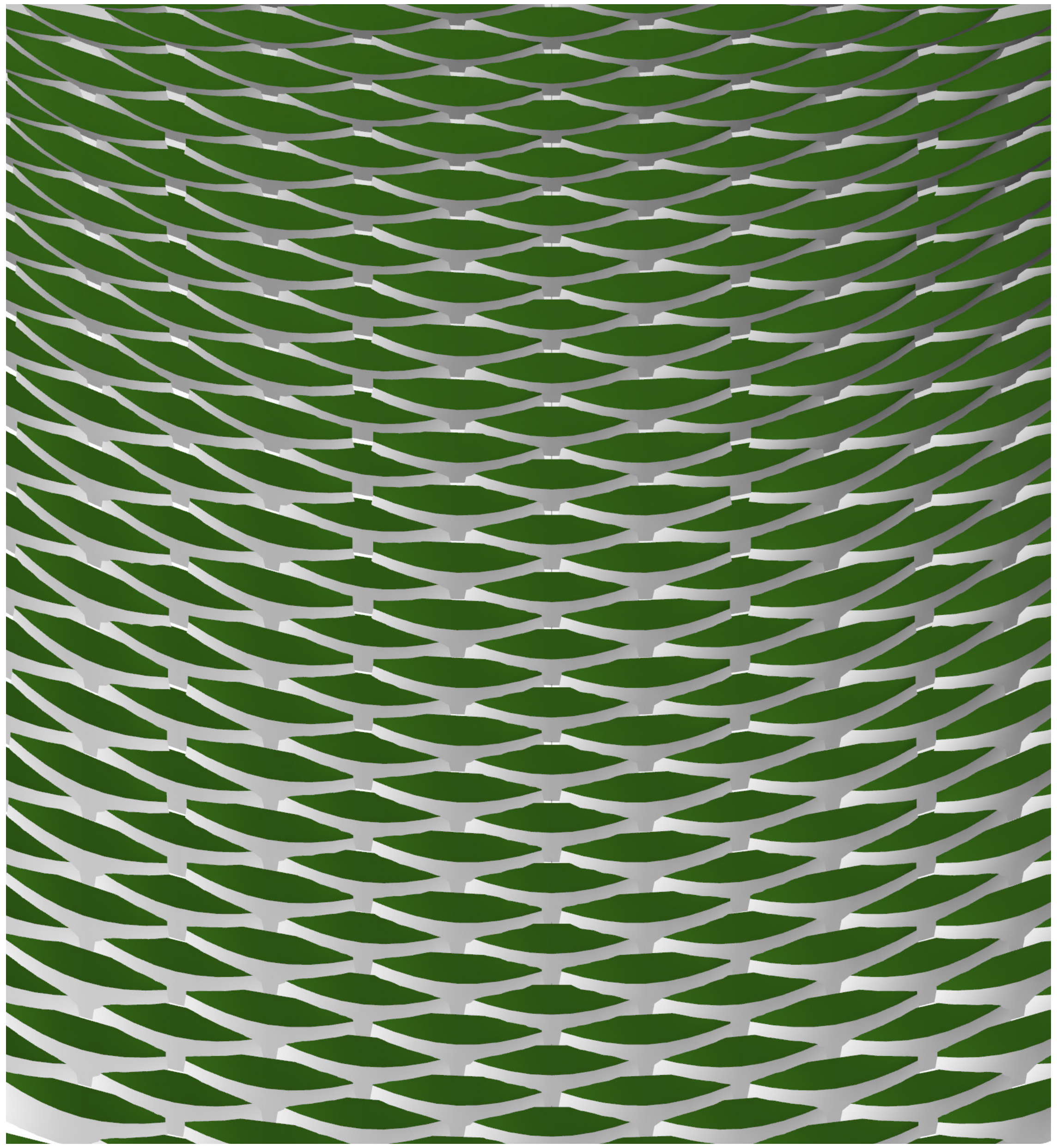

EARTH-SILE Project

Master Thesis

Master Program for Membrane Structures I M S e.V.
Ahmad Nouraldeen - Mateikel-Nr : 4063636

IMS e.V.

A COMPOSITE THERMAL MASS TENSILE DEPLOYABLE STRUCTURE

Master-Thesis

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master Membrane Structures

Submitted to :
Anhalt University of Applied Sciences
Faculty of Architecture,
Facility Management and Geo Information

by :

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28 - January - 2018
Tutor: Prof. Dr. Robert Off

IMS e.V.

Institute of Membrane and Shell Technologies

STATEMENT

I HEREBY DECLARE THAT THE WORK PRESENTED IN THIS MASTER THESIS, ENTITLED “**A COMPOSITE THERMAL MASS TENSILE DEPLOYABLE STRUCTURE** “ IS ENTIRELY MY OWN AND THAT I DID NOT USE ANY SOURCES OR AUXILIARY MEANS OTHER THAN THOSE REFERENCED.

BEIRUT, LEBANON, JANUARY 2018 AHMAD NOURALDEEN

INTRODUCTION AND THESIS

Introduction:

Light weight Structural typologies that rely on a tensile form found geometry creates an excellent optimized membrane surface that till now mainly serves as an effective solution for large span structures. This gives the membrane structures supremacy in material weight and construction time efficacy.
Since Frei Otto's research and realization of his timeless tensile structures till now, the application of these typologies didn't change a lot and continued to serve mainly the outdoor (stadiums, parks, canopies…) as a solar and rain protection application. Still membrane structures serve as a thin tensile sheet structures.

The problematic:

The light weightiness and the material poor thermal and insulation properties of tensile membrane still acts as a tent and a canopy system; thus, it remains unpractical to apply it as a main system for permanent architectural residence, dwelling or a structure and a skin that serves more than that.
Although we can see a lot of applications where tensile membranes act as a prominent secondary element in architecture, being used as a building shading skin or for semi outdoor spaces or even as a standalone temporary shelter, still in my opinion it didn't achieve its full potential of becoming a habitat and a skin with the adequate thermal comfort characteristics so that its structural skin can serve more than the tensile function.

Method:

The Research aims for tensile membrane structure to become as a main structural and skin element which provides permanent standalone architectural application parallel to its structural quality with a good thermal, comfort and spatial performance.
The research investigates developing a contemporary building method that utilize high performance tensile structural method to create a closed tensioned form found surface "radial membrane tensegrity". This structure serves as a platform that hosts thermal mass material on its composite membrane surface.
The challenge is in providing system acting as a skin and structure that is compact and light weight when un-deployed and transported, then upon simple deployment it becomes structurally self-bracing. The system includes the rib compression structure, and the main focus of this research which is the composite pocket tensile membrane that makes the skin serve as a thermal mass and insulation.

System Description:

The system needs just the anchorage to ground without heavy foundations that introduces usually the tension needed in the membrane. This is designed through utilizing a tensegrity concept "radial deployment of the tensioned skin", the membrane is pulled to a pre-stressed condition to account for its weight upon composite material filling on site.

OUTLINE

Thesis Research Outline:

I. Introduction Of Background

a. Background research

i. Case Studies of relevant research and projects that tackle tensile concepts in correlation to this thesis

ii. Discussing the pros and cons of the concepts

II. Methodology

a. Designing a deployable structure to apply the composite membrane on

i. Testing adequate kinetic tensile typologies for the feasibility, spatial and their structural quality

ii. Designing the tensile structure to serve the architectural qualities

iii. Kinetic simulation, structural analysis, patterning and details

b. Building a ½ scaled model for hands on experience and testing

i. Fabrication of the kinetic structure

ii. Fabrication of the membrane patterns and details

iii. Assembly and building the scaled model

c. **Thesis: The design of composite membrane structure to be utilized as a thermal mass skin.**

d. **Expanded thesis: Taking advantage of the tensile properties of the membrane structures and its light weight supremacy to design it as a membrane pocket system that could hold thermal mass thus rendered as a tensile thermal mass enclosure or a green "planted" building to protect against outer climatic environment**

e. Designing the composite membrane pocket system and fabrication

i. Testing different configurations of pocket systems, their size, and geometry optimization

ii. Fabrication of the pocket membrane skin, patterning and combining with the tensile patterns

iii. Deploying the full structure with the composite membrane and filling with thermal mass

III. Conclusions

a. Testing the thermal qualities of the composite tensile shelter and its performance

b. Testing planting the composite membrane and its potential

c. Future applications of the design

A. Background Research:

i. Case Studies and Relevant Referenced Research and Projects:

The following case studies briefly show case typologies of structural systems used as a light weight structures functioning as an enclosed habitat. The aim is to generally assess each system and what it has to offer.

1- Geodesic strut typologies:

CHHAT-Center for Human Habitat and Alternative Technology

The geodesic structural system was used as an efficient system that distribute stresses in a way that would enable it to handle large forces with its triangular braced system using minimal strut material. It is very strong in relation to its weight.

Although it is a very successful system for large span functions or temporary or emergency use, Buckminster Fuller ultimate dream was for it to become the house of the future. Lloyd Kahn who wrote two books on the geodesic typologies described this aim as “smart but not wise. This was due to several reasons:

The paneling of the triangular geometry was not efficient material wise and the connection details as well. Furthermore the material panel starts to be problematic when composite material for thermal insulation and thermal mass was introduced for it to be climatically controlled. Thus, the insulted skin then would make more sense if it keeps its rectangular fabricated shape. Therefore, making the geodesic system underneath a complication for the paneling work.
An additional hindering factor was its spatial quality that made the curved space hard to utilize architecturally.

2- Adobe construction:

A construction technique evolving from rammed earth construction, I am show casing this to highlight another dimension in a structural system. The advantages of advancement in this technique of adobe where it is coupled with polyester wrapping, is to increase its tensile strength.

“The long-lasting polypropylene (PP) tube acts as a formwork that stays is the wall giving a permanent extra strength to the structure.”

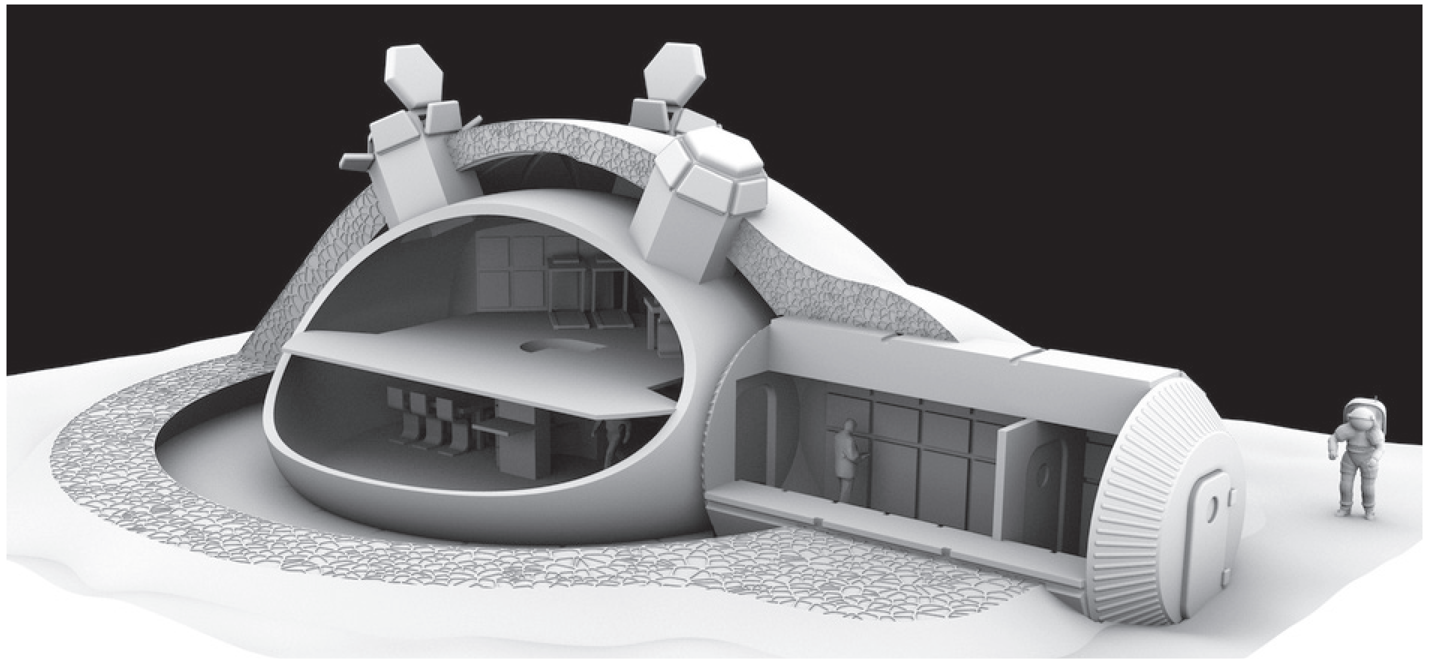
“Superadobe is like a large “superlong” adobe, an instant and flexible wall generator, which we can use to form long rows without intermission.” “http://www.superadobe.info/superadobe”

This system has a long list of advantages, mainly its environmental aspect and especially the indoor comfort quality through the thermal mass that the adobe construction provides. The only obstacle in my opinion is its compression gravity based construction technique that dictates long construction time and craftsmanship experience. Thus, for this construction type, the pre-fab quality doesn’t apply, and therefore it puts it behind the great advantages of theprefab.

3- The tensile typology

A super-efficient example of structure that creates enclosure in same time holding a spatial quality is the tension tent-sile. An example is the treetents by Dutch sculptor and designer Dré Wapenaar. Also another example is the Stingray by Tentsile. Although these are small dwellings and have a tent typology, but as a functional system this structure offers an interesting prefab.

4- Inflatable buried typology



This is still a concept design but it is to be adopted for space exploration missions. This is because this concept is a winner when it comes to material efficiency and environmentally protected skin. It needs inflation of a dome cushion then burying it with surrounding earth existing on site.

ii. Conclusion on the background research:

Earth coupled with tensile surfaces has a lot of potential as a prefab system that takes the advantages of both entities, the earth thermal, insulation and radiation protection qualities and the membrane tensile, prefab and lightweight qualities. Thus, the aim is to create a hybrid tensile form found closed system that can be filled on site with earth

II. Methodology and Testing Structures Though Building Small Prototypes

a. A deployable structure to host the skin:

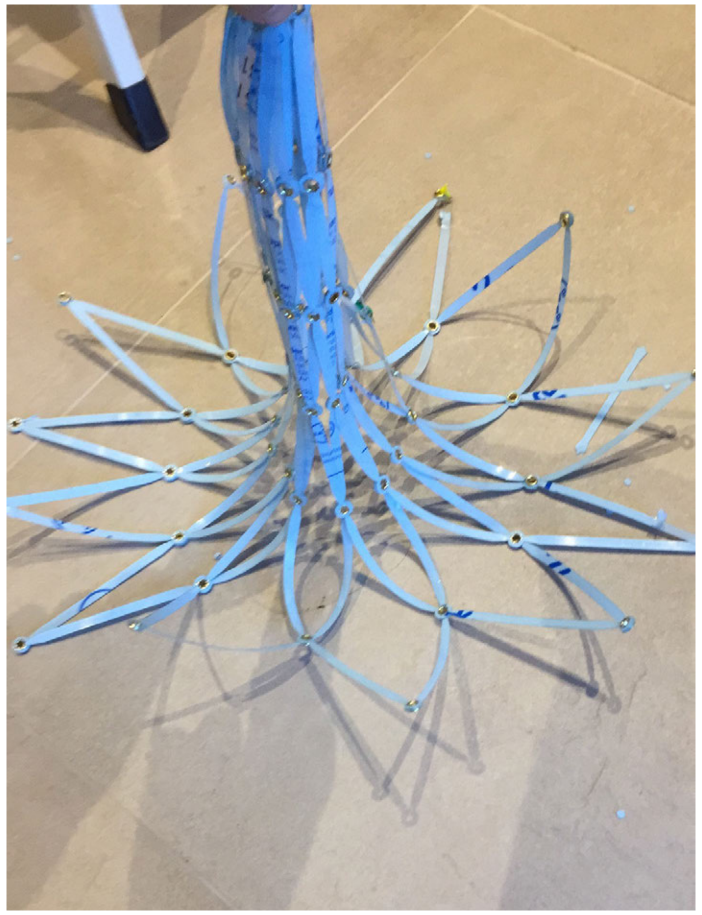
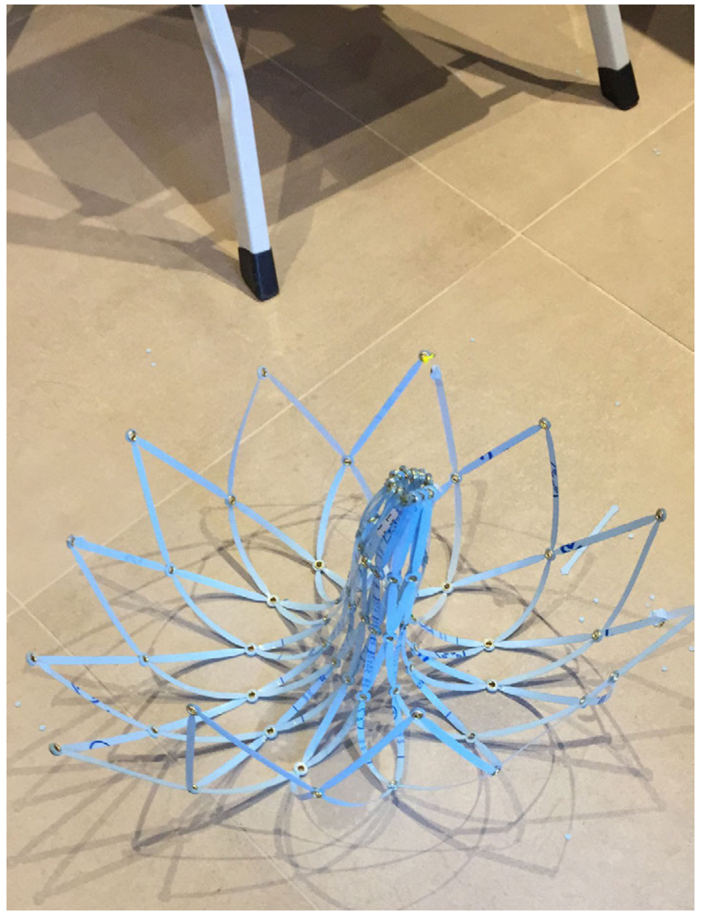
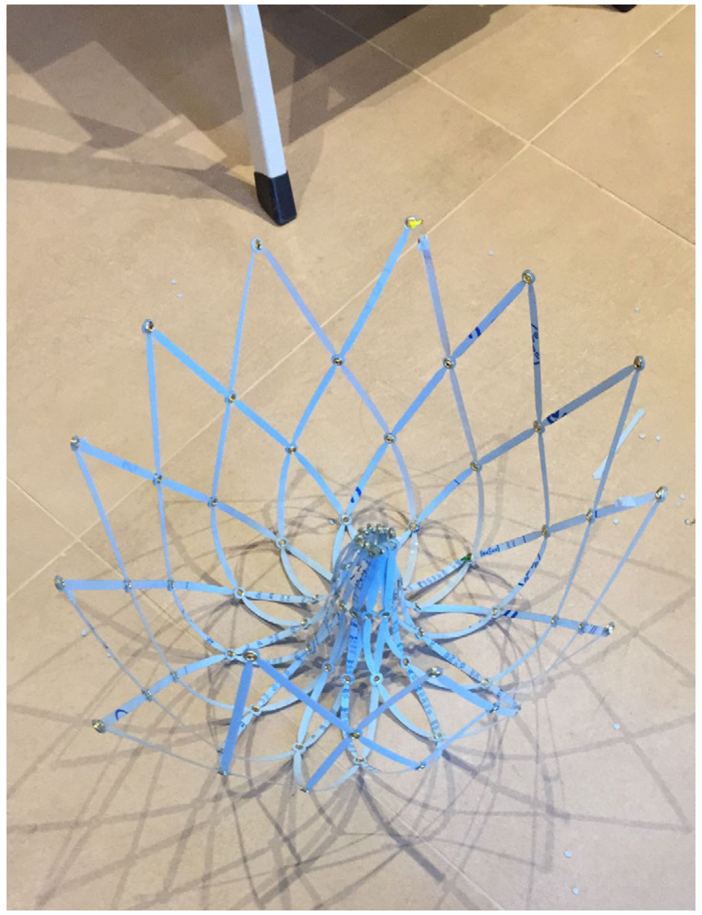
Why to adopt a deployable structure?
Construction of light weight structures and their assembly usually needs an experienced construction workers. Added to this is the transportation of the parts and details and then making sure everything is fitted in place. Time of erection is an additional important factor. These three factors will play an essential role in erecting a habitat or shelter in remote areas. The assembly process will be much more optimized and faster if it is prefab and pre-assembled in an in-door site and then taken deployed on site. Also this will cut the costs of labor ship of erecting the habitat on site. An additional advantage is that it becomes feasible for everyone to get the shelter and deploy it without any experience in construction.

