GNG 1103

Final Design Report

Greenhouse Construction

Submitted by

Construction Group 6

Ross McNamara, 300119731

Ebirim Praise, 300081723

Jack Graffi, 300130338

AK Au 300105733

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University of Ottawa

Abstract

Based on the problem and needs addressed by a client, a greenhouse is designed. The design process was used to plan and construct our final product, a fully functional greenhouse. The first steps of the design process centered around planning, which we used to create the list of needs and rank their importance. Next, benchmarking was done to find previous solutions and compare the best features of each. Once the best features were decided upon, various conceptual designs were created to highlight each feature and choose the best one, the global concept. Once the global concept was agreed on, our group was able to start construction. To construct this greenhouse, our team was allocated a budget of $500. Our team constructed the greenhouse during weekly 3-hour lab sessions, allowing us roughly 20-22 hours of construction. Due to the breakout of COVID-19, the greenhouse was only built up to the second prototype.

Table of Contents

List of Figures

List of Tables

List of Acronyms

Acronym	Definition
PVC	Polyvinyl Chloride
‘	Foot
“	Inch

1 Introduction

1.1 Relevance

Greenhouses are an important method of growing plants, and for some an excellent food source. Greenhouses provided many benefits to traditional farming techniques. With a greenhouse, one will have a longer growing season, plant isolation, reduced pest and insect exposure, and can avoid pesticides. The owner of a greenhouse has full control over their produce, making it a desired option.

1.2 User Requirements

Our greenhouse was designed to be very self-sufficient, thus the user is not required to provide high maintenance.

1.3 Why our Product is the Best

The differentiation in our design which makes our product better stems from the roof. Our pvc pipe frame roof is the easiest to construct, and the least time consuming. Our roof can support all weather conditions that will be faced in this region, and is built to last. The corrugated sheets covering the pipes are attached securely, preventing any water leaks or looseness. Our roof was originally planned to be constructed from wood. It would have been triangular shaped and the same height as our pipe roof. Upon construction, we discovered a better solution, the pipe framed semi-circle roof.

2 Need Identification and Product Specification Process

After the initial client meeting, the first step of our design process was to identify the needs and rank their importance. This can be seen in Table 1. After this was done, the following problem statement was identified: A 6'x6' clear greenhouse is needed to grow food during the spring, summer and fall. The structure must be large enough to fit a hydroponic system, it must collect rainwater and run with little maintenance and it must protect against rodents. After this was identified, we started benchmarking with past years projects, this is shown in Table 2. After the benchmarking, we ranked these designs by each need, and Group 1's greenhouse seemed the most appropriate. This ranking system can be seen in Table 3.

Number	**Needs**	**Importance (1-5)**
1	Dimensions: Base must not exceed 4 x 8, or 6 x 6.	*3*
2	Winter resistant	*4*
3	Easy to assemble/disassemble	*3*
4	Rodent proof	*4*
5	Require little to no maintenance	*4*
6	Easy to replace water	*2*
7	Height: Must fit in a workspace for transportation	*3*
8	Must house a solar panel	*3*
9	Must collect rainwater	*5*
10	Must fit hydroponics system	*5*

Table 1: Needs and Importance

Greenhouse:	*Greenhouse construction 4*	Construction Group 3 2018	*Greenhouse construction 1*
Length	6 ft	Frame of the base was 6’ × 4’. Walls were 5’ tall, plus ~2’ for the roof.	7 ft
Height	6ft		7ft
Width	4 ft		4 ft
Outer Material	Polyethylene	Polyethylene plastic sheets	Plexiglas
Cost	N/A (probably under $500).	N/A	Approximately $500
Assembly	-Sidewalls disassemble to 3 sections. Back disassembles to 2 sections. -Sides connected by nuts and bolts	-4 walls attached to the base by screws, walls attached to each other in the corners by bolts -The plastic sheets were stapled on the frame -The door was attached to hinges The roof was attached with many bolts and some brackets.	-The walls were secured to the base with nails. - The polyethylene was used to cover the frame using staples. -The doors were attached to hinges with screws. -The roof was attached to the frame using nails and bolts and the solar panel was attached using screws.
Gutters	Aluminum gutters	-Gutters were lined on the long sides of the roof.	N/A

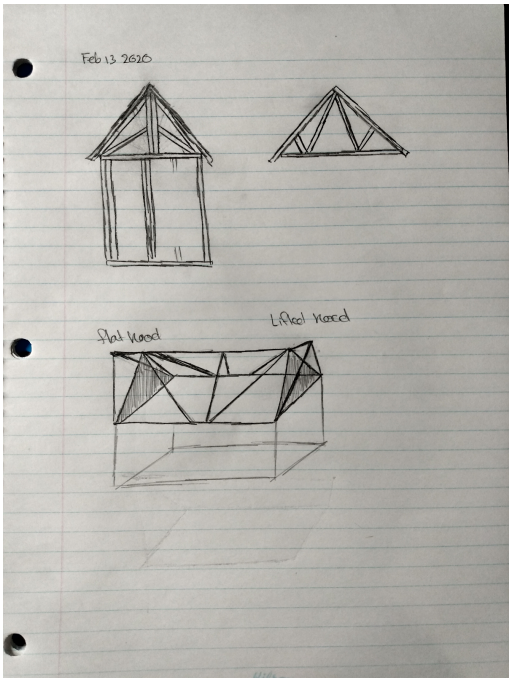
Table 2: Benchmarking

Example	Weather & rodent Resistance	Rainwater collection	Roof: complexity	Size (base & height)	Cost
‘Group 4’	Fair	Gutters	Simple	Good	~$500
‘Group 3’	Fair	Gutters	Complex	Good	~$500
‘Group 1’	Good	None	Simple	Good	~$500

