Project Title

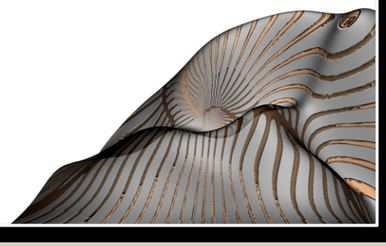
Porous Adaptive Membranes

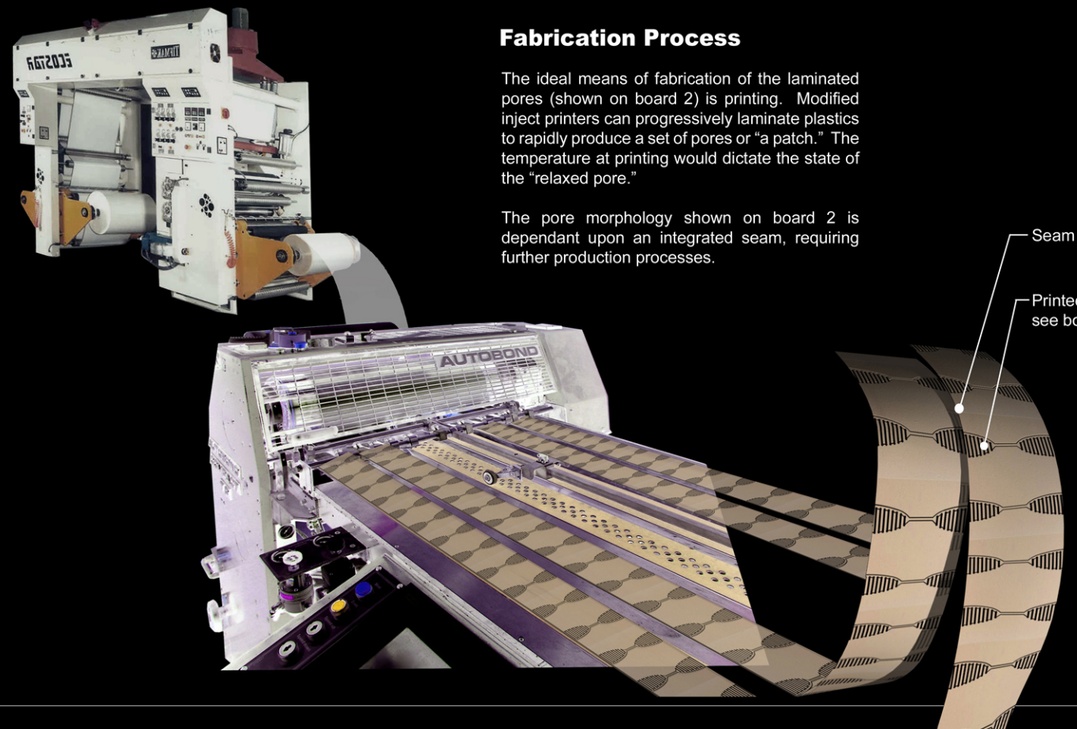
Wayne Jenski

-The ultimate goal is to develop an assembly that is adaptive or self adjusting to its environment. Utilizing the resultant deformations from laminated polymers with differing thermal expansions, a thermally reactive pore is envisioned. As the patterned, laminated polymers of the pore on board 2 are heated via solar gain, it buckles such that a seam is opened to allow ventilation. A field of pores with differing active temperatures can form a membrane allowing a building to "breath" as a lung.

-The need to control an inner condition (built space) relative to and outer condition (the environment) dictated that I begin with an envelope; specifically a membrane utilizing latent properties of its composite materials to, in effect, make it motile.

-One instantiation of this system was developed on boards 4 and 5: a clinic for Doctors without Boarders.





Fabrication Process

The ideal means of fabrication of the laminated pores (shown on board 2) is printing. Modified inject printers can progressively laminate plastics to rapidly produce a set of pores or "a patch." The temperature at printing would dictate the state of the "relaxed pore."

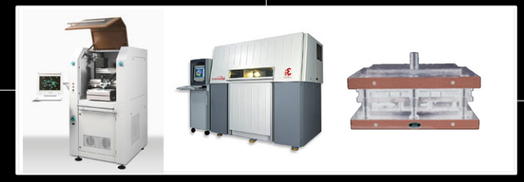
The pore morphology shown on board 2 is dependant upon an integrated seam, requiring further production processes.

