Hypertectonic Systems
Weather Sensible Structures

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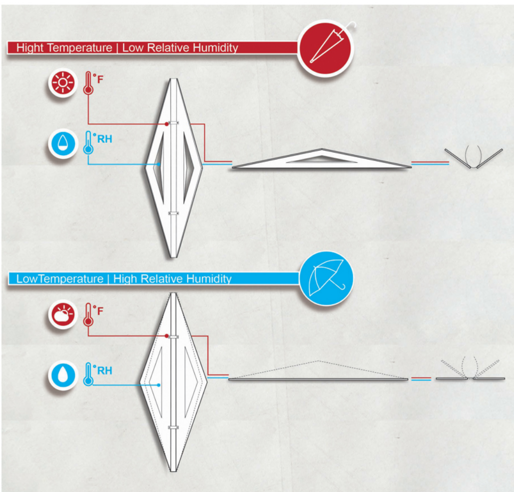

Biomimetic architecture is considered to be the interdisciplinary approach that combines biological evolutionary design and architectural schemas to address human technological dilemmas in a novel and efficient manner. The concept that is presented is an experimental hypertonic system design that employs structures that are sensitive to environmental cues and adapt to the latter. These weather sensible structures are inspired from biological organisms that are able to manipulate their physical attributes or change behavior, such as caterpillars, the species known as "Mimosa Pudica", honey bees and cockroaches. Inspired by their evolutionary design, we will demonstrate the ideas that lead to a chimeric design of the lightweight structure that can foresee environmental anomalies in temperature and humidity, for instance. Essentially, the development of a prototype structure which will shape shift based on external weather stimuli.

Keywords
Biomimicry; Environmental Cues; Weather Forecast Systems; Bimetals; Structural Technology

Introduction
Synced to the contemporary technological progression, emerging fields in architecture have developed to adjust to the evolutionary road. Novel areas of design such as high-tech architecture, eco-technology, responsive architecture and biomimicry are just some of the developing natured-focused movements pursuing new relationships between the artificial and natural. Of those mentioned; responsive architecture and biomimicry give way to the weather sensible structures experimental design explained further on. The first is characterized by measuring and assimilating environmental conditions, which are converted to data, and reacting to such by adapting, changing form, shape, color, character, etc. This type of architecture attempts to breaks the notion of buildings as hermetic and inelastic compositions. The second one proposes an architecture that seeks problem solving thru biological process understanding. Both imply a rejection of Le Corbusier's ideology that "the house is a machine for living" and introduce a new notion of architecture that asks architects to imagine buildings as living systems; what if architecture was then more than just a static shelter?

The development of technologies that consider the ever-changing climate and are nature sensible has been of particular importance in contemporary architectural and urban design practice. In light of the radical transformations that are occurring in weather forecasting models, especially in a tropical country like Puerto Rico, we look towards inspiration that can be drawn upon biological model species that are sensitive towards certain environmental cues. By doing so we can propose designs that read and react to climate in a way that offers architectural design an alternative other than sheltering humans taking advantage from its immediate context to meet other human necessities (comfort, water, etc).

Some of the species that bring inspiration to our prototype are honey bees and cockroaches. Honey bees possess micro-cilia that are reactive to changes in the environment, while cockroaches can sense changes in humidity thru hygroreceptive sencilla in their cuticular wall. Both species react to the specified stimuli by altering their behavior; for example if a bee is out foraging and it senses a rise in temperature, it will stop foraging and go back to the beehive to cool it in collaboration with other bees. Such capacity of sensing environmental cues and processing information so that it affects the specie's behavior is remarkable. So, what if such input would result in the changes of a specie's morphology? Asking this gave way to the idea of a surface that moves just like a worm, which is able to modify its bodily structure for locomotion, as a response to specific changing conditions. The chimeric design inspired by these species results in the weather forecasting structure proposed, one that senses environmental cues such as temperature (T) and relative humidity (RH) and reacts to those inputs meeting desired formal needs.

