Vertical Farming

Final Proposal

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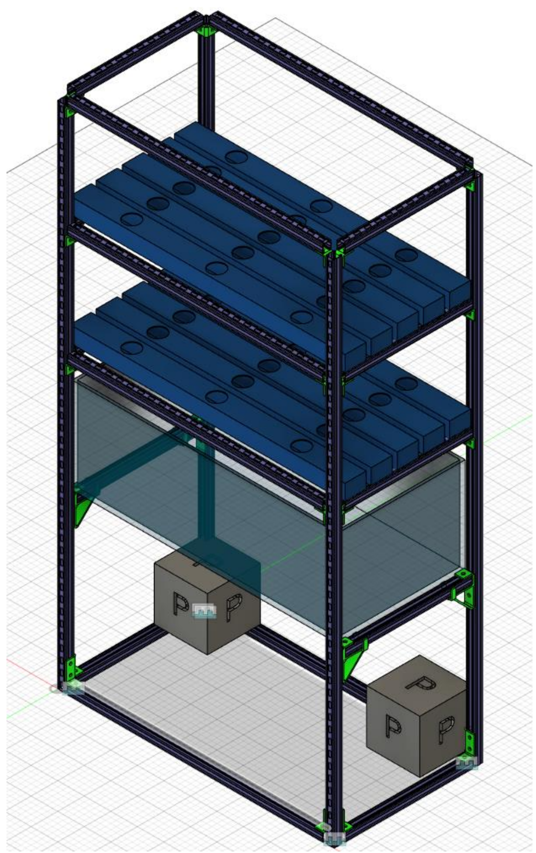

Figure 1. CAD model

Project Sponsor: N/A

Instructor: Dr. David Trevas

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

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Contents

1 BACKGROUND

1.1 Introduction

The goal of our project is to design a vertical agricultural system or facility that can meet the needs of individuals interested in agriculture and willing to grow plants. Vertical agriculture is a new concept since World War II. It has amazing advantages over traditional agricultural methods. For example, it can produce products with extremely stable quality, because all environmental factors are fixed and can be detected and controlled. And vertical farms do not need pesticides and herbicides, which means that there are no agricultural pollution emissions. The starter of our project is hunter, one of our members. He is very interested in vertical agriculture and expects to have a bright future in the future.

In modern life, people are exposed to the benefits of industrialization, but at the same time, more and more people will miss the previous environmental agricultural life. At the same time, there are a lot of people living in apartments. The relatively small size of the apartments makes it impossible for those who are interested in agriculture to realize their wishes. And now because of the outbreak of the COVID-19, more people will choose indoor entertainment instead of outdoor entertainment for the sake of safety. In order to meet the needs of these people, we designed this vertical agricultural system.

Our system can provide fresh and high-quality organic plants for individuals, beautify their living environment and satisfy their interest in planting. In order to achieve this goal, we need to solve some problems, such as the device should be as small as possible, if not, the customer does not know where to put it, because it is too large. At the same time, the device should be placed indoors, not affected by the weather, crops can grow in the best conditions throughout the year. We also need to find the most suitable conditions for plant growth to make the system run sustainably. After these conditions are met, the price can be cheaper, and more people can afford it.

In order to achieve the above requirements, we have adopted aquaponics from four vertical agricultural modes according to hunter's opinion and designed our system to realize the planting of plants under limited space and limited budget, and make the plants grow steadily. Through the system we designed, our potential users can benefit from it.

1.2 Project Description

Following is the original project description provided by the sponsor “Originally the idea was going to be that we wanted to have an easy to set up vertical garden that can be user friendly to install and was self-sufficient. This would not work in a hydroponics setup since there needs to be nutrient addition and the system would be too large based on current designs of aquaponics systems”.

2 REQUIREMENTS

The project requirements are the setup needs to be a professional looking setup that can go in any space including but not limited to an apartment, house, garage, or business waiting room. With a modular setup that can make the system work better for each user instead of one design fits all.

