DEUCES WILD: MEMO 3

TEAM 11: TUBE ANEMONE

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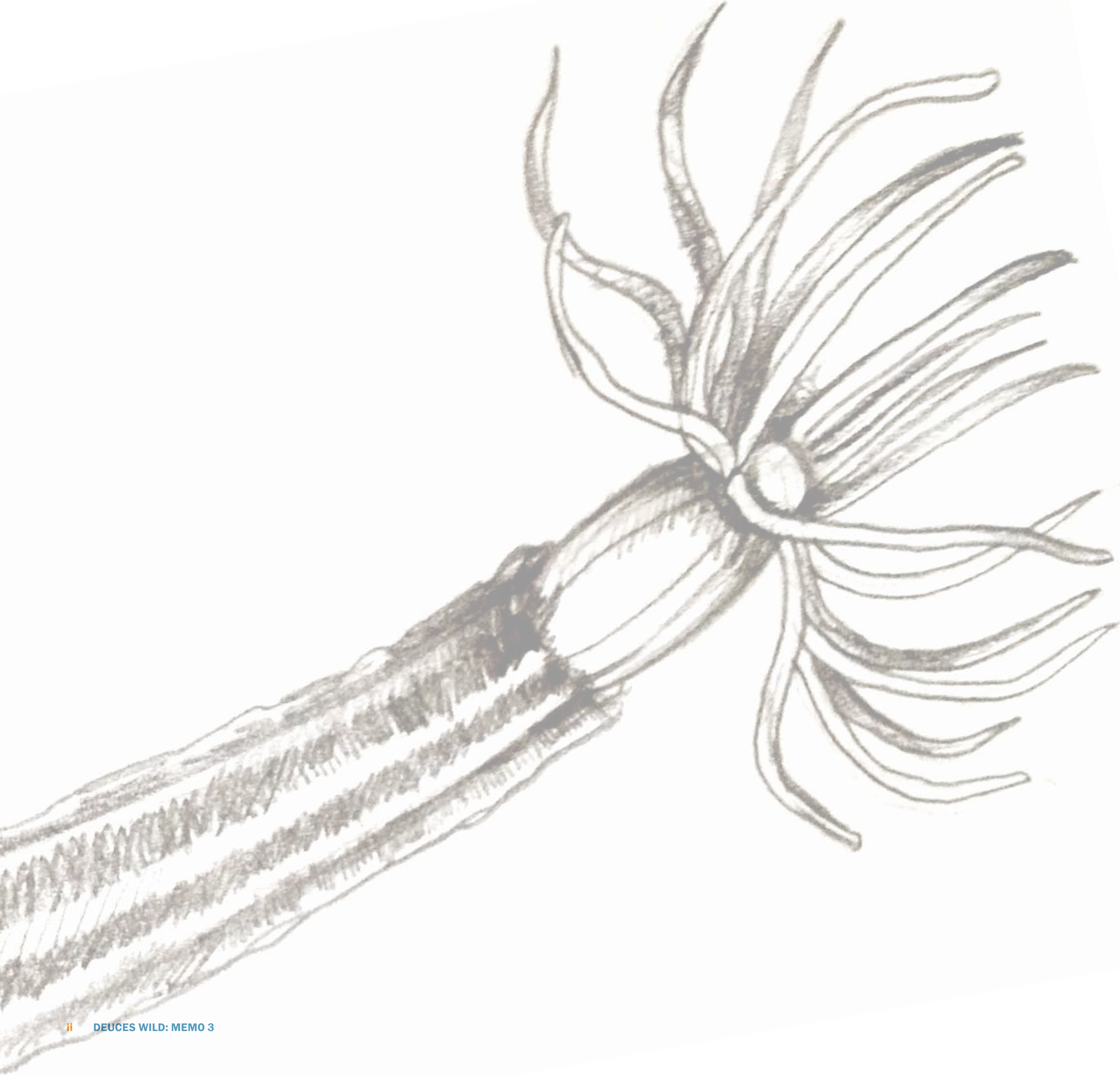
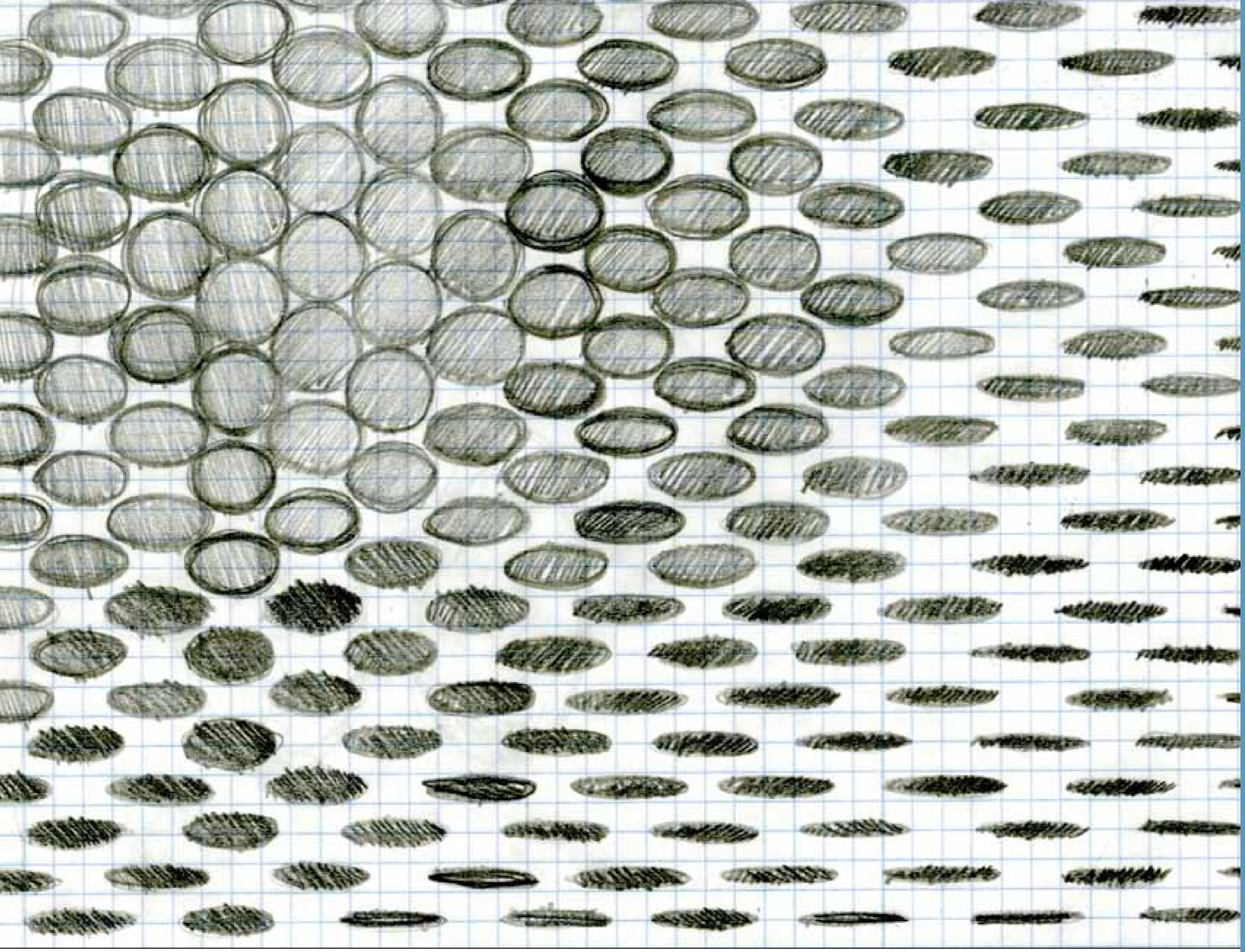
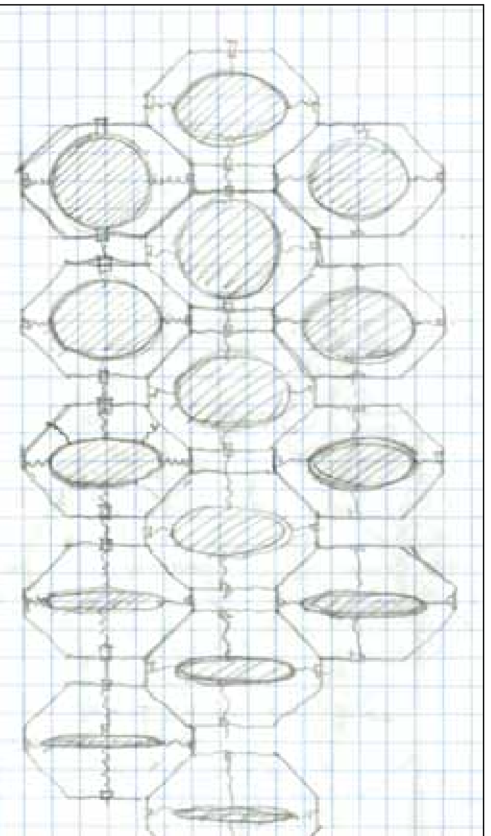
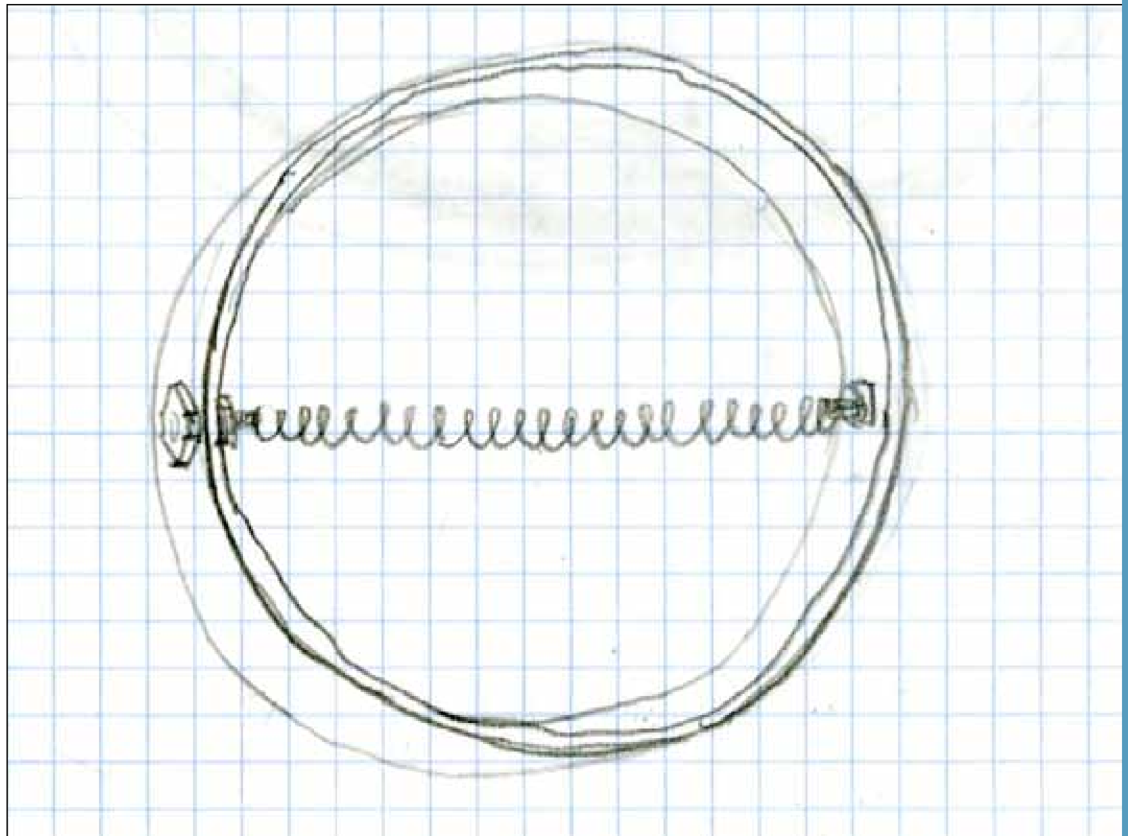


TABLE OF CONTENTS







1 WORKING HYPOTHESIS

The vertical mechanical force which is exerted by the tube anemone's longitudinal retractor muscles during contraction is translated into the built environment as a linear force which creates a corresponding change in the shape of a tensional membrane. The inherent properties of this membrane counteract the linear force to return the unit to its state of equilibrium when not activated. This concept can be applied as a bio-reactive building skin that serves as a solar shading device and creates an interactive experience for passers-by. The device can be applied to new construction or to existing structures in order to reduce strain on the HVAC system and create a dynamic façade.

HYPOTHESIS GENERATION

General research of the tube anemone was refined to hone in on its expansion and contraction processes. The contraction of the tube anemone's longitudinal retractor muscles alleviates hydraulic pressure within the organism's body cavity, facilitating its collapse in response to external stimuli. The tube anemone then uses diffusion through its body wall in order to return to its state of equilibrium (distended form), thereby placing the body wall in a state of tension.

The essence of the tube anemone's motion was translated into model form through experimentation with various materials and mechanisms. The model exploration of the expansion and contraction process focused on three (3) areas of the tube anemone's anatomy and biological processes:

1. Vertical motion of the longitudinal reactor muscles and the subsequent release of hydrostatic pressure through the opening in the aboral foot (and oral disc).
2. Build-up of hydrostatic pressure that creates tension across the surface area of the column wall through diffusion.
3. Variations in the density and opacity of the porous column wall due to tensional fluctuations.

In exploring motion the team studied a variety of mechanisms that are reminiscent of the tube anemone's longitudinal retractor muscles. The basic concept was expanded by including axis transfer and looking at different types of joint movements.

To demonstrate the integral relationship between muscular action and hydrostatic pressure, additional studies were made into systems that have the ability to detect internal pressure levels and have mechanisms or valves that allow the systems to release pressure at certain levels and reset. These systems could be activated by external triggers such as light, heat, or humidity that enable them to respond to changes in the surrounding environment.

Research revealed a direct connection between membrane opacity and surface tension Investigations were made into materials that could exhibit fluctuations in opacity/transparency in response to changes in ambient heat, light, humidity or direct pressure (tension). One of the materials that proved promising during the course of research is silicone (both in sheet form and moldable form). Another avenue of exploration involved multiple-layered skin systems, with a liquid or gel middle layer that could demonstrate variations on opacity, color, and/or luminescence.

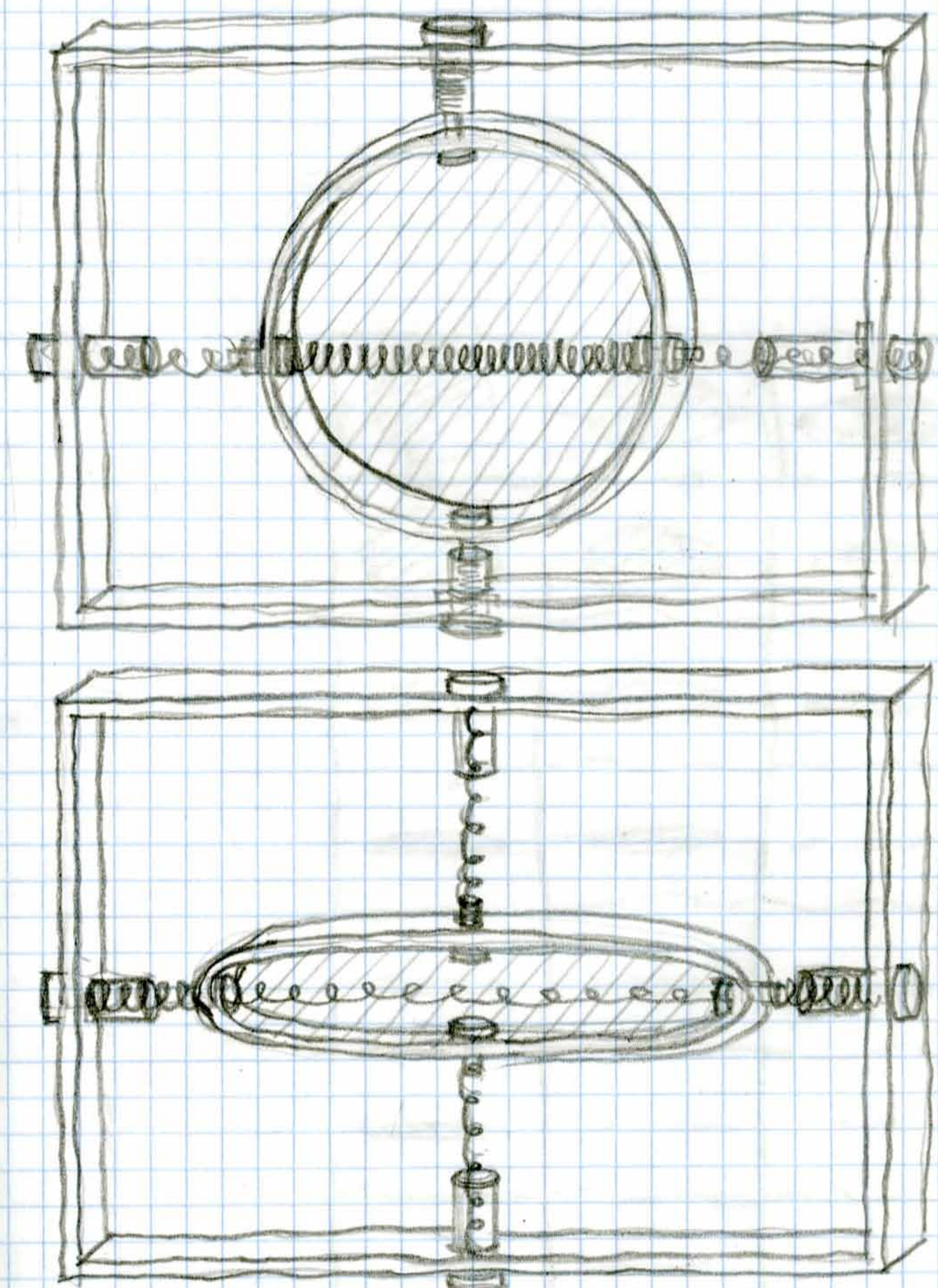
Exploration ultimately led to focusing on the translation of horizontal force into vertical motion. This became the building block for the applied building skin's base unit. Initial experiments involved an integration of frame and function. It was discovered that it was possible to separate the frame from the function by altering the physical properties of the membrane, allowing the device to operate independently from its structural support.