Seam Required

Printed Pore (half)- see board 2

Rapid Plastic Circuit Printing

Etching

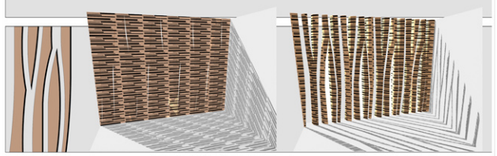


Progressive Lamination; Stereolithography

alternate processes

strip patches- light

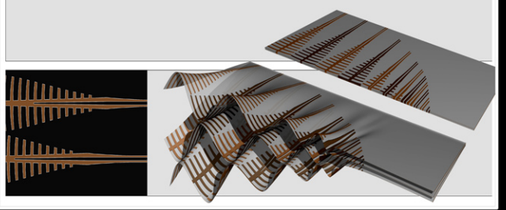
Plastic fins with printed strips flap open due to planer buckling when heated via solar gain. The resultant deformation yields a control of light translation.



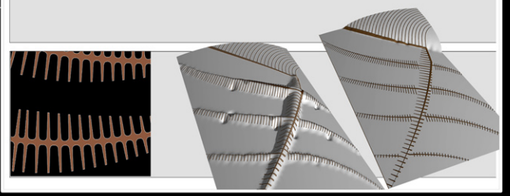
A pair of laminated membranes with complementary patterning. Deformation yields potential for insulation as well as control of light.

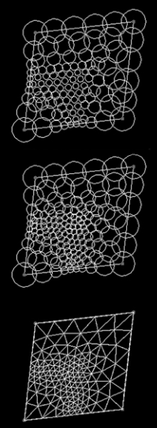
strip patches- air

A set of laminated polymer membranes; when heated (or cooled) the resultant deformation yields a thickening of section and the potential for adaptive insulation comparable to a bird ruffling its feathers.



A system of laminated polymer strips arrayed to inflate a circulatory system when activated; this could be used to stiffen the membrane or deliver fluids.



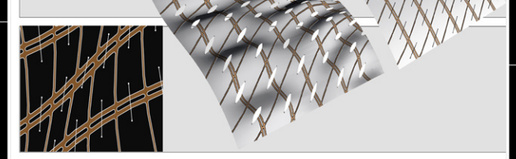


Arraying the Pore: The Patch

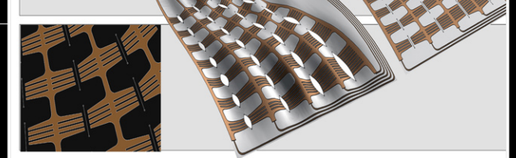
Pore morphology and distrobution can only be determined when considering performance. These pore patches were conceived of relative to their mediation of light and air.

In all scenarios, the pores are activated by differing thermal expansion rates. Solar radiation is the primary source of heat energy and all performances are designed to effect the translation of light or air through the membrane in response to the sun (and thus the time of year and day).