2.1 Customer Requirements (CRs)

The customer requirements needed to fulfill the project requirements are listed below along with importance ratings. A 9 is very important, 3 is moderately important and 1 is not important.

- (9) Monitor macronutrients - To grow plants efficiently the correct amounts of nutrients need to be given to the plants.
- (9) Sufficient lighting - Full spectrum lighting will be needed by the plants.
- (9) Maintain proper nutrient solution basicity - The plants, fish, and bacteria in the water all thrive in specific PH levels. A PH that will work for all needs to be determined.
- (9) Maintain water temp - Maintain a water temperature that both the plants and fish can thrive in.
- (9) Support fish tank weight - Ensure that the overall structure can support the weight of the fish tank as well as the water in the tank safely.
- (9) Adequate flow rate
- (3) Minimal electrical operating cost - Maximize amount of plants grown per cycle to reduce overall cost per plant.
- (3) Small footprint – Maximize number of plants grown in minimal square footage.
- (1) Quiet – Ensure a comfortable listening experience while in the vicinity of the system.
- (9) Low Flow rate alarm – Warn the user when the flow rate in troughs is insufficient.

2.2 Engineering Requirements (ERs)

The team has developed 12 engineering requirements to satisfy the customer requirements previously stated. The engineering requirements are listed in table 1 below.

Table 1. Customer requirements & Engineering requires

Engineering requirement	Target value	Upper target limit	Lower target limit.
Monitor macro nutrients	? ppm	? ppm	? ppm
Photosynthetic photon flux density (mol m-2s−1)	200 PPFD	300 PPFD	200 PPFD
Power of hydrogen (PH)	7	7.2	6.8
Water temperature (° Fahrenheit)	71°	74°	68°
Fish tank support (pounds)	1300 lbs	1310 lbs	1275 lbs
Volumetric flow rate (gallons per hour)	5 gph	4.5 gph	6.5 gph

Monthly electrical operating cost (USD)	60 USD	65 USD	50 USD
Area (Sq ft)	8 sq. ft	12 sq. ft	7 sq. ft
Operation noise (Decibels)	55 dB	60 dB	45 dB
Monitor flow rate	5 gph	5gph	4.9 gph

The original plan for monitor macronutrients was that they would be monitored in real time and adjusted when necessary. After research we determine this would be too costly and difficult to achieve. The team is currently working on a way to ensure correct nutrition by monitoring water Ph, electrical conductivity, and oxygen levels. The lighting used in the design will be photosynthetic active radiation (PAR). PAR is light with wavelengths in the range of 400nm to 700nm. The metric used to quantify PAR is photosynthetic photon flux density (PPFD). The leafy greens we plan on growing require a PPFD of 200 [5] The concentration of hydrogen ions in the nutrient solution will be checked using the PH scale in order to satisfy the basicity requirements. The target PH is 7 with and upper limit of 7.2 and a lower limit of 6.8. This rage of PH levels will accommodate the three main living components of the system: fish, plants, and nitrifying bacteria [1]. To meet the water temperature requirements the water will be kept at temperatures between 68°F - 74°F. The preferred temperature is 71°F. Plant root zone optimal temperature is 71.6°F, temperature range for bacteria growth and productivity is 62.6°F- 93.2°F, and the tropical fish considered thrive at temperatures between 71.6°F - 89.6°F [2]. A water temperature of 71.6°F will satisfy these requirements. The aquaponics system will house a 2ftx4ft fish tank. Preliminary back of the envelope calculations indicate that the water alone will weigh as much as 1260 lbs. To meet the fish tank support requirement the team will set the load carrying capacity target at 1300 lbs to account for the weight of the tank itself. The upper limit is 1310 lbs and the lower limit is 1275 lbs. Studies have shown that leafy green plants grow well at flow rates near 5 gallons per hour [3]. To meet the adequate flow rate requirement the target flow rate in each trough has been set to 5 gallons per hour with an upper limit of 6.5 gph and lower limit of 4.5 gph. These target values will also be used to trigger the low flow rate alarm. To meet the customer requirement of incurring minimal operating cost the target monthly operating cost has been set to $60 with an upper limit of $65 and a lower limit of $50. A prominent customer requirement was requiring the least amount of space for operation. This requirement will be satisfied by targeting a footprint of 8 sq. ft. This size will make it possible to use the vertical farm in a variety of different places. The footprint upper limit is 12 sq. ft and the lower is 7 sq. ft. To meet the customer requirement of quiet operation the target operating noise has been set to 55 decibels (dB). This level of noise is not much greater than a kitchen refrigerator [4]. The upper noise limit is 60 dB and the lower is 45 dba.

