The Thermal Organism And Architecture

Throughout the history of architectural discourse the concept of metabolic function in a building and a building's relationship to its creators is expressed by keen designers who understand the subtle linkage. Organismic homeostasis is a biological function found in all mammals including humans. The interior generation of heat classifies man as endothermic. Endothermic heat generation allows for a very controlled equilibrium and is a characteristic of more complex organisms. The body has produced highly evolved surface systems to help efficiently manage the flow of heat energy in and out of the body. Inherent in this projection are the same demands of envelope put forth in the body. In my research of anatomy I have found one system that has evolved to help facilitate endothermic heat regulation in mammals at the skin level, which is hair. How does hair transcribe into architecture? An analysis into the function of hair and its adaptable morphologies is studied. Hair is a thermal regulating system, its building equivalent are forms of thermal insulation and radiant barriers. Hairs goal is homeostatic equilibrium which has its architectural counterpoint known as the balance point. Hair is an adjustable system that mitigates between internal and external heat loading which is the goal of a building envelope. In conclusion the paper explores these issues and more in new building systems and design tactics that originate from the function of hair.

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Introduction

Thermal homeostasis is the biological function found in living organisms that strives to maintain a constant state of temperature by creating an open or closed looping feedback system. If an organism maintains homeostasis through internal generation of heat, it is considered endothermic. Endothermic heat generation allows for a highly controlled equilibrium and is a characteristic of more complex organisms.

The human body is an endothermic organism regulated by homeostasis. It generates heat from within and projects it outward. The building envelope represents a human need to project itself outward, beyond the body, in a process of prosthetic synthesis. One of the primary functions of this desired projection is to generate shelter for a greater area of controllable environment around the body. Inherent in most design intents for the building construct are the expectations that it produce an environment conducive to homeostasis in the human body.

Buildings designed from an endothermic perspective consume fuel to produce a stable environment from within. The increasing demand for fuel to provide energy to metabolize endothermic buildings has lead to unsustainable consumption of the world’s resources. Many current design solutions seeking to alleviate the demand for fuels using sustainable environmental controls, which rely on a passive ectothermic design philosophy, (They condition around an endothermic body often creates undesirable effects such as user dissatisfaction or equipment failure. Sometimes a hybrid strategy is employed but it does not always effectively address the needs of internal load management. For example, geothermal energy is a renewable fuel source that can generate heat internally within a building, allowing for endothermic design.

This research explores ways that biomimesis deepens our understanding of endothermic regulatory systems to create efficient solutions to proper management of heat within a building. The project investigates homeostatic heat regulation in the most successful endotherm, the mammal, and more specifically, mammalian hair. Hair is cutaneous and, due to its robust adaptability and responsive characteristics, has helped make mammals a dominant species in most ecosystems. The study offers new ideas involving thermal programming and design with the intention of providing a thermal infrastructure in which to test the applicability of hair function in a building.

Thermal conditions are generated from a geothermal spa program and are applied to an existing geothermal location in Big Bend, California through thermal gradient site maps and diagrams. The project addresses adaptation of energy modeling and how this might lead to the optimal building configuration for the mitigation of thermal flux according to programmatic restraints. The work also challenges the assumptions that a building’s thermal program must always facilitate thermal comfort, and researches programmatic conditions that deviate from the thermal comfort zone, not unlike thermal differentiation in the body. The research is conducted in three phases.

2 Phase One—Study of Hair

The first phase documents the primary forms of universal heat transfer, the biological system of heat transfer in endothermic bodies. It looks at hair as an individual unit and as tectonic, and within a larger system of arrangement and types. The critical data extrapolated from the research reveals the didactic strategy for heat regulation employed by hair. The primary strategy is the use of air films and air pockets to regulate thermal flux through the phenomena of convection. The secondary and complementary strategy is the regulation of solar radiation. The most effective and adaptable form of these regulation systems are explored in diagrams illustrating the flow of thermal gradients through a system of straight guard hairs. The straight hair is moved by a grouping of cells known as the Erector Pili. The hair has a range of movement, from standing perpendicular to the skin’s surface, to running parallel with the skin’s surface. At the apex of both states, the functionality of the system is most apparent.

When the hair is erect it is a response to cooler exterior conditions and it strives to maximize energy conservation and collection to help efficiently maintain homeostasis. The
erect hairs trap a greater amount of air in the matrix, slowing convection and allowing warmer air released by the skin to linger, lessening the thermal demands on the body. The erect hairs have also minimized the covering of the skin and allow for the cutaneous tissue to be exposed to solar radiation, maximizing the intake of radiant heat.