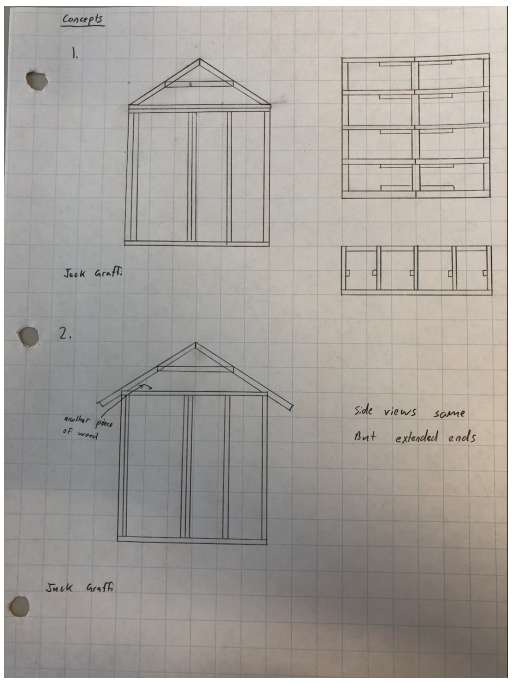
Table 3: Ranking system

3 Conceptual Designs

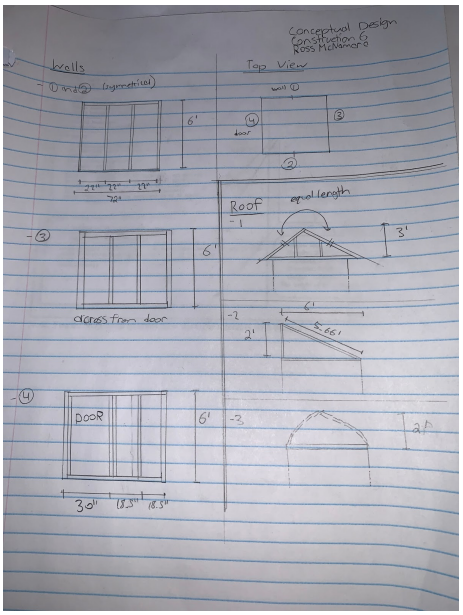
The following designs created by members of our group reflect the best specifications from benchmarking.



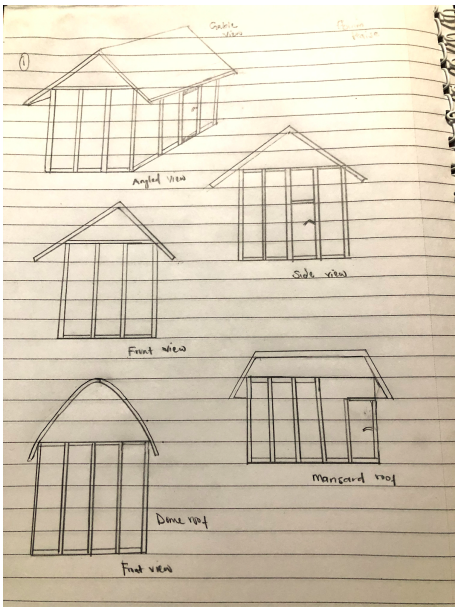
Team Design 1



Team Design 2



Team Design 3



Team Design 4

From the analysis and evaluation of the designs previously listed, the following global concept has been developed, Figure 5.

