Anisotropic Operations

Mark Weston
Abstract

Deliberately introduced unidirectional material weakening is explored as a means of producing material properties which exploit natural material tendencies rather than as a means to compensate for them. Such anisotropic operations take natural systems as a point of departure for man-made approaches to the augmentation of building performance in the realm of solar shading, but also for the creation of materially complex architectural environments.
1. ANISOTROPY

The history of the development of architectural materials has been guided by a hostility toward the natural tendencies of materials as found in nature. Over the course of history architects have devised ingenious ways to compensate for, reduce, or eliminate the inherent dimensional instability of materials. Concrete swells and shrinks with changes in temperature, and so needs movement joints to control cracking in predetermined ways. A metal railing on a wooden balcony will expand and contract to a different degree than its substrate, and so must be mounted in such a way that the two systems are able to slide past each other as they move lest the system buckle and become unsafe. Natural materials such as wood are notable because they exhibit properties which are orthotropic or directionally determinant in nature as it regards the direction of the grain of the material as it was naturally formed. In the design of buildings, the properties of lumber in its many forms are well known. Structurally, for example, lumber is known to have high compressive and tensile strength parallel to the grain, with contrastingly low shear strength. These traits are reversed perpendicular to the grain of the wood. Another interesting directional property of wood is its expansion in the presence of humidity; this effect is greater in a direction perpendicular to the grain of the wood than parallel to it [1]. Modern material engineering techniques have sought to produce building materials from wood which minimize or eliminate expansion and contraction due to temperature and humidity. Such materials as plywood, oriented strand board, and particle board are predictable in their behavior and dimensionally stable.

Industrialization provided the means to create predictable building materials, and gave rise to the modernist movement in Architecture and elsewhere. Modernists took material standardization as liberation from the in-situ improvisation of the craftsman in favor of abundant and identical materials. Architects today, however, are charged with building a world where the most insurmountable problem will soon be resource management [2]. “Green Design” is riding an extraordinary wave of popular culture, but much of the knowledge upon which this phenomenon is based was put in place generations ago; Sustainable design is now and has always been good design. That the face of design is changing, however, is impossible to deny. The explosion of new and more accessible technology has facilitated the creation of architecture of dizzying formal, material, and conceptual complexity. The human scale of buildings, once wrought in intricate handmade details, has returned in the form of formal intricacy [3]. and endlessly variable mechano-material operations made possible by computer controlled instrumentation.

At the crux of this discussion is the desire to set forth a philosophy which rejects the ornamentation of typical building typologies with “green bling.” [4] 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. It can be clearly seen in natural systems that specific situations demand specific and complex solutions. These solutions do not, however, spring wholly formed into the world but instead derive from a trial and error based problem solving. From the nano-structures on a gecko’s foot, to the naturally ventilated termite mound, natural systems have evolved to solve all manner of architectural problems [5]. This arsenal of biological approaches can be hybridized with anthropocentric and ages-old passive design strategies as a baseline for building design which can be utilized to exploit inherent material properties for enhanced performance of the built environment. Long before architects began designing for natural light, cross ventilation, and solar efficiency, nature perfected the art of resource management through a highly localized system of material deployment. This ad hoc material variation of natural constructions results in directional variations in strength, referred to as ‘anisotropy’ [6]. Such structural directionality as seen in the properties of wood grain, is the basis for significant current thinking in architectural materials research. This research explores the use of deliberately effected weaknesses in wood, fabric, and aluminum as a means to produce spatial phenomena, material complexity, and performative building components. These anisotropic operations take natural systems as a point of departure for man-made approaches to the augmentation of building performance in the realm of solar shading.

1.1. Shading

Solar shading is an essential component to passive energy design for buildings. Sun angles and building orientation are basic architectural considerations common to most regional architecture, and are commonly seen in such vernacular building formations as shotgun and dog-trot houses, or wrap-around porches [7]. Traditionally, solar design has come in the form of static shading devices applied to building openings, or in building forms which accommodate such strategies in their basic shape and orientation. Conformationally determinate devices are limited in terms of on-demand adaptability. New technologies, however, have created adaptive solar shading which responds to lighting conditions, time of day, and the presence of building occupants. Active shading devices currently do exist and take the form of motorized metal fins and roll-down shades. These technologies rely on mechanical solutions to architectural problems. The most advanced of current dynamic shading systems such as the adaptive fritting case study performed by Hoberman Associates and Buro Happold INC [8], are dynamically adaptable but are reliant on elaborate mechanical actuation in order to function, thus requiring expensive maintenance or in the famous
case of the Institut Du Monde Arabe [9], abandonment of the system entirely.