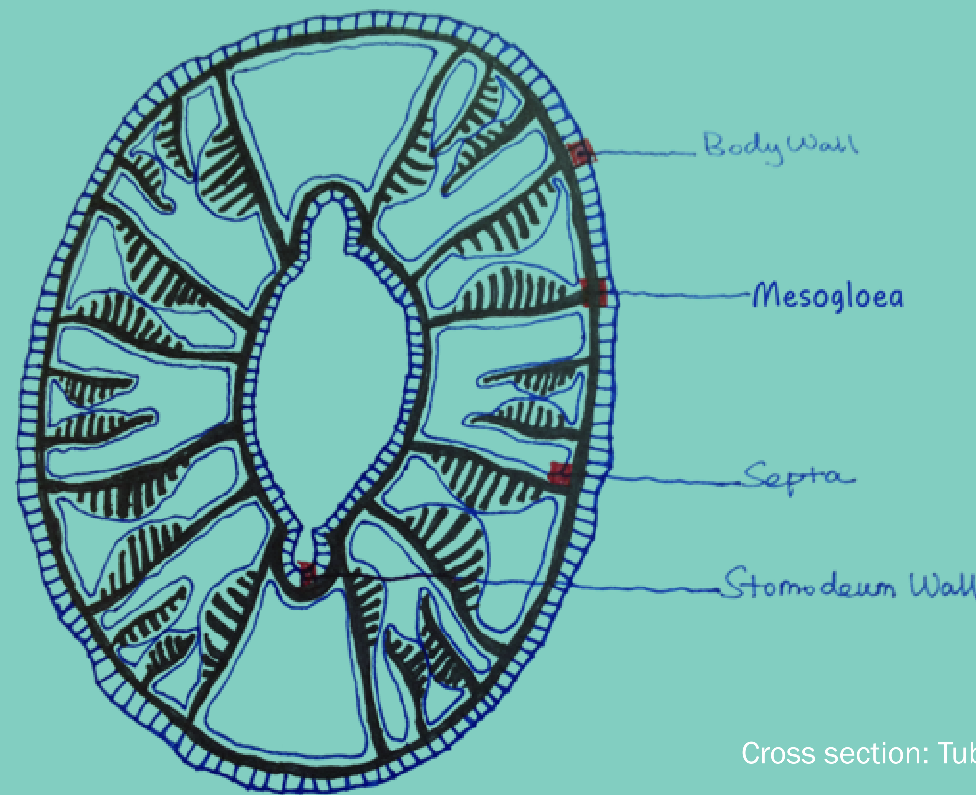
HYPOTHESIS APPLICATION

The applied building skin uses opposing forces of tension and compression which are conceptually based upon the tube anemone's contraction and expansion. The membrane is designed to maintain an elliptical form when at rest (in equilibrium). The base unit of this system converts the linear compression of a spring into the circular expansion of the tensional membrane by means of heat activation, opening the unit to provide shade and diffuse light as it reaches into the interior of the building. As the unit cools, the forces within the membrane cause it to return to its original shape, stretching the central coil.

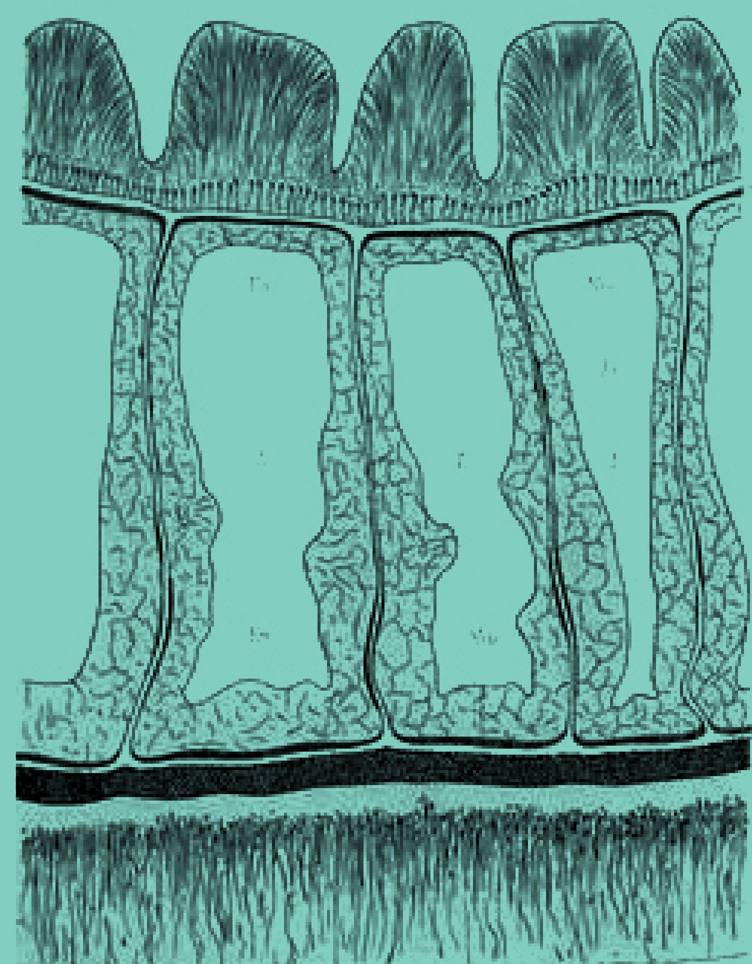
Theoretically, as the sun travels across the building façade the applied skin would mechanically shift in a wave that mimics the sun's movement, causing pattern alignments that diffuse the sun's rays. It would also reflect surrounding context that reduces solar heat gain, such as shade from nearby buildings and trees.

The system incorporates additional materials that visually react to changes in its environmental context, such as changes in ambient temperature or direct contact (by touch). These responses can include changes in color, texture, opacity and/or luminosity. The shading device could also be used to generate electricity through the use of flexible photovoltaic polymers.





Cross section: Tube anemone



Detail: Muscle wall structure

2 RESEARCH FINDINGS

MUSCULAR STRUCTURE

Tube anemones (often referred to by their Order designation, Ceriantharia) are solitary invertebrate water-dwelling predatory animals that create tube-like structures in which they live. They maintain the circular form of their soft, sack-like bodies by regulating internal water pressure. Tube anemones are ammonotelic (excrete nitrogenous waste in the form of amonia). Diffusion across the body and tentacle surface eliminates the ammonia from the body.

Generally tube anemones are nocturnal animals, remaining in their tubes in order to avoid light. They also withdraw into their tubes to seek protection, since they lack the sphincter muscles needed to retract their oral disk or withdraw their tentacles. Their primary predators are organisms that exhibit a resistance to the effects of their stinging cells, such as the dendronotid nudibranchs that latch onto and ingest the tube anemone's tentacles.

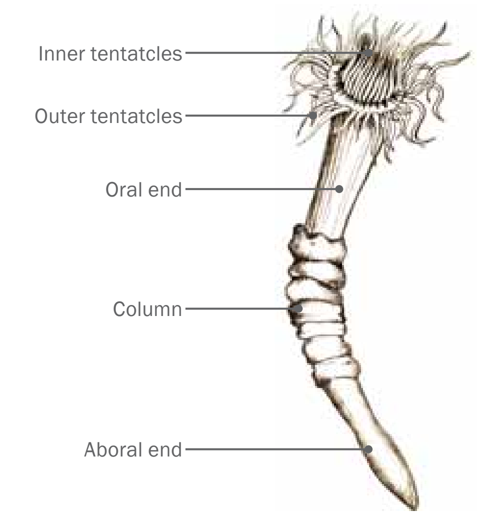
THE TUBE

Ceriantharia tubes are composed of a fibrous material which is made from mucus (secreted from gland cells of the column ectoderm) and threads of namatocyst-like organelles known as ptychocysts (specialized cnidae – the stinging cells of all cnidarians). The tube is reinforced by foreign objects (such as grains of sediment). The tube may be as long as 1 meter (3.3 feet), and is longer than the anemone that resides in it.

EXTERNAL ANATOMY

The tube anemone body is basically a tapering cylindrical column (maximum 3 cm diameter and 40 cm length) with a crown of tentacles and oral disc at one end (the oral end) and a "foot" at the other (aboral) end. There is a marked decrease in the thickness of the body-wall and especially of the muscular layer, toward the aboral end. The oral end exhibits greater sensitiveness to tactile and other stimuli, and greater contractility of the muscles of this region when stimulated.

The oral end terminates in an oral disc, which contains a slit-shaped mouth in its center. The aboral end terminates in a blunt point (foot) in which a small hole exists. The hole is used as a means for water to escape the distended animal during retraction into the tube. The column (main body) is hollow and contains the coelenteron (gastrovascular cavity).



Tube Anemone Diagram

The tentacles are hollow evaginations (out-foldings) of the body wall and contain extensions of the coelenteron. Their epidermis contains cnidocytes used for stinging either prey or predators. Tube anemones have two distinct whorls of tentacles on the oral disc. The outer whorl consists of large tentacles that extend outwards. These outer tentacles are used primarily in prey capture and defense. An inner ring or shorter "labial" tentacles surround the mouth and are used primarily for prey manipulation and ingestion. In many species the tentacles can be bioluminescent, which could be a visual "startle" defense against predators that may attack. The outer tentacles can grow up to 20 cm in length and can reach up to one foot in diameter when fully extended.

INTERNAL ANATOMY

Tube anemones are diploblastic, having two cellular layers separated by a jelly-like mesogloea in which skeletal elements can occur. The column wall (body wall) of the tube anemone is comprised of three layers of tissue: the ectoderm, the endoderm and the mesogloea.

The ectoderm or epidermis (outer layer) is composed of cells and muscular and nervous elements. The majority of the ectoderm's cells are elongated columnar cells (epithelio-muscular cells), which contain a nucleus and have cilia at their ends. Other types of cells found in the ectoderm include gland cells, sense cells, and cnidoblasts (which produce the "thread cells" or nematocysts).

The endoderm or gastrodermis (inner layer) is also comprised mainly of epithelio-musculer or myo-epithelial cells. It also contains gland cells and nervous elements.

The mesogloea layer (middle layer) is not a cellular layer, but a gelatinous substance secreted by the endoderm and ectoderm. Frequently cells will migrate from the ectoderm and endoderm into the mesoglea.

The mouth is an elongated slit in the center of the oral disc. The mouth is slightly expanded at each end. These expansions are the ends of vertical, ciliated grooves called siphonoglyphs. The cilia of the siphonoglyphs generate a constant flow of water into the coelenteron even when the mouth is closed. This maintains a positive hydrostatic pressure in the cavity and helps keep the column distended. The mouth opens into a short, flattened tube – the pharynx (throat). The pharynx leads into the coelenteron.

The coelenteron is partitioned by mesenteries that expand the inner absorptive surface. Mesenteries are longitudinal sheets of tissue that extend radially from the column wall to the actinopharynx. These "infoldings" of the endoderm and mesoglea extend from the body-wall into the gastrovascular cavity. The number of mesenteries also decreases toward the aboral end, until only a single pair remains; all new mesenteries appear first at the oral end and extend gradually aborally, thus indicating that growth in circumference begins orally.

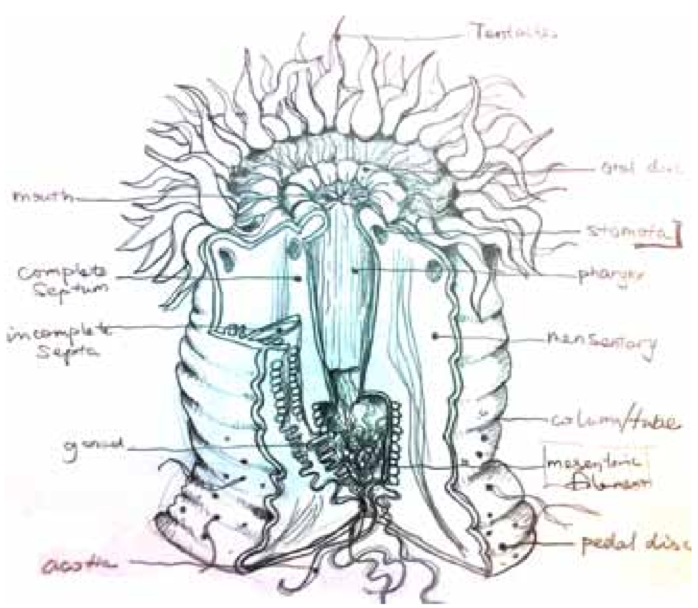
Free edges of the mesenteries bear structures that are termed acontioids (adhesive threads). Covering each surface of a mesentery is a sheet of flagellated epithelio-muscular cells. Between these two endodermal epithelio-muscular layers lies a fibrous mesogloea, similar to the mesogloea layer within the column wall. The function of mesenteries is to increase the surface area for respiration, digestion and uptake of nutrients. They also provide structural support. Attached to one face of each mesentery is a layer of longitudinal retractor muscle.

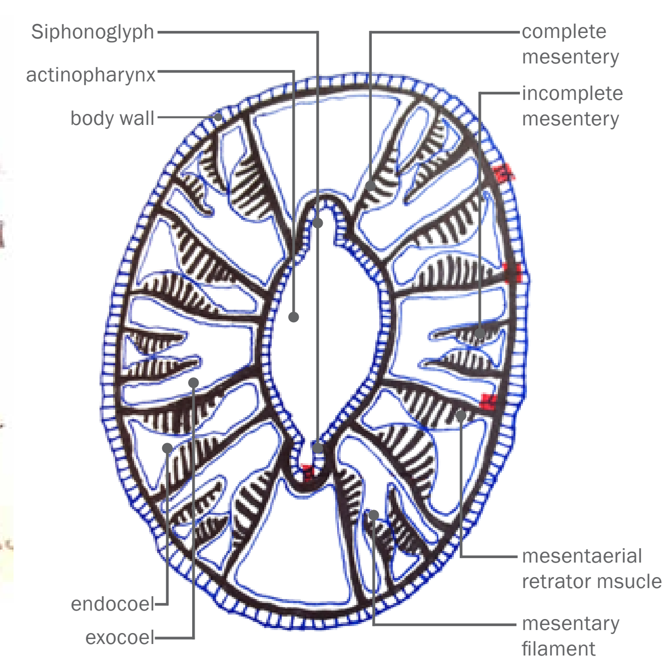
EXPANSION, CONTRACTION AND FLUID DYNAMICS

The expansion and contraction of the anemone within its tube is due to the vertical movement of these longitudinal retractor muscles. Even though these muscles react in a vertical direction, they create an inner force or tension within the body of the anemone that stretches the column wall taut and enables the tube anemone to retain its circular form when the digestive cavity is filled with water.

The expansion and contraction is integrated with the hydraulic pressures of the water that flows through the body as it distends and contracts. It uses water pressure to regulate its form in response to environmental and external stimuli. The inability of the animal to extend to its full length without the aid of water-pressure is due to the absence of circular muscles in the body-wall. Extension is passive, not active. The accumulation of water in the column appears to be the result of diffusion through the walls, and especially through the very thin membranes at the oral and aboral ends.

When undisturbed, the body and tentacles are usually more or less distended with water and the body-wall is always tense – under high amounts of pressure. If the body of a distended anemone is opened quickly by a small cut the water issues with considerable force. When a tube anemone contracts rapidly the water squirts from the aboral foot with great force.