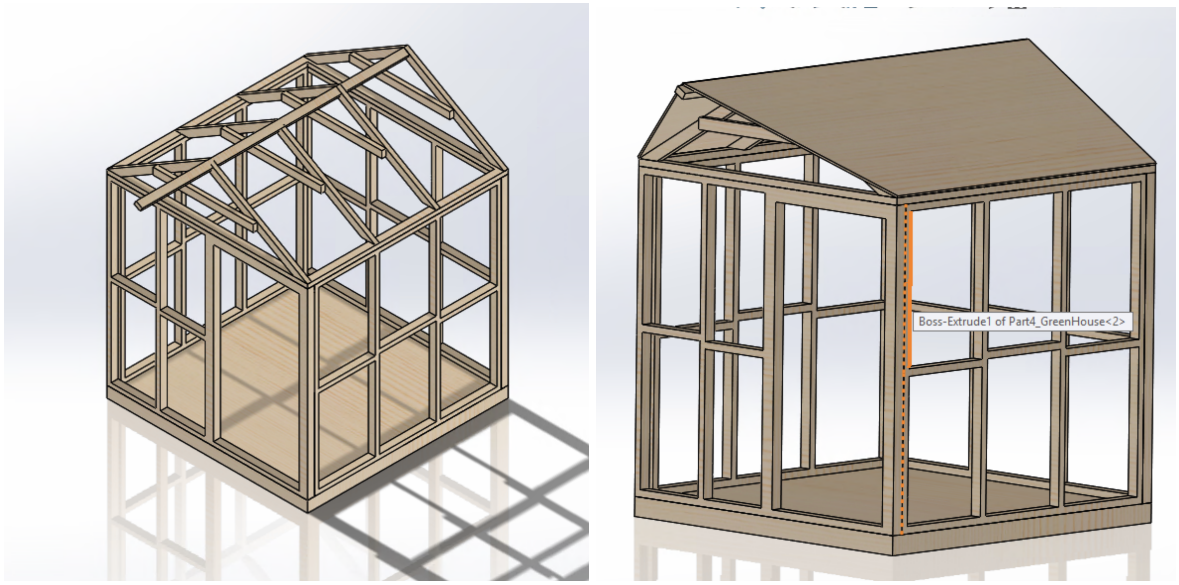


Figure 5: Global Concept

This concept combines the 6’ by 6’ base, walls of height 6’, and a roof extending 2’ off the ceiling. The base will consist of 2 by 4’s, and a plywood-type particle board. Three of the walls consist of 4; 2 by 4’s spaced 22” apart. The final wall contains the door, 30” wide doubled wood supports. The other 2 by 4’s are spaced 18.5’ apart on this final side. The idea for a triangle roof will be used. The triangle roof extends 2’ above the ceiling, making the structure 8’ tall above the bottom 2 by 4 on the base. It will be a triangular prism, however the side will extend out (can be seen in the figure).

Reason for our design:

Our Design is 6’x6’x8’ inorder to fit our hydroponic system while still being small enough to construct in a lab and for transport. The sides of the greenhouse will be wrapped in plastic inorder to allow sunlight to pass through while still remaining weather resistant. The roof will be covered with a hard plastic material to allow sunlight through while remaining rigid enough to endure 4 seasons of weather. The team is also contemplating laying down metal fencing underneath the plastic sheets so that animals cannot chew their way inside.

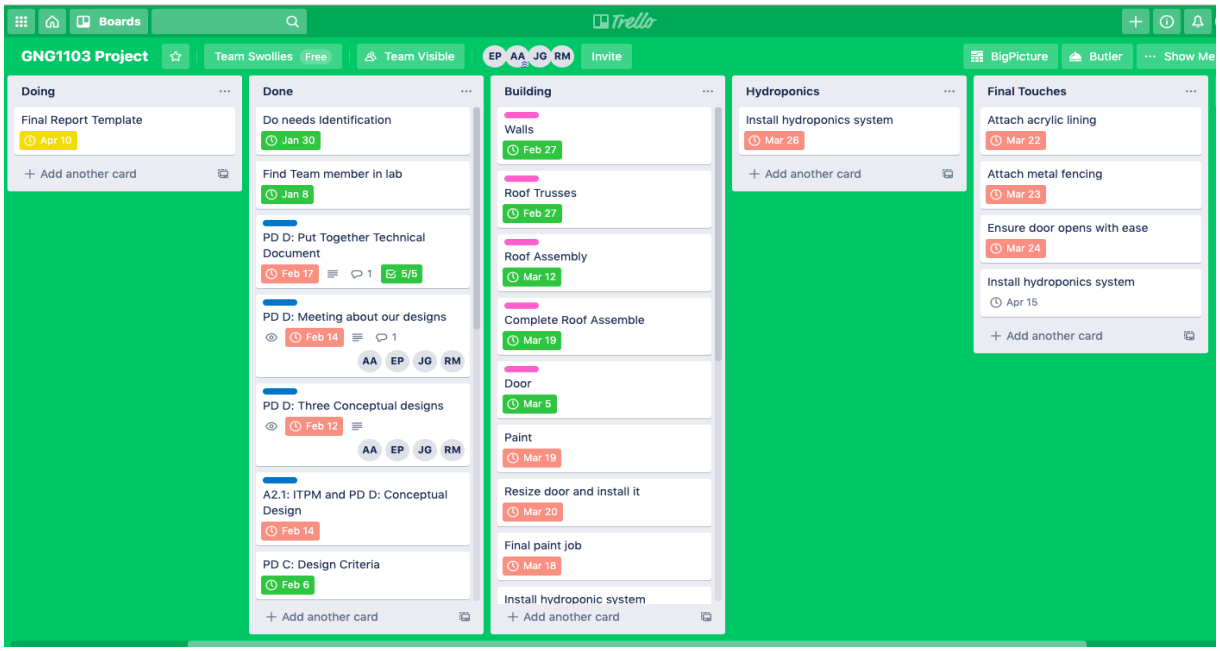
There will only be ceiling joists on the front and back end of the greenhouse. On the inside, seeing that the ceiling joists would be only 6’ above the ground, collar ties will instead be used to provide support while also maximizing the space inside the greenhouse. For the roof to extend outwards and hang over the walls, the ridge beam will be longer than the frame, perhaps 1-2 feet on both sides. The surface of each side of the rooftop will be made into a trapezoid, to

connect the ends of the beam to the frame. The Greenhouse is constructed in sections and bolted together for easy assembly/disassembly.