The prototype design senses the specific cues already mentioned (T and RH), and reacts to those inputs by stretching and closing to give cover to individuals (thus increasing surface area), then coiling back while opening to its original position (decreasing its surface area) when the desired environmental conditions are restored, showing resiliency. Just as in the old tradition of shepherds that relied on nature lore to forecast weather as guide of their daily activities, nature's patterns define how the structure will act.

The two stimuli chosen as the inputs for the structure to change form are key in weather forecasting. In a tropical climate such as the one in Puerto Rico, before it rains the temperature drops and humidity increases. For the purpose of controlling how the prototype will respond to inputs, it is necessary to establish a neutral range of temperature and humidity which will be defined as the good weather conditions (sunny) and changes in the defined parameters could lead to expecting bad weather (rain).

After a comprehensive study and understanding of the mechanisms that promote such sensibility in the mentioned species, a second study was made to pair each stimuli to a material capable of sensing and processing cues resulting in a change of form. The work of architects who are attempting to generate a climate responsive architecture was essential. Highlighted is the work of Doris Kim Sung's Bloom's Pavillion, which makes use of bimetal sheets that react to direct solar radiation; and Achim Menges' HygroSkin, which uses wood sheets that react to humidity changes, thus celebrating wood's inherent nature. Both materials are used in the prototype to react in sync as a response to a precise weather condition: rain.

Materials and Methodology

Shape memory alloys, also known as memory metals, store shape information in their molecular structure and have the capacity of altering their form as the result of changes in temperature. There are three types of memory effect; one way memory effect, two way memory effect and mechanical memory effect. Nitinol (NiTi), an alloy made of nickel and titanium, was the memory metal for the prototype. The NiTi plate used has a temperature transition of 115ºF. Given that the NiTi plate acquired by the Kellogg's Research Lab was "trained" (pre-heat treated) it had a configuration that reached a straight form when the material was heated at temperatures close to the 115ºF range, therefore the prototype's final position was the result of such pre-configured shapes shift.

Although the raw dimension of the plate used was of 6" x 1" x .04", a small portion (1" x 3/8") was enough in the proposed design to change the area occupied by the prototype. As shown in figure 1, the prototype was composed of two laser cut wood pieces of triangular shape (inspired by a flexible origami patter design) connected by the NiTi metal plate, which works as a hinge between the two parts, conferring the design an opening-closing movement.

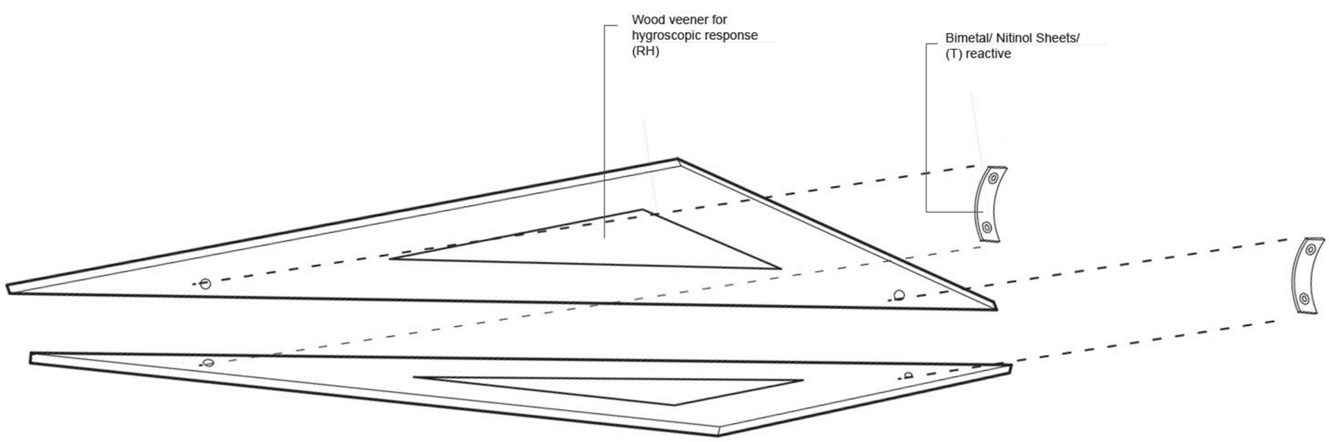

Figure 1. Prototype Diagram (G.Irizarry)