Rather than relying on complex mechanical actuation, a more efficient type of solar shading can be created which has the ability to change shape in response to solar demands and user needs. A novel material treatment is currently under development which relies on the properties of common materials to change shape while under strain, and return to their original shape when at rest. The behavior of this device is the result of deliberately introduced anisotropy in otherwise dimensionally stable composites of wood veneer, carbon fiber, metals, paper, fabric, or nearly any material with the ability to return to a baseline shape after deformation. As in the production of expanded metal meshes, alternating slits are introduced into the material allowing expansion in any selected direction. Unlike expanded metal mesh, however, the material memory of the selected materials results in the creation of what is essentially a flat spring; a mesh of material possessing a memory of the conformation under which it was formed. When under tension, the device expands. When tension is released, the device returns to its resting state (Figure 1).
This flexible mesh can be comprised of a generally any flat sheet of shape-memory material that can be deformed in one or more directions in response to an applied force, and return to its original shape when the force is removed. Irrespective of the material used to form the device, dimensions of the sheet, such as height and width, can vary greatly depending upon the intended application.

With particular reference to (Figure 1), which shows the variable screen in both its natural, closed and open orientations, the device comprises multiple elongated linear slits that extend through the sheet from its front surface to its back surface. In the embodiment of (Figure 1), the slits are each generally parallel to each other in two staggered rows and extend across the screen in a lateral direction that is generally perpendicular with the lateral edges of the sheet. The slits can be formed using any suitable cutting technique, including laser cutting.

By way of example, in double sided mahogany veneer in (Figure 2), each slit is approximately 8 centimeters long by 3 millimeters apart.

This ratio allows sufficient flexibility to produce a length of expanded wood which can be so expansive that it is possible to twist the device in a series of spirals with virtually no resistance. Increasing the slit spacing to one centimeter produces a mesh which, contrastingly, is capable of sustaining a tension of 5 kilograms. Two factors influence the flexibility of the system: slit length and distance between slits (blade width). By increasing the length of each slit, the flexibility of the device increases. By increasing the distance between slits (blade width) the flexibility of the device decreases. As is further shown in (Figure 1), each slit can terminate in a circular strain relief that prevents unintended progression of the slits, but can also serve to modify the direction of blade twist.
1.2. Analog Effects

By varying slotting patterns using parametric modeling techniques, digital means can be exploited to produce analog effects in architectural materials. Researcher Dustin Headly in Expanded Topographies [10] showed that permanent structural and spatial effects could be obtained by using alternating slotting patterns in permanently expanded metal walls. Similarly, temporary spatial effects can be obtained in meshed materials by using parametrically controlled curving patterns. Such spatial effects happen while the device is under tension, but when released, the assembly returns to its resting state.

In an architectural application, material mesh can change shape in response to ambient conditions and user needs in a system which relies on extremely simple mechanical actuation to create shading which is able to stretch (Figure 1), bend, and twist to adapt to lighting needs, passive energy strategies, and for the enrichment of architectural space. Such sunshades would contribute to the creation of a materially rich architectural environment, while still accommodating building performance and occupant needs. The proposed construct will take advantage of a novel and patent pending system which can be deformed not only to occlude or permit the passage of light, but also to produce optimal angles for the maximizing the interception of solar radiation of the surface of the device itself (Figure 3).

▶ Figure 3: “Blades” rotate as the device is stretched, shading the building while allowing diffused light to pass.
The actuation of the device is extremely simple. In one example, when pulled perpendicular to cuts in the surface, the device expands. As it expands, the blades turn as the material deforms to accommodate the movement. This permits efficient use of active solar technologies such as flexible photovoltaic cells applied to the surface. Optimal angles and opacities can also be created to shade buildings and building openings to allow the passage of diffuse light while blocking direct light, or to allow visibility through the screen from selective angles. Digital controls systems can be programmed to actively respond to solar angles, geographic location, and user preferences. When fully closed, the device can be made sufficiently strong to resist the damaging effects of hurricanes and major wind storms, to block sunlight, or to provide privacy. When fully open, the device can allow the passage of natural light and breezes, and to provide views to the outdoors.