Change of Design:

Although the base and walls from these designs were used in constructing our greenhouse, the roof was scrapped. Upon building our structure, group members found that there is a quicker and easier design for the frame of our roof. A basic idea for a semi-circular roof can be noticed at the bottom of Figure 4. This idea is the basis for the final roof we built, which is further explained in sections 4 and 7.

4 Project Plan, Execution, Tracking & Bill of Materials



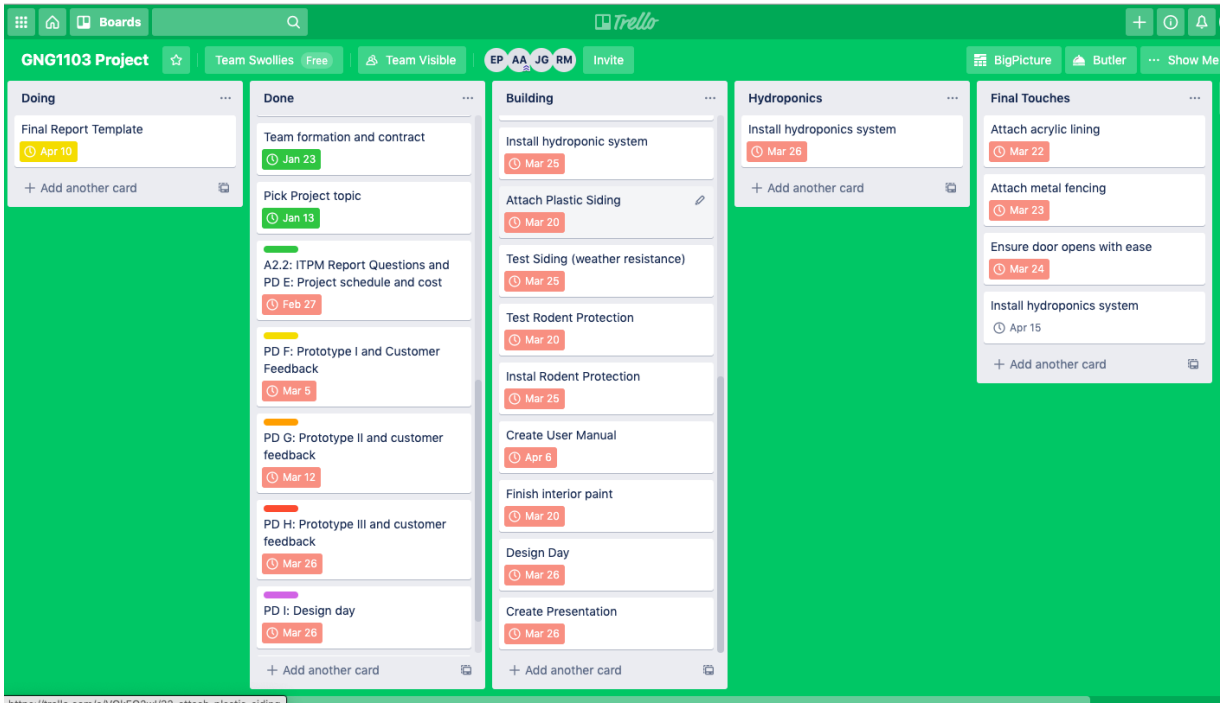


Table 4: Trello

Execution

Our Project commenced on Wednesday, the 8th of January 2020. We had a laboratory session and we divided ourselves into groups. Our group is the Construction group 6 and we are a team of 4 students. Every week for the last three months, we met for at least 3 hours to work on the building and then we write about our progress in the deliverables. In the course of study, we realised that the app Trello will help in our organization so we uploaded all our work on it. We also tracked our progress and were able to know the outstanding work and those completed. It also helped us finish and submit our deliverables before the deadline.

Firstly, we started by having the client tell us what exactly they would want, which is a hydroponic system that is less than 8’ high and can be taken apart and put together at will. It should also be able to withstand all weather conditions, especially winter.

Based on that we came up with a prototype, we made a domed roof structure that fits the description and also withstand extreme temperatures. We later started construction by making the foundation and floor. In the process of this, we made sure all the fasteners were screws instead of nails so that it can be taken apart. The dimension is 6’x 6’ and it was made typically of wood. The reason which includes the fact that the structure is designed to house a hydroponic system that weighs less than 50lbs so adding more materials like steel will be unnecessary. We ensured the floor could hold more than 70lbs by letting some team members stand on it.

We then moved on and made the frames for the walls which had a length of 6’ too. We made sure that the walls were sufficiently stable by adding a couple of wood pieces to specific places like the top and bottom of each edge and we also added more wood horizontally to maintain the balance of the other wood. While making the wall frames, we considered the placement of the door so we made a different dimension for that particular wall.

Furthermore, we started the roof which was a bit easier compared to what we thought, so we finished the frame in a day. We made the frame out of PVC pipes that were bent into shape. We then connected them at opposite ends of the walls with screws to ensure that it is stable. We also screwed in an extra pipe across the frame to hold up the other pipes. After ensuring the frame was strong enough, we covered it with clear plastic vinyl sheets for protection.