i. Tests on structural kinetic concepts:

In order to ensure the selection of the right system, hands on research and tests were made. Then upon several parameters I asses each system pro and cons as a process of how the final system evolved.

1- Bending scissor deployable structure:

This concept utilizes bending properties of material to test scissor structural behavior upon radial tensional force. Upon computer aided design and simulation, the model was manufactured and was working. The hindering issue was that the scaled model didn't show the precise behavior, due to material thickness and quality in the small model.

For this reason, I adopted a bigger scale and used bamboo as bending material to apply for the scissor structure. Initial trials on the model worked very good upon applying central compression, that would be translated into radial tension when the conical membrane is applied.

When the membrane was patterned, and applied to the radial scissors, the structure worked as supposed “figure 7”. The only problem was that the material bending properties changed after time being on the tensioned configuration. Thus, the ribs didn’t fully take on the initial resting straight form.





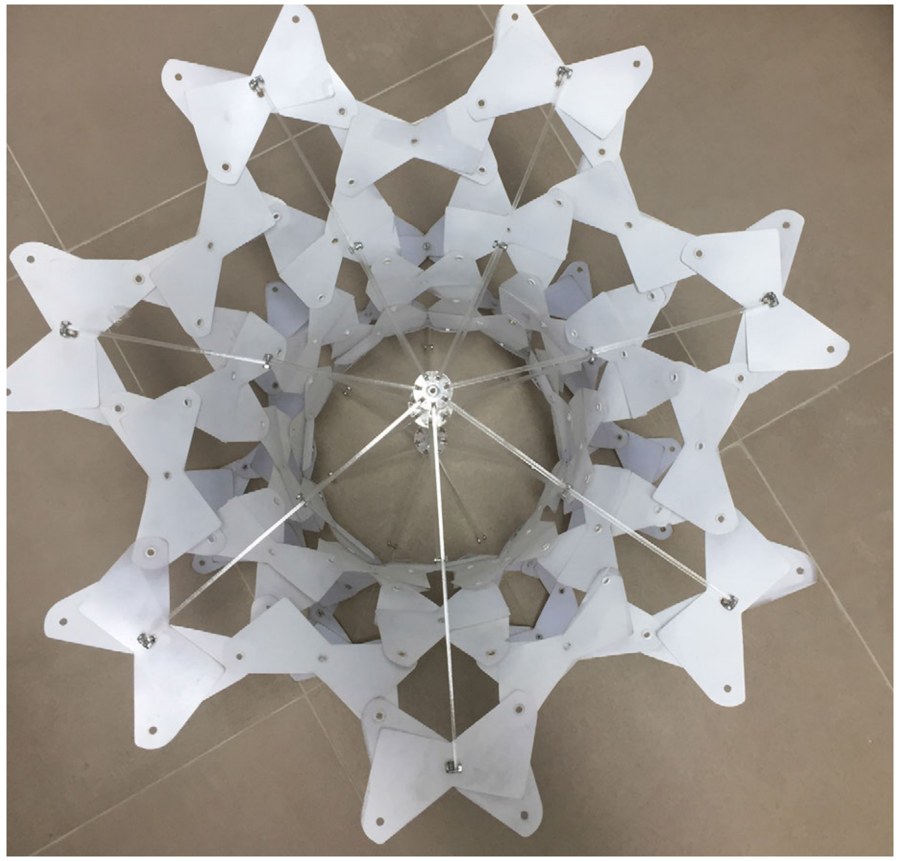


For the sake of this research, the aim is to use a functional working prototype. After testing with the bending materials, it didn’t show the adequate structural stability that is needed to insert the composite skin on. It showed that the structure was over bending therefore the skin membrane was sagging.

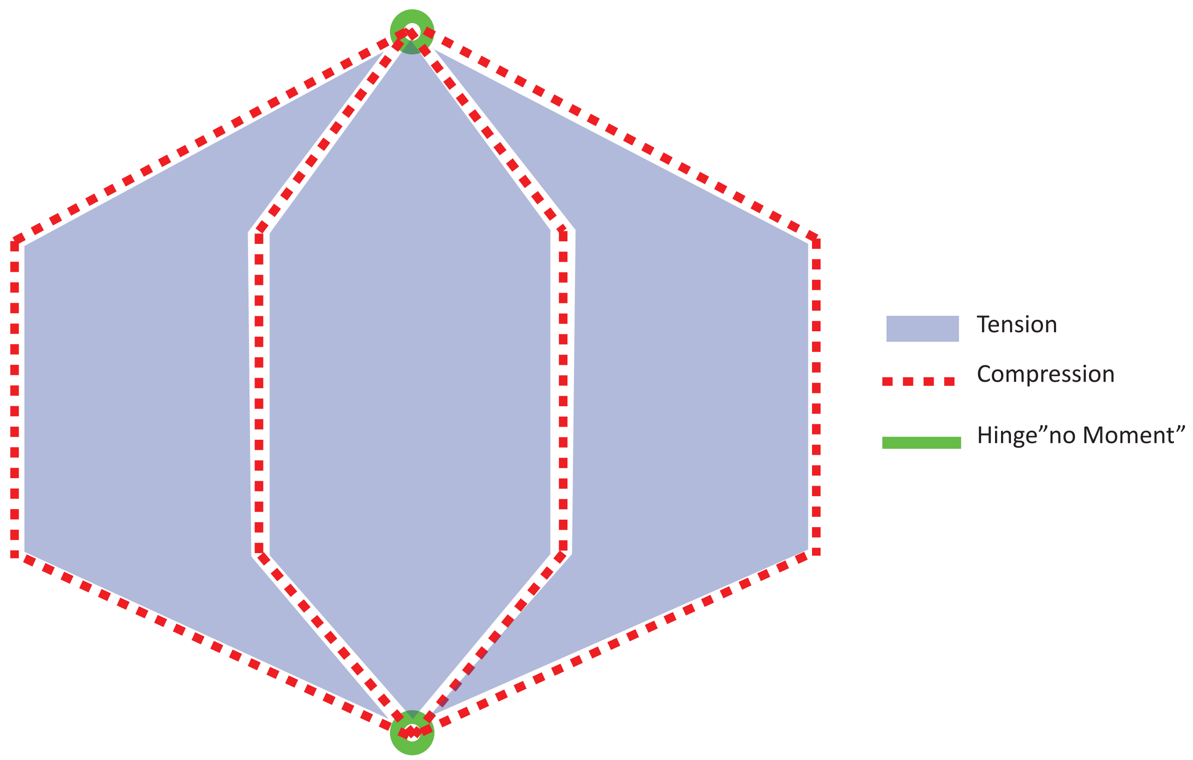
2- Umbrella Deployable tensile

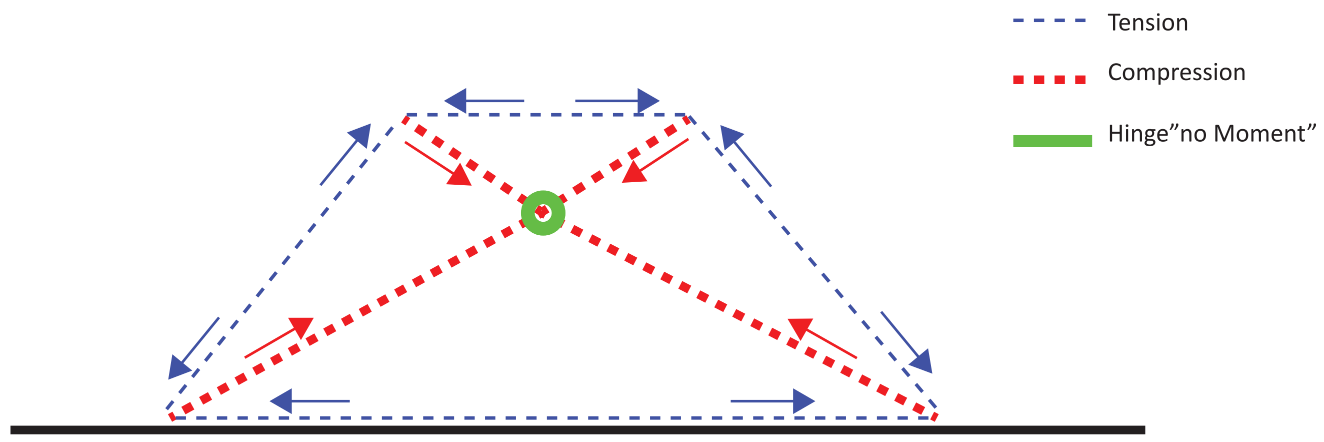
I tried two connected opposite umbrella structures that are connected in between with tension surface on the peripheries. It was an interesting experiment but turned out to be over complicated for the task. The kinetic structure in the middle proved to be intricate and occupying allot of space, also the details were complex.

The initial goal is to create something that could be feasible, simple and straight forward. For this reason in the next type i tried to make the simplest that i could achieve as a de-ployable structure, yet maintain the thesis goals.



3- A radial hinged deployable Frames





The methodology is to take trapezoidal frames hinged in two points that can be deployed radially and then closed by a membrane tension ring on the peripheries to give it its shape.

The trapezoidal shape gives more stability than the rectangular shape which transform and deform into parallelogram under stresses and moments.

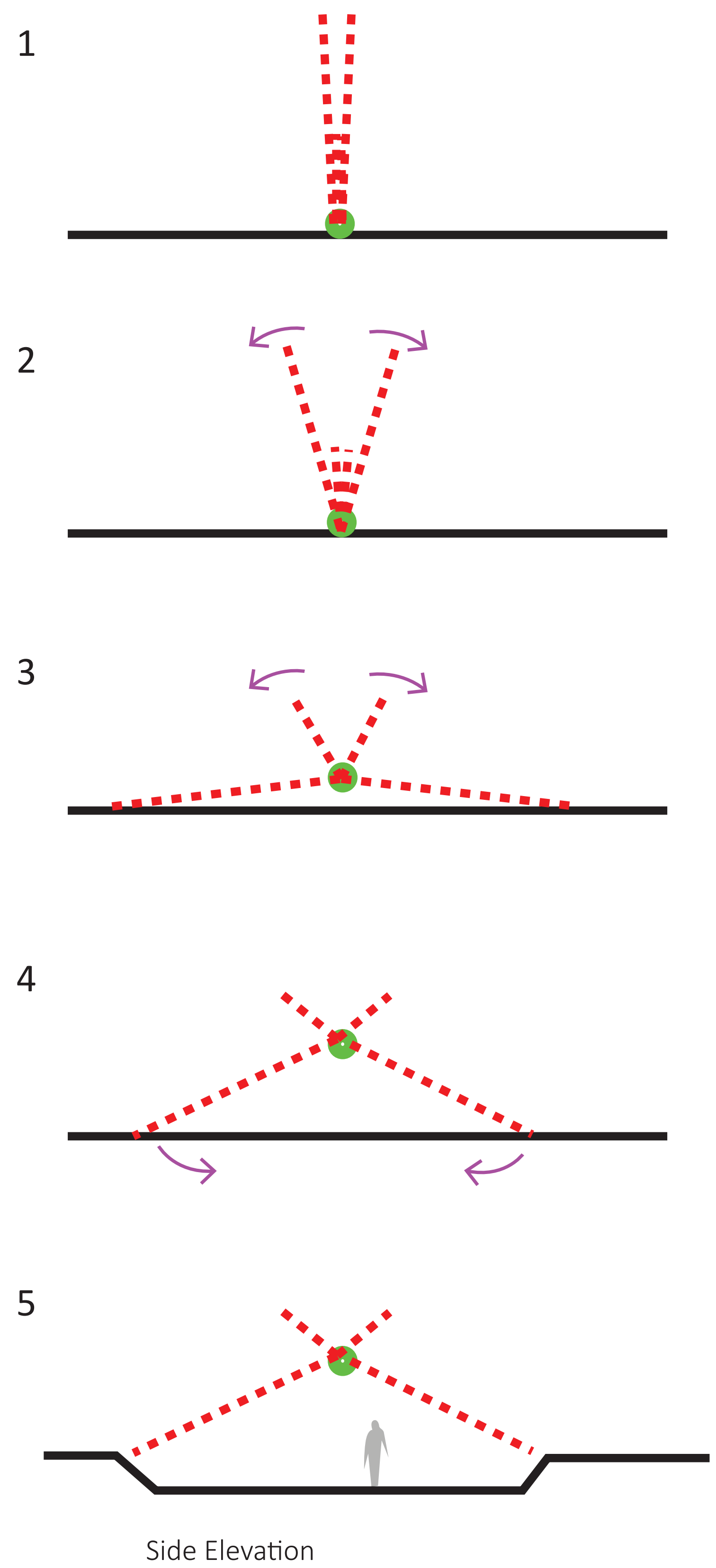
A potential was a Triangular shape, but then the spatial layout would not function architecturally in the best way due to the corners.

An architectural translation for this enclosure is a class room unit. Thus dimensions of the full scale unit has a clearance of 3 meters in the middle. Also taking into consideration a 4 meter maximum length for the ribs, so that materials can be used efficiently.

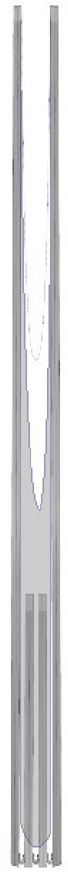
the deployment methodology is to have it folded and transported. On site the ribs are unfolded radially then tension is introduced through the tensile composite membrane skin between the ribs.

The final tension of the upper skin is then closed by tensioning cables embedded in the ground.
After the structure takes its meant geometry additional tension is introduced "a state of pre-stress" to accommodate for thermal mass filling weight.

