Sweetgum Panels

A periodic compliant mechanism for solar shading

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Abstract. The paper describes a novel technique for creating flat, bi-layer, compliant mechanisms for adaptive building components to be used in solar shading. Micro-actuation of these periodic, flexible devices cause innumerable three-dimensional micro-loops to erupt in the panel surface, permitting passage of diffused light while maintaining visual privacy and shade.

Keywords. Compliant mechanisms; biomimicry; passive energy design; solar shading; autonomous control; computer aided manufacture; parametric modeling.

COMPLIANT MECHANISMS
This paper presents an empirical framework, through built prototypes, for the design and implementation of periodic compliant mechanisms in architecture. The basis for this work centers on the creation of adaptive performance devices for energy control within an approach to architectural space-making which uses intensive materiality as an aesthetic driver. A compliant mechanism is defined as a device which uses elastic deformation rather than rigid mechanization to create complex movement (Kota and Trease, 2006). Nature is replete with such autonomous flexible devices which serve to augment energy performance (Benyus, 1997). For the purpose of this research, several such mechanisms in plant species of the southern United States are analyzed for clues in the creation of compliant mechanisms in solar shading. These concepts are then translated via computation and computerized manufacture into panelized systems; the resultant manmade devices are systematized, arrayed periodically, and used to create high performance, material-based architecture. The project begins by using detached motors to actuate compliant movement in a hybridized mechanical-flexible interface. This initial approach lays the groundwork for the embedding of compliant actuators and sensors within the devices themselves. Philosophically, this research is propelled by a desire to integrate traditional manufacturing techniques with digital techniques, and to produce hybridized systems of manufacture which bridge the gap between the handcrafted object and industrial processes. The goal is to produce a high performance, materially maximal architecture which uses 3d modeling and computerized manufacture to reintroduce handmade material quality to the stark modernist conception of space-making.
Microloop Light-Shelf Screening for Passive Energy Control

“Microloop” panels are a novel adaptive device for precise passive lighting control. These micro-perforated panels create controlled, diffused lighting conditions for interior and exterior spaces, while possessing an intensely saturated material quality. This research is centered on a novel perforation technique for flat, bi-material sheets which are carefully attached at elongated tabs, but arranged to slide past one another just slightly when mechanically actuated. The movement of the two sheets causes the tabbed attachments to bend into endless recursive material loops which appear to erupt from the face of the panel; the resultant microloop perforations allow diffused light to pass through the panel while maintaining visual privacy and blocking direct light (Figure 1).

These material loops bulge outward from the surface of the system to create a manifold light shelf (Figure 2) condition which will act to reflect diffused light toward the ceilings of interior architectural spaces. The light shelf can be further accentuated by adding material reflectors to the loops which will unfurl as the system opens.

The engines that drive compliant mechanisms in the biology of plants are largely managed using localized adjustments in hydraulic pressure. Manmade translations of this style of actuation have been exhibited (Menges, 2009) using the natural properties of wood grain, as well as using composites with similar properties (Weston, 2012). These projects, as in nature, rely on autonomous passive actuation over an extended period of time to effect changes in shape in compliant devices. The microloop concept diverges from this thinking with regards to the motive forces required to operate the panels; two types of devices are explored. One system uses traditional mechanical interface to translate rotary motion from an electric motor into linear motion to actuate the panels. This technique is similar to existing work which places the “engine” of the device outside of the mechanism itself (Kota and Trease, 2006) A second technique uses embedded shape memory alloy to mechanize the array. This method places actuator within the flexible device, and therefore contributes to the jointless character of the array. Ultimately, this research paves the way to also embed sensors and control circuitry in compliant mechanisms to approach the efficiencies of autonomous, adaptive devices in nature.