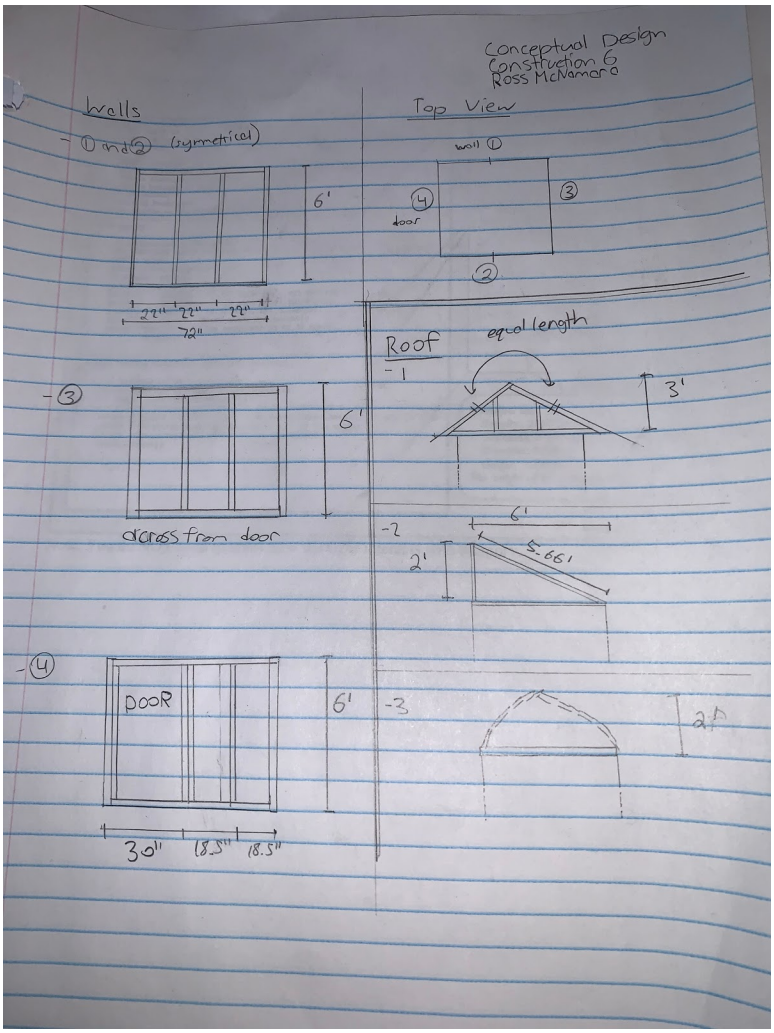
For external protection and finishing, we used different colours of paint to cover the walls, the door and also the floor. In the future, we plan on covering the entire building with the vinyl sheets, properly installing the door and the wire fencing to prevent rodents and other pests. Then we will install a gutter that will be able to collect rainwater that will be used by the hydroponic system.

Tracking & Bill of Materials

Material	Unit price($)	Quantity	Total Price
Corrugated Sheets (26'' X 8''	23	4	92
Polyvinyl Chloride (PVC)	8	5	40
Wood Planks, OSB (½'' X 4' X 8')	15	6	90
Screws	-	A pack	30
Paints	10	2	20
Vinyl Sheets, (50''X 90')	3	6	18
Wire fencing	50	1	50
Total	=		340

Table 5: Bill of Materials

5 Analysis



For the square base of the greenhouse, two adjacent beams were cut 3 inches shorter to fit on the inner section of the other two beams.

For the three non-door walls, support beams were placed 22 inches apart. The door wall was given a width of 30 inches, and supports beams 18.5 inches apart.

The roofs shown in Figure 8 were not used in the final design, as the pipe roof proved to be better.

Final analysis for the structure could not be completed due to the outbreak of COVID-19. (This would include metal fence dimensions, area of acrylic lining, etc.)

Figure 6: Dimension View

6 Prototyping, Testing and Customer Validation.

6.1 Prototype I

The test objectives of the first prototype are to ensure the strength of the structure. The first prototype gives the client an initial idea of what the team has accomplished. This will help the client tell the team if something is wrong before the team spends a lot of time and resources building something that doesn't work. The design will be successful if: If the base can support the weight of 3 people on all parts. If the wall can stand with minimal sway (within 1-2 inches of displacement) due to wind and other exterior forces.
The base is built initially from a 6’ x 6’ wooden frame, with many beams on the inside. Pieces of particle board are laid overtop, in flush with the beams, and were secured using a nail gun. Four walls are made in a similar fashion but without the plywood. They are placed on the side edges of the base and screwed in place. One of the walls is made to contain the door. Two strips of wood were laid along opposite sides of the frame on the top. Holes were drilled into these strips to hold the PVC pipes that would form the roof. The pipes were laid in so that the additional height given by the roof would not exceed 2’. The pipes were cut in half so that joints would attach both the pieces of the pipe together and also allow for the ridge at the top.
We used spruce wood for the base and walls and Polyvinyl chloride pipes for the roof to be able to achieve the roofing that had the shape of a semicircle. Particle boards were used for the floor. A picture of the first prototype one can be found as Figure 7.

Figure 7: Prototype I

6.2 Prototype II

This prototype is carried out to check the quality and stability of the roof and how well the door fits the frame. These tests are critical to perform because without a stable roof the greenhouse may collapse due to harsh winter conditions. Another important test objective is to ensure the pipe roof is strong enough to support certain weather conditions such as snowfall and wind. The door must be able to open and close without friction from the frame of the door and the door must keep the majority of the weather outside.

