Vertical Farming Applications:

Kali's Hanging Garden

Interdisciplinary Project-16: Vertical Farming
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I. PROBLEM STATEMENT (MD S. HAQUE, M. SURESH, R. BASRI)

Traditional farming methods are still the most widely practiced in the world today due to their low costs and the creation of job opportunities (Miller 2016). However, they are not sustainable and have several disadvantages. The most important issue with traditional farming is its inability to keep up with the growing population. The world population is expected to reach 9.7 billion by 2050, which will cause global food demands to double (United Nations 2019). Industrial development and urbanization have made enormous amounts of arable land unavailable. As of 2015, 33% of the world's arable land was declared unusable because of erosion and pollution (Grantham Centre 2015). The rapidly increasing population and the reducing available arable land makes it unlikely for traditional farming to be able to meet the world food requirements in the coming years. Some other problems of traditional farming include the damage they cause to the environment. Their use of fertilisers and pesticides causes water pollution when they contact lakes and rivers through soil erosion or runoff (NDSU 2017). These chemicals also make the product harmful for consumption. The farms are often located far away from the consumers because the food needs to be transported over long distances causing the emission of greenhouse gases. Traditional farming also causes water wastage as lots of the water gets evaporated or descends into the ground before the plants can absorb it. These drawbacks of traditional farming make it crucial to develop more efficient food production methods.

Vertical farming is considered a potential solution to these issues due to its many advantages over traditional farming. Their main advantages include high space and water efficiency. They also do not require pesticides due to their use of controlled environments.

However, vertical farming is not a perfect solution and has some challenges. The main drawback of vertical farms is that they are expensive to set up and maintain. Their requirement of complex structures and equipment such as LED lights and water pumps contribute to their high initial cost. Vertical farms' dependence on technology increases their energy costs which can contribute up to 50% of the total operational costs (Piechowiak, n.d.). Their other issues include the limited variety of crops grown in vertical farms and high energy consumption.

II. LITERATURE REVIEW

Overview of vertical farming (M. Suresh)

History of Vertical Farming

Vertical farming is not a new concept and has existed in various forms over thousands of years. Some of the earliest known forms of vertical farms include the "Hanging Gardens of

Babylon” from around 600 BC and the floating gardens of Aztecs from 1150 AD. The modern form of vertical farms began to develop in the 20th century, with the term “vertical farming” first being coined in 1915. The 1940s saw the first large-scale use of hydroponic systems to grow food in modern times, accompanied by several propositions throughout the 20th century of how vertical farming could be accomplished. The first modern vertical farm was built in 2009 by Sky Green Farms. Their facility, located in Singapore, contained more than a hundred towers that used rainwater and sunlight. Aerofarms’ vertical farm followed this in the USA, built in a 6500 square meter facility that used an aeroponics system and LED lighting. (Crumpacker 2018) (Piechowiak, n.d.)

Types of Vertical Farms

Modern vertical farms can be classified based on the technique they use, which can be either hydroponics, aeroponics, or aquaponics.

Hydroponics is the most common technique used in vertical farming. It involves the growing of plants without the use of any soil. Materials such as gravel and sand are used instead as substitutes for growing mediums for the plants. The plants’ roots are submerged in a liquid solution containing the required nutrients. Some of the nutrients contained in the solutions include calcium, nitrate, potassium sulfate, along with micronutrients such as boron, chlorine, and iron.

Aeroponics, like hydroponics, is a soil-less system in which the plants’ roots are suspended in air and sprayed with a nutrient solution in the form of mist. Aeroponic systems are highly water-efficient and use 90% less water than a hydroponic system, and require 60% fewer fertilizers while increasing the yield by 45 to 75% (Gupta and Ganapuram 2019). NASA used an aeroponics-based system in its attempts to grow plants in space (NASA 2007). A drawback of this system is its high energy consumption to operate the sprayers.

Aquaponics is a combination of aquaculture, the farming of fish, and hydroponics. In these systems, water is circulated between a hydroponic system and a fish tank. When the water is transferred from the fish tank to the plants’ grow tray, it contains organic wastes produced by the fish, making it rich in ammonia. Bacteria present in the grow bed of the plants then convert this ammonia into plant nutrients. Once the solid wastes have been dissolved and absorbed by the plants, the purified water is then returned to the fish tank (Gupta and Ganapuram 2019). This way, the system reduces the costs of nutrient solutions for the plants while purifying the fish tank water with minimum wastage.

Vertical farms can be further classified based on the structures they are built-in.

Building-based vertical farms are those that are built-in old or abandoned buildings. ‘The Plant’ is a building-based farm located in the USA that uses an 87-year-old former meatpacking factory to house its vertical farm along with other setups. It uses an aquaponic system built across a 2800 square meter area and produces mushrooms and other plants (Vinnitskaya 2012).

