PROJECT DELIVERABLE J

FINAL REPORT

University of Ottawa

Hydroponics Team #4

Engineering Design [GNG 1103]

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Abstract

Throughout the semester, we have worked with a client to formulate and implement a solution to their problem. The main focus of this project is societal accessibility to adequate amounts of natural food produce. Our mission has been to design and create an efficient and natural self-sustaining hydroponics system, seamlessly integrated with a greenhouse to produce food for an underprivileged community.

After empathizing with our client, we moved into the ideation phase, through which we developed various designs based on our client needs. From thereon in, the genesis of our prototype began, and eventually, we shifted to the testing phase, in which we gained valuable client feedback based on interactive demonstrations of our prototypes. Following the testing phase, we utilized client feedback to evolve our design to ensure its compatibility with the needs of our client.

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1.0 Introduction

Access to fresh produce is something that we often take for granted in cities; however, in remote areas, fresh produce can be hard to come by. Our client, Monique Manatch, is a representative of a remote Algonquin community in Northern Quebec. She requested that we build a hydroponics system that could supply the community with fresh produce year round. This hydroponics system needed to be able to produce food for the community of roughly 50 people, remain functional during the cold winter months, and be resistant to pests such as mice and insects.

With our design, we aimed to satisfy all of the customer requirements and to add extra features to improve the user experience. One of the features that makes our hydroponics system stand out from other hydroponic systems is the fact that it requires no electricity to operate. The Algonquin community does not have access to electricity so we built our system with a hand pump and manually controlled valves to eliminate the need to install solar panels, which would be costly and difficult to maintain during the winter. The community also does not have access to running water so we added a rainwater collection system that feeds directly into our hydroponics system. The following report will describe how we used the design process to create our hydroponics system.

2.0 Process

2.1 Needs Identification

With the information that we gathered from our client, Monique, we developed the following problem statement: “A rural Algonquin community in Le Domaine, who’s representative, Monique Manatch, of the Algonquins of Barriere Lake needs a weather-tolerant greenhouse to grow vegetables such as lettuce, spinach and other greens year round for approximately 50 people. The project will be completed by the week of November 26th 2018 with a budget of $100.”

A few constraints we needed to incorporate into our design is that the hydroponics team will have a budget of only $100 and the construction team will have a $150 budget. We were also informed that many different animals such as squirrels and mice may try to dig into the construction. We were not given a space limit but we needed to take into account that it is sand ridden land with variety of pests. The greenhouse structure must also be able last year around, including in -40℃ weather.

The greenhouse will be based off a modular design with raised beds and cabins made out of logs. Our greenhouse must operate without running water, and electricity.The greenhouse will be used to grow different plants without the use of soil. The hydroponics system had to be able to fit inside a 6x4 feet structure. Monique had empathized to us that the growing period is short so our design must be able to capture rain-water. Monique also wanted a lock on the door so people could not disturb the hydroponics system.

2.2 Benchmarking

To construct our design, we researched existing hydroponic designs and gathered ideas from each. One of the designs we benchmarked, the AeroGarden Bounty, was over double our budget and only grew 9 plants at a time; this is too little to feed 50 people. Group C-7 2018 design was roughly $50 over budget and could grow 24 plants. The third benchmarked design, the 4 Bed Canadian Bubbler Hydroponic Garden, was $100 over budget and could only grow 4 plants at a time. After gathering information from existing systems we realized we should incorporate features from each design. A few features that our design should incorporate: a water storage able to support up to 15kg, small enough to fit within the structure, yield enough plants for 50 people year round, and the diameter of the holes must be large enough to fit and enclose the roots from multiple plants being grown.

Three of the designs that we benchmarked we summarized in a table. The results of this comparison can be seen in *Table 1*. From the benchmarking, we came to the consensus that group C-7's hydroponics project from 2018's GNG 1103 class performed the best in the areas that we deemed to be the most important.

Table 1. Benchmarking Researched Designs.

Hydroponics system	Group C-7 2018[1]	AeroGarden Bounty[3]	4 Bed Canadian Bubbler Hydroponic Garden[2]
Cost	$151.69	$368.86	$179
Number of plants that can be grown	24 plants	9 plants	4 plants
Water usage	Unknown	Unknown	16L/hour
Energy usage	Uses electric water pump	45 W	Uses electric air and water pumps.
Size of System	175.26 cm high with unknown length and width	43.18 x 27.94 x 17.78 cm	47 x 30 x 25 cm

3.0 Conceptual Designs

After benchmarking, each group member was given the task to come up with a concept design. Afterwards, each concept design was analyzed and the group discussed the pros and cons of each one. As a group, all aspects that were deemed pro from each concept design was combined in our final concept design.

3.1 Cameron's Design

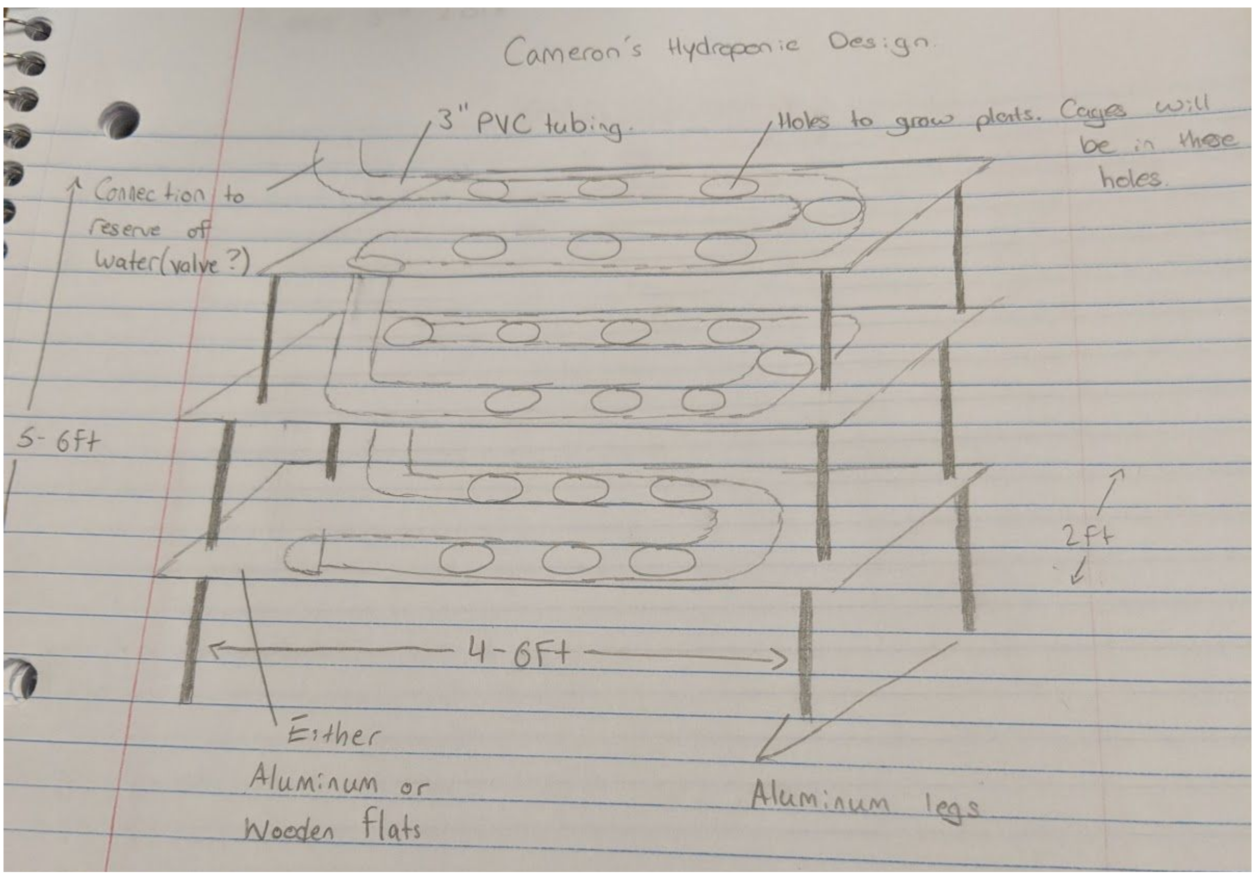


Figure 1. Cameron's concept design.

There were many customer needs addressed in this concept design. One of the main goals of this design is to avoid the use of a pump by using gravity; a water tank would also sit above the hydroponics system and via a valve, water would be released into the system. The water flow would be able to be controlled via a valve between the water tank and the top layer.

Each layer would be able to hold at least 20 plants; these plants can vary in variety. In each plant hole there would be a plastic cage to help guide the roots growth towards the water. The whole structure will be made of Aluminum and should weigh approximately 30 lbs. The dimensions of the design is 6 ft x 6 ft x 3 ft