After the pipes were measured and cut to fit the frame, we connected them and together in bits and used the PVC pipe connectors to create a dome and after this was done, we added screws to the edge of the frame for more stability. To test if this method worked, we tried to apply pressure to the joints and areas of connection to see the parts that were still weak and we fixed it either by moving its location or adding screws.

To create this prototype, a door needs to be cut to 68'' height and the width can remain untouched. The door then needs to be connected into the frame through the hinges. 4 PVC pipes that need to be cut to 4' halves and assembled onto the roof frame, then attached up top. Next, an acrylic roof must be fastened over the pipes on the roof.

The door was built of wood and so was the sill, the knuckles to enable the door swing was made of iron and also the lockset to lock and open the door is required to. The estimated cost for these additions to the prototype is $95. A picture for prototype II can be found as Figure 8. Figure 8 displays our prototype after painting, however the complete roof and door cut to size can be seen.

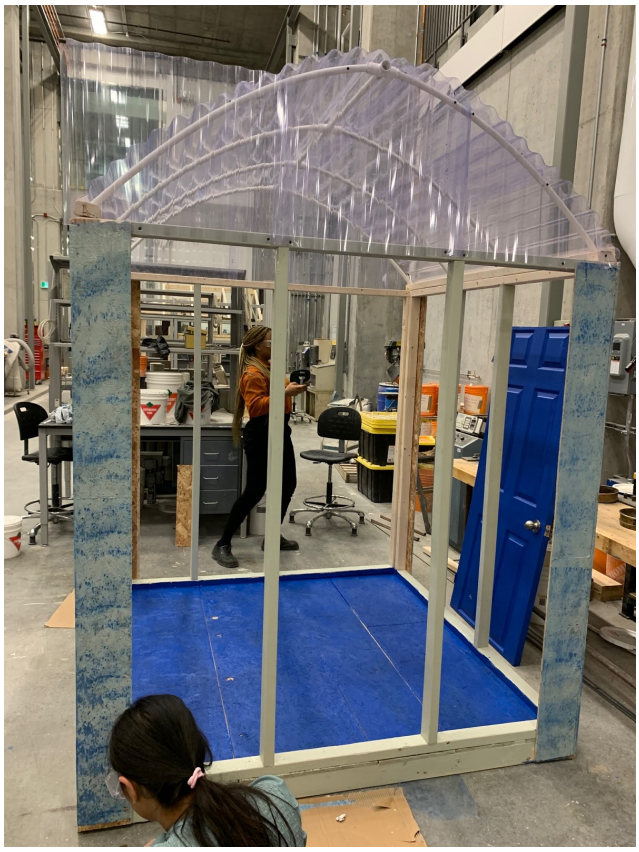


Figure 8: Prototype II

6.3 Prototype III

Due to the breakout of COVID-19, the third prototype was not able to be completed. The main aim is to verify the resistivity of the greenhouse to rodents and pests. The second test is to ensure the outer lining is strong enough while remaining translucent enough to allow sunlight in for the hydroponic system. The results from this test will determine the size of metal fence spacing in order to prevent rodents. For the outer lining, these results will determine the type of material and the number of layers of material needed.

For a rodent-proof system, success is an exterior that will block all rodents from entering the greenhouse. We will stop testing once we have a completely sealed structure that can not be torn or bitten by rodents. For the outer lining, the test will be successful if the greenhouse can withstand multiple significant weather events outside without tearing or allowing water inside, while still allowing enough light into the greenhouse. To make the greenhouse rodent-proof, metal fencing will cover the exterior of the structure up to 2 feet high. The fence will be purchased and placed around the building excluding the door to enable entrance and exit. For the outer lining, it will be placed outside next time a significant snow or rain storm is forecasted or we could spray it with a hose.

For this setup, we will require a fence and screws for support. The prices are $56 and $5, respectively and this sums up to $61. We will need approximately 132 square feet of outer lining, costing about $46. To complete this prototype, will need to find a metal fence tight enough to block any rodents from entering the structure. A metal mesh fence is preferred as it will stop the largest variety of rodents. Once we know that the fence has the correct dimensions, we will wrap it around the lower exterior walls of our structure, and attach it. We must also find an outer lining that will surround the walls of our greenhouse. Once we have it, we will adhere it to the frame, tight enough to resist water and looseness. We are required to select a paint that will be visually pleasing for the customer, once we find it we can coat the wood frame and door with it. There is no image available for prototype III, as it was unable to be constructed due to COVID-19.

7 Construction Process/Final Solution

The final solution was assembled via numerous sections that were nailed together to make a greenhouse large enough to capacitate a finished product from the hydroponics team. Although a few components were not allowed to be completed due to unexpected/uncontrollable circumstances, they will nonetheless be included in the final solution.