Tube Anemone Cross Section

Below are some interesting notes about tube anemone expansion and contraction from C.M. Child's scientific investigations of tube anemones:

- When the body is distended the œsophagus, with the exception of the siphonoglyphe and perhaps some grooves and crevices, must be closed.
- When contraction occurs the water first issues from the aboral pore; then when the pressure is sufficiently reduced to permit it, the œsophageal walls are separated by muscular action and the remaining water issues from the mouth, often accompanied by mesenterial filaments. Thus the oesophagus is widely open only during extreme contraction.
- The cilia on the endodermal surface of the body-wall produce a current flowing orally in each mesenterial chamber. The water passes from each chamber along the aboral face of the marginal tentacle, back on its oral face beneath the disc toward the stoniodaum, probably into and out of the labial tentacles and aborally along the stomodaum. In all probability cilia along the sides or margins of the mesenteries force it further aborally.
- The internal water-pressure plays a large part in form-regulation in Cerianthus. The general pressure affects the rapidity of growth wherever it may be taking place and it is possible that the local pressure exerted on the body-wall by the currents passing orally in each mesenterial chamber is the formative stimulus for the marginal tentacles.
- Regeneration of tentacles is impossible unless mesenteries are present. The reason suggested for this is that in the absence of mesenteries there is no localization of the currents corresponding to the intermesenterial chambers, and, moreover, the water being unconfined between mesenteries, exerts less pressure on the inrolled oral end than if mesenteries were present.
- Local retardation or inhibition of tentacle-regeneration can be brought about by preventing distension of a part or parts of the oral region.

ITEMS OF ADDITIONAL INTEREST:

Regeneration: The rapidity of regeneration is dependent on the position which the anemone section occupied in the parent body, a decrease in the rapidity of regeneration occurring with increasing distance from the oral end. The effect of position has a similar impact on rapidity. Not only is there a decrease in the rapidity of regeneration toward the aboral ends, but the total amount of oral or aboral regeneration also decreases in the same manner.

Opacity: The pigmentation of the body is closely connected with the presence and arrangement of the muscular layer. When the muscle layer is thick, or under less tension, it become more opaque. When it is under tension, either from internal water pressure, or due to the regenerative or growth processes, the column wall becomes more translucent.

Tube Anemone: expansion and contraction diagram

Clockwise:
Models 1-8

3 MEMO 1 MODELS
EXPANSION/CONTRACTION

1 HOW TENTACLES REACT, CAPTURE PREY:

The tube anemone has two sets of tentacles, an inner and an outer group. The tentacles of the inner group continuously make small spontaneous bending movements which are increased following light mechanical stimulation. The outer tentacles are food grabbers and transfer food to the shorter inner tentacles. The following model attempts to create the mechanism of tentacle movement through the use of sensors and electricity. Tentacles react to stimulation such as touch. In this case electricity conducted through a wire is used as a medium for stimulation. Electrode tips receive the signal and stimulate an alternative current. The spiral starts to spin providing movement to the gears. The connecting rod turns providing a back and forth spinning motion, moving the tentacles.

2 TENTACLE REGROWTH:

The tube anemone's tentacles are a source of food for certain organisms such as the Nudibranch, and therefore are sometimes substantially damaged by these feeding organisms. However the tube anemone utilizes an interesting mechanism that allows the tentacles to regrow and regenerate. The tentacle is formed through a process called evagination, which is the outward folding of the tube anemone skin. The model idea is to create a double-layered skin. The inner layer extrudes outward as the tentacle grows (or regenerates). This is accomplished with a system of tension vs. compression. The model created uses metal wire and elastic string to hold the system in equilibrium. Heat is applied to release kinetic energy, allowing the tentacle to extend.

3 FORM REGULATION:

This model focuses on the form regulation of the tube anemone and its ability to expand and retract due to internal water pressure. The enteric cavity is distended with water which in turn expands the body of the tube anemone. When the anemone contracts the water is expelled through the aboral pore and through the stomodeum and mouth. In this model air is used as the energy source to create the inflation mechanism. Air inflates a balloon which is placed inside a flexible vinyl tube. As air inflates the balloon the tube expands to a regulated state. The energy of heat is then used to puncture the balloon causing a release of air pressure deflating the balloon and causing the tube to collapse.

4 TUBE RETRACTION VIA TOUCH OR SENSORY:

The model demonstrates tube retraction via touch through the concept of strings in tension and compression. When tension is increased the spring retracts and the strings compress causing the tentacles to retract within the tube.

5 TUBE RETRACTION VIA TOUCH:

The purpose of the models is to reflect the ability and process of the animal to retract into its protective tube. The spring-loaded model includes a coiled spring held by a trigger that is released by movement of the tentacles, which are represented by flexible plastic tubes. When the tentacles are disturbed, the spring snaps into standard position, thus pulling the tentacles into the protective tube – the PVC pipe.

6 TUBE CREATION:

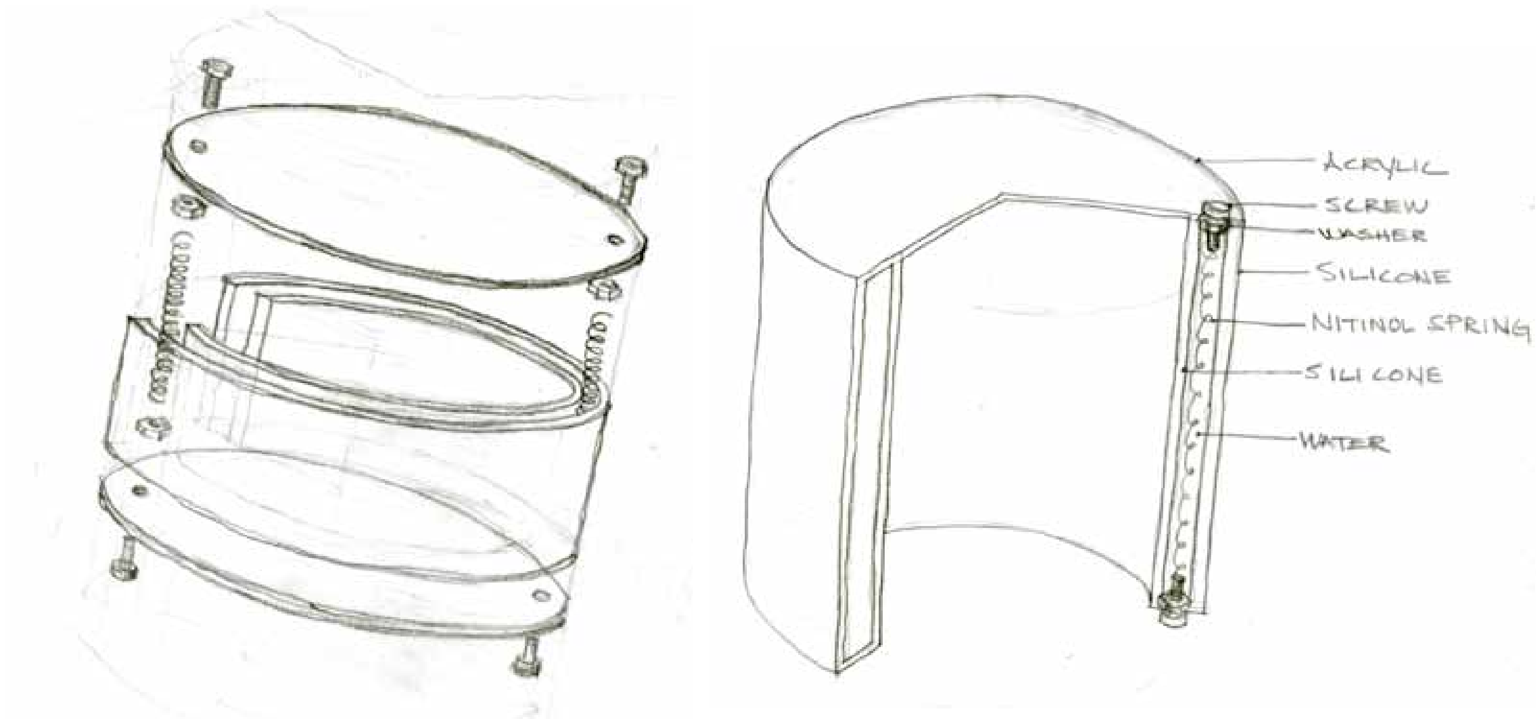
The tube is a product of the tube anemone. The anemone creates the tube from cells capable of discharging mucus saturated fibrous threads which forms with sand and sediment from the tube anemones natural environment. This sand and sediment behaves as an aggregate in the formation of the tube. By constructing a tube made of loosely woven fabric doused in fiber glass resin the basic idea of an anemone without a tube is created. Next the tube is pulled from a sandy bed; what can be seen is how sand adheres to the tube during the creation.

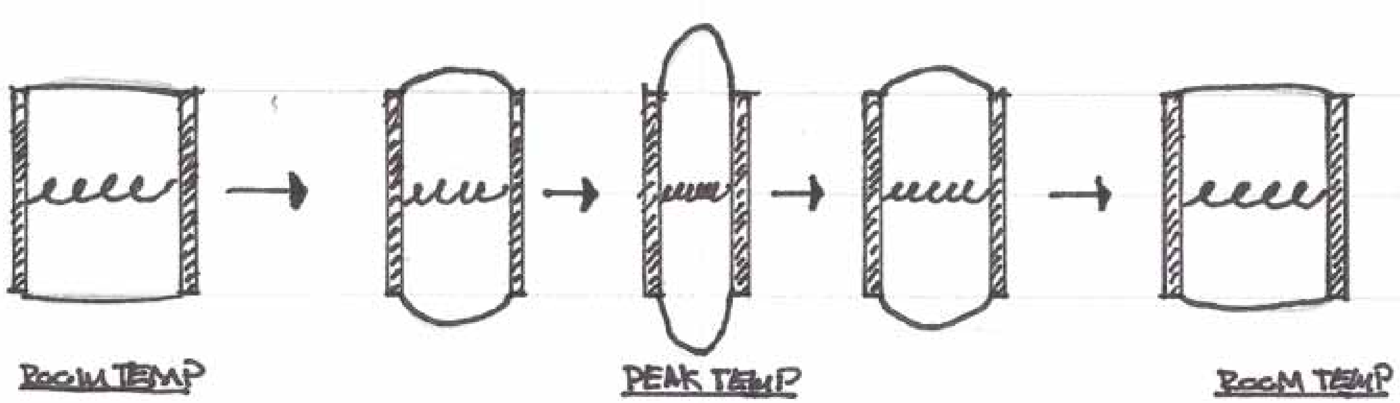
7 BIOLUMINESCENT TENTACLES:

The tentacle of the tube anemones are smooth cylindrical tubes. They taper from the oral end and the proximal end is perforated by a pore. There are two sets of translucent tubes within the oral disk of the tube anemone. These translucent tubes carry strands of ptychocyst held together by mucus. These ptychocysts are stinging cells discharged from the bioluminescent tentacles that scare off prey. The tentacles also have the ability to change color with sunlight. The model shows a flexible tube with strands of fiber stringing throughout. The fiber strings puncture the tube at different stages to allow for the light to filter through. The blue LED has a light sensor attached. When no light is present the LED glows bright and the light streams through the fiber strand which is then transferred through the tube. The tentacles light source is derived from one end therefore, the intent was for the fiber strands to transfer the light to the opposite end.

8 TUBE EXPANSION:

Focusing on the Tube Anemone's ability to extend itself out of the tube led to the use of potential energy. To facilitate this action a rubber band was used as the potential energy. The theory behind this was to turn the horizontal force of the rubber band into vertical movement. This was achieved by using the outward movement of the top of the wires to climb up the cylinder. This demonstration used heat as a trigger by severing the anchoring element. Further research would be to explore a "rubber band" that had inherited expansion and contraction properties.





4

MEMO 2: STUDY MODEL 1

EXPANSION/CONTRACTION

This model explores the activities of the organism's body wall during expansion and contraction. Three separate phenomena are investigated:

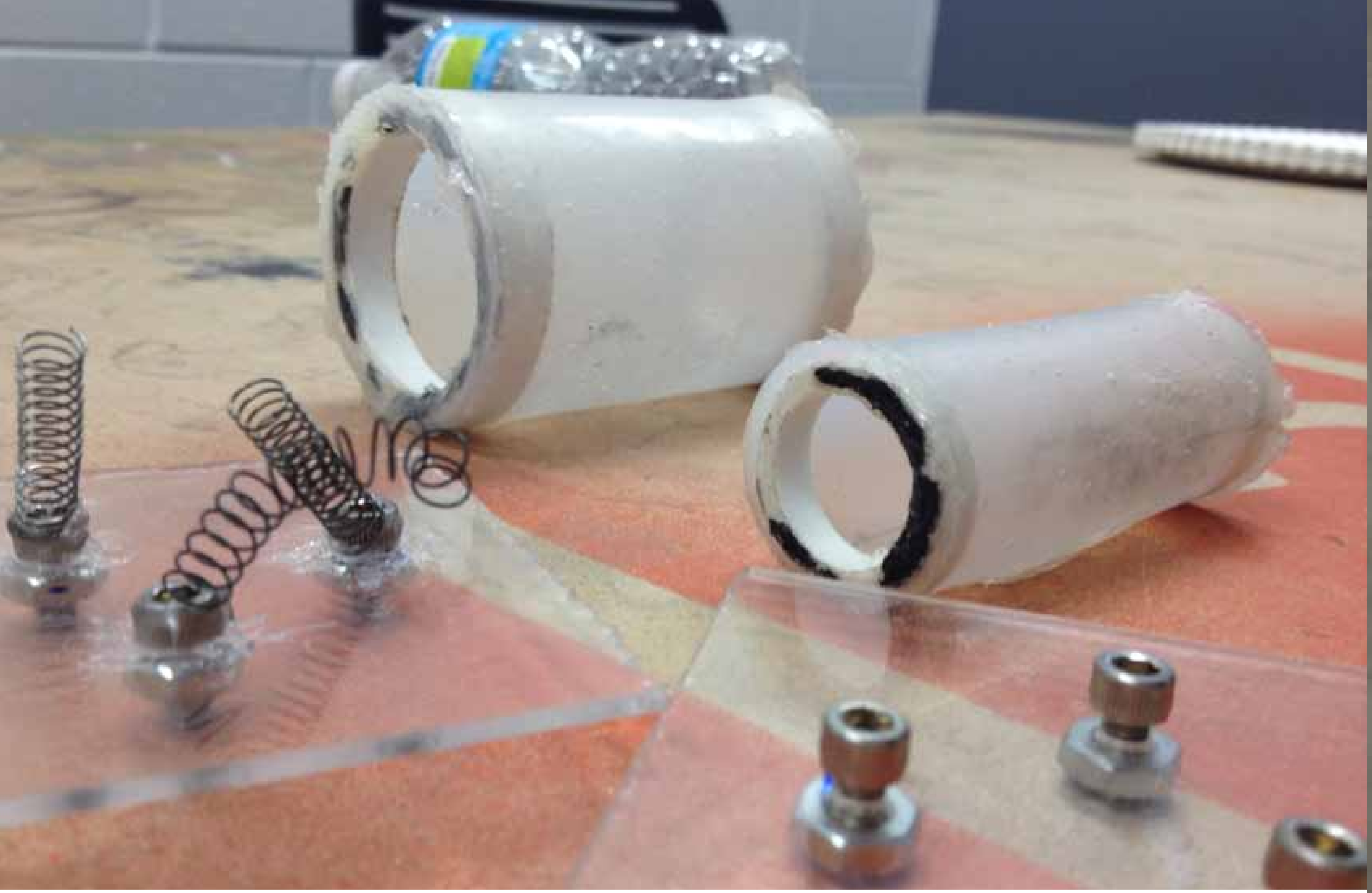
1. The movement of the longitudinal (mesenterial) retractor muscles
2. The water pressure of the body wall
3. The opacity of the body wall

When the longitudinal retractor muscles constrict a chain reaction ensues. The result is a release of the internal water pressure on the body wall. As the body wall compresses, the tension on its surface decreases and the membrane increases in opacity. As the water pressure within the body cavity builds back up during the expansion process, the tension on the surface of the body wall increases, making it more translucent.

Exploring the movement of the retractor muscles involves placing helical Nitinol wires between two acrylic planes, representing the inner and outer body wall. The acrylic planes are cut to the desired shape using a 3-axis C & C Machine. The inspiration for using the C & C Machine is derived from similar equipment used at Quality Metal Craft. As the helical wire is heated it contracts, pulling the acrylic planes closer together.