3.2 Karan’s Design

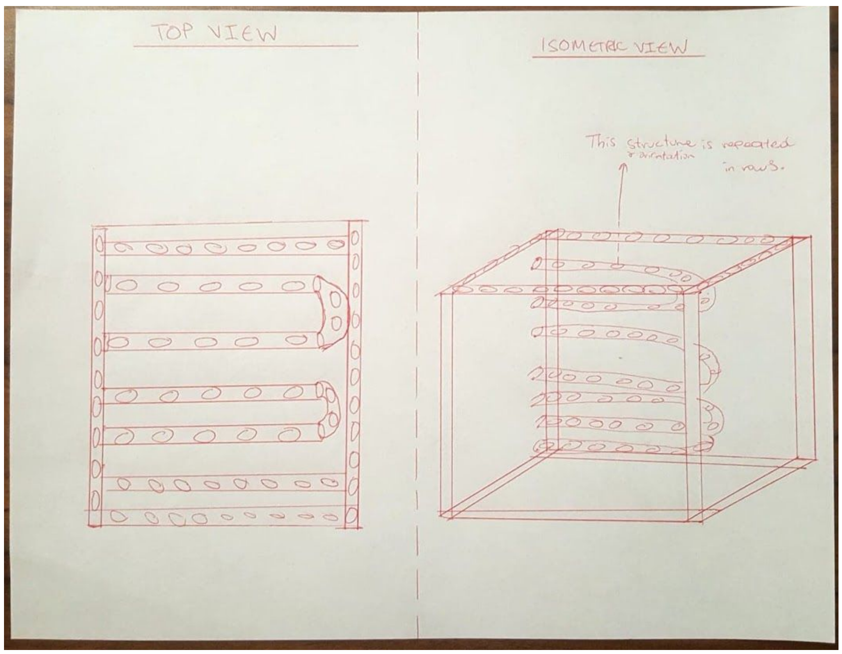


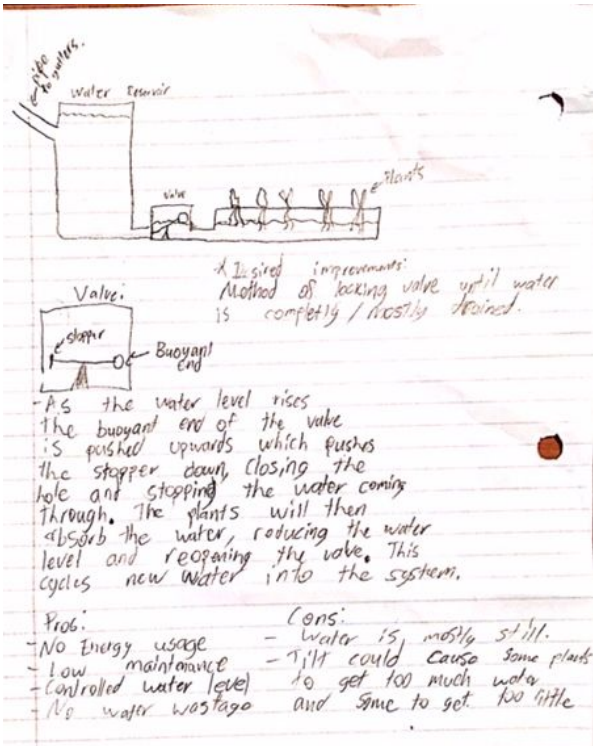
Figure 2. Karan’s concept design

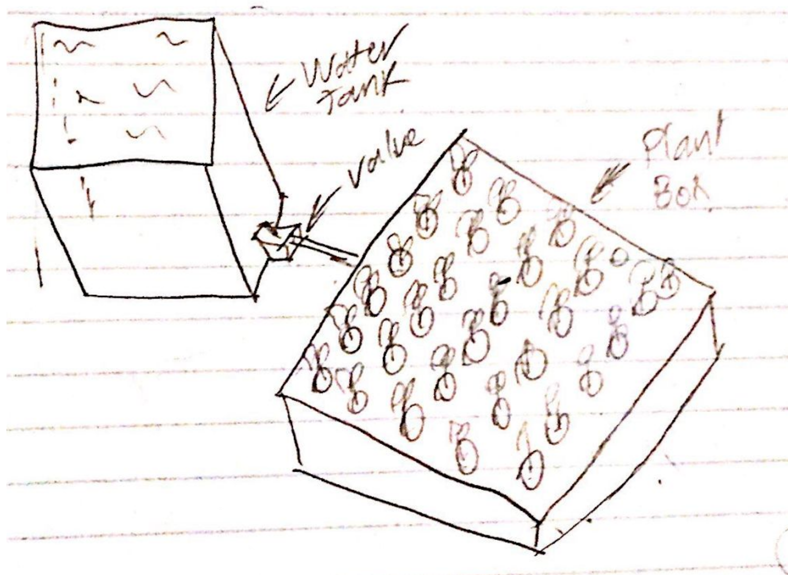
The idea behind this concept design was to create a cubic structure that could rely on gravitational potential, rather than electrical power. In addition, a compact, but efficient system could be created by incorporating more plants by creating pods in the material that creates the borders of the structure, as you can see in the image to the left.

There would be approximately 5 or 6 rows of these pod-holding structures, to allow a higher amount of food to be produced for the community. The pressure of the water in the tank would combine with the force of gravity to effectively push the water through to all plants embedded within the entire cubic structure. However, the dimensions and characteristics of the cubic structure would be dependent and based on how the construction team plans to structurize the entire greenhouse.

Moreover, the pipelines and plant pods would be made of PVC Plastic, and the cubic structure would be made from solid wood, and to allow structural rigidity and stability, the borders would be joined by bars of thickly extruded aluminum billets. The water tank would also be made of either PVC plastic.

3.3 Rohan's Design





Figures 3 and 4. Rohan's concept design

The main goal of this design was to create a hydroponics system that could function without electricity and still be a fairly hands off system. The system is filled with water by gravity which eliminates the need for an electric pump. The water level is controlled by a valve containing a lever with a buoyant end and an end with a rubber stopper on it. When the water level rises the buoyant end is pushed up, which forces the rubber stopper down and blocks the water flow, thus controlling the water level. The box and reservoir should be made from plastic.

The hydroponics system will rest upon an aluminum or wooden frame to keep it off the ground. The plant box should be able to hold 25 plants in a 5x5 square. The diameter of each plant holder should be about 4'' and the total dimensions of the box should be about 3'x3'x1'. The reservoir should be a bit bigger than the box with dimensions of about 3'x3'x3'.

3.4 Mason’s Design

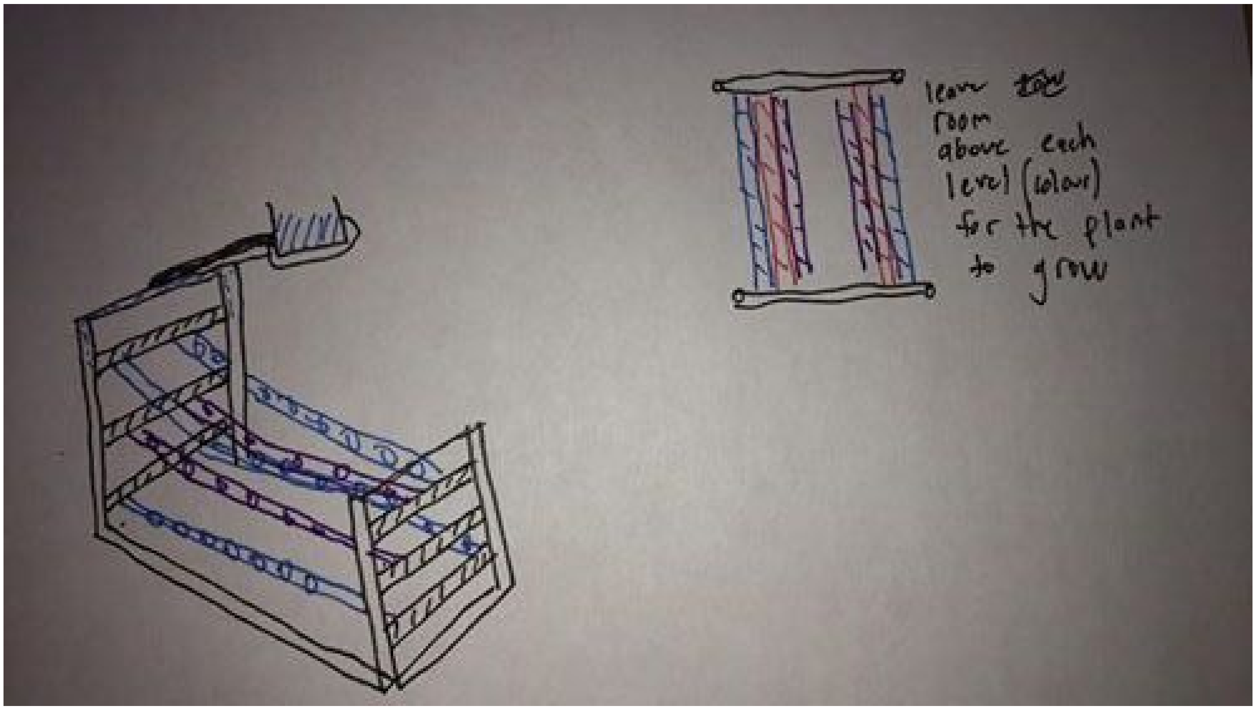
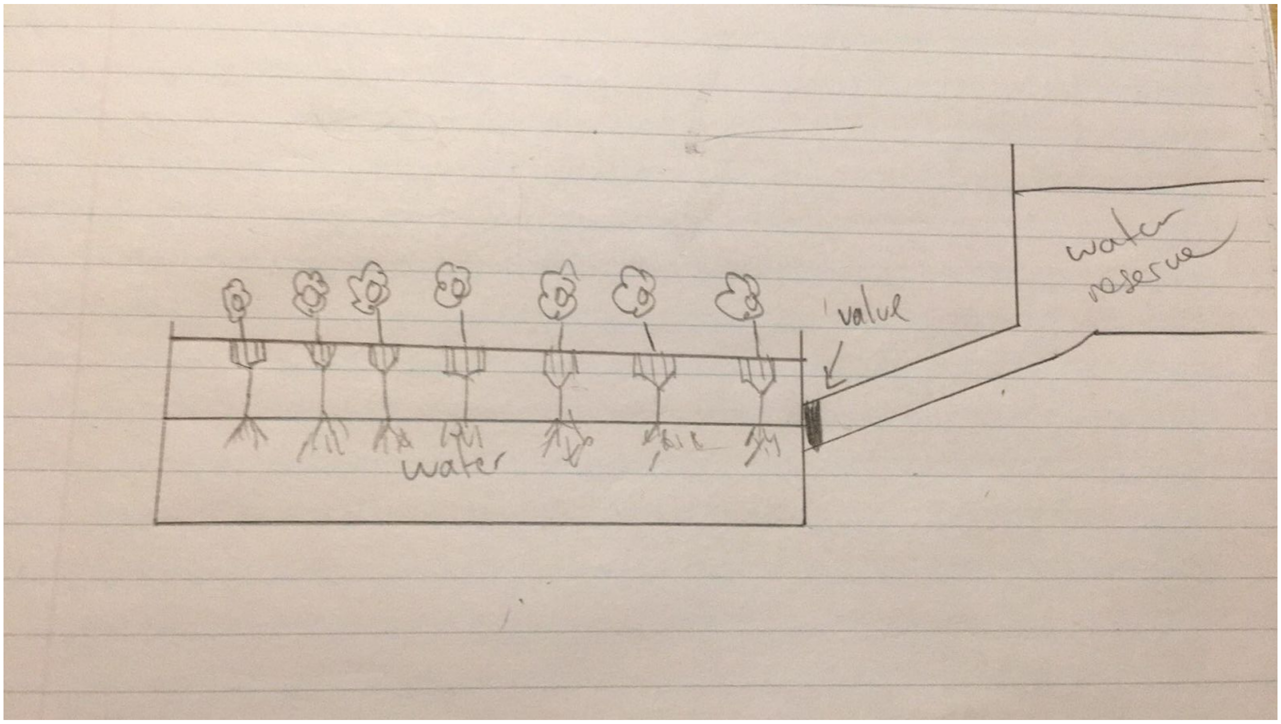
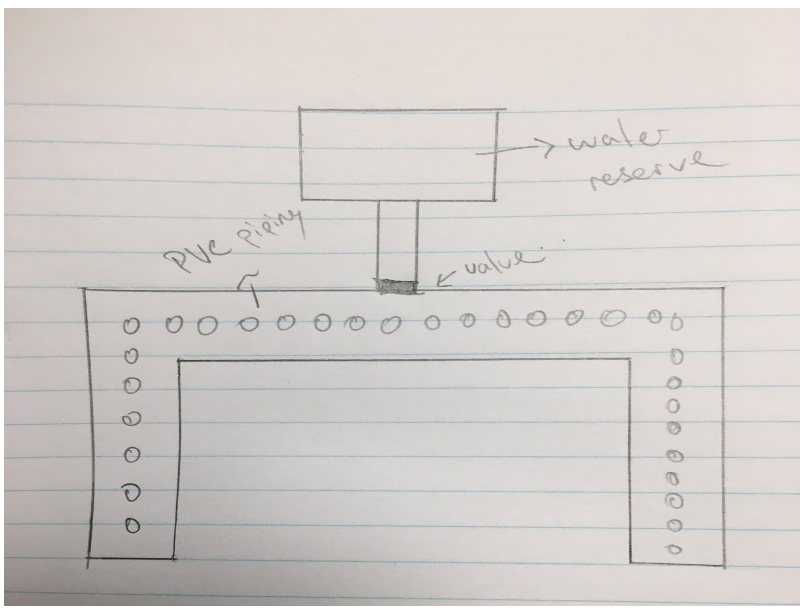


