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One Square Meter Yield:
A Hydroponic System Design

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Abstract:

Vertical hydroponic farming is a developing sector that has the potential to mitigate the adverse effects of conventional farming while also meeting the demands of rapidly urbanizing populations. The global food system is responsible for up to 30% of anthropogenic GHG emissions, with primary production accounting for the majority of these emissions. Hydroponic farming is a type of crop production in which the plants grow without the use of soil. It is mainly done indoors. Hydroponic production has various advantages for the food system, including water efficiency, space efficiency, year-round production, and system productivity. Despite many advantages mentioned in the literature, hydroponic farming has certain drawbacks, including a reliance on electricity to grow, a limited choice of crops appropriate for hydroponic cultivation, and a higher product price. This paper examines the obstacles and describes how integrated modular farms might be implemented in Sweden to improve urban food resilience. This project aims to design a modular solution for a closed hydroponic farm using various data gathering and design methodologies. In one year, the designed hydroponic system generates about one ton of lettuce in a one-square-meter area while saving 91.27% of water compared to conventional farming methods. The secondary goal was to assess the designed system's long-term viability in terms of social, environmental, and economic sustainability indicators and study the structure from an engineering standpoint.

Keywords: Hydroponics, Urban Food Resilience. Modular Design, Sustainability

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Summary:

Urban farming has the potential to narrow the gap between food supply and demand, resulting in a dramatic shift of food production and its supply chain, as well as making the global food system more sustainable and resilient for improved food security. Vertical farms, among the several ways of urban farming, can play a critical part in a city's social, economic, and environmental sustainability. Vertical farms allow Sweden to produce food all year, especially during the winter months when traditional local farms are unable to do so, enhancing the country's food security and contributing to long-term urban development.

The purpose of this thesis is to design a modular vertical farming unit with the idea of producing mini-Romaine lettuce in One-meter square area. Vertical farms can take on many forms, and this study investigates the possibility of vertical hydroponic farms, with an emphasis on food production capacity, efficient resource usage, and consumer reach. In Sweden, the retail sector accounts for 80% of direct food consumption, with the ICA group holding the largest share and demonstrating an interest in food sustainability. To further understand the workings, maintenance, and reach of the idea, a case study was undertaken at an ICA grocery outlet that has the first integrated vertical farm project in Sweden. In addition, to build a modular vertical hydroponic farm, research procedures such as literature review and questionnaire were used to select the crop, understand efficient hydroponics processes and the import patterns of lettuce in Sweden. Based on the research, a modular hydroponic vertical farming unit was designed using computer aided design. The system is made as human independent as possible by collecting and analysing data using sensors and IoT technologies.

By analysing the environmental, economic, and social aspects of the hydroponic system, this thesis addresses 7 of the 17 sustainable development goals. Plants grown vertically facilitate a more efficient usage of space and a greater output capacity which is the core of this thesis. Even though this is a modular system, it can be made even more user-friendly and customer centric. In technical elements such as engineering drawings, material selection, and price, a little more knowledge was required to improve the hydroponic system. It may be tough to instil the idea that people can grow their own greens in their minds. This modular hydroponic system could be a feasible business approach in the future.

Keywords: Hydroponics, Urban Food Resilience, Vertical Farming, Modular Design, Sustainability

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1. Introduction

This chapter gives the background information and sets the context for the topic that this thesis further analyses. The concept of urban food resilience and hydroponics is explained throughout. Consequently, the aim and research questions of the thesis, together with limitations, are described.

1.1. Background

Food is one of the crucial topics in sustainability debates today on a global platform. According to (FAO, IFAD, UNICEF, WFP, 2020), 690 million people are hungry, and from the year 2015, 10 million people are being added to the count every year. The main reasons for the rise are deteriorating economic conditions, high commodity import-export dependency, and increasing frequencies of extreme weather conditions. It is estimated that we need a 70 percent increase in food production by 2050 (FAO, 2009) to feed the growing population. (UN-DESA, 2021) in its fifty-fourth session of the Commission on Population and Development, considers population size and distribution as critical drivers of food demand. With a shift in living standards and per capita income rise, the minimum dietary energy requirements vary. Today, urban areas cover only 2 percent of the world's total land area (Pacione 2009) but hold 56 percent of the total population, which is projected to rise to 70 percent by 2050 (UN-DESA, 2020).

Resource use is one of the main challenges faced by urban areas. With the current scenario, the vast majority of the resources needed and used by a city must be produced and brought in by places outside the cities' borders (Zeeuw and Drechsel, 2015). This is referred to as urban ecological footprint: "the total area of productive land and water required continuously to produce all the resources consumed and assimilate all the wastes produced, by a defined population, wherever on Earth that land is located" (Rees and Wackernagel, 2012). The ecological footprint is measured in terms of annual land and water consumption per capita, and it has risen in recent years, owing to rising energy consumption for a variety of reasons, including mobility, heating and cooling, long-distance transportation, storage, and processing. (Zeeuw and Drechsel, 2015). Land and water availability are two main factors on which the agriculture sector is dependent.

There are enormous discrepancies in food availability worldwide, between countries and within, where some sections have enough food while others have none. Food insecurity is mainly caused by the following factors: availability, affordability, accessibility, and adequacy. Food tends to have significantly less prominence in urban developmental policies as it is usually associated with agriculture, in turn, with rural boundaries (Zeeuw and Drechsel, 2015). To efficiently administer the rapid outbreak, identifying and developing agro-productive urban spaces is necessary, if not now, then in the near future.

With a total land area of 447,420.00 square kilometres (The World Bank, no date), Sweden is the third-largest country in Europe, yet only 6.5 percent of its total land area is dedicated to agriculture. One of the main reasons being its poor growing conditions in terms of weather and availability of farming land. Rapid urbanization and structural changes caused are adding up to the agriculture sector on a degenerative curve, currently contributing only 1.6 percent of the total GDP (Central Intelligence Agency, no date). According to (SCB, 2019), total agricultural products and food imports have skyrocketed from 41933 SEK millions to 164144 SEK millions over the last decade. Hence, Sweden is undeniably dependant on other countries for fresh fruits and vegetables. According to (FAO, no date), over 70 percent of the fresh fruits and greens are being imported, which comes with an environmental, economic, and social cost. Talking about unsustainability and food insecurity, all the above-mentioned factors, from availability to the adequacy, are compromised in this system.

1.1.1. Supermarkets

Food is wasted at every stage of the food supply chain, but due to the size and complexity of the food delivery system, there are considerable differences in amounts over time, between goods and between various types of businesses. However, since each phase adds more value in terms of both money and energy (Eriksson & Strid, 2013; Strid et al., 2014), waste reflects a more significant loss of value at the chain's end sub-processes have gone to waste (SEPA, 2012). Supermarkets are almost at the end of the food supply chain, and they often collect vast amounts of food in a small number of geographic locations. As a result, even though supermarkets contribute a small percentage of waste compared to other stages in the food supply chain, these are potentially good targets for waste reduction initiatives (Jensen et al., 2011a; FAO, 2011; Göbel et al., 2012). Retail, restaurant, and catering are the three main sectors relating to fresh fruit and vegetables in Sweden. The retail sector has two main subdivisions, supermarkets, and specialized food stores and 80 percent of direct food intake occurs in this sector. Three large and one smaller groups account for approximately 74% of retail sales: ICA Group - 35%, KF Group - 19%, Axfood – 18%, and Bergendahls – 2%. (FAO).

In Sweden, lettuce consumption is subject to the product's availability and the supply strength from both local and Spanish manufacturing. Spain is the leading Swedish lettuce supplier, and in the last five years, its share has been around 69.5% to 72.5%. Spain supplies a minimum of 20,000 tons of lettuce annually to the Sweden market. The highest volume was 23,000 tons in 2013, and the lowest volume was around 19,000 tons in 2017. (Export Development Authority and Green Trade Initiative, 2018b). According to the Food and Agriculture Organization's (FAO) released data, lettuce production prices in Sweden in 2016 were roughly 766 USD/ton. At the same time, the Comtrade statistics show that the average import price amounted to 1243 US dollars/tonne. The market consumption of lettuce is expected to increase in future years due to a significant interest in fresh food and healthy food, particularly fresh vegetables, and fresh salads by Swedish households. The demand for organic vegetables and organic lettuce should also grow exponentially; this market is now a fast-growing niche segment. Sweden has been one of Europe's most demanded bio-product countries.

1.2. Problem Formulation

In industrial food production and distribution, the most commonly used soil preparation methods, irrigation, harvesting, refining, refrigeration, transportation, and packaging, rely on massive inputs of fossil fuels, especially oil. Oil and natural gas are also used to make synthetic fertilizers and pesticides widely used throughout the production process. Furthermore, according to (Mosier et al, 1998), current farming activities around the world accounts for roughly 70 percent of all human-produced nitrous oxide, which is 300 times more harmful than carbon dioxide (Peoples et al., 2004a), leading to climate change which is further expected to reshape the agricultural landscape of the world.

(World Resource Institute, 2000) says that the deteriorating quality of world soils and available arable land is another direct derivative of industrial agricultural practices. Industrialization, deforestation, extensive chemical use, and overgrazing are all contributing factors. In several areas of the world, extensive irrigation has also reduced freshwater table levels. According to the Food and Agriculture Organization (2005), agriculture accounts for nearly three-quarters of global freshwater consumption. Erosion, desertification, siltation, eutrophication, and salinization are all exacerbated by such irrigation practices.

Despite being founded in the early 1900s (Pandey, Jain and Singh, 2009), hydroponics has not managed to reach the core and solve issues related to food security on a large scale. Thus, one of the reasons why hydroponics has not achieved mass scale are constraints to its adoption by households. There is an obvious need to integrate modular designs into the vertical farming process to overcome this and explore the actual capacity of vertical farms in terms of establishing urban food resilience. This will help reach as many segments as possible which can adapt to the present and future user requirements.

1.3. Aim and Research Questions

This thesis aims to understand strategies to promote sustainable food systems, the current state of lettuce imports in supermarkets, and design an efficient hydroponic system to increase local food resilience. Even while we will not be able to totally replace lettuce import trends, we can minimize them to boost country resilience. Uppsala City is considered the study area to streamline the research, and the ICA Supermarket chain considered the case concerning lettuce imports.

It has three main objectives:

1. *To give an overview of current import trends of lettuce in Sweden.*
2. *To produce a well thought modular hydroponic system design in one square meter, keeping in mind its functionality and efficiency.*
3. *To weigh the sustainability factor of the hydroponic system in terms of environmental, social, and economic aspects.*

The following research questions guide the report:

1. *How can vertical farming be efficiently integrated into existing spaces to benefit both food markets and end-users?*
2. *How can hydroponics systems contribute to social, ecological, and economic sustainability?*

1.4. Limitations

1.4.1. Research Limitations

1. Despite other alternatives such as aeroponics and aquaponics being explored today, this study is confined to hydroponic vertical farming systems.
2. The end-user perspective questionnaire was circulated amongst the reachable groups.
3. The variety of plants that can be effectively grown is increasing as hydroponics develops and is used worldwide. However, this thesis concentrates on one lettuce cultivar, mini romaine lettuce, to simplify and facilitate the study and design of the hydroponic system.

1.4.2. Design Limitations

1. Basic prior knowledge, imagination, and case studies were used to design the system. Because it is not at the prototyping stage, it can take many different forms and may require additional work.
2. Business Model Canvas -Because they demand more time and extensive examination regarding business approach, some pre-existing aspects in the business model canvas such as key partners, channels, and customer relationships are not considered in this report.
3. Specifications - The specifications are based on the materials and products currently available on the market. As the design is still in the conceptual stage, it cannot be very design specific. Limiting factors related to the designed external structure are considered for the cost calculation.

2. Theory and Concepts

2.1. Urban Farming

Food security is an answer to how countries can achieve the second Sustainable Development Goals (SDG) proposed by the UN. This goal aims to end hunger and ensure access to sufficient, safe, and nutritious food through the year by 2030. Urban farming is a system with the help of which food security can be achieved (Kennard and Bamford, 2020). Urban farming is defined as "the growing of plants and raising of animals for food and other uses within and around cities and towns, and related activities such as producing and delivering inputs, processing, and marketing of products" (FAO 2007). Urban farming can be a reliable source of nutritious, healthy food products for distinctive families, urban markets, and community groups. With the climate change initiatives in place worldwide, cities need to develop themselves to produce a small percentage of their food supply. Foreseeing global supply chains being affected due to natural calamities, urban farming is the only way out (Kennard and Bamford, 2020).

There are various types of Urban farming today, including backyard gardens, street landscaping, forest gardening, greenhouses, rooftop gardens, and vertical farming. Vertical farming is a method where plants and livestock are cultivated on vertically inclined surfaces in urban areas, where there is no sufficient land and space available (Kalantari *et al.*, 2018). There are two different types of vertical farms: vertical home farms and indoor vertical farms. All three systems can grow salads, microgreens, and herbs. The consumer can fully control vertical home farms via smartphone in terms of produce, lighting, and nutrient supply. By contrast, the in-store vertical farm is a glass cube in grocery stores, where consumers can watch the growth process, see the product, and put the product in their shopping carts from a shelf next to the cubic system. Finally, the products of indoor vertical farms are only found yielded and packaged without any direct consumer contact with the system (Jürkenbeck, Heumann and Spiller, 2019).