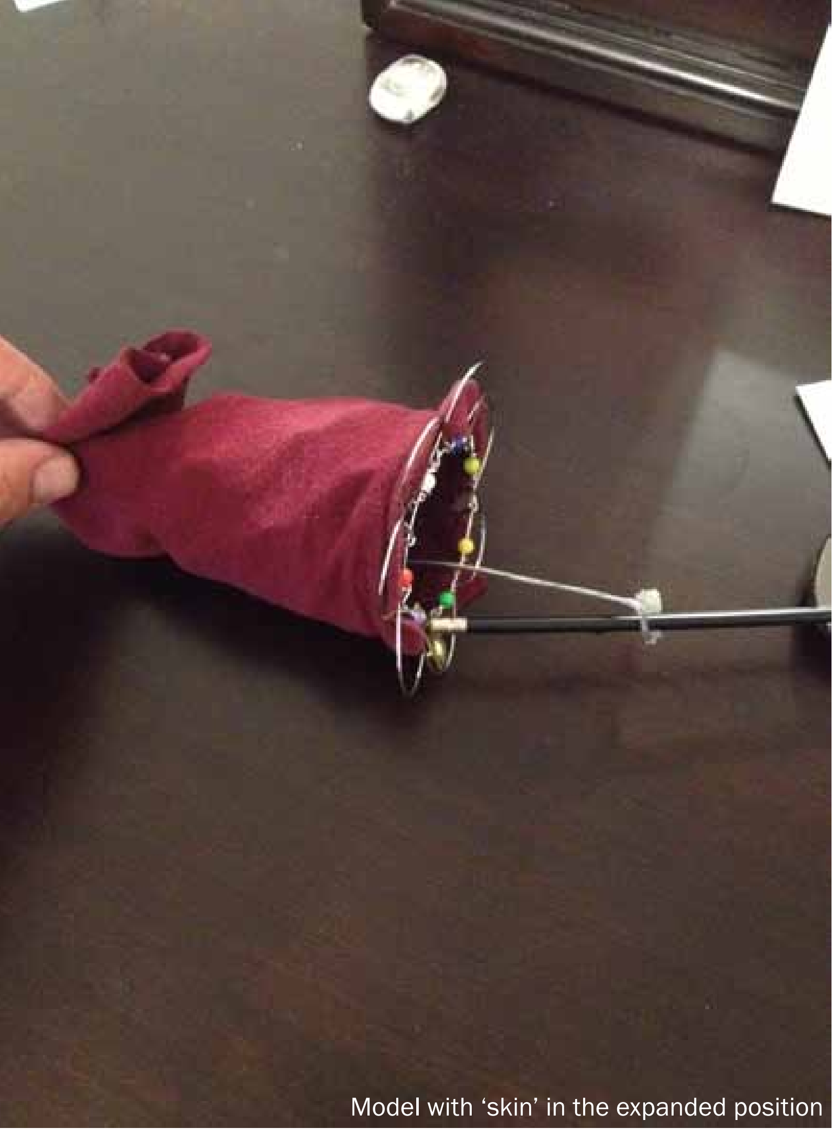
The planes and wire are surrounded by a silicone sleeve which is cast in a form, much the same way Ransom and Randolph and Quality Metal Craft use casts to form jewelry and dies respectively. The silicone is flexible to allow for the movement of the acrylic planes. The air now enclosed by the silicone sleeve and acrylic planes can be replaced by fluid. Once heated the acrylic planes move closer together, increasing the fluid pressure inside. This increased tension on the membrane surface reduces its opacity. Once the helical wire has cooled the internal pressure causes the planes to reset back to their original positions.

This model allows for exploration of material properties and fabrication processes, providing a better understanding of the actions of the tube anemone during the process of expansion and contraction.

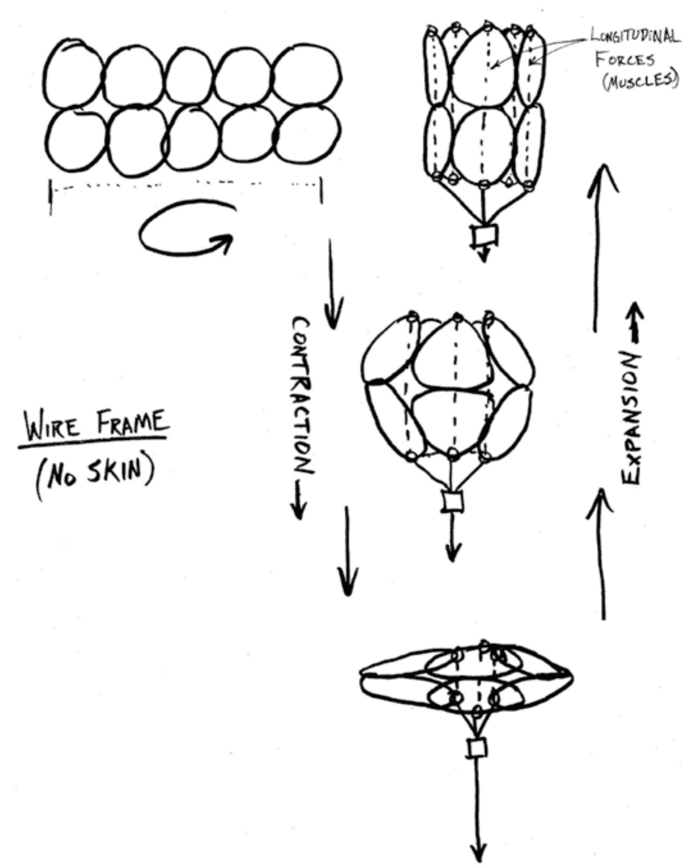


left page:
construction
process of model

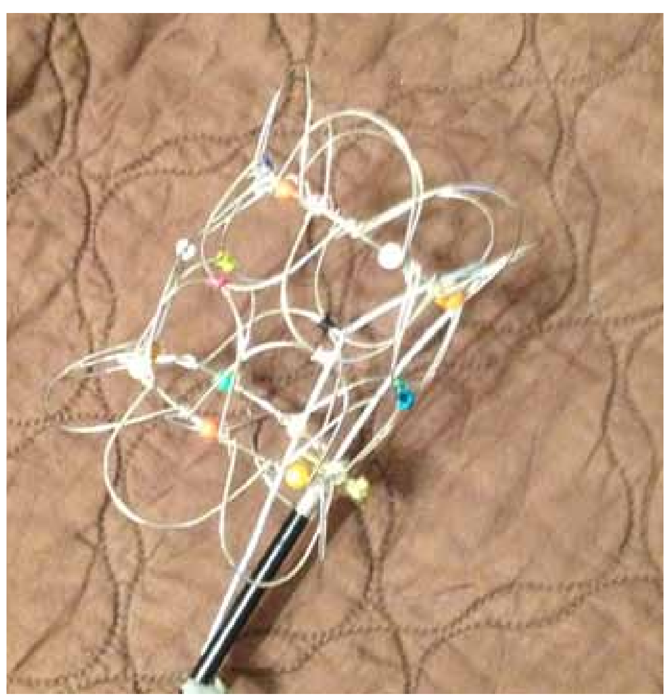
right page:
complete model



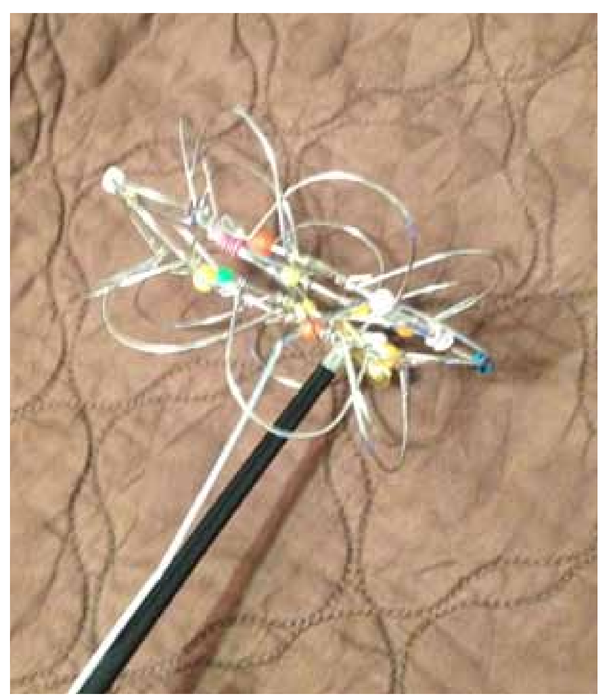
Model with ‘skin’ in the expanded position



model development sketches



Model in the expanded position



Model in the contracted position

5 MEMO 2: STUDY MODEL 2

EXPANSION/CONTRACTION

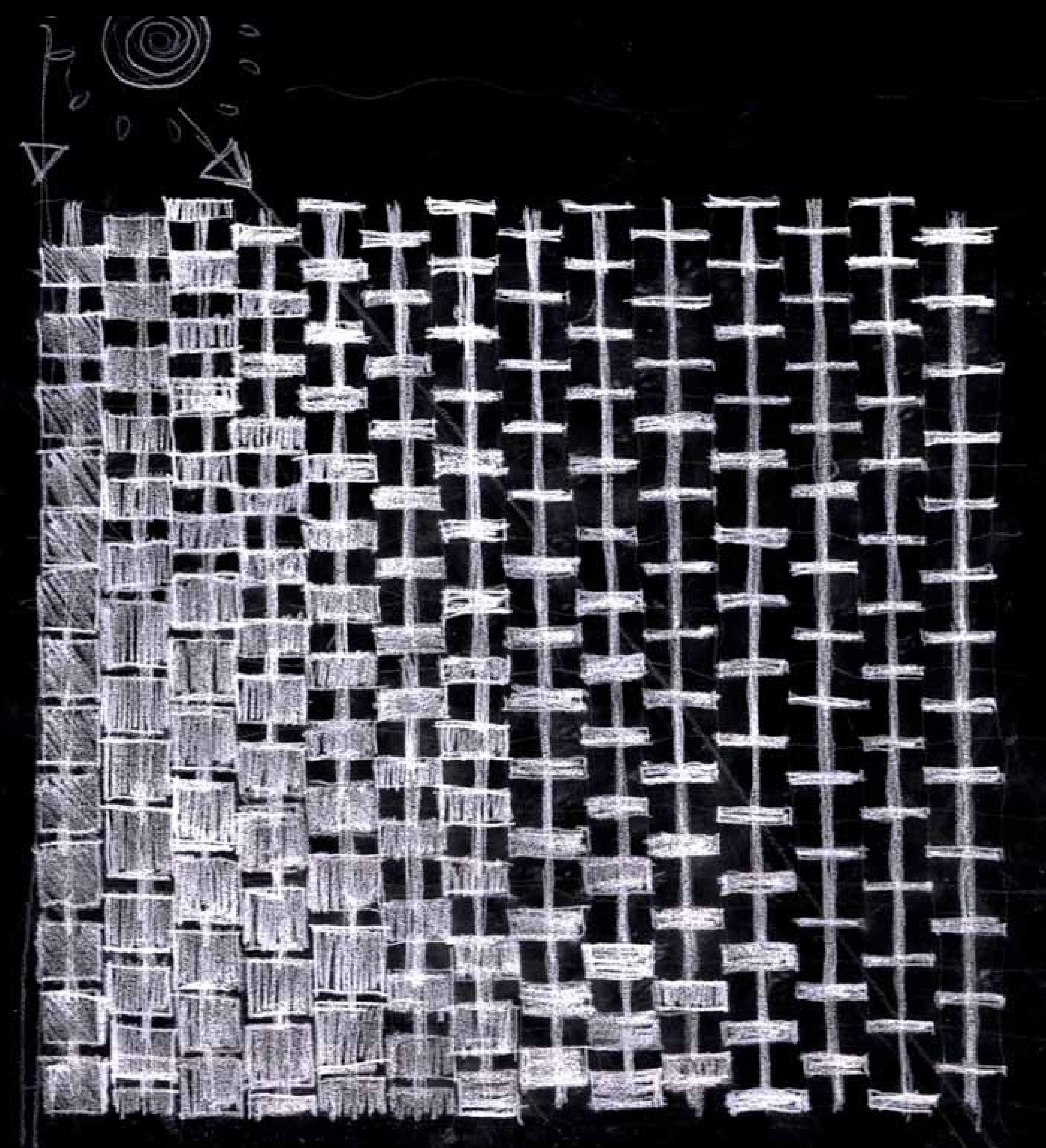
The tube anemone contracts sharply when sensing danger by using longitudinal muscles to pull downward, releasing stored water through the aboral “foot”. This allows the body to compress. The expansion is a much longer process. The organism must replenish its membrane with water through diffusion, which usually takes days.

In this model, the break wire that is connected to the top and bottom of the frame represents the longitudinal muscles that cause the organism to contract rapidly. The body of the tube is made up of a series of connected wire rings that move in synchronization with each other. The skin is a flexible cotton/spandex material that conforms to the shape of the tube in all positions.

Direct coordination of the materials working with and against each other to create simultaneous movement is comparable to the stamp press used at Quality Metal Craft. Once metal is stamped into a mold at QMC it has a tendency to slightly return back to its original position or shape. With this model the cotton/spandex material can be held in resistance or freely allowed to return back to its original form.

As the break force is applied, the tube model contracts rapidly, flattening almost completely. The longitudinal forces contract vertically, causing horizontal expansion around the middle of the tube. Once settled, the expanded center of the tube then starts the slow process of returning back to erected form by means of soft springs and bands that pull together.

This model provides detailed exploration in the way hinge connections interact, and the transferal of lateral and longitudinal forces. The cause and reaction is more than simply a domino effect— it is instantaneous. One portion of the body cannot move without another. All parts work together as one.



6 MEMO 2: MODEL 3 (WORK IN PROGRESS)

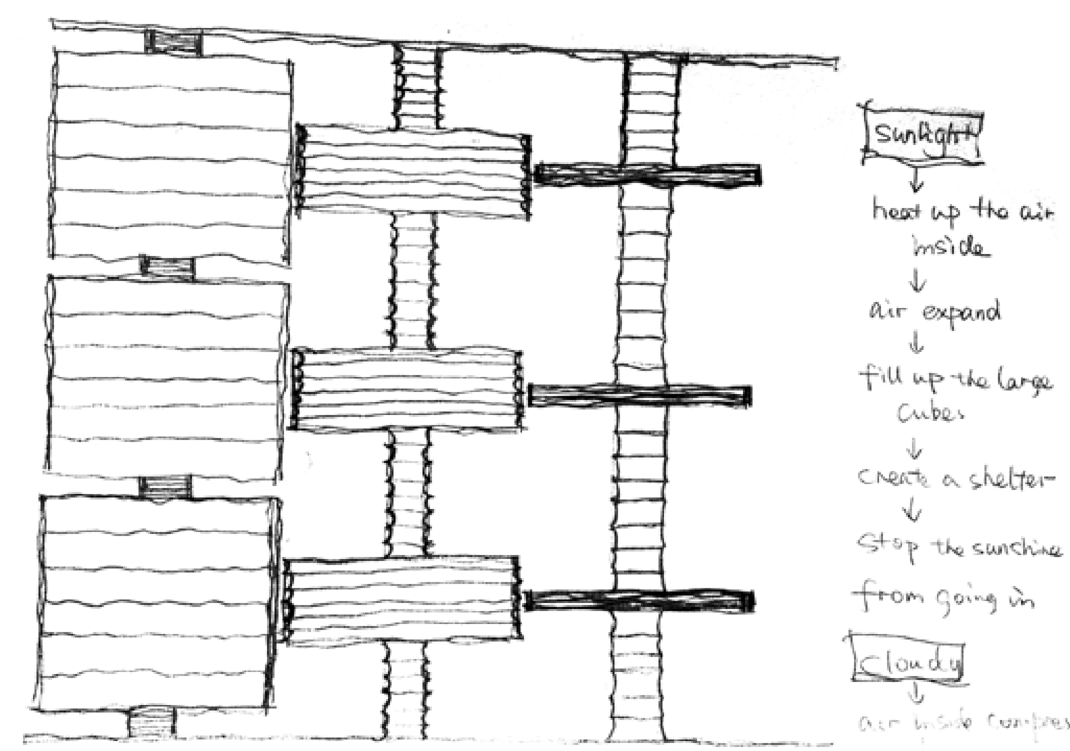
EXPANSION/CONTRACTION

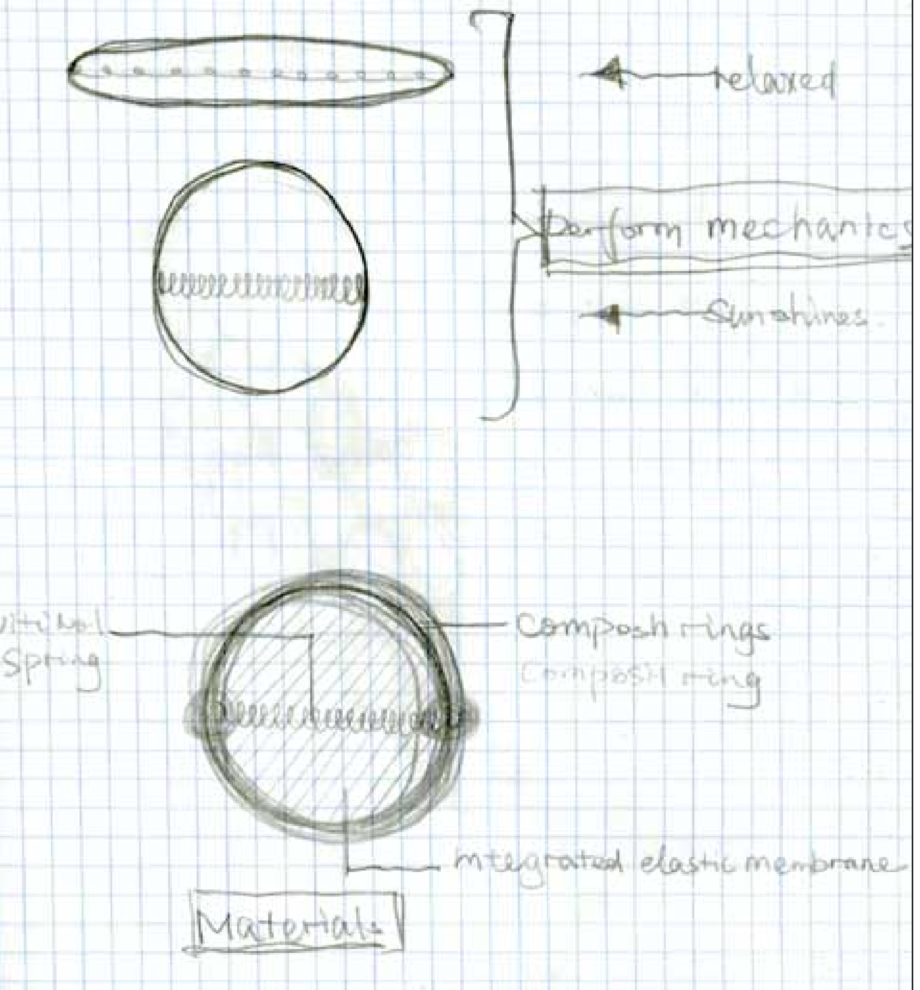
This model applies the tube anemone's expansion and contraction as a potential shading device. The main part of this model consists of two thin square boards placed parallel to each other. Their corners are connected with four springs to form the frame of a cube. This frame is sheathed with super elastic plastic. Each board has a hole in the middle which is connected to a tube made of temperature-sensitive material.