Shipping container vertical farms use 12-meter long shipping containers, which are modified to house the farms. The containers are equipped with hydroponic or aeroponic setups and LED lighting and are often used to grow crops like leafy greens, mushrooms, and strawberries. Freight Farms, Farm Box Foods, and Drop & Grow specialize in the refurbishing of shipping containers by setting up the hardware and software required to facilitate vertical farms (Discover Containers 2021).

Case Studies (Md S. Haque, R. Basri, 2022)

AeroFarms Since its founding in 2004, AeroFarms has received over $130 million in funding, making it one of the most well-known vertical farming enterprises. The firm uses its unique aeroponic technology, which allows for more accuracy and production while posing no damage to the environment. AeroFarms, based in New Jersey, claims that its methods utilize 95 percent less water than traditional arable farming (Murray, 2020).

In its farms, AeroFarms uses aeroponic technology. Aeroponics, unlike hydroponics, uses a closed-loop system to spray nutrients, water, and oxygen to the roots of the greens. The growing cloth medium comprises post-consumer recycled plastic that is BPA-free (Murray, 2020).

Microgreens from AeroFarms have a greater nutritional density than their mature greens counterparts, making them an effective method to boost vitamins, minerals, and phytonutrients. In July 2021, the firm announced the addition of five different leafy greens to its range: Baby Bok Choy, New Zealand Spinach, Micro Arugula, Micro Broccoli, Micro Kale, and Micro Rainbow (AeroFarms - Wikipedia, 2021).

Agricool AgriCool has been using aeroponic technologies to grow fruit and vegetables in the French capital, Paris, since its inception in 2015. It provides strawberries, coriander, parsley, basil, and lettuce and has garnered over $40 million in investments. Through its "Cooltivator" technology, the company, which exclusively utilizes renewable energy, has established urban farms by enabling individuals to cultivate their fruit and vegetables using the software. This software is an additional service for drugstores. (Murray, 2020).

In marine containers modified into a space dedicated to producing fruits and vegetables, Agricool now grows strawberries right in the city. Cooltainer strawberries, according to Agricool, contain 20% more sugar and 30% more vitamin C than conventional retail strawberries, thanks in part to the fact that they are collected when perfectly ripe and transported only a short distance from harvest to store. The declared goal of Agricool is to grow vast quantities of healthy, pesticide-free fruits and vegetables in the city and make them available widely at a reasonable price. The enterprise can produce 7 tons of strawberries yearly (AeroFarms - Wikipedia, 2021).

CropOne is situated in Dubai, inked a $40 million agreement with Emirates Airlines in 2018 to create the world's largest vertical farming operation. Through its hydroponic technique, the firm, launched in 2011, promises to utilize only 1% of the water required for arable cultivation (Murray, 2020).

They aim to develop innovative methods to feed the globe by transforming the multibillion-dollar global leafy greens market via innovation. Customers may enjoy healthful, tasty food they can feel good about delivering fresh to their local supermarket or favoured pickup location within 24 hours through their retail brand FreshBox Farms. They utilize up to 95% less water than conventionally cultivated crops. In addition, for all their goods, they utilize 100 percent post-consumer recycled packaging that is 100 percent recyclable (Why Crop One — Crop One, 2022).

Bowery Farming has raised more than $140 million in funding since its launch in 2015, making it one of the fastest-growing start-ups in the industry. In its operations, the New York-based firm, which serves multiple restaurants, employs no pesticides and non-genetically modified seeds. Bowery Farming boasts that its methods utilize 95 percent less water and are 100 times more productive on the same land as traditional agriculture (Murray, 2020).

Bowery is the largest vertical farming company in the United States, with produce harvested year-round at peak freshness and delivered within days of harvest to more than 850 grocery stores in the Northeast and Mid-Atlantic regions, including Albertsons Companies (Safeway and Acme), Amazon Fresh, Giant Food, Walmart, Weis, Whole Foods Market, and specialty. Grocers. Bowery Farming is based in Kearny, New Jersey, and maintains three commercial farms and two research and development sites. It employs patented technologies and vertical farming techniques to grow its food within industrial buildings in New Jersey, Pennsylvania, and Maryland, with no pesticides and a low water impact (Bowery Farming, 2022).

III. METHODOLOGY (J.CHEN)

This research paper explains creating a vertical farming system prototype with an emphasis on sustainability and modularity by Rhein-Waal University of Applied Sciences students. Extensive research first began in the planning phase to gather information from all available contemporary VF systems to determine, as preliminaries, the most suitable combination of techniques that would yield the highest saving of water and energy allowed within the test environment. Secondary quantitative data were collected from existing studies that demonstrated the effectiveness of VF systems superior to traditional farming methods, followed by a more focused approach to examine data in the local vicinity of the experiment, the North-Rhine Westphalia region of Germany. Water quality, climate change factors, and energy costs were assessed during this stage.

