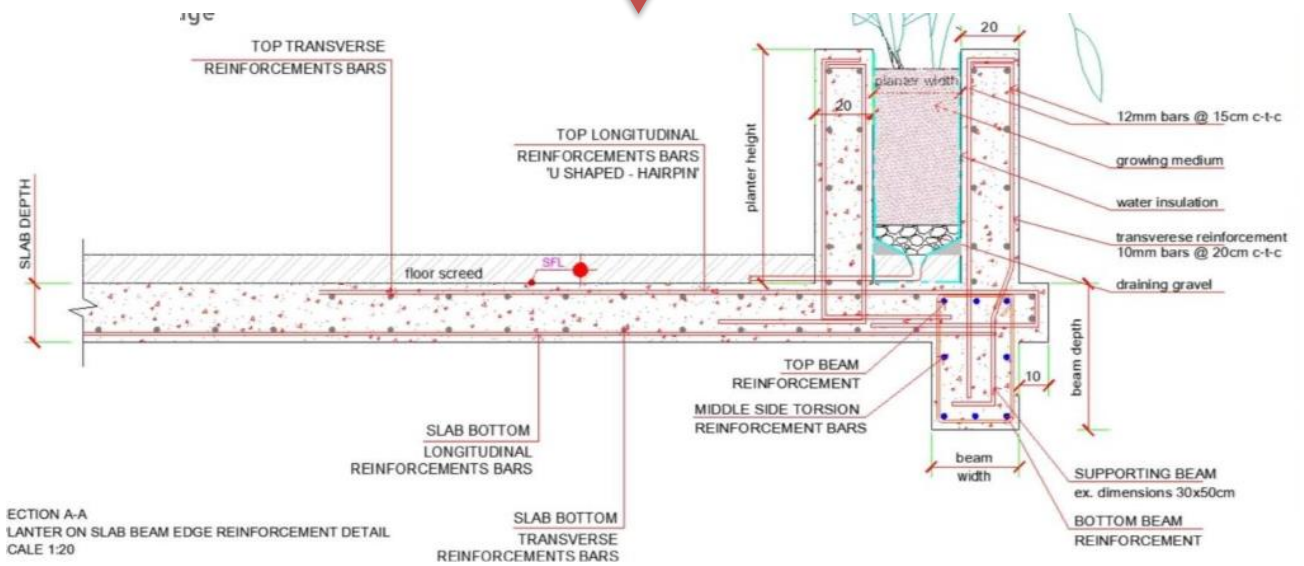


Figure 5.14 Detail of Planter and connection with slab

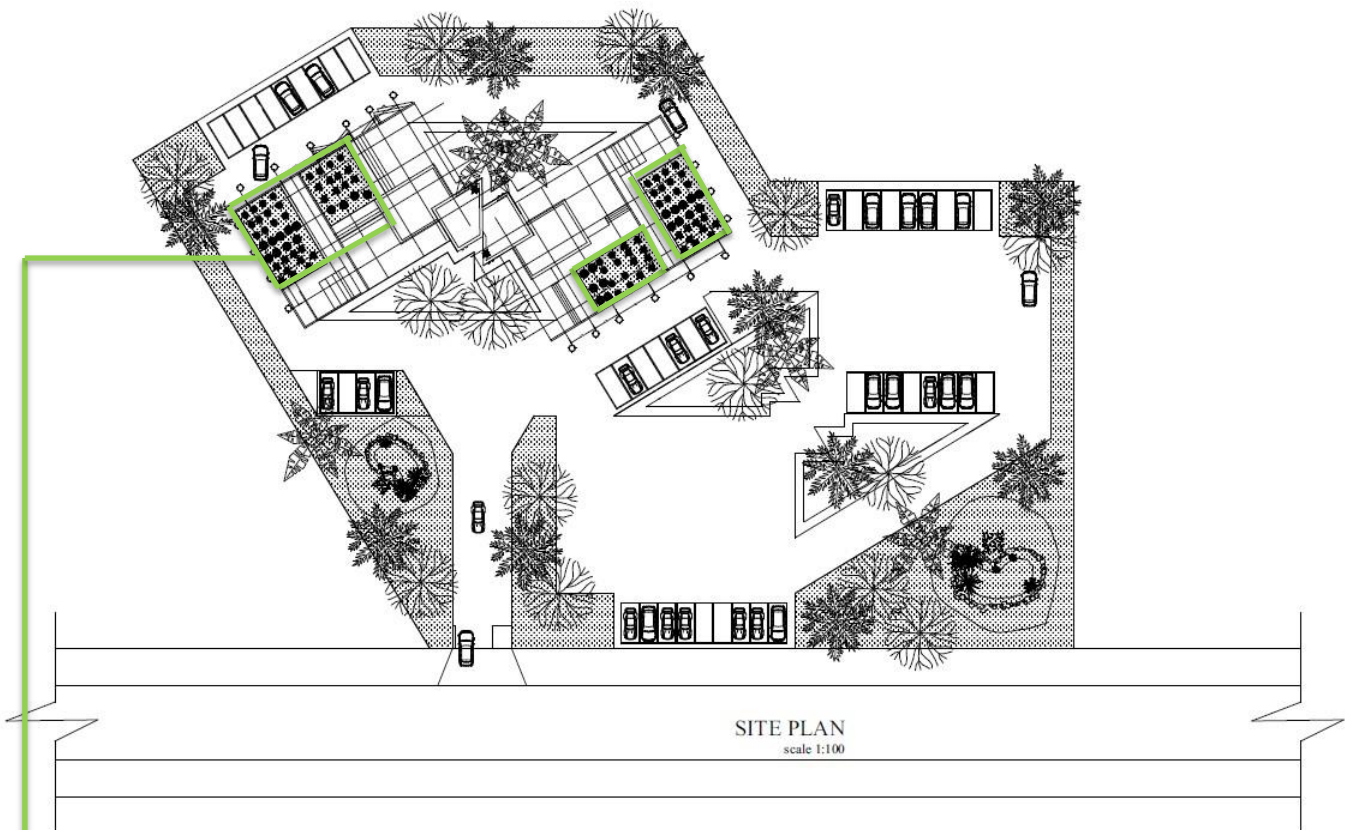


Figure 5.15 Figure 6.16 Greenery