Apart from different types of urban farming, urban farming can also be divided based on the method used to grow plants. Hydroponics, aeroponics and aquaponics are different methods in urban farming used to grow plants. Hydroponics uses liquid, sand, gravel, and other materials to grow plants away from a soil environment. The plants' roots get nutrients from water that is enriched with liquid plant food. Aeroponics is a method of growing plants in a moist environment. The plants are suspended in an enclosed setting, and water is sprayed onto the roots mixed with plant food. Aeroponics systems are frequently employed in an enclosed environment like a greenhouse so that the temperature and humidity can be accurately regulated. Although sunlight is the principal light source, some additional lighting may also be added. Aquaponics is unlike both hydroponics and aeroponics. Aquaponics uses a combination of aquaculture (raising fish) and hydroponics. By adding fish into the equation, a natural ecosystem exists, in which fish, plants, and bacteria flourish off each other. The waste from fish and the living bacteria in an aquaponics system delivers all of the plants' nutrients. The fish and the bacteria create a cleaner, non-toxic environment for the fish to live in. This also eliminates the need for a nutrient solution mixed with chemicals (Len Calderon, 2018).

2.1.1. Hydroponics

Hydroponics is the process of growing plants without soil. Instead, plants are grown in a growing medium, and the roots get nutrients from a water-based solution that they are directly immersed in (Griffiths, 2014). Understanding the purpose of soil in a plant's life can give a clear insight into how hydroponics work. Soil is the medium that gives air, support, and balance to a plant, and most importantly, retains water and nutrients and supplies them to the roots (Mason, 2005).

In hydroponics, the support and balance are provided by a growing media, which also helps in maintaining a good water/oxygen ratio and nutrients are delivered by the system adapted.

2.1.1.1. Hydroponic Media

In hydroponics, the term 'media' refers to the solid material(s) used to replace soil. The hydroponic media should be chemically inert and stable, clean, drain well without waterlogging, have adequate water and air holding capacity and good ability to resist changes in pH. Hydroponic media can be categorized into three main groups: media derived from rocks, media derived from synthetics and organic media. (Mason, 2005). Rockwool is the most often used rock medium. However, using organic materials is always recommended from an environmental and health standpoint.

2.1.1.2. Hydroponic systems

There are two types of hydroponic systems, active and passive. To carry nutrients directly to the roots of a plant, passive systems use a capillary or wick system. Nutrients are consumed by the growing medium or a wick and passed to the plant's roots in this way. Passive systems are straightforward to use; they do not even require electricity to operate. Active systems are more complex than passive systems, but the degree of complexity varies depending on the system. Pumps or other machines are used in active systems to transfer the solution from a reservoir to the roots continuously. This results in much better-growing conditions and nutrient efficiency. (Incemehmetoğlu and Yildiz, 2012). Open and closed hydroponic systems differ in that the nutrient solution is introduced fresh for each watering cycle in open systems, but it is continually recirculated within the system in closed systems. (Deaconu, 2020). There are many techniques in hydroponics that allow for optimum customization of the growing operation. Irrespective of the size of the farm, there are growing techniques to cater to all the needs. A combination of these techniques can also be used in tandem, and it is not limited to adapting one particular technique (Maboko et. Al, 2011)

- Deep Water Culture (DWC)

It can be done in various ways, but it is most commonly done in PVC or Styrofoam boards. A hole is drilled in the board to the size of the growing media, and the seeds are placed inside the growing media. It is then placed inside the drilled holes. The roots of the plants are suspended in an oxygenated nutrient solution until the crop is harvested. Since it does not require much root support, it is ideal for short leafy greens and herbs. The Deep-Water Culture system also carries a large amount of water. Deep Water culture carries large amounts of water, which slows any chemical changes in the solution. Furthermore, if a Deep-Water Culture system's pump fails, the system will have enough water to back up the need of the plants before any severe issue occurs or the root dries out. (Majdi et al, 2012)

- Nutrient Film Technique (NFT):

This flexible technique involves running a very shallow stream of water to the roots through channels or troughs set up at a slight angle for drainage. It is possible to do it on a timer or in continuous flow. The solution is held at the lowest point in a reservoir with a submersible pump and typically air stones for optimum dissolved oxygen and stagnation prevention. The water flows back into the reservoir after saturating the roots. Nutrient Film Technique (NFT) is better for short-statured plants, including Deep Water Culture., but these systems carry far less water per plant and are easier to stack, clean, and customize according to the requirements. (Yuvaraj and Subramanian, 2020)

- Ebb and flow

The Ebb and flow system may be as simple as a small plastic bucket filled with expanded clay pellets or other rock media and watered and drained by hand. It may also be complicated to connect an aquaponic device to a large media filed bed and fill it with the system's liquid waste. The grow tray is saturated with the solution for a few hours in each case, submerging the roots before returning to the reservoir. Ebb and flow systems are ideal for growing almost anything due to the root support and oxygen levels. It is to be made sure that the system can support the weight of the entire media and water and the containers are completely drained. (Yuvaraj and Subramanian, 2020)

- Drip system

Drip systems, which use a pump on a timer to deliver a slow feed solution to the base of each plant individually, are another popular and simple technique. The excess solution may be stored or added to the reservoir. It works well with growing mediums that retain much water (i.e., coco coir, Rockwool, or peat moss). When the device is functioning correctly, it requires low maintenance and produces high output, but the drip lines become clogged, resulting in dried-out plants. Since organic materials clog lines even faster, synthetic nutrients are the reasonable alternative for these systems. (Yuvaraj and Subramanian, 2020)

2.1.1.3. Limitations

- Hydroponics is a type of high-tech urban farming that requires a significant initial investment.
- To maintain their productivity in commercial applications, growers require skills and knowledge.
- Diseases and pests can quickly infect every plant in open hydroponic systems because they share the exact solution of nutrients.
- Water collection and circulation problems in closed systems can arise if not regularly monitored and cleaned.

2.2. Urban Food Resilience

Today, food systems are up and running due to a global network encompassing production, processing, distribution, and consumption. These food systems in place, be it the supply systems or the distribution systems, are always prone to uncertainty and disruptions from natural and human-generated threats. The threats can range from natural disasters to extreme weather to political unrest and economic crises, to name a few (Hecht *et al.*, 2019). These food systems should have the ability to combat and overcome such hazards to decrease the vulnerability that the population has towards its impact. This can be done by improving the agricultural landscapes within urban developments. The flexibility brought about in urban areas by improving biodiversity and enhancing agricultural ecosystems is known as urban food resilience. Maintaining agriculture inside and along the outskirts of cities is an essential step in urban planning and food security (Kennard and Bamford, 2020).

2.3. Sustainability

"Back in 1700, the acute scarcity of timber in Saxony (present-day Germany) is what led to 'Carl Von Carlowitz' speaking about the need for mindfulness and responsibility concerning deforestation. The thought that we should not cut down more trees than required that will grow again to replace them is what the basic principle of sustainability is all about" (Narsipur, 2021). Sustainability has become one the most widely used term because of the possibility of associating it with anything. However, in a generic context, sustainability can be categorized into three different things, economic, environmental, and social sustainability. These three are interconnected and interdependent to each other.

Environmental sustainability is a multi-disciplinary term that involves maintaining and sustaining the quality of our planet through biological and eco-friendly methods. It is the mindful and responsible interaction with the planet, ecosystem, and resources such that the needs of future generations are not jeopardized (EVANS, 2020). "Economic sustainability focuses on that portion of the natural resource base that provides physical inputs, both renewable (e.g. forests) and exhaustible (e.g. minerals), into the production process" (Goodland and Bank, 1995). It involves inculcating practices that support long-term economic development without adversely affecting society's social, environmental, and cultural aspects. Adapting to formal and informal institutions and interactions to produce healthy and liveable communities for current and future generations. Social sustainability can only be achieved through systematic community participation and substantial social involvement. There is a need for social capital to be generated to attain social sustainability (Goodland and Bank, 1995).

2.4. Business Model

A comprehensive study of business models by (Zott, Amit and Massa, 2011) has shown that there is no clear definition of the business model concept due to its scientific novelty. (Teece, 2010) describes a business model that gives management insight into how value is created, delivered, taken into account, and converted into profit. This method is divided into nine building blocks known as the Business Model Canvas (BMC) (Osterwalder and Pigneur (2010). The Business Model Canvas is a valuable tool for analyzing the performance and organization of a vertical farm, which should be adapted to the urban circumstances of the city (Polling et al., 2017). Alexander Osterwalder developed the BMC in 2008 and consisted of nine elements that offer a full view of key drivers of the business (Osterwalder & Pigneur, 2010). Entrepreneurs usually evaluate business model innovation because it gives a transparent and focused view while flexible for changes.

The nine blocks of the business model canvas are vital partners, key activities, key resources, value proposition, customer relationships, channels, customer segments, cost structure, and revenue streams.

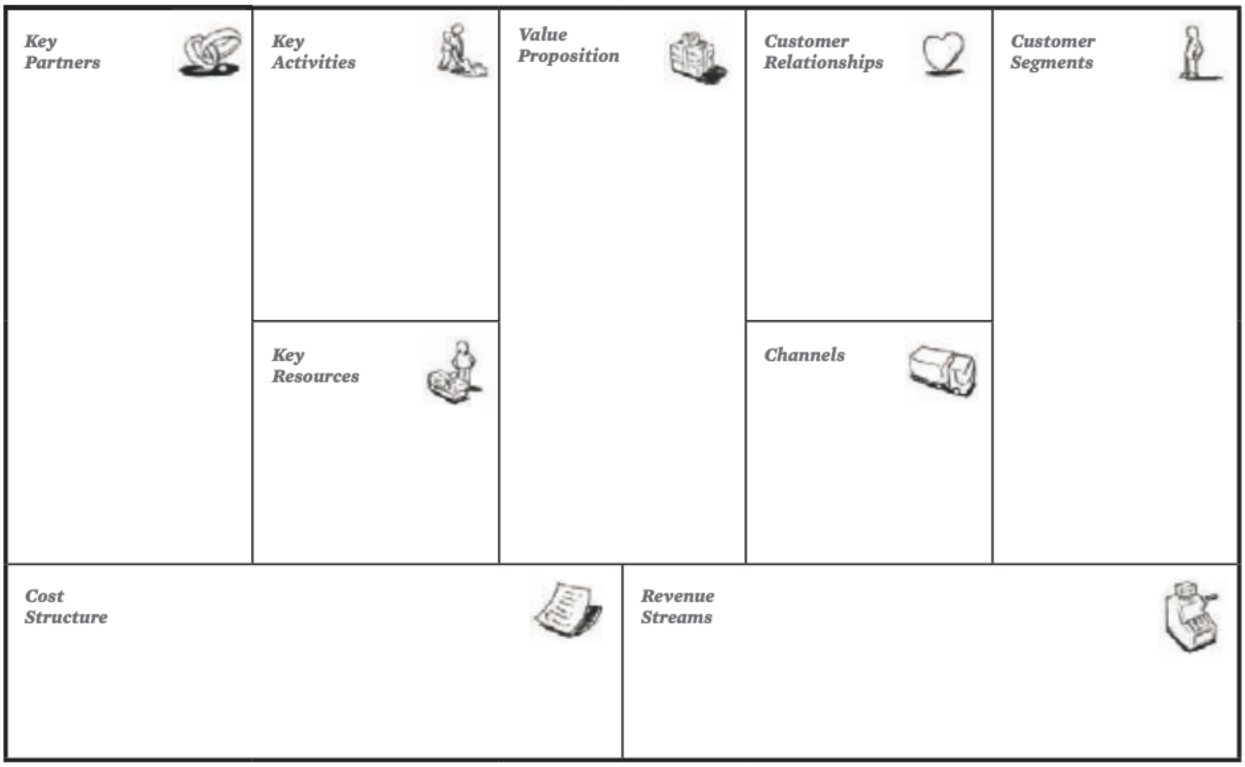

Fig 1: Illustration of how the Business Model Canvas is presented by Osterwalder & Pigneur (2010).

3. Methods

To answer the two research questions, several methods were used throughout the thesis. This chapter describes the methods used in further detail, starting with the methods used to gather and analyse quantitative data and ending with the methods used to design the final concept of the product.

3.1. Literature Review

Literature evaluations serve a variety of purposes and accumulate information on the topic of interest. They reveal knowledge gaps and significant areas of disagreement and uncertainty; they aid in the identification of patterns in findings from similar studies; they aid in the exploration of causes for disparities in contradictory findings; they aid in the definition of terminology; and they aid in the identification of research procedures and instruments (Booth & Dixon-Woods, cited in Robson & McCartan, 2009:52). A literature review achieves these goals by systematically finding, locating, and assessing publications such as articles, abstracts, reviews, monographs, dissertations, books, research reports, and electronic media (Gay & Airasian, cited in Robson & McCartan, 2009:52).