1.3. Macro to Micro spatial effects

Just as temporary spatial effects can be obtained by exploiting the form-making characteristics of slotting patterns at a macro scale (Figure 4) by making curved patterns in flat material, so too can spatial effects be controlled at an extremely local level by minutely adjusting slotting patterns.

Keyed slots (Figures 1, 3) can be useful as strain relief devices in material which has a tendency to shear under the complex forces involved in stretching slotted material. These keys, however, can be made to serve a dual purpose: to direct the orientation of the rotation of each slot in the array. By pushing the keys in toward one end of the array (Figure 5) the rotational tendencies of the blades can be biased in that direction.
This rotational bias need not be constant throughout the array; indeed, an array can be made to change direction mid-span (Figure 2), in multiple locations in a span, or even alternating from blade to blade. Endless local and global variation is possible within slotted devices not just by altering the direction of the slot terminations, by varying the length of each slot, as well as the distance between each slot, and the distance between each row of slots, the elastic qualities of a device can be moderated along the length of the array (Figure 6).

1.4. Regional Acumen

Every geographical region poses environmental demands on its inhabitants which, over time, produce unique regional skill sets. The products of these skill sets produce buildings which lend distinctiveness to the respective location. Such regional specificity can be seen in the intricately shingled Hill House, designed by Brian MacKay-Lyons [11]. Such hand laid shingling is only possible due to a type of skilled labor which can only be found where the house was built.

In the creation of conformationally adaptive mesh shading constructs, it was desired to apply a regional specificity to the concept for both economy and for place making. In the central region of the State of Florida there exists a robust boat building industry. Boats of all sizes, materials, and
purposes are built in within the boundaries of the state, and skilled labor for techniques such as the making of high quality fiberglass is readily available. Additionally and perhaps less obvious is the parallel existence of a sail-making industry. Sails are made from fabrics of every description, starting with nylon, but including carbon fiber and kevlar textiles. Sailboat sails are commonly made with inlaid fiberglass battens to give form and resiliency.

Using sails as a model, a fabric mesh shading structure was devised which combined alternating expansion slots in the fabric with channels for thin fiberglass battens (Figure 7).

Reinforced control points transfer shear stresses diagonally through the system as the device is stretched. Fabric blades are revealed, bordered by the paired battens, which bow when stretched, but resume their shape when at rest, allowing the system to return from an open to a closed conformation. (Figure 8).
The initial prototypes employ rip-stop nylon as the primary material, but investigations are underway for explorations in composite sail materials. Materials such as kevlar will add stiffness to the system while allowing for a unique translucency.

1.5. Passive Machines

Further research combines the memory mesh concept with the natural anisotropic properties of wood with respect to humidity. In the presence of humidity, wood expands more perpendicular to its grain than in parallel to it. Traditionally, building techniques seek to minimize this effect by creating tolerances for material movement. However, the expansion and contraction of wood can also be thought of as potential energy for the actuation of passive machines. Researcher Achim Menges has exploited this phenomenon produced “performative wood” structures by using bi-layer veneer sheets with alternating grain to create passively actuated pyramidal pores in a skin surface [12].

This concept can be hybridized with the expended mesh technique. By producing a hybrid slotting pattern in memory mesh, a surface can be created which opens and closes passively in response to humidity, actively in response to mechanical actuation, or both (Figure 9).

This device uses a laminate of a non-expansive material such as plastic or metal, with wood veneer. Menges’ method of using a longitudinal layer of wood as the non-expansive layer in the laminate pair is extremely effective but tends to produce a cupping effect in the direction opposite the intended curl of the flap. Accordingly, the passive-active mesh substitutes this layer with an effectively non-expansive plastic or metal layer to counteract this phenomenon. Thus, as humidity increases or decreases, the resulting “humidity gate” can be seen to open and close as the wood expands and contracts in relation to its non-expansive laminate pair without cupping (Figure 10).
Additionally, tension applied in the direction of the expanding pattern will cause the device to expand as before, albeit with a more complex opening than shown in the simple expanding pattern.