Figure 5. Mason’s concept design

This concept design involved a 3 or 4 layer base held by two metal poles on each end or four metal poles on every side depending on cost and the idea of the construction team. Every pipe containing the plants should be shifted to the left or right of the previous layer to allow room for the plants to grow (shown in top right picture colour coated to layer). A bucket at the top will also be used to collect rainwater. This bucket would then distribute water through the poles to each layer of the plants. We might need to add more pipes per layer for the plants depending on how many plants we can grow.

3.5 Kasper's Design





Figures 6 and 7. Kasper's concept design side view and bird's eye view

Our team had decided on a hydroponic design that did not require electricity and would use gravity to ensure the water would flow through the system. After looking at other hydroponic systems, an idea for the system was one in which there was a water reserve at a raised height. It would flow down a PVC tubing where it would be stopped by a valve. There would then be a valve stopping the water which could then be opened and shut to allow the necessary amounts of water to flow into the system.

Once water has been allowed by the system, it would rest in PVC tubing with a substantially larger diameter. Here the water would rest to allow the roots of the plants to be emerged in the water and to absorb the water. The PVC tubing would have holes in the top where plastic caging would hold the plant but allow the roots to go into the tube and absorb the water.

As seen from the bird's eye view, the system would occupy a U-shape where the person utilizing the system would be able to stand in the middle and access all the plants with ease. The system could be altered to incorporate multiple levels but as it is, only consists of a one layer tubing design.

3.6 Osilama's Design

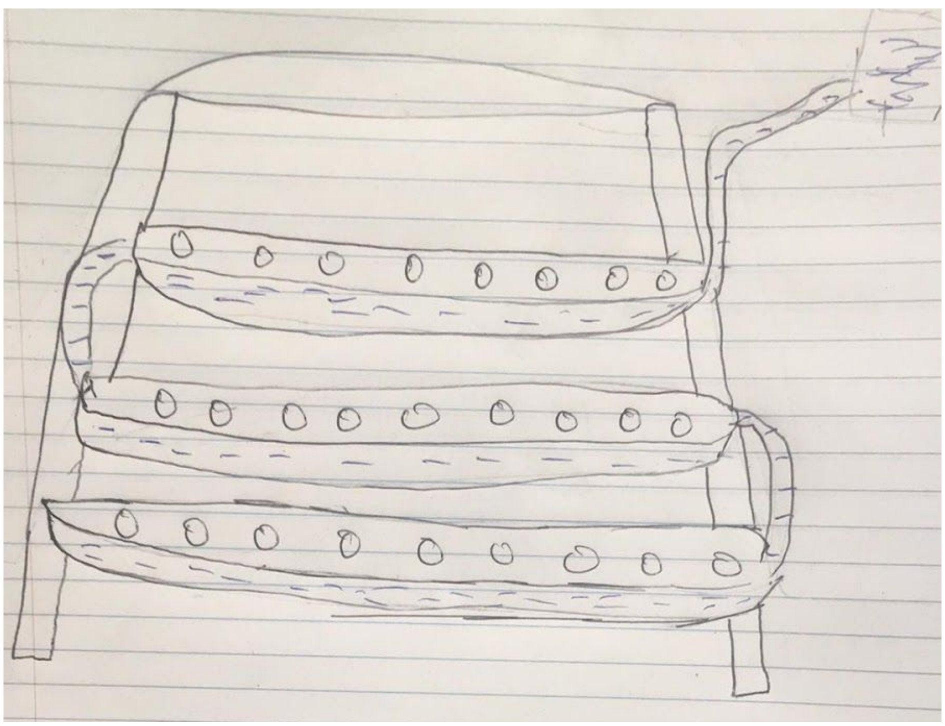


Figure 8. Osilama's concept design.

The system would start at a water reservoir at the top of the system. Via gravity, it would then travel down 4" PVC piping towards the first layer of plants and eventually snake through each layer until it reaches the bottom. The water flow can be controlled via valve between the reservoir and first layer of plants.

The pipes would be a on a gentle decline such that water has the ability to sit in the pipes so that plants can absorb it. Each layer would be able to hold approximately 8-10 plants; the system will hold approximately 24-30 plants. From a side view, the design resembles a ladder design.

3.7 Original Concept Design

For our original concept design we incorporated ideas from everyone's individual designs. From Cameron's, Osilama's, and Mason's designs, we took the idea of a gravity fed system with multiple levels. From Kasper's, Rohan's and Karan's designs, we took the idea of plant bins. With these aspects from each design, we managed to come up with the design seen in Figures 10-12.

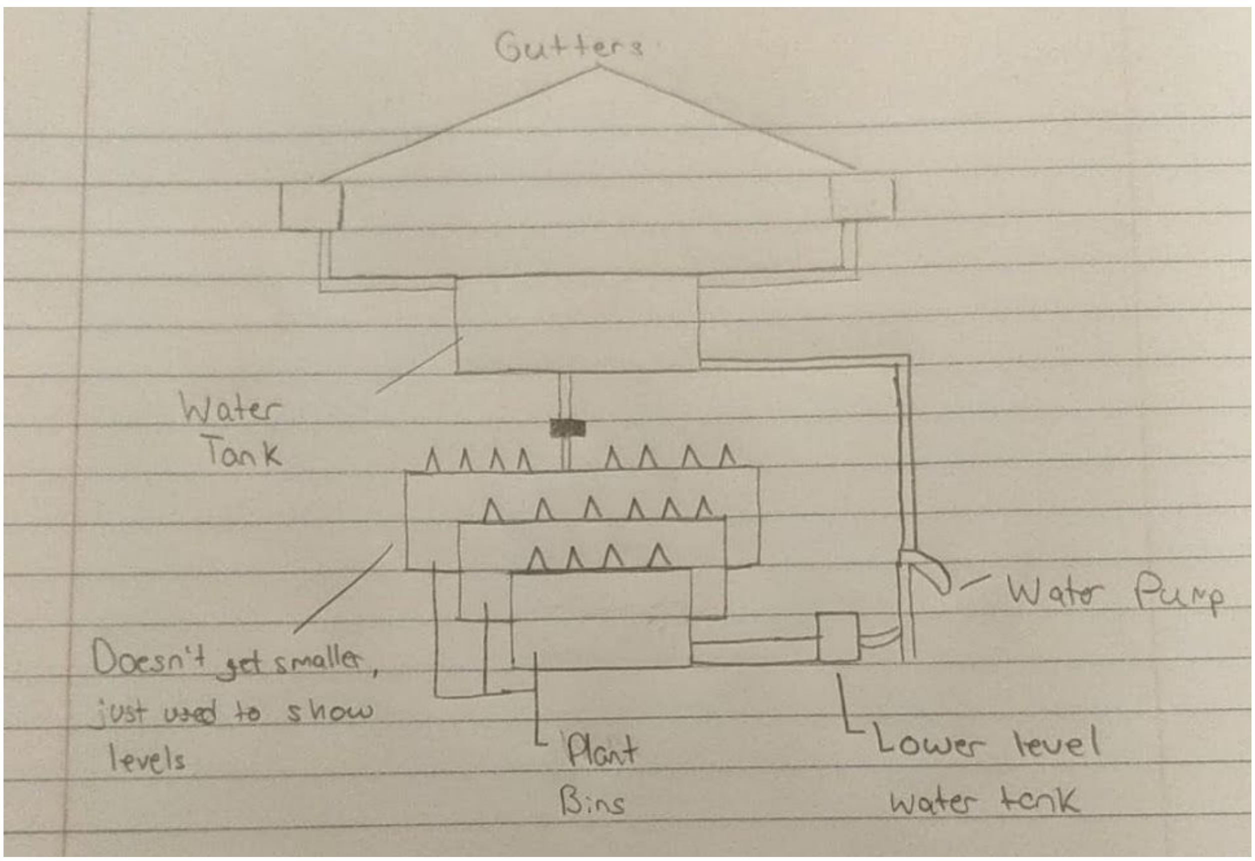


Figure 9: Front view of our original concept design.