3.2. Data Collection Methods

3.2.1. Case

According to (Robson, 1993), a case study is a “strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence” This method helps researchers to keep the holistic and substantial aspects of real-life (Yin, 2009). Case studies capture a range of perspectives instead of the single view an individual gets with a survey response or interview.

3.2.2. Questionnaire

A questionnaire is a written document in which respondents are given a series of questions or statements to which they must react either by writing their replies or selecting from a list of pre-determined answers (Brown. 2001). In other terms, a questionnaire is a research tool that consists of a series of questions designed to collect information and data from people (Schuman, H., & Presser, 1979). Sir Galton Francis, a renowned English philosopher and academic, was the first to employ a questionnaire in a survey. Questionnaires often ask questions that give rise to ideas, results, preferences, and facts (Yakub, 2019). The questionnaire was a combination of several types of questions. The questionnaire consisted of the questions that were asked openly when the respondent was given the opportunity of answering an issue based on his comprehension and explanation. It consisted of close questions where the respondent was not given an adequate answer to a question but specific options to choose from and a few dichotomous questions with a yes or no option.

3.3. Computer Aided Design (CAD)

In Autocad, a preliminary 2D CAD model was created followed by a 3D model on SolidWorks and tested to determine whether the design and method of scaling proposed for the product are technically viable. In order to find out the behavior of the product during installation, a stress simulation and analysis was carried out using Ansys with the following points in focus: total movement; Von Mises stress in relation to the output strength of the used material and security factor.

3.3.1. AutoCAD

It is a computer-aided design (CAD) and drafting software application. AutoCAD stands for Computer-Aided Design, developed by the company Autodesk. It is software that engineers generally use to make precise 2D drawings. The 2D design of the system is constructed using AutoCAD 2020. AutoCAD is a software application for commercial, computer-aided design and drafting. This software is generally used for creating 2D drawings. As this software is available free of cost for students, AutoCAD is used in this thesis for 2D drawings. The part drawings were created using AutoCAD 2d, but sheet metal drawings are easier to create in SolidWorks as they have sheet metal drawing tools.

3.3.2. SolidWorks

This software is a solid modeling computer-aided design (CAD) published by Dassault Systemes. SolidWorks uses an approach based on parametric features. Parameters refer to limitations, the values which determine the design or assembly's form or geometry. Parameters can either be numerical or geometric parameters such as tangent, vertical, horizontal or concentric. The use of relationships can link numerical parameters, allowing them to capture the design intention. (*SolidWorks*, no date).

Key SOLIDWORKS 3D solid modeling capabilities (*3D Solid Modelling Solidworks CAD*, no date):

- 3D solid models for any component irrespective of the dimensions and complexity.
- The integrated association automatically tracks changes and updates all 3D models, 2D drawings, and other synchronized design and production documents.
- Check key design parameters to modify designs quickly.
- Creates 3D geometry surfaces irrespective of the complexity.
- In-depth 3D model analysis immediately on a wide range of features: weight, density, inertia moments.

3.3.3. Ansys

ANSYS software is a mechanical Finite Element Method Analysis (FEA) used in simulating 3D models of structures or analyzing the mechanical components for toughness, strength and temperature distribution, etcetera. Ansys determines how a product works without actually building the test product. It can also be tested for different specifications. Simulations are done using the Ansys workbench. The structure is broken down into smaller fragments and tested individually by adding weight, pressure, and other physical properties. Ansys will simulate and analyze movements, fractures, fatigue, and other effects over time (*Ansys*, no date). Simulation of the model is done by importing the 3D model from solid works.

4. Data Collection

4.1. Literature Review

The purpose of this literature review was to gather background information on significant subjects important to product research. It was based on publications gathered from reputable academic libraries and databases and worldwide research institutes and organizations such as the Food and Agriculture Organization of the United Nations (FAO), The World Bank, The United Nations Department of Economic and Social Affairs (UN-DESA). This was followed to guarantee that only scientific papers were chosen, improving the study's credibility. Google Scholar, SpringerLink, Research Gate, and the Uppsala University Library were the most frequently used databases. These preliminary searches lead to more specialized and extensive searches. Many of the articles were also discovered utilizing the databases" recommended articles' feature, which gave a list of similar articles.

The literature review started with the books "Cities and Agriculture" and "Commercial Hydroponics," which looked at how robust urban food systems are developing. These books served as the starting point for this research, particularly in terms of urban food systems, hydroponic, present agricultural patterns, and the need for change to attain resilience. Urban farming, food security, current food production systems, demographic prospects and future urbanization, sustainable cities and urbanization, urban agriculture, agroecology, and vertical farming were among the topics covered in the literature that followed.

"Can vertical farms outgrow their cost? An analysis of the competitive strength of vertical farms in Sweden", "Vertical Farming Sustainability and Urban Implications," and "Designing an indoor modular micro-farm" provided an idea for building the framework of the thesis along with introducing concepts like business models for urban agricultural systems and product design.

4.2. Case

In collaboration with ICA Group, the leading food retailer in Sweden, a leading Swedish AgTech company opened its first integrated farm in one of ICA supermarket outlets in Gothenburg. With close to 1250 stores across Sweden, ICA is the leading supermarket brand with an annual sale of 91684 million SEK and an operating profit of 4240 million SEK in 2020. ICA Gruppen also aims to minimize the group's own environmental impact, create a climate-neutral business, and also influence customers to make more sustainable choices. Parallelly ICA is working with experts and researchers to identify areas where changes have the ability to make a difference for more sustainable food systems. Swegreen, a leading Swedish AgTech company opened its first integrated farm in one of ICA supermarket outlets in Gothenburg. This is the first initiative of urban farms with supermarkets. Since this thesis study deals with integrated modular farms, this case can significantly input how integrated farms operate in real life (ICA Gruppen, 2020).

SweGreen, led by CEO Andreas Dahlin, was established in 2019 and provided smart urban farming as a service model enabled by an AI-driven monitoring and remote management system. The business manages the Stadsbondens brand for a City-Farm in Stockholm that grows herbs all year. Their Vertical Farming system is based on multi-layer growing structures that enable plant growth in a very space-efficient and small footprint. Plants have optimum humidity, irrigation, CO_2 for photosynthesis, temperature, ventilation, nutrition, and even lighting in ideal settings (SweGreen, no date). ICA Focus is a one-of-a-kind grocery store that has served as a gathering spot for foodies in Gothenburg for over 25 years. With over 35,000 products to choose from, you have roughly twice as many options as you would in a regular Ica store. In addition, ICA Focus has its bakery, charcuterie, and restaurant (Swegreen's cultivation service takes place at ICA Focus in Gothenburg, 2020).

Farming as a service, ICA Focus, Gothenburg

The site was visited on the 3rd, 4th, and 5th of March 2021. ICA Focus has installed an in-store hydroponic vertical farming unit that produces fresh, nutritious leafy greens throughout the year. This is accomplished by the use of a controlled environment and the monitoring of variables like as pH levels, nutrient intake, water circulation, moisture, humidity, and so on.

The total area covered by the farm is 44 square meters (7.1 m X 6.2 m), with a height of 3.5 meters. The farm is a closed system and is not open for visitors, however, the process is transparent as the walls are made of glass, and people can observe the ongoings. A technician monitors the farm daily who is responsible for basic operations like transferring the plants to the hydroponic system from the nursery, harvesting, etc. Also, they have an appointed in-charge is who is responsible for the farm overall. To make development easier to handle, SweGreen has created a cloud-based control and monitoring system. The system will continuously improve and further optimize cultivation processes by using artificial intelligence. So, the factors to be taken care of are the production process from seed germination to harvesting. The plants are grown under artificial LED lighting.

The farm is being divided into three parts according to the growth process. The process of farming is divided into three phases: germination, nursery, and harvest units. The germination occurs in a closed germination chamber where Rockwool cubes are placed in trays and stacked up inside the chamber. Once the seeds have germinated, they are transferred to the nursery. Nursery is made up of vertical compartments where trays can be shifted straight from the germination chamber. Here, the plants are provided with the light and mild nutrients to develop a robust root system. Once the plant grows 3 – 4 cm tall, they are transferred to the growing tracks. The growing tracks are made of square PVC tubes through which the nutrient water is circulated for the roots to absorb. Holes are drilled on top of the tubes to hold the hydroponic medium containing plants. The plant takes 14 days to mature in the system.

Greens such as basil, Pak-choi, lettuce, thyme, coriander, salad greens, and others are grown on the farm. The harvested crops are again transferred into a deep-water culture PVC tray that acts as an open shelf to increase the shelf life. At full size, the cultivation facility in the ICA Focus store can harvest nearly 300 units of fresh lettuce and herbs every day. The water is recycled up to 95 percent as the irrigation system acts as a cycle. Nutrients are also recycled, and carbon dioxide is supplied to the plants through a filtered air intake from the supermarket.

Fig 2: Farming as A Service inside ICA

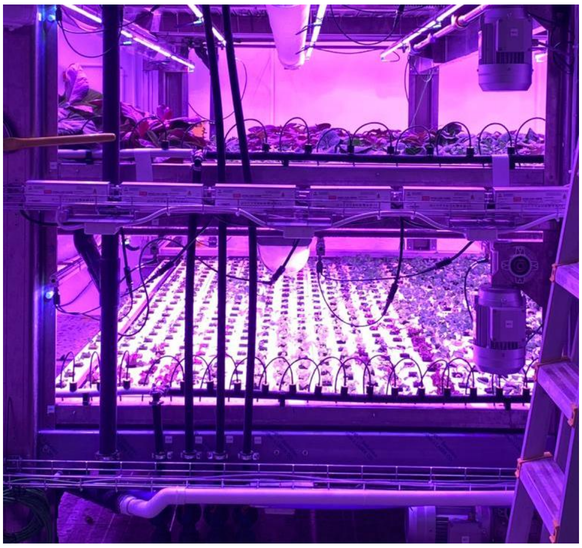

Fig 3: Hydroponic grow unit

Fig 4: Produce in rockwool medium

Fig 5: Germination trays with grow media

Fig 6: Grow pot with coco peat as a grow media

4.3. Questionnaire

Vertical farming is a relatively new idea and has been under implementation only in recent years. Thus, the purpose of this survey was to identify the public conception of vertical farming and assess the acceptance of the idea. The survey has been conducted on 85 students at Uppsala University. Uppsala is a multicultural student city and thus, provides the perfect environment for the study group.

Food preferences are different in different locations. Therefore, surveyees were questioned on their geographic background, which could help study patterns of answering based on location. General public awareness of sustainable food production could indicate the acceptance of this idea and the survey questions on students' educational background to understand if surveyees outside the field of sustainability and environmental studies have prerequisite knowledge of these fields. Further, the survey also helps to measure the surveyees' knowledge in the basics of vertical farming and inquire about their interest in vertically farmed produce. In case of disinterest, the survey enquires the reason for it.

Diet is often a direct result of affordability, and thus, this may be a factor to consider in a local production plant. The survey tests out this postulate. An essential discussion with vertically grown produce is the concept of price vs. location. In the current agriculture scenario in Sweden, with most vegetables being imported, the product's price is highly dependent on the import cost, and thus, there is a significant fluctuation in the prices based on the season. However, with the product being grown locally and in-stores using hydroponics technology, these fluctuations may be controlled, and products can be sold at an average price throughout the year. This advantage is subjective, and the survey assesses surveyees' interest in it.

The pandemic has resulted in people wanting to shift to a healthier lifestyle, and many people have begun exercising more and eating healthy. Thus, this may have a direct consequence on the supply and demand of green vegetables. Another exciting aspect is that in certain countries, people have been skeptical about eating meat, given the circumstances of the pandemic, and thus, the reduction in consumption of meat could directly lead to an increase in the consumption of green vegetables. Thus, to sufficiently corroborate this, the surveyees were asked about their consumption of greens in the pandemic. Finally, the surveyees are asked about their preference among locally grown produce and imported produce, which provides a direct indication of the market and economic valuation of the product.

The survey had a few limitations. Firstly, the spread of people and diversity in a denomination that was expected was not achieved. Secondly, a few responses from the surveyees were uninformative. In the future, this survey can prove to be an essential tool, but changes must be made to make surveyees more interested and included. Also, the study group's size must be increased to identify patterns and similar behavior clusters.

5. Design

The process of product designing is based on analyzing the problem, identifying market opportunities, developing a solution for that problem, and endorsing it with real users. Product design is a three-dimensional approach that employs aesthetic, symbolic, and functional dimensions. Product design is a concept based on Gestalt's theory which states that the entity is more than the sum of its parts. According to Gestalt's theory, a product can be measured based on two different levels: atomistic and holistic. In the atomistic level design, elements such as color and shape are considered, while in the holistic level, the design of a product is measured through consumers' holistic perception (Homburg, Schwemmle and Kuehnl, 2015).

