GNG5140

Design Project User and Product Manual

Super Greenhouse

Submitted by:

Sustainable Food Storage – Team B

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1 Introduction

Deep Roots Food Hub (DRFH) is grassroots, volunteer-run non-profit organization based in West Carleton, Ontario, focused on fostering a sustainable and secure local food system. The organization supports agricultural professionals by assisting with the cultivation, storage, and distribution of locally produced food, ensuring that communities have access to affordable and healthy options. In 2020, DRFH advanced its mission by designing and constructing an off-grid root cellar, providing a sustainable method for safely storing root crops while enhancing local food accessibility.

Figure 1 – Deep Root Food Hub's Sustainable Root Cellar

After discussions with Dr. Bruce from DRFH, the GNG5140 Team B was tasked with designing a new Greenhouse for the facility. Growing structures in agriculture, like greenhouses and high tunnels, serve for plant propagation, extending seasons, and boosting and regulating crop production. Both structures typically share a design of metal frames with walls and roofs made from materials such as polyethylene, polycarbonate, or glass. According to the client's requirement, The Greenhouse that is to be designed should be off-grid with a sustainable energy source and preferably capable of being built by volunteers within the area.

Figure 2 - Satellite view of DRFH and suggested location of the greenhouse

Our team's greatest source of inspiration for this project is a Greenhouse situated in Nebraska called the "Greenhouse in the Snow" [1]. At 91, Russ Finch, a retired U.S. Postal Service worker, developed a natural method for heating his home, which led him to design a greenhouse that maintains a stable indoor climate year-round. By using the Earth's consistent temperature of 52 degrees Fahrenheit, which is found 8 feet below ground, his geothermal system warms the greenhouse in winter and cools it in summer, conserving energy and lowering operational costs [2]. Greenhouse in the snow can be seen in Figure 3.

Figure 3 – Greenhouse in the Snow

This report aims to describe the final prototypes and provide insights into the prototype specifications and test results, and also design and practical considerations of the project.

In the following sections, first the problem and prototype are explained, then a guide to setting up the structure of the greenhouse is provided. After that, details about using and troubleshooting system are explained. Finally, product documentation about the making and testing of the product is presented.

2 Overview

The solution is a Sustainable off-grid Greenhouse with self-reliant energy source similar to greenhouse in the snow, with considering the specific needs of environment in Ontario, Canada.

Based on the discussion with the client, a matrix of client requirements was designed (Table 1). By using this matrix, a list of critical benchmarking metrics was developed. These critical Benchmarking metrics are empirical and theoretical values required by the client to ensure that the design is functional for its intended use. Table 2 shows a list of these metrics.

Table 1 - Client Requirement Matrix

ID	Description	Priority
1	Green House to be Self sustainable and Off Grid	5
2	Structure must capable to be built by Volunteer's with less skills	5
3	Sustainable Energy Source for heating / cooling	4
4	Sustainable Material Usage	4
5	Size / Shape of the Building Requirement	2
6	Space to Grow large Trees and Plants	3
7	Need of different Chambers for Material Storage	3
8	Construction Cost of building to be within budget	4
9	Operation Cost of the building	4
10	Temperature Control within the Greenhouse Building	5

Table 2 - Critical Benchmarking Metrics

Bench Mark ID	Requirement ID	Description	Benchmark
A	1,5,6,7	Desirable size of the building	2400 Square feet Approx.
B	1,5,6,7	Height of the Building	10 Feet Approx.
C	9	Desirable temperature within the green house	19 Degree to 25 Degree Celsius
D	9	Humidity Requirements	60 to 90%
E	3	Energy Source Requirements	Needs to be evaluated
F	9	Operational Cost of the Building	Nil - To be self-sustainable
G	3,9,10	Environmental Control Disturbance Events (Door Opening)	5 Times a Day
H	2	Structural Load Requirements	To be designed
I	8,9,4	Target Cost of the Building	15000 Canadian Dollars

2.1 Analysis of Existing Product

The 16'x80' backyard greenhouse is designed like a Walipini, also known as a pit greenhouse, with the floor dug 4 feet below the ground. This underground structure helps maintain stable temperatures by using the earth’s natural insulation. The roof is angled to capture the maximum amount of sunlight from the south, ensuring efficient heat and light for the plants.

The roof is made from 3-inch-thick polycarbonate sheets, which have a twin-wall design. This provides excellent durability, heat retention, and light transmission while being lightweight and resistant to harsh weather conditions.

This greenhouse primarily utilizes geothermal energy as its source for environmental control. The system features closed-loop pipes buried underground, where the temperature remains relatively constant throughout the year. These pipes contain a liquid, typically a mixture of water and antifreeze, which absorbs heat from the ground in winter and dissipates heat back into the ground in summer for cooling.

The liquid is circulated through a heat pump, which transfers heat when the temperature drops to 50°F or lower, making it especially useful in winter to efficiently heat the entire space by using the Earth's consistent warmth. In winter, the heat pump extracts heat from the liquid and transfers it to the building’s air via a heat exchanger. In summer, the process is reversed: heat is extracted from the indoor air and transferred to the ground through the liquid in the loop. The heated or cooled air is then distributed throughout the building using a conventional duct system.

2.1.1 Technical performance of the Existing Product

Table 3 shows the product’s performance, Based on our list of critical performance metrics.

Table 3 - Existing Product Specifications

Target Benchmark ID	Requirement ID	Description	Benchmark
A	1,5,6,7	Size of the Building	32' Feet Length x Required
B	1,5,6,7	Height of the Building	10 Feet
C	9	Desirable temperature within the green house	Minimum 11.1 Degree
D	9	Humidity Requirements	60 to 90%
E	3	Energy Source Requirements	6 to 7 inch Tubes (Clusters of 5 Nos Used)
F	9	Operational Cost of the Building	Not Provided
G	3,9,10	Environmental Control Disturbance Events (Door Opening)	Frequent
H	2	Structure Load / Material	Structural Steel Frame /Polycarbonate Roofing /Open Foam Insulation
I	8,9,4	Target Cost of the Building (36')	$ 249 per Feet (Only Hard-shell)

2.1.2 Additional Design Constraints Compared to the Existing Product

- More severe winter than Nebraska, USA that the design has to withstand
- Prolonged cloudy days would increase the heat demand of the thermal energy storage system.
- Energy demand of the heat pump may require additional costs towards the renewable source.
- Potential Operation cost due to energy demand caused by extreme duration of winter.
- Less skilled labor required to set up the structure

3 Using the System

Since this project is built on the request of a specific client with regard to their current system (root cellar), client’s requirements have been used as the basis of the inputs.

3.1 Client Requirements as Input

The primary input for this system is the client's specific requirements for the greenhouse building, detailed as follows:

1. **100% Volunteer Design**: The structure must conform to a complete voluter shape for optimal stability and visual appeal.
2. **Sustainable Materials**: All materials used must be eco-friendly and sustainable to align with green building standards.
3. **Local Materials**: The design must prioritize the use of locally sourced materials to reduce environmental impact and support the local economy.
4. **Low Cost**: The structure should be designed with cost-efficiency in mind while maintaining quality and meeting other requirements.
5. **Energy Independence**: The greenhouse must incorporate systems or features that allow it to operate independently of external energy sources, such as renewable energy technologies.

3.2 Client Requirements as Input

The outputs of this system are the key performance characteristics of the greenhouse building:

1. **Structural Stability**: The volunteer design contributes to the overall stability of the structure, ensuring durability and resistance to environmental loads.

2. **Thermal Efficiency**: The design and material selection ensure superior thermal performance, maintaining optimal conditions for plant growth with minimal energy use.

4 Troubleshooting & Support: Gabion Wall Design and Structural Stability

This section outlines the troubleshooting process and error correction procedures undertaken during the gabion wall design for structural stability and cost efficiency. It provides step-by-step explanations of the issues encountered, the adjustments made, and the resolution achieved.

4.1 Problem Identification

During the structural stability validation, challenges arose in determining the most cost-effective dimensions for the gabion wall that would ensure both stability and functionality.

4.2 Trial and Error Process

4.2.1 Trial 1:

Configuration: A gabion wall with a depth of 600mm and a height of 3 meters was tested.