The structure ribs are designed to be aluminum and the moment connection between the aluminum is steel plates.



iii. Kinetic simulation, structural analysis, patterning and details



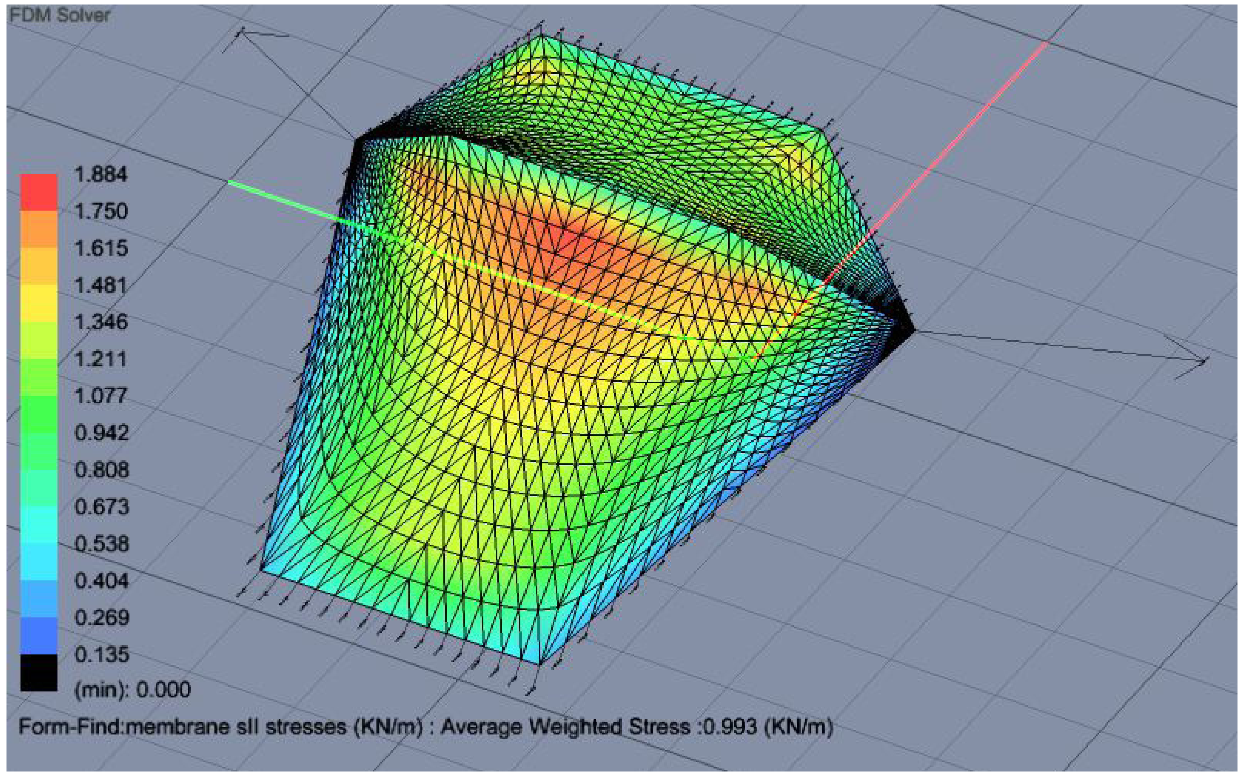
Closed condition

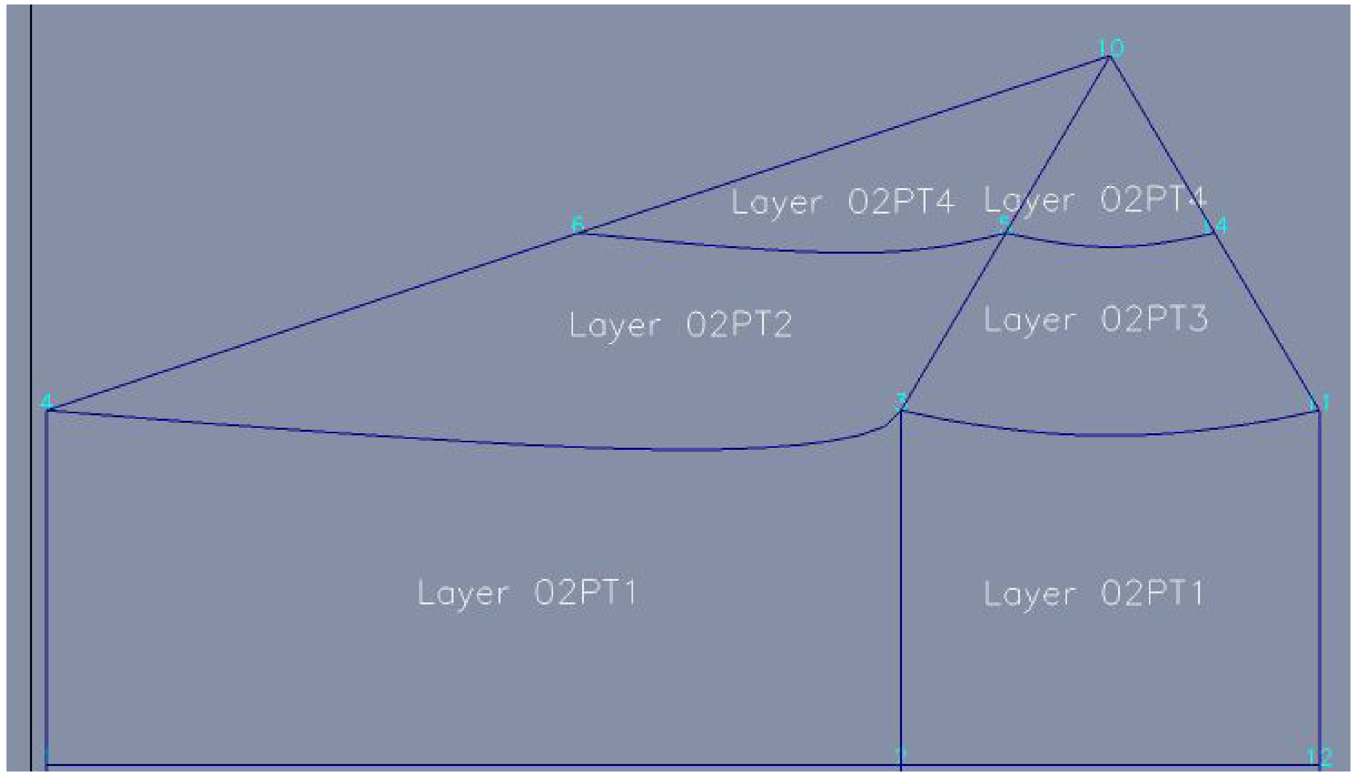
Side elevation of the structure in closed position with sagging membrane between the ribs

Opened condition

Side elevation with the deployed structure and the tensioned membrane through the lower tensioning cables.

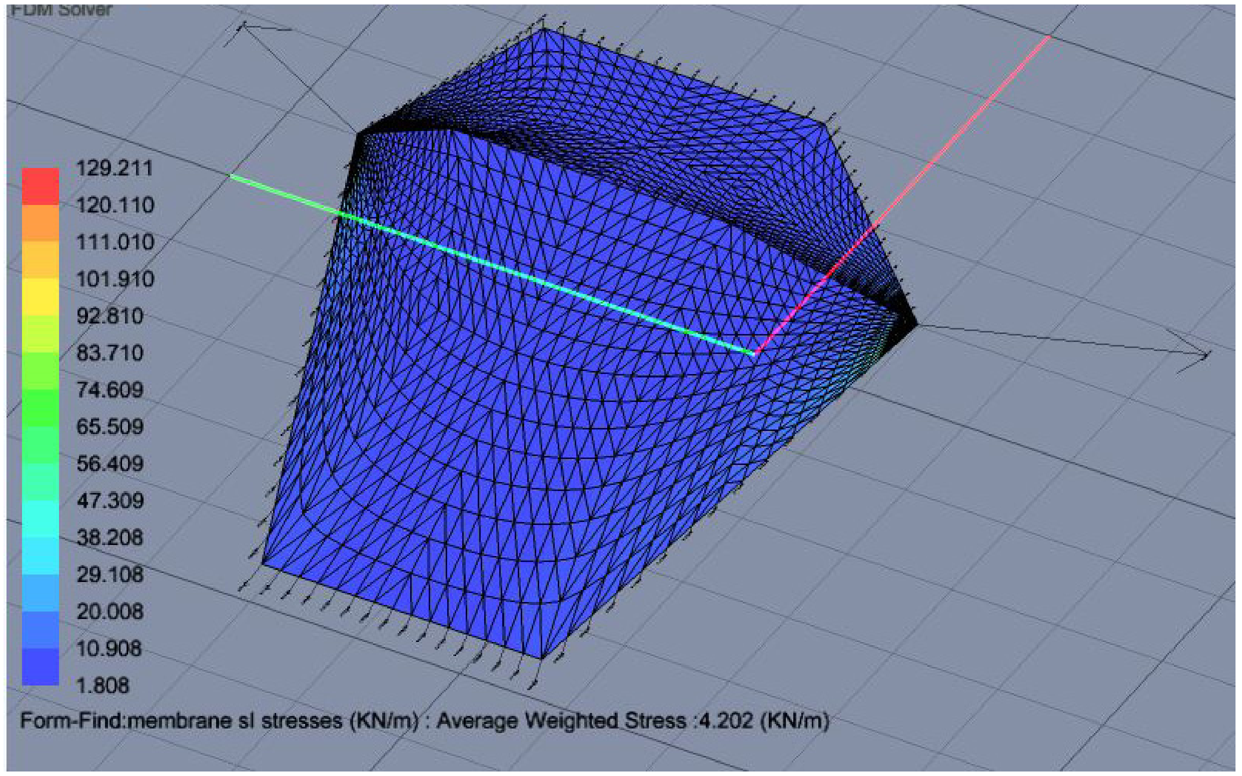
Model Analysis

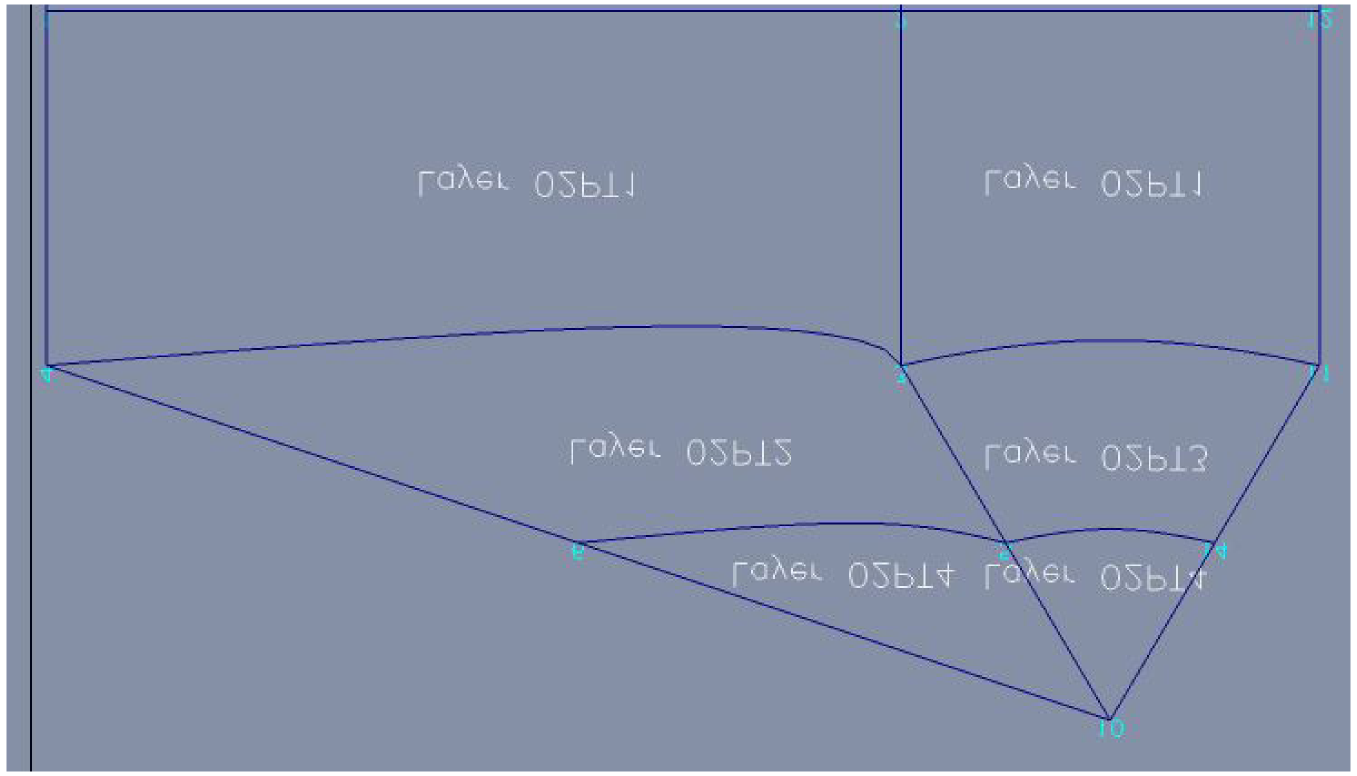




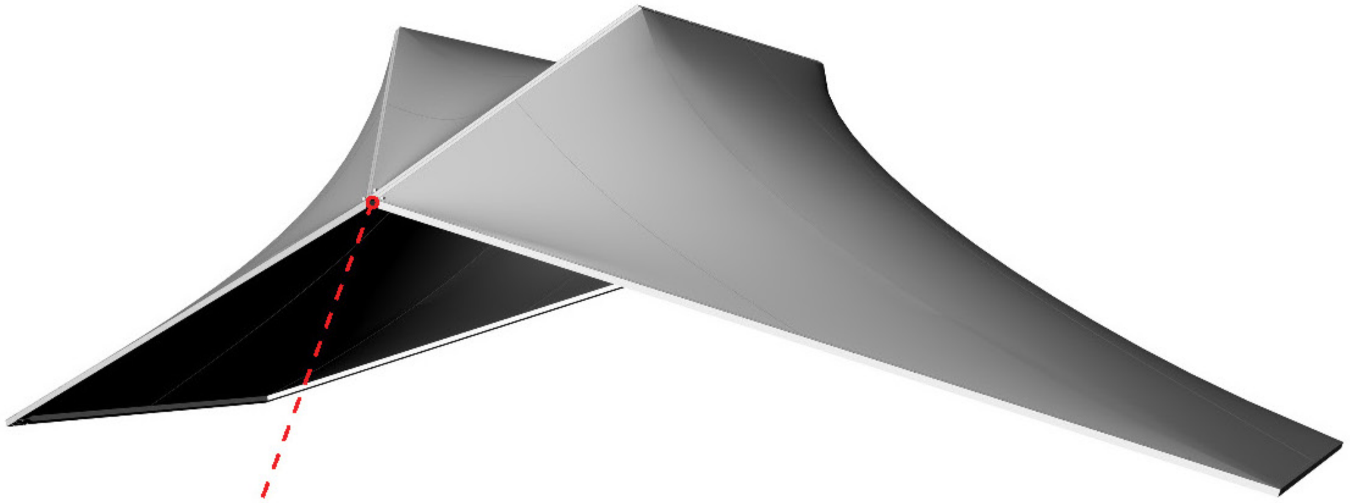
Stress analysis on the membrane to understand critical points

Pattern distribution and layout

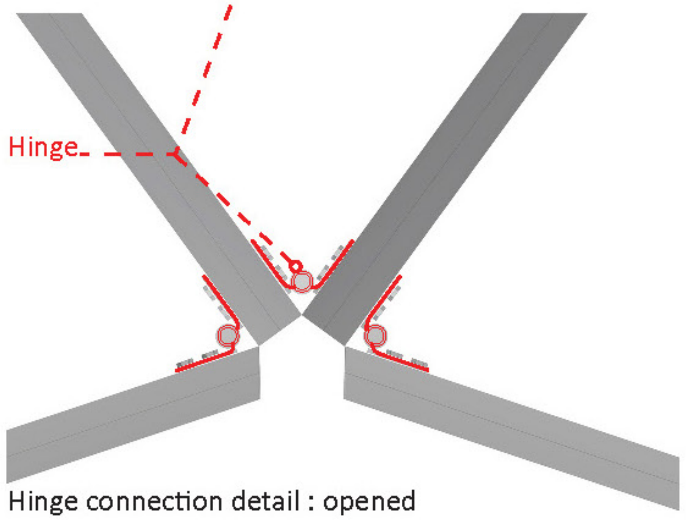




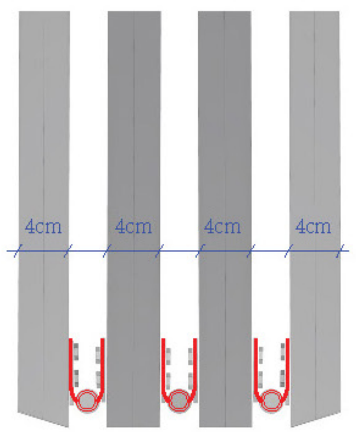
Central Hinge Connection And Details



The hinges ought to be aligned on the same vector between the two nodes of the structure so it can be deployed as simulated.

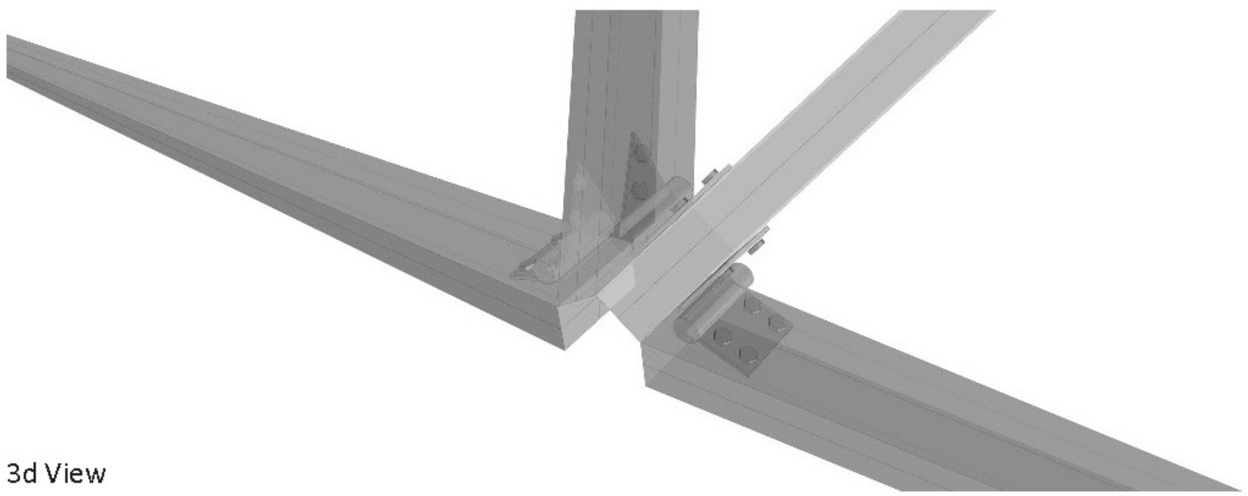


Hinge connection detail : opened



Hinge connection detail : Closed

The smaller aluminum ribs edge is used to connect the membrane to.