The physical aspect of the experimentation was prefaced by the drafting of two competing hydroponic system-based ideas formed by students split into the respective groups. Internal discussions continued through the design process from early concepts to the final matured design each group presented. These discussions included all individuals from both groups ranking each of the designs through various factors ranging from energy-saving potential, spatial utilization, durability, modularity, and ease of maintenance and harvest. Ethical considerations were made in the designing process to ensure the goal of an efficient and clean production environment and safety of workspace for the non-automated aspect of the Vertical Farm where human interaction is required to harvest the yield, such as having enough space to maneuver while in these interactions. The result of this is the convergence of the two design concepts into the basis of one engineering prototype, where the outline of each VF module is taken from the first concept in the form of a 'pyramid-like' shape while integrating the modularity of the second 'box' shape design that allows the vertical expansion of each system in the form of stacking layers of aluminum profiles with attached plant holders to the desired height that maximizes the spatial utilization within the limits of the closed environment.

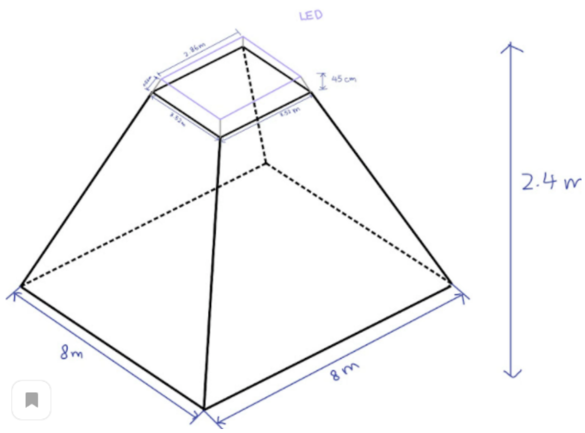

Figure 1: pyramid concept

Figure 2: Modular box concept

Once the overall design has been agreed upon, a data-collecting effort was made to gather all existing information for running a sustainable

VF within the allocated test environment. The variables included material costs of seeds, aluminum profiles, power costs for running LED lights and water pumps, all according to the real-time price in the test region (North Rhine-Westphalia), which led to the closest reliable estimation possible both the yield and total operational costs. As a result, after running through a series of physics-oriented calculations revolved around the production yield, energy consumption of LED lights and pumps, which outliers such as the density of fluid being of the nutrient solution being substituted with density of water, the total yield (468 plants/year) vs energy expenditure per constellation (379 kWh/year lights+ pumps) was obtained. Then the constellations of the VF system within the 300m³ test environment were planned. This was done in order to compare vertical farming prototypes. At the same time, the final hardware was being designed on CAD, adhering to the criteria of maximizing the use of space to produce the highest yield to cover the operational costs and materialize a return on investment to justify its real-world use case.

We found it productive to work in groups according to each member's ability to specialize; thus, the work on assembling the final VF system prototype was conducted in three groups, each covering a different area from configuring the code and sensors for automation to planting seeds to the assembly of the hardware frames and tubing. In the end, this ensured the successful assembly of the closed-loop hydroponic VF prototype with a degree of modularity, fully up and running. In reflection, it was clear that the collective effort made was able to arrive at this point through the sheer volume of internal discussion and communication every step of the way. The team was able to overcome the obstacles of lack of information and direction at periods due to the nature of this new field of agricultural technology that precise information was not always readily available for research; thus, quick decisions had to be made regarding changes to design elements, where adequate compromises were made after internal debates.

IV. IMPLEMENTATION: CONSTRUCTION, ELECTRONICS, AND CODE (Ö.Ö.ÜNGÜDER & M. ABDULLAH)

The implementation of the project can be divided into two parts. One part is the construction of the constellation itself and the germination of plants. The second part is constructing the control system using different sensors, microcontrollers, and code for it all to work.

Part I: The Constellation

Workshops

At the beginning of the project, various workshops were held which helped design the final construction of the constellation.

Construction

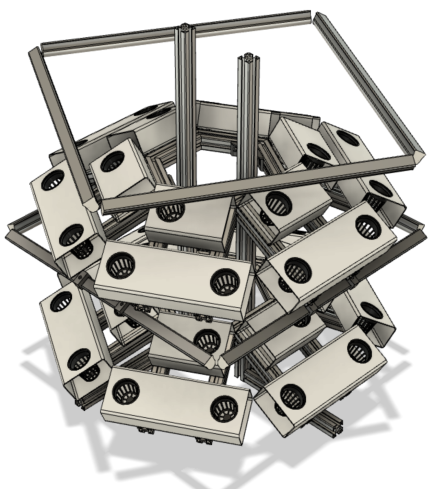

Figure 3: Vertical Farming Model of Kali's Hanging Garden.