5.1. Vision and strategy

Vision - To achieve maximum production of nutritious leafy greens yearlong with least possible environmental impact.

Strategy
- To build a sustainably compelling product by reengineering the delusion of 'farming as a complicated task'.
- To build an efficient system by using well-thought materials and strategies to make it available for each person on the globe to farm at the comfort of their own space.
- To lead way towards transition by building community resilience on food.

5.2. Product Business Model

Business models allow us to understand the value of a product on the market, its skills, market sustainability, drawbacks and parts that require greater focus. It helps us understand today's competitive state and the innovation and ideas that must stand up against current competitors. Therefore, it can be a good start before a product design is specified.

Key Activities
- Recognizing space for installation
- Installing system
- Seeding
- Harvesting
- Maintenance
- Environmental control

Key Resources
- Raw materials – for the system installation and farming
- Energy source
- Manpower

Value proposition
- Reduced Water Usage
- Improved Productivity
- Locally grown vegetables
- Pesticide free
- All year produces
- Consistent price and quality

This model over present systems
- No additional infrastructure cost
- No extra storage required
- No transport/ delivery systems involved

- No mediators/ distributors or wholesalers involved
- No extra processing and packaging

Customers
- Supermarkets
- Hospitals
- Large- scale restaurants
- University buildings

Cost Structure
- System implementation
- Utilities
- Raw materials – farming
- Energy – usage of LED lights/solar power installations
- Maintenance

Revenue streams
- Supermarket sales
- Restaurant sales
- University café sales, Involvement and hands-on projects for interested student groups

5.3. Concept Ideation

Food demand is increasing in today's scenarios, and as previously stated, limited agricultural land availability, high food waste owing to long value chains, and restricted resources are some of the primary reasons why we cannot attain the required numbers with the current system. Evidently, much research is being conducted in order to produce food in a more sustainable manner, and vertical farms are one of the most widely used methods. Vertical farms are becoming more popular around the world, and Sweden is one of the countries that has a large number of them.

The majority of vertical farms on the market are large-scale production units with a high initial capital expenditure. Despite the fact that a growing number of small-scale vertical farms are springing up, they are experiencing challenges with delayed return on investment because the initial investments in this industry are significant, and the produce is limited to the scale of the firm. Sustenance in the market can be difficult due to their lower societal popularity and limited client reach.

In Sweden, 70 percent of fresh fruits and vegetables are imported, and the fresh food sector is dominated by large retailers. As a result, having the greatest consumer reach. The customer reach of expanding vertical farms can be maximized if they are coupled with retailers. Because most retail outlets are already operational, finding enough space to rearrange existing premises can be difficult, as it necessitates energy, investment, and causes disruptions in store operations.

As a result, modularity mobile units can be extremely useful in today's environment. Modular units can save money since investors can choose the scale that best suits their needs. An easy-to-build system is more like an appliance in that it can be moved around and still function. The concept of a one-meter-square-area design was developed as a result of this. This was the foundation of the design.

5.4. Product Components

5.4.1. Crop Selection

A vertical farm can grow almost any crop as long as all necessary conditions are met (Platt, 2007). When deciding which crop to cultivate, the first thing to consider is which plants can be best bred indoors. For this thesis, Lettuce is considered.

In leafy vegetables, Lettuce or *Lactuca Sativa* is one of the essential crops encompassing seven main cultivars commonly described as morphotypes*. They are categorized as butterhead lettuce, crisphead lettuce, cos lettuce, cutting Lettuce, asparagus lettuce, Latin Lettuce, and oilseed lettuce (Noumedem *et al.*, 2017).

Lettuce is an annual herb with an erect stem and a thin tap root system, and it can grow up to 30 to 100 cm tall (Křístková *et al.*, 2008). The capitulum* has approximately 24 florets supremely developed for self-pollination; therefore, the crop is mainly self-fertilizing (Křístková *et al.*, 2008). Lettuce has a combination of high-water requirements and shallow roots. Hence, it grows best in well-drained, consistently moist soils. Cool-weather conditions favor lettuce growth the maximum along with an optimal pH range of 6.0 – 6.7 (*Plant Toolbox - Lactuca Sativa*, no date).

In Sweden, the annual consumption of Lettuce has increased from 55 thousand metric tons in the year 2009 to 151 thousand metric tons in 2019 (Rider, 2021). Even though its popularity, Lettuce is viewed as a crop with low nutritional value. However, based on the cultivar and the growing conditions, it contains health-promoting nutrients. One of the most common Lettuce in the Swedish market is iceberg lettuce (Export Development Authority and Green Trade Initiative, 2018a). Based on a study conducted by West Virginia University, Romaine lettuces have higher nutritional value than icebergs in higher insoluble fiber content, higher fatty acids, higher iron and bone health-promoting minerals, and higher β-carotene and lutein content (Kim *et al.*, 2016). Hence, Mini Romaine is considered for production in this thesis.

Mini heads are a smaller version of classic Romaine's. They are space savers with their compact structures while producing dense and tightly wrapped hearts. According to (*Mini Romaine Lettuce*, no date) they reach maturity ten days earlier than the full-sized ones making growing medium available faster for plating successions.

5.4.2. Lighting

Need for an external light source – External light sources are used in places with little to no light source. The main idea behind using this artificial light source in plant growth is to replicate sunlight in terms of light composition. However, it was not until the emergence of LEDs (light Emitting Diodes) that customizable spectra became possible. Plant growth is influenced by a variety of elements such as light, water, nutrients, temperature, and humidity. Light is one of the most important factors for plant development as it is responsible for photosynthesis happening in a plant. The photosynthesis process can be understood as a series of processes by which plant pigments absorb photons. (Bures, Gavilan and Kotiranta, 2018)

Using LEDs as a source of lights for plants is becoming more common. Long life, energy conservation, and the ability to target specific wavelengths to improve photoperiod management are some of their benefits. LEDs with a longer life span and lower cost are good options (Kalantari *et al.*, 2017). Another benefit of the LEDs is that they can monitor the proportion of red and blue lights to get the best results from the plants. Stem elongation is also increased if the proportion is poor.

There are numerous ways of measuring the intensity, but all the methods developed to measure the quality and quantity of light are only visible to the human eye. The intensity of light is measured in terms of Lumen or LUX.

Lighting technologies like High-Pressure Sodium (HPS) light and fluorescent lights have only been available with only a limited number of spectrum variations. With today's LED technology, it is possible to build a custom-made spectrum, resulting in energy savings and other advantages that were not possible previously. Generally, LED manufacturers to combine red and blue lights in different ratios for horticultural uses mainly to match the absorbance of the chlorophyll curve (Bures, Gavilan and Kotiranta, 2018). The best colors for LEDs are red and blue. Any color with a longer wavelength than blue is preferable. LEDs with these wavelengths were among the first to be produced, resulting in units that lasted longer and performed better. In addition, if 20% blue light is added to red, these crops take on a more natural appearance (Perez, 2014).

5.4.3. Water Pump

Hydroponics is gaining popularity in recent times because of its ability to use comparatively less water than conventional production methods (M. Chowdhury *et al.*, 2020).

Choosing the pump is a vital part of this method because the pump will use around 25%-50% of the total energy based on the system. Pumps with insufficient capacity reduce the system performance, while pumps with large capacity can harm the system. In addition to wasting electricity, an oversized pump has a higher operating cost. Pumps must have a flow rate and pressure which matches with the intended use. Hence, the capacity of the pump must be optimized according to the need. Since using the same pump for various arrangements will minimize system performance, a pump's capacity (flow rate and pressure) must be adapted for particular systems. The target area, total head or pressure against this area, desired flow rate, suction lift, pump operating procedure, and application must be considered when choosing the pump. (M. Chowdhury *et al.*, 2020)

The interaction period of roots with water is influenced by water flow properties, which affects direct nutrient absorption by plants. There are two types of water flow in a Vertical farming system: continuous flow and intermittent flow. In media-filled beds, intermittent flooding and drainage cycles provide uniform nutrient distribution during the flood and increased aeration during the drain phase. In continuous flow, a higher rate of water retention time increases contact time with roots and species, but at the same time, it can also contribute to lower oxygenation rates and nutrient availability. Ebb and flow system is implemented in this thesis. (Maucieri *et al.*, 2018)

Ebb and flow irrigation is common practice in which potted plants are sub-irrigated to prevent leaching and substrate settling. This method usually involves placing potted plants in trays that have been flooded to a sufficient depth for up to 10 minutes to enable the potting substrate to absorb the nutrient solution through diffusion before being drained. The nutrient solution may either be recirculated to reservoirs for reuse or drained into the waste stream. At the same time, aggregate bed systems are being used to grow crops that need a lot of water (e.g. watercress). Long aggregate-filled channels are lifted off the ground in these structures. The aggregate is then flooded regularly, and it may be sub-irrigated or top irrigated (Chidiac, 2017)

5.4.4. Nutrient Solution in Hydroponics

The nutrient solution in a hydroponic system is a solution of inorganic ions from soluble salts of essential elements for higher plants. The nutrient solution performs a specific physiological function, and its absence disrupts the entire plant life cycle (Trejo-Tellez and Gomez-Merino, 2012). The quantities of nutrients vary between various types of plants and throughout a plant's life cycle. Low levels can cause deficiency diseases, while high levels promote the growth of algae and bacteria. To ensure the well-being of the plants, the nutrients must be held within a certain amount. The essential nutrients for a wide variety of plants are divided into macronutrients required in large quantities and micronutrients required in much smaller amounts (Lundin and Olli, 2017). However, since many plants grow in a similar range, a system with healthy plants can be introduced without paying particular attention to these variations (Lundin and Olli, 2017). The essential elements are derived from the growth medium, except carbon (C) and oxygen (O), supplied from the atmosphere. Other elements, including sodium, silicon, vanadium, selenium, cobalt, aluminum, and iodine, are beneficial because some of them can stimulate development. Just nitrogen, phosphorus, potassium, calcium, magnesium, and Sulphur are essential nutrient solutions supplemented with micronutrients. (Trejo-Tellez and Gomez-Merino, 2012). The electrical conductivity and osmotic potential of a solution are determined by the nutrient composition (Trejo-Tellez and Gomez-Merino, 2012).

The electrical conductivity of the water-nutrient solution is used to determine nutrient concentration. Nutrients are primarily made up of molecules that split into ions when dissolved in water. Since conductivity rises in proportion to nutrient concentration, the degree of concentration can be determined implicitly. Other variables, however, will influence conductivity and must be calculated together to obtain an accurate value. Temperature and pH content and naturally occurring ion concentrations in the water are the most critical factors. (Lundin and Olli, 2017)

The pH of the nutrient solution - The pH of a solution measures its acidity or alkalinity. The pH scale ranges from 0 to 14, with 1 indicating a strongly acidic pH and 14 indicating a strongly alkaline pH, and 7 indicating a neutral pH, indicating that the concentrations of H+ and OH are similar. Changes in pH are highly non-linear, so any attempts to manage them should be made with caution to prevent instability (Lundin and Olli, 2017). The ions in solution and in chemical forms that plants can consume are essential in nutrient solutions, so plant productivity in hydroponic systems is closely linked to nutrient absorption and pH control (Trejo-Tellez and Gomez-Merino, 2012). In a hydroponic method, the pH of the nutrient solution should be kept within a specific range, which varies depending on the plant species grown. Nutrient absorption is disrupted if the pH falls outside of this range, slowing or even stopping plant growth. pH is regulated by adding acids and bases to water based on pH meter readings. The pH of the water would be affected by the addition of concentrated nutrient solutions (Elmér, 2020).

5.4.5. Sensors

5.4.5.1. Temperature sensor

The temperature regulates the growth rate of the plant. In general, chemical processes continue at faster rates as temperatures increase. In plants, most chemical processes are controlled by enzymes that perform best in a narrow range of temperatures. Over and below these temperature ranges, the enzyme activity begins to deteriorate, slowing down or stopping chemical processes. Plants will be stressed at this point; growth will be reduced, and the plant may eventually die. For quick and successful maturation, the temperature of the plant environment should be optimized. The temperature of air and water must be monitored. (Brechner and Both, 1996)

5.4.5.2. Water level sensor

Hall effect sensor is connected to the microcontroller. It is to be calibrated before measuring the flow rate. The water flow sensor can precisely measure the flow rate by the hall sensor for pulsing the water falling, and the microcontroller counts the number of pulses for measuring water flow (M. E. H. Chowdhury *et al.*, 2020). When there was fluid at the level of the sensor, the capacitive water level sensor read '0' continuously.

However, if the water evaporates or loses because of the consumption of the plants, the water level sensor releases "1" to trigger the fresh-water pump until freshwater is supplied from the reservoir, so that the pump does not have to frequently be turned on (M. E. H. Chowdhury *et al.*, 2020).