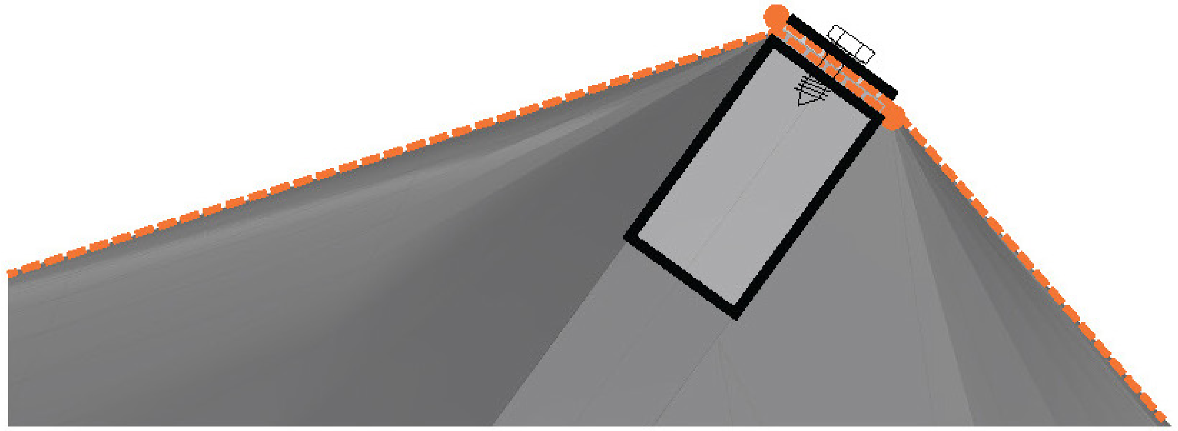


3d View

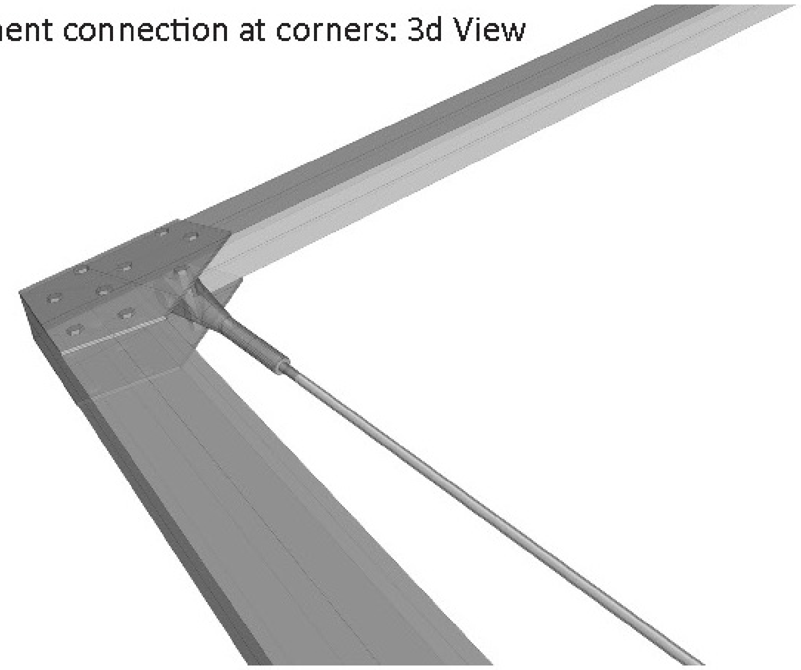
Wooden strips are inserted inside the aluminum on the hinge corners to give a better moment of inertia to the structure at stress areas.

Central Hinge Connection And Details

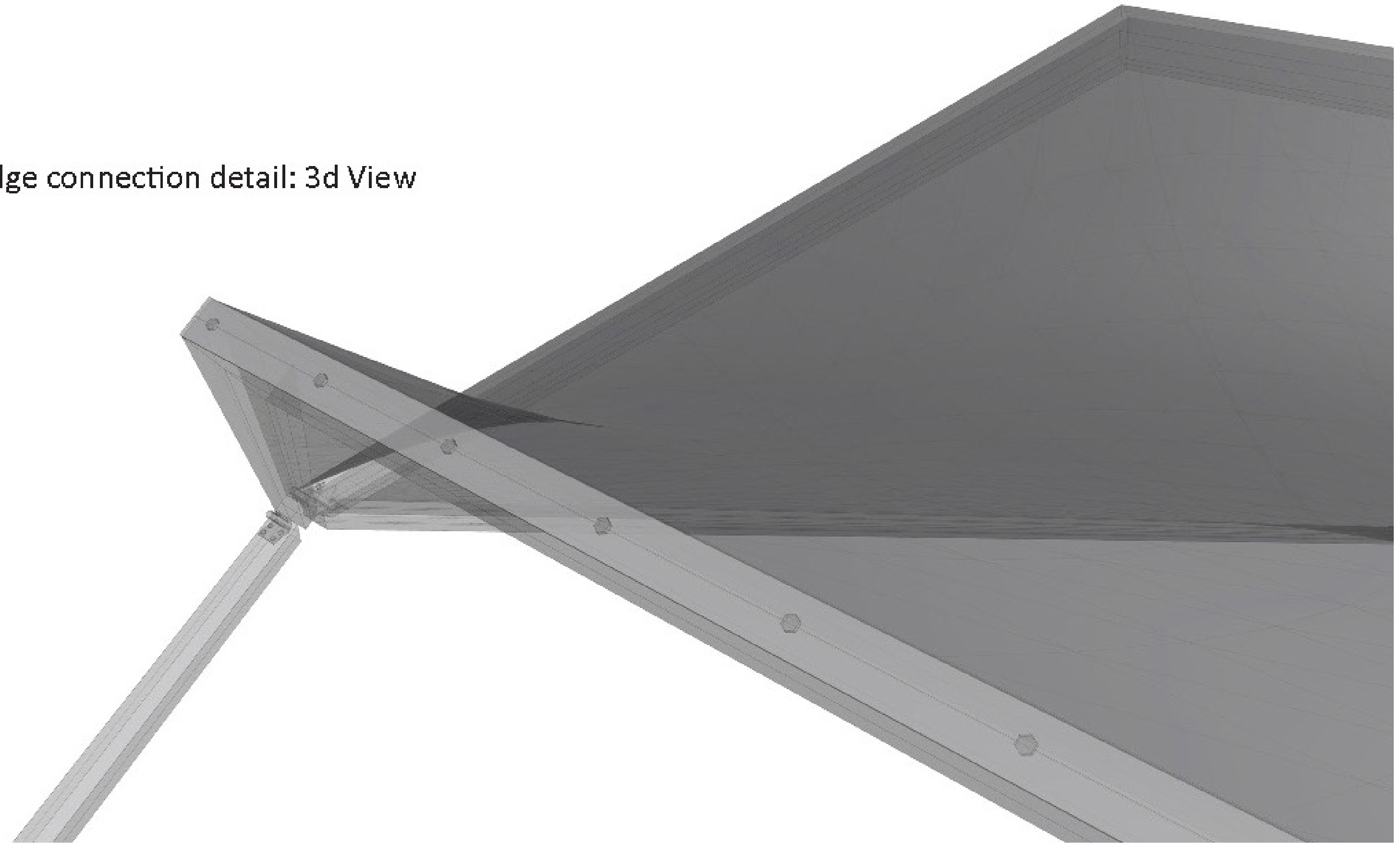
Fixed edge connection detail



Moment connection at corners: 3d View

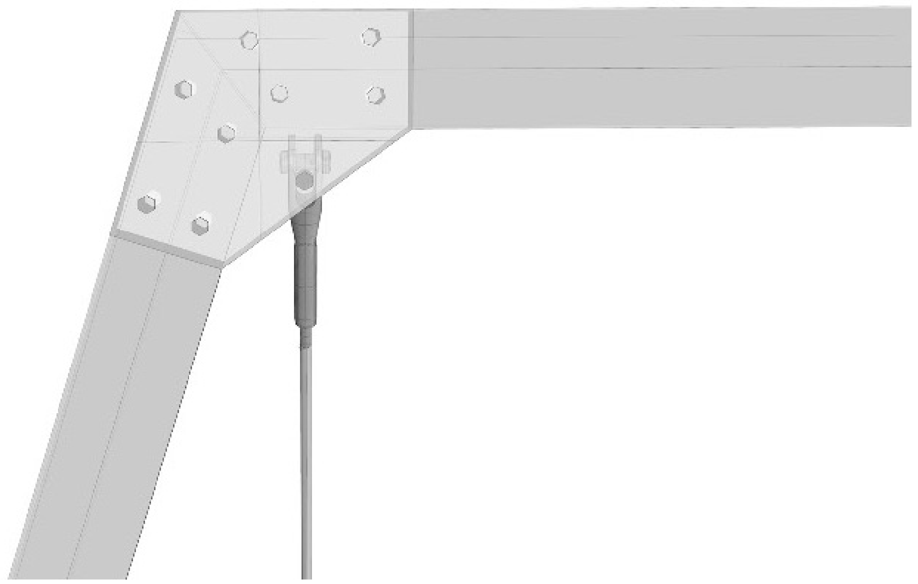


Fixed edge connection detail: 3d View



The frame without the skin weights 12 KG

Plan : tension cable attached to corner plate



Pattern assembly before tensioning with the lower cable

b. Building a ½ scaled model for hands on experience and testing

A SCALED PROTOTYPE

Tensioning The Structure Through Cables

Tensioning The Structure Through Cables

The frame without the skin weights 12 KG

Pattern assembly before tensioning with the lower cable

A SCALED PROTOTYPE

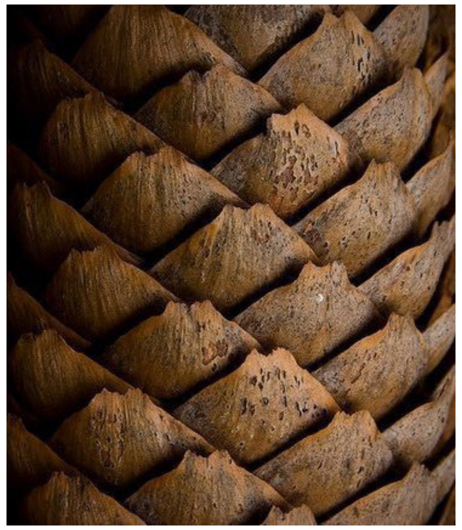
A SCALED PROTOTYPE

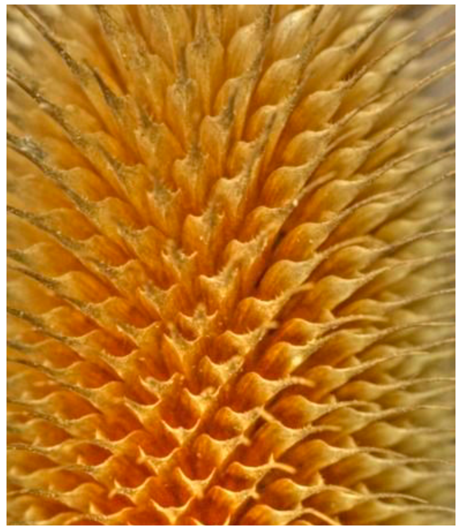
A SCALED PROTOTYPE

A SCALED PROTOTYPE

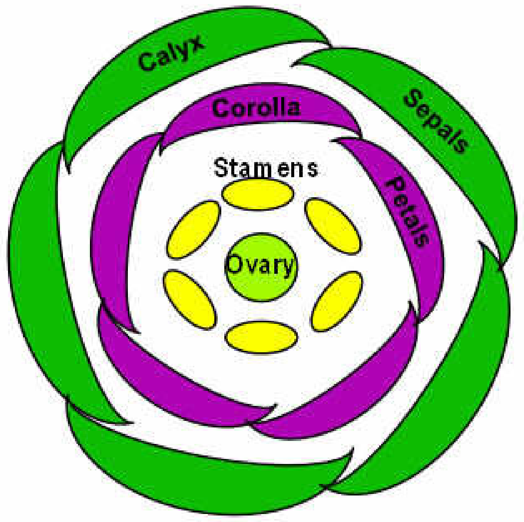
A SCALED PROTOTYPE

c. A Composite Membrane Structure





Pocket system exists widely in nature. Its Structural system and maximization of surface area that it provides gives it an evolutionary edge. The structural shape relies on folding. This system is found in petals, broad-leafs and several biological system. Maximization of surface area of the petals and pocket system is utilized in gaining more solar radiation on the floral structure.

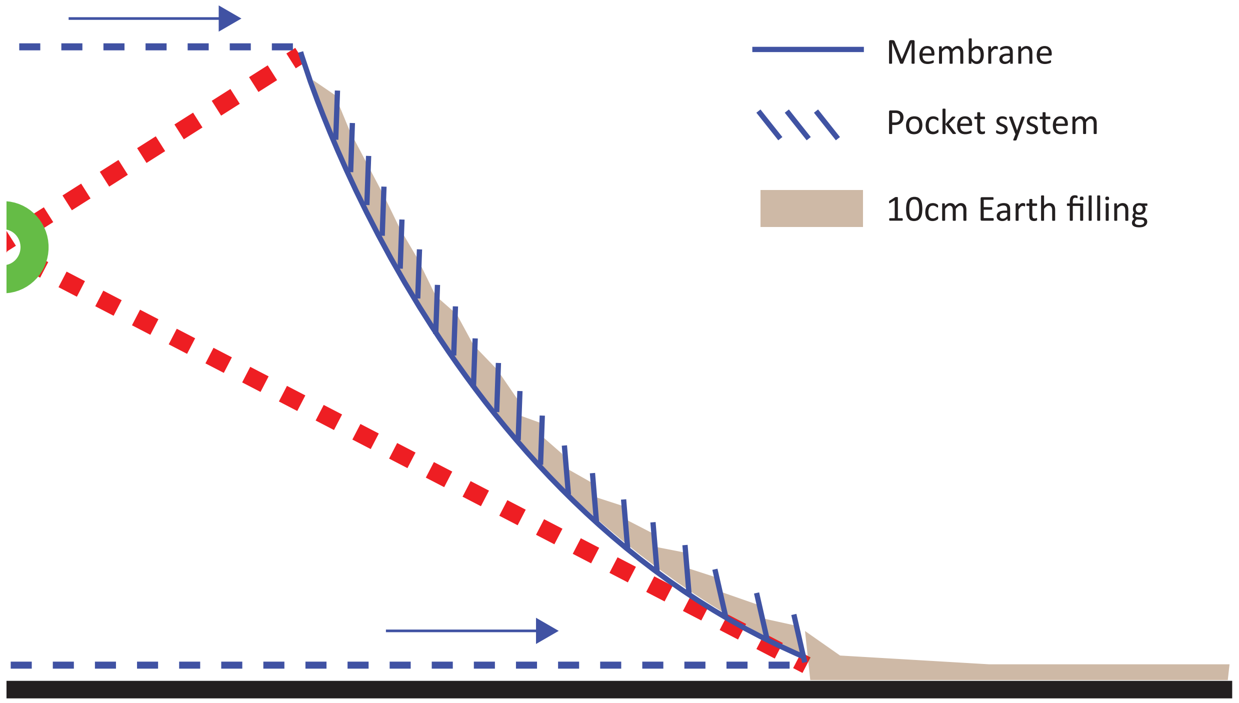
In addition to this pocket system help distribute water between the pockets upon irrigation and also to hold water inside them for longer time.

c. Designing the composite membrane pocket system and fabrication

i. Testing different configurations of pocket systems, their size, and geometry optimization

The intention is to keep a minimum thickness of 10 cm earth in the pockets. This will dictate an optimized geometry that responds to slopes in the membrane, the fabrication process and the thickness of earth the pockets will hold.

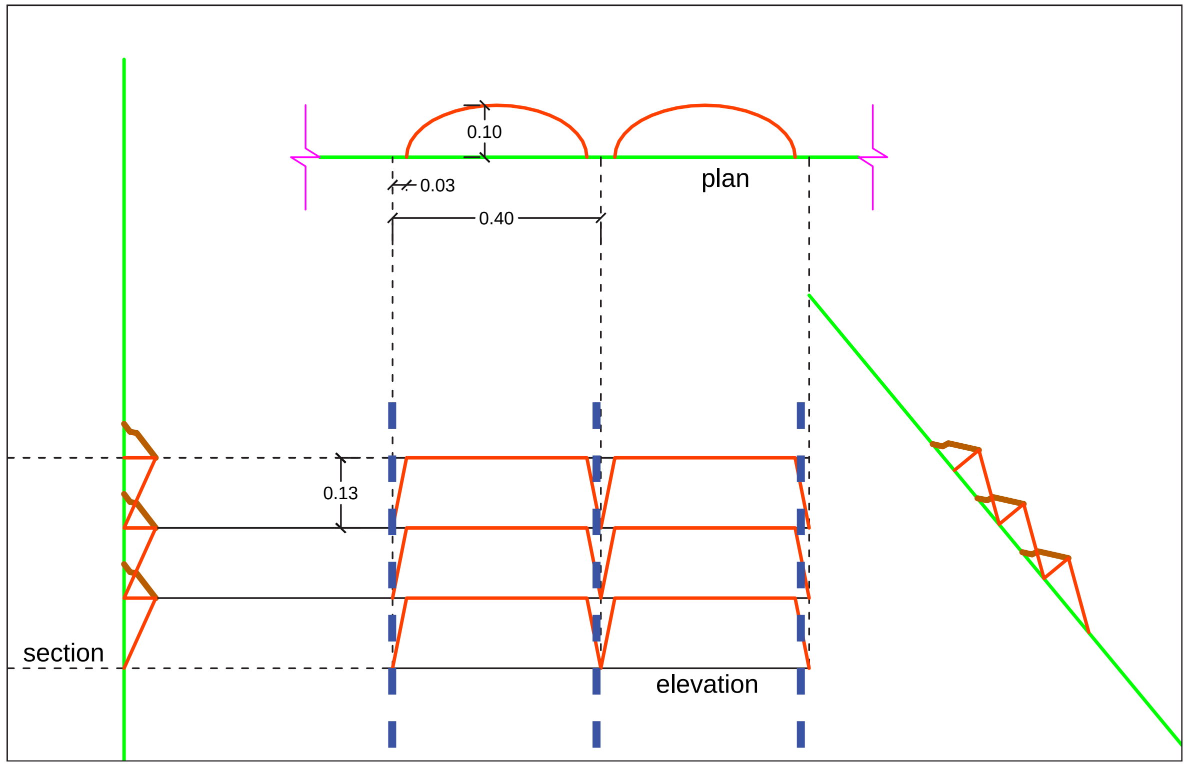
For future potential, the idea is that the tensile membrane is fabricated directly with the pockets attached.



