RESPONSIVE EXPANSION

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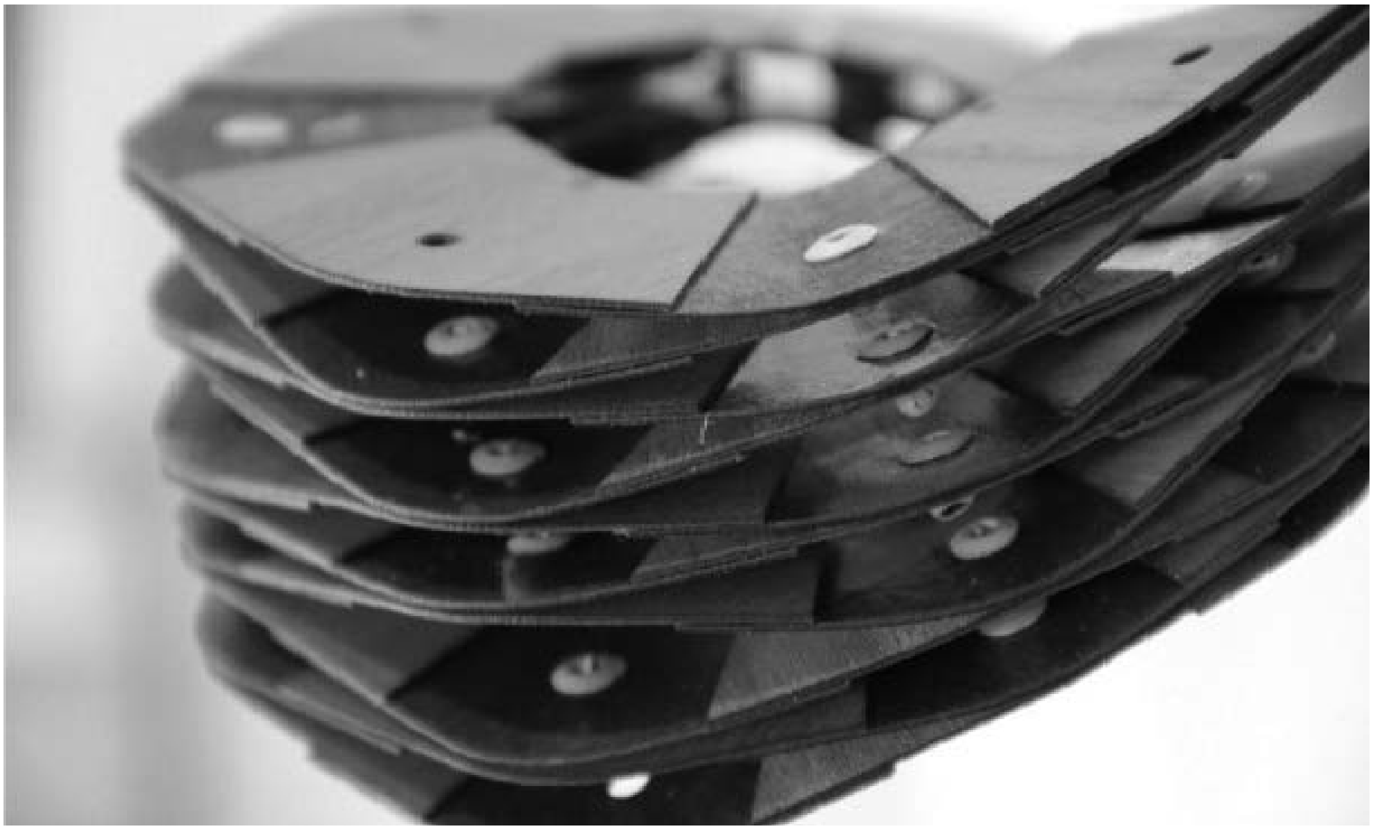


13c Differential hydrothermal expansion detail

ABSTRACT

Although commonly considered problematic within the wider range of standardized isotropic construction materials, wood's mechanical deficiencies are simultaneously an asset for the adventurous designer. These anisotropic and organic characteristics can be critically investigated, even exaggerated, with the possibility of productively yielding a complex and adaptive building material.