5.4.5.3. Electrical Conductivity sensor

Its electric conductivity is the basis for the concept used for measuring nutritional concentration in water. Naturally, pure water can conduct electricity, but very low, but the adding of charge particles can increase this capacity. The ions will conduct a current between them briefly when two electrodes are inserted in the solution. The nutrients required for growing plants have the same ability, and the concentration of nutrients can be measured by measuring the conductivity of the solution. This method can only measure and cannot separate all nutrients' conductivity (Lundin and Olli, 2017).

5.4.5.4. pH sensor

The potential electrical change from pH to the reference electrode is measured through the digital pH sensor. Usually, the electrode consists of glass. Analog and digital meters are available, and the latter has the advantage of using a data analysis computer interface. Temperature-sensitive digital pH meters may be possible. However, the majority of digital pH meters are equipped with Automated Temperature Compensation (ATC). Whether it is analog or digital, it is essential to calibrate the meter (Lundin and Olli, 2017). Because plants prefer a specific pH value to grow optimally, the pH value of the nutrient solution needs to be correctly read. Several factors affect pH; the pH is expected to decrease mainly by adding too many nutrients to the water reservoir (Lundin and Olli, 2017).

5.5. Crop Production Process

The production of lettuce can be categorized into three areas:

Germination Chamber - A germination chamber is a closed, warm, and humid cabinet where seed germination occurs. Germination is the growth of a plant within a seed resulting in seedling formation (Delouche, 1979). Providing an optimum environment for seed germination can improve uniformity, decrease the germination time and increase the number of seeds that germinate (*Seed Starting for Indoor Farmers: Propagation Chambers*, 2014).

Nursery **-** Once the seeds are sprouted, they are moved into the nursery. The main aim of this stage is to establish a healthy root system. the plants are now introduced to a diluted nutrient solution and lighting.

Hydroponic Trays **-** Once the plant grows 2 - 4 centimetres tall, they are shifted to the production unit or hydroponic grow trays to provide proper nutrition. Once the plant matures, it is harvested in this unit.

5.6. Design Calculations

5.6.1. Crop

Mini Romaine Lettuce
Average Size = 4 - 6 inches ≈ 0.20 m

5.6.2. External Structure

The structure is designed around the concept of 'one square meter', I.e., the system covers a floor space of one square meter. The external structure is a rectangle model with 5 units: a reservoir, a germination chamber, a nursery, a storage space, and a hydroponic grow space. The system is divided into five vertical parts of 40 cm each as a first phase. Lettuces grow to a height of 20 centimeters on average, and they require plenty of air circulation to thrive. As a result, 40 cm was considered after doubling the average height. The first four portions are utilized to grow hydroponically. The reservoir, storage, germination chamber, and nursery are all housed in the lowest part.

According to ISO 1006 building construction basic module (*ISO 1006: Building Construction - Modular Coordination*, 1983), the width of a standard slab is 0.6 m. Considering a structural allowance of 0.1m for accessibility,

Total width of the structure = 0.7 m

Now that the width and the area covered is fixed,

Length X breadth = area

Length = Area / breadth

= 1/.07
= 1.43 m = 1.5 m (convenient for construction)

Total length of the system = 1.5 m

According to ISO 1006 building construction basic module (*ISO 1006: Building Construction - Modular Coordination*, 1983), the standard height of an entrance (residential) is 2.1 m.

To serve the purpose of easy portability, the system height is taken as 2.0 m.

Total height of the structure = 2.0 m

System Dimensions = Length X Width X Height
= 1.5 m X 0.7 m X 2.0 m

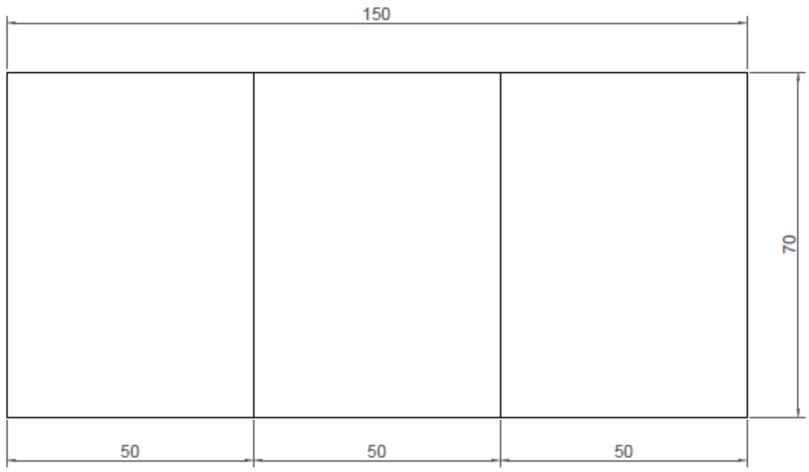

Fig 7: Top View – External Structure

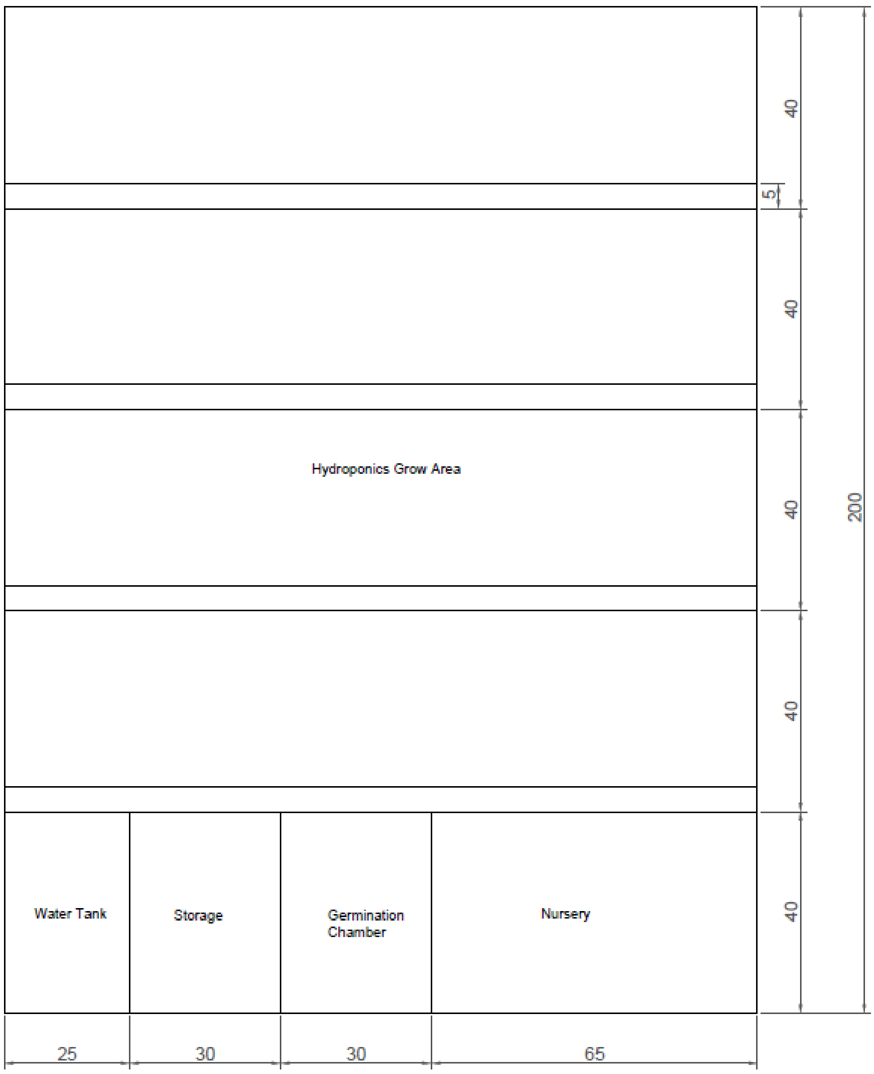

Fig 8: Front View – External Structure

Dimensions in cm

5.6.3. Hydroponic Grow Tray

The plants in a hydroponic grow unit grow and mature in trays until they are ready to be harvested. Hydroponic grow trays are trays with holes drilled in the top surface for placing grow pots. Grow pots are mesh-like support pots that hold the growing medium for the plant. The overall number of plants that can be harvested in the system is determined by the grow tray design. As a result, the grow tray design is the most essential factor in determining the system's productivity.

Total length of the system = 1.5 m, therefore, the length available to fit in grow trays will be 1.5 m. Based on my case study, the depth of the grow trays will be 0.05 m.

The product was created with a 'user-friendly' notion in mind. Because harvesting, washing, and transporting plants are all done by hand, trays must be more flexible. As a result, each layer is separated into three portions, and three separate trays are inserted. On each level, a fully loaded system will place 50 kg of weight, including water and fully grown plants. As a result, the weight must be distributed evenly and supported by the trusses below. As a result, this design is appropriate from both an engineering and an accessibility standpoint.

Therefore,
Dimension of one grow unit at one level will be

Length of the hydroponic grow unit = 1.50 m
Width of the hydroponic grow unit = 0.70 m
Depth of the hydroponic grow unit = 0.05 m

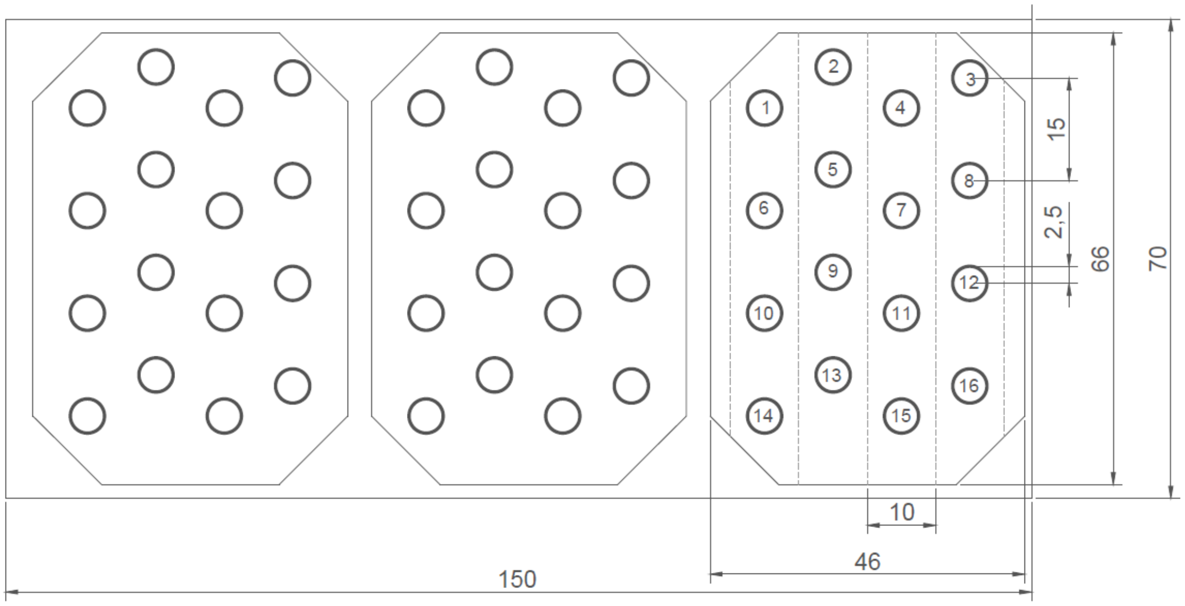

Fig 9: Grow tray detailed drawing

Dimensions in cm

Each level has 3 grow trays and dimensions of one grow tray will be

Length of the one grow tray = 0.66 m
Width of the one grow tray = 0.44 m
Depth of the one grow tray = 0.05 m

Each level can hold 48 plants, and in total the system can hold 192 plants.

5.6.4. Water Tank Design

As per (Barbosa *et al.*, 2015), one kilogram of lettuce requires 20±3.8 liters per year.

Considering the upper limit,
1 kg of lettuce per year consumes 23.82 liters of water.

Converting it into consumption per day,
(23.8 l/kg)/ (365 days) = 0.065 l/kg/day

Therefore,
Water consumption = 0.065 l/kg/day

5.6.4.1. Water required for the system

1 Grow tray consists of 16 plants and each level has 3 trays = 3 X 16 plants
= 48 plants

The system has 4 levels = 48 X 4 plants
= 192 plants

Therefore,
The system can hold 192 plants.