The shape shifting mechanism of the bimetal hinge was our prototype's response to heat gain. The bimetal plate (which had been previously riveted to the wood fragments) was bend by hand force up to where the material's malleability allowed curving before breakage. Once the metal was bent, the prototype was measured to calculate the initial area occupied. Then with a heat gun the prototype's temperature was raised, simultaneously measuring the metal's temperature change with a thermometer gun. The heat intake triggered the shape change in the metal that forced the wood pieces to move, altering the prototype's physical configuration. After movement stop, the design model was measured, to determine the change in area. This procedure was repeated several times, Table 1, summarizes the prototype's changes in area and change in temperature.

Figure 2. (Left) Prototype at room temperature, initial position. (Right) Prototype after rise in temperature, final position (G.Irizarry)

Figure 3. Sequence of prototype's Shape Shift during increase in temperature (G.Irizarry)

Regarding changes in relative humidity, the material used was a dark wood veneer sheet. Wood is a natural found hygroscopic material, therefore it naturally absorbs water from its surroundings leading to fiber shrinkage or swelling which can result in form change at a microscopic level. Fiber manipulation leads to hygromechanical qualities that alter the material's form. After finding a wood veneer sheet that had a readable linear pattern, the sheet was soaked in a fresh water bucket and gently bent thoroughly, this to configure how the wood would bend when dried. Then it was dried with the heat gun. This process though informal introduced a simple way of pre-configuring the wood's shape shift.

Table 1. Prototype Change in Temperature and Area by NiTi hinge shape shift effect (T= temperature, i=initial, f=final)

T(i) ºF	T(f) ºF	T∆ ºF	Area(i) sq.in.	Area(f) sq.in.	Area∆ sq. in.
86	115	29	19.32	20.895	1.575
90	113	23	19.48	20.475	0.995
88	114	26	18.59	20.685	2.095

Discussion

Resource and equipment limitations lowered the possibility of a more accurate prototype response for each trial. Deficient precision and accuracy readings may have been the result of human error during temperature measurements with the thermometer gun. Also, manual bending the bimetal hinge, made it difficult to repeat the initial area position. To control this last observation it would be favorable to reconfigure the metal's shape shift thru previous heat treatment. This could be done with a controlled laboratory furnace, heating the bimetal up to a 200-400ºC range and then setting a second memory shape (considering the first memory shape had already been set by the manufacturer), that way when heating the bimetal to a temperature higher than the manufacture's transition temperature (which in this case was 115ºF) it takes up the given form.

Since the average annual temperature in Puerto Rico is around 90ºF, the used NiTi wouldn't be the best fit for the island's temperature shifts. Considering the bimetal used had a transition temperature of 115ºF the new configuration would have to be higher, therefore it would be outside the island's natural temperature range. Given that the proposed design is meant to expand before it rains and contract in sunny weather, the higher temperature mark should prompt a closing hinge mechanism; when temperatures are lower the hinge makes an opening mechanism, thus increasing its area.

The second material introduced for the chimeric design response though it has the natural ability to react to changes in humidity, as shown in figure 4, the fiber movement manipulation control was difficult to achieve. We could not achieve a standardized manipulation of the material so that a specific (more controlled) reaction was achieved. Another problem the material presented was that it broke easily after several attempts of drying for shape shift to occur.