Given wood's fibrous make-up, as derived from its ecological function as an evaporative capillary system, wood as a material is predisposed to react to environmental and contextual fluctuations—moisture in particular. As a consequence of its cellular and chemical anatomy, wood—unlike other standard construction materials—will morphologically react to changes in moisture. This reactivity is derived from interactions such as rehydration and swelling at the cellular level which accumulate to induce formal transformations at the macro level. This responsiveness, when coupled with the affordances of industrial standardization, reframes wood within architecture as a reactive material capable of consistent transformation well-suited to parametric definition within computational modeling.

In the interest of exploring wood's performative capacity as facilitated through computational modeling, the following two projects present the beginnings of a larger investigation exploring the implications of wood as a hygroscopic reactive material within architecture. Both projects are predicated upon the instrumentalization of the dimensional change of a wood composite as a switch between resting and active states caused by differential hydro-thermal expansion at the cellular level. This transformation of material state is dictated by the application of heat and moisture. The first project investigates the implications of digitally parameterizing wood's transformable behavior as a means of geometric description. The second seeks to extend the methods of the former to explore the spatial consequences of cooperative material transformation across multiple elements inducing the motive force necessary to generate deployable architectural objects and spaces; ultimately seeking a way of providing habitable spaces that incorporate material behavior catalyzed through energy (Hensel 2006).

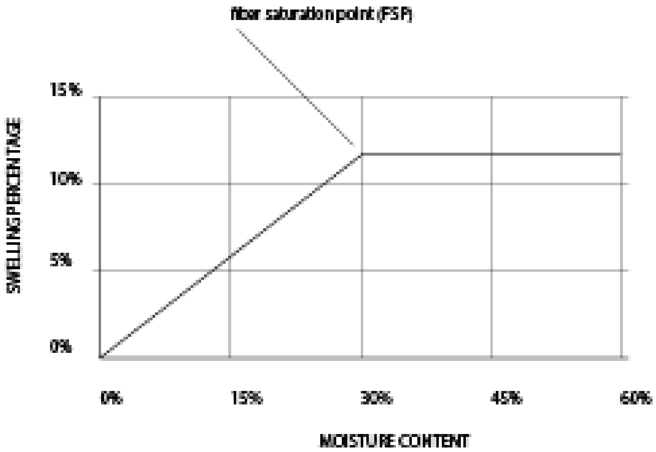
INTRODUCTION

Within the timber and construction industry, significant effort is made to minimize the organic and anisotropic performative aspects of wood. The interest lies in reducing its complex material qualities into a standard behavior, defining a consistent and mechanically stable performance. In effect, the organic organizational structure is suppressed in the interest of ensuring structural consistency constituted in the logic of industrial machinery and production. The consequence is a fundamental gap in understanding the complex responsive attributes of wood that derive from its cellular composition. Among the attributes suppressed is its hygroscopic behavior which constitutes wood as a water-reactive material.

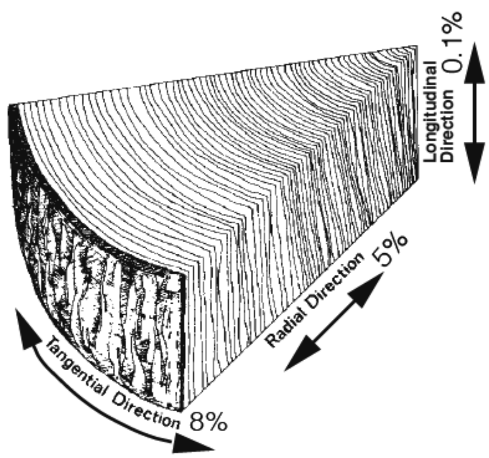
However, within the scope of contemporary computational design research, the hygroscopic performative possibilities of wood have experienced a renewed investigative interest (Menges 2009). This burgeoning body of research seeks to excise the productive architectural implications of wood's unique compositional makeup relative to other classes of construction material. The result is a standard material reconceived through its organic structural makeup as an articulate and responsive system capable of complex transformations.