From my case study at ICA, each plant weighs approximately 200 g

Therefore,
Weight of 192 plants = 192 X 0.2 kg
= 38.4 kg

Considering factors like dried leaves, extra growth, and safety factors,
Total weight of plants is considered as 50 kg

Designing the tank for full capacity,
Water requirement for 50kg/day = (0.065 l/kg/day) X (50 kg/day)
= 3.25 l

Designing the tank for 7 days (1 week),
Capacity of water required = 3.25 l X 7
= 22.75 l

Considering the factor of safety of 2.0 and adding the submersible pump weight as 2 l (2kg),

Tank capacity = (22.75 l + 2 l) X 2.0
= 49.5 l ≈ 50 l

5.6.4.2. Tank dimensions

Height of the tank is confined as each level in the system is 0.4 m tall. Giving an allowance of 0.05 m for fitment,
Height of the tank = 0.35 m

Width of the tank is confined to 0.7 m as per the structure design. Giving an allowance of 0.05 m for fitment,
Width of the tank = 0.65 m

Length of the tank is to be determined

50 l = 0.05 cubic meters

Volume = Length X Width X Height

0.05 = Length X 0.65 m X 0.35 m

Length = $(0.05\ m^3) / (0.65\ m \times 0.35\ m)$
= 0.22 m
≈ 0.25 m (fitment)

Water Tank Dimensions = Length X Width X Height
= 0.25 m X 0. 65 m X 0.35 m

5.6.5. Germination, Storage and Nursery

Based on the harvest rate, the design of the germination chamber and nursery is calculated. The system is assumed to reap 6 complete trays at once. Therefore, for transferring from the nursery to hydroponics grow tray 96 plants must be accessible right after the harvest. In the remaining portion, extra storage is provided to store additional seeds, grow media and trays needed to run the system.

5.7. Specifications

Sl. no	Components	Material Used	Unit	Total Quantity	Cost per quantity (in SEK)	Total Cost (In SEK)
1.	External structure	Mild Steel	Kg	11	4,24	46,64
2.	Grow Tray	PVC	Numbers	12	25	300
3.	Connecting Pipes (water circulating pipes)	PVC	meters	10	15	150
4.	Plastic Capillary Tubes	Acrylic	meters	2	170	340
5.	Grow Pots	Plastic	Numbers	216	3,4	734,4
6.	LED Lights	Plastic	meters	17	26	442
7.	Grow media	Coco coir	numbers	324	1,688	546,912
8.	Germination trays	Plastic	Tray (each tray 72 plants)	4	40	160
9.	Seeds		Packs of 100	2	67	134
10.	Submersible Water Pump	Plastic	numbers	1	200	200
11.	Nutrient Solution		Kg	1	165	165
12.	Air Stone	Mineral stone and plastic	numbers	1	123	123
Total						**3341,952**

Table1: Component Specifications Table

The Specifications table takes into account the majority of the design considerations. Due to time constraints, some elements are omitted out of the design and specifications. The components in the table can be divided into two categories: one-time investments (with a longer lifespan) and elements that need to be replaced on a regular basis. External structure, grow tray, connecting pipes, capillary tubes, LED lights, germination trays, water pump, and air stone are all one-time investment parts. Seeds, nutrient solutions, and grow media all need to be restocked on a regular basis. The cost is only calculated for a single system. When the system is produced in large quantities, the price drops even more.

5.8. Structural Analysis

Structural analysis is significant because it establishes a foundation for structural design and determines if a particular structure can withstand external and internal loads and pressures. The structural analysis aids in the identification of the reason of a structural breakdown. The exterior structure is the major load carrier in the planned hydroponic system. A structural study was performed using the SolidWorks and Ansys softwares to determine the external structure's strength.

First, a 3-Dimensional drawing of the external structure was created. By choosing the thickness, 2-Dimensional AutoCAD models were utilized to generate them. The structure's strength is then assessed using Ansys software. The material in the 3D model is specified, as are the loads occurring on the system.

Each completely loaded hydroponic grow tray weighs in at around 50 kilos, which includes fully grown plants, full water capacity, grow media, and the tray's weight itself. This weight is converted into Newtons, i.e. force, and the model specifies the load acting directions and locations. Based on these, the software identifies the deformations and does a stress analysis. A color scale is used to depict the level of deformation in the stress analysis diagram. The colors blue and red are at opposite ends of the spectrum. The blue color denotes safe zones, while the red color denotes fracture zones.

5.8.1. Finite Element Analysis

Simulation
Analysis Type: Static
Material Used: Mild Steel
Pipe Cross section: 33 mm diameter, 4 mm thick
Total weight of the structure: 130 kg

Fig 10: 3D model of the external structure in Solid Works

Boundary conditions
Load acting at each level = 50 kg ≈ 500 N
Each level has three trays, so the load acting on each tray, and these trays are mounted on the rib provided in the frame, in each level there are 12 ribs
So, load acting on each rib = 500/12 = 42 N

As shown in the figure below,
- In ANSYS, a vertically downward force of 42 N is applied on each rib.
- Fixed supports are used for bottom face of each leg to constrain all degrees of freedom
- Entire structure is meshed using tetrahedral elements.
- Analysis was performed to predict the Von-Mises stress induced in the structure
- Induced stress was found to be 13.07 Mpa, which gives us a factor of safety of 19.23.

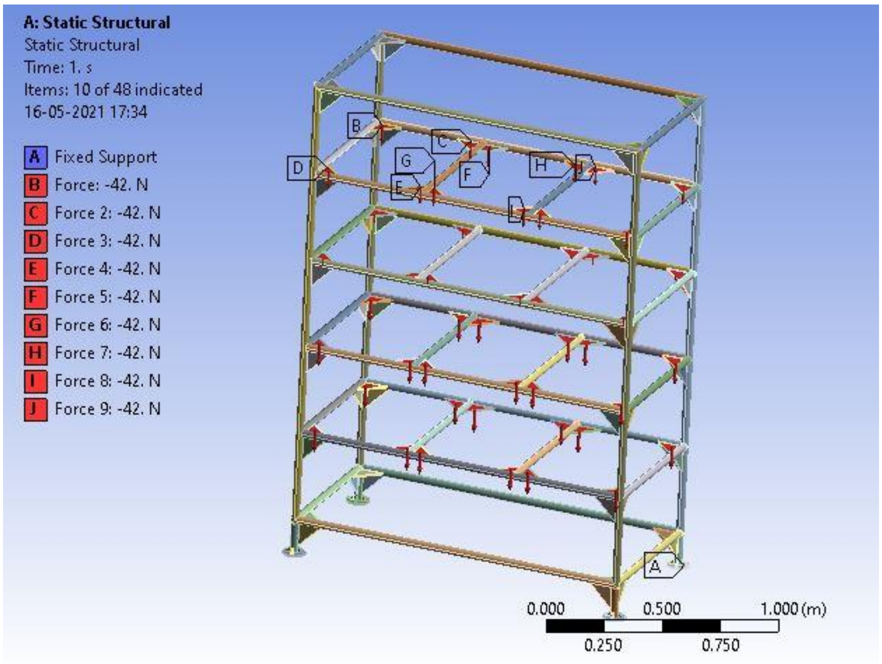

Fig 11: Load Analysis of the structure in ANSYS

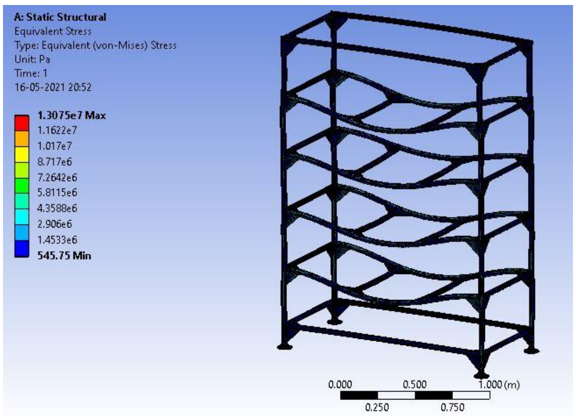

Fig 12: Stress Analysis Diagram

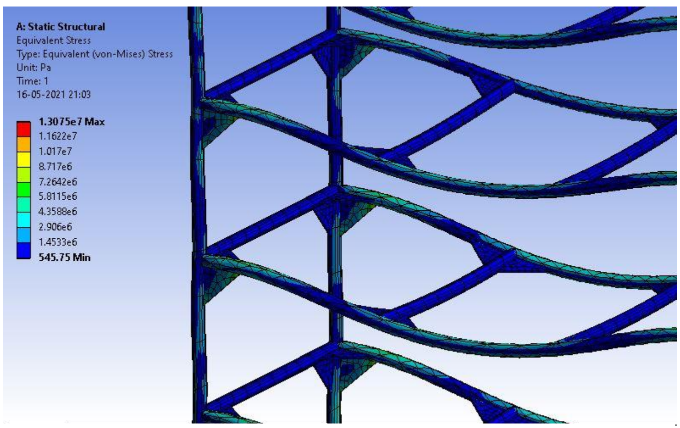

Fig 13: Close up view of the stress acting points

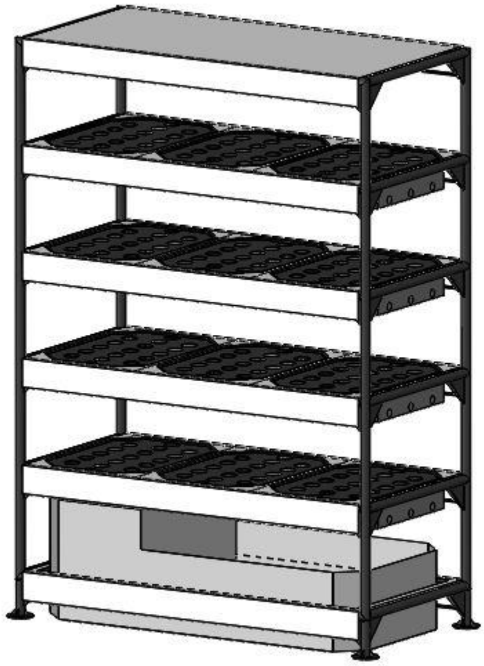

Fig 14: Assembly drawing

Fig 15: 3D Exploded view of the assembly drawing

5.9. Sustainability

The optimal utilization of local resources such as water and land are also essential for long-term sustainability. Vertical farms make better use of these resources than greenhouses and traditional farming methods (Naus, 2018). According to a recent study, the quantity of water consumed by traditional farming to produce 1kg of lettuce is equivalent to filling a large freezer. Greenhouses, on the other hand, use 92 percent less water to grow the same amount of lettuce (Barbosa et al, 2015), which is equivalent to a bucket's contents and vertical farms, a medium-sized pan (Graamans et al, 2018). The environmental, social and economic sustainability factors are assessed below for the designed system based on the business model value proposition.

Value	**Environmental**	**Economic**	**Social**
Reduced Water Usage	- No overfertilization of rivers - Reduced over usage of water resources	- Cost reduction	- Not compromising water resources
Improved productivity	- Reduced land use requirement	- Increased output per area - Increased scalability	- Better urban supply-demand balance - Increased urban employment
Local Produce	- Reduced transportation, hence reduced CO_2 emissions, air pollution, fuel usage and noise pollution	- Reduced supply chain, No unnecessary transport, packing, storage and repacking costs - Reduced waste - No additional distributors involved	- Availability of fresh produce - Improved nutritional value and product quality
Pesticide free	- Reduced soil degradation and other environmental impacts	- Reduced cost	- Increased consumer health
Yearlong produce	- Decreased off-seasonal imports - Prevented poor harvests from climate change	- Reduced market fluctuations - Easier economic forecasting	- Increased food security
No additional infrastructure	- Reduced land use - Reduced material usage and construction processes	- Reduced capital investment due to additional material, labor, construction costs	- Modularity of the product - Easy retrofitting and access,

Table 2: Environmental, Social and Economic sustainability assessment table

6. Results

6.1. Questionnaire

The majority of the study group were from Asia, which represented 51.8% followed by Europe with 41.2%. The other 4 demographics, namely North America, South America, Africa and Australia saw a smaller number of participants and there was a total of 85 participants. 87.1% of the study group knew that most of the food consumed in Sweden was imported and 12.9% did not know this. A majority of people had a prerequisite understanding of vertical farming and only a few people were unaware. A large denomination of the study group was unsure of buying vertically farmer products, about 38% were strongly affirmative and about 6% were strongly against the idea. The reasons for skepticism amongst the study group was mainly due to cost concerns and the procedural concerns of vertical farming. Most surveyees preferred to travel 3 kilometers for a cheaper and healthier option than pay high prices for the same at a nearby store. Also, for most of the study group cost was identified as a major factor while choosing a store for vegetables purchase and this, about 50% of the study group said they would prefer constant pricing over market fluctuations. Unlike the expected hypothesis l, the pandemic did not see a rise in the consumption of green Vegetables. Ultimately, people in majority prefer locally grown vegetables to imported produce and thus, vertical farming can prove to be a lucrative methodology.

6.2. Design Results

6.2.1. Hydroponic System Yield Calculation

According to my case study, the cycle takes 14 days to complete from the time plants are transferred to the hydroponic tray to the time they are harvested. Divide the growing cycle into 2 halves to keep the sequence and produce simultaneously throughout the year. Half of the system can be harvested, while the other half will be ready to harvest in 7 days, and the cycle will continue.