Issue: This configuration resulted in a point failure due to excessive force acting on a specific area, compromising stability.

Corrective Action: The wall height was reduced to minimize the force acting on the structure.

4.2.2 Trial 2:

Configuration: A gabion wall with a depth of 600mm and a height of 2 meters was tested.

Issue: Despite the reduced height, the same stability issue persisted, indicating that depth adjustments were necessary to distribute the forces more evenly.

Corrective Action: The width of the wall was decreased to evaluate its effect on force distribution.

4.2.3 Trial 3:

Configuration: A gabion wall with a reduced width of 300mm and a height of 3 meters was tested.

Issue: This resulted in an overturning failure, where the wall became unstable due to the higher center of gravity and insufficient base width.

Corrective Action: Both height and width adjustments were made to lower the center of gravity and improve stability.

4.2.4 Trial 4 (Successful Design):

Configuration: A gabion wall with a width of 300mm and a height of 2 meters was tested.

Outcome: This configuration successfully addressed the stability issues, with no point or overturning failures observed. The dimensions were determined to be both cost-effective and functional.

4.3 Corrective Actions Summary

The final design configuration of a 300mm wide and 2-meter-high gabion wall will be implemented in the model, ensuring stability and cost efficiency.

4.4 Guidelines for Error Correction

- To replicate or troubleshoot similar designs, follow these steps:
- Start with standard dimensions based on initial design requirements.

- Test for design failure
- Adjust height, width, or depth systematically to find the optimal configuration.
- Evaluate each configuration for performance metrics and identify the failure modes.
- Finalize the configuration that meets stability criteria with minimal cost and material usage.

Figure 4 – Trial and Error Method

4.5 Error Messages or Behaviors

4.5.1 Error 1: Determine the Forces Acting on the Wall

When designing a gabion wall, it's essential to accurately determine the forces acting on the structure. If the system fails to calculate these forces correctly, the entire design may be compromised, resulting in an inaccurate or unsafe structure. This issue can arise from incorrect or incomplete input data, such as the soil properties, the dimensions of the wall, or external load factors like wind or seismic forces. To correct this error, it is crucial to thoroughly review all input data for accuracy. Additionally, recalculating the forces with precise values, and ensuring that the external loads are modeled correctly, will ensure the wall's stability and safety. Proper force determination is fundamental to ensuring that the wall can withstand all expected stresses and pressures during its lifespan.

4.5.2 Error 2: Resisting Moment Don’t Exceed Overturning Moment by a Suitable Safety Factor

The resisting moment in a wall's foundation is the force that counters the overturning moment caused by external loads such as wind or soil pressure. If the resisting moment does not exceed the overturning moment by a suitable safety factor, there is a significant risk of the wall tipping over or collapsing. This situation often arises when the design of the wall's base is inadequate or when the height-to-base ratio is too large. To resolve this issue, the base of the wall must be either widened or deepened to provide more resistance to overturning forces. The design should also incorporate a safety factor to ensure that the resisting moment remains sufficient even under extreme conditions. Ensuring that the resisting moment is greater than the overturning moment helps prevent structural instability and increases the safety of the wall.

4.5.3 Error 3: Sliding Resistance Don’t Exceed Active Horizontal Force by a Suitable Safety Factor

Sliding resistance is crucial for ensuring that the wall remains stationary and does not move under the influence of active horizontal forces, such as wind or ground movement. If the sliding resistance of the wall is insufficient to counteract these forces, the wall may slide or shift, compromising its stability. This problem is typically caused by inadequate friction between the wall base and the underlying soil or a poor design of the foundation. To correct this issue, the base of the wall should be designed with a greater width or a material that offers higher frictional resistance. Additionally, the sliding resistance should be recalculated and ensured to exceed the horizontal forces by a suitable safety factor. Proper design of the sliding resistance ensures that the wall remains stationary, even under extreme conditions, and prevents the wall from shifting or toppling.

4.5.4 Error 4: Resultant Force Falls Outside the Middle Third of the Wall’s Base

For a wall to be stable, the resultant force, which is the combined effect of all applied and resisting forces, must fall within the middle third of the base. If the resultant force is located outside this area, it can cause excessive pressure at specific points on the foundation, leading to potential instability or failure. This issue typically arises when the geometry of the wall is incorrect, or the forces are not evenly distributed across the base. To address this issue, the design should be adjusted so that the resultant force remains within the middle third of the base. This may involve modifying the height, width, or shape of the wall to ensure a proper force distribution. Ensuring that the resultant force remains in the middle third of the base is vital for maintaining uniform pressure and preventing localized failures in the foundation.

4.5.5 Error 5: Maximum Bearing Pressure Exceeds Allowable Limit

The maximum bearing pressure is the force applied to the foundation per unit area, and if this pressure exceeds the allowable limit, it can lead to foundation failure. This error typically occurs when the wall's base is not large enough to distribute the forces effectively, causing concentrated stress on certain parts of the foundation. To correct this error, the base of the wall should be enlarged to spread the load more evenly across the foundation, reducing the bearing pressure. Additionally, it is essential to ensure that the material beneath the base can withstand the maximum pressure without failing. By recalculating and adjusting the base dimensions, and ensuring that the materials can handle the stress, the wall’s stability and safety can be maintained, preventing potential foundation issues.

4.6 Special Considerations

Site-Specific Adjustments: Since the gabion walls are porous the structure needs to be build above the water table of the region, high ground is preferred this is main disadvantage of the system. and ensure the wall design is tailored to the soil type, slope, and environmental conditions of the site. Conduct site-specific load testing to verify design stability.

Local Regulations: Local regulations on the structure and codes need to be adhered. Verify compliance with environmental regulations.

4.7 Maintenance

Regular checking of the structural integrity and water ingress needs to be studied. Inspect for corrosion or damage to the wire mesh and replace if necessary. Water drainage if required to be provided to avoid water pressure and ingress in the system.

5 Product Documentation

During our early meetings, we came up with different sketches of the greenhouse building, which is the final goal of the project, as can be seen in Figure 5. this is greenhouse building is comprised of five different parts, described as below.

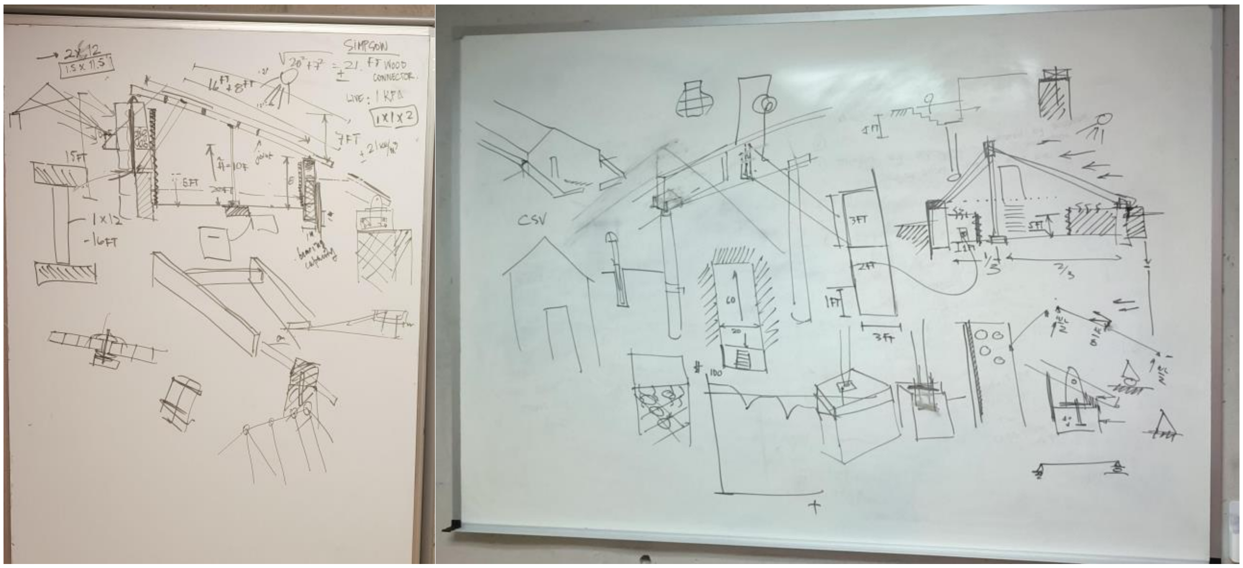


Figure 5 – Early Sketches

5.1 Sections of the structure

There are five main sections in the structure designed for the greenhouse.