2.3 Functional Decomposition

The focus of the project is to have a setup that a typical person could have and operate. The system would need four main things, one a nutrient creator that being the fish waste and added micronutrients. Two being a water flow system including pumps and hoses. Third a sensor setup that could make the project self-sustaining week to week, and finally lighting to photosynthesize the plants that the user would like to grow. When broken down like this it sounds like a simple project only that there isn't any research to how many fish it will take to grow a set amount of plants, just a rule of one inch of fish per gallon of water. And lighting poses its own difficulties since the team learned that there are different light cycles for different plants such as a normal 18 hour max constant lighting source vs a flowering lighting when the source of light varies due to where the plant is in its growth cycle. The systems Black box uses power, water, and food for the fish as the input through the black box and the output would be a great looking self-sustaining aquarium that the user can grow food from.

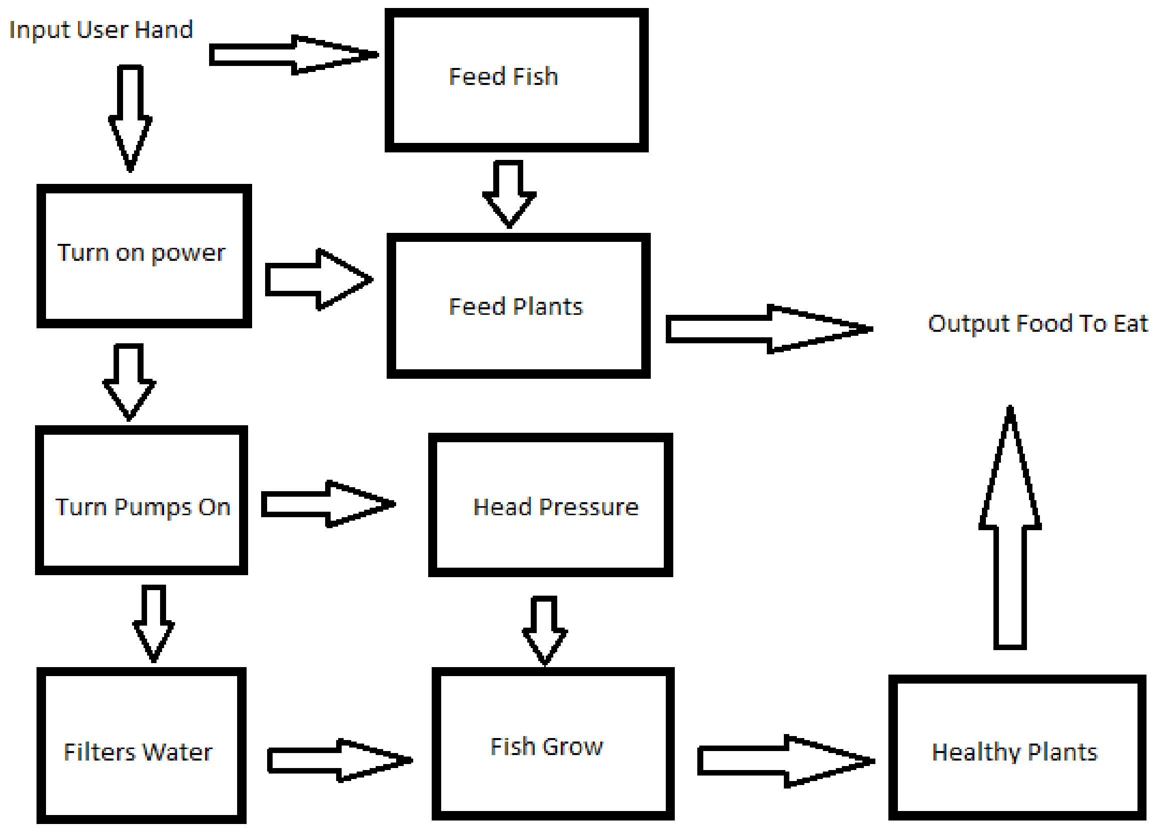

Figure 2

The only changes in the design process that could be changed are the structure and the lighting the rest of the project has already been decided upon because they are all needed values to have the tank running efficiently to feed the plants.

2.3.1 Functional Model/Work-Process Diagram/Hierarchical Task Analysis - Hunter

Our project will be a large task to accomplish that has the possibility of very large amounts of mishaps that can happen long the way including a tank busting, the structure not holding the 1000 pound plus tank and gear, and even the fish stock dying off to some unforeseen reason.

The complexity of the project warranted a model the team chose to be simplifying to the eyes, a functional model. The reason for this is that the black box model is too vague while the functional model goes over everything as well as simplifying the problems that need to be solved. The diagram shows the team each thing that needs to be done while not listing it out like a Gannt chart, Work Process Diagram, or Hierarchal Task Analysis which can be overwhelming at times. We can keep revisiting to make sure we aren't overcomplicating the project further than it already is also with this diagram. The beginning starts with two hand movements and the power grid accomplishes the rest. The simple yet very complicated result of having food to eat started with just those two movements is an amazing feat that technology has given the team the capability to accomplish.