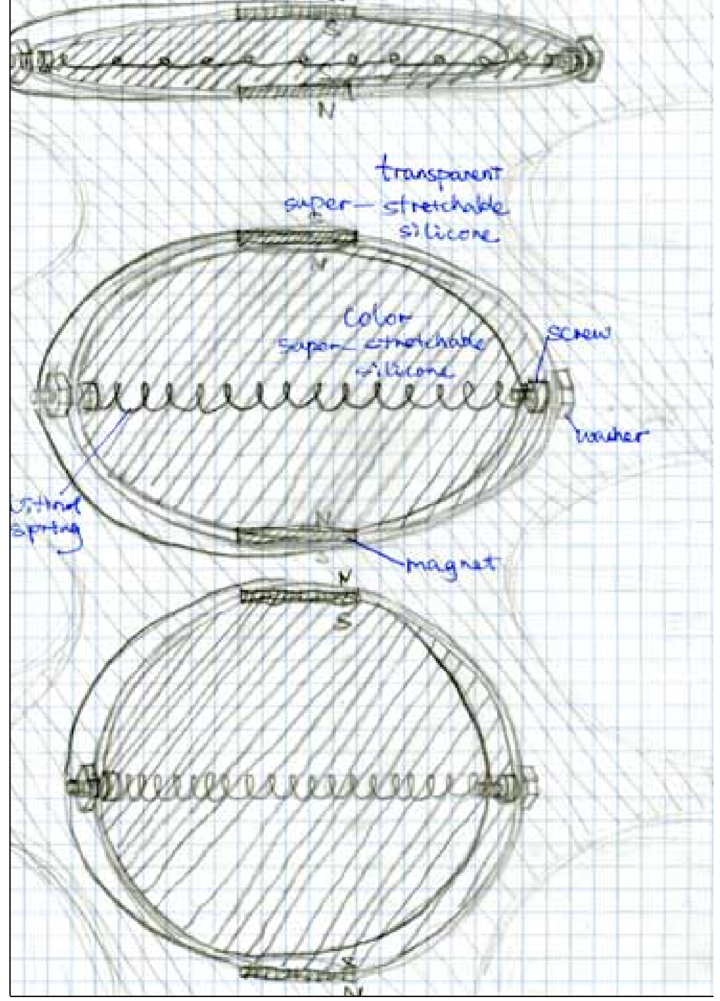
During the tour to the Glass Pavilion, two different kinds of fire were discussed: practical fire and phenomenal fire. Practical fire is used in a basic sense – to heat, provide light, etc. Phenomenal fire creates an experience with the user - it goes beyond the necessities and can also continue, start, or stop another process.

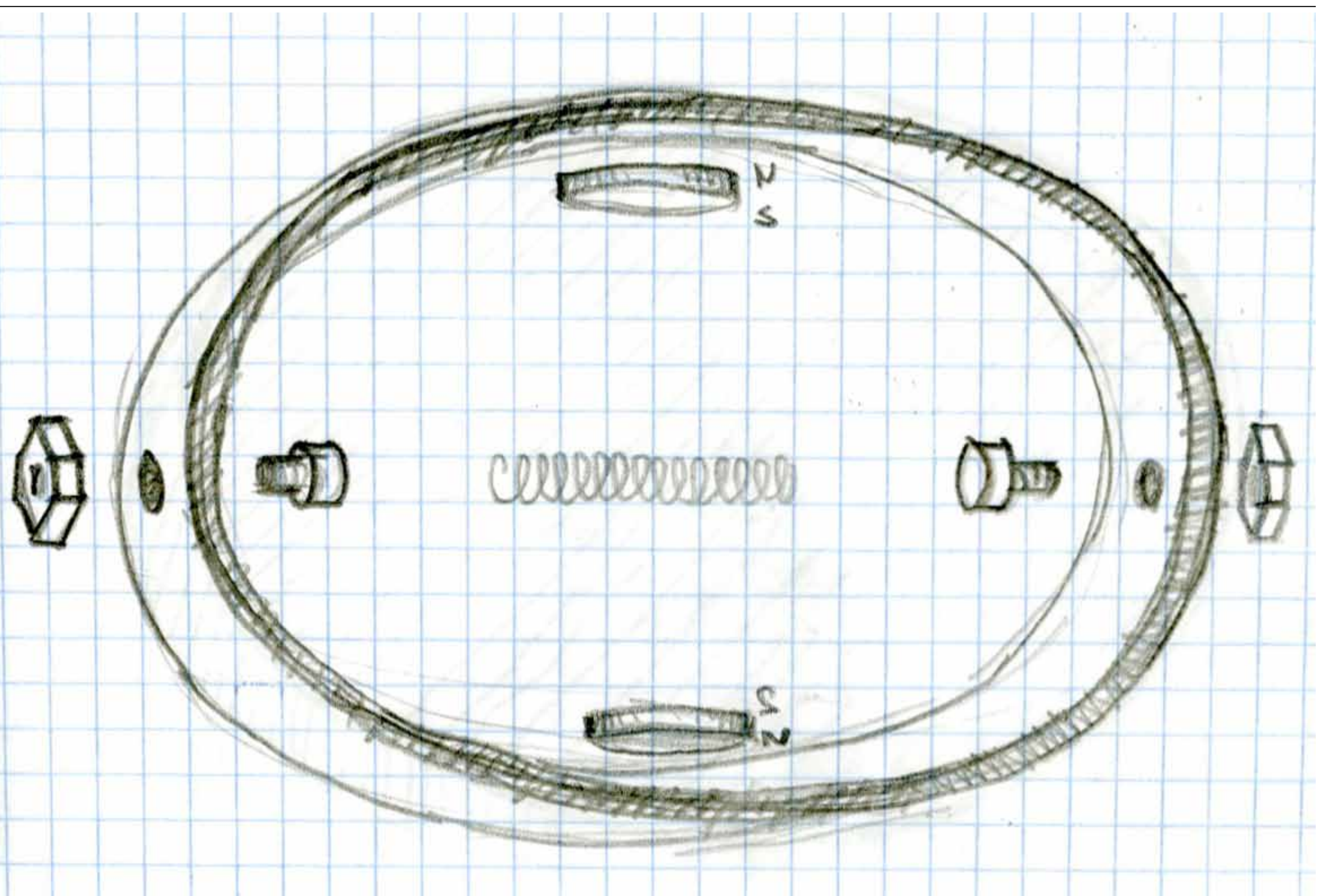
In this instance, the sun serves as both practical and phenomenal fire. It is practical fire because it offers heat and light. It is phenomenal fire because it activates the model. When the sun shines directly on the model, the tubes warm up, causing expansion of the cube. As the sunlight fades, the device cools down, contracting to its original position.

This device can provide shade when solar heat is strong and close when the temperature lowers, allowing more light and heat into the building. It is possible to carry this further to form a system. Several tubes and cubes connected to each other can create a second building skin over the glazing and act as a spontaneous organism to protect the building's interior from excessive solar heat gain.









7 PROTOTYPE

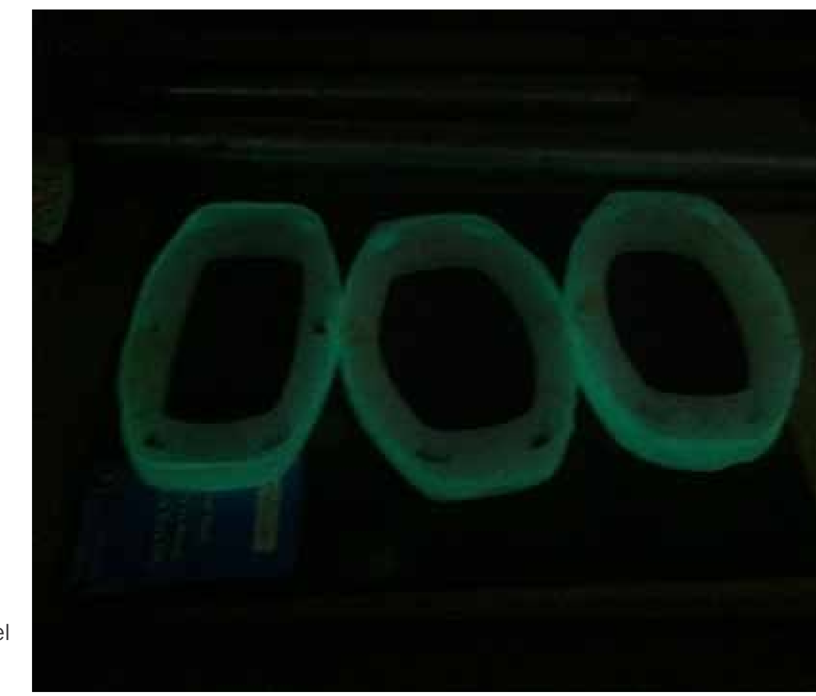
EXPANSION/CONTRACTION

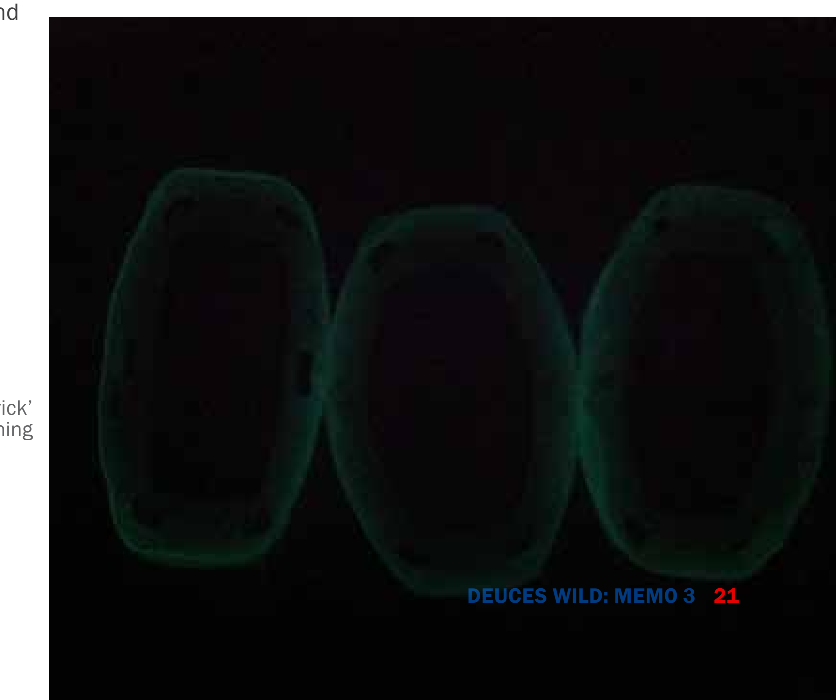
The model is based on the tube anemone's self-regulating process of expansion and contraction, and is a continuation of ideas developed during the Memo 2 assignment. The tube anemone uses the contraction of its longitudinal retractor muscles to release hydrostatic pressure within its body cavity, allowing it to withdraw into its protective tube. The organism then uses diffusion through its body wall in order to distend back to its resting position, placing its body wall in a natural state of tension.

The model uses Nitinol wire in a manner comparable to the longitudinal retractor muscles. The device is self-regulating because it has the ability to be activated by an external trigger (in this case heat) and returns to its original position without mechanical assistance. In order to accomplish this, a composite membrane is developed, whose physical properties cause it to return to its natural elliptical form when not activated by the Nitinol wire.

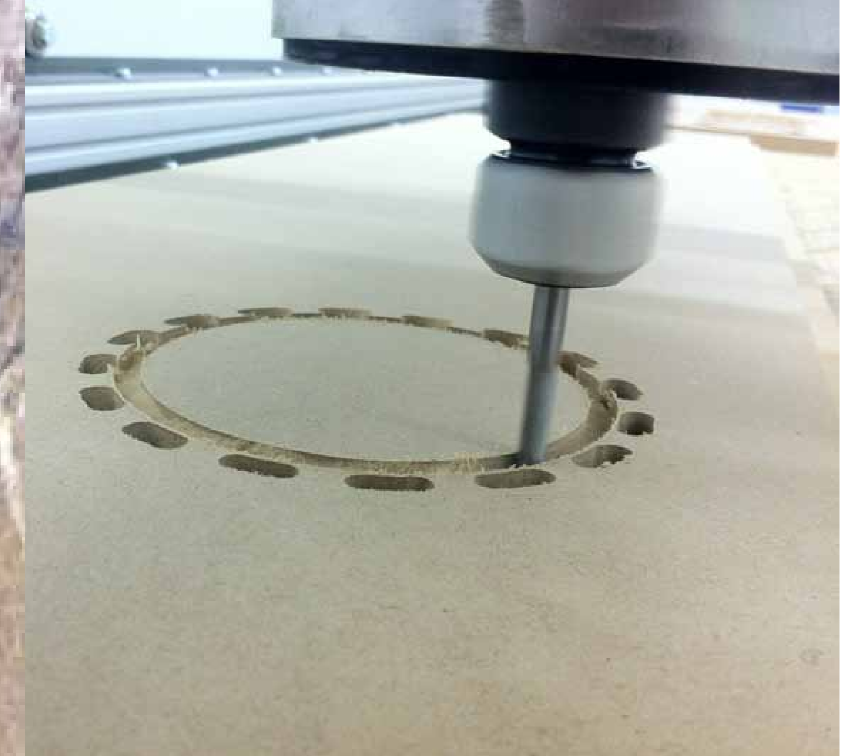
The goal is to create a device that translates horizontal force into vertical movement. The unit has an elliptical profile when in its relaxed position and transforms to a rounded, circular profile when in its activated position. Model activation is by heat gain. In order to facilitate the transferal of lateral force to longitudinal motion, the Nitinol wire is directly connected to the composite silicone membrane and held in tension until activated. The silicone membrane's thickness and openings are designed for maximum unit expansion in unison with the Nitinol contraction.

In addition to the model's expansion and contraction, consideration is given to incorporating additional materials that change in color, opacity or luminosity. These materials allow the model to provide a more interactive experience during times when the model would not otherwise be activated. Such materials include glow-in-the-dark tape and color-changing fabric.





luminescent material in 'brick' from daylight to evening



Left Page: 'Brick' unit

Right page, Clockwise:
CNC milling of molds, silicone casting,
Quality Metal Works sand casting,
Ransom & Randolph pressure casting

Model Testing Procedures

8 TESTING

EXPANSION/CONTRACTION

The flexible silicone structural membrane is essential to the model's design and performance.Therefore much analysis was done to determine the appropriate silicone composition to usein the molds. Durometer is the measure of hardness of a material. We tested silicone with twodifferent durometer readings in the molds, the first had a higher capacity for flexibility (lowerdurometer) than the other.

THE MOLDING PROCESS

Initially the mold was CNC milled out of MDF and coated in Polyurethane. Cutting the mold was a bit tricky – MDF has a tendency to peel apart because it is essentially compact saw dust. The initial form was a circle with evenly spaced punctures. There are holes puncturing the ribbon to help with flex and when cutting. However during the molding process the machine knocked a few of them loose so this had to be compensated for. Once the silicone frame was set and removed from the mold it had to be connected to the model actuating device – the Nitinol spring. The Nitinol spring was attached to the silicone frame from midpoint to midpoint with a nut and bolt.