5.1.1 Geothermal Heating for Structures

The design of our underground structure incorporates a geothermal system to capture heat from below ground, inspired by the Greenhouse in the Snow model used in Nebraska. This system utilizes the earth’s natural heat to maintain a stable temperature inside the building, particularly during the colder months. According to Canadian building standards, specifically the National

Energy Code for Buildings (NECB), energy efficiency is a priority for heating systems. Geothermal systems align well with these requirements by leveraging the thermal energy stored in the earth, which significantly reduces the reliance on external heating sources.

Building the structure 6 feet below ground enhances heat capture and retention, as this depth places the foundation below the frost line, where the ground temperature remains relatively warm year-round. This design feature ensures that the geothermal system can effectively provide consistent heating, even during harsh winter conditions.

5.1.2 Gabion Walls for Retaining and Temperature Regulation

Gabion walls, widely recognized for their thermal mass and permeability, support natural ventilation and temperature control. The Canadian Standards Association (CSA) covers guidelines for retaining walls, ensuring structural stability and environmental performance. The porous structure allows airflow, which promotes cooling during hot summers by facilitating passive ventilation. This is in accordance with energy efficiency goals outlined by CSA S478-19 on durability in buildings and environmental separation.

The gabion walls are also a cost-effective option for this project. As you can see in the figure below, we did a cost analysis to compare the gabion wall with concrete wall. As it is shown, based on the costs evaluation, the structural retaining wall costs 4.4 times higher than gabion wall.

Table 4 – Gabion Wall Cost Judgement

S.No	Description	Quantity	Length	Breath	Height	Total	UOM	Rate	Amount
Gabbion Wall :									
1	Gabbion Wall (1m x 0.5m x 0.3m)	1				1	Nos	65	65
2	Boulders / Rock for Infill	1	1	0.3	0.5	0.15	Cum	52	7.77
3	Labour Charges - Erection of Gabbion Wall					0.2	Hours	16	3.2
4	Labour Charges - Infill of Gabbion Wall					0.5	Hours	16	8
5	Direct Overheads @ 10%								8.397
								Total Cost of Gabbion wall (1m x 0.5m x 0.3m):	**92.4**
								Cost per Cum	**616**
Conventional Reinforcement Wall :									
1	Concrete- (1m x 0.5m x 0.3m)	1	1	0.3	0.5	0.15	Cum	779.20	116.88
2	Scaffolding Material	1	1	0.3	0.5	1.3	Sqm	20	26
3	Shuttering Charges - Plywood	0.16667	(Repitations Cost Loaded)			1	Sqm	10	1.72
4	Reinforcement Charges		(100 Kgs/Cum)			15	Kgs	5	76.91
5	Labour Charges - Concreting					1	Hours	25	25.00
6	Labour Charges - Shuttering					4	Hours	25	100.00
7	Labour Charges - Reinforcement					1	Hours	25	25.00
8	Direct Overheads @ 10%								37.15
								Total Cost of Retaining Wall (1m x 0.5m x 0.3m) :	**408.66**
								Cost per Cum	**2724**
								STRUCTURAL RETAINING WALL IS 4 TIMES HIGHER THAT GABBION WALL :	**4.4**

The retaing wall may need sleder cross section considered to Gabbion wall to retaing the same amount of soil, However it is to be noted that the retaining base slab is not considered in this calculation. In any case the retainig wall would be consideratbly costly and require skilled labour

5.1.3 Timber Beams for Structural Support and Insulation

Timber is a cost-effective, sustainable material, known for its insulating properties, which reduce heat loss. Canadian building codes, under CSA O86 - Engineering Design in Wood, provide specifications for the use of wood as a primary structural material. Timber beams not only provide strength but help maintain a stable internal temperature, reducing heating costs. Its ease of construction also makes it suitable for volunteer-based projects.

5.1.4 Polycarbonate Roofing for Light and Heat

Polycarbonate sheets are highly effective for roofing, allowing natural light and heat to enter the structure. This material meets Canadian standards for light-transmitting plastics (CAN/ULC-

S102.2), ensuring safety, energy efficiency, and proper heat and light distribution. It is also durable and offers UV protection, ensuring longevity in extreme climates.

5.1.5 Scaffold Posts as Structural Columns

Using scaffold posts as columns to support timber beams follows CSA S16 standards for structural steel design, ensuring proper load transfer from the beams to the ground. The design distributes loads effectively, preventing structural deformation while allowing flexibility in the construction process.

The AutoCAD version of our early plan of the model is shown below.

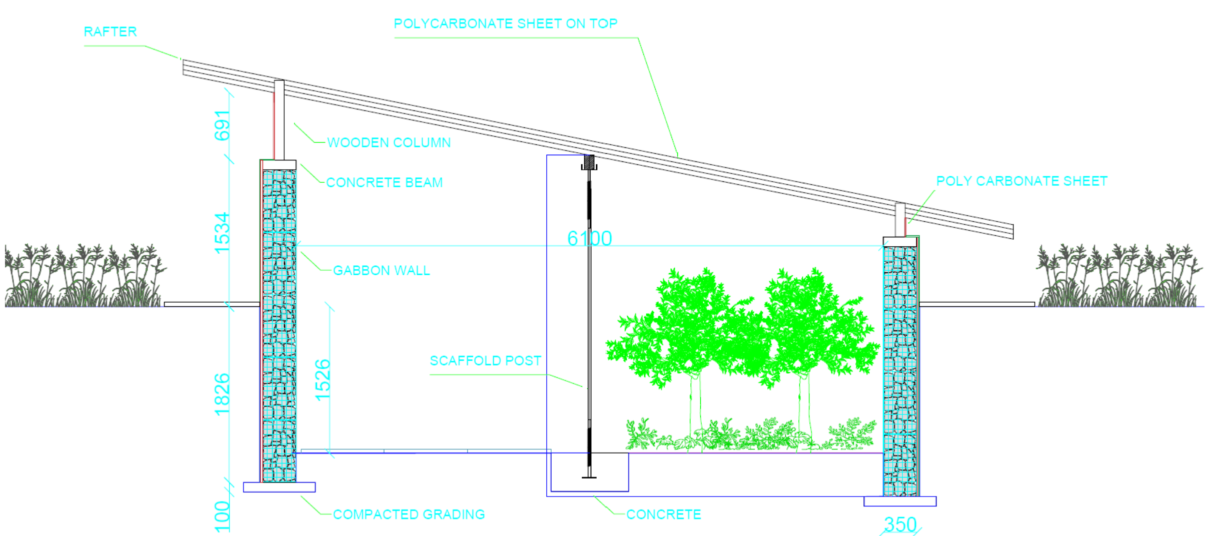


Figure 6 – AutoCAD model, Initial Design

After calculating the forces acting on the wall and the bearing pressure, it was shown that the initial design was a failure. After that we came up with a new design, which has thicker and shorter gabion walls. this design can be seen below.