2.4 House of Quality (HoQ)

Below is a QFD created by the team. The QFD helped ensure that all customer requirements were fulfilled by an engineering requirement. The QFD has shown us that maintaining the required water flow rates and macronutrient concentrations are the most important.

Table 2. QFD

Customer Requirements \ Engineering Requirements	Importance	Photosynthetic photon flux density (mol $m^{-2}s^{-1}$) [1]	Power of hydrogen (PH) [2]	Water temperature (Fahrenheit) [3]	Fish tank support beam load capacity (lbs)	Volumetric flow rate per planter (Gph) [4]	Monthly electrical operating cost (USD) [5]	Area (Square feet)	Operation noise (dB) [6]	Nitrogen concentration (ppm)	Phosphorus concentration (ppm)	Potassium concentration (ppm)	Calcium concentration (ppm)	Magnesium concentration (ppm)	Sulfur concentration (ppm)
Monitor macronutrients	9									9	9	9	9	9	9
Sufficient lighting	9	9													
Maintain proper nutrient solution basicity	9		9	1						1	1	1	1	1	1
Maintain water temp	9			9											
Support fish tank weight	9				9										
Adequate flow rate	9					9									
Minimal electrical operating cost	3						9								
Small footprint	3							9							
Quiet	1								9						
Monitor flow rate	9					9									
Technical Importance: Raw Score		81	81	90	81	162	27	27	9	90	90	90	90	90	90
Technical Importance: Relative Weight		**7.4%**	**7.4%**	**8.2%**	**7.4%**	**14.8%**	**2.5%**	**2.5%**	**0.8%**	**8.2%**	8.2%	8.2%	8.2%	8.2%	8.2%
Techanical Target Value		200	7	71	1300	5	60	10	55						
Upper Target Limit		300	7.2	68	1310	4.5	65	12	60						
Lower Target Limit		200	6.8	74	1275	6.5	50	7	45						
Units		PPFD	PH	fahrenheit	Lbs	Gph	USD	ft^2	dB	ppm	ppm	ppm	ppm	ppm	ppm

9 Important
3 Moderate
1 Not Important

Correlation KEY:
9 -Strong
3 -Medium
1 -Weak
Blank - None

2.5 Standards, Codes, and Regulations

Table 3. Standards & codes

Standard Number or Code	Title of Standard	How it applies to Project
NEC Article 680	Requirements for pool, hot tub, and fountain installations	Compliance will reduce the risk of electrocution
ISO22000	Food Safety management	Will help create an effective food safety management system.
HACCP	Hazard analysis and critical control point	Compliance will ensure safe food is produced by identifying and controlling food safety hazards.
NEC 210-23(a)	Permissible loads	Will determine the maximum load that can be placed on a wall outlet
ASME Y14.5	Dimensioning and Tolerancing	Standard for engineering drawings