Pore Patch One

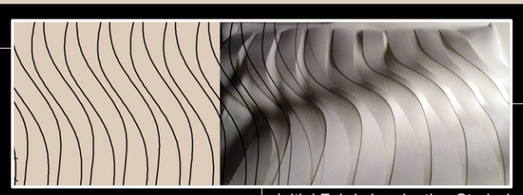


Pore Patch Two

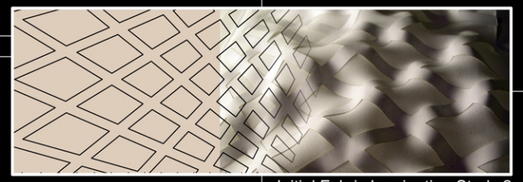


initial pore patches

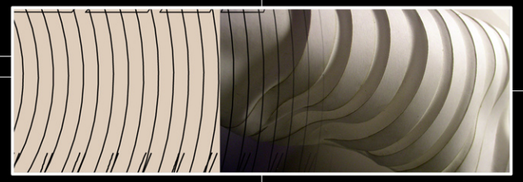
lamination/ deformation studies



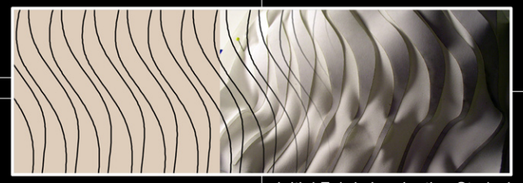
Initial Fabric Lamination Study 1



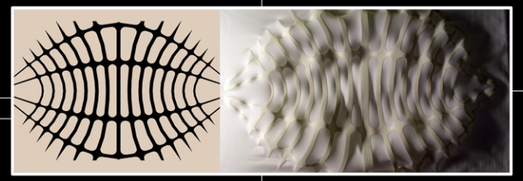
Initial Fabric Lamination Study 2



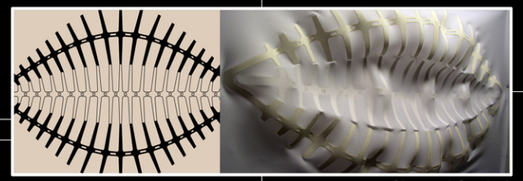
Initial Fabric Lamination Study 3



Initial Fabric Lamination Study 4

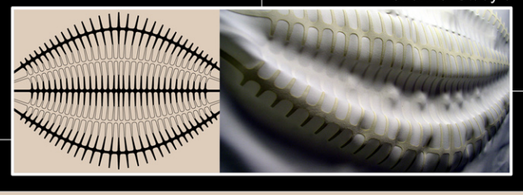


Channel Study 1



Channel Study 2

Channel Study 3



Laminated strip study set for finding the relationship between laminated pattern and resultant deformation

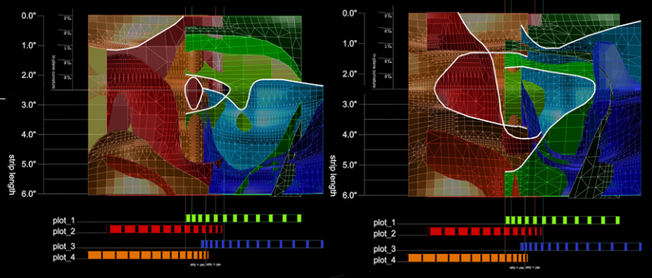
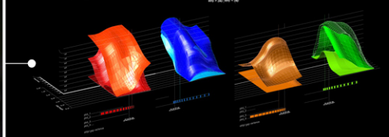
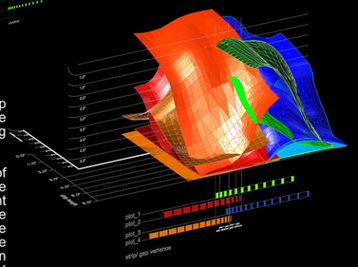


Chart Sections





Laminated Pattern to Resultant Deformation Chart

Initial Studies:

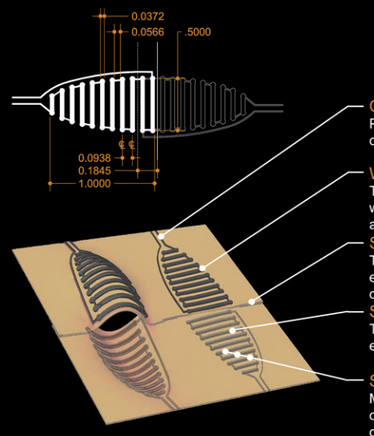
The first models explored the relationship between a laminated pattern and the resultant deformation due to planer buckling (left).

A simpler and more qunantifiable set of patterns were devised (above) to examine the exact relationship between resultant buckling radius and strip-gap ratio, in plane curvature, and strip width-length ratio. The results were graphed; the graphs were consolidated into a 3d graphic chart. When sectioned at the needed deformation, a set of required physical properties are revealed.

Property	Description	Polymer "A" range	Polymer "B" range	Units
ex	Elastic modulus	272720 - 89923	42060 - 203052	psi
nuxy	Poisson's ratio	x	.35 - .40	(na)
gxy	Shear Modulus	x	159541 - 188550	psi
dens	Mass density	0.03356 - 0.52384	0.03750 - 0.04660	lb/ in^3
sigxt	Tensile strength	227 - 3103	3335 - 5366	psi
sigxc	Compressive strength	580 - x	1595 - 2393	psi
sigyld	Yield Strength	725 - 1541	2465 - 5366	psi
alpx	Thermal expansion coefficient	0.0001277 - 0.0002700	2.777e -5 - 6.660e -6	in/ ° F
kx	Thermal conductivity	2.4e -6	2.6749e -6	BTU/ (in.s.F)
c	Specific heat	0.2 - 0.4	0.33 - 0.57	BTU/ (lb.F)

-Silicone R.T.V.
-Chlorosulfonated Polyethylene Rubber (CM, CSM)
-Medium Density Polyethylene (MDPE), Film Grade
-Dyneon Aflas™ FA-150L PTFE Fluoroelastomer

-Acetal Copolymer, Unreinforced
-Ethylene Vinyl Alcohol
-Nylon 12, Film Grade
-Nylon 66, Conductive
-PETG Copolyester
-Polyarylate
-Polybenzimidazole



Circuit:
Potentially included to override thermal deformation due to environment

Widened, rounded strip end:
To distribute force of shear and buckling without delamination stress accumulation about corners

Seam:
To prevent reciprocal buckling due to extreme temperatures; it can only open one direction