The construction in the vertical farming unit is determined after workshops, discussions, and calculations. At the initial phase of the project, two different approaches in the construction are designed and evaluated in terms of yield per volume, water and energy consumption, realization, and maintenance. Then the third and the latest alternative is designed covering the best properties of the initial two design alternatives. The main target in the latest design is to create a construction that can benefit from sunlight and therefore consumes less energy. Extruded aluminum profiles are chosen as the primary construction material since they are lightweight, easy-to-cut, and easy to assemble. Connection elements are both ordered and produced using 3D printers. Two straight profiles are used as the pillars of the system. Two short profiles are assembled to the bottom of each pillar to support the system and provide a solid standing of the VF unit. Then hexagonal support units are assembled by connecting Al profiles with 3D printed surface brackets, T-nuts, and screws. Each support unit is then connected to the pillars. After assembling the pillars and the hexagonal support units, the holders for the plastic boxes for the plants are connected to the main structure.

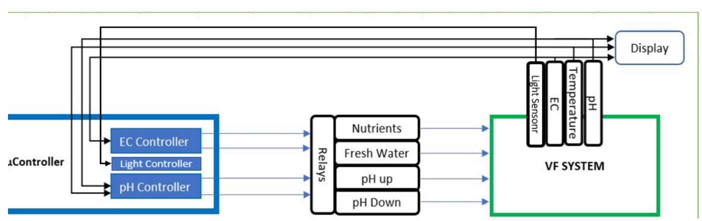

Figure 4: The control system of Kali's Hanging Garden.

Germination

After the workshops and the discussions, it was decided to use the iceberg lettuce seeds. The first step of the cultivation process in the vertical farming system is to germinate the seeds. To germinate the iceberg lettuce seeds, prepared seedling pellets are used as the substrate. A seed is inserted into a pellet, and then a nutrient solution is poured into each pellet so that the required humidity and the nutrients for germination are provided. The nutrient solution is prepared by mixing different types of liquid fertilizers according to the suggested amounts of each component which are optimum for the iceberg lettuce.

Part II: The Electronics and Code

The control system that was constructed for the system consists of an Arduino Mega 2560 microcontroller and, with it, some sensors. Namely, a pH sensor, an electrical conductivity sensor, multiple phototransistors, and a temperature sensor. An I2C LCD display was used to display the most relevant growing parameters, namely, temperature, pH value, electrical conductivity, and the luminance value of the system. A relay was used with pumps to pump nutrients to the system. An Analog to Digital converter was used to accommodate multiple phototransistors. In the early stages of development, LED lights were used instead of the relay and pump to debug the code with ease. Below is an overview of the whole system.

The Sensors

pH Sensor

pH Sensor measures the pH of the nutrient solution in the vertical farming system. pH Sensor consists of two main components. The first one is the main circuit, and the second component is the probe. The main circuit supplies voltage to the electrode inside the probe so that the gel layer is charged with negative ions. This negatively charged gel layer attracts the positively charged hydrogen ions in the solution. Depending on the number of hydrogen ions in the solution, voltage difference occurs in the system. That voltage difference is amplified and provided by the main circuit so that the Arduino microcontroller can read and process it. In the project, three reference solutions calibrate the pH sensor, an acidic solution with pH 4, an alkaline solution with pH 9, and a neutral solution with pH 7. After getting samples from each solution, the voltage-pH graph of the sensor is drawn, and the line equation is determined. Since the pH value of the solution is critical for the plants, the pH range for optimum growth condition is checked by the microcontroller by setting lower and higher thresholds for the pH Values. If the pH value is outside that range, the microcontroller makes the required adjustment in pH value by controlling the pumps related to the pH adjustment.

Temperature Sensor

In the control system, a 1-Wire type Digital Thermometer is used to measure the solution temperature. This sensor consists of a temperature sensor and memory components. The analog sensor in the digital thermometer reads the temperature, and analog to digital conversion is performed in the sensor. Then the converted result is transmitted bit by bit. Since the thermometer is digital, the digital input pins in the microcontroller are chosen for the connection. Two external libraries are implemented in the code to obtain the temperature results.

EC Sensor

The electrical conductivity sensor, or the EC sensor, is used to measure electrical conductivity. The EC sensor kit contains an analog electric conductivity meter board, an electrical conductivity probe, and two buffer solutions. One has very high conductivity, and the other solution has low conductivity. If described, the EC sensor works by passing current at a specific frequency in the solution and measuring the number of ions present. More ions present means higher electrical conductivity. The EC sensor used in our system outputs an analog value which can be converted to the actual conductivity value using the library provided by the EC sensor manufacturer. The library can also be used to calibrate the sensor before using it using the included buffer solutions. It is done by running a command in the serial monitor of Arduino IDE, which is included in the library, and by dipping the probe into one of the solutions first then the other. The program calibrates the sensor automatically. Electrical conductivity is dependent on the temperature of the solution. So, the value obtained from the temperature sensor is used here to calibrate the sensor also and adequately in test solutions. The electrical conductivity of the solution corresponds to the amount of nutrients present in the water solution of the vertical farm. Based on a conductivity value, it is possible to turn on a pump to pump nutrients to the solution. When it reaches a particular conductivity value, it can be turned off.