SILICONE MEMBRANE VARIATIONS

After the initial model was constructed, it was ready for activation. Being 1" thick and having a 5" radius, it was a little heavy and the material tended to droop due to its own weight. There was also no real control of the bending points since the holes were evenly spaced.

The next phase of experimentation involved casting three molds. These molds had more controlled punctures – focusing on areas that are critical in the model's expansion and contraction. The holes were placed on the four corners to control where the silicone bends and also provide for better spring back.

The first model had the corner punctures as well as on the midpoints of the top and bottom strand. This was decidedly too flexible and would not work properly. The second model had the corner punctures, but none anywhere else. The thickness was also half of the first model, .5". This model held its shape and flexed properly. The third model was similar to the second model but had an increased thickness. This model did not retract as well, and the weight of the silicone made it droop.

The shapes of each of these three models were also adjusted to be more elliptical in relaxed form, in order to provide greater differential between the relaxed and activated states. The C- shaped sides were also made wider than the rest of the model.

Each of the three new model iterations had a strip of illuminating ribbon laminated on the exterior radius. The ribbon held well in the silicone for the most part, but in some cases the silicone was too thin to properly attach. The band that laminated the best was on the second model, which also turned out to exhibit the best expansion and contraction of all the models tested.

In the future, when laminating the ribbon to the silicone it would be better to create a channel in the center of the mold for the silicone to sit in. That way the illuminating ribbon would be set into the silicone frame rather than sitting on top of the frame, and therefore be more secure.

WORKING WITH NITINOL

The Nitinol wire was attached from center point to center point of the C-channel sides. After pulling Mold #2, holes were drilled for the nut and bolt to fit within the silicone and provide a secure connection for the Nitinol. The silicone reacted appropriately with the Nitinol attached so we proceeded with the attachment of the temperature sensitive material. After a few struggles getting the materials to appropriately attach, the model was tested again. Adding the temperature sensitive material increased the model's resistance to the Nitinol wire. The wire was still activating, but the silicone was no longer moving appropriately.

MATERIAL EXPLORATION

The initial idea for the temperature sensitive material was to cover the silicone shape like a drum skin so that it would be stretched and pulled with the activation of the Nitinol. We initially tried to sew the material through the silicone to cover it all. However, not only did the material prove resistant to the attachment method, but it also exhibited reduced flexibility.

Since using the material as a sheet proved ineffective, it was removed and cut into a ring strip that wraps the silicone frame. The material was sewn to the circular frame at the top and bottom and left loose in the center. This reacted allowed the model to react in an appropriate way, but did not provide the desired coverage for the center of the model – the central shading mechanism.

FRAME ATTACHMENT

In order for the unit to be applied as a building skin, it has to be mounted to a structural framework that can be attached to the building. The self-healing quality of the silicone allows for the insertion of plastic tubing. This tubing provides a runway for a braided cable to be pulled through. On the other end the cable is fixed to the silicone. The cable is then stretched through the top and bottom of the frame to hold tight.

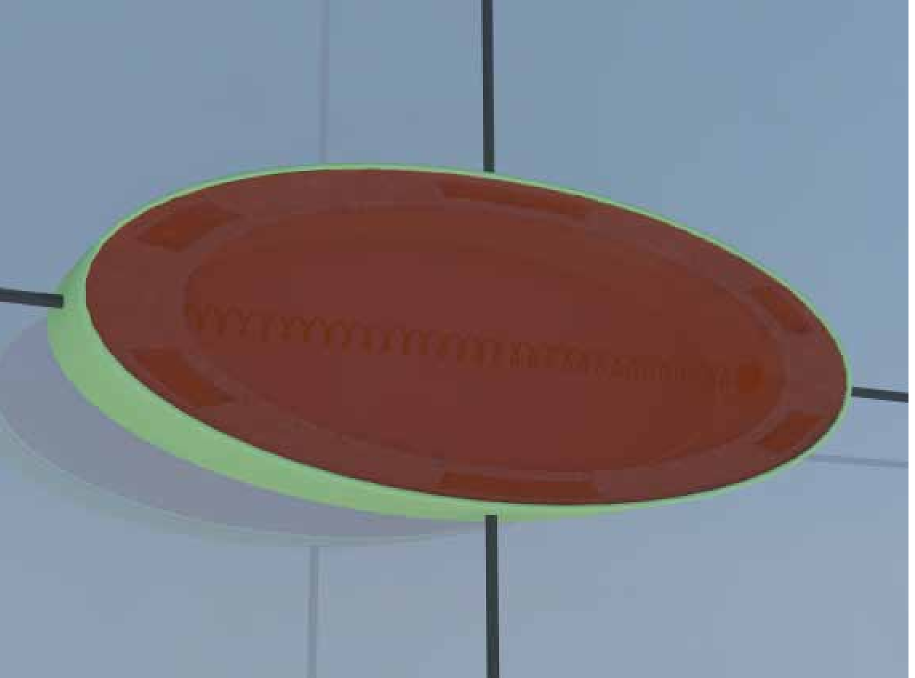
Providing one fixed point and one flexible point of connection allows the model to expand and contract independently while remaining in a fixed position on the building's façade.

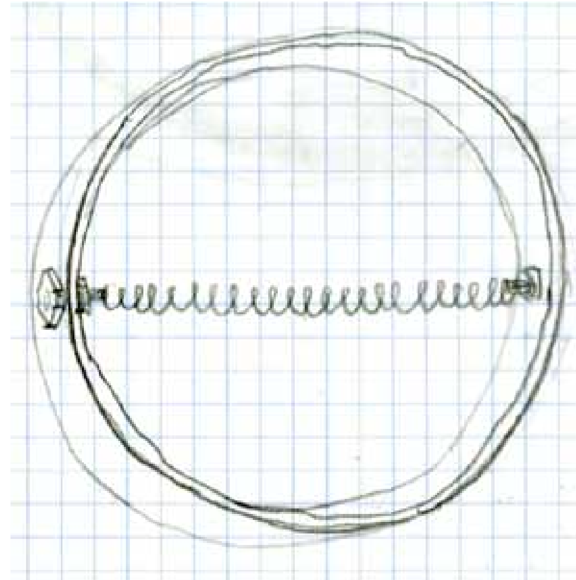
MODEL PROGRESSION

Once the mechanics of the model demonstrated functionality, it was a matter of refining the model's motion. Two Nitinol springs were added to give the unit more power. This was effective but the model experienced a lot of torque. A hinge system was added to help counteract this torque and help to control the temperature sensitive materials' compressed position.

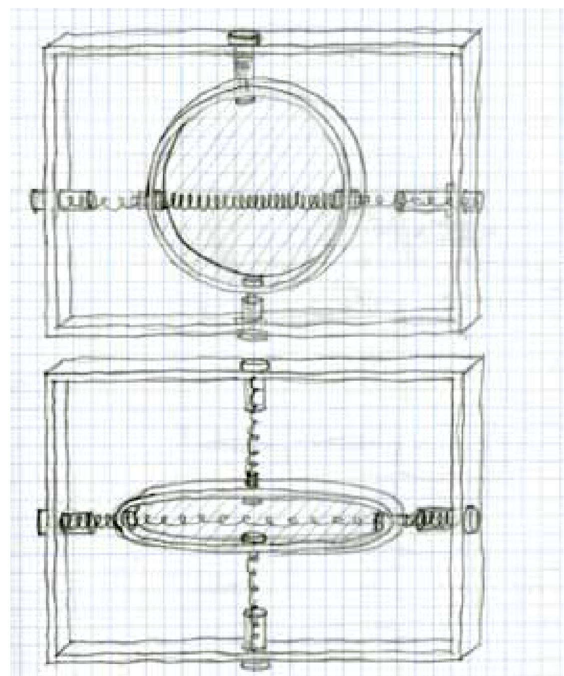
The functioning model was taken outside to see whether it would work in a "real world" application. The exterior temperature reached 100 degrees Fahrenheit with full sunshine. The model's expansion and contraction were noticeable. The fabric around the perimeter of the model also glowed when it was removed from the sunlight and put in a darker environment, which is desirable for the nighttime application of the unit.

Additional modifications and refinements are still needed. For example we are reconsidering the use of super elastic plastic material as a skin because of its ability to stretch and change opacity. However the results of recent model experimentation prove promising.

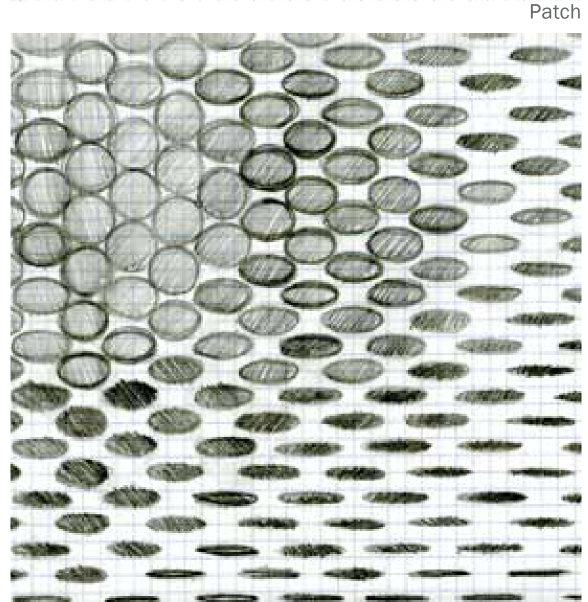

Brick: Cloudy day


Brick


Brick: Sunny day


Patch


Brick: Evening


Infill

9 PERFORMANCE
BRICK, PATCH AND INFILL

As the form and function of the model are developed, it can be applied on an architectural scale and replicated as part of a larger system. In this case the application is an external shading device that can be retrofitted to an existing structure, or applied to a new structure. The device can reduce demand on a building's HVAC system and create an interactive experience for building inhabitants and passersby. It also reflects the microclimate around the building by tracking the sun's path of travel and possibly relaying environmental data in a conceptual visual manner. The system has three levels: the brick, the patch, and the infill.

BRICK

The "brick" refers to the self-regulating base unit of the system, which is fully and independently functional. As developed in the model exploration, the brick is comprised of a Nitinol coil in its center. This coil is in a state of tension when the brick is in its relaxed position. When the brick is activated, the coil contracts horizontally, creating vertical expansion in the frame. This opens up the circular form and reveals the brick's skin, which provides shade and diffuses light for the interior of the building. When the Nitinol wire cools, the forces within the frame cause it to return to its resting (closed) position.

The frame of the brick is comprised of flexible silicone that has been cast from a mold. The silicone frame is elliptical in profile, with holes cast into it to provide greater range of motion. The frame also is thinner in some areas to facilitate its expansion and contraction.

Various skins can be applied to the brick in order to react to various external stimuli and provide an interactive experience at different times of the day (or night) and in all seasons. These skin materials include glow-in-the-dark tapes, color-changing fabrics, LED lights, etc.

PATCH

Each brick is mounted on a supporting rigid vertical frame that can resist lateral deflection. Since the bricks are circular in form, they have to be layered in alternating courses in order to effectively provide shade and diffuse light.

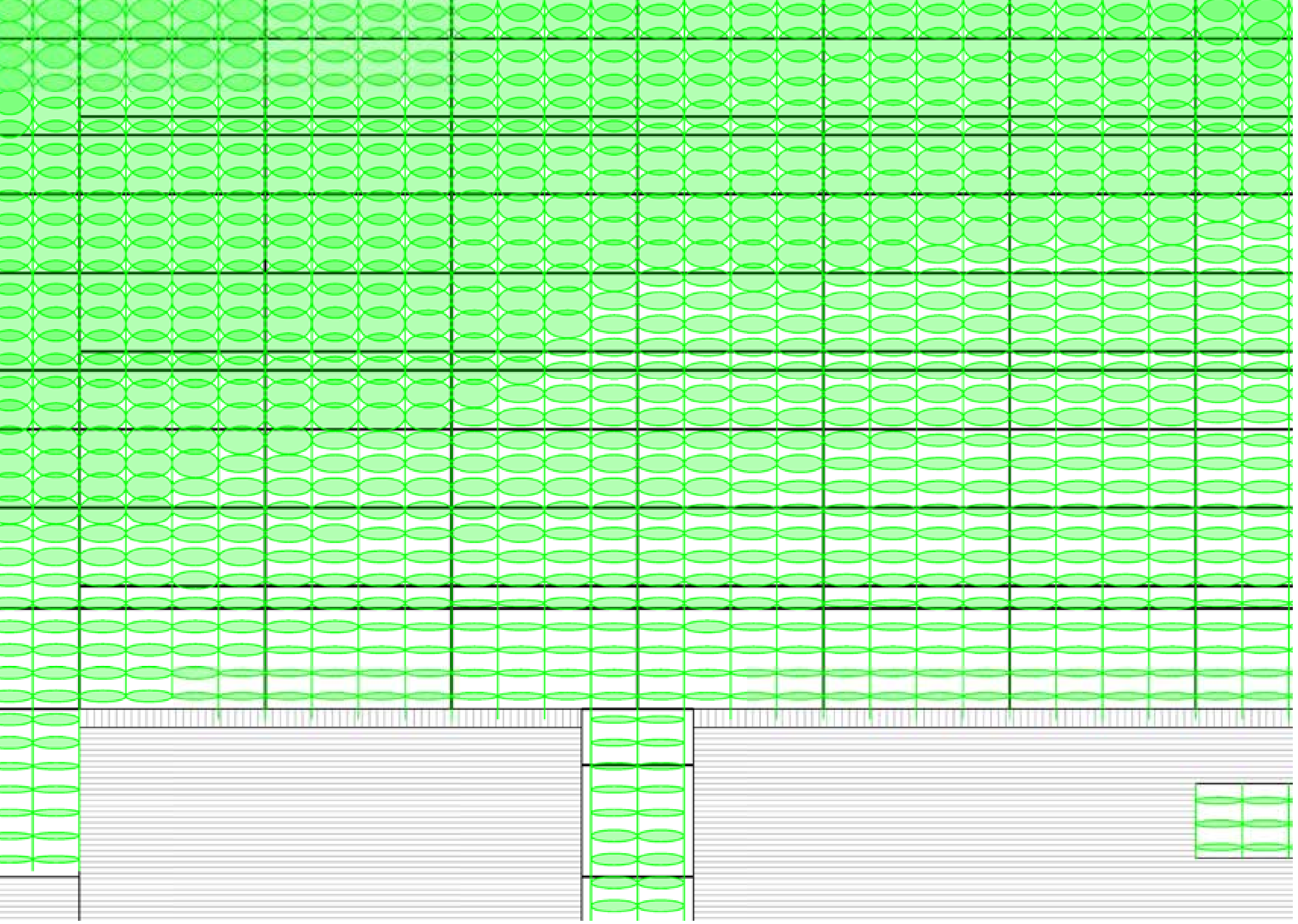
The "patch" can be defined as a grouping of bricks that serve the same function, are comprised of the same materials, and are in proximity to one another. Bricks that are part of a patch do not have to be physically connected to each other. They do not have to be the same size. Nor do they have to share the same support frame. However they do have to exhibit the same characteristics when exposed to the same external stimuli.

Different types of patches exist for different purposes on the building's façade. For example, patches may serve as energy producers. Bricks in these patches could have skins that are comprised of flexible photovoltaic polymers. Some patches may absorb light during the daytime and glow at night. Other patches may function solely as shading and light diffusion devices, or may be wired with LED lights which glow in response to external stimuli; while other patches may respond to physical touch by changing color. There is also the issue of vision versus spandrel glazing. Spandrel glazing is more opaque than vision glazing, and therefore light diffusion is not essential in those segments of the façade. Therefore patches over spandrel glazing can focus on applications that provide less transparency to the interior.