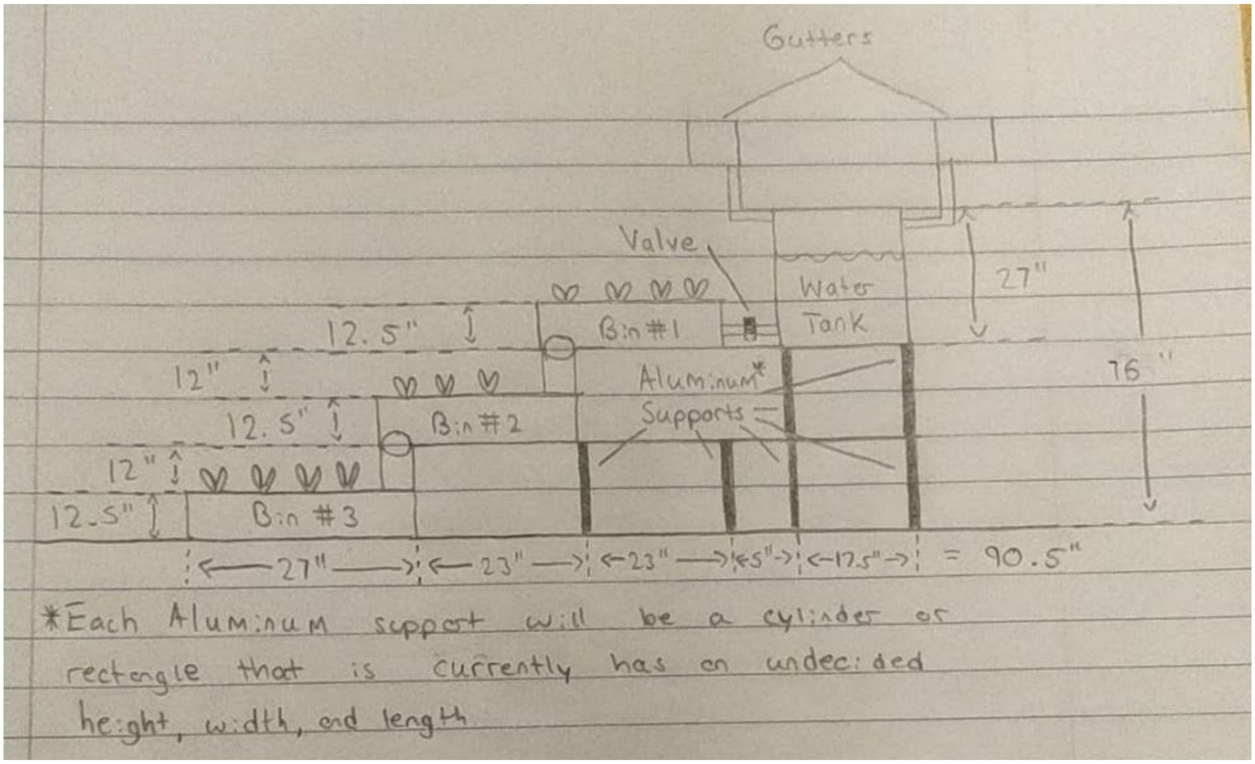


Figure 10: Side view of our original concept design.

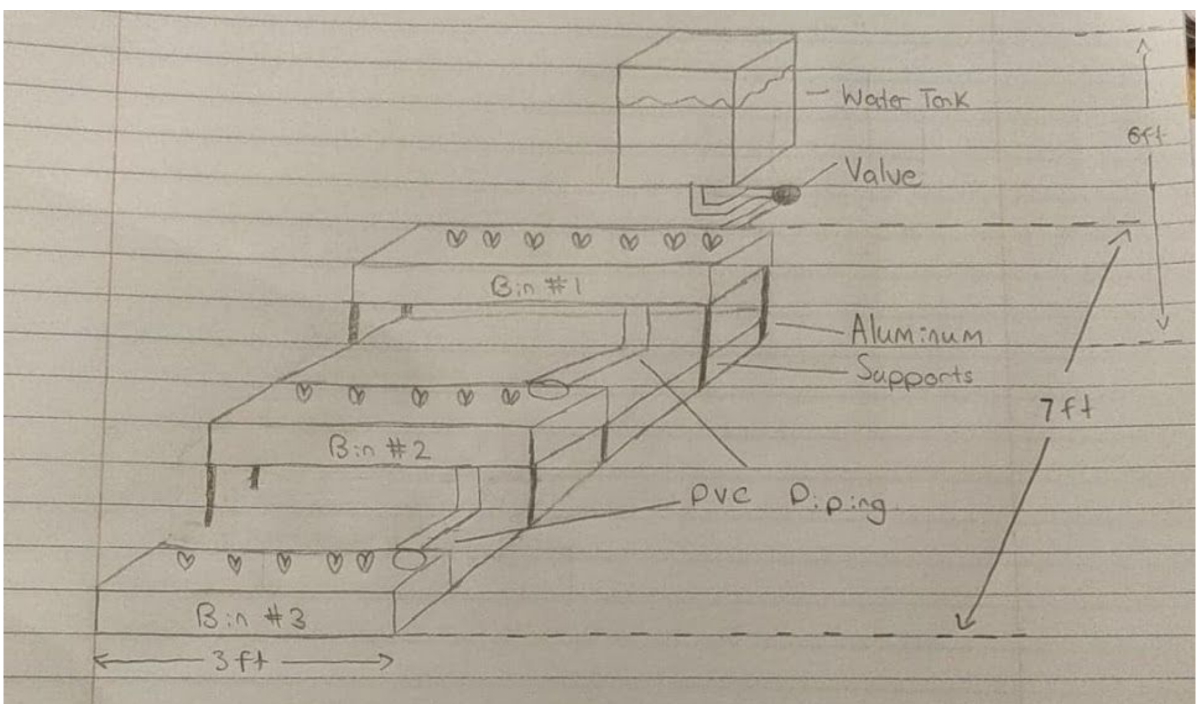
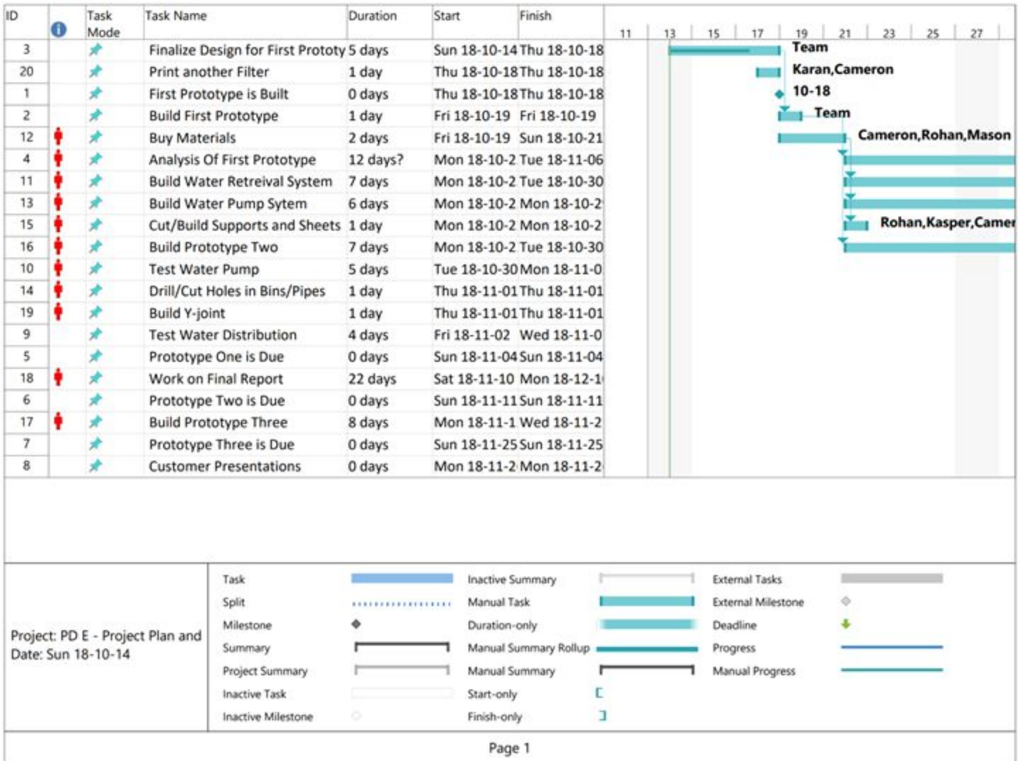
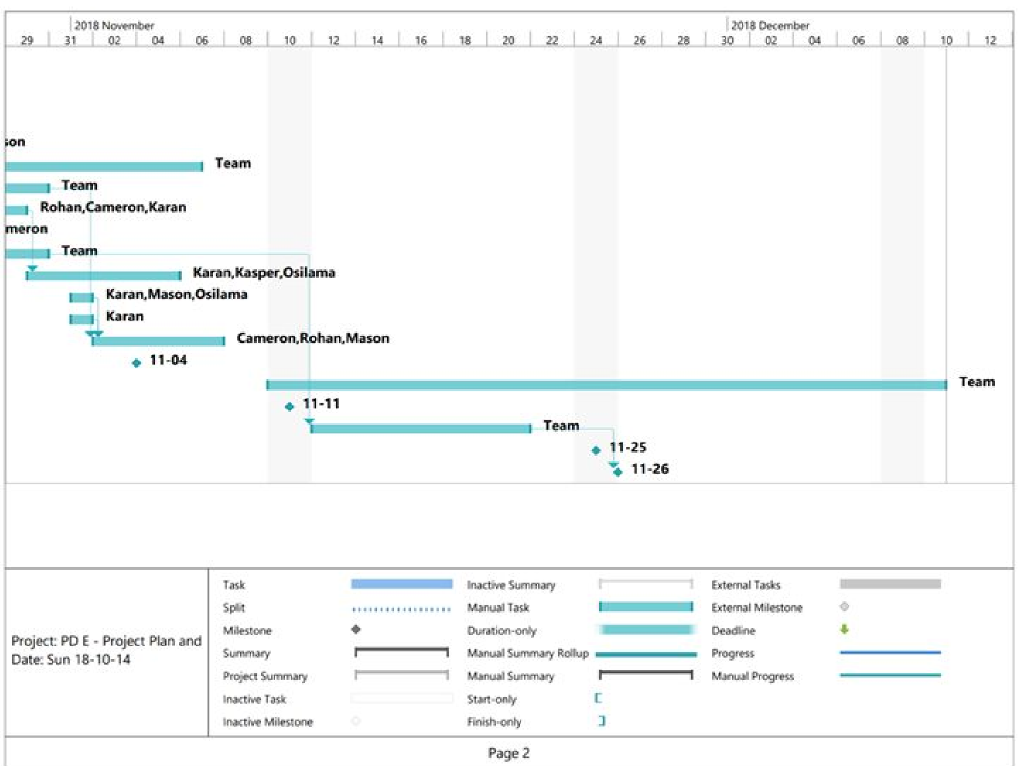


Figure 11: 3D sketch of our original concept design.