Given that the system harvests two levels every 7^{th} day,
1 level = 3 trays
1 tray = 16 plants
The system has 4 levels of grow area.
Therefore, total number of plants the system can hold = 16 X 3 X 4
= 192 plants
Two levels will hold = 192/2 = 96 plants
96 plants are harvested every 7th day. According to the market description, each plant will weigh roughly 200 grams. i.e 0.2 kg.

Yield per 7 days = 96 X 0.2 = 19.2 kg.
Yield per year = (365/7) X 19.2 = 1,001.142 kg
≈ 1,000 kg = 1 ton

As a result, in 1 square meter, the designed hydroponic system produces 1 ton of mini romaine lettuce in 1 year.

6.2.2. Water Consumption

1 kg of lettuce uses 23.82 liters of water per year, according to (Barbosa *et al.*, 2015). Using my yield

data, 1 ton of lettuce consumes approximately 24000 liters per year. Conventional farming, according to (Barbosa *et al.*, 2015), uses 275 liters of water each year to grow 1 kg of lettuce. As a result, if the lettuce were grown in the traditional way, it would use 275000 liters of water each year.

The system is thus designed to save 91,2% of water by growing 1 kg of leaf a year

6.2.3. Structural Analysis

The Von Mises stress reached a maximum value of 13.07 MPa. When a component made of a given material is loaded, the Von Mises stress reaches a value known as yield strength, the material begins to yield (Von Mises yield criterion, 2020). The measured value is lower than mild steel's yield strength of 250 MPa, giving a factor of safety of 19.2 indicating that no substantial deformations occur.

7. Discussion

This thesis aimed at designing and evaluating the environmental, economic and social aspects of a modular, integrated hydroponic system. The study was based on two main research questions. The important findings for each of them are explained and expanded upon in the following sections.

Case studies, surveys, contextual analysis, and data analysis from an economic, social, and environmental perspective were used to achieve the main aim of this study and answer the research questions. The case study and questionnaire results corroborated prior studies on the advantages of vertical farming, strengthening the case for vertical farming as a viable alternative to conventional farming. Environmental and social benefits were recognized for both the producer and other stakeholders, pointing to more sustainable farming methods. The hydroponic research and expertise gained from this frame of reference had a significant impact on the product's design. It helped translate the advantages of hydroponic cultivation into product features, modules, and design decisions.

The first research question guiding this paper was *"How can vertical farming be efficiently integrated into existing spaces to benefit both food markets and end-users?"*

As a result of this thesis, it was discovered that integrated models outperform current big and small-scale vertical farms in terms of investments, reaching a bigger audience, land utilization, and other factors. Today, there is a risk of vertical farms being matched by the low margin of the food industry so that it never becomes profitably enough. Where an industry sees unusually high margins, new entrants will likely emerge unless sufficient barriers are present. This is particularly the case in commodities, where companies operate at a low margin with high volumes and high commodity sales. When profit margins are unusually high or when technological moats are strong enough to keep competitors in check, the vertical farming industry will require further research and development. An integrated small farm is easier to manage and control, and it can respond to customer demand more rapidly. Temperature, humidity, pH, and CO2 concentration are primarily controlled via supervision technology, while crop health is physically monitored. This lowers the initial investment expenses and reduces the reliance on technology in operations. While a big farm relies more on its distribution network, in small farms, the challenge of matching demand with delivery times can be mitigated. Lower production also makes it easier to sell to the end client to prevent intermediaries directly. Since it is difficult for small farms to sell to retailers to become profitable, they are likely to sell to consumers directly. These customers may pay a higher price because they do not try and profit from a higher price than retailers. The removal of an intermediary that doubles or triples the buying price of the product could give small farms more profitable opportunities on the market. The integration solution's difficulty is to ensure that the benefits outweigh the high upfront costs. Finding someone skilled and competent to handle the farm for 20 hours a week is a struggle for many businesses. While an integrated farm succeeds in eliminating intermediaries and gaining a competitive advantage, it lacks the size and automation necessary to achieve economies of scale.

At present, production is restricted to high-value crops, such as leafy grasses and herbs. No player succeeded in profitably cultivating calorie-dense crops. Therefore, vertical farming is not the solution to all the food industry problems. It complements the greens and herbs that are imported. In theory, vertical farms can supply Sweden with the overall demand for green plants, which would reduce imported alternative crop production at the current state of technology. With imported greens exceeding SEK 4 billion, vertical farms can grow before competing with local suppliers. All alternatives to the greens imported would reduce carbon footprint, reduce traffic, improve forecasting, and provide healthier products for consumers, manufacturers, and suppliers.

The second research question guiding the study further was *"How can hydroponics system contribute to social, ecological, and economic sustainability?"*.

The study addressed 7 out of the seventeen Sustainable Development Goals

Goal 2: Zero Hunger

Goal 3: Good Health and Well-being

Goal 9: Industry, Innovation and Infrastructure
Goal 11: Sustainable Cities and Communities
Goal 12: Responsible Consumption and Production
Goal 13: Climate Action
Goal 15: Life on Land
These objectives were selected because they were closely related to the type of product being developed. The product vision and objective, which was to produce sustainably to boost urban food reliance, was directly linked to goals 2,3,9,11, and 12. Goals 13 and 15 dealt with the environmental impact that the community can have when the product is implemented.
The designed product's long-term viability from an environmental, social, and economic standpoint is explored below.

Environmental Sustainability

Vertical farming does not solve all environmental problems but can compete in many respects with traditional farming. (Despommier, 2010) believes that many existing environmental problems can be solved with the vertical farming. Vertical farms allow the use of emission-free resources that do not degrade ecosystem services, hence, can be more ecological and carbon footprint-intensive than farming today. To achieve the full environmental benefits of vertical farming, farms should strive to meet the principles of the circular economy of renewable energy, water looping, sustainable nutrient use and synthetic pesticides outlined by the (Ellen Macarthur Foundation, 2019). Water is an integral part of hydroponic systems; renewable energy is a prerequisite for sustainable cultivation of vertical farms. Moreover, because of a closed environment, pesticides are completely avoided.

Carbon Footprint - Vertical farming has a variety of advantages, one of which is the ability to install it in city centers, which leads to a variety of favorable effects. More local production becomes a vital aspect of the move to reinvent the food sector as cities grow. By decreasing transportation, local production is a critical step toward a more sustainable society. There is already a demand for local product, and it is in everyone's best interests to eliminate the non-value-adding segments in the food value chain (Dahlberg and Linden, 2019). Agriculture is nearly fully reliant on regular oil supply for cultivation and water pumping, as well as gas for fertilizer production. Five calories of energy are consumed for processing, storage, and distribution for every calorie utilized by agriculture (*Energy Expenditures Related to Food Production*, 2010). Energy consumption is one of the major limitations of vertical farming systems due to the need of artificial lighting, control systems, and water pumps, among other things. Sweden is thus a favorable country for vertical farming in terms of energy consumption, with large amounts of renewable energies and relatively low energy prices.

Water and Land Use - Vertical farming can reduce water consumption by up to 99% compared to conventional farming (Khokhar, 2017). The designed system circulates the water and provides the exact amount of water required by the plants, ensuring that no water escapes the premises, causing eutrophication in rivers or contaminating the local ecosystem. Arable lands are scarce, and the existing ecosystem often gets destroyed when new lands are found that favor food production. According to (Kalantari et al. 2017), depending on the crops grown and farm height, vertical farming can improve agricultural yield by up to 100 times. This reduces the need for additional farming and allows the natural ecology to recover. The designed hydroponic system, due to its modularity, can fit into small spaces just like any other appliance. This allows the customer to design the farm according to the space availability and yield requirement.

Reduced Food Waste - Food loss and waste is defined as a reduction in the amount or quality for human consumption of edible foods. Food waste and food loss are not the same. Food loss is primarily due to malfunctioning of the food supply and production system, or to its institutional and policy framework. Management and technological constraints, such as lack of proper storage facilities, cold chain, proper food handling practices, infrastructure, packaging or effective marketing systems, could have caused this. Whereas food waste means the removal of the food from the food supply chain which still remains fit for human consumption either by choice or after the food has been damaged or expired by misuse or negligence in stock management. (Rezaei and Liu, 2017) Food waste usually occurs at the retail and consumers level, but food loss occurs during production, post-harvest and processing stages at earlier stages of the food supply chain. The designed vertical farming hydroponic systems reduce the steps from the value chain and follows 'farm to shelf' method which helps cut down food waste and food losses.

Pesticides - The two ways pests are exposed to plants are from soil and the atmosphere. As the system does not use soil and is closed, bacteria and pests are kept away from the produce. The system is often only opened during the harvest and transfer period, the bacteria and dust entering through atmosphere is bare minimum. An extra layer of covering can be provided to avoid it further.

Resilience - Vertical farming provides benefits as crops can be stacked in layers and can be grown throughout the year. This omits the problems related to uncontrollable external factors like sudden weather changes, climate change adversities, seasonal changes and natural disasters. As soil is not used in hydroponics, crop rotation is also not required, hence crops can be produced simultaneously without any breaks yearlong.

Social Sustainability

Health - Indoor-grown crops have the potential to be more nutritious and healthier for humans to eat. Growing precision, increasing nutritional content, and harvesting at the pinnacle of the growing cycle are all possible because to the highly regulated growing conditions. Because of the enclosed enclosure, pesticide and herbicide use can be eliminated, resulting in a healthier, better-tasting produce. Because of the lack of transit, storage, and refrigeration, the product may be more nutritious. Greens that must ripen while in transportation are harvested early, preventing the crop from reaching its full nutritious potential. Nutrients can also degrade throughout the storage phase.

Local business and Safe Farming - Food production in city centers is projected to boost the area's economic growth (Specht et al., 2014). Moving production closer to customers can save transaction costs, improve collaboration, and create new jobs. In Europe, farmers are currently led by the older generation, and few young farmers desire to stay on their family farms and pursue a degree rather than move to the metropolis (European Commission, 2017). In the EU, less than 6% of farmers are under the age of 35, while over 31% are over 65, and young farmers are frequently restricted by land or financial access (ibid.). Hence, small modular vertical farms can provide young people with more opportunities to enter the field. By removing the need for heavy machines, vertical farms could be much safer than a conventional farm since their use is always a risky activity and high risks of damage are associated to these machines. Vertical farms have the challenge of creating easy-to-use equipment, which the designed system solves.

Economical Sustainability

Economic sustainability has been the constraint to the fact that vertical farming is not sooner successful, although there are obvious environmental and social benefits. The difficulty for vertical farms is overcoming costs like as capital investment, maintenance, and energy through a combination of increasing sales and lower expenses. Capital Investment - Vertical farms have high initial investments involved, especially on large scale, which require relatively longer repayment time. Smaller systems can be economical and accessible to a larger audience, and just not on a commercial scale.

Raw materials - The price of the land in urban centers, where conventional farms are situated, tends to be significantly greater than outside the city. Since the designed system is a closed small-scale modular system, the highest amount of investment is shared between the raw materials, energy and monitoring systems. The initial investment and maintenance costs are significantly reduced because the designed product does not involve any infrastructural cost or rent. The use of district heating to recycle heat produced during the growing process is another solution to reduce the energy costs. District heating technology is already well established in Sweden when excess heat is generated for households located next door by cooling ice rinks or public baths (Mattsson, 2019). The system is semi-automated and mainly sensor controlled, which reduces labor costs.

8. Conclusion

To sum up, integrated modular vertical farms are now better suited to societies where more people can participate and learn about sustainable food production systems. Space efficiency is increased when production is structured in vertical levels, and agricultural land is given the opportunity to heal and be replanted, resulting in societal advantages. Finally, this research resulted in a comprehensive supermarket design idea that incorporates both modularity and scalability as fully functional aspects, completing the thesis' scope.

9. Future Research

The design process focused on developing a modular, system design that meets the requirements of the identified customer segment, developing a scalable solution for the product and outlining its features. Manufacturing, assembly line, material, technical drawings, weight, pricing, and other issues were all regarded secondary during the design process, although they were not completely overlooked. Further exploration and analysis of these topics to make the design stronger is required at a production stage. More time, expertise, and research are also required to determine which business model is best for widespread vertical farming adoption. There are solutions for both household and commercial use for various range of customers, but they are not explored in this thesis. The development and distribution of such systems is simple and inexpensive but persuading people to grow their own greens is a difficulty. Their potential impact on reducing the demand for imported greens has yet to be properly examined, and customer acceptability is difficult to predict. Hydroponic systems for home usage are an alternate business model that could be explored further in the future.