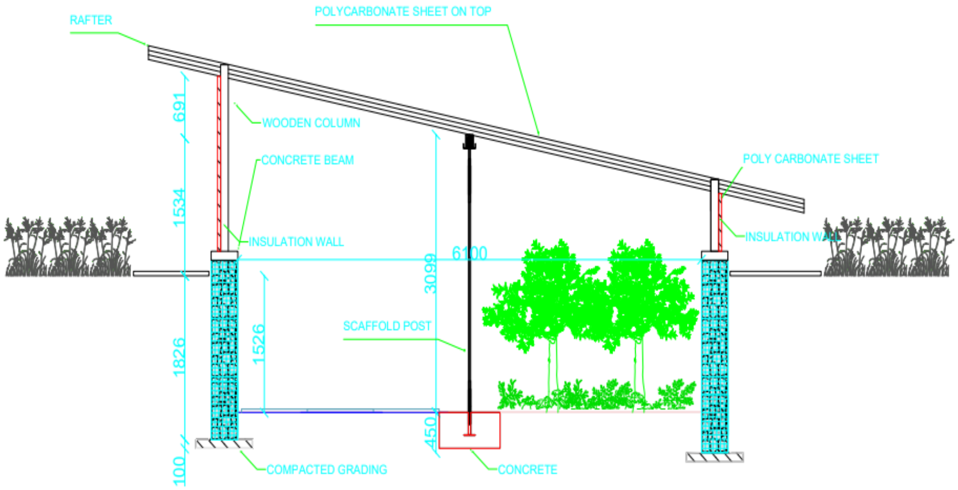


Figure 7 – AutoCAD model, Revised Design

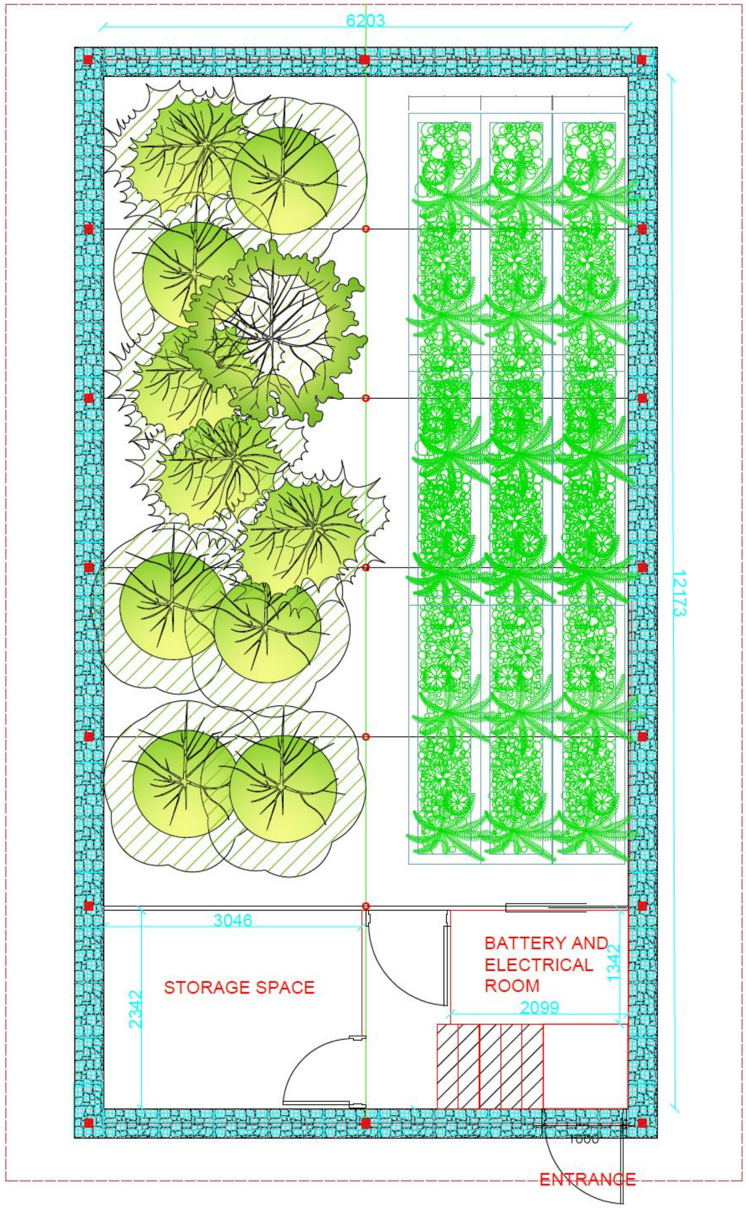


Figure 8 – AutoCAD model, Plans

5.2 Gabion Wall's Suggested Materials and Instructions

5.2.1 Gabion Wall's Suggested materials

we came to an agreement with the client to focus on one part of the building, which is the gabion walls and its insulation. So, designing that part of the prototype and testing it has become our main priority.

Figure 9 – Sample of a Gabion wall

Various types of gabion filling material and their densities are presented in Figure 10:

Flint rejects and whole stone	14.5 KN/m³
Crush stone	15.0 KN/m³
Sandstone	15.5 KN/m³
Limestone	16.0 KN/m³
Granite	17.0 KN/m³
Basalt	20.0 KN/m³
Aggregate fill	16.0 KN/m³ (geotextiles lined units)

Figure 10 – Gabion filling materials and their densities

For the Gabion wires, there are some different options in the market, presented as follows [3]:

- Unprotected, Uncoated Wire: these are 5mm diameter wires which are used for temporary work.
- Steel wire: these are high quality low carbon 2mm to 4mm diameter having strength of 38kg/m2.
- Galvanized wire: Hexagonal woven mesh gabions should be made from galvanized wire (low carbon mild steel wire with a heavy-duty coating of zinc or Zinc-Al alloy.
- PVC coated galvanized steel wire: The radial coating applied to the galvanized wire core should be a minimum of 0.25 mm. The PVC should be sufficiently bonded to the galvanized wire core to prevent capillary flow of water.
- Polymer Plastic Rope Mesh: New materials such as Tensar, a heavy-duty polymer plastic material, have been used in some applications in place of wire mesh. Nylon or polypropylene rope gabion baskets are usually used for anti-erosion works.

5.2.2 Gabion Wall's set-up Instructions

5.2.3 Foundation:

The foundation requirements, determined by the engineer, depend on factors such as site conditions and the height of the gabion structure. Typically, the topsoil is removed until a layer with sufficient bearing capacity is exposed. In some instances, the foundation may involve placing and compacting suitable fill material to achieve at least 95% of Proctor density.

5.2.4 Assembly:

Arrange the empty gabions (Weldmesh) on the prepared foundation in the designated layout. Once the first layer is in place, secure adjacent gabions by attaching vertical spiral binders along the full height at all corners. Fasten the edges of each diaphragm with spiral binders and crimp the ends to lock them securely. Corner stiffeners are installed diagonally across the corners at 1-foot intervals for gabions 3 feet or taller. These stiffeners must be hooked over intersecting wires and crimped at both ends, Before filling the gabions.