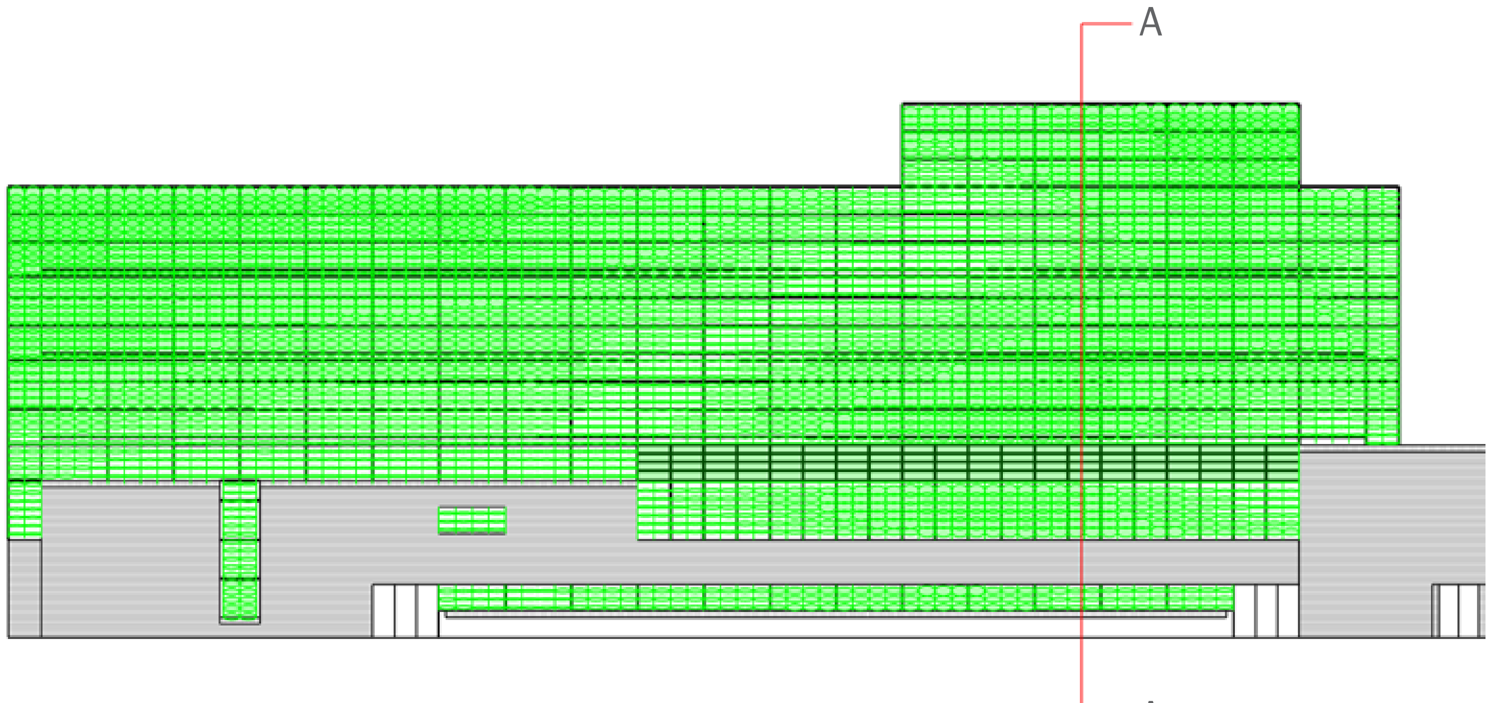
INFILL

The supporting framework for the patches is attached to the building's structure – possibly to the mullions of a curtain wall system. Each structure has a unique microclimate. The size, shape, and organization of the patches on a building's façade are designed for that particular building's needs and location.

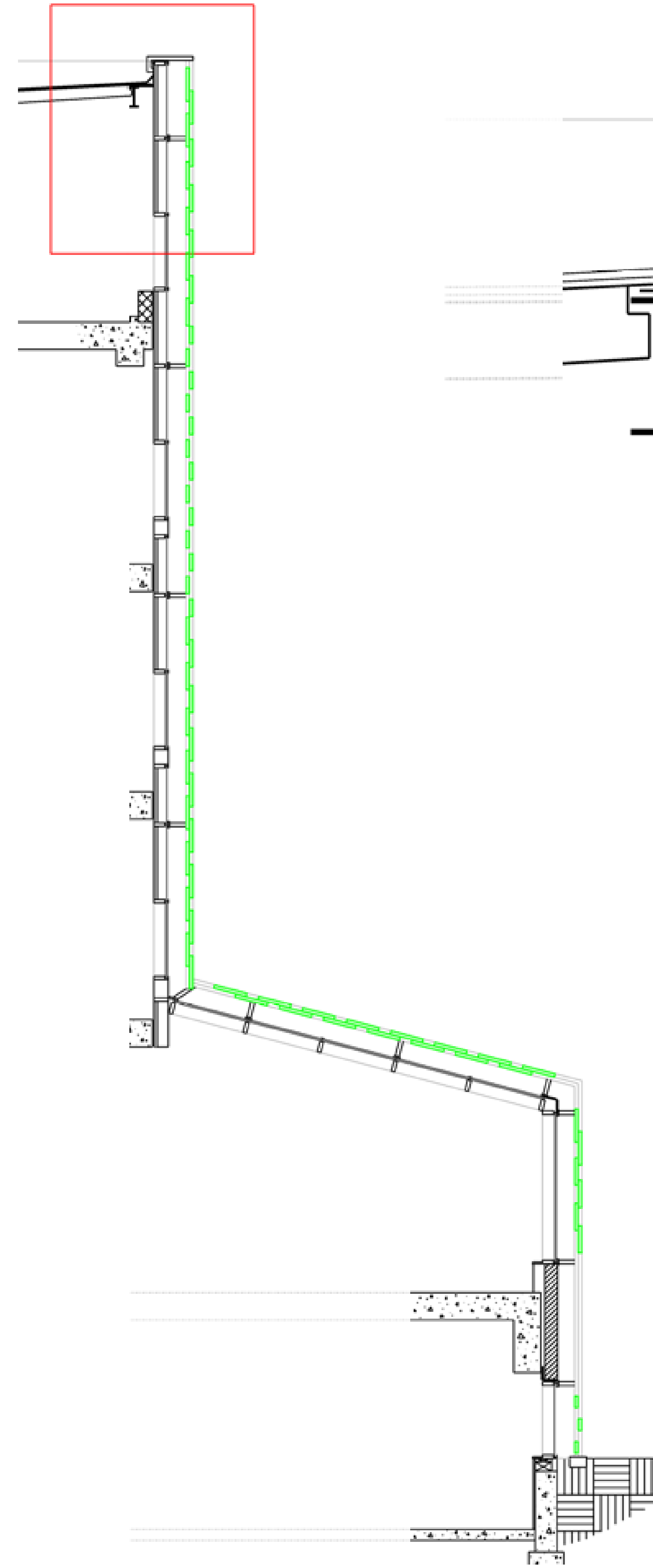
The "infill" is the arrangement of patches on a building's façade, and is customized for each side of the building. For example the North façade may have various patches on its surface, but it would have a different infill pattern than the West façade because the West elevation typically has more solar heat gain.