It is in this emerging field that this two-fold project finds its niche, detailing the performative aspects of wooden composites and actively using wood's capability for hydrothermally activated morphological change to explore the larger implications of this system as a means of producing adaptable objects and environments.

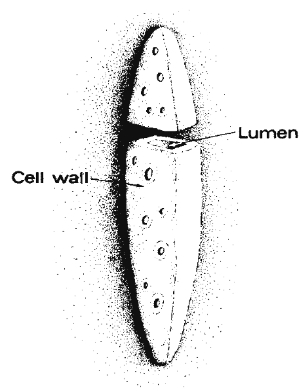
This investigation seeks to instrumentalize the hygroscopic reactivity of wood to generate transformations of morphology. Thus, the use of very thinly dimensioned material is ideal because it enables the cellular makeup of wood to hold a greater influence



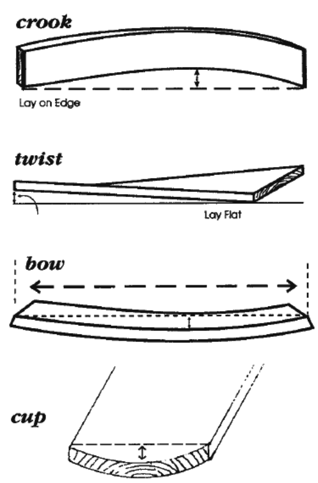
1 A graph mapping the relationship between moisture content (MC) and the swelling of wood; reactivity occurs between 0–30 percent MC



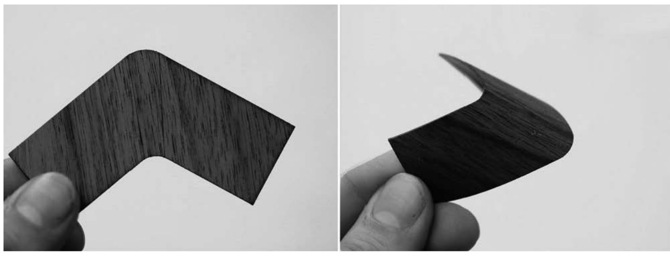
2 Swelling rate relative to grain direction