Phototransistors

A phototransistor is a semiconductor device that has a light-sensitive base region. When light hits the base of the phototransistor, it induces a little current which then gets amplified. The current generated by the phototransistor is proportional to the luminance. So, the more light it gets, the more current it outputs. A microcontroller like an Arduino measures this output current to measure the luminance of the vertical farming system. An example case can be described as such. If there is not enough sunlight available for the plants, the LEDs can be turned on or vice versa.

Analog to Digital Converter

Analog to Digital Converter converts analog signals to digital signals. In short, it is called an ADC. ADCs can have multiple use cases. They can increase the number of analog inputs of a microcontroller or increase the precision of the data received from analog devices. Some microcontrollers don’t include any analog ports. In that case, ADCs can include using analog devices with the microcontroller. Multiple ADCs can also scale up the number of analog inputs in a microcontroller. In our system, we connected all the phototransistors to an ADC, so it frees up all the other analog ports in the Arduino.

The Code

The microcontroller we are using in our project is an Arduino Mega 2560. The code was written in Arduino Programming Language using Arduino Integrated Development Environment (IDE).

These are the libraries used in code available in the official Arduino repository.

- OneWire - For the temperature sensor and the EC sensor
- EEPROM - For the EC Sensor
- DallasTemperature - For the temperature sensor
- Wire - For the LCD Display
- LiquidCrystal_I2C - For the LCD Display
- Adafruit_ADS1X15 - For the ADC

A custom library made by the EC Sensor manufacturer DFRobot_EC was also used.

After importing all the libraries, pins for different sensors and LEDs were defined, and variables to store data from the sensors were initialized. Then the thresholds for different actions were set, for example, pH sensor threshold, when the pump should start pumping acidic or base solution, EC sensor threshold to determine when to pump nutrients, etc. Then the LCD display and the needed objects to use the temperature sensor were initialized. An array to store sample data from the pH sensor and a calibration offset variable for the pH sensor was created.

Then in the setup method required to run Arduino codes, different processes to use the sensors were started, for example, the ADC, temperature sensor, LCD, etc. The LEDs were also initialized here.

Then the method loop starts where sensor data are retrieved, and based on that data; actions are taken. Firstly, the LCD display is started. Then the data from all the photoresistors connected to the ADC are taken, averaged, stored, and then shown in the LCD display. The data from the pH sensor is sampled and stored in the array, and averaged. Then using the formula described in the pH sensor manufacturer's website, the proper pH value is calculated.

After that, the temperature value is retrieved and stored using the same method used for all OneWire devices as the temperature sensor used here is a OneWire device.

The electrical conductivity is measured next by the EC sensor. Using the manufacturer's custom library and formula, it is calculated and stored.

Then all the values retrieved are displayed on the LCD display.

In the next section of the code, depending on the value retrieved from the pH sensor, EC sensor, and the phototransistors, actions are taken. Depending on the pH value, the pump for the acid or base is turned on or off if it reaches the set threshold. The same goes for the EC sensor value. If conductivity is low, the pump is turned on, then turned off when it reaches the threshold. The LEDs also turn on if the luminosity is low and turn off if it gets high.

V. POTENTIAL (K. GAURI, L. SKAF)

Vertical farming is a significant step towards a more sustainable agricultural sector. Vertical farms are based on a controlled environment (temperature, light, pH, fertilizers..etc.). Hence, pesticides are not required, resulting in healthier crops (Eden Green Technology, 2021). A tremendous initial boost of venture capital is required to maintain a controlled environment. Once the constellation runs, a stable income from food production will be sustained. Feeding highly dense urbanized areas will be profitable because all the fuel price fluctuations' concerns about shipping food are gone. Thus, vertical farms can save on transportation costs since they are closer to consumers (Mehlhouse, 2021). Vertical farming helps with climate adaptation by providing various controlled environments to produce food efficiently rather than preventing damage in traditional farms. Yields in vertical farms can grow up to 20 times more while using only 8% of the water usually used in traditional agricultural fields (Vyas, 2021). Additionally, vertical farming prevents arable land exploitation leading to a reduction in total ecological footprint. Bearing all that in mind, vertical farms have great potential to achieve economic, environmental, and social sustainability.