locations on building terrace and rooftop

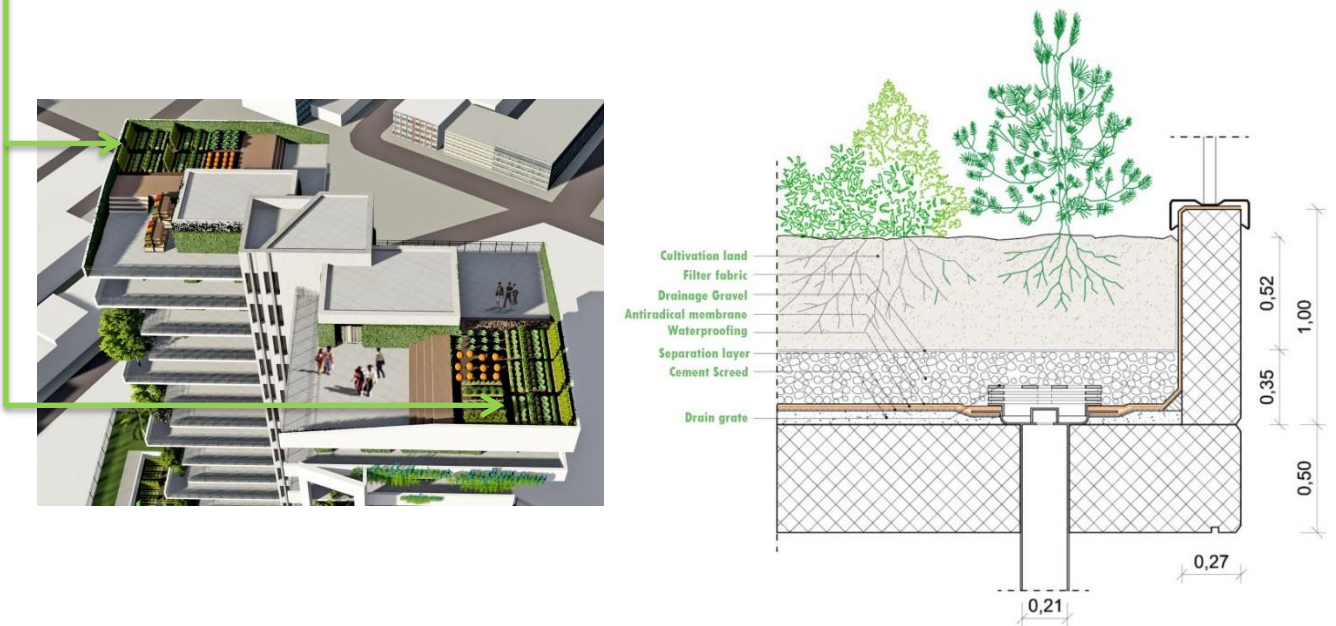


Figure 5.16 Bird Eye view roof top Farming (a) & Detail of Green roof on slab (b)