Through prototyping, material variations are also explored for use in architectural compliant devices. Combinations of wood, plastic and metal are used to create variations in the size of panel perforations, to optimize the shape memory inherent to the panels themselves, and for architectural effect. Computational techniques are leveraged to create variations in the array pattern in order to optimize lighting conditions, material behavior, and spatial effect. The bi-layer nature of the panels themselves presents opportunities for performance variation. Flexible materials can be combined with rigid materials to produce spatial effects in addition to material effects. The potential is illustrated for producing compliant devices which simultaneously approach the skin and structure of a building in one seamless device.
The manufacture of compliant devices is also central to the research. Prototyping panels explore manufacture from flat sheet stock based on simple repetitive patterns effected with CNC tools. The goal of this approach is to produce emergent material characteristics and performance qualities from readily available materials in order to devise passive energy control devices which can be quickly ready for the marketplace using simple assembly methods. Commonly available compliant mechanisms are typically made from plastics (Kota and Trease, 2006), and so must use industrial thermoforming techniques. These methods require lengthy machine setup procedures, molds and dies, traditionally associated with factory settings and the production of large production. By contrast, the microloop approach privileges techniques which are friendly to local manufacture and distribution and to small machine shops using CNC tools which can switch seamlessly between vastly different projects. This approach encourages the use of locally sourced, sustainable materials and site-specific alteration to the products in question.

**Compliant Mechanisms from Nature**

The actuation of microloop panels is modeled after the seed pod of the American Sweetgum tree, Liquidambar Styraciflua (Figure 3). The actuation of the ejection of the seeds from their pods is the result of a bimaterial pair powered by differential drying of the seed in the air (Small, 1933). The outside membrane stiffens and begins to shrink as it loses water, while the inside membrane remains saturated and therefore longer, creating a flap which curls outward to eject the seeds as the two membranes slide past one another. The outer membrane is pre-perforated ensuring that flaps erupt evenly over the entire pod. In related species such as Witchhazel, this effect is so immediate that an audible “pop” can be heard as the seed ejects. Visually, the physical character of the Sweetgum pod possesses an intensive material saturation common in nature. As an approach toward architecture, these pods illustrate the possible outcome of a process which foresees the creation of buildings possessing a saturated material character by virtue of the use of performative, intelligent components which blur the boundary between beauty and pragmatism.

Analogous to the bi-material actuation of the sweetgum seed, the microloop panel similarly uses two sheets of material, one perforated, the other tabbed, to create a compliant mechanism, arrayed periodically. A tiny linear actuation (Figure 4) of one surface relative to the other is sufficient to cause loops to erupt from the face of the device as slots in the device become shorter, forcing the tabs to push outward from the center.

Wood veneer prototypes for the microloop panels (Figure 5) were created from two dimensional grasshopper factories which associated slotted panels to tabbed panels. By varying the width, length, and number of slot-tab pairs, panels can be made to accommodate material thickness, wood species, and desired mechanical resistance. Modeling in kangaroo accounts for material behavior and was used to predict material failure, but ultimately, repetition and empirical observation were more essential in
the initial prototyping phases. Notably, it became necessary to bias the tabs in one direction by rolling the tabbed sheet prior to assembly to ensure that loops would emerge in one direction, rather than randomly to one side or the other. Additionally, a rigid frame is needed for both front and back panels to ensure actuation, otherwise the very flexibility that ensures actuation caused random and unmanageable panel separation. Successful trials produced motorized veneer, plastic, and metal panels which relied on various types or frames for rigidity.

An operable architectural model demonstrates the spatial and performance possibilities for the concept (Figure 6). Materials loops allow for light penetration and diffused day lighting while blocking direct sunlight. Initial tests however, indicate a system which itinerantly resists to actuation. The additive effect of multiple compliant devices produces a resistance which increases proportionally to the number of loops incorporated. To compensate for this, tabs were scored at their bases to reduce elastic behavior, or employed oversized strain reliefs to achieve the same result.

Concluding
This research is propelled by a desire to integrate traditional manufacturing techniques with digital techniques, and to produce hybridized systems of manufacture which bridge the gap between the handcrafted object and industrial processes. The goal is to produce a materially maximal architecture which uses 3d modeling and computerized manufacture to reintroduce handmade material quality to the stark modernist conception of space-making. At the crux of this discussion is the desire to set forth a philosophy which rejects the ornamentation of typical building typologies with „green” ornamentation. Instead we must see it as our responsibility to use the possibilities of an endlessly mutable architectural palette to create architecture which takes building performance and regional acumen as the basis for a materially complex and morphologically precise built environment

References