Lettuce has a growth cycle of approximately six weeks in a hydroponic system (sown in typically post-germination) (M. Eck et al.Water, 2021). This system requires a continuous flow of water of 6L/min (B. Baiyin et al. Horticulturae, 2021). This is the case typically for leafy green vegetables (B. Baiyin et al. Horticulturae, 2021)

Table 1:Yield calculation

Number of plants per module	= 18 plants (as seen in figure 3)
Number of modules per constellation column	= 3 modules
Total number of plants per constellation column	= 18 plants x 3 modules = 54 plants per growth cycle.
Yield per year	$= 54 \frac{plants}{week} \times 52 \frac{weeks}{year}$ $= 468 \frac{plants}{year}$

The energy required to pump water (JUWEL Ecco flow pumps)

The vertical farming constellations are assumed to be in a space that is. The water is pumped using the JUWEL Ecco flow pump, which can pump 1000L/h, 6.5 W, and reach a maximum height of 1.6m.

Table 2: The energy required to pump water

Total head	= 3.0 m (Height of the room)
Number of Pumps required	= Total head / Maximum height of the pump = 3m/1.5m = 2 pumps
Amount of water required by the system per week	$= 6\frac{L}{min} \times 60\frac{min}{h} \times 24\frac{h}{day}$ $= 8640\frac{L}{day} \times 7\frac{days}{week}$ $= 60480\frac{L}{week}$
Number of hours water is pumped	$=60480\frac{L}{week} \div 1000\frac{L}{h}$ $= 60.48\frac{h}{week}$
The energy required to pump the water	Pump's Energy Usage x Duration x Number of Pumps $= 6.5W \times 60.48\frac{h}{week} \times 2$ $= 786.24\frac{Wh}{week} \times 52\frac{weeks}{year}$ $= 40.884\frac{kWh}{year}$

From the calculation above, we deduce that around 40.8 kWh of energy is required to pump water into a constellation column (3 modules on top of each other) in *Kali's Hanging Garden*.

The energy required for LED system (PFLANZENLEUCHTEPAKET - T5-INTEG40-2)

Lettuce requires approximately 12 hours of sunlight for optimal growth. And in Germany, there are approximately 130 full days of sunlight in a year (Selunin, 2022).

The LED device used has an energy consumption of 10 W per LED strip.

Table 3: The energy consumption of LED system

Number of LED strips required in a constellation column	= 4 LED strips per module x 3 modules = 12 LED strips
Number of hours the LED is required per year	=365 days - Number of days without full sunny days = 365 days – 130 days = 235 days x 12 hours/day = 2820 hours per year
Electricity consumption in a year	= Electricity consumption x number of hours used 10 W x 2820 hours = 28.2kWh
Total consumption	= 12 LEDs x 28.2 kWh = 338.4kWh

From the calculation above, we deduce that around 338.4 kWh of energy is required to power the LED system in one constellation column (3 modules on top of each other) in *Kali's Hanging Garden*.

Table 4: Calculated yield vs. energy consumption

Yield	468 plants/year
Energy Required: LED System	338.4 kWh/year
Energy Required: Water pumps	40.88 kWh/year

Kali's Hanging Garden project uses the principle to pump and recycle water, and the closed-loop system enables us to save water. Furthermore, our farm uses artificial light and sunlight for plant growth, which minimizes costs and optimizes yield production by the growth period. The recirculation water system saves up to 90% of the water used in traditional farming.

VI. DISCUSSION (D. LAROSE & R. JEEWON)

A comparison of vertical farming to conventional farming (R. Jeewon)

As mentioned above in section I, with a decline in conventional farming and a rapid pace of urbanization, there needs to be an innovation in food production; otherwise, almost 9.7 billion people will starve, causing mass hunger (The Impact Investor, 2021). Vertical farming seems to be the solution for the increasing food requirement in the future. In addition to being sustainable, it also deals with a significant social issue.

Vertical farming provides many ecological and environmental benefits compared to traditional farming. It helps solve existing problems caused by open-field agriculture such as greenhouse gas emissions, soil degradation, pollution caused by fertilizers & pesticides, etc.

1. Greenhouse Gas Emissions

The use of nitrogen fertilizers is among the significant contributors to greenhouse gas emissions as it produces nitrous oxide (N_2O), which is equivalent to 300 times the carbon dioxide emission. Consequently, nitrogen-based fertilizers in crop production contribute to one of the leading environmental impacts of conventional farming (Eden Green Technology, 2021).

However, in a hydroponic system, there is no requirement for fertilizers as the crops are grown in a nutrient-rich solution instead of soil, whereby the plant gets all the required nutrients directly from the medium, hence minimizing the emission of N_2O to almost zero (Eden Green Technology, 2021). The reduction of nitrous oxide is in itself a substantial environmental benefit.

2. Pollution caused by Fertilizers & Pesticides

Another major issue encountered by traditional farming is small and large weeds, pests, and the fertilization of crops. In the pursuit of fertilizing the crops and driving away from the weeds and pests, many chemicals are used, which go into the ground and/or eventually runoff into the water supply (Eden Green Technology, 2021). Vertical farms use a controlled environment for plant growth, where a nutrient-rich medium is used instead of soil and fertilizers. The required nutrients added to the water are instantly bioavailable to the plants. Moreover, no toxic herbicides are needed, and there are almost no pesticides. Another benefit is no water runoff as the water used is being recycled into the system.