## 5.8 Detail of outdoor planter box-based system

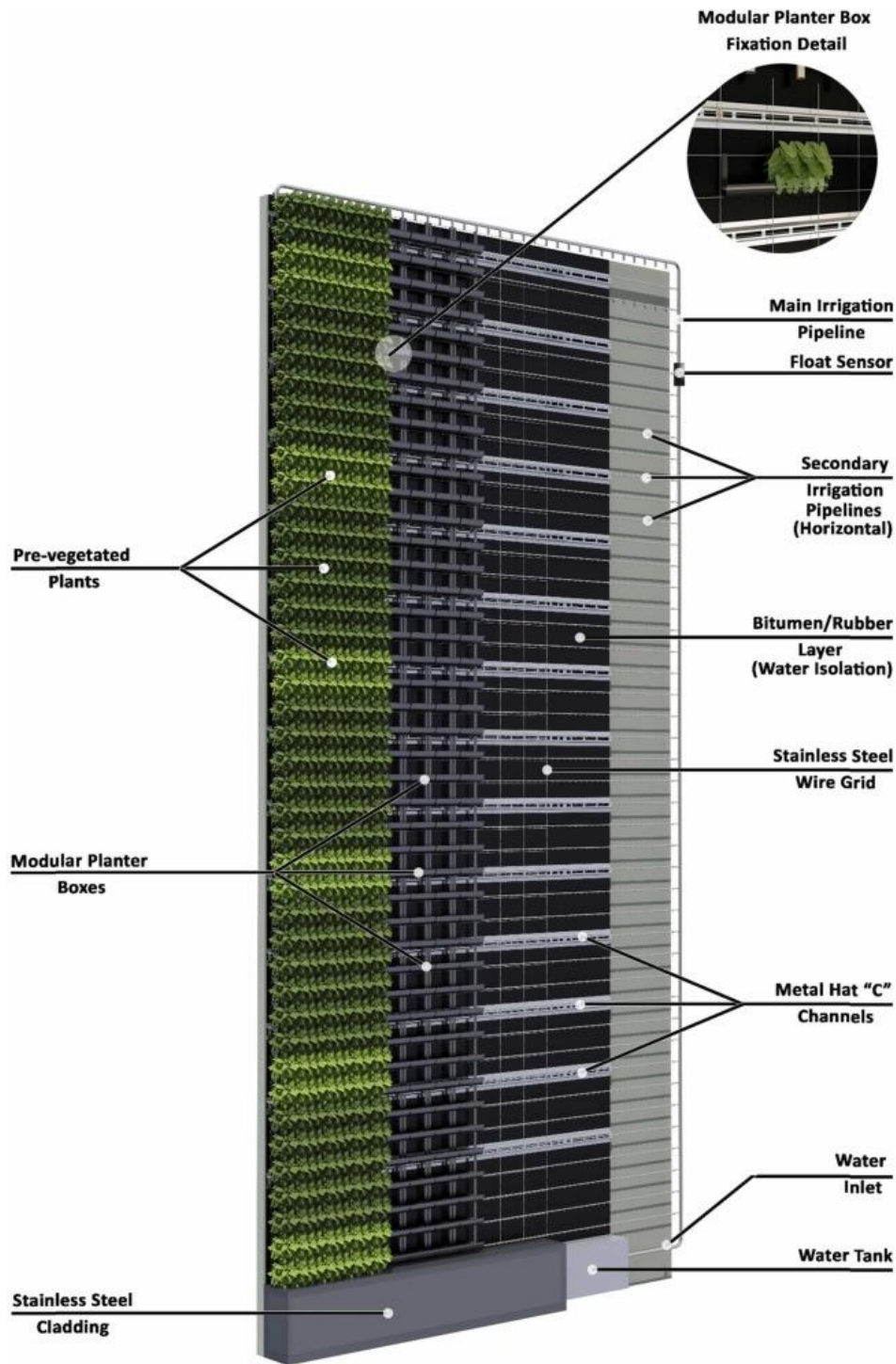


Figure 5.17 Detail of outdoor planter box-based system showing its main components and fixation to the wall.

## 5.9 Estimation of cultivation

This 17-story proposal incorporates a design for a vertical farming integrated apartment building. The plan allocates spaces for greenery across three areas:

First Floor Plan: 250sq.m, Rooftop: 180sq.m and Balconies: 1098sq.m

This totals 1530sq.m dedicated to area for edible farm, with the potential for vertical farming on walls as well. As chapter five provides calculations to estimate the possible yield of Tomato, Onion and Potato (TOP) solely focusing on the rooftop and first-floor greenery spaces, which total approximately 430sq.m.

Based on the previous calculation, if 878kg of tomatoes are cultivated from 40sq.m, we can estimate the number of tomatoes possible from 430sq.m with a simple calculation of Three times Cultivation for year  $878 = 878\text{kg}/3 = 293$  one time cultivation, There for;

- $293 \times 430 / 40 = 3150\text{kg}$  of Tomato can be cultivated from one time harvest
- $889 \times 430 / 40 = 9557\text{kg}$  of Onion can be cultivated from one time harvest
- $1601 \times 430 / 40 = 17,211\text{kg}$  of Potato can be cultivated from one time harvest



Figure 5.18 Bird Eye View of Proposed Building



Figure 5.19 3d view of Proposed Building

## 5.10 Surface and Rain Water Harvesting System



Figure 5.1 Surface an Rain Water Harvesting System

This system will manage both surface water runoff and rainwater for irrigation purposes. Surface runoff from the site will be collected through open-grate ditches and directed to two central, artificial ponds or water reservoirs located at the site border. Rain water will be captured in barrels positioned at building corner. This harvested water will then be utilized for on-site irrigation needs, promoting water conservation and resource efficiency.

## 5.11 Sewage Drainage System



Figure 5.1 Sewage Drainage Systems

The building's wastewater will be separated into two streams: Blackwater and greywater. After undergoing a multi-stage treatment process, the greywater will be reused for irrigation within the building's vertical farms. Meanwhile, the Blackwater will be discharged from the site and rejoin the municipal sewage line at the main road.

## **CHAPTER SIX: CONCLUSION AND RECOMMENDATION**

### **I. Conclusion:**

Given the fact that Ethiopia is the most populated country in Africa where greatest number of citizen's leaves under extreme poverty, the concept of familiarizing vertical farming to overall population will create greater outcome as to the production of edible crops which in turn guarantees food security to the country gradually. With land being the most scares resource in urban areas, the population in the city must be enlightened on how to have simultaneous use of the resource land.

The research on integrating vertical farming into apartment buildings in Addis Ababa accomplishes an essential conclusion that underlines the transformative potential of this innovative approach. In the context of a rapidly growing city facing challenges of food security, urbanization, and sustainability, the study illuminates the promising benefits that vertical farming can offer. By providing a sustainable source of fresh produce, reducing dependence on imported food, and improving environmental quality, vertical farming emerges as a key solution to tackle many-sided challenges for the city Addis Ababa.

During the research, the researcher encountered unexpected level of readiness from the society both from respondents that were included in the interview and questioner and from those that didn't take part. The idea of vertical farming is appreciated by all individuals whenever the researcher got a chance to explain the idea. This positive response shows the potential for vertical farming to not only enhance food security but also to substitute a more flexible and sustainable urban environment. The researcher can justly express that minimal support or encouragement from government to people who actively involve in vertical farming projects will guarantee visible change in the city with regards to promoting self-sufficiency.

As Addis Ababa remains to expand its developmental projects, it's best to consider ways and means to integrate vertical farming into apartment buildings which presents a unique opportunity to pave way for future to create a more sustainable and livable city. This will then be adopted to other cities of the country and gradually to the continent Africa.