Strip:
This form is used to bias the thermal expansion in only one direction

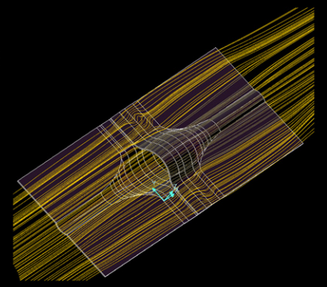
Strip array:
Many strips are used to cup the surface of the membrane to facilitate translation of air from side to side

Pore Development:

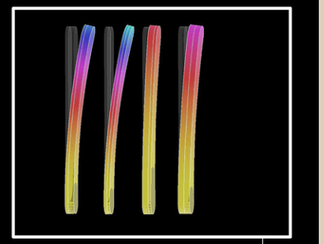
The method described and depicted at left is specific only to the materials originally studied (however the method is universal). To more efficiently and accurately explore material properties relative to the needed pore morphology, finite element analysis was used (graphics at right). Rapid evolution of pore morphology was possible.

Above are the mechanical properties explored and possible matching materials.

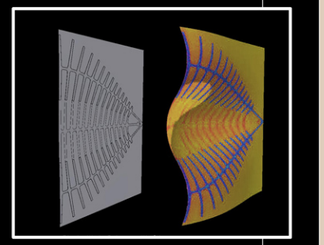
Pore morphology relative to venting is still being refined with fluid dynamic simulation.



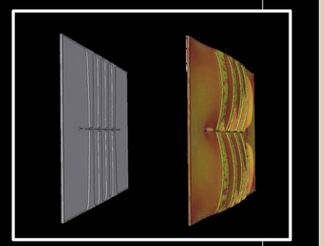
Bi-Material Strips:
Buckling occurs due to the laminated strips having different thermal expansions. Each strip has the same constituent materials; deformation differences occur due to relative lamination thickness.



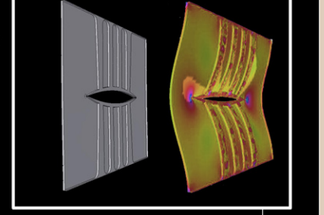
Ripple Study:
An examination of patterned strips on both sides of a membrane to achieve a channel when deformed.



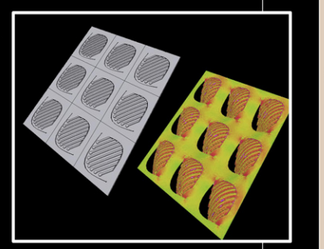
Initial Pore Study A:
The expectation was to open the slit in the membrane upon application of heat; instead, it closed tighter.



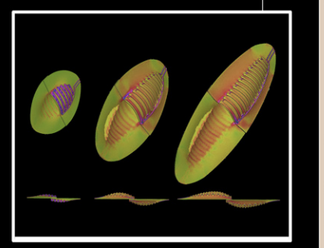
Initial Pore Study B:
A variation of the pore above. The undeformed state is open; when heated it begins to close. Note the stress concentrations indicated at the corners of the opening.



Flap Pore Study:
A simple flap with little stress concentration. It will open forward and backward at extreme low and high temperatures, respectively.

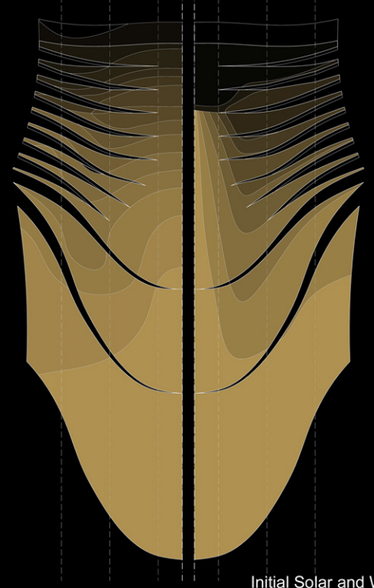


Flap Pore Variation:
This pore morphology is primarily in response to the desire to open at high temperatures and close tight at low temperatures. More details are above and left.