4.0 Project Plan



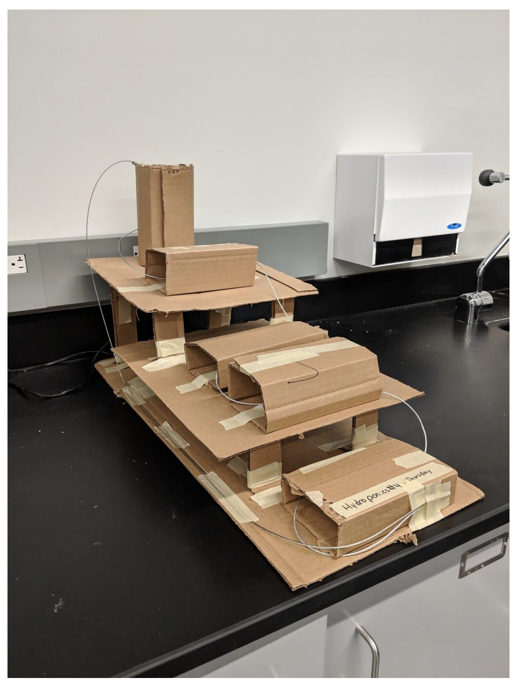
ID	Task Mode	Task Name	Duration	Start	Finish
3		Finalize Design for First Prototy	5 days	Sun 18-10-14	Thu 18-10-18
20		Print another Filter	1 day	Thu 18-10-18	Thu 18-10-18
1		First Prototype is Built	0 days	Thu 18-10-18	Thu 18-10-18
2		Build First Prototype	1 day	Fri 18-10-19	Fri 18-10-19
12		Buy Materials	2 days	Fri 18-10-19	Sun 18-10-21
4		Analysis Of First Prototype	12 days?	Mon 18-10-2	Tue 18-11-06
11		Build Water Retreival System	7 days	Mon 18-10-2	Tue 18-10-30
13		Build Water Pump Sytem	6 days	Mon 18-10-2	Mon 18-10-2
15		Cut/Build Supports and Sheets	1 day	Mon 18-10-2	Mon 18-10-2
16		Build Prototype Two	7 days	Mon 18-10-2	Tue 18-10-30
10		Test Water Pump	5 days	Tue 18-10-30	Mon 18-11-0
14		Drill/Cut Holes in Bins/Pipes	1 day	Thu 18-11-01	Thu 18-11-01
19		Build Y-joint	1 day	Thu 18-11-01	Thu 18-11-01
9		Test Water Distribution	4 days	Fri 18-11-02	Wed 18-11-0
5		Prototype One is Due	0 days	Sun 18-11-04	Sun 18-11-04
18		Work on Final Report	22 days	Sat 18-11-10	Mon 18-12-1
6		Prototype Two is Due	0 days	Sun 18-11-11	Sun 18-11-11
17		Build Prototype Three	8 days	Mon 18-11-1	Wed 18-11-2
7		Prototype Three is Due	0 days	Sun 18-11-25	Sun 18-11-25
8		Customer Presentations	0 days	Mon 18-11-2	Mon 18-11-2



5.0 Prototypes

Our group planned prototype one to be made out of cardboard while we would analyze the water collection system, bins and valves. Our second prototype would test the water collection and expanding subsystem; we would figure out the number of liters of water we should collect, how much we could collect, and the rough amount of water per bin and how much water we should expect in the cold season. Our third prototype would be a functional example of the final system incorporating all previous elements tested.

Prototype one was a low fidelity model and was mainly used to check for flaws in our physical system. We built the water tank, plant bins and aluminum structure out of cardboard while the plastic tubing was metal wiring. Afterwards we used a combination of hot glue and tape to hold everything together. The water pump was not included in this prototype because the focus was the main body of our system. After finishing prototype one, we came to the conclusion that the circular aluminum rods were not feasible due to the need to weld them to the aluminum sheets being installed. Instead hexagonal rods would be installed using brackets and therefore saving 1.7kg of weight. Secondly, we decided to go with a smaller plant bin size. This would increase the speed at which the water reached all the plants.Additionally, Paul suggested that we changed our aluminum sheets to wooden as it would be easier to assemble and weigh less. However, we decided to keep with the decision of using the aluminum as Spectra Aluminum was donating aluminum to our project.

Figures 12 & 13. Top and front views of prototype one.

The goal of prototype two was to reduce cost. Our group was over budget by $20 after building our BOM. Fortunately, after research, our group decided that we would 3D print remaining valves and funnels instead of buying them. We also decided that we would use a funnel instead of using the Y-joint. Two PVC pipes would let water fall into the funnel, sitting on top of the water tank. Seed Holders would be 3D printed from a design found online and the number of aluminum supports was changed from 16 to 10 due to weight issues. After analysing this prototype it was found that the number of rods could be reduced from 16 to 10 remarking in a weight lose of 7.3kg. We also decided that wooden sheets were much more practical than aluminum so we saved another 7.9kg from switching to wooden sheets.

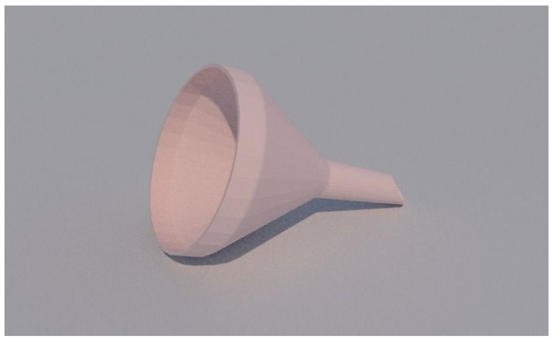
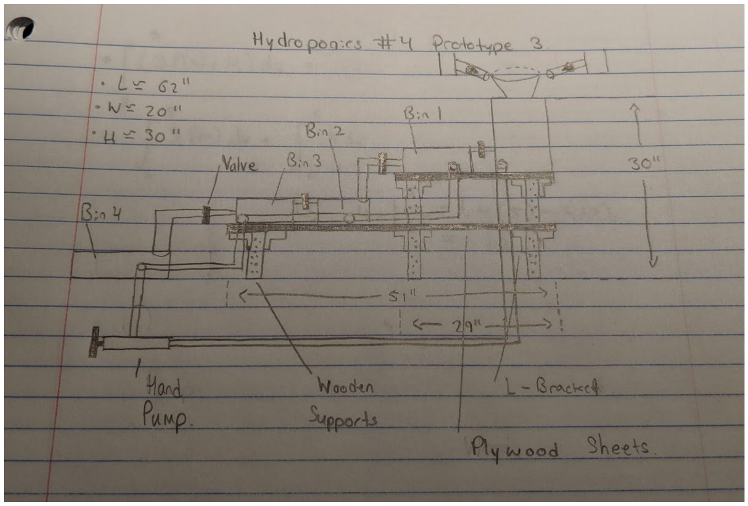
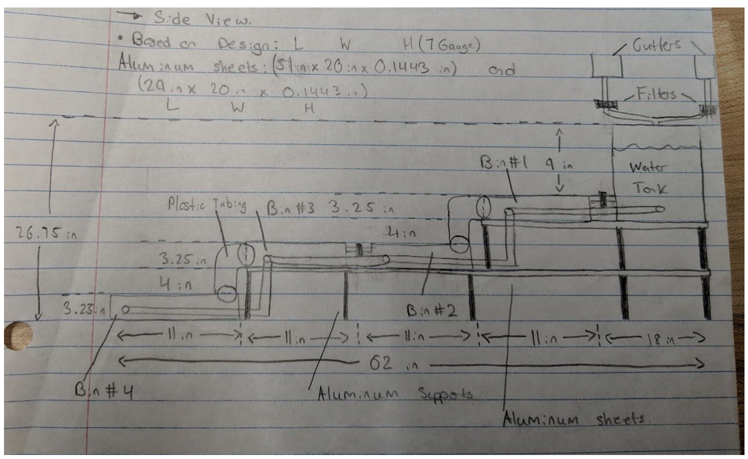


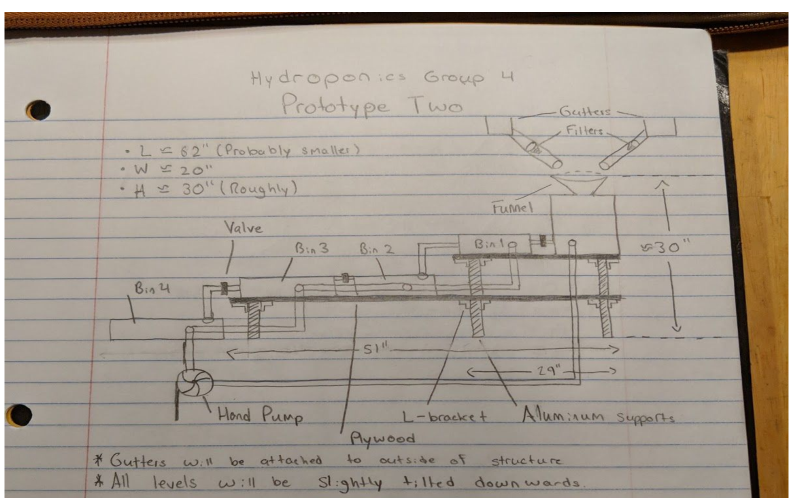
Figure 14. An example of the funnel was 3D printed.

Prototype three was built to resemble our final project. Our design required a continuous water flow. In this prototype we decided to buy valves, and a hand pump instead of 3D printing as we ran into leakage issues. We also changed our aluminum supports to wooden supports as wooden supports weighed only 0.94% of the weight of the aluminum supports. For this prototype, a leakage and water flow tests were performed with success.

Figures 15 and 16. The hand pump and valve that was bought for prototype three.







Figures 17, 18, & 19. Progression of prototypes.

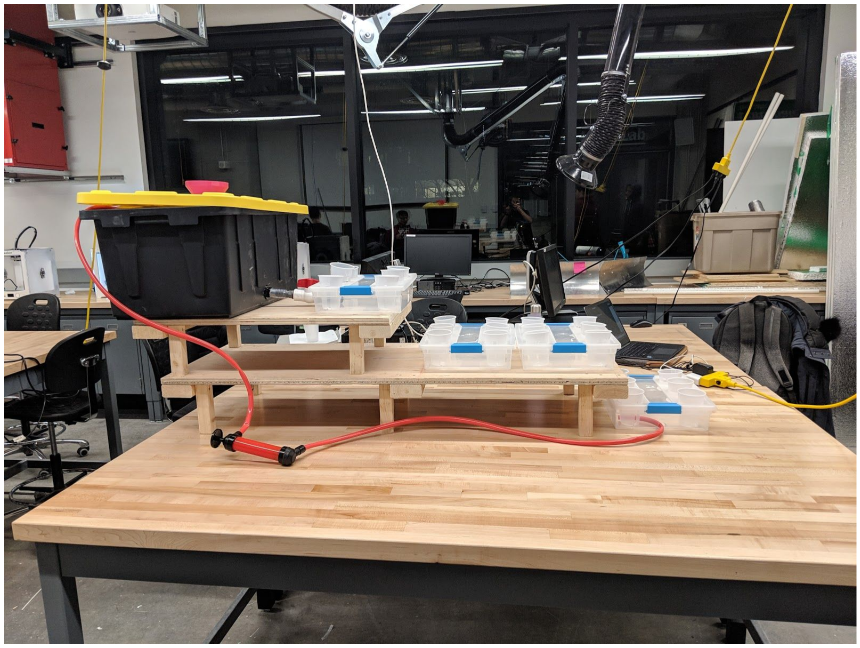


Figure 20. Prototype three.