## **II.Recommendation**

Based on the findings from the research, it's highly recommended that policy makers would work collaboratively with stakeholders as to the practicability of the concept of implementing vertical farming into cities. Authorities can create opportunities to investors who would be willing to do a pilot project that consider the integration of vertical farming and vertical living with effective use of the scarce resource land.

The concept of integrating vertical farms in apartment buildings is new to our country as at now. Even though many people would be willing to get involved in this kind of innovational frameworks finance will be one of the great hindrances to adopt vertical farming on the existing structural buildings. Apart from creating awareness, government can implement the below.

- Tax holiday: - many companies who are in manufacturing industry in Ethiopia are supported by the government in getting tax holiday for certain period. If any potential stakeholder who would like to see vertical farming happening on the existing apartment buildings must be given a chance of like exempt from property tax for couple of years.
- Loan Facilitation: - as part of corporate social responsibility, loan can be facilitated to apartment/ buildings owners to do a simulation of how adopting vertical farming practices in apartment building positively or negatively affects the building/apartment.

Furthermore, the implementation of pilot projects and continued research efforts are essential to demonstrate the feasibility of vertical farming in diverse urban contexts within Addis Ababa.

These kinds of initiatives will not only be bound to help Addis Ababa city but also the nation in general. Allies within government entities, private sectors, stakeholders, and every community will bring in successful integration of vertical farming.

In conclusion, the recommendations point out the possible way of going forward by which the city can be transformed with this kind of innovative projects which can therefore help the citizen and ease burden of the government. Self-sustained city can promote a greater environmental benefit which can lower reliance on imported resources which will have a direct impact on strengthening the economy and also in creating a society with possible social well-being. All this will create an energetic and independent population which is something that is highly needed in an underdeveloped world.

### **III. Policy Interventions for Integration of Vertical Farming on Apartment Buildings:**

#### **1. Regulatory Policy:**

Government must develop an all-inclusive regulatory policy that mentions guidelines for the integration of vertical farming into apartment buildings. This policy should address zoning regulations, building codes, and land use policies to ensure the safe and efficient implementation of vertical farming practices within urban residential structures. There should be a means that non-compliant people should be contacted and get the necessary awareness.

#### **2. Financial Incentives:**

Introduction of financial incentives such as tax breaks, grants, subsidies or loans to encourage building owners to invest in vertical farming infrastructure.

#### **3. Awareness Creation Programs:**

Organizing trainings, workshops and educational programs to different stakeholders to enlighten the positive impacts associated with vertical farming and the outcome of integrating vertical farming into apartment building.

#### **4. Public-Private Partnerships:**

Partnerships between different stakeholders to strengthen the outcome of vertical farming projects. Networking technical experts and those that have the capacity of funding projects can address and tackle obstacles of the realization of the innovative projects.

#### **5. Research and Development:**

Budgeting for research and development projects for experts to work on pilot projects, which will help to make informed decisions and make technological advancements as to know how and where to apply the innovative idea and know the best cost-effective environmentally friendly best practice.

#### **6. Community Engagement:**

Promote community engagement and participation in vertical farming projects by establishing community gardens, rooftop farms, and shared common spaces within apartment

buildings. Encouraging urban communities to actively participate in food production to decrease the use of import goods or buying products that are coming from neighboring cities.

### **7. Monitoring and Evaluation:**

Establish monitoring and evaluation mechanisms to track the progress, impact, and outcomes of vertical farming initiatives in apartment buildings. Regular assessments can help measure the effectiveness of policy interventions, identify areas for improvement. Consistency is the key to ensure long-term sustainability of vertical farming practices in urban settings.

If the above-mentioned recommendations with the addition of policy interventions are implemented, Addis Ababa can create an enabling environment for the successful integration of vertical farming on apartment buildings, thereby promoting food security, environmental sustainability, and community resilience in the city.

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## **Appendix**

- I. Appendix A – Research Schedule
- II. Appendix B – Verification Survey respondents Questions and Answers
- III. Appendix C – Supplementary Visualizations

## Appendix A – Verification Survey Respondents Questions and Answers

### Integration of vertical farming into apartment buildings – Verification Survey

Thank you for taking the time to complete this questionnaire. This research aims to understand resident interest and perspectives on integrating vertical farming (VF) systems within apartment buildings in Addis Ababa.

Your responses are completely anonymous and will be used for research purposes only.

Please answer the following questions to the best of your ability.

Apartment Name: \_\_\_\_\_  
Occupant Name: \_\_\_\_\_

#### Section 1: General Information

1. Age
  - 18-24
  - 25- 34
  - 35-44
  - 45-54
  - 55+
2. Occupation
  - Student
  - Employed
  - self - employed
  - retired
  - other
3. How long have you lived in this apartment?
  - Less than 1 year
  - 1-3
  - 4 - 6 years
  - 7-10 years
  - More than 10 years

#### Section 2 – Awareness and Interest in Vertical Farming

1. Have you heard of the concept of integrating vertical farming on apartment buildings?  
 Yes      No
2. If yes, please briefly describe your understanding of vertical farming (focusing on farming edible on roof tops, Facade and Balcony areas).