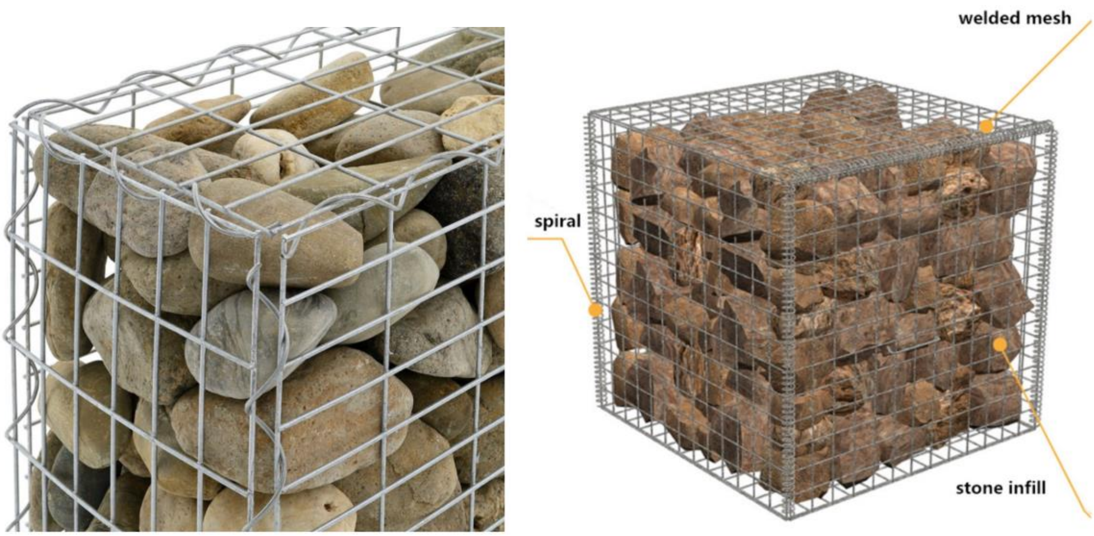


Figure 11 – Detailed Examples of Gabion Walls

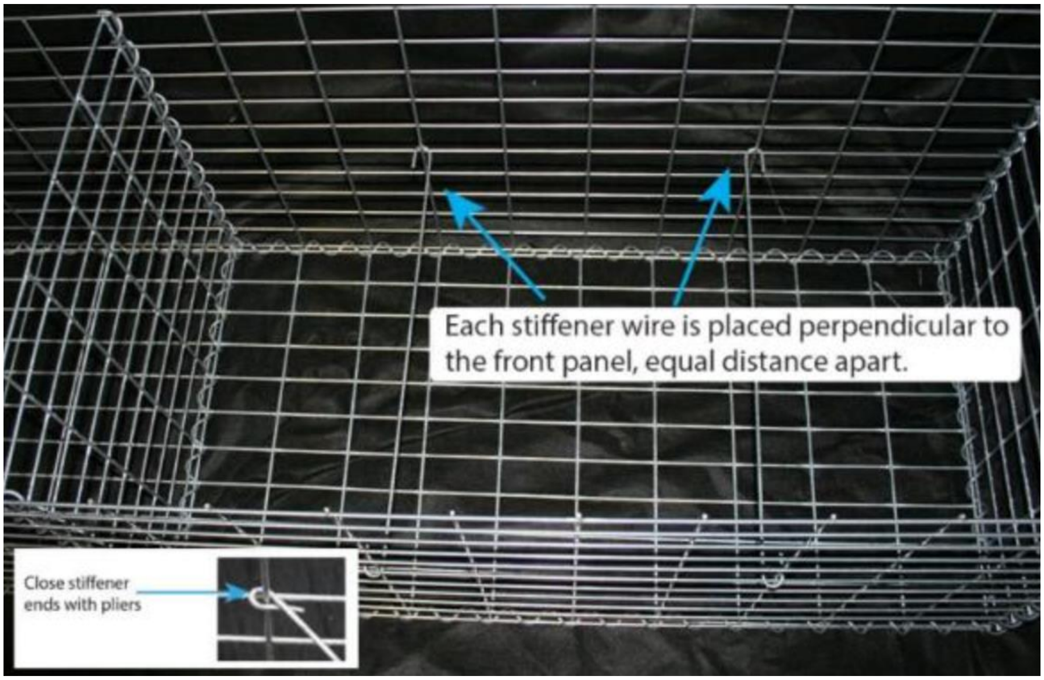


Figure 12 – Stiffener Wires

Source of Picture ; https://www.nova-gabion.com

5.2.5 Filling:

The fill material must meet the engineer's specifications, possessing adequate compressive strength and durability to withstand loading, water exposure, and weathering. Typically, clean, hard stone ranging from 3 to 8 inches is recommended. Using well-graded stone fill can enhance density. Place the stones in 12-inch layers with power equipment, and distribute them evenly by hand to minimize voids and create an aesthetically pleasing finish along the visible faces. Ensure that the baskets remain square and the diaphragms are properly aligned. The height difference in the fill between adjacent cells should not exceed 1 foot. Level the final layer of stones, ensuring the tops of the diaphragms remain visible. Close the lids and secure them along all edges and at the diaphragms' tops using spiral binders, or alternatively, tie or lacing wire can be used for this purpose.

5.2.6 Successive Courses:

Position the next layer of assembled empty gabions on top of the filled layer, ensuring that the joints are staggered to offset the vertical connections. Secure the empty baskets to the filled ones below using spiral binders or tie wire along all external bottom edges. Fasten the vertical edges of the gabions together with spiral binders and follow the same assembly process used for the first layer. Continue placing and securing each successive course in this manner until the entire structure is completed.

5.3 Structure's Suggested Materials and Equipment

5.3.1 BOM (Bill of Materials)

The bill of materials for a greenhouse structure with the size 40 feet * 20 feet can be seen in the figure below.

Table 5 – Greenhouse Structure Bill of Materials

	Structure Size 40 Feet x 20 Feet					
S.NO	**Description**	**Length**	**Breath**	**Height**	**Total Quantity**	**UOM**
A	Designed Elements					
a.1	**Aggregate for Gabbion Wall**					
1	Gabbion Wall - Left Side	12.17	0.3	2	7.30	Cbm
2	Gabbion Wall - Right Side	12.17	0.3	2	7.30	Cbm
3	Gabbion Wall - Front	6.20	0.3	2	3.72	Cbm
4	Gabbion Wall - Back	6.20	0.3	2	3.72	Cbm
				Sub Total :	**22.05**	Cbm
a.2	**Weldmesh for Gabbion Wall**					
1	Gabbion Wall - Left Side	12.17		2	48.69	Sqm
2	Gabbion Wall - Right Side	12.17		2	48.69	Sqm
3	Gabbion Wall - Front	6.20		2	24.81	Sqm
4	Gabbion Wall - Back	6.20		2	24.81	Sqm
				Sub Total :	**147.01**	Cbm
B	**Non Designed Elements - Approx Quantity**					
	(Exact quantity may vary as per the design)					
1	Scaffolding Post				7	Nos
2	Timber Beam			(As per design) - Future		
3	Timber Column			(As per design) - Future		
4	Polycarbonate sheet				120.8	Sqm
5	Insulation Materials - RD40-60 Spray			(As required per final design) - Future		
6	External Insulation Boards					
	Left Wall	12.173		2	24.35	
	Right Wall	12.173		0.65	7.91	
	Front Wall	(Approx Changes as per Slope of Roof)			10	
	Back Wall				10	
				Sub Total :	**52.26**	Sqm
7	Doors and Windows			As per Client requirement		
8	Internal Partitions			As per Client requirement		
9	Foundation Concrete for Scaffolding x 7 Nos	0.3	0.4	0.4	0.336	Cbm
10	Concrete on top of gabbion wall	36.75	0.3	0.2	2.21	Cbm
11	Reinforcement for Structural Concrete			(100 Kgs/Cum)	254.11	Kgs
12	Concrete for side protection - On periphery	36.75	0.5	0.1	1.84	Cbm

5.3.2 Equipment list

3. **Structural Stability**: The volunteer design contributes to the overall stability of the structure, ensuring durability and resistance to environmental loads.

4. **Measuring Tools:** Laser levels, measuring tapes, and plumb bobs to ensure accuracy in layout and alignment.

5. **Excavators**: For digging and leveling the ground to prepare the foundation.

6. **Concrete Mixers**: For concrete foundation and beam works, However handmade mix can also be done.

7. **Rebar Cutters/Benders**: For preparing reinforcement bars. However ready made can be purchased.

8. **Lifting Equipment**: Cranes, forklifts, or scissor lifts for handling and placing large structural components.

9. **Drills and Screwdrivers:** For fixing the frame components with bolts or screws.

10. **Welding Machines:** On-site welding for metal components.

11. **Wrenches and Spanners**: For tightening bolts and nuts in the frame structure.

5.4 Testing & Validation

Two main series of testing have been done on the project. On series focused on structural design and how safe it is to use, and the second series focuses on energy efficiency of the project.

5.4.1 Structural Testing

The structural design followed a trail and error method where over 10 combinations of height and size are made until we arrived at the final design. first set of tests focused on force acting resistant, sliding resistant and overturning resistant. A visual explanation of these resistant types can be seen below.