The fish tank in our design will hold approximately 90+ gallons of water. This body of water being placed next to an electrical outlet means that we need to meet code requirements listed in NEC article 680 for installation, design, and inspections to protect people from electrical hazards. Requirements include electrical equipment cord lengths not exceeding 3ft, cords must have copper equipment grounding not smaller than 12 AWG that terminates to a grounding-type attachment plug, all receptacles used must be GFCI protected and equipment disconnecting means must be accessible within sight (within 50 ft).

ISO22000 is an internationally accepted standard used by organizations involved in food production and distribution. The objective of ISO22000 is ensuring food safety. ISO22000 requires us develop a food safety management system and a risk analysis to evaluate every food safety hazard identified in the design.

HACCP main principles are identification and assessment of hazards associated with the food product, determination of the critical control points to control the identified hazards, and establishment of a system to monitor the critical control points. HACCP will require us to conduct a hazards analysis, determine critical control points, establish critical limits for the control points, establish a monitoring system for each control point, establish corrective actions, establish varication procedures, and establish documentation/record keeping.

Outlets in homes in the United States can carry maximum loads of 15 amps or 20 amps. Multiplying this by the standard 120 volts gives us the maximum loads of 1800 watts or 2400 watts. NEC 210-23(a) reduces these amounts to 1440 watts and 1920 because it requires that only 80% of the maximum capacity is used.

3 Testing Procedures (TPs)

Testing procedures will aim to verify that certain engineering requirements are met. In the process of accomplishing these tests, the measurable engineering requirements are experimentally justified. The tests will also show the legitimacy and functionality of the Vertical Farming team design.

3.1 Testing Procedure 1: Electricity Draw

In this first test, our team will seek to identify how much electricity our design will use for full operation and identify how much lighting is used for a standard vertical farming setup. These two engineering requirements are annotated as [1] and [5] on table 2. QFD. This test will be completed over a 24-hour period using an electricity monitor to record the values and offer an average set of values that can be extended to an annual use value. A PAR meter will be used to measure how much light is being emitted from the lamps to ensure sufficient lighting is used also over a 24-hour period.

3.1.1 Testing Procedure 1: Objective

The test will be conducted by connecting the power cord of the entire system to one electricity usage meter. This is then connected to a power source which will be a standard 120-volt wall outlet. In conjunction with the electricity monitor, team members will record the data shown on a PAR meter which reflects the amount of lighting given off from the grow lights. Data collection times will be standardized for both sets of data and after all data has been collected will be used to estimate the annual cost and average lighting being emitted for the desired plant system.

Electricity draw and lighting is being tested due to the importance reflected by the customer and engineering requirements. For the project to be desired by the customer, a low-cost system should be developed along with plant producing equipment, such as lighting. Therefore, the testing of these two aspects is essential to the success of the team design.

3.1.2 Testing Procedure 1: Resources Required

The required resources for this test procedure are listed below:

- 1-2 team members to record the data.
- Spreadsheet to collect data.
- PAR meter—light intensity gauge.
- P3 Kill A Watt electricity usage monitor.
- Location with a standard 120-volt wall outlet plug.
- Completed vertical farming system connected to single power cord or power strip.

3.1.3 Testing Procedure 1: Schedule

The test itself will take place over a 24-hour period only after the vertical farming system is completely set up or close to being completely set up. This is due to the requirement of getting a complete view of how much electricity the design is using. Therefore, all lights, pumps, and monitoring systems should be functional before starting this test, placing the date of the test somewhere mid-semester once all materials have been purchased and assembled. The location used will be a team members residence which will make it easier to monitor the meters over the length of the test. To cater to the schedule of each team member during the semester, four data collection times will be conducted across the 24-hours. The initial readings will be recorded at time zero which will be 8:00 p.m. at a date to be determined. The second recording will be at 6:00 a.m. followed by the third at 12:00 p.m. The final data collection time will be at

8:00 p.m. when the testing is concluding. All times will be Mountain Standard Time-zone. The flexibility of the 24-hour window allows for the testing to be accomplished either during the week or weekend and can be split between the team members.