When the exterior temperature is above the thermal comfort zone, the hair follicle is relaxed and the hair lays close to the skin. The proximity of the exterior air to the skin minimizes the insulation produced by air films or pockets, which maximizes the effects of convection of heat away from the body. When the hair is relaxed, the surface area of the skin that is covered is at one hundred percent of its ability and blocks out solar radiation.

The movement between these two extreme states produces a great deal of variability, allowing internal homeostatic body conditions to remain more constant. This helps with primary metabolism and allows for a less demanding schedule on larger, more energy-demanding systems. The research reveals that hair is a very complex and productive thermal system. In the proceeding examples only a few causes of performance in thermal regulation of hair are explored, since the initial research revealed an immense and intricate web of types and morphologies of hair that can alter performative characteristics.

3 Phase Two—New Strategies for Thermal Design

In the second phase of the project, the thermal conditions of site, program, and schematic design are examined. A hypothetical infrared map of the site is produced, showing the ideal spring and fall conditions and the median temperature experience for the site. This map is then demarcated by zones that are within the human comfort zone. Human paths of travel are also documented and reveal a tendency for circulation to exist at the border between exposed homeostatic comfort zones and colder forested zones. This map is then used to inform the location of the building’s programmatic thermal zones. The programmatic requirements of the spa and hotel include the thermal experiences needed in each part of the geothermal complex. The square footages of the constituent parts are researched and compiled. The relationship of square footage and thermal requirements are drawn as scaled ovaloids with corresponding thermal gradient maps radiating from the center outward, as would be the case when energy is released in a void. The scaled diagrammatic massing is then reorganized around seven therapeutic thermal pools that range between extreme cold and extreme hot based on the program’s heat gradient relationship. The internal relationships of the scaled diagram are then messaged onto the thermal site map, responding to thermal comfort zones, geothermal activity, thermal circulation paths, location of the geothermal pools and topography.

Using a energy field simulator, energy particles are placed at the center of each of the thermal zone’s centers. The energy released by the particle is a parametric number that responds to the amount of energy needed in the zone and the total area of the zone. The energy field and subsequent modeling that are produced document the path of least resistance for the flow of heat out of the thermal massing arrangement.

These paths are converted into a field of data points that are then used to construct a single, topological surface that express the maximized containment of the energy/heat without enclosure. This topological surface can be thought of as a performative envelope or skin on which the exploration of hair components can happen. Darcy Thomas explored the issue of biological form and thermal forces which later influenced Greg Lynn who calls for this type of surface modeling.

This multi-type, or performative envelope, does not privilege a fixed type but instead models a series of relationships or expressions between a range of potentials. Similarly, independent interacting variables can be linked to influence one another through logical expressions defining, size, position, rotation, direction, or speed of an object by looking to other objects for their characteristics. This concept of an envelope of potential from which a single or a series of instances can be taken, is radically different from the idea of a fixed prototype that can be varied.

GREG LYNN, 1999
The topological mesh can retard the flow of heat through density and complexity of form but has no true enclosure, and eventually all excess heat is released. The topological surface is the intermediary of spaces of different thermal conditions and therefore becomes the milieu between two temperature states and program. This is a prime surface for testing biomimetic building strategies based on functional aspects of hair.

4 Phase Three—Hypothetical Building Systems

The third phase of the research looks at four strategies informed by thermo regulating system analysis. All four are generated using parametric modeling techniques. The use of parametric components was important.” Buildings are collections of objects. If the design changes, as it would or should do, then these collections of objects have to respond. The content of the collection will change, and the individual members of the collection also have to respond uniquely to changes in their specific context.” (Achim Menges March/April 2006) Given the complexities of form and the differing geometries at localized positions for greater thermal performance parametric modeling became critical to the implementation of the design schemes. Three strategies use associative modeling to produce building components and systems that enhance the environmental performance of the space. Two strategies use modeling techniques appropriated from animation techniques and a four dimensional concept of modeling. All of the systems are aggregated into a triangulated system of components. “Since a basic triangle of members is a stable form, it follow that any structure made of an assembly of triangulated members is also a rigid, stable structure.” (Daniel Schodek 2004) The use of the triangle was the most effective way to make a convincing argument for such a complex structure as the single topological surface in this project.