3 Wood cell composition, displaying elongated axis

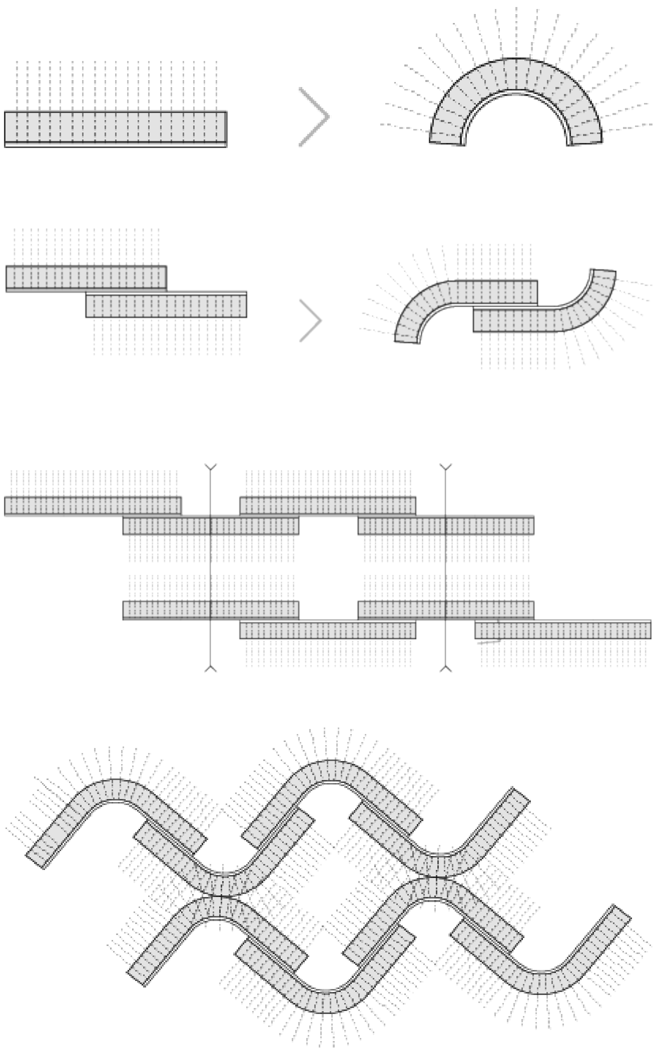


4 Variations of warping as dependent of grain orientation



5 Active versus static state

6 Uneven swelling detail



7-10 Extension of differential expansion as a hinge, and the aggregation of this element as a discretizing system

on overall geometric properties (Dinwoodie 2000). Wood veneer provides an optimal solution of consistent standardized quality coupled with appropriate dimensions to allow local cellular interactions to dictate global behavior. At the cellular level, the absorption of moisture into the lumen (the cavity of the wood cell that holds water) and the interior of the cell walls to the point of "fiber saturation" causes a swelling within the wood cellular matrix (Figure 1). This accumulated swelling induces a global volumetric expansion which warps the surface. (Figure 4) This process can be further extended by introducing heat as means of more thoroughly permeating the veneer with moisture.

This hydrothermal expansion is exhibited along all directions of the wood fiber, however as seen in Figure 2, the tangential direction presents the dominating expansion, making rotary-cut veneer (veneer that is shaved from the log in a continuous strip using a rotary tool) ideal for research purposes (Dinwoodie 2000). It is this material expansion that defines the motive force enacting the transition between resting and active state, however the presence of a directional constraint is necessary to generate describable global behavior out of local relations. The subsequent research therefore explores the introduction of an additional material system constituting a composite through which a differential in response can be generated.

COMPOSITES

Instrumentalizing hydrothermal expansion within architectural design requires a rigorous definition of the morphological transformation undergone. In order to implement the reactive possibility of wood towards productive aims, the transformation undergone must be controlled and analyzed quantitatively (Menges 2009). The nature of wood due its environmentally influenced growth postulates an indeterminate expansion both in rate and directionality (Skaar 1988). Consequently, thermal expansion—as an innate property of wood—lacks a broader range of instrumentality within architecture unless this expansion is proposed as a differential relative to another material. Composites are therefore a means of formally controlling the reactive system. As illustrated in Figure 6, the uneven swelling of the two materials along the grain direction produces a consistent controlled curvature.

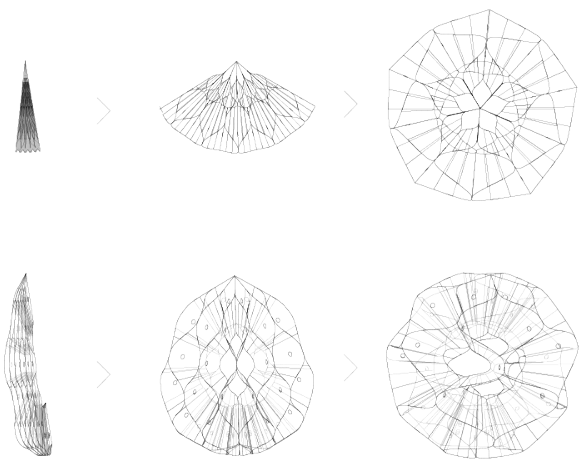
It is this introduction of an additional planar material with limited reactive properties to water that facilitates the establishment of a metric of material transformation. Without the dynamic found within a composite to constrain the behavior of hydrothermal expansion, there is little means to define the transformative relationships computationally. Initial experimentation with steam-forming and veneer-saturation designated the use of a veneer composite as the optimal means through which the material reactivity could be parameterized. The parameters defined vary between wood species, and it was decided that walnut veneer with a low modulus of elasticity (Zink-Sharp 2003) was ideally suited for the experimental method.