Individual sections:

The Base was produced starting with two 2”×4”×6’ members (spruce), and two 2”×4”×(6’-3”), assembled into a 6’×6’ piece by a framing nail gun. Two extra 2”×4”×(6’-3”) members were laid inside of the piece dividing the area into thirds. Perpendicular to these, extra studs were laid, cut specifically to the measured distances in between the members inside which they were laid. Aligned with these studs, chip wood planks were set over top of the truss, also nailed by the framing gun. The finished base is 6’×6’

The Walls were produced starting with two 2”×3”×6’ members (spruce), and two 2”×3”×(6’-3”), assembled into a 6’×6’ piece by a framing nail gun. Two extra 2”×4”×(6’-3”) members were laid inside of the piece dividing the area into thirds. With the exception of the door, which had a 3 foot gap for the door and the remaining section was divided into thirds (see appendix ii for more images)

The Roof was constructed with a 6’x6’ wood frame and was made with 2”x3” members (spruce). Then, four 1 inch holes were drilled into 2 parallel sides of the frame 24 inches apart at a 30-45 degree angle. Then eight 4’ PVC pipes were placed in the holes and connected at the top with a PVC pipe connector. Then three 2 foot PVC pipes were connected at the top of each arch for stability. Then corrugated plastic sheets were cut and placed and screwed into the PVC pipe structure. The two ends were also covered in corrugated plastic sheets cut to side and screwed into the PVC pipe and wood frame.

External components

Wire fence was to be laid on top of the clear sheets which would wrap around all the walls. This combination would allow sunlight to pass through, and based on the fencing would not allow large animals or smaller rodents to enter. These two materials are very inexpensive, and were to be laid on the very exterior of the greenhouse, which allows for easy maintenance should they become worn out.
Corrugated sheets were used to cover the roof from all angles. This material is transparent and UV ray resistant which is perfect in terms of lighting. It is also very resistant to environmental factors that would usually slowly deteriorate a greenhouse, such as scratching and rotting. Aluminium Gutters would be used alongside the roof due to its resistance to rusting. Nearly all visible angles were painted, mostly a light shade of blue.

Assembly

The walls were screwed into the base and screwed to each other at the corners. To increase stability, 6”x76” plywood boards were cut and screwed into the base and walls at each corner. Then the roof was screwed on top of the walls. Then the door was screwed into the frame using outward facing hinges. The final step was to wrap the

structure in plastic wrap which was attached with staples.

Final Design

The final greenhouse is 6’×6’ in base area, and 6’-8’ (based on where you stand) in height. It is sturdy, capable of collecting rainwater, and its large capacity is able to store much more than just the hydroponics equipment (water storage, generator, etc). The outer materials make the greenhouse weather and rodent resistant, and the assembly is simple enough so that maintenance will be very easy. It was coloured in bright shades of blue, and along with the curved roof makes it look pretty.

8 Conclusions and Recommendations for Future Work

As we started finishing the sections, we had connected them together right away. This made it difficult in some cases to connect other components or to make further adjustments because they would be out of reach, or the main structure up to that point was heavy and difficult to move/rotate. Assembling the roof required us to make screws on top near the ridge, which was dangerous while the half completed section was already connected to the structure so that it was 8 feet above the ground. Had we assembled the sections individually, or atleast built the roof before planting it on the main structure, the process would be much easier. Brackets should have also been used to connect the sections together so that the greenhouse could be easily disassembled later on.

The stiffness of the PVC pipes used for the roof was underestimated. Two pieces of wood were lined parallel on top of the walls to be an anchor in which the pipes were connected to. The pipes were naturally straight and were being bent, so there were exerting a great force that bent the anchors which made them look noticeably crooked. The wooden anchors should have been doubled up and also connected to one another, instead of being just connected to the walls. Metal brackets, or just simply wooden plates could have been nailed to the connecting from the anchors to the walls to tightly secure them together, much like those used to secure the walls to one another.

In conclusion, extra planning with respect to the more specifics connecting sections, and the use of materials would have improved the quality of the final greenhouse.

9 Bibliography

https://makerepo.com/

https://www.homedepot.ca/en/home.html

External resources past benchmarking from MakerRepo and price finding from Home Depot were not required for the construction of the greenhouse.

APPENDICES

APPENDIX I: User Manual

Features: A fully functional greenhouse able to fit 3 people inside. A rodent proof metal fencing with acrylic lining to allow maximum sunlight and block rain. A sturdy corrugated plastic sheet roof which allows maximum sunlight and blocks rain and snow. An easy to use door which closes tightly to prevent any rodents from entering.

Maintenance:
-Ensure the door is closed at all times not in use.

Parts List:
-Six 6 feet long 2 by 4's of spruce wood for the base.
-Six 6 feet long 2 by 4's of spruce wood for the 3 non-door walls.
-Seven 6 feet long 2 by 4's of spruce wood for the wall with the door.
-Two 6 feet long 2 by 4's for the roof.
-Four 8 feet long PVC pipes bent for the roof.
-One straight 6 feet long PVC pipe for the roof.
-Four 6 feet tall corrugated plastic sheets for the roof.
-One 6 feet tall corrugated plastic sheet to be cut to fill gaps on the roof.
-Minimum 85 nails with nail gun.
-Door cut to a height of 69 inches and standard 36 inch width
-4 litres of blue paint (colour optional)
-One piece of 6' by 6' particle board for the floor.

Capabilities: Able to support the weight of 3 persons, ~36 square foot base for growing plants. Fits persons of all heights (peak at 8 feet). Allows maximum sunlight in all directions. Metal-mesh fence blocks entrance of rodents. Remains structurally stable in rain, snow and wind.