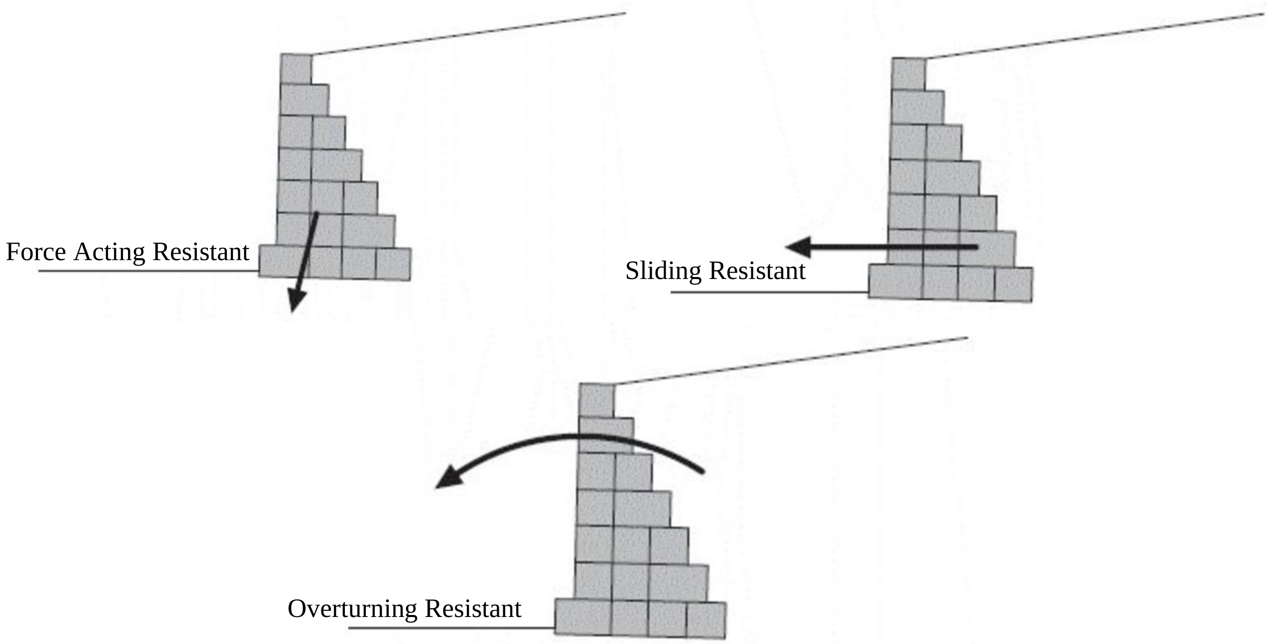


Figure 13 – Resistant Types

After defining the characteristics we were looking for, our set of tests began and some examples of different iterations of the model can be seen below.

Initially, we proposed a wall width of 300 mm. However, after performing thorough design calculations, we found that the 300 mm width was not safe. As a result, we revised our design and increased the width of the retaining portion of the wall to 500 mm.

Load, Pressure and Sliding Calculation for the 500mm width is presented here.

Load Calculations :

Below Ground Level - Gabion Wall

Height	:	1.826	m
Width	:	0.5	m
Length	:	1	m

Above Ground Level - Gabion Wall

Height - Hr	:	1.534	m
Width	:	0.3	m
Length	:	1	m

Back Filled Soil :

Compacted in layers not exceeding 150mm to form a dense stable mass

Effective Cohesion	(c')	=	0	kpa	
Effective angle of internal friction	Φ'pk	=	40	Degree	(Typical)
Unit weight	(Y)	=	20	KN/Cum	(Typical)

Foundation Soil :

Assumption of Firm Clay

Effective Cohesion	(c')	=	0	kpa	
Effective angle of internal friction	Φ'pk	=	20	Degree	(Typical)
Unit weight	(Ws)	=	20	KN/Cum	(Typical)
Allowable Bearing Capacity	q_{allow}	=	250	kpa	(Assumed)

Surcharge loading = Considered Nil

Restoring Force :

Components:	Base (m)	Length (m)	Height (m)	Unit Wt (kN/Cum)	W (kn)	Distance to CG (m)
Wall 01	0.5	1	1.826	20	18.26	0.25
Wall 02	0.3	1	1.534	20	9.204	0.15
					27.464	0.384

Disturbing Force / Moments :

α=	0	Slope Angle of Backfill surface
β=	0	acute angle of back face lope with vertical
δ=	0	angle of wall friction
φ=	40	angle of internal friction of soil

$$K_a = \frac{\cos^2(\phi - \beta)}{\cos^2\beta \cos(\delta + \beta)\left[1 + \sqrt{\dfrac{\sin(\phi + \delta)\sin(\phi - \alpha)}{\cos(\delta + \beta)\cos(\alpha - \beta)}}\right]^2}$$

$=\cos^2(41) / [1 + \sin(41)]^2$

Ka = 0.2174

Ka =	Active earth pressure Co-efficient			
Φ'pk =	Angle of Internal Friction			
Hr =	Height of the Wall			
Pa=	Lateral Earth Pressure on wall'			
ws=	Soild Denstiy			
Components		Φ'pk	Ka	Hr
Retained Soil		40	0.2174	1.826
	Pa	=	0.5 x Ka x Ws x Hr^2	
		=	7.250144	Kn
	Surcharge Load (Psurcharge)	=	0	Kn
	P Total	=	Pa+Psurcharge	
		=	7.250144	Kn
	Point of Rotation (d)	=	Hr/2	
		=	0.913	
	Overturning @ 0 Deg (M)	=	Pa x d	
		=	6.619382	Kn.m
Resistance to Overturning (Mr)		>	Overturning Moment (Mo)	
10.5476		>	**6.619**	

Resistance to Overturning is higher than the Overturning moment hence the design is safe.

Resistance to Sliding:

μ	=	Co-efficient of Friction b/w wall and soil
W	=	Weight of the Wall
F resistance	=	μ X W
M	=	0.5
W	=	18.26
Hence		
F resistance	=	9.13
Sliding Force	=	Pa
Pa	=	7.250144
9.13	>	**7.250144**

Resistance to Sliding is Greater than Sliding Force hence the design is safe.

Resultant Point Calculation

B =	0.5	Width of Base
Mr =	10.5476	Resisting Moment

Mo=	6.619	Overturning Moment
Wv=	18.26	Sum of Vertical Forces (Weight of Wall)

e = B/2-(Mr-Mo)/Wv

e = **0.0349**

is e <B/6

0.0349 < 0.083333

Position of the resultant is with in the middle third of the foundation - design satisfied

<u>Foundation Pressure Calculation</u>

$$P = (W_v / B)(1 + 6e / B)$$

P = 51.80276 Kpa

51.8027589 < 250 (Hence Safe)

along with paying attention to structural considerations, we developed heat simulations to test the wall's insulation and temperature control inside the building.

5.4.2 Energy Efficiency of Architectural Plan

The following calculations show the Energy Efficiency of the revised design. Material Dimensions are provided in Table 6. Also, the overall comparison of temperature in summer and fall based on the average actual data is provided in Table 7. Finally, a more detailed overall comparison of temperature for winter season can be seen in Table 8. Figures of each table can be seen beneath it.

Table 6 – Material Dimensions and Heat Gain Calculations

Material Dimensions						
Element	Gabion wall (long)	Gabion wall (short)	Wooden beam (horizontal)	Wooden beam (vertical)	Polycarbonate sheet	Door and portions
Length (m)	12	6	12	6	15	2
Width (m)	0.3	0.3	0.15	0.15	8	0.76
Height (m)	5	5	0.15	0.15		
Thickness (m)	0.3	0.3			0.25	
Heat Gain Calculations						
Thermal conductivity ($W/m^2.k$)	2.2	2.2	0.9	0.9	2.2	3.75
Total numbers	2	2	15	7	1	2
Area (m^2)	3.6	2	1.8	0.9	120	1.52
Total Area (m^2)	7.2	3.6	27	6.3	120	3.04
Solar radiation intensity (W/m^2)	450	450	450	450	450	450
Solar Heat Gain Co-efficient	0.1	0.1	0	0	0.5	0.4
Time (s)	3600	3600	3600	3600	3600	3600
Indoor Temperature	25	25	25	25	25	25
Outdoor Temperature	-6	-6	-6	-6	-6	-6
ΔT	31	31	31	31	31	31
Heat loss (Q loss)	1,767,744	883,872	2,711,880	632,772	29,462,400	1,272,240
Heat Gain	1,166,400	583,200	0	0	97,200,000	1,969,920