METHOD

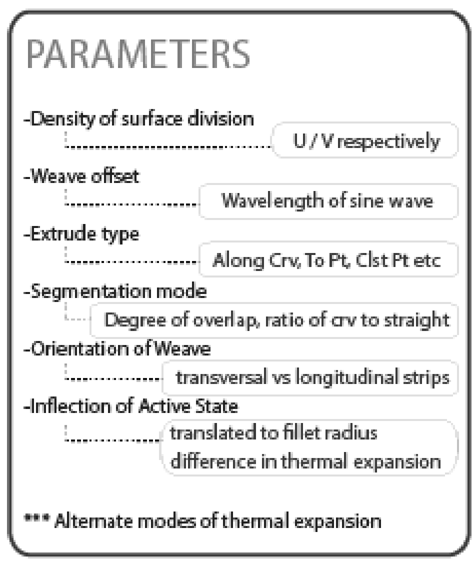
Research exploring the veritable degree of hygroscopic response in wood is already well documented (Menges 2009). However, these investigations profile veneer as a climatically responsive material, instrumentalized as a means of surface paneling. Rather than detailing the intensive adaptability of wood as a material in response to humidity levels, this investigation explores the reactive states (resting, active) of veneer when entirely permeated with moisture to describe overall geometric conditions. This is achieved through boiling. The following investigations define the material as either being in a dry resting state, or in a saturated active state of hydrothermal expansion. Wood in this condition operates as a morphological switch, and therefore both projects work to explore the development of an architectural method in two phases. The first is the computational definition of the reactive material to be fabricated. Once the system is constructed, the second phase constitutes "flipping the switch," or permeating the system with moisture through heat to generate a desired resultant geometry. To this end, all resultant geometry is an investigation in bistability of form.

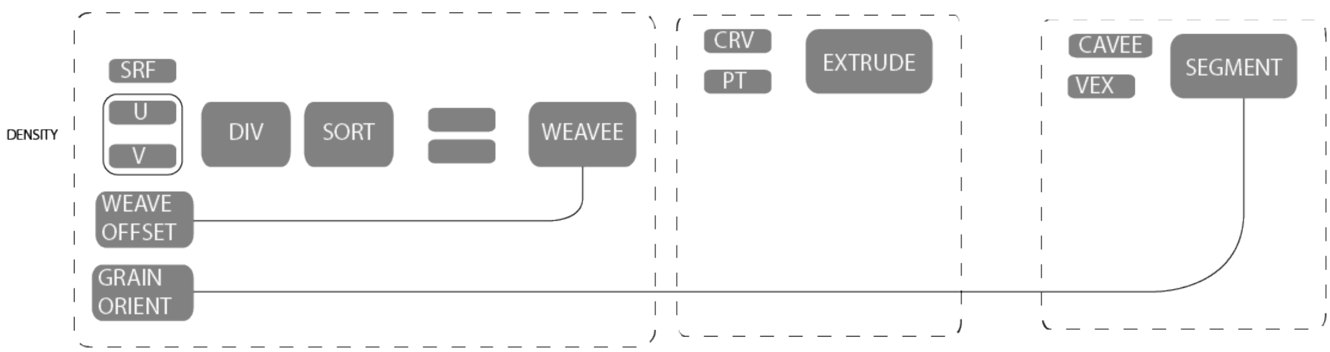
PROJECT ONE

The change of material state is essentially the transition of a straight two-dimensional element into an inflected three-dimensional element (Figure 7). Through the mechanical standardization of the material, as well as the use of expansive constraints through composites, the controlled inflection of the material is describable, and further, parameterizable within the computer (Figure 12). These levels of explicit control over material behavior allow a digital system to be established through which overall developable geometries are composed from sub-segments. In the translation of material behaviors into computational models, developable geometries are decomposed into a series of segmented linear elements corresponding to discrete zones of inflection. Due to the