3. Food Transportation

Food is imported and exported across countries and worldwide for the population to have access to all kinds of food regardless of the season. In doing so, an enormous amount of fossil fuels is wasted, and also, the food loses some of its nutrients and freshness as compared to locally grown food. One of the advantages of vertical farming is that it requires less space than traditional farming. For a hydroponic system on an area of about one and a half acres, it is estimated to yield about 2.7 million leafy greens annually (Eden Green Technology, 2021). Additionally, the production of these crops in vertical farming is all year-round and independent of the season or weather conditions as they are grown indoors. Vertical farms can be placed even in closely packed urban settings, leading to the transportation of the food from the farms to the store shelf in a shorter amount of time while maintaining the freshness of the food and using less fuel in the transit(Eden Green Technology, 2021).

4. Water Consumption

A vast amount of water is wasted in conventional open-field farming. The water meant for crops is evaporated or dissolved into the ground before the plants absorb it. Consequently, farms running just on water would have significant water consumption issues. However, this is not the case in a vertical hydroponic farm. With a hydroponic system, there is a minimum freshwater requirement for the system to run as the water used is being recycled continuously through the system (Eden Green Technology, 2021). It is estimated that about 98% of water is saved on average with these vertical farms compared to traditional farms, making a massive difference as the saved water can be used for other purposes.

5. Soil Degradation

According to estimates, in the last 150 years, around ½ of the world's topsoil has been lost, which makes soil degradation a big issue globally (Eden Green Technology, 2021). The problems encountered due to soil degradation include the loss of soil structure, erosion, brininess from excessive freshwater use in irrigation, and nutrient degradation. As vertical farms do not use soil, they don't contribute to these issues. In addition, the healthier the vegetables are grown from a vertical farm, the less will be the load on the globe for other plants that can not grow within a hydroponic system, such as potatoes (Eden Green Technology, 2021).

6. Efficiency & Yield

The vertical farm is a more efficient way of growing crops than conventional farming, but despite that, it can not feed the world population a hundred percent like the traditional one (Eden Green Technology, 2021). On top of that, some plants can not be grown hydroponically like root vegetables such as potatoes and carrots. Hence, there will still be a need for traditional farming alongside vertical farming.

A broad range of essential micro herbs and nutrient-filled leafy greens can be grown in vast quantities in hydroponics and waste fewer resources (Eden Green Technology, 2021). Annually, harvests can be produced eleven to thirteen times within the monitored environment of the vertical farm which adds up to a steady supply of fresh and healthy available food in places where farming was not entirely possible.

Considering all the factors, vertical farming is a more sustainable option for producing healthy food that everyone needs to grow and prosper.

The different Constellations of Vertical Farming (D. Larose)

There have been several different forms of vertical farming constellations that have been developed throughout the years, some being as simple as growing your crops on your balcony to vertical farms adapted from horizontal farming. The vertical farms are made up of different constellations that can use hydroponic, aeroponic, or aquaponic systems installed in controlled environments to provide a more efficient yield and energy use.

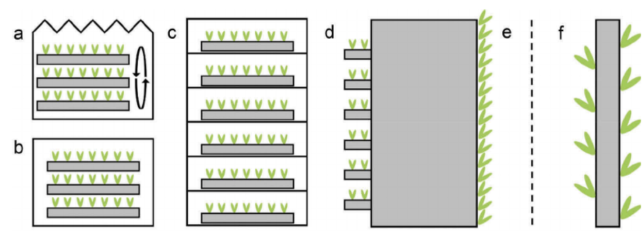

Figure 5: *The different vertical farming constellations*

Source: Source: (Beacham et al., 2019) [*https://www.researchgate.net/figure/Representation-of-vertical-farming-VF-types-Stacked-horizontal-systems-comprise_fig1_331130061*](https://www.researchgate.net/figure/Representation-of-vertical-farming-VF-types-Stacked-horizontal-systems-comprise_fig1_331130061)

Stacked horizontal systems (Fig 5 a,b,c) are among the most common constellations. It consists of several levels of conventional horizontal growing platforms. They can be built as multi-floor towers where a broad range of crops can be grown simultaneously, considering each level has different conditions. The horizontal stacks can be rotated to allow each level access to equal amounts of sunlight and artificial lighting. This constellation is very often used in large commercial vertical farms. (Beacham et al., 2019) Sky Greens' based in Singapore, uses a rotating A-Frame which is a variation of the rotating structures. The use of refurbished shipping containers is an alternative way of using horizontal stacks. The containers are organized to create the optimum environment where the temperature, light, and humidity are controlled and monitored. (Birkby, 2016)