Table 7 – Temperature Comparison in Summer and Fall

Summer (Solar radiation intensity (W/m2) = 650)													
Timings	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM
Indoor Temperature	19	19	20	24	24	24	23	23	22	21	20	19	18
Outdoor Temperature	20	22	24	26	28	29	28	27	26	24	23	21	19
Fall (Solar radiation intensity (W/m2) = 450)													
Timings	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM
Indoor Temperature	18	19	18	19	20	20	19	18	18	19	18	18	17
Outdoor Temperature	5	6	8	10	12	13	12	10	8	6	5	4	3

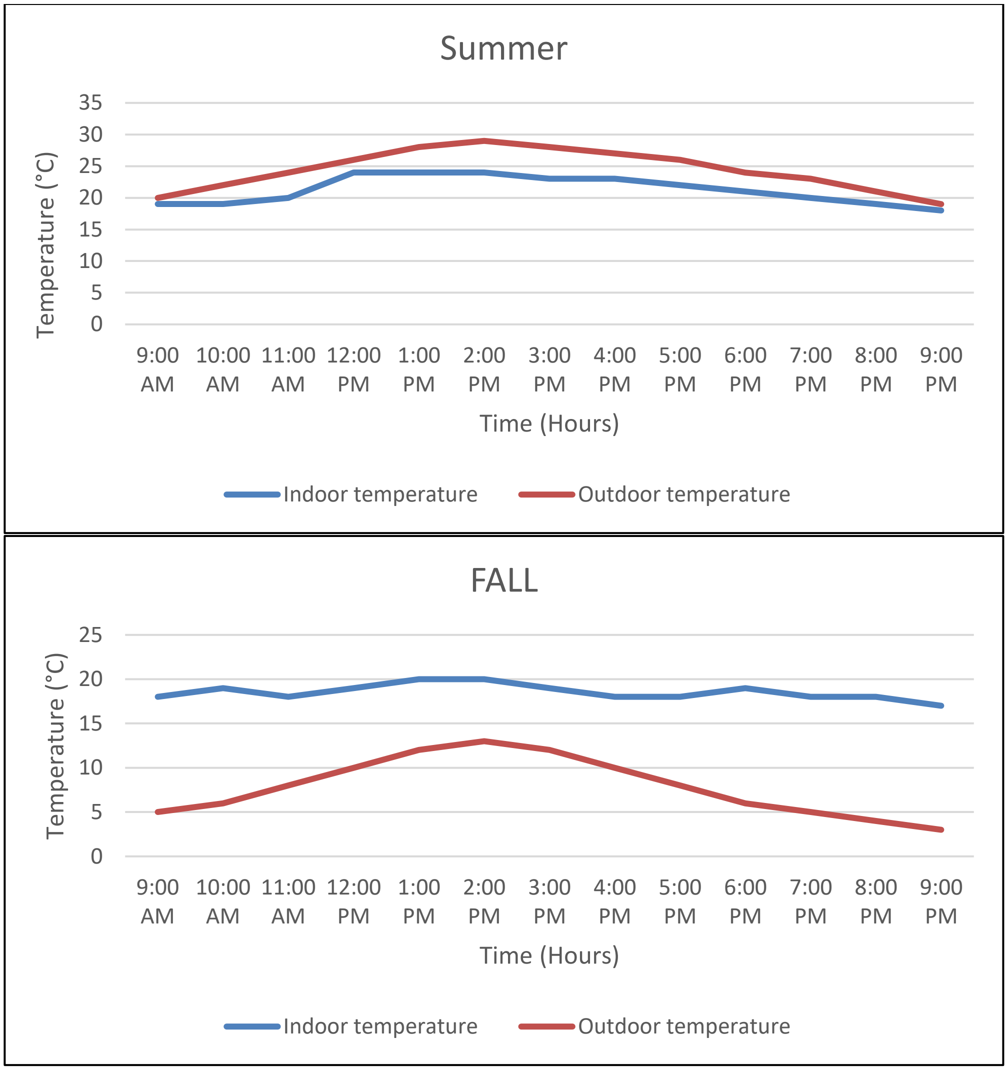
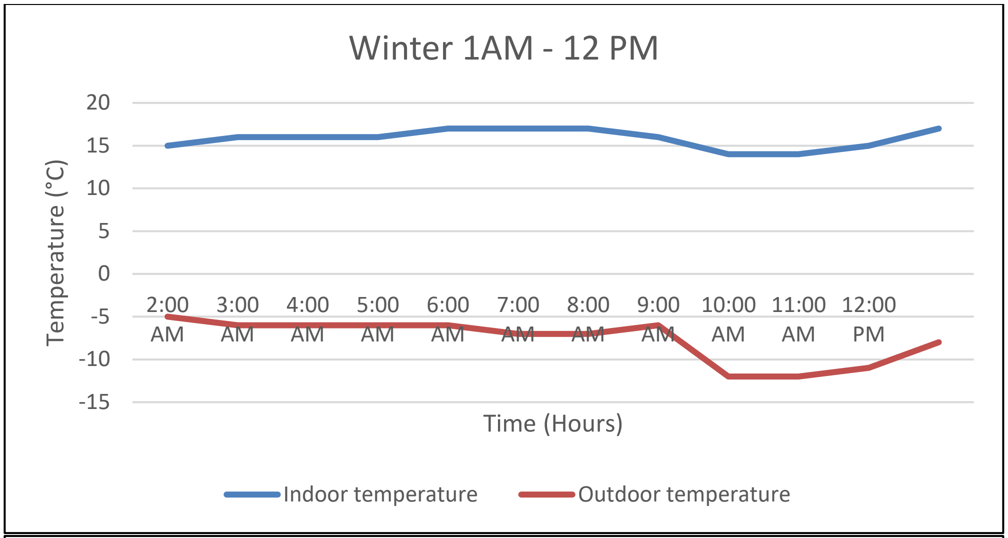


Figure 14 – Temperature Comparison in Summer and Fall

Table 8 – Temperature Comparison in Winter

Winter - 1:00 AM to 12:00 PM (Solar radiation intensity (W/m2) = 200)												
Timings	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM
Indoor Temperature	15	16	16	16	17	17	17	16	14	14	15	17
Outdoor Temperature	-5	-6	-6	-6	-6	-7	-7	-6	-12	-12	-11	-8
ΔT	20	22	22	22	23	24	24	22	26	26	26	25
Winter - 1:00 PM to 12:00 AM (Solar radiation intensity (W/m2) = 200)												
Timings	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM
Indoor Temperature	15	16	16	14	14	14	13	13	14	16	17	17
Outdoor Temperature	-6	-7	-6	-10	-8	-9	-10	-12	-11	-4	-5	-5
ΔT	21	23	22	24	22	23	23	25	25	20	22	22



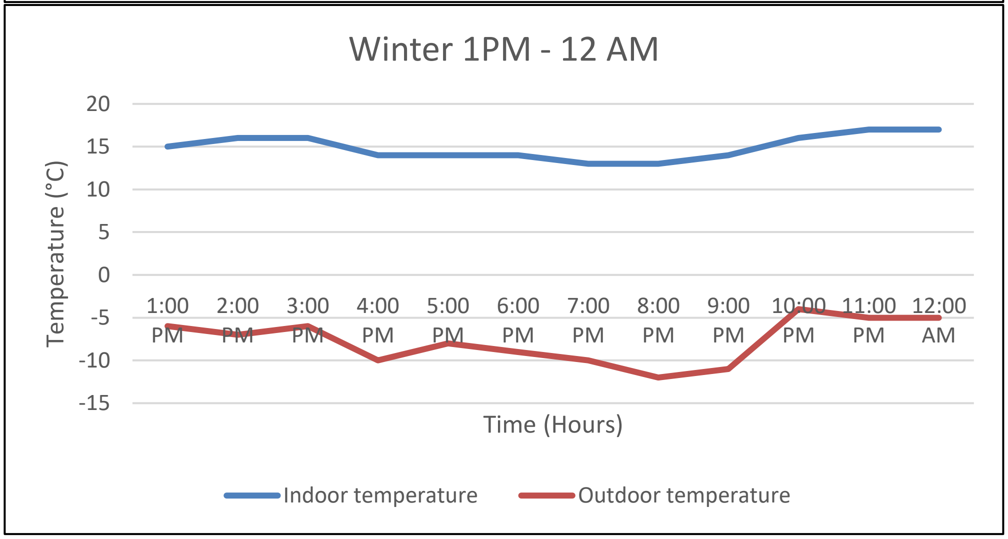


Figure 15 – Temperature Comparison in Winter

6 Conclusions and Recommendations for Future Work

Super Greenhouse can play a pivotal role in addressing global challenges related to food security, waste reduction, and environmental sustainability. As the global population continues to grow, so does the demand for effective food preservation techniques that minimize spoilage and extend the shelf life of perishable items. This research seeks to explore innovative, low-impact solutions that can reduce food waste, improve access to nutritious food, and mitigate the ecological footprint of food systems. In this user manual, we examined the final product and how it can be used. In the future, teams can focus on other parts of the project such as Roofing or Geothermal energy systems. Also, an agricultural research on what types of plants are befitted for the greenhouse can be done as well.