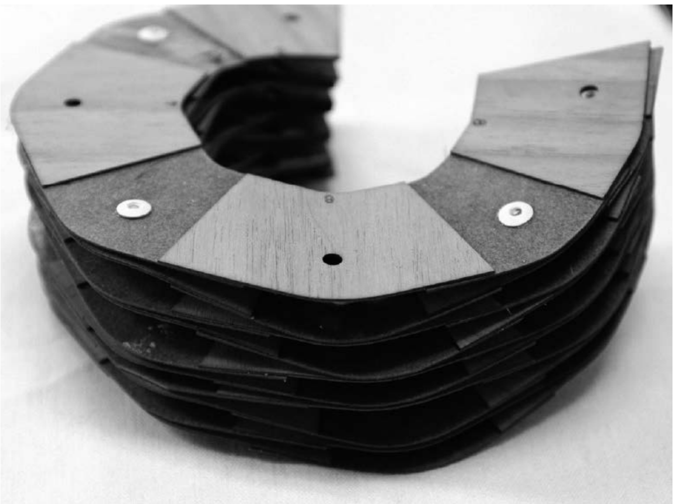


11 Change of material state from two-dimensional to three-dimensional





12 Pseudocode and parameters

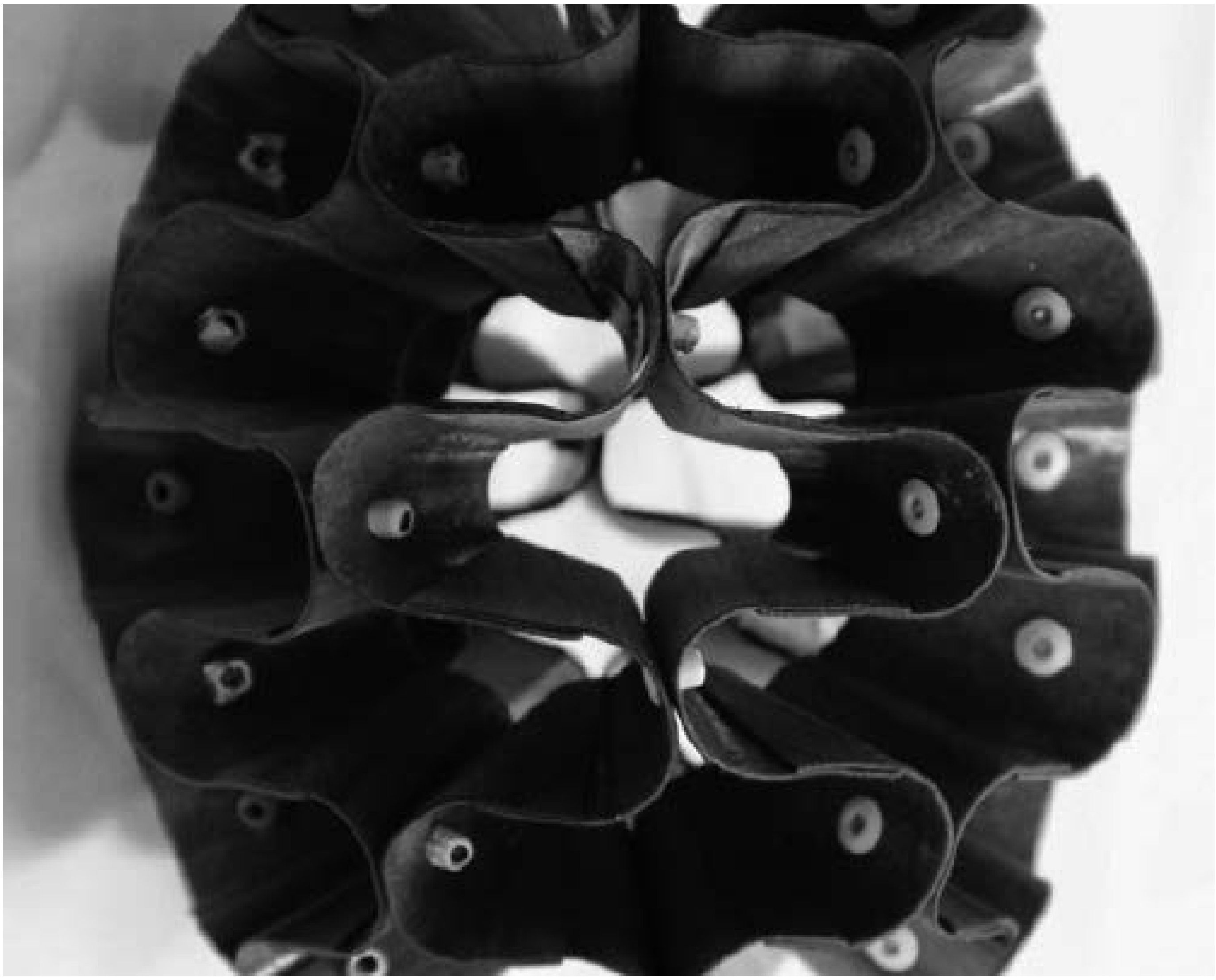


13ab Differential hydrothermal expansion animation

planar nature of the material, all overall formal conditions must be defined within a two-dimensional logic (Figure 8).

Thus, the overall morphology is described as a linear series of reactive components that when concatenated describe overall geometric properties. The resolution of segmentation is contingent upon the complexity of curvature. Two strips overlapping with opposing angles of activated inflection nullify one another's curvature to create a straight section (Figure 8).

As outlined in the two-phase process of fabrication, this method of description defines a particular form only when activated through exposure to heat and moisture. The active state defines the desired