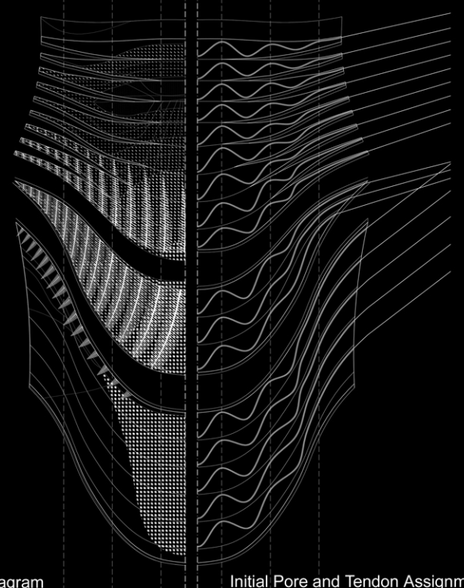


finite element analysis- pore studies

pore assignments relative to solar gain



Initial Solar and Wind Diagram
Upon Unfolded Skin



Initial Pore and Tendon Assignments

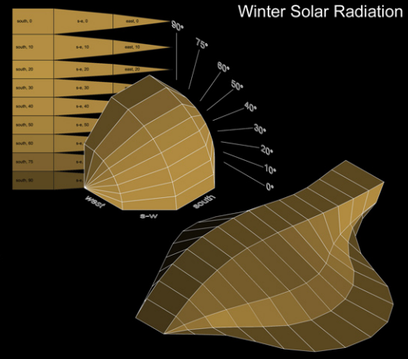
Emergence of Program

To develop a system that could support the porous membranes, a more defined set of conditions had to be defined: specifically a program. Paralleling the development of program was the structural system: the means of supporting the skins. The mechanical properties of the porous membrane are not conducive with a tensile membrane system. Instead a "wrinkled" system was devised. This wrinkling effectively corrugates the skin while adding more surface area to accommodate the pores.

Pore distribution and zone assignments were determined through studies of solar radiation upon the surface of the skin.

winter

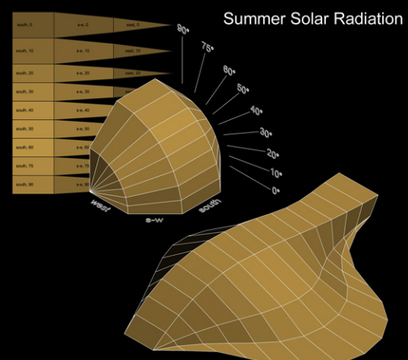
	0°	10°	20°	30°	40°	50°	60°	75°	90°
east	58%	58%	57%	55%	53%	49%	45%	39%	32%
s-e	58%	67%	75%	79%	83%	83%	83%	76%	69%
south	58%	70%	82%	89%	96%	98%	100%	94%	88%
s-w	58%	67%	75%	79%	83%	83%	83%	76%	69%
west	58%	58%	57%	55%	53%	49%	45%	39%	32%



Winter Solar Radiation

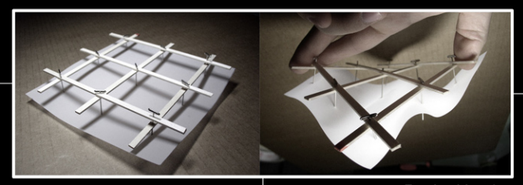
summer

	0°	10°	20°	30°	40°	50°	60°	75°	90°
east	95%	94%	93%	90%	86%	79%	72%	59%	46%
s-e	95%	95%	95%	94%	93%	87%	81%	67%	50%
south	95%	97%	100%	97%	95%	89%	82%	67%	49%
s-w	95%	95%	95%	94%	93%	87%	81%	67%	50%
west	95%	94%	93%	90%	86%	79%	72%	59%	46%