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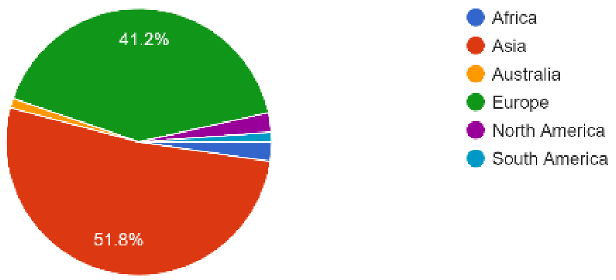
Appendices

Appendix I - Questionnaire result pie charts

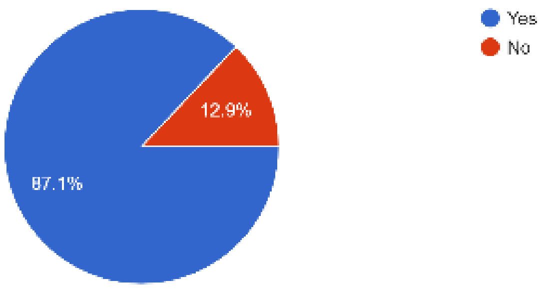
Which part of the world are you from?

85 responses



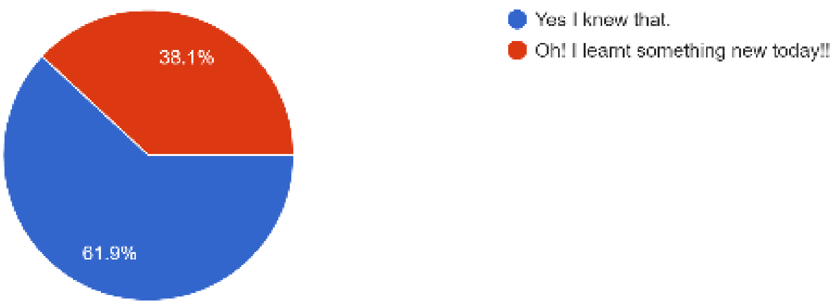
4. Are you aware that most of the food consumed in Sweden are imported?

85 responses



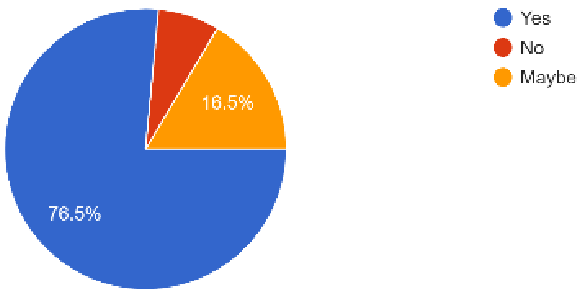
Vertical farming is the practice of growing crops in vertically stacked layers. It often incorporates controlled-environment agriculture, which aims to... such as hydroponics, aquaponics, and aeroponics

84 responses



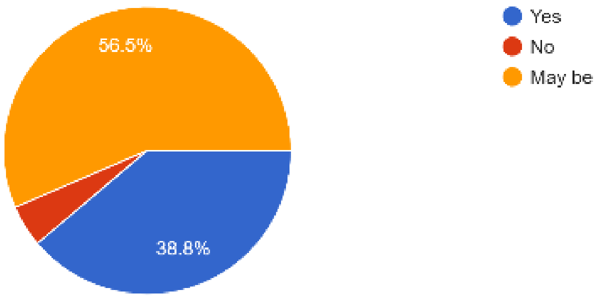
Is the cost factor affecting your food preferences?

85 responses



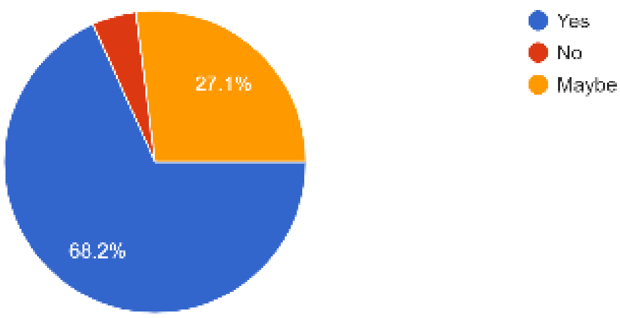
Would you prefer to buy a vertically farmed product?

85 responses



Would you prefer more locally grown food within Uppsala county ??

85 responses



Appendix II – Types of grow media

1. Media derived from rock or stone
Vermiculite Vermiculite is a mineral that has been extracted from mined mica. It appears to be very light and spongy, but different grades of vermiculite have varying weights. This mineral is excellent at retaining air, water, and nutrients, making it suitable for hydroponics. The pH of vermiculite is occasionally slightly acidic or slightly alkaline, but it does not affect the growth. To achieve the best results, vermiculite must be combined with other media. Even though it can hold a lot of air, it can also hold a lot of water for many plants.
Perlite Perlite is a processed mineral, similar to vermiculite. It is less spongy and better drained than vermiculite and has excellent water-holding properties. A silicaceous volcanic rock is used to make perlite. Perlite is often used alone or in a 50/50 blend with vermiculite. Perlite may be slightly acidic or neutral. It has a low pH buffering capability and no capacity for cation exchange. Although this does not affect the plants, it can clog pipes and other components in a recirculating system.
Sand Sands that are granitic or silica-type should be used. Calcareous sands are extremely alkaline, making them inhospitable for plant growth. Because of the high salt content, beach sand is not suitable. When bought, some sands contain a lot of dust or other fine material, which must be washed out before use. The best sand is coarse granitic sand, which is used by nurserymen to propagate plants and in fish aquariums. Sand, on its own, would necessitate a regular, if not continuous, flow of irrigation to keep the plants alive.
Gravel Gravel is similar to sand, with the exception of particle size. Gravel particles range in size from 2 to 15 mm, while sand particles are smaller but still gritty. Gravel cannot retain water as well as sand.
Pumice It is somewhat similar to perlite in terms of properties, but it is thicker and does not absorb water as readily. To make a hydroponic medium, pumice is often combined with peat and sand.
Rockwool Horticultural rockwool comes in loose fiber or preformed slabs in a variety of shapes and depths. Since rockwool slabs are more than 90% air, they can carry a lot of water while maintaining a high degree of aeration. Rockwool is one of the most common and widely used media in commercial hydroponics because of this property.
2. Synthetic Media
Sponge foams In certain parts of the world, sponge-like materials are increasingly being used for propagation (cuttings). Hydroponic culture has successfully used the same materials. They are usually expensive.
Expanded plastics These are inert materials and are relatively low priced. They have a hard time retaining moisture or nutrients. They're very light, and when combined with other materials, they tend to separate to the top and they give almost no support to the crop.
3. Organic Media
Sawdust Before using, hardwood sawdust should be composted. Since certain softwood sawdust contains highly toxic chemicals, it should never be used. If sawdust is not composted first, it will decompose while the crop is growing, and the bacteria will draw nitrogen from the nutrient solution during this period, leaving insufficient nitrogen for the plants.
Peat Moss In cool temperate climates, peat moss is taken from swampy ground. It is made up of partly decomposed plant remains (mostly mosses and sedges). Although the basic characteristics of peat differ from deposit to deposit, the following generalizations can be made. It has high water-holding capacity, it is always acidic and have high pH buffering capacity.
Coco Peat/ Coco coir Coir fiber has quickly gained popularity as a high-quality hydroponic growing medium, and it's now available in a variety of forms, including propagation cubes, blocks, and slabs that look like rockwool, as well as a loose, granular product. Water-holding capacity and air-filled porosity is high in coco-peat and it keeps it shape over time. It can be used for several years.

Appendix III – AutoCAD 2D model

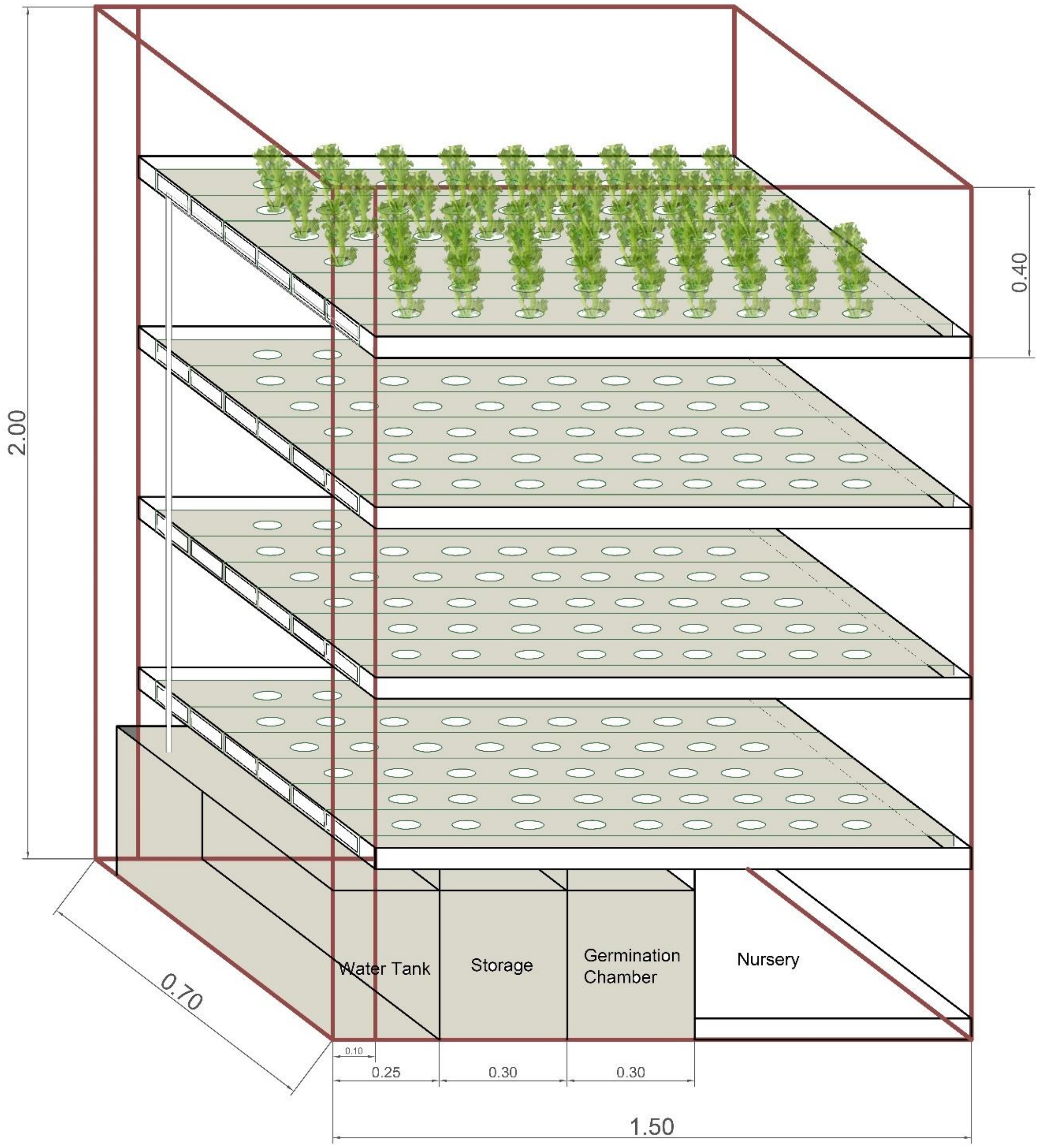
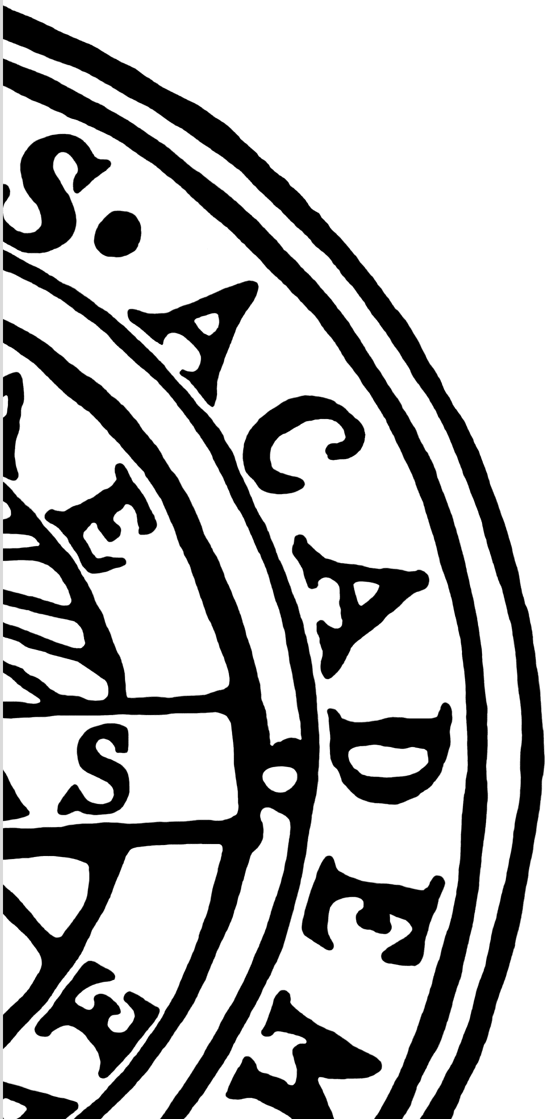


Figure: AutoCAD 2D model of the designed system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