geometric outcome (Figure 15), however, the process of segmentation and concatenation results in the geometry in its resting state (Figure 16). The method is similar to the behavior of protein folding, where a single strand is embedded with the in-



15 Euclidean volume description of active state

16 Euclidean volume description of resting state

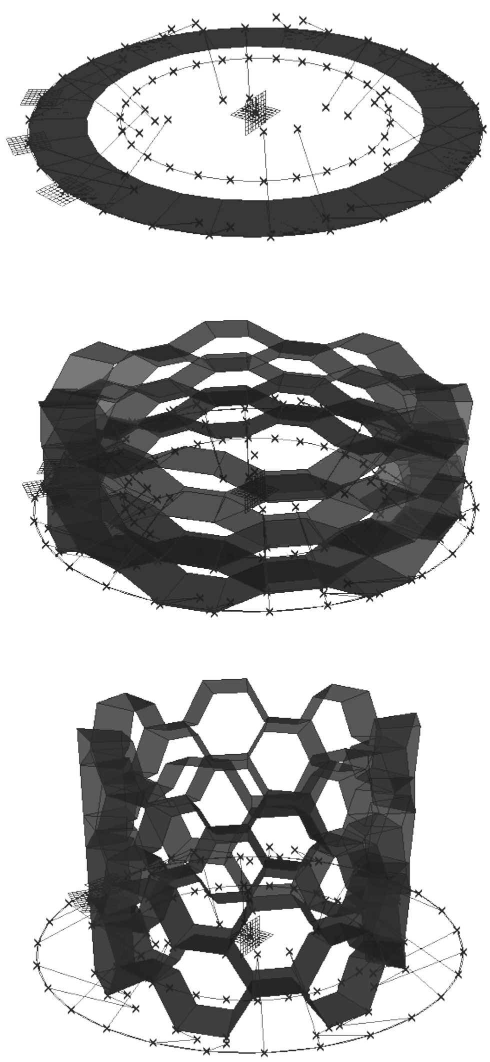
formation necessary to define a complex formal outcome given activation energy. Each segment operates as a reactive hinge at a prescribed angle (Figure 5) which acts serially to generate a resultant form. The computational definition of material behavior is defined by an identical set of relationships as those operating in the physical prototypes. This research into material computation functions only to describe forms which are reducible into single linear chains. The concatenated method cannot yet resolve branched or non-linear structures.