Side Section

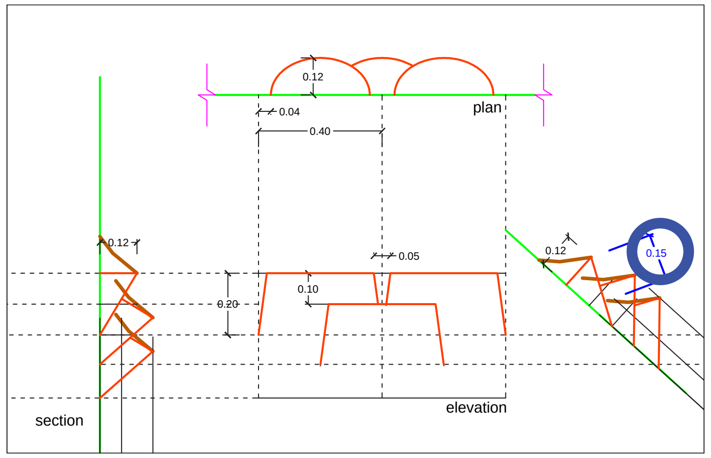
Designing the pockets

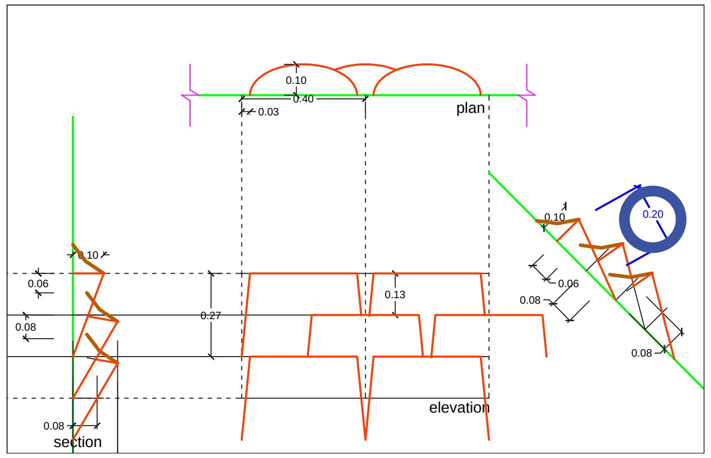
1. A trial for non-overlapping pockets was made, but it shows that on slopes above 15 degrees the earth will not hold between the pockets, " the blue line between the pockets" thus it will be creating spaces where it won't be filled with earth between the pockets.

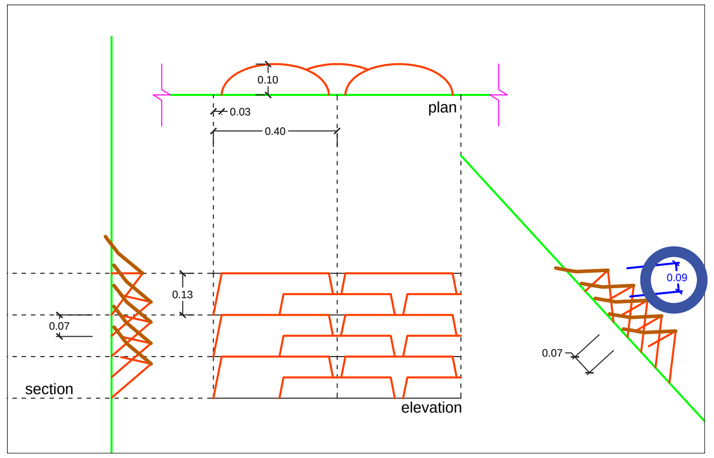


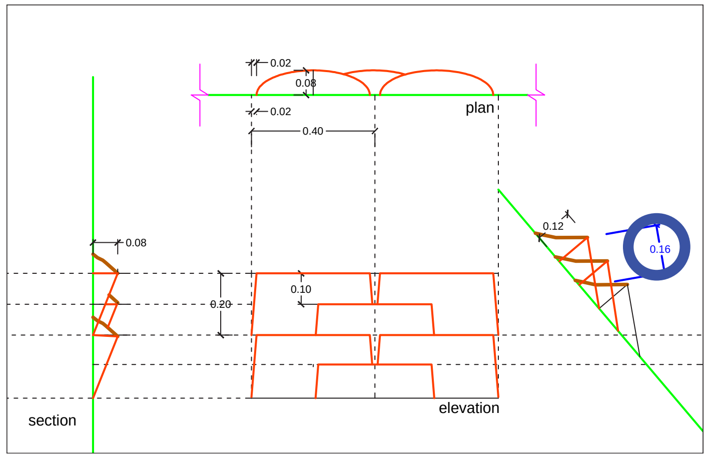
In order to fill this line i had experiment in alternating the pockets in the second design

2. The second trail is for alternating, overlapping and equidistant pockets, the aim for the scaled prototype is for the pockets to have 8 cm earth capacity. I conducted several studies taking into consideration that the membrane is at 45 degrees' angle. Another assumption is that earth will rest horizontally inside pockets when the membrane is tilted. The parameters to optimize for are mainly three: overall earth thickness on the membrane, material usage and most importantly is the dimension indicated in blue. The blue dimension is how much will be showing from the membrane in the worst case where earth slides and is just retained horizontally inside the pockets. Membrane area which is showing, doesn't mean that it is just the membrane, in fact it is the upper part of the pocket and the pocket is still filled inside by earth.
Several studies were conducted through a section, elevation and plan for each study:









RESEARCH ON SKIN

For the fabrication i used laser cutting to create slits in the lower membrane where pocket edges are attached. The pockets are made from a single membrane to be efficient material wise thus the v shape occurs when the pocket is folded to its shape.

I experimented as well on long deep pockets, but the steep angle it creates in the deep part makes it difficult to be filled with earth, so wider pockets were adopted

The best case showed to be study number 6 "Figure 6" where the pocket has a length of 40 cm and height of 16 cm. The pockets overlap in the middle and has a maximum depth of 8 cm.

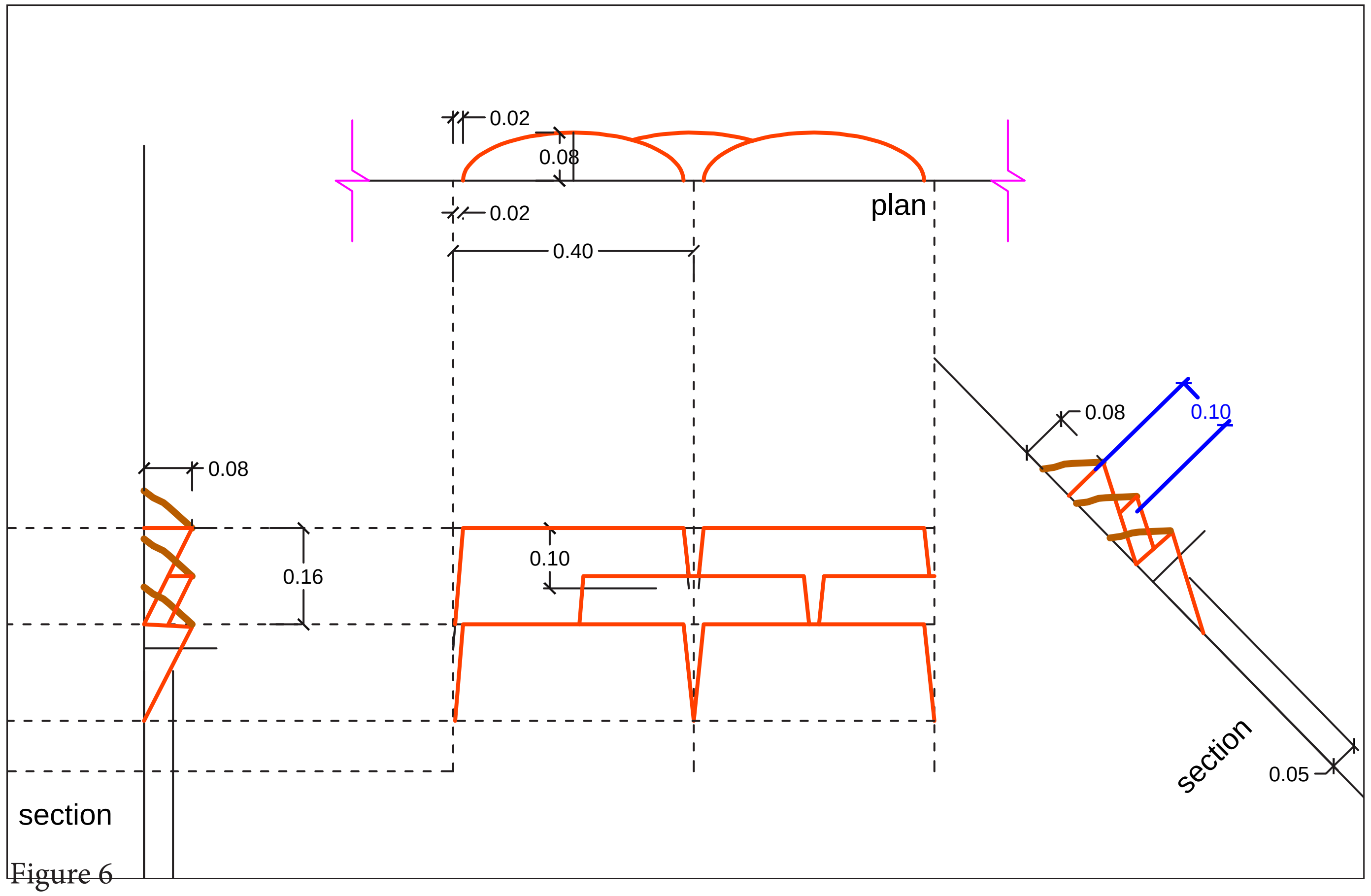
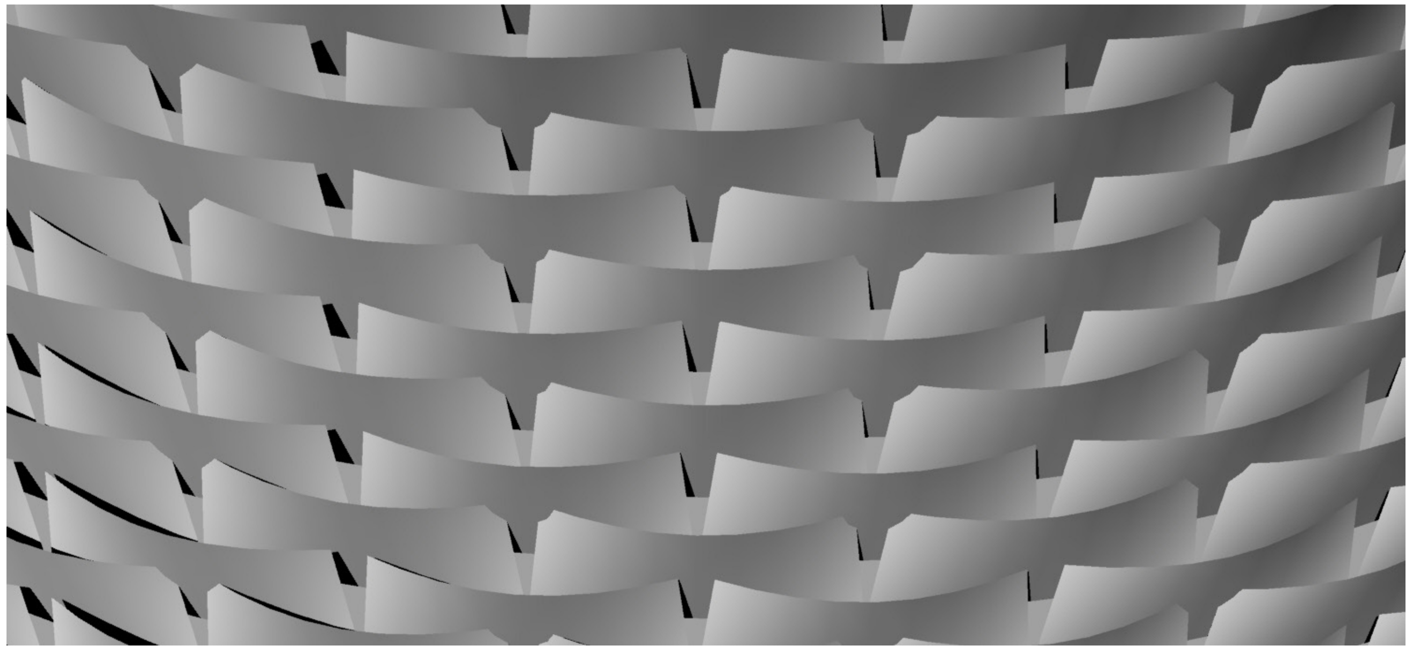
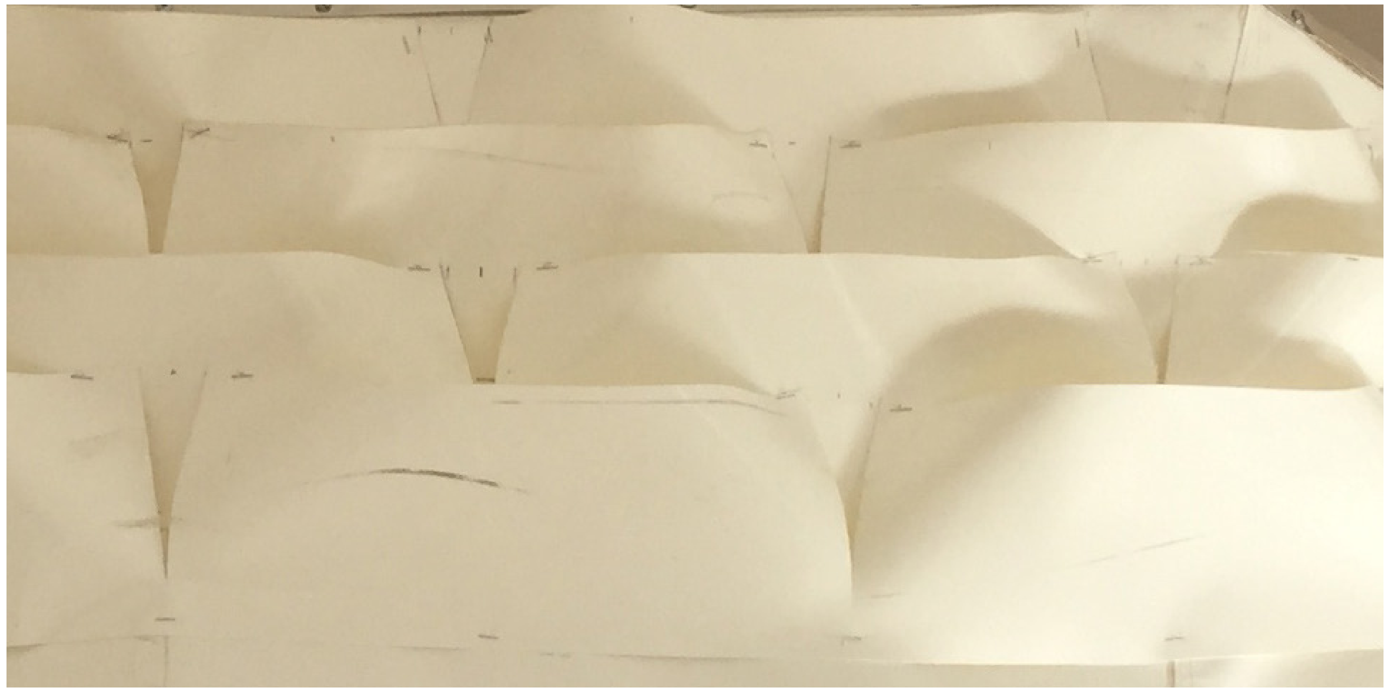
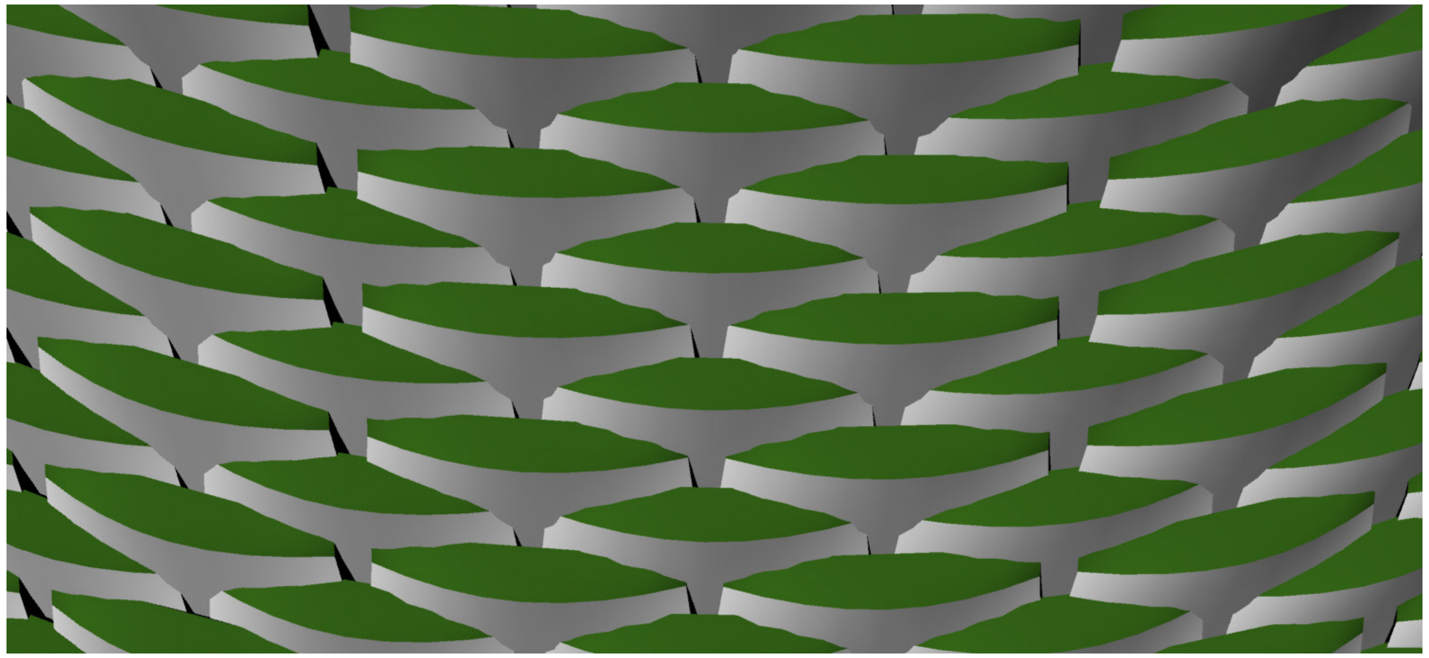