Summer Solar Radiation

mech. wrinkle studies

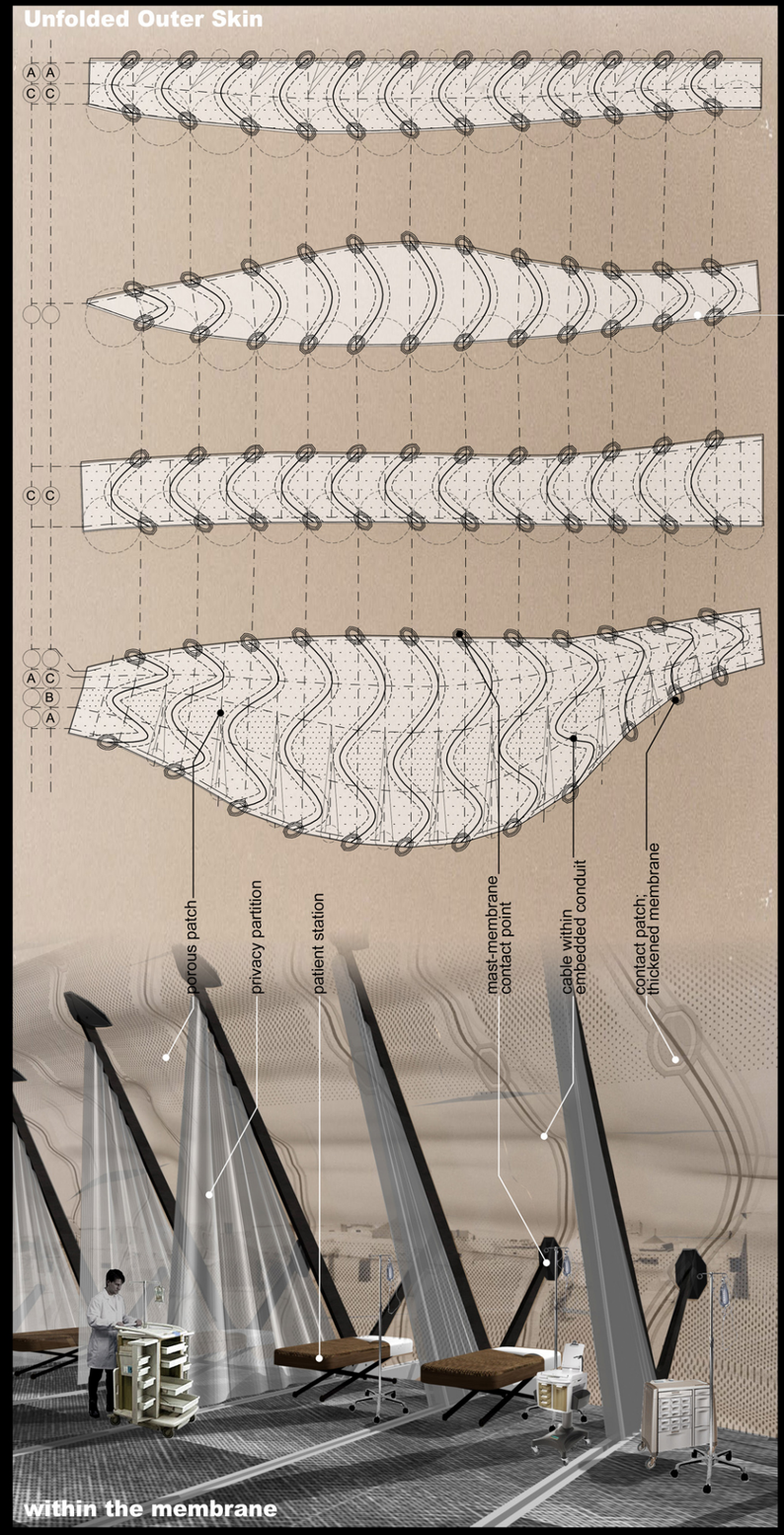


Racked Lattice

Membrane Mounted on
Moment Brackets (1)

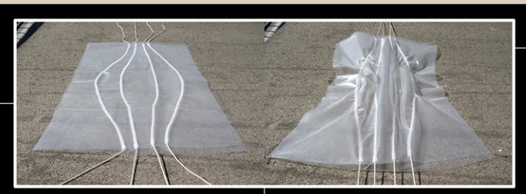
Membrane Mounted with Sleeves

Unfolded Outer Skin

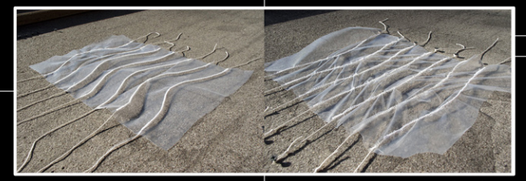


within the membrane

wrinkled membrane studies



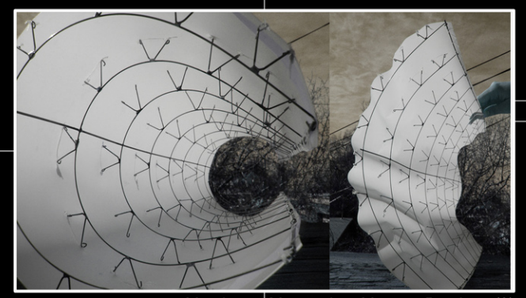
Tendon Config. 1



Tendon Config. 2

Tendon Config. 3

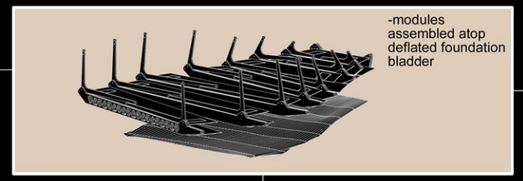
Tendon Config. 4



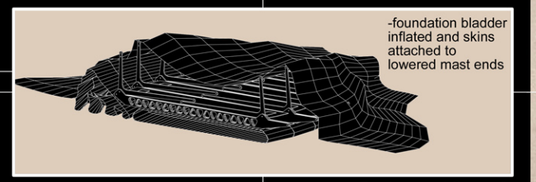
Membrane Mounted on Moment Brackets (2)