3.2 Testing Procedure 2: Water Flow and pH checkout

The second test will check the functionality of the water flow regulator and pH balance monitor. Referencing the QFD in table 2 items [2], [3], [4], and [6] will be verified for this project's engineering requirements. The projected time for completion of this test is one week to consider different variations in water conditions. To interpret the data, a pH controller will be tested and used along with a temperature sensor, and a water flow sensor. All data will be collected at the very least twice a day over the course of a week.

3.2.1 Testing Procedure 2: Objective

The entire system will be operating to complete this test phase. Water must be flowing to and from the fish tank to ensure the water flow sensor, pH controller, temperature sensor, and heater are all working properly. The process of data collection will be shared across the team and recorded on a shared spreadsheet. Once the system is turned on and everything is calibrated to their respective limits, the process of checking each sensor and controller will begin. Each day the collected data will be compared to the initial settings to ensure all figures are within set tolerances. If any discrepancies are found, then the team will come together to identify what is causing an out of limits data set for that day.

3.2.2 Testing Procedure 2: Resources Required

The required resources for this test procedure are listed below:

- 3-4 team members for data recording
- Excel spreadsheet to collect data
- Milwaukee MC122 PRO pH controller
- DS18B20 digital temperature sensor
- Aquarium heater
- Silicone mat
- Gravity: water flow sensor
- Water pump

3.2.3 Testing Procedure 2: Schedule

This test will be the last test conducted before placing fish and plants into vertical farming system. After the full assembly of the design, this test will follow to ensure it is safe to place fish and plants in their respective areas. The test will require every team member's contribution since it will take place over the span of a week. At a minimum the team will collect data twice a day, once in the morning and once in the evening. A third check in the afternoon is optional since there will be no fish that could be harmed if something goes wrong with the sensors or pumps. The target values of each area are noted on the bottom of the QFD in table 2.

4 DESIGN SELECTED – First Semester

In this section, the team will discuss changes to the design chosen in the preliminary report as well as the overarching elements of the design and why we believe it to be the correct choice.

4.1 Design Description

Building on the design selected in the preliminary report, the team has continued forward with a frame based on Unistrut and mounts produced by the company.

Irrigation Systems

The team has modified the design to utilize downpour spouts instead of rain gutters due to the size being smaller, 3x4 inches instead of 5x5 inches, and the ability to fit an extra row of plants per level. The team has also modified the design to fit a second level of gutters above the tank as seen in the CAD model below. Because of these two changes, the team can grow more plants at one time thus reducing the overall cost per plant.

Framing

Using Unistrut P1100, the frame can be created to hold the fish tank, troughs, and pump systems. To assemble the frame, the team is currently using mounts produced by Unistrut as well, shown in green in the CAD model. The CAD models for these mounts and pieces were provided by Unistrut directly as helped shorted the design time quite a bit.