4.1 PERMEABLE STRAND WALL

The first system, named permeable strand walls, uses hollow tubes that extend between the ceiling and the floor which are tied into the geothermal infrastructure of the building. They can be used to define a thermal space and generate a convection or radiation break from surrounding zones. The thickness of the tube, the density of their weaving, the modulation of their profile and the varying temperatures of water which can be pumped through the tubes can produce a wide range of thermal effects. The flow of water is regulated by nitinol valves that respond to internal or external environmental needs. Their programming is ingrained in the metallurgy of the valve and requires no software or sensor. The localized emergent behavior generated from this system is similar to its biological equivalent in hair where localized control of hair function can better deal with thermal differentiation and is independent of a global response. Some hypothetical areas where this strategy could be employed are indoor/outdoor areas, circulation corridors, semi-private bathing and resting...
areas, or in the division and production of steam baths. This is the only strategy that tests a biomimetic strategy at the human scale. It is generated using an animated, parametric and modifier based modeling system. The strategy can be adapted to specific areas by manipulation of animation paths. Performance of the system can be adjusted by parameters involving diameter, scale and density of allowed population, and form can be changed using noise and shape modifiers.

4.2 ASSOCIATIVE BAFFLE VENTS
The second system, named associative baffle vents, is designed for areas that require regulated ventilation into other thermal zones, but adapt to maintain certain environmental conditions. The system explores concepts of performance based associations and localized response mechanisms. A project by Steffen Reichert addresses many of the same issues of global and local controls in a smart material skin. “The component’s direct responses to environmental changes suggest a locally controlled system in which each sub-location senses and reacts independently as part of an emergent overall environmental modulation.” (Michael Hensel, Defne Sunguroglu and Achim Menges March/April 2008)

The system geometry is designed in a waffle pattern of ventilation shafts. At the end of each shaft is a flap that uses smart material as a simple two way nitinol wire hinge system which can open or close at varying degrees based on temperature. The associative component is defined by a topological surface and a thermal point in the 3d model. The point is considered a concentrated emanating source of heat and, in the case of this project, it would be a geothermal vent or pool. Based on the distance from the point and the topological surface, the sectional thickness of the baffle vent is defined. As the component moves farther from the heat source, it must trap more air in the baffles to maintain the same temperature within the zone. The variable depth and variability of trapping air in the baffles is the primary difference gleaned from a performative hair strategy vs. a performative skin strategy.

4.3 STATIC TUBE ASSEMBLY / RECYCLED BOTTLE WALL
The third system is referred to as the static tube assembly and it is drafted using associative geometry. It is the least adaptable and offers a single thermal solution. It is also the
least complex system. The form, length, width and density of the hollow tubes are generated from measurements taken from an existing topological surface which is then replaced with the generated component. The direction of the bottle tubes are always aligned towards a heat source represented by a free point in the computer model. The tube is embedded in an inert solid material such as wax, fat or solidified oils, which uses a structural mesh as a rigid framework. The system is used in areas of the program that require a strong thermal insulation at all times. It does not allow for ventilation into other spaces but could allow radiation heat depending on the transparency of the materials. A proper use of this system would be in the mud bathing areas or massage rooms.

4.4 POROUS INFLATABLE WATER PILLOW / THE GLORIOUS ORGANISM

The fourth and final system is affectionately called the glorious organism. Conceived of as a porous pillow that regulates ventilation, convection and radiation, it is the most adaptable system. The pillow inflates with heated geothermal water when the environment is cold. As
the pillow inflates, pores begin to swell shut, stopping ventilation through the system. In tandem, synthetic strands in the form of tassels are pulled into an erect form, maximizing the amount of trapped heated air convecting from the pillow. The erect tassels also allow the free flow of solar radiation through the pillow, increasing the internal warmth. As the temperature begins to warm, geothermal water flow will subside, lessening the amount of heat generated. The pores will begin to open as the pressure on the sphincter is released, which will allow greater ventilation. The tassels will begin to relax and spread, acting as a filtering device for the ventilation pores, and also acting as a radiant barrier. The glorious organism is the closest to the original function and form of skin and hair and in many ways is too complex to be an effective building solution, but it also illustrates the multi layered complexity required to be at par with biological models.

5 Conclusion
The primary influences of this research are: biomimicry in architecture, sustainability and advanced computer modeling and representation. The goal was a prototypical design solution that tested the findings on the topics of endothermic building design and biomimetic thermal regulating systems generated from the study of hair. It is my hope that the research and work will produce new and exciting avenues in which we as architects can expand our field and understanding of the built environment.

6 References