Woven Tendons Similar to Config. 3

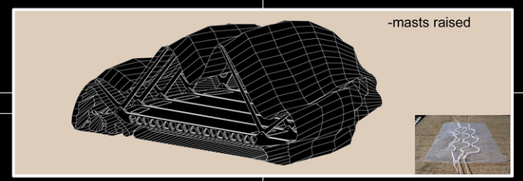
deployment strategy



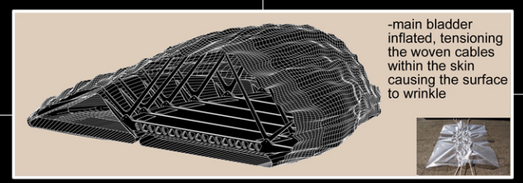
Deployment Stage 1



Deployment Stage 2

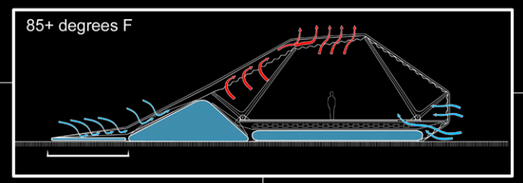


Deployment Stage 3

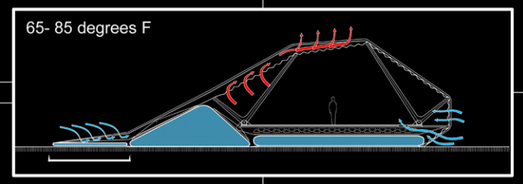


Deployment Stage 4

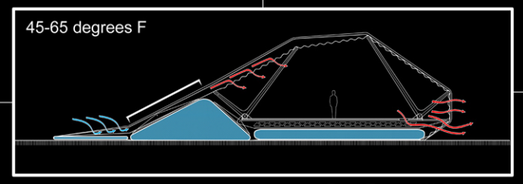
ventilation strategy



Pore Zones (A+B+C) Engaged

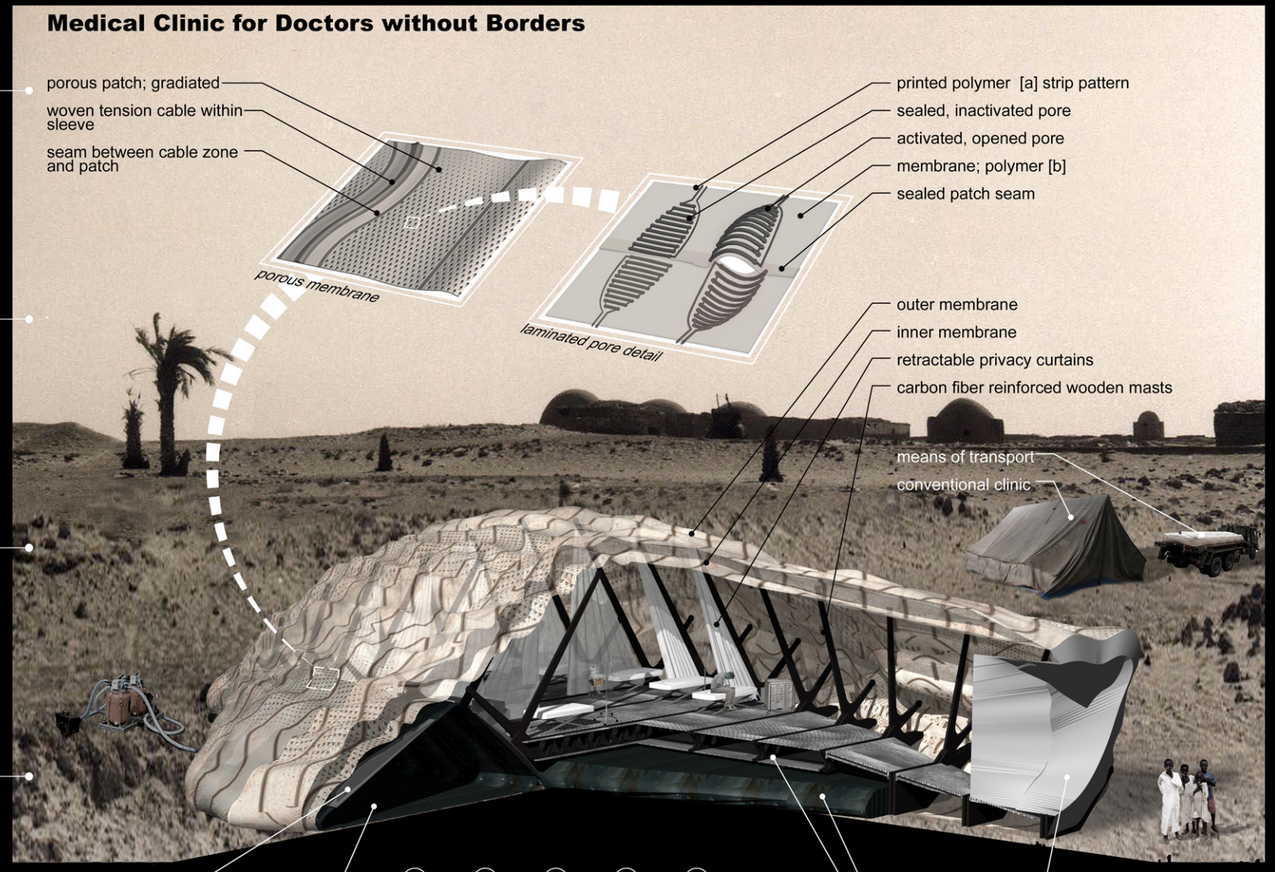


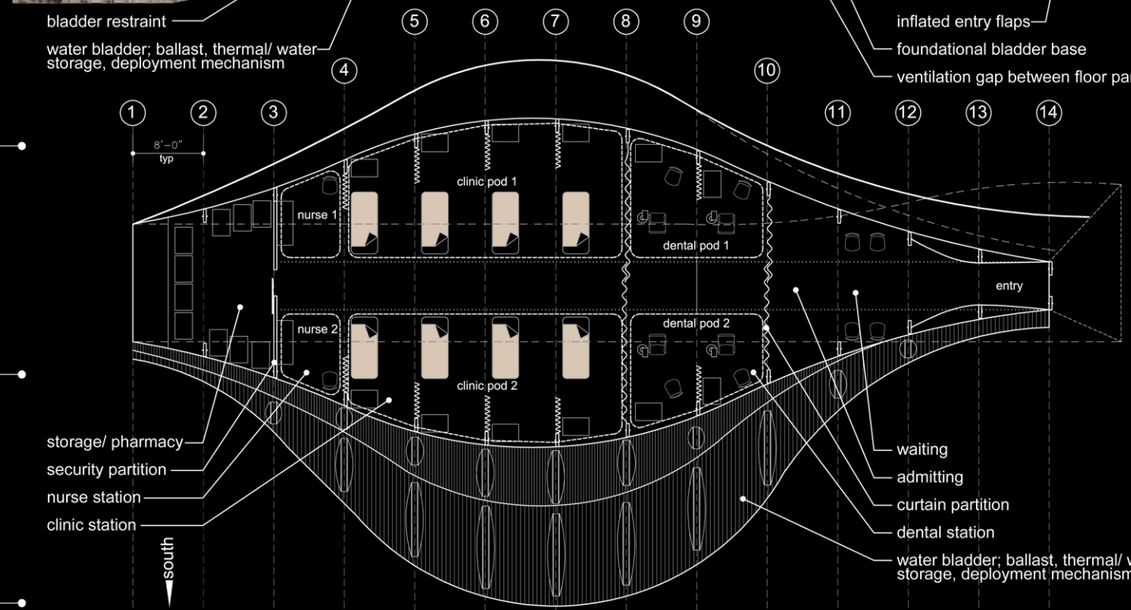
Pore Zones (A+B) Engaged



Pore Zones (A) Engaged

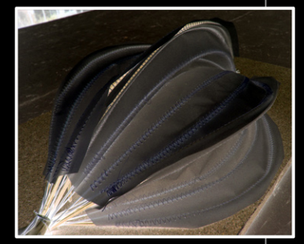
Medical Clinic for Doctors without Borders





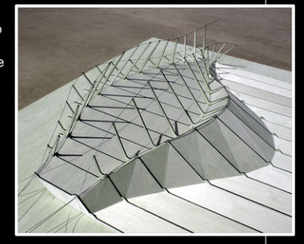
form studies

Study 1:
Wrinkles are induced by a rigid frame collapsing upon itself, inducing planer buckling.



Study 2:
Wrinkles are induced by weaving "tendons" through the skin. The frame is poorly conceived and is unresponsive to the skin. Refer to the membrane study on the above board for more details.

Study 3:
Here, the structure develops into a set of pivoting masts to accommodate the moment of the skin system. Mounded earth is meant to be used as thermal storage to charge the thermal flue of the membrane.



Study 4:
The crude mounded earth is replaced with a set of bladders which serve as ballast, thermal storage for the flue, water storage, and a deployment mechanism.

Bladder Detail:
The bladder is secured by attached restraints. Uplift occurs, requiring the placment of the weight in model. The installation of the skin will balance this force.

Model Detail:
Interior of model with one of two membranes installed.