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3. Would you be interested in having a vertical farming system integrated into your apartment building mainly (Rooftop, Facade & Balconies)?
  - Strongly interested
  - Somewhat interested
  - Neutral
  - Somewhat uninterested
  - Strongly uninterested

### **Section 3: Potential Benefits and Concerns**

1. What potential benefits do you see in integrating vertical farming into your apartment building? (Select all that apply)
  - Increased access to fresh, local foods
  - Increased food quality and safety
  - Reduce reliance on external food sources
  - Improved building aesthetics
  - Improved air quality
  - Fostering a sense of community
  - Educational opportunity
  - Reduce environmental impact
  - Increased building value
  - Potential cost savings on groceries
  - Many more
  
2. What potential concerns do you have about integrating vertical farming into your apartment building? (Select all that apply)
  - Space limitations within the building
  - Potential odor issues
  - Shortage of water resource
  - Ensuring optimal growing conditions**
  - Increased maintenance costs for the building
  - Potential negative impact on the building aesthetics
  - Other (Please specify)

### **Section 4: Specific Interest in locations**

1. Considering the potential locations for vertical farming systems in your building, rank your level of interest:
  - Facade (exterior wall)
  - Rooftop
  - Balconies

### **Section 5: Additional Information (Optional)**

1. Would you be willing to pay a small monthly fee to support the maintenance and operation of a vertical farming system in your building?
    - Yes
    - No
    - Not sure
  
  2. Please share any additional comments or suggestions you have regarding the integration of vertical farming in apartment buildings.
- 

**Thank you for your valuable participation!**

Appendix B – Supplementary Visualizations



(a)



(b)



(c)

**Figure C117 3D Views of Proposed Vertical farm Integrated Apartment Building (A-I)**



(d)



(e)

(g) & (f)





(h)



## **Annex**

### **Annex I: Article**

**Addis Ababa University, Ethiopian Institute of Architecture, Building Construction and City Development (EiABC) – Architectural Engineering**

**Title: - Feasibility of Integrating Vertical Farms within Apartment Buildings in Addis Ababa Ethiopia: Challenges and Opportunities**

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## **Abstract**

*In Addis Ababa, rapid urbanization driven by housing demands and limited agricultural access prompts interest in vertical living and farming. Integrating vertical farms into apartment buildings shows promise for food security and sustainability, with 72% of residents in Bole Sub City expressing strong interest. Rooftops are favored locations, though concerns arise about water scarcity and space limitations. Despite challenges, over 70% are willing to financially support such initiatives. The study, "Harmony in Vertical Living," evaluates the feasibility of integrating vertical farms into residential structures, focusing on sustainable retrofitting solutions. It recommends collaboration between policymakers and stakeholders, advocating for pilot projects and financial incentives like tax breaks. Research emphasizes collaboration for successful integration, providing insights for residents, government bodies, and policymakers. Vertical farming is seen as transformative in addressing food security and urbanization challenges, with widespread societal support indicating its potential. Government support is crucial for visible change towards self-sufficiency. As Addis Ababa expands, integrating vertical farming presents an opportunity for a more sustainable city, with potential for adoption across Africa. Optimizing land use in rapidly urbanizing areas is underscored as architecturally valuable.*

**Key Words:** Urbanization, Vertical Living (VL), Vertical Farming (VF), Integration of Vertical Living, Sustainable Solutions,

## **Introduction:**

Addis Ababa, Ethiopia's capital grapples with the challenges of rapid urbanization, driven by a growing population and a shortage of affordable housing (Central Statistical Agency, 2024). As the city's infrastructure struggles to keep pace with this expansion, issues such as food insecurity and agricultural imbalances exacerbate the strain on resources. With the population exceeding 5 million, the demand for housing and access to fresh produce is ever-increasing, prompting the exploration of innovative solutions to address these pressing urban challenges. One such solution gaining traction is vertical living, which involves residing in high-rise buildings. Vertical living offers several advantages, including increased population density, reduced land consumption, and easier access to amenities (Bates, 2023). Importantly, it also presents opportunities for integrated vertical farming, a practice that involves growing crops within vertically stacked layers in controlled environments (Despommier, 2010). This method addresses food security challenges by enabling urban crop production, regardless of land availability or weather conditions.

The integration of vertical farming into apartment buildings holds promise for Addis Ababa. Beyond bolstering food production, these farms have the potential to contribute to improved air quality, reduced noise pollution, and enhanced aesthetic appeal within the city. Moreover, they offer a sustainable solution to the city's reliance on imported food sources, thereby reducing the strain on global markets and promoting self-sufficiency at the local level.

However, the integration of vertical farming into vertical living spaces poses several challenges that warrant careful consideration. Technical, economic, and social factors must be thoroughly analyzed to ensure the feasibility and effectiveness of such initiatives. Additionally, practical issues such as water scarcity, maintaining optimal growing conditions, and space constraints need to be addressed through innovative solutions and strategic planning.

In conclusion, the integration of vertical farming into apartment buildings presents a promising opportunity to address the complex urban challenges facing Addis Ababa. By fostering collaboration between policymakers, stakeholders, and communities, it is possible to develop sustainable and resilient solutions that enhance food security, promote environmental sustainability, and improve overall quality of life in the city.

## **Materials and methods:**

This research aims to explore the positive contributions and challenges of integrating vertical farming (VF) into apartment buildings in Addis Ababa, aiming to establish a harmonious relationship between urban living and sustainable food production. The methodology adopts a mixed-method approach, combining quantitative and qualitative data collection and analysis to provide a detailed explanation for the research questions mentioned in chapter one.

Addis Ababa, the capital of Ethiopia, faces rapid population growth, leading to a scarcity of land for cultivation. The city is divided into ten sub-cities, among which the researcher selected Bole sub-city, the fourth largest in terms of population size. Bole sub-city is characterized by modern high-rise apartment buildings with suitable structures for the implementation of vertical farming. This area was chosen due to its relatively modern population, who tend to be more receptive to new technologies and innovations like vertical farming.