6.0 Final Prototype Testing Plan

6.1 Why are we doing this test?

We tested our medium fidelity focused prototype to ensure that it complies with and satisfies the community's food provision requirements and the customer needs previously determined in the prior stages of the iterative design thinking process. In addition, prototype testing allowed us to identify failures in our design and any other unforeseen defects in the various aspects of the design that we needed to rectify, modify, and or improvise.

We intended to create a physical model, which would present the basic mechanics and the general idea or objective with our ultimate model. Also, since this is a community focused project, we made sure that the major purpose-dependent aspects of the design worked practically as well as theoretically.

6.2 Test Objectives Description

6.2.1 Specific Test Objectives

One specific test objective of making a focused prototype is to communicate with the community representative, a few of the most critical design aspects of the product which not only outline its basic functions, but more importantly, are the most uncertain and risky components of the project. This is to ensure that we the group have empathized and come to understand the major functional needs of the hydroponics system.

In addition, the focused prototype will effectively present the group's idea of how the main critical functions will work, thereby, establishing a superior level of understanding between the group and the customer regarding how the final product will work. Doing so, will eliminate any risk of presumptions and potential uncertainties, which may lead to a product that doesn't properly satisfy customer and user needs. Ultimately, this will establish confidence on us from our client, assure them of the final product and its quality, and ensure that our product satisfies their requirements and that they can use it in its entirety to the maximum potential.

6.2.2 Learning from the Prototype

Using the medium fidelity focused prototype, we are trying to communicate how the water will be distributed from the tank to the plants, how additional sources of water will be collected to compensate for potential water shortages, and how the water will be recycled throughout the system to ensure efficient water usage. We are communicating the critical mechanics of how the system will run, and run efficiently to produce sufficient food for the community for a long period.

6.2.3 Potential Results

1. The pipe and filter fittings aren't sealed enough to enable completely secured water recycling, thereby, reducing the efficiency and causing degradation in the system's usability and functionality.

2. The pipes and filters work properly in harmonized synchrony, while the hand pump, which allows for manual water flow distribution will fail due to potential damage caused by a build-up of water pressure due to improper water flow network designing.

3. While the gutters from the rainwater collection system are extremely weather tolerant, improper channelling of the water to the tank may result in an inefficient rainwater collection design that doesn't satisfy the needs of the plants, thereby, rendering the entire hydroponics system very unreliable.

6.2.4: Decision Making & Concept Selection

1. The first potential result will determine how we reliably join the water flow and distribution network, so that it is completely sealed and effectively recycled throughout the plants' ecosystem. If this result turns out to be true, then we will have to analyze and evaluate all options of modifying, completely redesigning, or selecting a previously discarded idea for the water flow system, so that it functions as desired, while it's fabrication still lies within the given budget of $100.

2. The second potential result will decide how we integrate the hand pump with the system, or whether we use a hand pump at all. If this result holds true, we will have to find out a feasible way of designing the water flow, so that even potential damage to system over its life should not cause pressure build up, and consequently, burst the pump. The pump is a key aspect of the reliability and usability of the hydroponics system as when water recycling is not proper enough in certain weather conditions, it can be manually done using the hand pump. If no feasible alternative can be devised, we will have to discard the idea of integrated a hand pump, and figure out a fail-proof way to ensure the perpetuity of water flow and recycling throughout all of the plants.

3. The third potential result will decide whether or not we have to modify how the water is guided from the gutter to the water tank, and more significantly, whether or not we need to discard the idea of using aluminum gutters and resort to different feasible alternative. If this result holds true, then we may have find a more secure alternative through the which the water is guaranteed to fall into a pipeline connected to the water tank (e.x: a funnel placed at the tip of the gutter to allow a large volume of water capturing space). Alternatively, we might find that the shape of the aluminum is not conducive to a structurally rigid connection to the perimeter of the greenhouse, consequently, causing potential collapse of the aluminum gutter, therefore, forcing us to resort to the idea of using ideally carved PVC pipes as gutters.

6.2.5: Testing Criteria for Success/Failure

1. Test #1: If water leaks from any point in the structure of the water flow and distribution network, it will be deemed as failure. Minute water leaks will deem the system as improvable, thereby indicating a preference of secure modification. No leaks at all will deem the system properly designed and functional, therefore, a success. However, if there are no leaks at all, we will have to do further testing for plant hydration by using sensors. If we detect inadequate and disproportionate plant hydration the water flow and distribution system will be deemed as a failure. If the collected sensor data shows a lack of plant hydration, we will just have to open the valves to allow more water to be in the system's

recycling loop. However, if the collected sensor data indicates adequate and proportionate plant hydration, the water flow and distribution network will be deemed as an overall design success.

2. Test #2: If the hand pump bursts due to high water pressure, or starts leaking, it is going to be deemed as a failure. We will then have to determine the problem in the pump's functionality or flaw in its integration with the plant hydration system using the hydration sensors, then rectify the error via means of modification, further sealing, complete replacement, seeking a feasible alternative, or completely discarding the idea of integrating a hand pump. If that happens, we are going to have to guarantee reliability of the life of the hydroponics solely by perfecting the plant hydration and water recycling system. However, if the hand pump seems to work properly in accordance with collected sensor data, it will be deemed as a success of design integration.

3. Test #3: If all or the minimum amount of water collected within the gutters doesn't drain into the pipe connecting to the water tank, it will be deemed as a failure. However, if water collection via gutter accumulation is efficient and sufficient enough, so as to absorb all water that falls into the gutter, it will be deemed as a success. If the gutter is deemed to be a failure, we will have to formulate a feasible alternative, such as using caulking to seal the gutters and place them at a slightly steeper angle to allow smoother water collection through the gutters. We may even have a to formulate a completely different water collection process that is stable and still weather tolerant.

6.3 How is this being done?

6.3.1 Type of Prototype & Reasoning for Selection

The type of prototype we created is a medium fidelity focused prototype. The reason behind the selection of this type of prototype is that this particular project has a long life, along with numerous functional requirements, a lot of which carry high risks and functionalities. It also requires numerous amounts of work to create and test a prototype that possesses all or the majority of the main design aspects. In addition, it costs too much time and money to create comprehensive or other prototypes, and other prototypes are not ideal for testing this particular project due to its practical and tangible nature. However, focused prototypes allow us to test the major and critical components of the entire project, which are the constituents of its foundation and main purpose, and which carry the highest risks and uncertainties with them.

If practical testing of the critical components successfully or sufficiently matches the ideal theoretical values of testing criteria, then other aspects of the design can be designed and improvised in accordance with requirements, standards, and constraints. Furthermore, focused prototypes cost much less than other kinds of prototypes, and due to the nature of the given budget and timeline for this project, focused prototypes seem to be the most feasible and effective way of testing our design for the hydroponics system, and therefore refine the design to allow the creation and delivery of a much superior final product.

6.3.2 Testing Process

First, you must determine and establish the purpose of testing the prototype. According to this prototype, the idea is to showcase the most critical components of the system which are basic and fundamental to the final product desired by the client. The most critical aspects happen to be the water flow and distribution system, water recycling mechanism, and the gutter-based rainwater collection system. You will need to frequently utilize the resources at hand, particularly at the STEM building [Makerspace, MTC, Brunsfield Centre, etc].

You will use these resources to:

1. Customize and Fabricate PVC and Braided Vinyl Tubing for pipeline connections between the tank and the bins, and make holes in the bins to hold plants.

2. Implant a manual water pump connecting the tank and the last of the bins to adequately regulate water flow and recycling.

3. Cut appropriately sized aluminum gutters to affix them to both of the sides of the greenhouse at an angle, attach a 3D printed funnel at the end of both gutters and at the top of the central water tank inside the greenhouse.

4. Attach tubes to the gutters' funnels and direct them to the funnel on top of the central water tank inside the greenhouse to allow efficient and reliable water collection.

5. Construct a wooden structure which will hold the tank at its peak, and hold the bins with the plants at a few different levels beneath the water tank.

6.3.3 Information Being Measured

The following are the major design aspects being measured. However, since this is a focused prototype, these aspects must be measured observationally.

Note*: To better understand the following, please refer to both of the pictures below.

Pipelines and Other Connections: Length of PVC and Braided Vinyl Tubing; Must be adequately sized to connect all of the bins with each other and the water tank, while still allowing the entire system to be properly placed on the wooden structure; Must have adequate flow rate.

Plant Pods: Diameter of holes in bins; Must be correctly sized to allow pipeline fittings for water flow and distribution; Must be correctly sized for holding all of the pods containing the various plants.

Water Pump: Pumping Pressure Capacity; Must be enough to push water effectively through the pipelines.

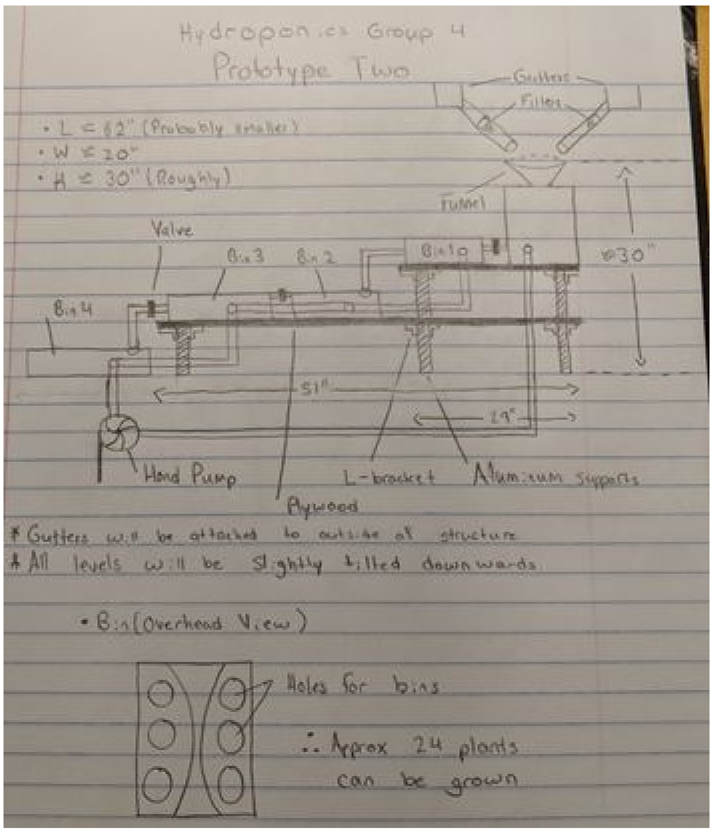
Gutters: Length & Angle; Must be long enough to be affixed to the sides of the greenhouse; Must be on a steep enough angle to allow rainwater to be gravitationally channelled to the central water tank through the funnel-pipe connection system.