Figure 6

The pockets are modeled to be applied on the double curved surface

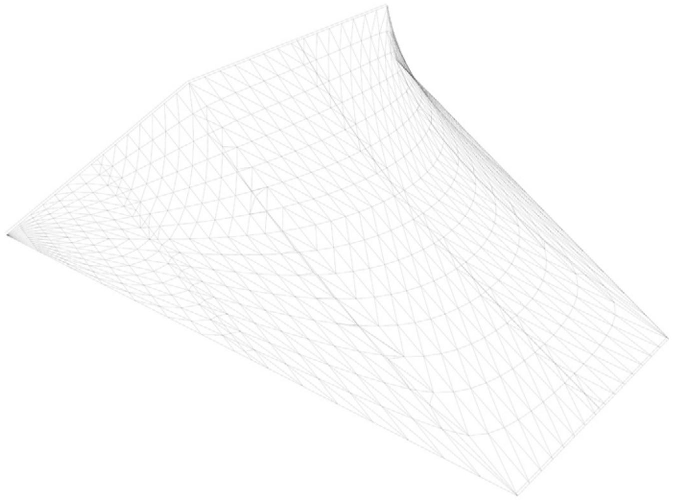


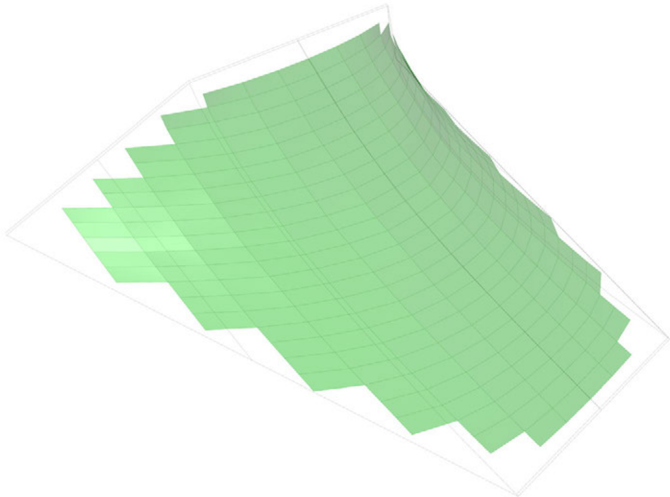




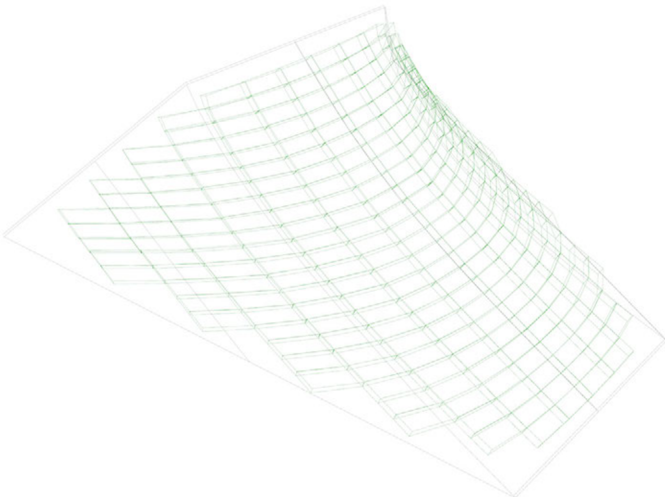
Computer modeled pocket

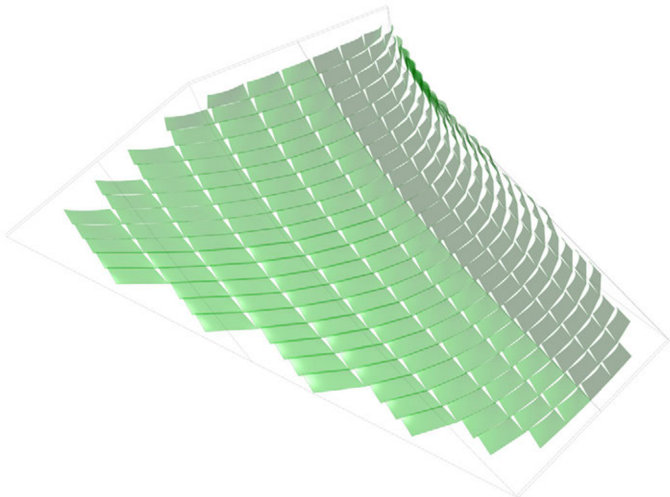
Parametric design



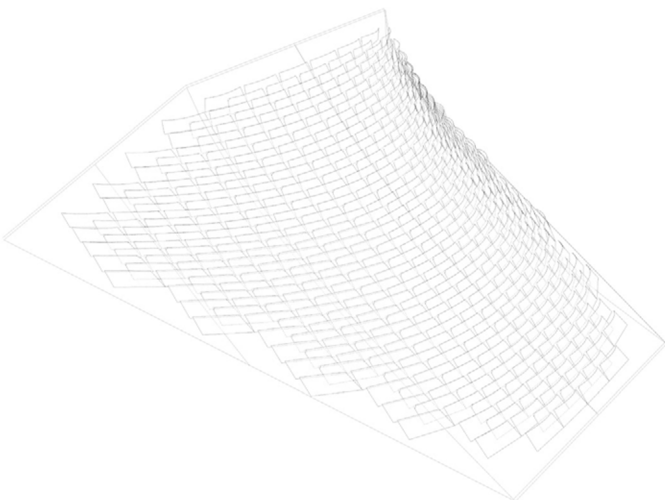


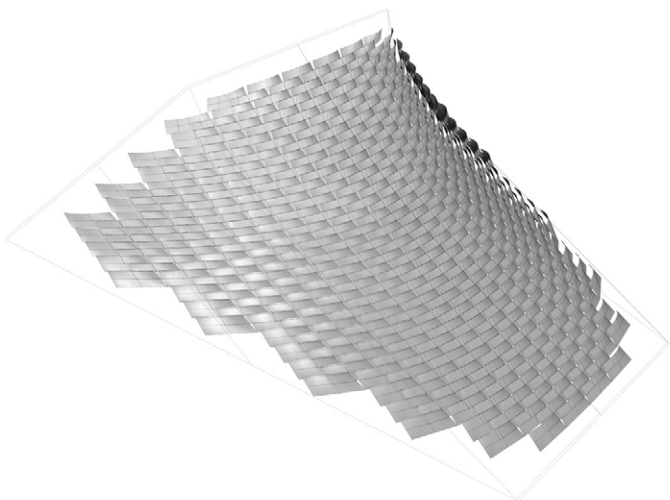
The double curved system is divided into quadratic panels to host the pockets



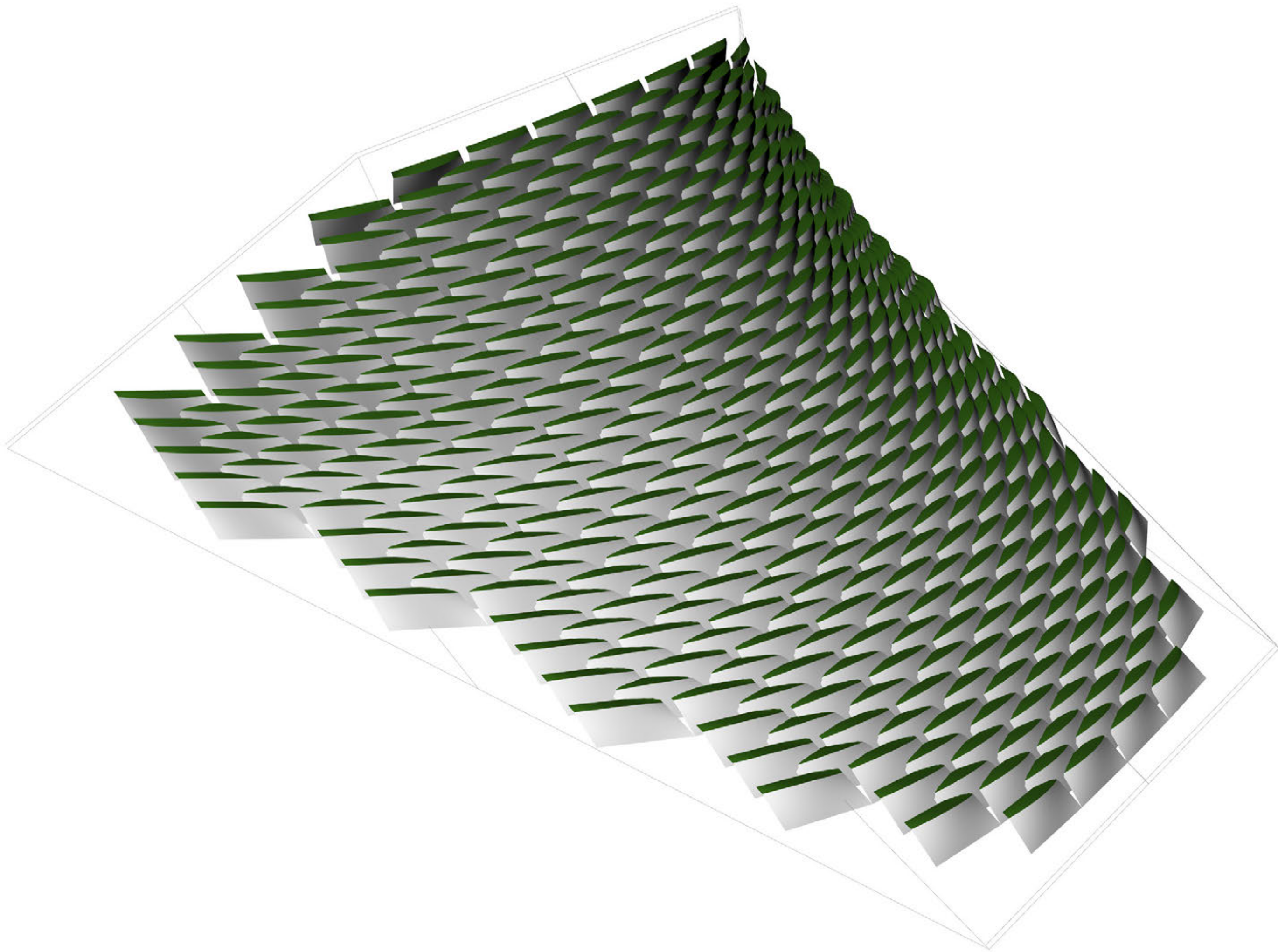


pocket thickness is given and area is compensated



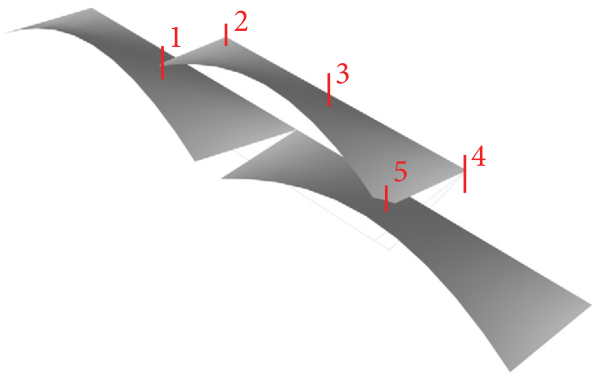


second layer of pockets is inserted to creat the overlaping

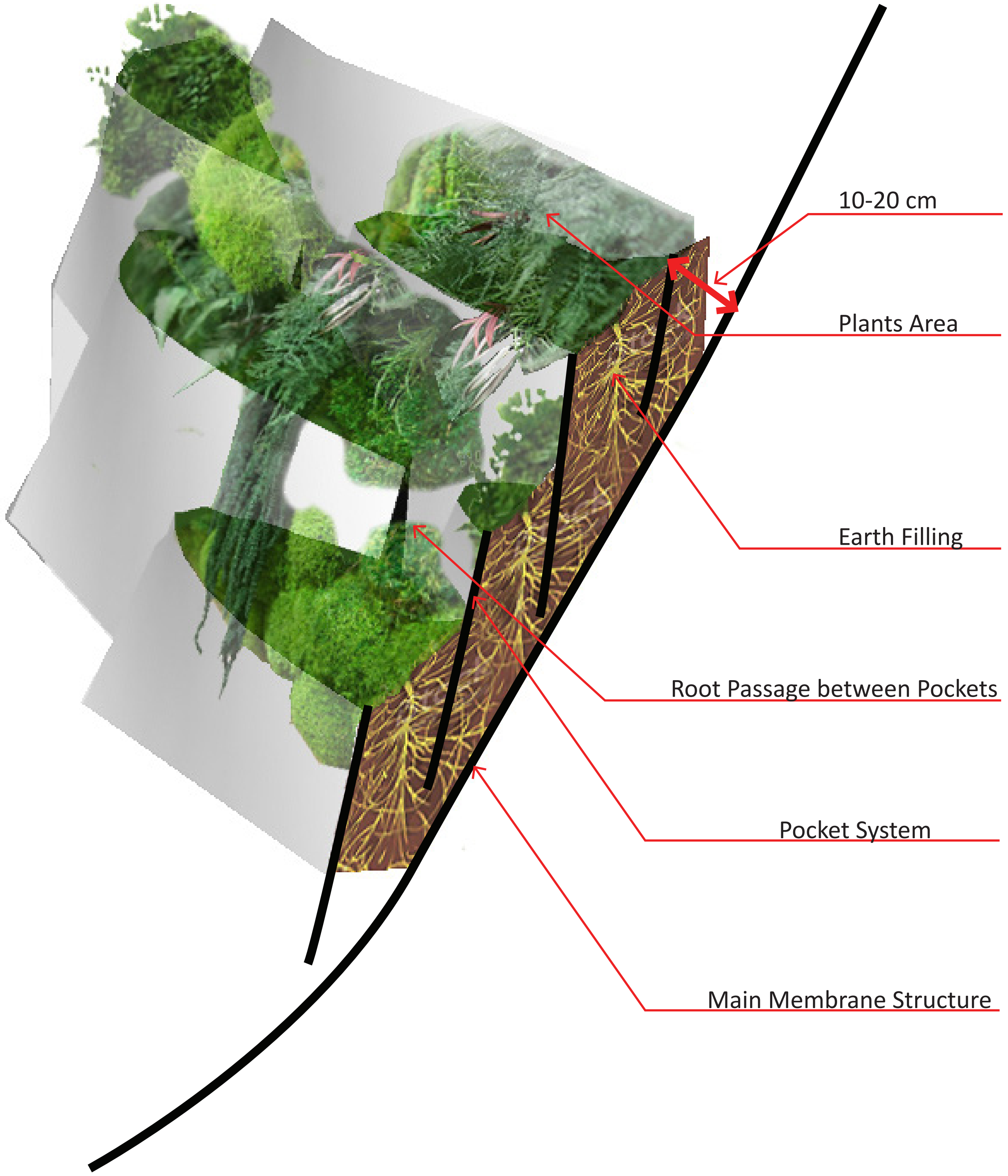


Overlapping layers are filled with earth “green color” . Pockets are open to the side partially to distribute earth within the pockets. Also excess earth will slide from pocket openings to the underneath row of pockets . this as well serves for water distribution inside the pockets.

The pockets geometry and fabrication are studied so roots can go from one pocket to the other. For this reason each pocket is attached on 5 points. Between these points roots can expand to the neighboring pockets thus giving more rigidity for earth.