Another category of the constellation is the vertical growing structures. One of these structures is green walls, whereby the growth surface of the plants is the wall of a building that is either vertical or inclined. (Beacham et al., 2019) As well as green walls, vertical structures include cylindrical growth units, where the nutrients are supplied within the cylinder using either hydroponic or soil systems or vertical farming towers. The vertical farming towers are somewhat similar to the cylindrical units. Still, they are hydroponic systems that include a water reservoir at the base where the water along with nutrients solution are pumped one time to the top and eventually flows back into the reservoir after going through the whole structure. A timer regulates the on and off cycles of the pump to create a constant water flow. (Agrotonomy, 2018) Our structure uses this same concept of a closed-loop system that enables us to recycle and save water. One of the UK's most giant vertical farms owned by the company Shockingly Fresh makes use of multiple vertical towers placed next to each other in a greenhouse. With sunlight and rainwater catching systems, approximately 2 million lettuce heads can be produced per year. (Corbley, 2021)

VII. CONCLUSION (Y.WANG)

Vertical farming as an essential part of sustainable agriculture has been widely used nowadays. It helps us save land, energy, and human resources, increase the yield and provide specific nutrients for plants. By looking through some existing case studies and different types of vertical farming setups, the group has come out of two initial ideas. After discussing and modifying the earlier ideas, *KaLi's Hanging Garden* is then developed, covering all the strengths of the initial ideas. This setup here provides a new idea for vertical farming, which takes count of the energy and space efficiency, the nutrients required for specific plants (iceberg lettuce), and the region according to the sunlight condition (Germany). The yield of this module is relatively high (54 plants per module) and energy-efficient (32kWh per module), and most importantly, the water is being recycled by using a closed-loop system. Less water is wasted and thus is environmentally friendly. *KaLi's Hanging Garden* is built up by aluminum profiles and some 3D printed parts in the FabLab. There is the modularity of this system as it can be built higher or lower by adjusting the number of layers. Most of the system is controlled and monitored by the electronic control system designed and tested during the last months: the temperature sensor, pH sensor, EC sensor, phototransistor, and Analog to Digital Converter. The electronic control system gives the advantage that the necessary condition for specific plant growth is ideal all the time and can be modified easily. All in all, *KaLi's Hanging Garden* is sustainable in environmental, economic, and social aspects and can be adjusted to different plants and regions.

VIII. OUTLOOK (A.BATSON)

The following steps of *Kali's Hanging Garden* are testing the structural prototype in a 300m³ room (10m length x 10m width x 3m height). With automation in water dispensing, nutrient supply, pH balancing, and light supply, the complete structure will be deployed to test the viability of growing spinach from seedling stages to harvest.

Kali's Hanging Garden is a succinct fit for the 300m³ room it was designed for; it's a specific fit project. This is the primary strength of the project. The vertical scalability of the structure is optimized for a 3m height room. Other design parameters of the structure, however, are more generally optimized. Therefore, horizontal space use, maintainability, ease of harvesting, etc. fit both the space and can be further developed and adapted features for other vertical farming projects.. A limitation of the design, therefore, is the limit of scaling the design vertically in a different spatial setting. Under different (vertical) spatial parameters, the project is therefore limited, although overall well-tailored.

In comparison, other structural models and constellations have considerable pros and cons compared to *Kali's Hanging Garden*. For example, the box structure in figure 6 may provide more yield and lower structural complexity while simultaneously complicating harvesting and utilizing more energy compared to Kali Hanging Gardens. In any case, the design of a constellation is a process that must be harmonic to the growing space available. This growing space was also introduced as a means to compare different vertical farming models. Core vertical farming parameters such as yield, maintainability, automation, modularity, and energy efficiency are challenging to address entirely and effectively. That's why there's always room for improvement and optimization!
In a follow-up to our work, developers can look to synchronize their available growing space with an optimized constellation. Considering *Kali's Hanging Garden*, a test run is needed to conclude how well the system will perform in natural light conditions, the feasibility of maintenance and the durability of the operation season after season. Nonetheless, the future looks quite positive.

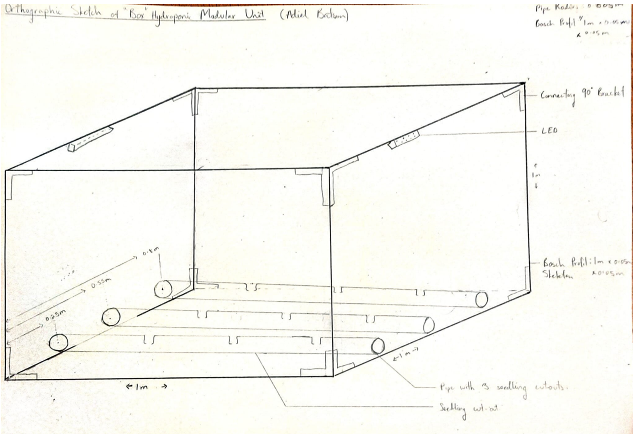

Figure 6: Cubic Unit with pipes

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