Although the designed prototype reacted as hypothesized, there's still needed experimentation to achieve the synced reaction of both materials. The bimetal is the ideal material for the temperature reaction, another experiment considering the actual temperature range in Puerto Rico is the next step for the temperature reaction study. On the other hand though wood has the natural capacity to shift its form due to increasing humidity, experiments raised questions such as the material's durability, and how to get to the specified form desired? Maybe wood isn't the best material and further experimentation could consider other materials with hygroscopic qualities.

the aspiration to control climate, but that doesn't mean should isolate us, like probably modern architecture has done. Taking part in the nature-focused movement ideologies the design offers a new connection to our natural world. It proposes another idea of how future technology can accomplish building intelligent systems that react to environmental information in a specific context (in this case a tropical climate). It does not only establishing a dialogue between the built environment and the living natural space but it is site specific, meaning that the parameters that give way to the resulting reactions are not conditions that happen everywhere.

Although the resulting forms of this prototype are centered on offering shelter to people while forecasting rain, other configurations can be achieved to provide comfort without the necessity of

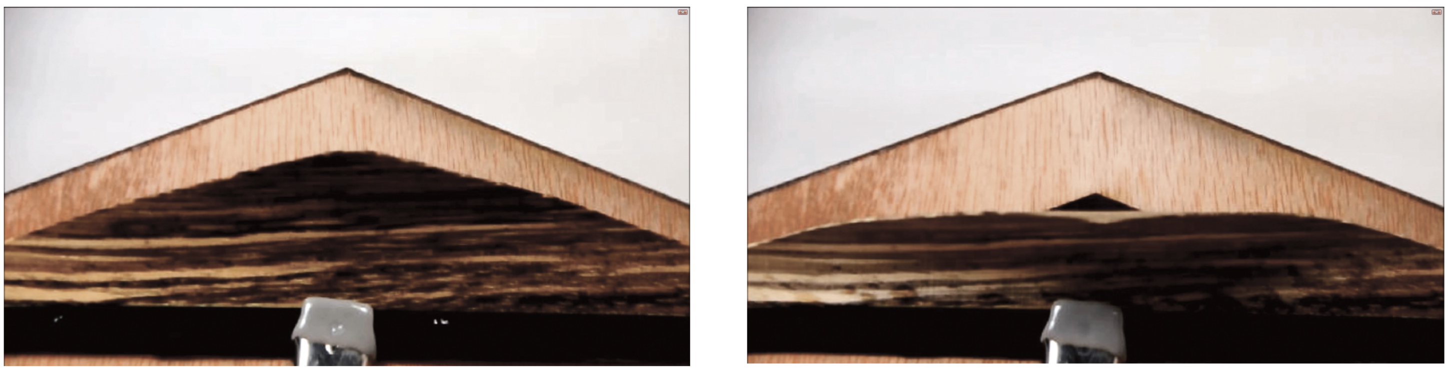

Figure 4. (Left) Humid wood sheet, (Right) Dried wood sheet (G.Irizarry)

Conclusion and Future Work

As mentioned originally the suggested response was a dual feedback resulting from the input of two environmental cues: temperature and humidity. The researched achieved a more quantifiable study for the temperature response material. The second material used for the humidity response, the wood veneer, showed a characteristic response of expansion and contraction to humidity of an erratic nature which was hard to measure. This point to the need of a different material that has a similar response to humidity while showing measurable consistency. On the other hand, the bimetal used for the temperature response needs a more thorough study, with heat treatment so that a more controlled system may be achieved, reducing inconsistences in the prototype's change in area.

Future work proposes more experimentation and other design configurations for bimetal manipulation and the inclusion of other materials that responds to changes in humidity. In time, the proposed design could meet the desired reacting systems.

The weather sensible structure hypertectonic system design's importance lies in it being an audacious proposal on how buildings could be like in a tropical climate. Architecture originated out of mechanical systems. The prototype provides an understanding of how nature can inspire design and innovate the built space experience through integration and dialogue.

Author Biography

Glorimar Irizarry is an undergraduate research student at the School of Architecture of the Pontifical Catholic University of Puerto Rico. She holds a bachelor degree in Biology from the University of Puerto Rico at Mayagüez, and a film minor from the same institution. Her work on biomimetic technologies has been widely featured by the local media in Puerto Rico.

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