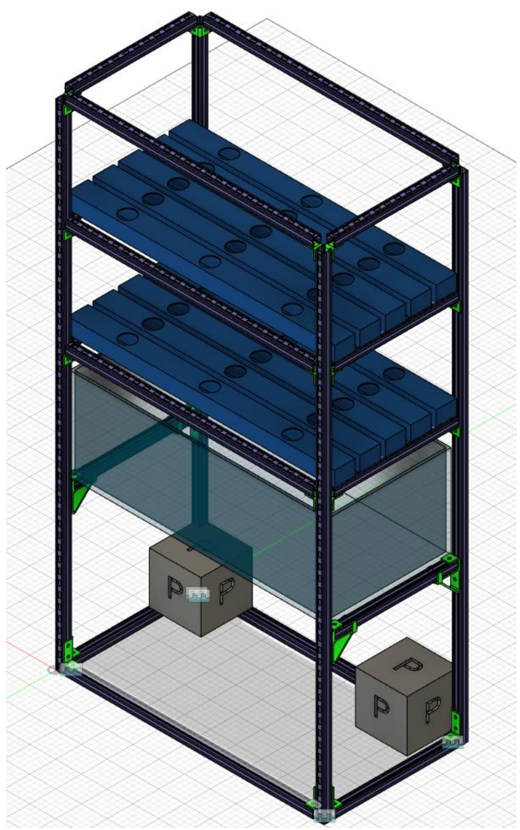

Figure 3

Tank

The fish tank has been a difficult part of the design to maximize space and minimize weight. At this point, no solid solution has been found between building our own tank or obtaining a prebuilt one. The team will need to do more research into this and decide on a method that can reduce weight and will not be too costly.

Electronics/Systems

At this point in time, the team has not decided fully on what can be implemented for user convenience. This will depend on space as well as budget for the design. Systems that will be implemented include an Arduino based flow alarm for detecting flow in troughs, a low tank water level alarm, and timed lighting. Systems that the team is considering implementing include an automatic feeder, Ph detection (if needed), and a device for automatic nutrient dispersal.

4.2 Implementation Plan

For our project implementation and testing, the team is going to build a full-size model. Using this model, we can test for flow rate, plant survival, heating, and other factors to ensure the design is functional. In order to do this, we need to obtain the needed parts from various places such as Amazon, Home depot, and our chosen Unistrut provider. Using these materials as well as tools from team members, as well as some school resources such as welders, we should be able to build a full-size project. An approximate cost is detailed below in the bill of materials along with potential suppliers and quantity needed.

Currently, the plan is to build the farm as soon as a budget is acquired. The sooner the farm is built, the quicker the team can begin testing individual functions and modifying the design. Due to the current coronavirus situation, there is no guarantee if the budget or facilities will be available for capstone teams. If the team cannot build the full project, we will individually test smaller subsystems at home to ensure those work and create a detailed CAD model for demonstration. If any large or major design changes occur, the team will validate the new design and attempt to either modify the existing build to fit or complete these design changes before building begins.

Table 4. Bill of materials

Bill of Materials

Material	Amount	Pricing	Total Price (USD)	Supplier	Total	1823.1 $
Unistrut P1100	92 (ft)	270 $/50 ft	540	Gordon Electric Supply		
Unistrut P1075	2 Pieces	13.15 $/Each	26.3	Gordon Electric Supply		
Unistrut P2223	12 Pieces	11.3 $/Each	135.6	Gordon Electric Supply		
Unistrut P2224	4 Pieces	13.55 $/Each	54.2	Gordon Electric Supply		
Tank	1	500 $	500	Self Built		
Downpour spouts	52 (ft)	27 $/10 ft	162	Home Depot		
Pumps	2 Pieces	30 $/Each	60	Amazon		
Lights 100W	5 Pieces	40 $/light	200	Amazon		
Arduino Components			100	Arduino/Amazon		
Tubing	30 ft	10 $/10ft	30	Home Depot		
Vibration Dampener Mat	1	15 $	15	Amazon		

5 CONCLUSIONS

In conclusion, the Vertical Farming project being proposed in this paper is a viable option that fulfills the customer and engineering requirements identified by the team. Creating a product that is user friendly and has a small footprint is what drove our team to the design mentioned in this paper along with distinguishing ourselves from other products currently in circulation. The design includes numerous vertical troughs that will both guide water and hold prospective plants in place while drawing water from a fish tank below. The fish within the tank will help feed the plants above while creating an aesthetically pleasing view throughout the growing process. Regulated with sensors, monitors, and pumps, the design is aimed to be easily operated after setup and will yield crops for the user to enjoy. More detailed requirements for the design team are planned to be satisfied after the testing process. Overall, this project is set up for success after the hours invested by the Vertical Farming team and each member's input throughout the design process.

6 REFERENCES

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