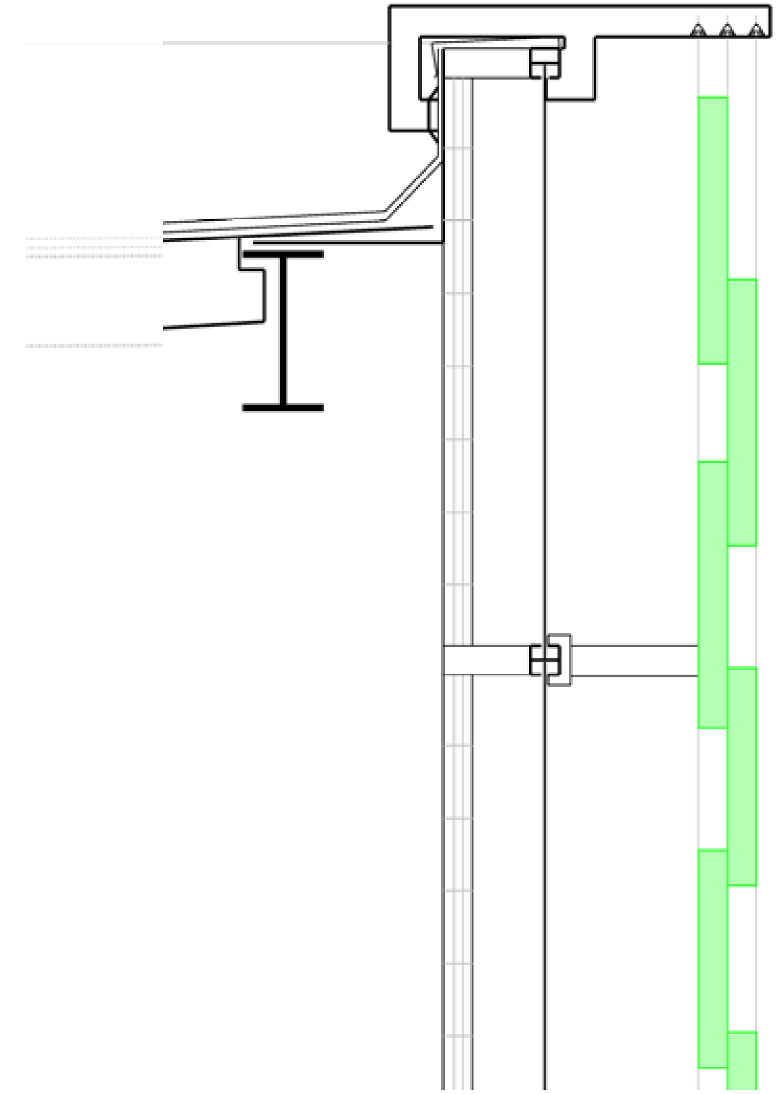
Elevation detail



'Infill' applied to elevation

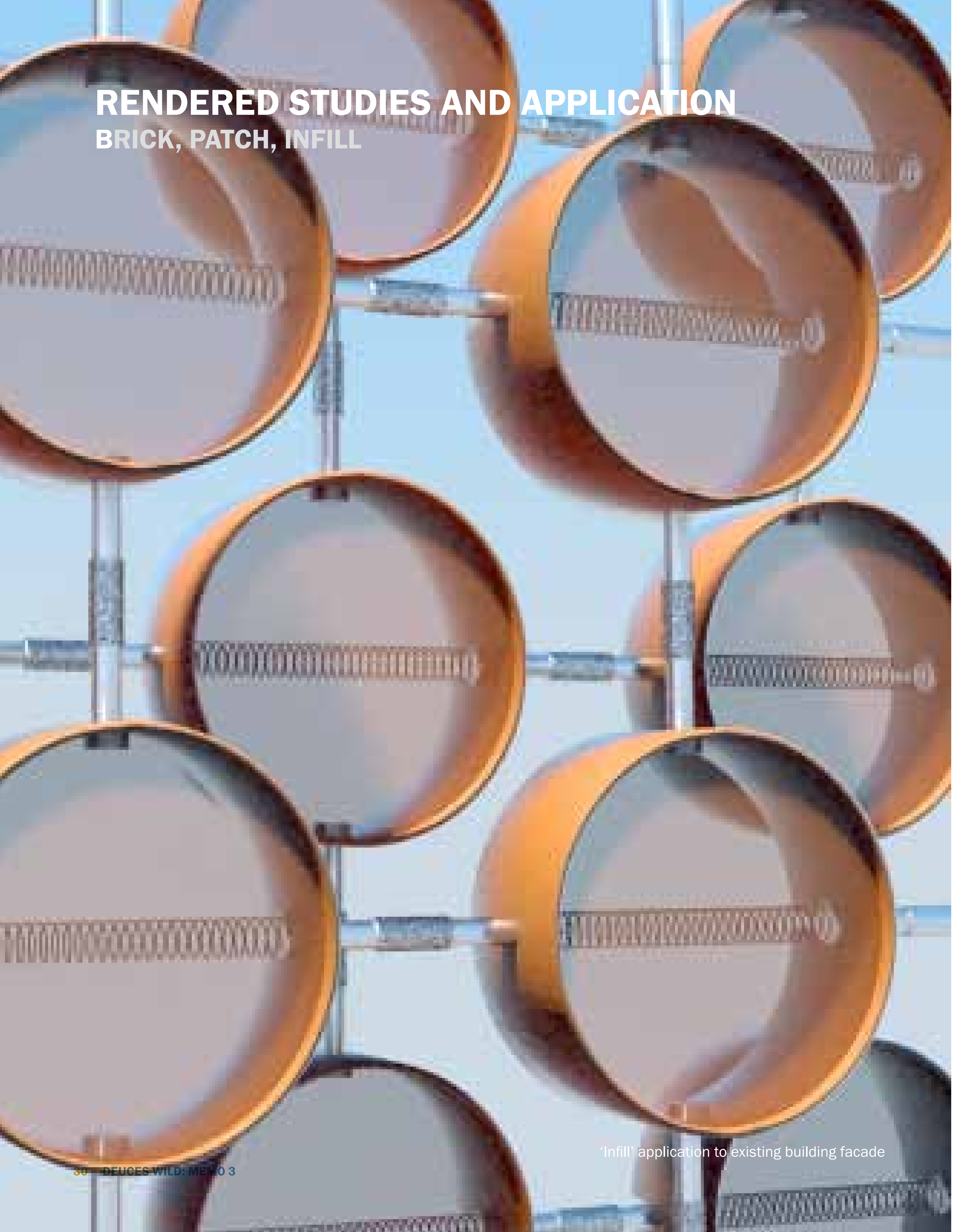


Wall Section AA

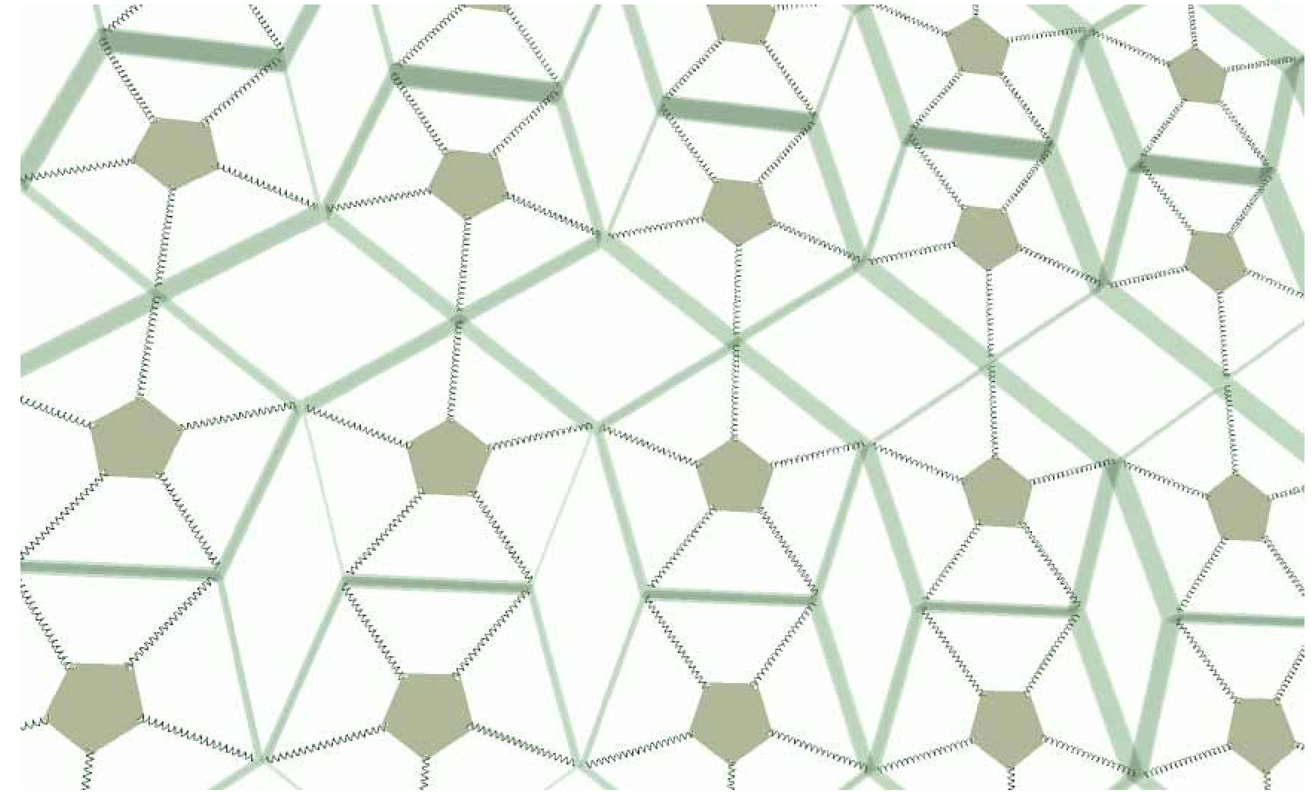


Section detail

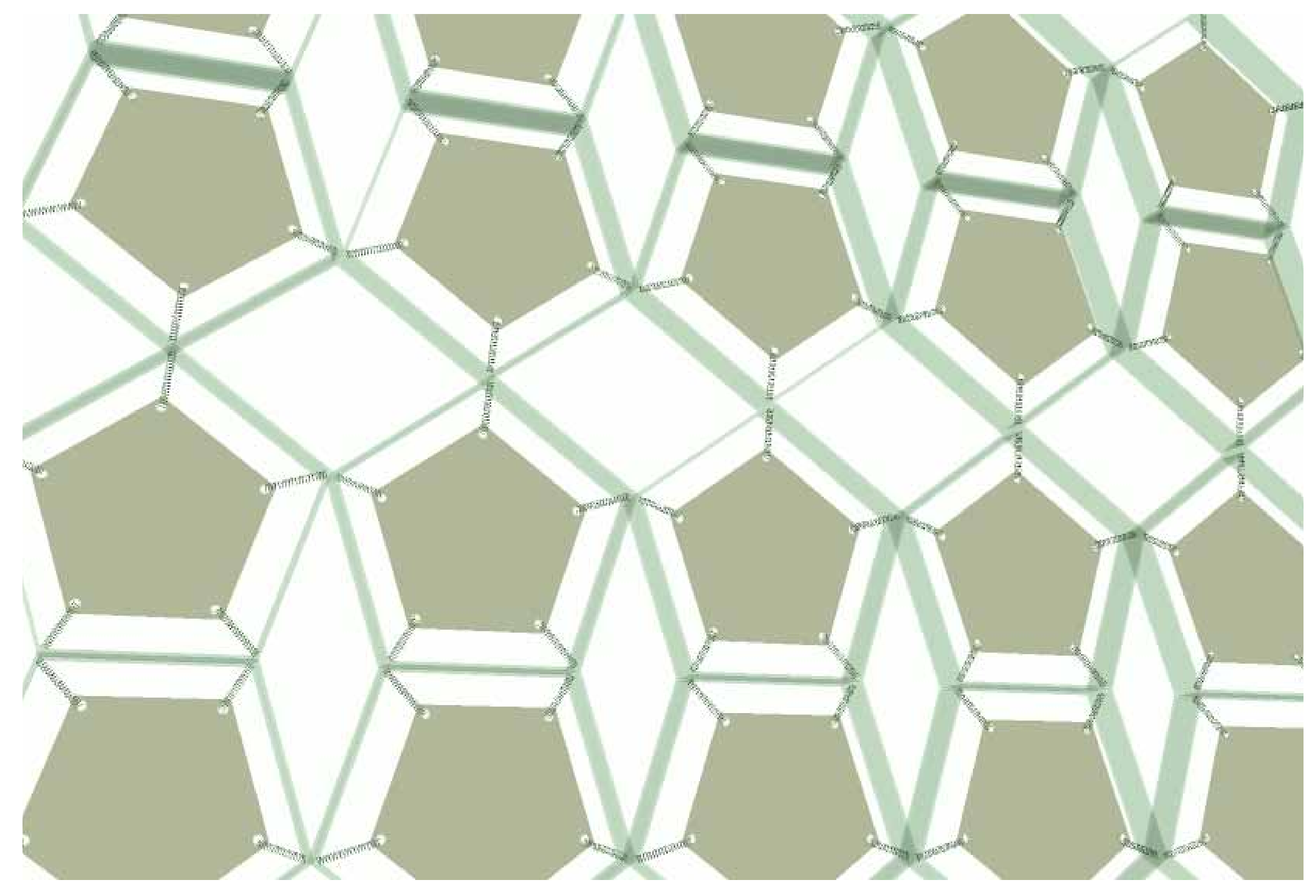
RENDERED STUDIES AND APPLICATION
BRICK, PATCH, INFILL

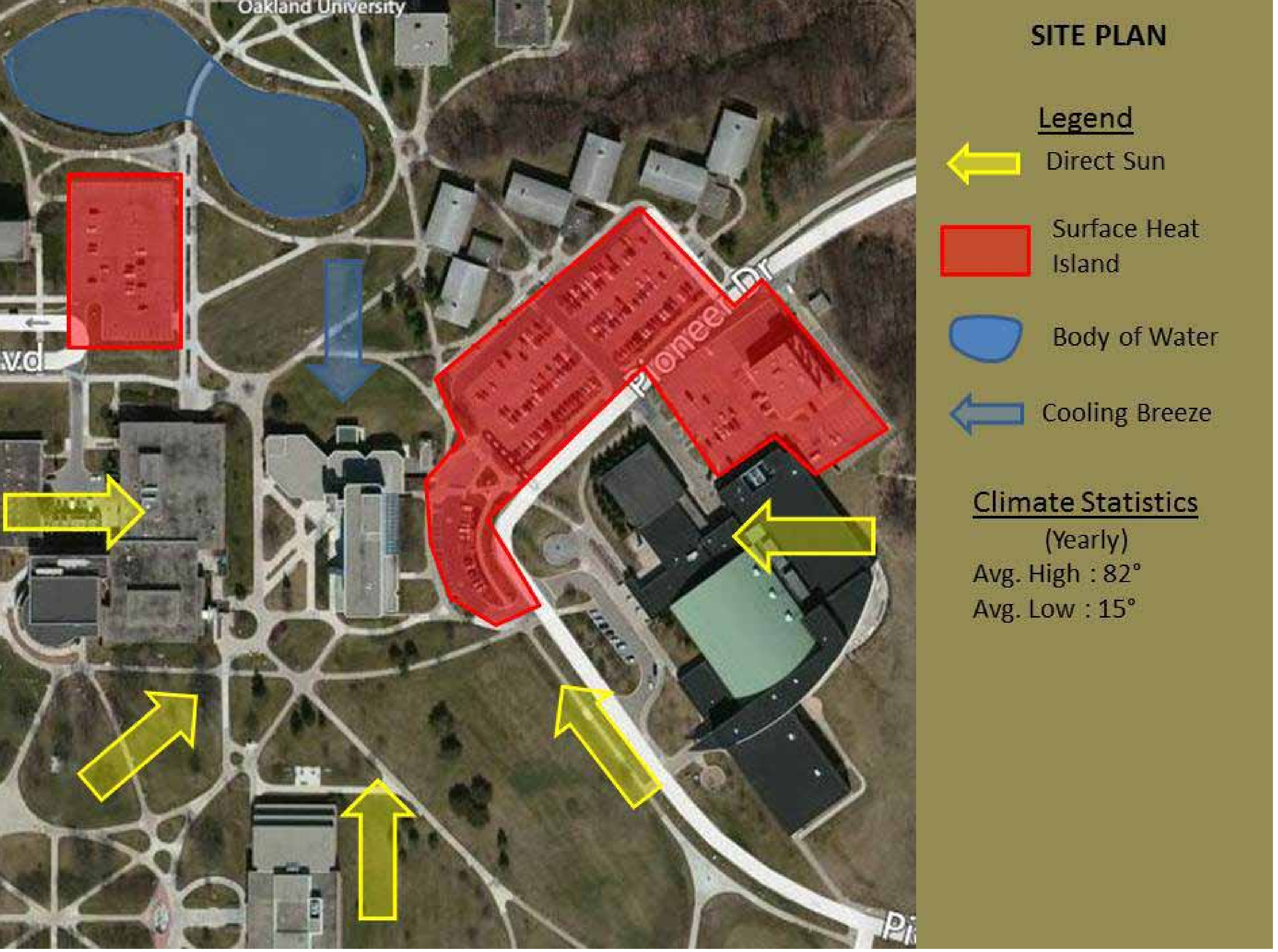


'Infill' application to existing building facade



'Patch' studies





10 APPLICATION

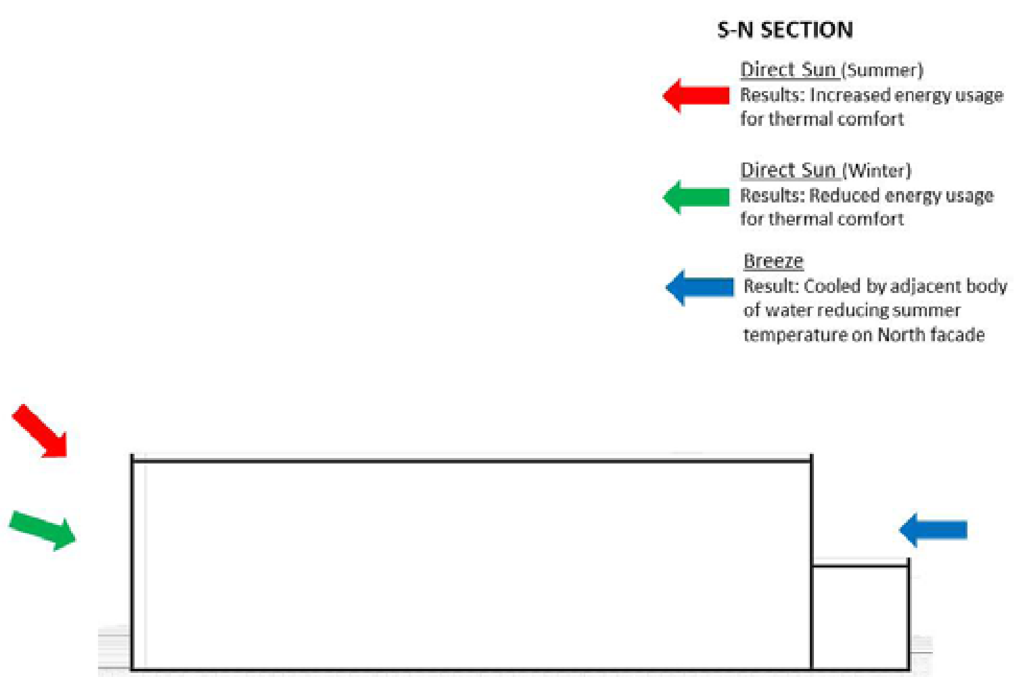
SCENARIO: OAKLAND UNIVERSITY, ROCHESTER, MICHIGAN

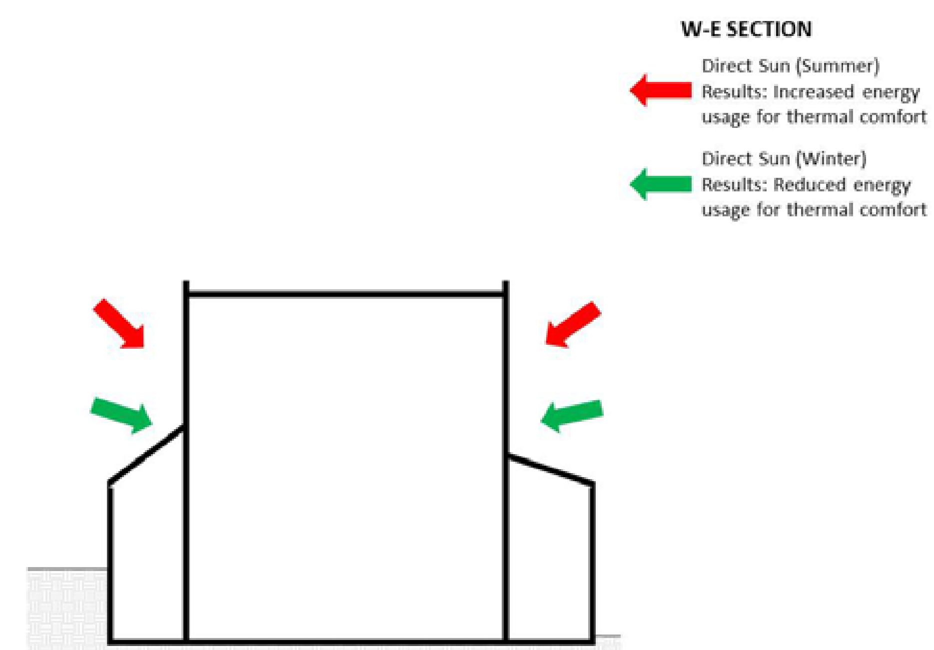
Effective system development must begin with a thorough analysis of the site. O'Dowd Hall, located on the campus of Oakland University in Auburn Hills, MI presents an opportunity for our research to greatly affect both the function as well as the aesthetics of the hall.

Many factors affect the microclimate immediately surrounding the sight. Throughout the year the site experiences average temperatures between 15°F and 82°F. The presence of water to the North of the site lowers the air's temperature as it moves across the water toward the building. However, working against that cooling effect are heat islands created by the adjacent parking lots, which raise the surrounding temperature. The last and most influential factor is the direct sunlight that the East, South, and North façades are exposed to.

The effects of direct sunlight on the predominately glass façade are twofold. In summer the large amount of heat gain causes the HVAC system to use additional energy to keep up with the cooling demand. During winter, however, the heat gain from the direct sunlight helps reduce energy consumption.

The challenge is to provide shading that can actively change as needed but is passive in that it uses no electricity in its actuation. The ideal shading system would work in harmony with seasonal demands, increasing heat gain in colder temperatures and providing maximum shading to reduce heat gain in warmer temperatures. The result of an effective system will reduce energy consumption in both the winter as well as summer.





11 CONCLUSION

One feature of the tube anemone which makes it unique among sea dwelling organisms is its ability to expand and contract into its protective tube. This process is made possible by its powerful longitudinal retractor muscles and self-regulation of form through hydrostatic pressure. This expansion and contraction can be applied architecturally as a dynamic self- regulating shading device that is retrofitted to existing structures. This shading device can reduce demand on a building's HVAC system and provide an interactive experience for users.

MATERIALS & MANUFACTURING PROCESSES

As part of the research and development of a prototypical unit for this shading device, many materials and manufacturing processes were explored. Molding, shaping, forming and fabricating techniques observed during the tours opened up new methods of model design and exploration with casting variations from molds. This casting process enabled the team to change the density, proportions, shapes and sizes of multiple-layered membranes to determine which combinations produced the best results.

A website that contained a wealth of materials knowledge is www.inventables.com. Information was obtained about materials ranging from super elastic plastic to glow-in-the-dark tape and color-changing fabric. Many of these materials were tested and experimented with during the model-making process.

One avenue of exploration was embedding actuating materials into responsive materials in the mold. In this process the nature of the material itself is transformed and a new material is created which can then be applied in more "traditional" building technologies to transform the way we design and shape our built environment. Combinations were researched such as the effects of adding sand to fiberglass resin, which created a flexibility that is atypical of fiberglass without sand aggregate.

The advantages of using castings and combining materials in the fabrication process were made manifest in the prototype by the design of a structural silicone membrane whose inherent properties enable it to return to its original form after model actuation, and by the potential embedding of various skins or aggregates into that membrane which give it new properties such as the ability to glow in the dark or change color.

TEST CHAMBERS AND EXPERIMENTATION

Initial models focused on emulating the tube anemone in shape, form and motion. As the models were refined, attention was given to narrowing in on the essence of the tube anemone's mechanical motion and its process of self-regulation through expansion and contraction.

The basic concept of vertical contraction and expansion was expanded by including axis transfer and examining different types of joint movements. Simultaneous tests led to the integration of flexible membranes that facilitate motion through tension and compression. The use of test chambers enabled the team to study the opacity of and light diffusion through materials as they stretched.

It was also discovered that varying the thickness of the prototype at various locations and providing openings in the profile made it easier for the form to respond to the Nitinol activator. It was also discovered that altering the location of the unit's "fixed point" has an impact on its ability to expand and contract.

Some materials are more easily embedded in the silicone. However, many materials had to be mechanically fastened to the silicone, and the materials varied in flexibility. Therefore alternative methods of applying skins to the base unit had to be explored.

PROTOTYPE & SELF-REGULATING ARCHITECTURAL APPLICATION

The developed model serves as the base unit for an external shading system that can be retrofitted to an existing structure, reducing demand on a building's HVAC system and creating an interactive experience. The system has three levels: the brick, the patch, and the infill.

The "brick" refers to the self-regulating base unit of the system, which is independently functional. When the brick is activated the unit opens up, providing shade and diffusing light for the interior of the building. When the brick cools the forces within its structural membrane cause it to return to its resting (closed) position. The "patch" is a group of bricks that exhibit the same characteristics when exposed to the same external stimuli. The "infill" is the arrangement of patches on a building's façade, and is customized for each side of the building.

In addition to serving as a shading device, the system can also serve as a communication feature for the community. For example, sensors can be embedded in the units or supporting frames. These sensors can detect changes in the environment such as pollutants, etc. and send a signal to LED lighting embedded in the system, triggering it to light up a certain color at night so people will know how the air quality was for that day. The energy for this display could be provided from the system itself, requiring no additional power source from the existing infrastructure.

The system can also incorporate materials that respond to heat, light and humidity in various ways in response to external stimuli. These features enable the system to be dynamic 24/7 – not limited by solar heat gain during extreme seasonal temperatures.

SITE APPLICATION

The selected site application, O'Dowd Hall at Oakland University's campus in Auburn Hills, MI has several microclimate factors that impact the shading system's design. For example, areas which are exposed to direct sunlight during the summer, such as the south façade, require a greater number of shading units than other areas of the building. When portions of a façade are shaded by trees or adjacent structures, the units will not be activated, therefore mirroring the

SURROUNDING CONDITIONS.

Portions of the building that are exposed to public view, especially at night, provide opportunities for visual communications that relay information about the surrounding environment. The building's relatively large ratio of spandrel glazing does not require as much shading, but does allow for visual variations in response to heat and light. These areas also serve as potential locations for photovoltaic flexible membranes. The lower portions of the building, within reach of the average human, provide greater options for interactive experiences with the integration of materials that respond to touch. Also, the size of the units at the lower locations can be decreased in order to be more human in scale.

The financial savings and impact on the energy grid as these systems are retrofitted to existing structures can be substantial in ideal applications. These types of designs also create architectural phenomena – interactive experiences that allow the users of spaces and places to do more than just look at their surroundings. This is where the dividing line between spatial and structural or practical and phenomenal is crossed. It is our goal to further blur this distinction and blend the world we actually experience with the world we can conceive.

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DEUCES WILD