A passive-active humidity gate is under development for use in experimental building skin systems which would take advantage of the heat of evaporation of deliberately introduced moisture to reduce cooling loads on buildings in warm climates. The Humidity gate is used as an autonomous control surface which opens in response to the humidity generated by moisture behind the skin in the heat load of the sun. Hundreds of tiny flips open to provide increased surface area, evaporation, shading, air flow, and heat conduction. At night, as the temperature decreases the flaps bend inward to channel night time condensate into a water collection system. The water collection and control of this configuration are based on the botanical adaptations of succulents, such as cacti [13].

1.6. Stressed Flaws

Wood Veneer is more flexible when bent parallel to its grain, than perpendicular to it. For this reason plywood is made with alternating layers of veneer oriented perpendicular to one another. In this way a flat, dimensionally stable building material is created. In a three layered plywood sheet, however, two portions of veneer are parallel to one another, on either side of a single layer of veneer oriented in the opposite direction. This creates a piece of wood that is so flexible that it can be rolled into a tube, yet resilient enough to resist breakage. This technique has been used to great effect in the furniture and cabinetmaking industry whenever a curved surface is desired.

This same bending phenomenon, however, can be exploited to create structural effects in perforated plywood screens. Using a CNC machine, slots are created in a tri-layer plywood sheet (Figure 11) in such a way that tabbed languets remain it a t-shaped formation.
The resultant “drop” from the perforation is deliberately retained for use as a strut in order to reduce material waste while maintaining design continuity for the piece. The languets are bent into position relative to one another, and held in place by the tabbed struts. The resultant screen is a structurally curved, perforated shading device. The bent plywood remains under stress, pushing the panel into a rigid curved shape. Tabs can also be alternated to produce a flat, rigid screen which still retains the expressive material depth of the stressed perforations. In this way it can be seen that the deliberately exploited anisotropic property of the bendable plywood can be used as a strengthening factor in perforated screens.

1.7. Deformational Flaws

Directionally dependent structural operations are not limited in scope to elastic modifications to wood. Permanently deformable materials such as steel and aluminum can be modified to exhibit anisotropic properties by creating arrays of multifunctional and permanent alterations. A series of bent flaps in aluminum (Figure 12) can be used to create shading devices which allow the passage of diffused light while blocking direct sunlight for the hottest parts of the day.
These slots effectively create structural angles in one direction of the material, thereby causing rigidity in the long direction of the slot relative to the uncut material. Conversely, (a slightly greater) flexibility remains against this artificial grain. Such material unidirectionality can be exploited to reduce the girth of supporting structural elements in buildings for both live and dead loads as applied along the grain of the new semi-structural material.

2. CONCLUSIONS

The modernist ethos embraced the honest expression of industrial materials as a point of departure for a new way of thinking about architecture, and allowed a vision of clean minimalist space making to install itself in the mind of the architect. Abundant standardized components were a new set of tools, and new tools lead to new methods. The profession of architecture now exists in a new machine age, one in which architecture as a machine for living has gone wireless, been reduced to the size of a wallet, and migrated to the pocket. Digital technology, however, is not a tool for saving time, but rather a means for rationalizing an era of complexity. The computer is a tool that can situate architecture between art, construction, and the environment rather than be used as a mere method for technical problem solving. Deliberately introduced unidirectional material weakening is one such method for producing material properties which exploit natural material tendencies rather than as a means to compensate for them. Such anisotropic operations take natural systems as a point of departure for man-made approaches to the augmentation of building performance in the realm of solar shading, but also for the creation of materially complex architectural environments.

References

8. Drozdowski, Z., Adaptive Fritting as Case Exploration for Adaptivity in Architecture, ACADIA 09: reForm( ) - Building a Better Tomorrow, [Proceedings of the 29th Annual Conference of the Association for Computer Aided Design in


Mark Weston
University of South Florida
School of Architecture and Community Design
4202 East Fowler Avenue
Tampa FL 33620
mw@usf.edu