System Components

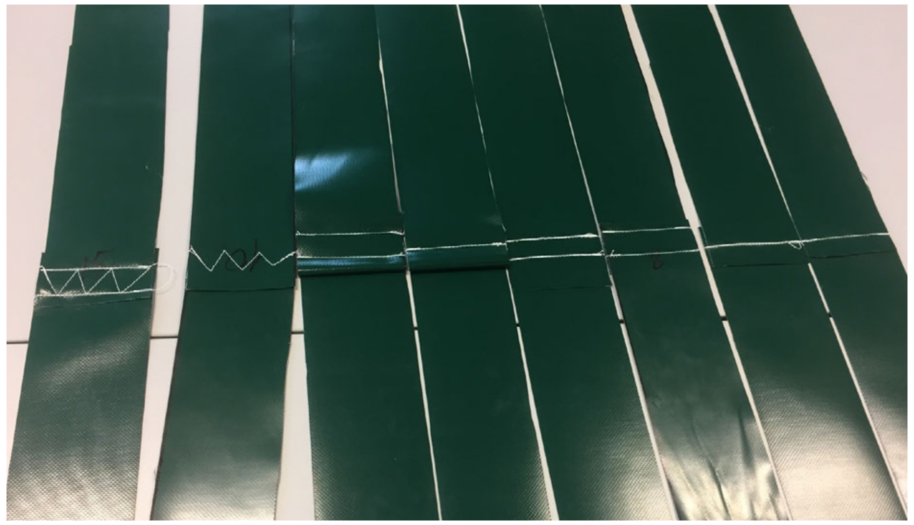


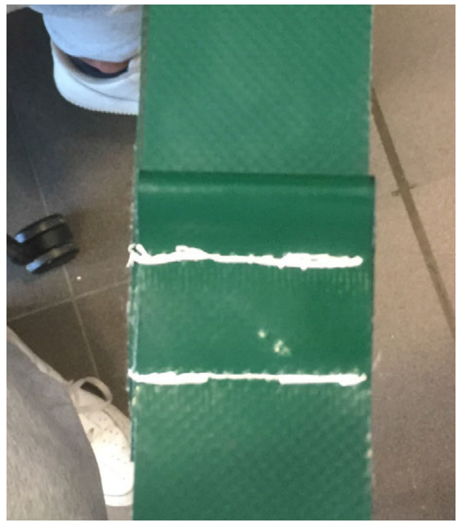
Tests Multiple Sewing Methods to Attach Pockets

I adopted sewing to attach the pockets to the tensile membrane.

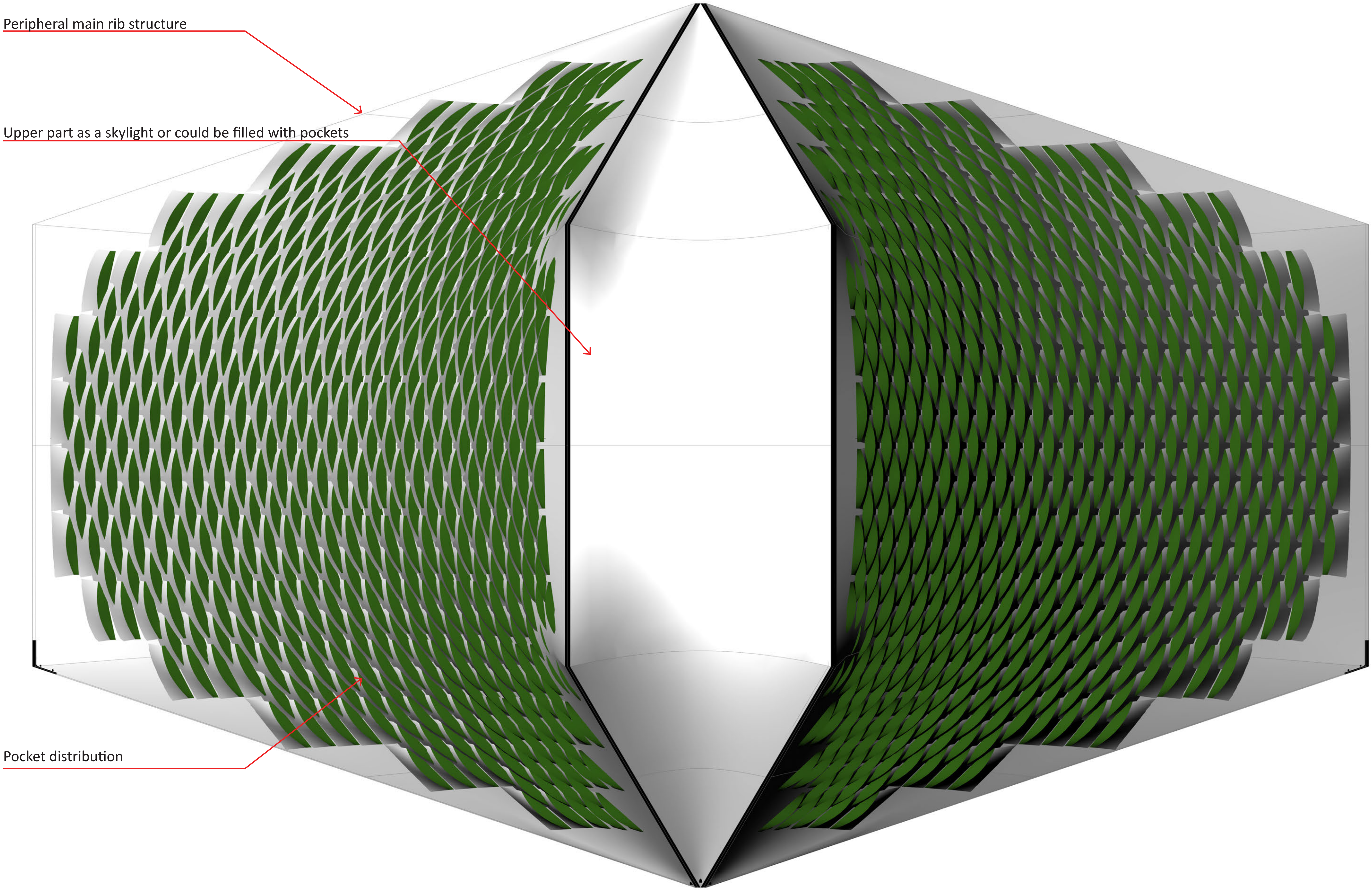
For this reason I have made tests on the best stitching geometry that will hold the pockets in place.

a single stitch is more than enough to hold the weight of the earth inside the pocket, using Tenara threads.



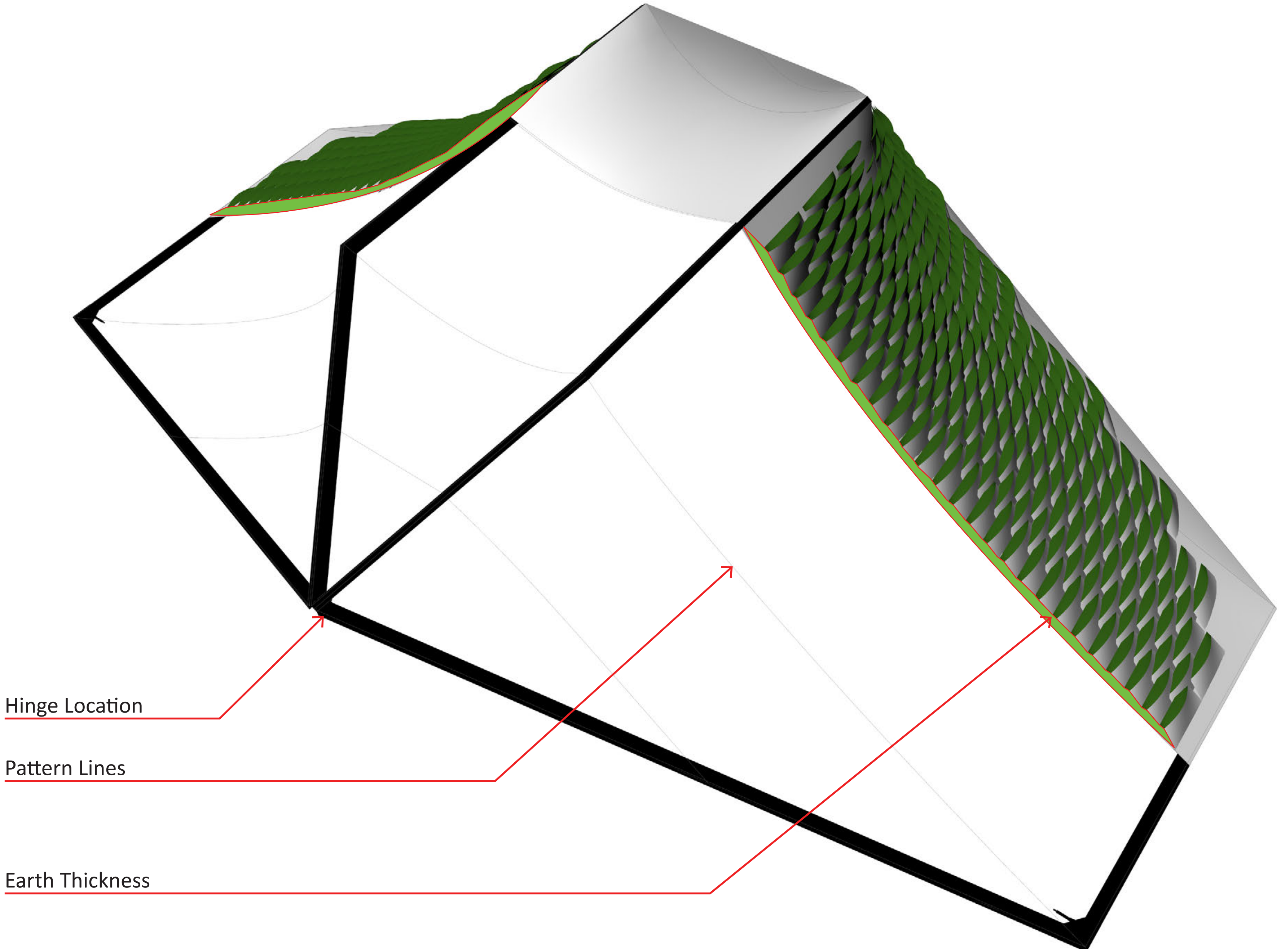


Structure and Skin Top View

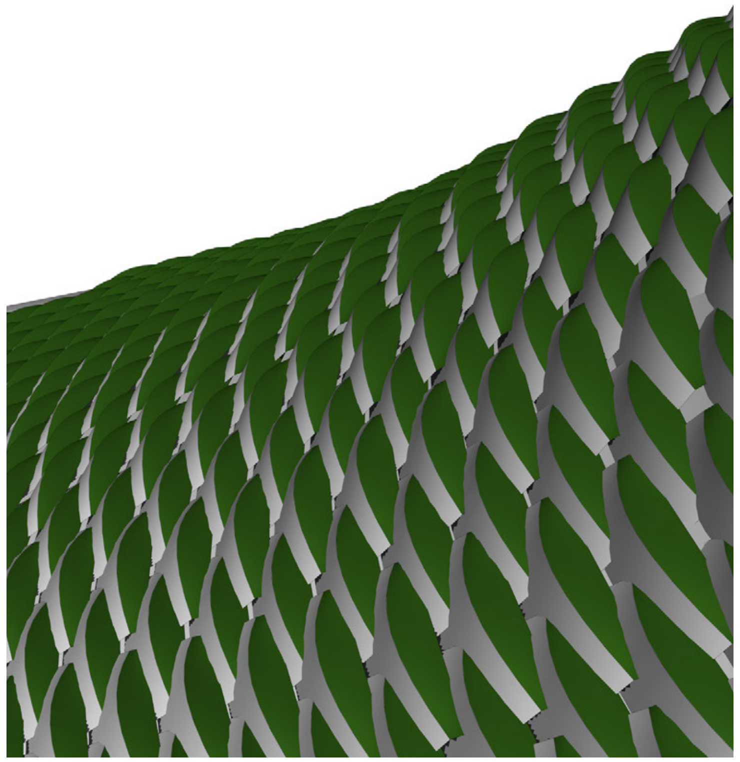


STUDYING THE SKIN

Axonometric Section Exploded Section



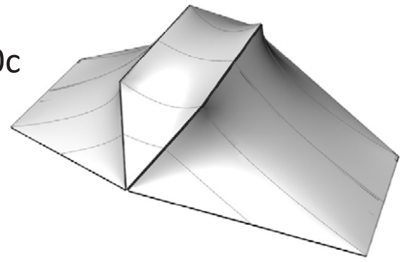
Skin Close-up



Thermal Simulation and Data Comparison
Using Energy Plus and Grasshopper

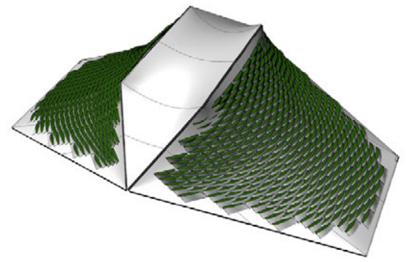
The Simulation was carried in purpose of investigating only one aspect, a tent with and without earth pockets. All other factors were disregarded " other optimization parameters "

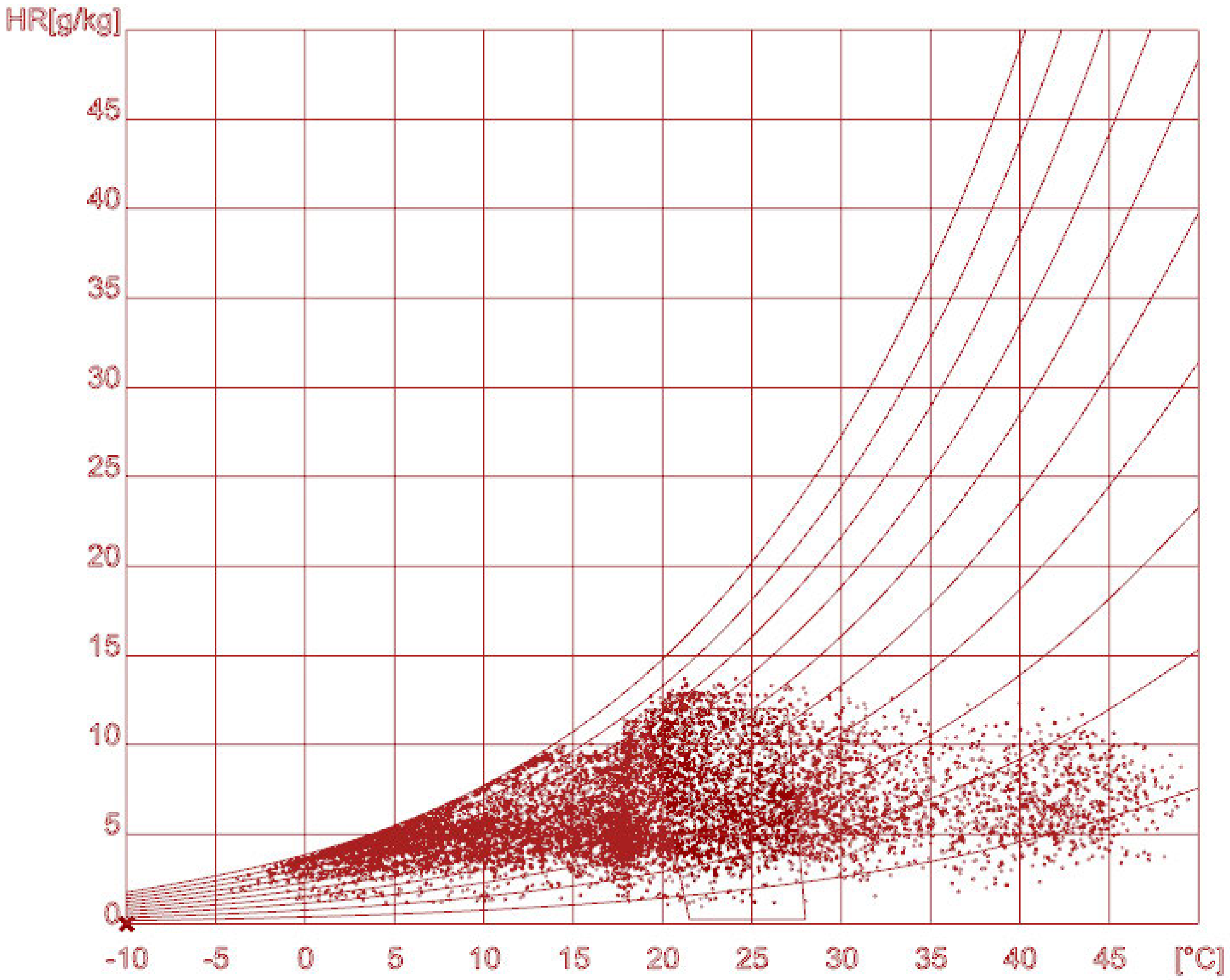
1- Bekaa Valley , Lebanon Weather data taken
2- 0.7 air changes per hour for how much sealed is the tent
3- tent is ventilated if outside temperature between 10c and 30c
4- With no occupancy
5- With no internal gains
6- hourly annual temperature and humidity inside the zone
7- Small opening " 50cm"50 cm " toward south