The study aims to explore the feasibility and potential benefits of integrating vertical farming systems into apartment buildings in Addis Ababa, Ethiopia. Being a city center, Bole sub-city has many concentrated apartment buildings, making it an ideal location for this investigation.

The study population consists of residents of apartment buildings in Bole sub-city, Addis Ababa. Diverse representation will be considered in terms of age, gender, income level, and level of interest in urban agriculture, with a special emphasis on vertical farming.

A multi-stage sampling approach with stratified random sampling technique will be implemented to select participants, ensuring representative samples are covered out of the total population. Stratified random sampling will enable gathering a representative sample of the demography and guarantee a richer understanding of residents' perspectives on integrating vertical farming into their apartment buildings.

Through a systematic approach, apartment buildings in Addis Ababa with accessible rooftops and balconies were identified as potential case studies. The selected buildings include Grand View Addis Apartment, Bimer Apartment, and Tsehay Real Estate Apartment. These buildings were chosen based on specific sampling criteria, including building type and physical space availability for vertical farming systems.

Data collection will involve administering questionnaires to apartment residents to assess their attitudes, needs, and preferences regarding vertical farming integration. Measurements on selected case buildings will be taken to analyze their impact on vertical farming integration, including location, orientation, height, and layout.

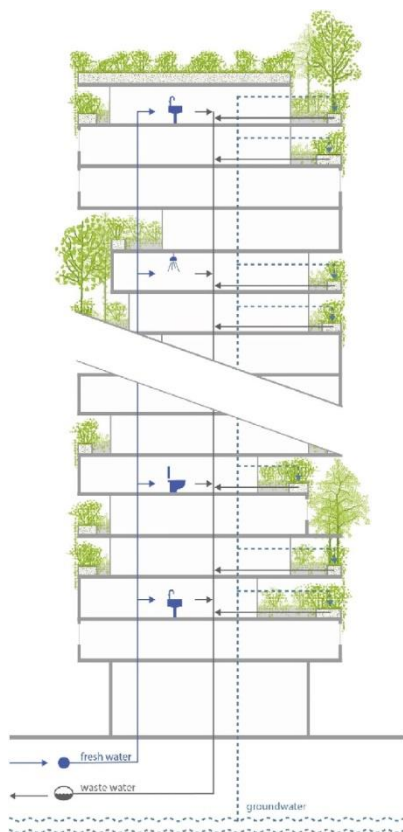
Quantitative data collected from the questionnaires and measurements will be analyzed to gain a general understanding of the potential for integrating vertical farming in apartment buildings. This analysis will involve organizing and tabulating the data, followed by a comprehensive examination of trends and relationships within the context of the research question. Qualitative data from in-depth interviews and focus group discussions will complement the quantitative findings, providing a more nuanced understanding of the research topic.

This data analysis will yield valuable insight into the benefits and limitations of vertical farming in densely populated urban environments. These insights will encompass economic viability, potential contributions to sustainable food production, and the feasibility of integrating vertical farming into future Addis Ababa development initiatives. Ultimately, the findings aim to equip policy makers and urban planners with knowledge about the potential of vertical farming as a strategy for enhancing urban sustainability.

## Vertical Farming Systems:

Vertical Farming includes numerous soilless cultivation techniques, such as hydroponics, aeroponics and aquaponics. These systems enable vertical crop production, which is frequently done indoors or in controlled conditions. They eliminate the need for soil and supply nutrients straight to plant roots using water-based solutions. However, adopting these systems often necessitates a significant capital investment, access to advanced technology, and expertise in managing light, temperature and humidity. Recognizing these challenges this study investigates the feasibility of integrating vertical farming into apartment buildings. The study will look into the viability of using architectural elements such walls/facades, rooftops and balconies as prospective vertical sites.

**Façade Farming** – These platforms will allow for crop cultivation right on the building’s surface, transforming facades into useful living walls. This integration may holds promise for



benefits beyond food production, such as improved building insulation and air quality. In addition to producing fresh vegetables, façade farming has the ability to greatly improve urban aesthetics by bringing vivid greenery to formerly barren walls. This novel method to agriculture can assist maximize limited space in densely populated places while also fostering sustainability and self-sufficiency. Furthermore, façade farming has the ability to reduce urban heat island impacts by providing shade and cooling to buildings. Overall, the approach exemplifies the possibility of integrating nature into urban landscapes, serving both environmental and aesthetic purposes.

Figure 18. Integration of vertical farming on roof, Façade and Balcony areas.

**Balcony Farming** – Particularly those in high-rise residential complexes will provide an excellent chance for large-scale vertical gardening. This approach provides for the effective utilization of horizontal spaces, enhancing potential crop production. Implementation could include hanging growth frames on hooks or permanently mounting structures to allow for easy automation of drip watering systems. This concept might potentially be extended to facades and unused spaces within the building structure, so increasing the overall impact of the vertical farming endeavor.

**Rooftop Farming** – provide intriguing opportunities for integrating both simplified and complicated vertical farming models. These places can be used in a similar way to grow a variety fruits, vegetables and herbs. Notably, rooftop agriculture can be smoothly integrated into new and existing structures (Caputo et al., 2017). Research indicates that green roofs, aside from their role in food production, offer additional environmental benefits such as rainwater storage.