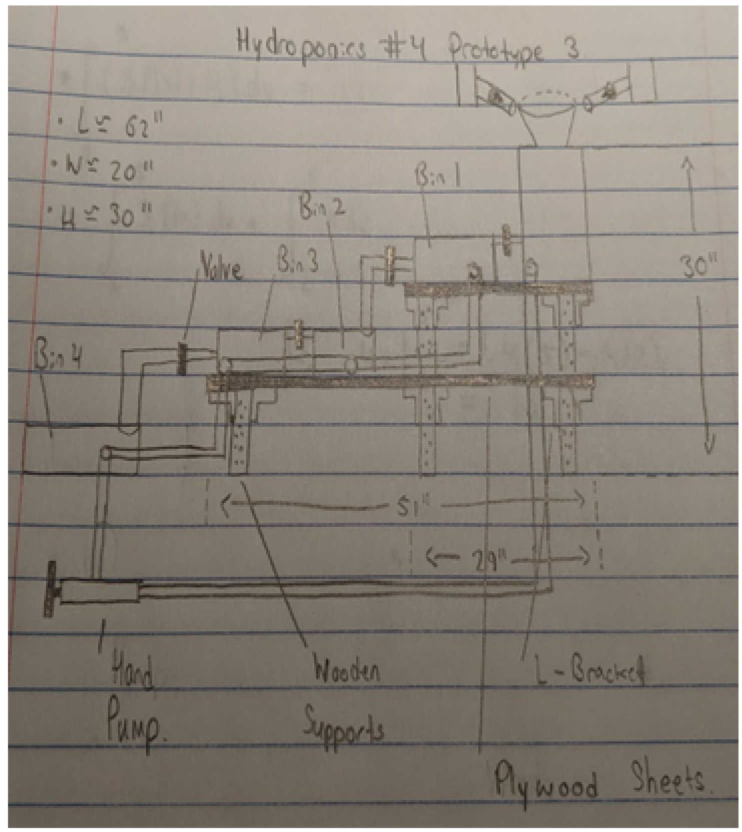
Funnels: Diameter and Size; Must be wide enough to cover the entire possible range of motion that the water flowing down the gutter can take, allowing all of it to be collected at the water tank; Tip must be sized adequately so that it can fit through the Braided Vinyl Tubing connecting them to the water tank.

Water Tank: Size, Durability, and Thermal Insulation; Must be large enough to contain all water being recycled throughout the system and all water that can possibly be accumulated throughout the year, this will be based on collected regional rainfall data; Must be durable enough to withstand great water pressure and quantity without risks of leakage; Must effectively insulate water, enough to not allow it to freeze.

Wooden Structure: Size, Structural Rigidity, and Weather Tolerance; Must have enough equally sized levels of elevation; Must be long enough to fit all bins in succession, yet short enough to properly fit within the area of the interior of the greenhouse; Must be rigid and strong enough to withstand extreme weather and still be able to function.

Ultimately, as all of the testing criteria are observational in nature, measurements are established and determined based on failure or success in satisfying all of the testing criteria. Below are a few pictures of the prototypes drawing in the ideation phase of the iterative design thinking process.





Figures 21 & 22. Prototype two (left) and prototype three (right)

6.3.4 Observations & Data being Recorded

The following are the major design aspects and the method of measurement, observation, and or recording.

Pipelines & Other Connections: Length of PVC and Braided Vinyl Tubing; We are using a measuring tape to determine the length of each piece of piping. We also need to measure the required length of Braided Vinyl Tubing to properly connect the gutters' funnels to the central water tank. For the remaining areas, whether to use PVC or Braided Vinyl Tubing for piping, will depend on the budget, and the length required. The constraint that the entire structure must fit on the wooden structure will be factored in when determining the ideal piping pieces' lengths. Also, we will equationally determine how big the valves and piping must be, in order to facilitate ideal water pressure to allow proper water flow and distribution throughout the entire system.

Plant Pods: Diameter of holes in bins; All we need to do, fill one bin with plants to see whether or not they are too clustered, and subsequently, whether or not they need space. Based on that, we can measure and determine the ideal diameter of holes in the bins to properly hold plants.

Water Pump: Pumping Pressure Capacity; We will fill the central water tank with some water, then we will also fill in some water in the plant-holding bin which is at the lowest elevation and furthest point on the wooden structure. After that, we will connect the pump to the system, and test whether it can easily pump water with enough pressure to adequately facilitate manual water flow and distribution.

Gutters: Length and Angle; We will have to measure the length of the longest sides of the greenhouse, then accordingly cut the aluminum gutters to the same size. Then, we will have to draw lines on both sides of the greenhouses, which will indicate the ideal angle at which we need to affix the gutters to the greenhouse on both of the long sides; the ideal angle will be the one which most effectively allows water to be channelled and guided towards the funnel and into the central water tank via gravity.

Funnels: Diameter and Size; We must measure the width of the aluminum gutters, then pour some water in it and let it drain from one side at an angle. We will repeat this in multiple angles to approximate the complete angular range between which the water can possibly fall out of the gutters. Based on the determine maximum angular range, we will determine the ideal diameter of the funnels that must be placed, one each, at the bottom-rear point of each gutter. Furthermore, the tip of the funnel will be dimensioned to just a tiny-bit less than the diameter of the Braided Vinyl Tubing, to allow proper a proper connection between them. The final funnel designed will be printed 3 times, one each for both of the gutters, and one to be placed on top of the central water tank to channel in collected water from the Braided Vinyl Tubing connecting the gutters from both sides.

Water Tank: Size, Durability, and Thermal Insulation; We will make sure to buy a water tank that has adequate thermal insulation to prevent water stock from freezing. Furthermore, we will ensure that the water tank will have an easy opening/closing mechanism, yet be durable enough to be impervious to natural external forces, thus, preventing it from breaking or leaking. Furthermore, we will make sure that the water tank is the ideal size to fit on the wooden structure, yet be large enough to collect all water that can possibly be collected over the year. The area of the base of the water tank will depend on the space remaining on the wooden structure to accommodate it. The height of the water tank will depend on the volume required to hold the maximum possible year-round collected rainwater, and it will also depend on the height of the greenhouse and the wooden structure.

Wooden Structure: Size, Structural Rigidity, and Weather Tolerance; For Size, we need to measure the perimeter and area of the interior of the greenhouse, then we must decide on how much space clearance there should be on each side for someone to enter the greenhouse and conveniently pick vegetables. After doing that, we can then determine, the maximum area, length, width, and height possible for the wooden structure. We need to find the maximum of all of the dimensions, so that it will be easier to fit the hydroponics system on the wooden structure. For Structural Rigidity and Weather Tolerance, we will use rectangular prisms made of wood as supports, to make sure that the structure doesn’t wobble at all, making it rigid and impervious to natural external forces like wind turbulence or ground vibration. We will use wooden platforms at different elevations with the supports appropriately placed above and below each platform at each elevation. The wooden platforms will be thick enough to support all weight, and durable enough to withstand natural external forces. Also, the wood used for both the supports and the platforms will be the type that does not absorb water, so that if there is any snow or water leakage from the roof or piping, the structure will not become soggy, and succumb to structural failure.

Figure 23. An example of the leakage test.

6.3.5 Required Materials & Approximate Estimated Cost(s) [BOM]

Table 2. The Bill of Materials (BOM)

#	**Item**	**Quantity**	**Dimensions (LxWxH)**	**Material**	**Cost**	**Link**
1	Gutter	2	6’ x 3” x 3”	Aluminum	$0.00	Spectra
2	Bins	3	27” x 15.56” x 6.51”	PP Plastic	32.37	Home Depot 1
3	Water Tank	1	27” x 18” x 12.5”	N/A	$12.40	Home Depot 2
4	3” PVC Pipes	1	10’ x 4” (Diameter)	PVC Plastic	17.96	Home Depot 3
5	Aluminum Supports	12	15’ x 0.75” (Diameter)	Aluminum	$0.00	Spectra
6	Braided Vinyl Tubing	10	10’ x 1”	Vinyl	$32.43	Home Depot 4
7	12 Gauge Aluminum Sheets	2	5’ x 3’ x 0.1’	Aluminum	$0.00	Spectra
8	Valve	5	N/A	PVC Plastic	$30.74	Home Depot 5
9	Filter	2	3” x 3” x 3”	PLA Plastic	$0.00	Makerspace 3D Printer
Total					$125.89	

6.3.6 Work Required to be Done

We need to research and decide the ideal materials to buy, based on well defined metrics and target specifications. Of course, we will ensure that they satisfy all constraints and requirements to the best of our capability, allowing the client to help us improve our design. We also need to 3D print funnels, appropriately cut properly measured aluminum gutters, wooden supports, wooden platforms, and holes in the bins for plants and pipeline connections. Ultimately, we may then construct our medium fidelity focused prototype, conduct testing, gain valuable feedback from our client, and evolve our design to the final prototype.