7 Bibliography

[1] "Greenhouse in the Snow," [Online]. Available: https://greenhouseinthesnow.com/. [Accessed 23 September 2024].

[2] W. &. K. K. ren, "A Study on the green buliding trend in china - From 2001 to 2022," *Sustainability,* vol. 15, no. 13505, p. 18, 2023.

[3] Liu, F., Li, Y., Wang, Y., Zhang, Q., Gao, W., & Cao, Y. (2023). A Numerical Investigation of the Thermal Performance of a Gabion Building Envelope in Cold Regions with a Mountainous Climate. Applied Sciences, 13(15), 8809. https://doi.org/10.3390/app13158809

[4] V. Patil, N. Chopade, and G. Nadkarni, "A Review Paper on Gabion Walls," *International Research Journal of Engineering and Technology (IRJET)*, vol. 6, no. 1, pp. 507-509, Jan. 2019.

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APPENDICES

8 APPENDIX I: Design Files

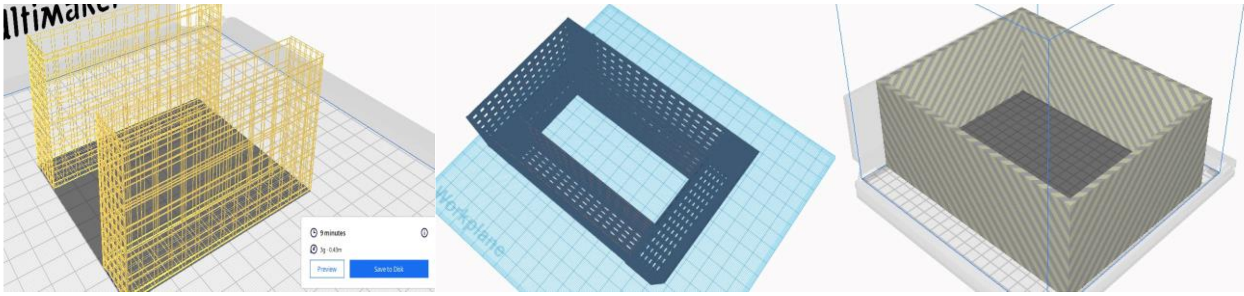

Figure 16 – Initial 3D Design of Gabion walls

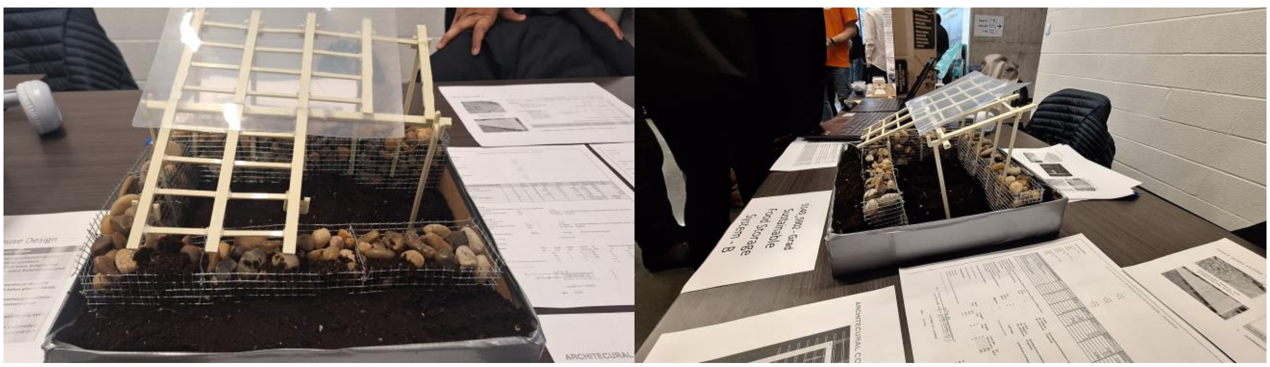

Figure 17 – Final 3D Design of Greenhouse

9 APPENDIX II: Other Appendices

Calculations for 300mm width wall:

Load Calculations :

Below Ground Level - Gabion Wall

Height	:	1.826	m
Width	:	0.5	m
Length	:	1	m

Above Ground Level - Gabion Wall

Height - Hr	:	1.534	m
Width	:	0.3	m
Length	:	1	m

Back Filled Soil :

Compacted in layers not exceeding 150mm to form a dense stable mass

Effective Cohesion	(c')	=	0	kpa	
Effective angle of internal friction	Φ'pk	=	40	Degree	(Typical)
Unit weight	(Y)	=	20	KN/Cum	(Typical)

Foundation Soil :

Assumption of Firm Clay

Effective Cohesion	(c')	=	0	kpa	
Effective angle of internal friction	Φ'pk	=	20	Degree	(Typical)
Unit weight	(Ws)	=	20	KN/Cum	(Typical)
Allowable Bearing Capacity	q_{allow}	=	250	kpa	(Assumed)

Surcharge loading = Considered Nil

Restoring Force :

Components:	Base	Length	Height	Unit Wt	W	Distance to CG
	(m)	(m)	(m)	(kN/Cum)	(kn)	(m)
Wall 01	0.3	1	1.826	20	10.956	0.15
Wall 02	0.3	1	1.534	20	9.204	0.15
					20.16	0.287

Disturbing Force / Moments :

α=	0	Slope Angle of Backfill surface
б=	0	acute angle of back face lope with vertical
δ=	0	angle of wall friction
φ=	40	angle of internal friction of soil

$$K_a = \frac{\cos^2(\phi - \beta)}{\cos^2\beta \cos(\delta + \beta)\left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \alpha)}{\cos(\delta + \beta)\cos(\alpha - \beta)}}\right]^2}$$

Ka =	Active earth pressure Co-efficient			
Φ'pk =	Angle of Internal Friction			
Hr =	Height of the Wall			
Pa=	Lateral Earth Pressure on wall'			
ws=	Soild Denstiy			
Components		Φ'pk	Ka	Hr
Retained Soil		40	0.2174	1.826
	Pa	=	0.5 x Ka x Ws x Hr^2	
		=	7.250144	Kn
	Surcharge Load (Psurcharge)	=	0	Kn
	P Total	=	Pa+Psurcharge	
		=	7.250144	Kn
	Point of Rotation (d)	=	Hr/2	
		=	0.913	
	Overturning @ 0 Deg (M)	=	Pa x d	
		=	6.619382	Kn.m
	Resistance to Overturning (Mr)	>	Overturning Moment (Mo)	
	5.7852	<	**6.619**	

Resistance to Overturning is failed, the design in Failure.

Resistance to Sliding:

μ	=	Co-efficient of Friction b/w wall and soil
W	=	Weight of the Wall
F resistance	=	μ X W
M	=	0.5
W	=	10.956
Hence		
F resistance	=	5.478
Sliding Force	=	Pa
Pa	=	7.250144
5.478	<	**7.250144**

Resistance to Sliding is Greater than Sliding Force hence the design is safe.

Resultant Point Calculation

B =	0.3	Width of Base
Mr =	5.7852	Resisting Moment
Mo=	6.619	Overturning Moment
Wv=	20.16	Sum of Vertical Forces (Weight of Wall)

e = B/2-(Mr-Mo)/Wv

e = **0.1914**

is e <B/6

0.1914 < 0.05

Position of the resultant is not with in the middle third of the foundation - design not satisfied