### **Benefits of Integrating Vertical farming systems on apartment buildings**

Vertical farming offer promising benefits for urban contexts, such as increased food security and more sustainable land-use practices; however, its successful implementation in Addis Ababa would depend on overcoming resources constraints and infrastructure development obstacles. Land availability, demography, and the prevalence of housing types will all have a substantial impact on project viability. Despite these hurdles, incorporating vertical farming systems directly into existing apartment buildings provides a one-of-a-kind chance for inhabitants to reap various economic, social and environmental benefits. Traditional agriculture will be constrained in densely populated metropolitan places like Addis Ababa due to a lack of available ground space. However the large wall surfaces of multi-story

buildings presents a good opportunity for vertical farming initiatives. This strategy has the potential to provide a number of benefits economically, socially and environmentally.

### **Economic Benefits**

Vertical farming has numerous economic benefits, particularly in urban contexts. One of the most significant advantages will be the potential for enhanced crop yield with a smaller foot print. This strategy can help to improve food security and reduce reliance on foreign food sources. Furthermore, reducing water use when compared to traditional agriculture. This translates to better conservation of natural resources and less concern about water scarcity.

Furthermore, vertical farming approaches can help to reduce the fuel consumption involved with long-distance food delivery. This will improve the environment by cutting greenhouse gas emissions while also lowering overall operation costs. According to studies, vertical farms may even enhance property values in surrounding areas due to their aesthetic appeal and environmental benefits (Specht et al., 2013).

Vertical farming has numerous potential energy-saving benefits. Vertical farming systems can help to reduce building energy expenses by offering acoustic insulation and temperature reduction. This results in lower operating costs and a smaller environmental footprint in the long run.

Generally, vertical farming presents a compelling economic opportunity for urban settings. Vertical farming, by improving food production, preserving resources, lowering transportation costs, and promoting energy efficiency, can help cities achieve a more sustainable and economic future.

## **Social Benefits**

Integrating vertical farming on apartment buildings provides a number of social benefits for occupants and the surrounding community. One key advantage is the possibility of good psychological consequences. According to studies, exposure to vertical greenery systems, such as those used in façade farming, can reduce stress and increase building occupant productivity (Taib and Prihatmanti, 2018).

Furthermore, vertical farming can help to address food security issues in urban area. By establishing vertical edible landscapes on building facades and utilizing spaces such as balconies, these systems can provide residents with access to fresh, locally grown produce. This strategy can foster a sense of communal self-sufficiency and allow inhabitants to directly participate in their own food production (Specht et al., 2013).

Apart from the immediate benefits to building inhabitants, vertical farming efforts have the potential to provide greater public benefits. This includes:

- **Boosting neighborhood food security:** Vertical farms can help to boost food availability in urban areas, reducing food insecurity for residents who have limited access to fresh vegetables.
- **Providing educational facilities:** vertical farms can serve as educational tools for communities, encouraging a better understanding of sustainable food production process.
- **Connecting customers to food production:** Vertical farming allows consumers to engage directly with local food producers, promoting transparency and trust in food chain.
- **Inspiring design:** Vertical farms' creative nature can serve as inspiration for architects and urban planners to develop more sustainable and visually beautiful urban surroundings.

Generally, vertical farming is a viable way to improve social well-being incites. Vertical farming has the potential to significantly improve the lives of individuals and the larger

community by increasing mental health, creating community self-sufficiency, and contributing to a more sustainable food system.

### **Environmental Benefits**

Vertical farming offers a compelling solution for sustainable food production in densely populated urban environmental. One notable advantage lies in its ability to combat the urban heat island effect. Vertical greenery systems, a key component of façade farming, act as natural cooling mechanisms. By increasing plant growth area, these systems promote enhances CO<sub>2</sub> sequestration through photosynthesis, leading to lower ambient temperatures and improves thermal comfort in urban contexts (de Carbonnel et al., 2022).

Beyond from CO<sub>2</sub> sequestration, vertical farming provides several other environmental benefits:

- Precision agriculture: vertical farming systems can be built to maximize growing conditions while reducing the requirement crop protection chemicals. This reduces environmental pollution caused by traditional agricultural practice.
- Precision control over water and nutrient distribution in vertical farms may significantly decrease water and fertilizer inputs when compared to traditional approaches. This results in a more sustainable use of limited water resources.
- Efficient land use: vertical farming minimizes the need for large areas of land agriculture, potentially protecting natural ecosystems and reducing deforestation.
- Reduce transformation emissions: by moving food production closer to consumption sites in urban areas, vertical farm can significantly reduce post-farm-gate emissions associated with long-distance food transportation. This not only benefits the environment but also reduces overall food production costs.
- Improved food quality: controlled environments in vertical farms can minimize the risk of contamination and spoilage, potentially leading to improved food quality for consumers (de Carbonnel et al., 2022).

Generally, vertical farming is an appealing approach to sustainable food production in urban environments. Vertical farming can help our cities and the planet achieve a more sustainable

future by minimizing urban heat island effects, lowering CO2 emissions, and reducing resource usage.

## **Site Selection and Design Consideration**

This research will propose a conceptual design for 17-story apartment building in Addis Ababa that seamlessly integrates vertical farming systems throughout the structure. The design will allocate dedicated spaces for plant production, including

- On a total of 1,098sq.m Balconies –vertical farming systems will be integrated along railings. This space could potentially utilize vertical planters or hanging gardens for smaller, climbing leafy green, herbs or other plant varieties.
- On a total of 180sq.m Rooftop area and 250sq.m space on the first floor –Square foot gardening will be adopted for rooftop environments by implementing lightweight raised beds constructed from materials like recycled plastic. Additionally, a specifically formulated PVC planter box will be incorporated to address the increased water requirements arising from rooftop exposure to wind and sun.