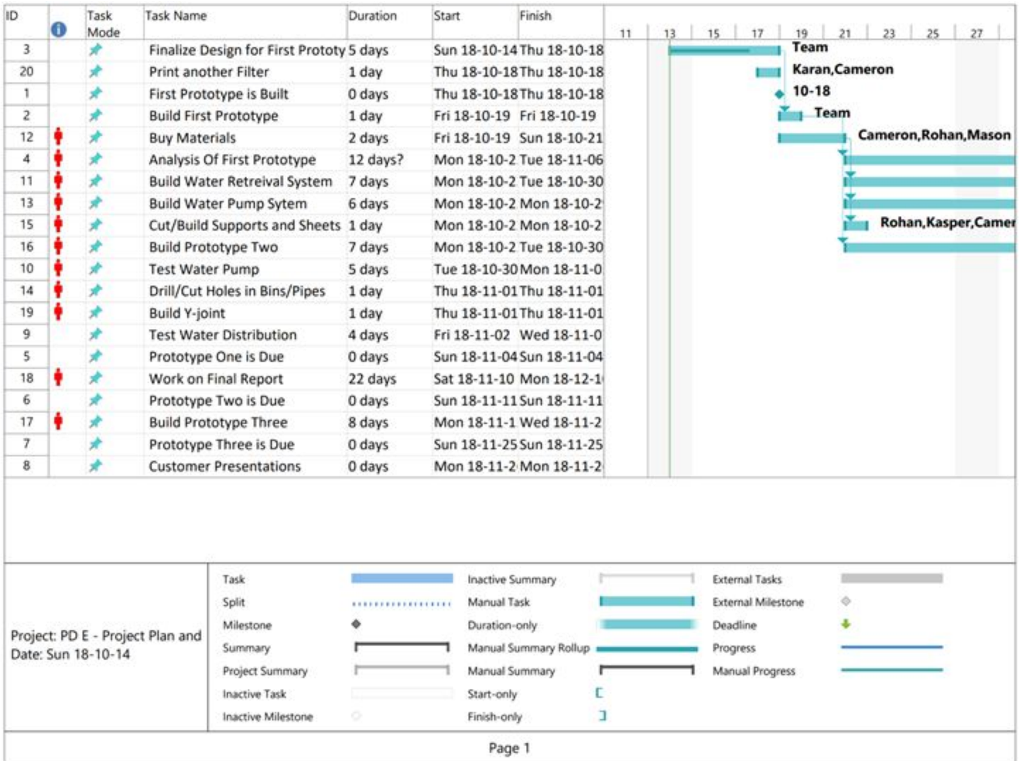
6.4 When is it happening?

6.4.1 Duration of Test, Dependent Factors or Pre-Test Tasks

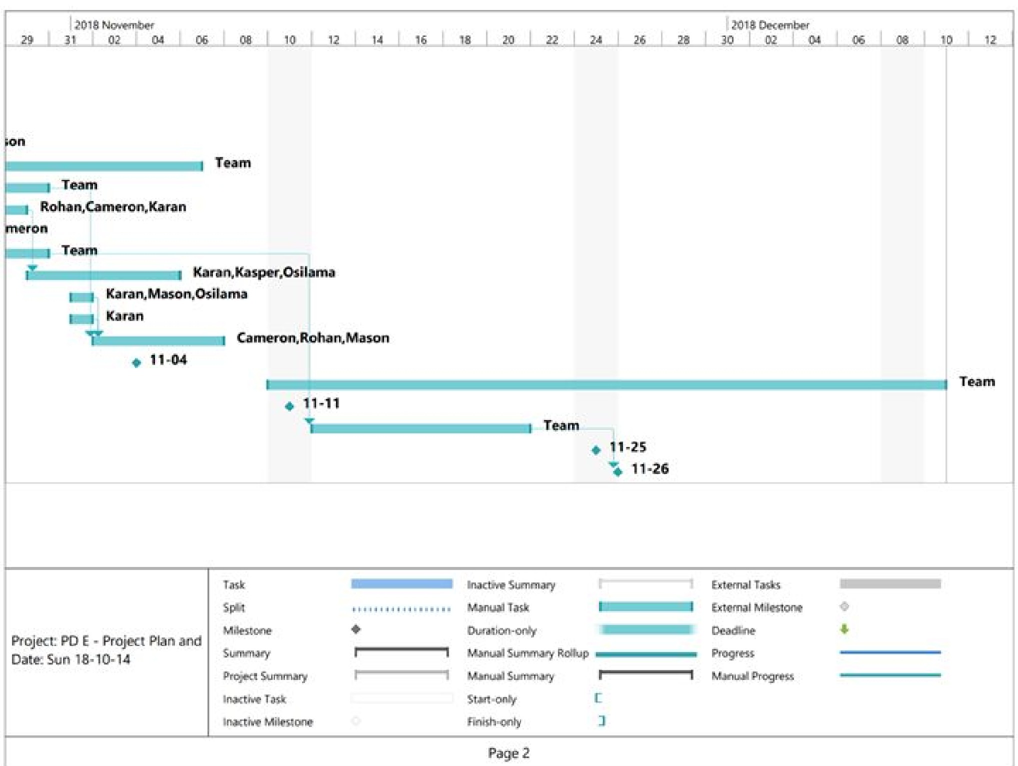
The duration of the prototype testing would depend on team members' availability, stock of material for construction of prototype, and overall team productivity and efficiency. There are other tasks that must be done before prototype testing, and completion of our prototype is based on the majority of those tasks. All of the relevant variables and pre-test tasks have been factored into the Gantt Chart you will find below.
We will be using all resources at our disposal, including, but not limited to: Makerlabs, Makerspace, MTC, Brunsfield Centre, and Hydraulics and Structural Lab, and etc. We always consult our Project Manager, T.A, and the other engineers around at the STEM Complex, to identify and use the most efficient and ideal tools for any task that we must do to formulate our medium fidelity focused prototype.

This final prototype primarily depends on further feedback from our clients upon consultation in accord with the focused prototype. This was done in class, when the representative of the community came for a client meet and follow-up. Following the collection of valuable feedback from our client, we executed a thorough analysis and discussion to go forward with implementation of additional features, and modification or adaptation of existing features in our design. We established a superior and clear understanding with the client regarding the overall and final design and any changes suggested to them and the reasoning behind said changes. We then used the final feedback to make any necessary changes or modifications, adaptations, and additions to our design, and finally present a high fidelity comprehensive prototype of our hydroponics system.

6.4.2 Integration of Prototype Testing with Gantt Chart



ID	Indicators	Task Mode	Task Name	Duration	Start	Finish
3			Finalize Design for First Prototy	5 days	Sun 18-10-14	Thu 18-10-18
20			Print another Filter	1 day	Thu 18-10-18	Thu 18-10-18
1			First Prototype is Built	0 days	Thu 18-10-18	Thu 18-10-18
2			Build First Prototype	1 day	Fri 18-10-19	Fri 18-10-19
12			Buy Materials	2 days	Fri 18-10-19	Sun 18-10-21
4			Analysis Of First Prototype	12 days?	Mon 18-10-2	Tue 18-11-06
11			Build Water Retreival System	7 days	Mon 18-10-2	Tue 18-10-30
13			Build Water Pump Sytem	6 days	Mon 18-10-2	Mon 18-10-2
15			Cut/Build Supports and Sheets	1 day	Mon 18-10-2	Mon 18-10-2
16			Build Prototype Two	7 days	Mon 18-10-2	Tue 18-10-30
10			Test Water Pump	5 days	Tue 18-10-30	Mon 18-11-0
14			Drill/Cut Holes in Bins/Pipes	1 day	Thu 18-11-01	Thu 18-11-01
19			Build Y-joint	1 day	Thu 18-11-01	Thu 18-11-01
9			Test Water Distribution	4 days	Fri 18-11-02	Wed 18-11-0
5			Prototype One is Due	0 days	Sun 18-11-04	Sun 18-11-04
18			Work on Final Report	22 days	Sat 18-11-10	Mon 18-12-1
6			Prototype Two is Due	0 days	Sun 18-11-11	Sun 18-11-11
17			Build Prototype Three	8 days	Mon 18-11-1	Wed 18-11-2
7			Prototype Three is Due	0 days	Sun 18-11-25	Sun 18-11-25
8			Customer Presentations	0 days	Mon 18-11-2	Mon 18-11-2



6.4.3 When are results required?

Prototype testing results are required in time for the next client meet, and before we commence operations of building the third prototype, which will be a high fidelity comprehensive prototype. Certain key factors of the project plan which depend on the timely completion of prototype testing include: gaining further feedback from the client, deciding changes/modifications, additions, and adaptations required to implement in our third prototype, presentability on Design Day, and ability to submit relevant deliverables and documents on Brightspace. The complete details of our plan to acquiring results, and completing this project are given on the two pages of the Gantt Chart above. Please refer to it to more clearly understand what our final project plan is, and how duration and date of completion of prototype testing results affect it.

7.0 Lessons Learned

This project taught us many important lessons that will be extremely valuable in future projects. From this project we learned the importance of using appropriate materials for the given project, the importance of delegating tasks, and the importance of time management.

In the beginning our team wanted to use aluminum for supports because we were getting aluminum donated to us from Spectra aluminum. Even though the aluminum was free, it was much more difficult and expensive to attach to the system as opposed to wood. The additional strength of the aluminum was also not needed for the project. In the end we decided to go with wood for the supports and learned a valuable lesson about using materials that are appropriate for the given project.

Delegating tasks and time management were very important for this project. As a team we had to identify the tasks that needed to be accomplished and divide them evenly among the group members. By giving each team member a specific task we were able to stay organized and finish our project efficiently. The use of a Gantt chart was extremely helpful when delegating tasks. We also had to use the time we were given efficiently and stay focused on the task at hand to ensure the project was completed on time. The lessons we learned about delegating tasks and time management will undoubtedly be useful in future projects.

8.0 Conclusions

Our prototype testing plan as a whole, conveys a thorough explanation of our third prototype regarding the complete encapsulation of what would be done, what is the reasoning behind it, and how it would be executed. Our third prototype is considered to be our final product, if not, at least for design day it will be. Its foundation will comprise that of our group's collective fundamental understanding of all potential uncertainties, risks, and failures which have been completely tested, and will also be based on feedback gained from the previous prototypes presented at the client meets which have happened in our class previously.

Ultimately, we think, the third prototype will be the most superior evolution of the previously constructed prototypes, and will encapsulate all feedback acquired from our client. Therefore, we envision and expect our third prototype to be fully functional, and be the final representation of the product which will be delivered to the clients.

We intend to have the client tangibly interact with the prototype and test it themselves to determine if they see it fit to their needs and requirements. Although, potentially, a few design aspects of our prototypes may not completely suffice our client's expectations, we still consider it to be the most feasible and superior solution, with regards to budget and time constraints.

9.0 Bibliography

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3) Jaymon, et al. "Miracle-Gro AeroGarden Bounty with Gourmet Herb Seed Pod Kit-903110-1200." *The Home Depot*, The Home Depot, 14 Jan. 2018, www.homedepot.com/p/Miracle-Gro-AeroGarden-Bounty-with-Gourmet-Herb-Seed-Pod-Kit-903110-1200/302330922.