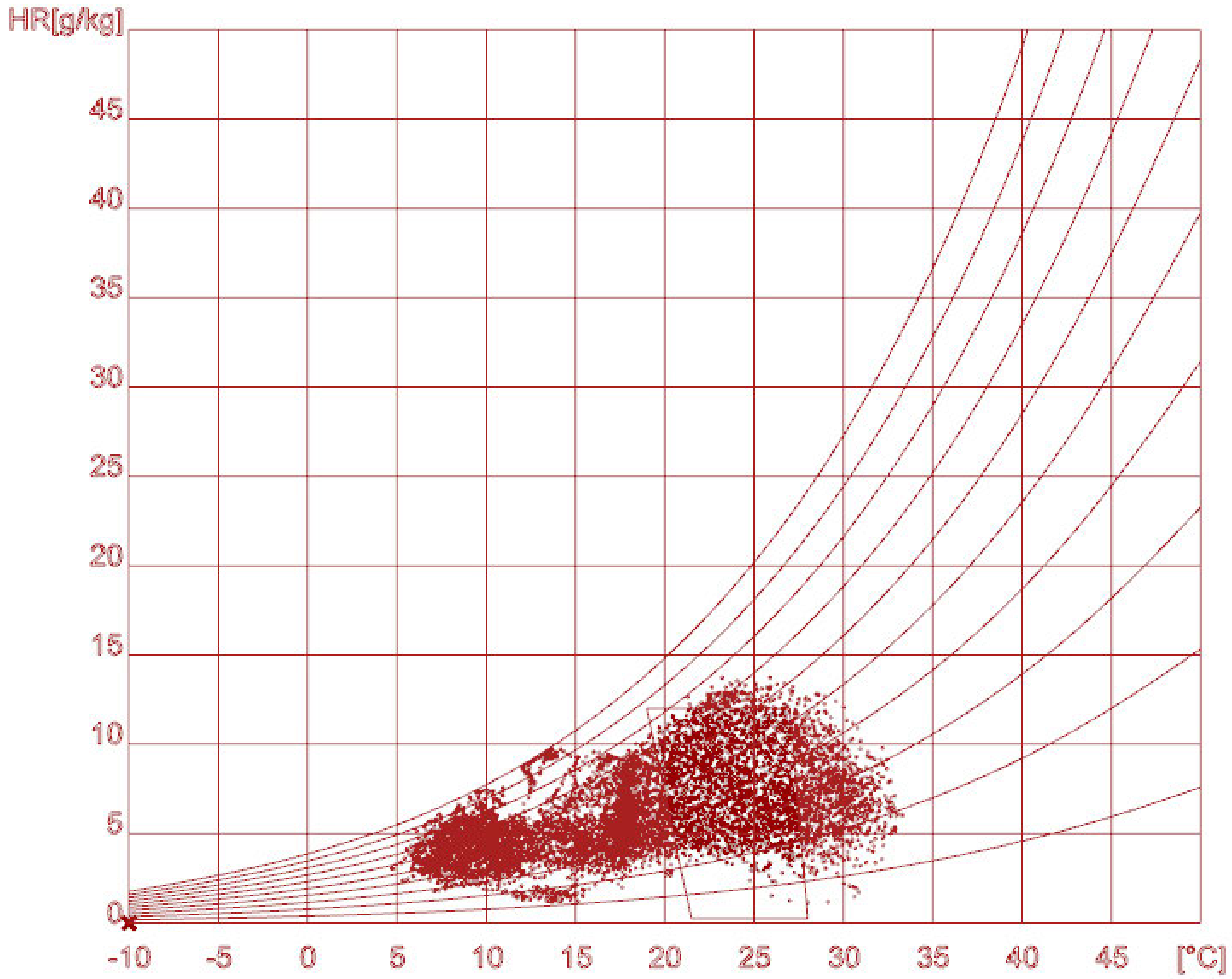
Earth Properties indicated :

1.5	Conductivity (W/mK)
2000	Density (kg/m3)
1300	Specific Heat (J/kgK)
0.9	Thermal Emittance (0-1)
0.6	Solar Absorptance (0-1)
0.6	Visible Absorptance (0-1)





Tent with only PVC membrane 1000 g/m2 modeled as a thermal zone

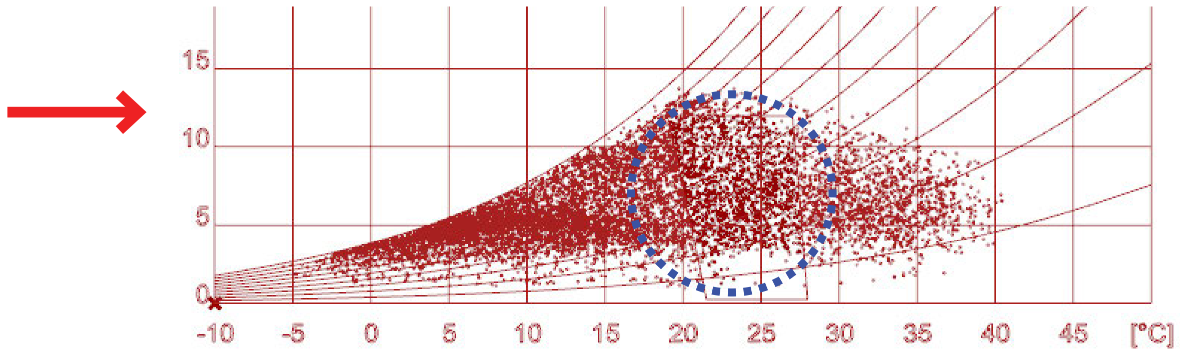


Tent with 20 cm Earth layer on top and PVC membrane 1000 g/m2 modeled as a thermal zone

Thermal Simulation Outcomes

Outdoor Conditions

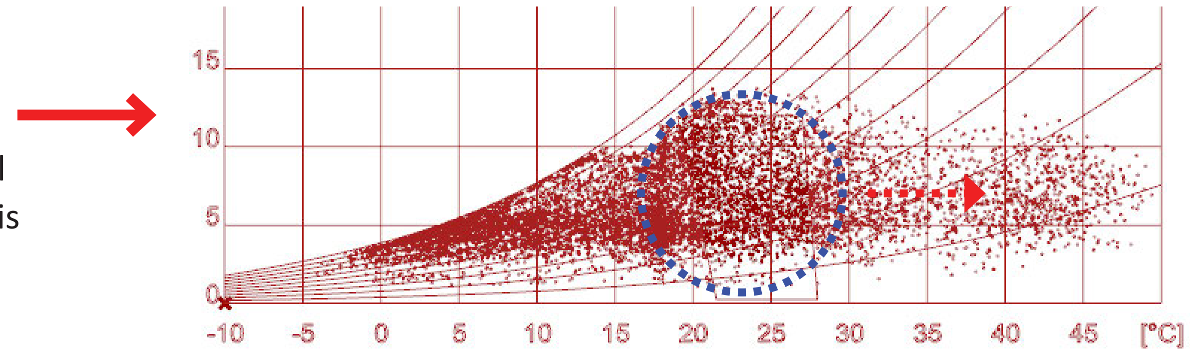
Diagram 1 showing The outdoor temperature and humidity in bekaa valley. temperature range from extreme -5 in winter degrees to 40 degrees in summer. With allot of variation between daytime and night time especially during summer.



Outdoor temperature and humidity

With No Pockets

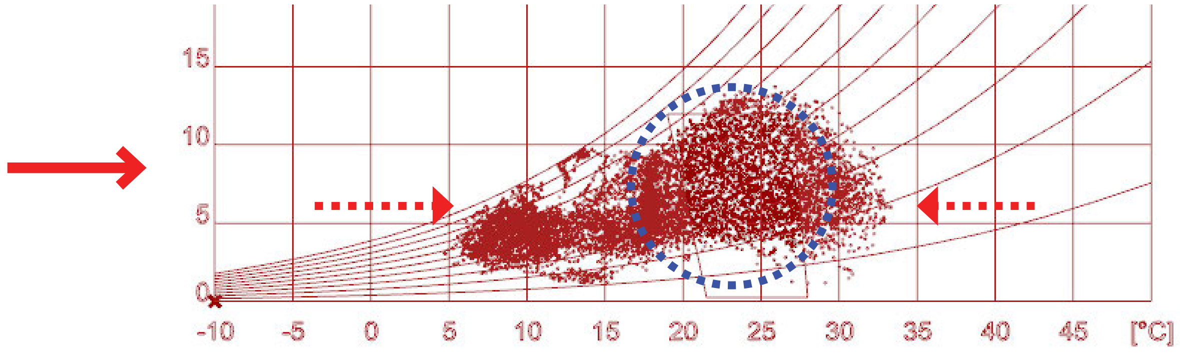
The second diagram shows the thermal behavior of regular enclosed and sealed tent " 0.7 ACH" with only membrane as a skin. it shows that in summer time a-lot of heat is being trapped even when the tent is naturally ventilated. Thus at such time staying outdoor or under a tree would be better than being inside the tent. in winter the thermal performance is similar to outdoor thermal and humidity conditions. so basically the tent is only surveying as for rain protection.



Tent with only PVC membrane

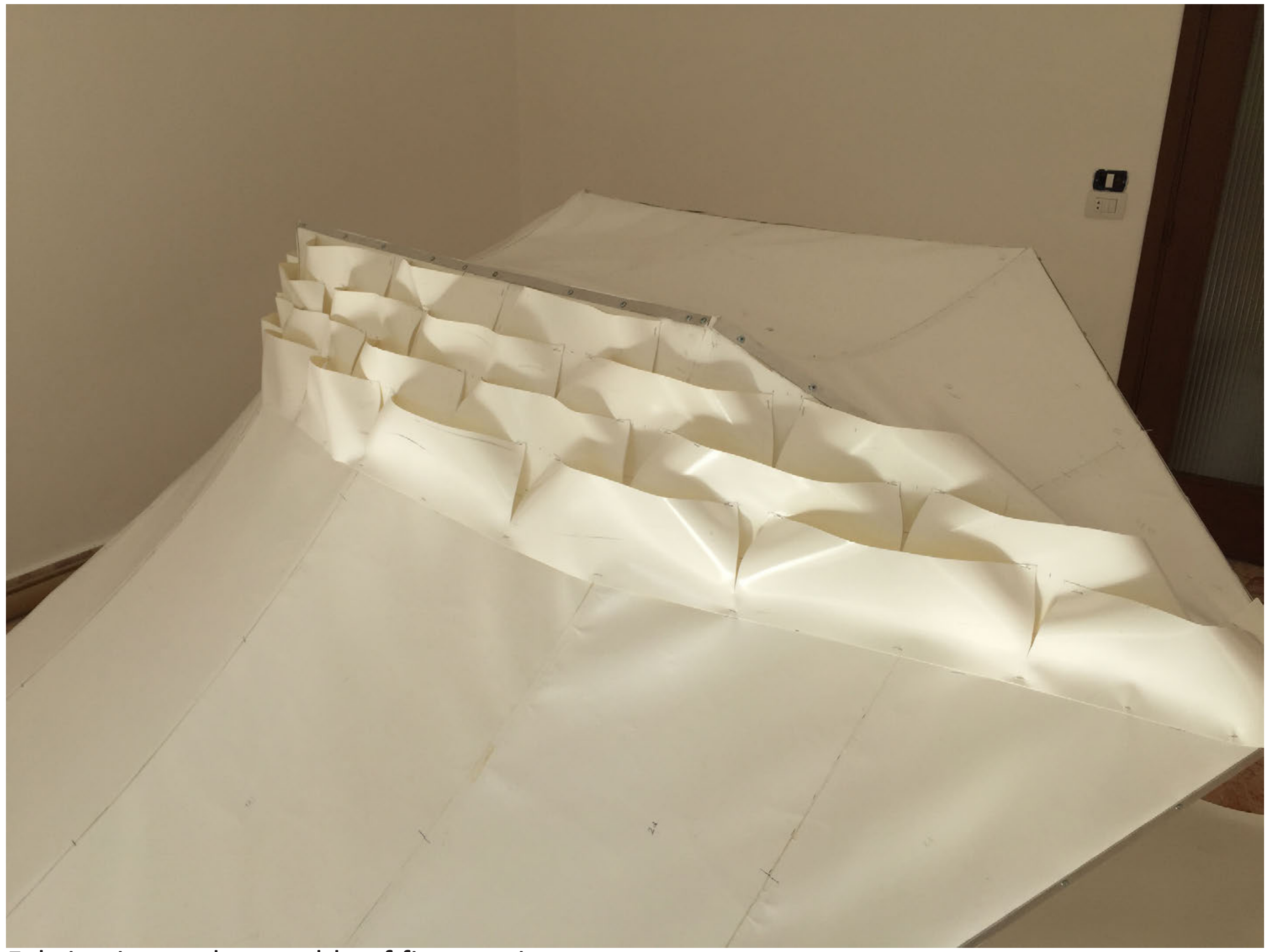
With Pockets

In the third diagram, The thermal mass or the heat capacity of the earth is working and phase shifting temperatures works best in such a climate because of the temperature difference between day and night. There is more hours in the comfort zone and the extreme outside temperature of the bekaa valley is diluted.



Tent with Earth and PVC membrane

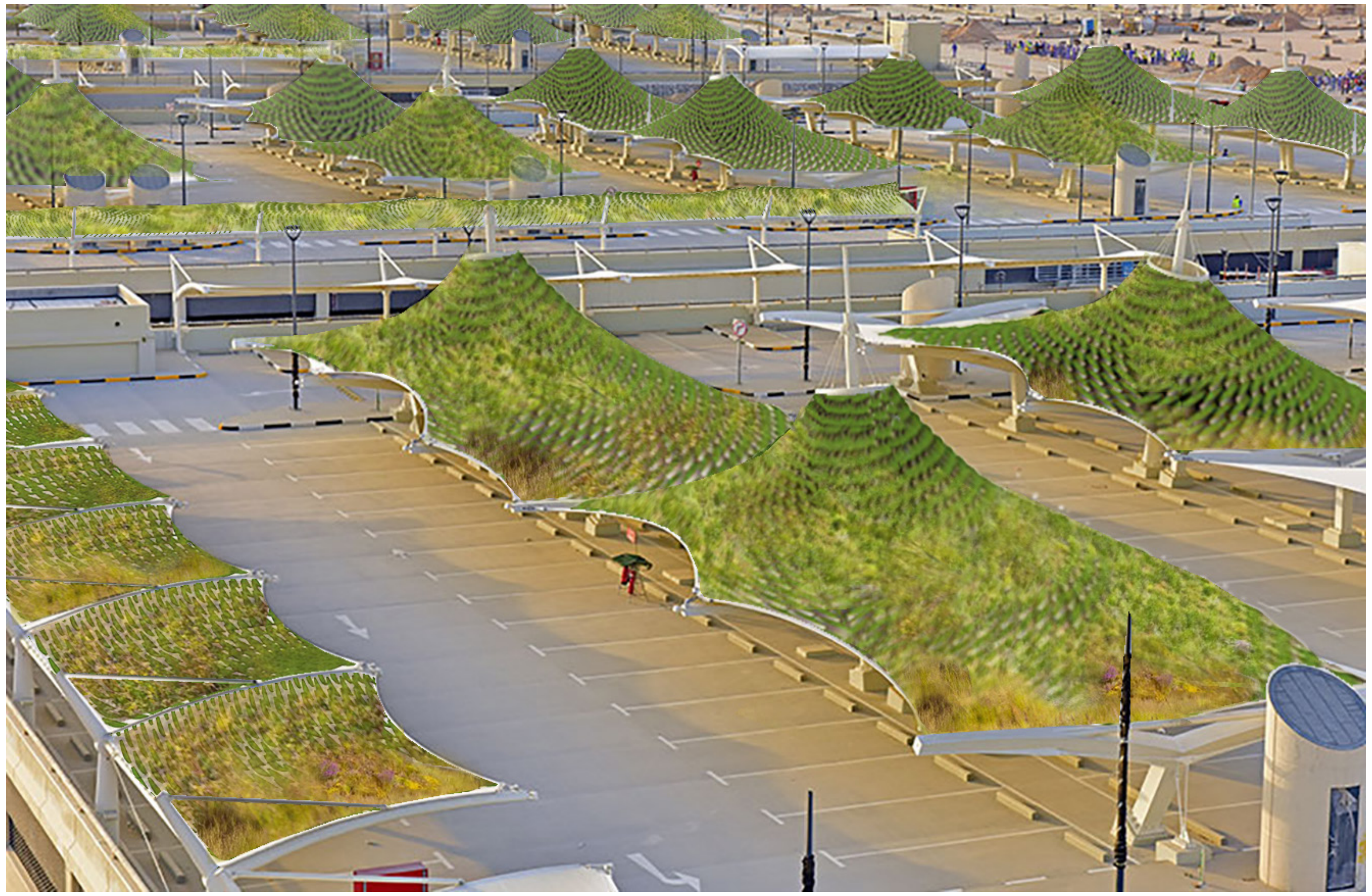
Pocket Assembly on Structure and Filling



Fabrication and assembly of first section

Filling pockets with half capacity

Filling All The Structure



Tensile membrane pocket system can have allot of added advantages in different scopes:

On the micro scale " A habitat" :

Thermal mass and thermal insulation can give the membrane shelter the advantage of having a better indoor climate. This gives the structure as well more stability against wind. Planting the membrane would serve as well as a controlled farming environment.
the mass the pocket membrane creates serves as well as for better noise absorption from the outside.
in the cases of snow or sand the membrane is filled to give the shelter better insulation against extreme weather conditions.

On the macro scale " urban tensile structures"

Tensile pocket membrane maximize the green space in the city, thus recovering the green Areas Urbanly. A green membrane would as well improve rainwater management and conserve energy as well as prevent the urban heat island effect, also it will create a better biodiversity in the urban space.

The costs and fabrication of tensile green membrane is much lower than the cost of preparing a traditional green roof. The design of the pocket membrane as well could serve for vertical green surfaces that could be used as well for building facades due to its high tensile strength over long facades.

Acknowledgments

I would like to thank three important groups of people, without whom this dissertation would not have been possible: My Tutor and inspiration Prof. Robert Off and the wonderful Heike Kleine , My caring wife and my family, My student Mohammad Nazar for helping me in cutting the patterns for the shelter.

Thank you
Ahmad Nouraldeen