Installation Instructions: Refer to Sections 7 and 4 for detailed installation instructions.

Safety Guidelines: Watch for nails that may have loosened after reconstruction.

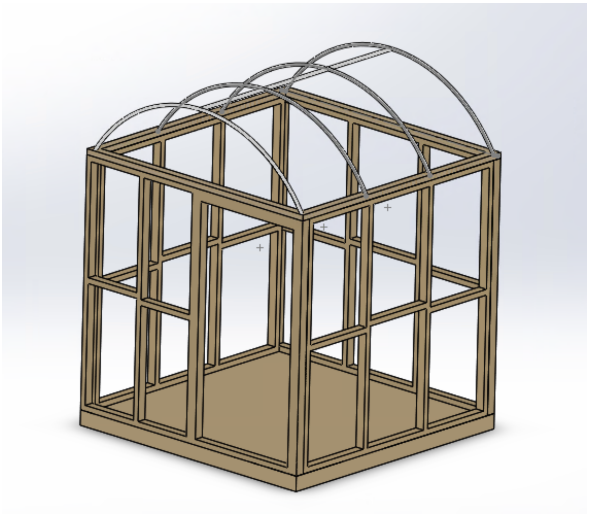
Precautions: Do not enter the greenhouse if there is suspected damage to structure/supports.

APPENDIX II: Design Files

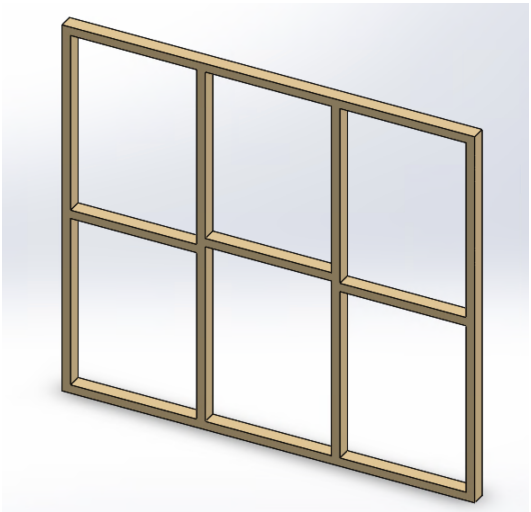
Our project can be found on MakerRepo as “Greenhouse Construction 6 W2020”.

-https://makerepo.com/RossMcNamara/greenhouse-construction-6-w2020

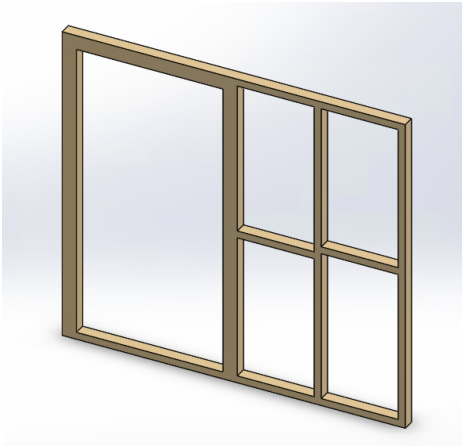
Found below are the components of the structure software generated.



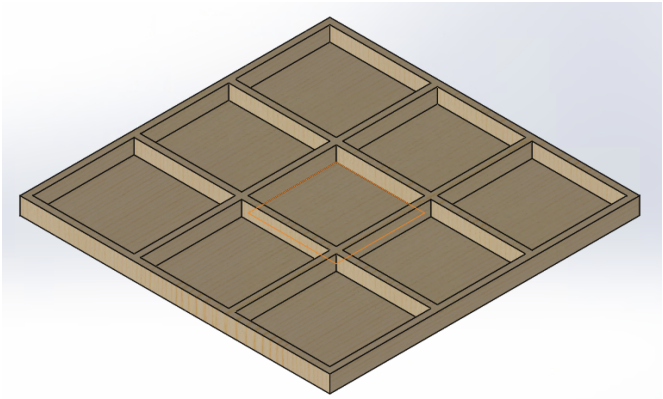
3D modeling of frame using CAD software Solidworks



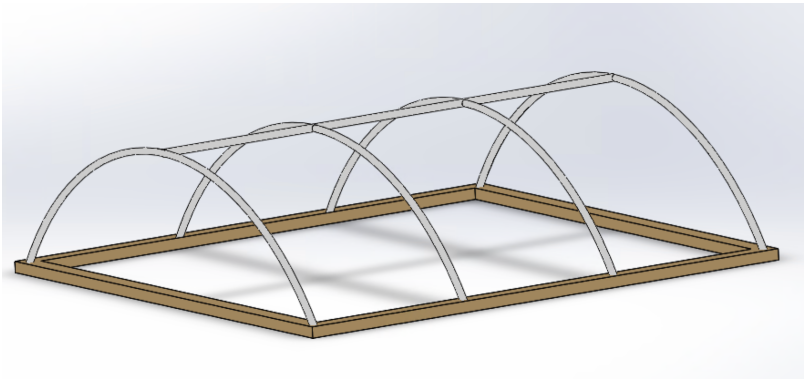
Left, right and back wall



Front wall containing door



Base



Roof