The design will further explore the possibility of incorporating vertical wall space within the building to maximize opportunities for vertical farming. Chapter five will present calculations to estimate the potential yield of key crops (Tomatoes, Onion and Potatoes) based on dedicated area of 430sq.m.

## **Water Management System**

An efficient water management system will be crucial for the successful operation of vertical farming within Apartment buildings. This proposed system incorporated a multi-pronged approach to maximize water utilization and minimize environmental impact.

- **Rain water Harvesting:** Rainwater will be captured using strategically placed barrels positioned at building corners. This harvested water will then be directly utilized for on-site irrigation needs in the vertical farming systems. This will help reduce the reliance on municipal water sources and minimize environmental impact.
- **Groundwater Utilization (If applicable):** The system will explore the potential of utilizing shallow groundwater resources for irrigation purpose, subject to a thorough hydrological assessment. This assessment will determine the availability and long-term viability of extracting groundwater without compromising the aquifer. Permits and regulations related to groundwater use in Addis Ababa will also be carefully considered.

- Greywater Treatment and Reuse: Greywater, wastewater generated from household activities like laundry, showers, and washing machines (excluding toilet waste), can be a valuable source for irrigation after proper treatment. A dedicated greywater system will be implemented with the following steps:
  - Collection and Separation: a separate plumbing system will be installed to capture greywater from designated sources. This ensures it is not mixed with sewage from toilets.
  - Treatment: The collected greywater will undergo a treatment process typically involving filtration and disinfection to remove contaminants and ensure it meets irrigation safety standards.
  - Irrigation Applications: The treated greywater will then be directly utilized to irrigate landscaping elements, rooftop gardens, and vertical farming systems within the building complex.
- Surface water runoff Collection: Open-grate ditches will collect surface water runoff from the building site. This collected water will then be directed to two central, artificial ponds or water reservoirs located at the site's border. The stored water can be subsequently used for irrigation purposes, promoting resource efficiency.
- Underground storage for all water sources: excess rainwater, treated greywater, and any utilized groundwater (if applicable) will be diverted to strategically placed underground storage tanks. This stored water will serve as a vital resource during dry periods, ensuring a consistent water supply for the vertical farming systems.

This smart use of water resources in apartment buildings for vertical farming promotes responsible environmental management and leads to a more sustainable urban environment.

## **Synopsis**

These studies on vertical farming in Addis Ababa will investigate the potential for integrating vertical farming into apartment buildings. The findings suggest that vertical farming offers a promising approach to increasing food security, reducing environmental impact, and promoting community engagement within the city. By implementing the outlined recommendations, Addis Ababa can become a leader in sustainable urban agriculture and pave the way for a future where well-being and a healthy environment are central to urban living. Additionally, the research highlights the importance of policy support and infrastructure development to facilitate the widespread adoption of vertical farming in urban areas. With proper planning and investment, Addis Ababa can transform its landscape into a thriving hub of sustainable food production. This transformation will not only benefit the city's residents by providing access to fresh, locally grown produce, but also contribute to reduce carbon emissions and increasing food security. Ultimately, embracing vertical farming can lead to a more resilient and sustainable future for Addis Ababa.

## **Conclusion**

The integration of vertical farming into apartment buildings presents a transformative opportunity for Addis Ababa to emerge as a leader in sustainable and livable urban environments. By implementing the recommendations outlined in this study, the city will create an enabling framework for this innovative approach to food production. Vertical farming holds significant potential for:

- **Enhance Food Security:** By increasing local food production within the city limits, vertical farming will contribute to a more secure and reliable food supply for residents, particularly in the face of climate change and population growth.
- **Reduce Environmental Impact:** Vertical farming utilizes less land and water compared to traditional agriculture, minimizing the environment footprint associated with food production. Additionally, it will contribute to reduce transportation emissions by shortening the distance food travels from farm to table.
- **Foster a more engaged community:** Community gardens and shared spaces associated with vertical farming will foster social interaction and encourage residents to become more involved in their food production systems. This will lead to a more resilient and engaged community.

As Addis Ababa continues its urban expansion, embracing vertical farming presents a clear path towards a future where urban living and sustainability are seamlessly integrated. This innovative approach will pave the way for a future where well-being and a healthy environment are central to the urban experience.

### **Recommendations for Successful Vertical Farming Integration in Apartment Buildings**

Based on the research findings, the following recommendations will be proposed to help with the successful integration of vertical farming into apartment buildings:

- **Regulatory Policy:** The government should develop an all-inclusive regulatory policy outlining guidelines for integrating vertical farming into apartment buildings.
- **Financial Incentives:** Financial incentives , such as tax breaks, grants, subsidies or loans should be introduced to encourage building owners to invest in vertical farming infrastructure.
- **Awareness creation programs:** Trainings, workshops and educational programs should be organized for stakeholders to raise awareness of the positive impacts associated with vertical farming.
- **Public-Private Partnership:** Public- private partnerships should be fostered to strengthen the outcome of vertical farming projects. Collaboration between technical experts and potential funders will address challenges and facilitate project realization.
- **Research and development:** A budget should be allocated for research development projects. Pilot projects will inform decision-making and technological advancements related to cost effective and environmentally friendly practices.
- **Community Engagement:** Community engagement and participation in vertical farming projects will be promoted. This can include establishing community gardens, rooftop farms, and shared common spaces within apartment buildings. Increased community involvement in food production can decrease reliance on imported goods.
- **Monitoring and Evaluation:** this mechanism should be established to track progress, impact and outcomes of vertical farming initiatives. Regular assessments should be conducted to measure the effectiveness of implemented strategies and identify areas for improvement. Consistency will be key to ensuring the long-term sustainability of vertical farming practices in urban settings.

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