PROJECT TWO

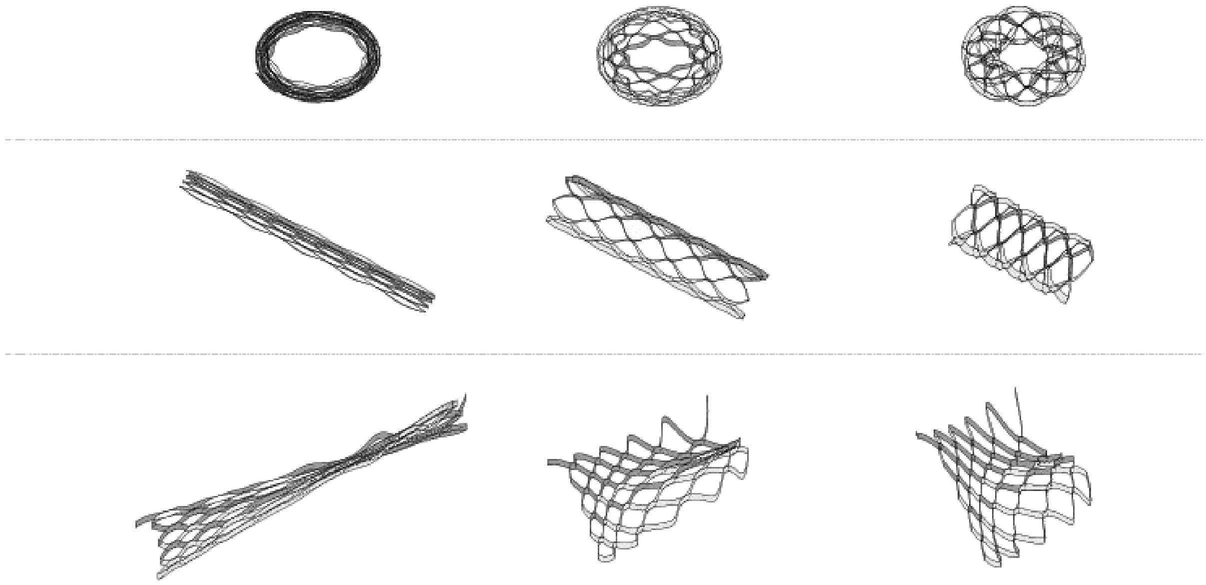
The second line of research explores the cooperative behavior of multiple subdivided elements. In this investigation, the serial operation of each linear element is expanded to explore the spatial implications of a network of elements undergoing reactive transformation collectively. (Figure 9, 10) Rather than a series of discrete modulations, the accumulated force of multiple directionally aligned elements produces a unified global transformation of morphology (Figure 11). Thus, this method of material investigation explores expandable structures, where the transition from resting to active state produces the motive force necessary to create a global reconfiguration of form (Gantes 2001). These systems are nascent research investigating the use of reactive wood composites to create bistable expandable structures. Rather than implementing any mechanical or electrical secondary system to coordinate the adaptability of form, all reactive material qualities are the derivative of operations occurring at the cellular level accumulating in coordination to induce changes at the macro scale.

FURTHER RESEARCH

Differential expansion and its potential for the parameterization of local convexity and concavity allow the discretization



14abc Hinge transformation



19 Discretization iterations and process of transformation from static to active

18 Video depicting the process of responsive expansion

of larger surfaces and introduce the condition of a multi-stable structure (Zhoung 2011). These characteristics—as detailed before—are fundamentally embedded into the nature of wood as a biologically produced composite. Further research trajectories entail the refinement of computational models defining reactive material behavior (Figure 14).

This research initiates a dialogue that could transcend wood as a material and seek to replicate this material behavior in composites that operate with greater success at an architectural scale. Differential expansion is not a characteristic unique to wood. The possibility of exploring alternate material conditions capable of effectively inducing global transformation is thus a central line for future inquiry. At work is an animation of the fundamental relationship between form and materiality.

However, although responsive behaviors are exhibited at larger scales, the internal forces at work in thin wood composites are insufficient to induce global transformations of morphology. As such, future research entails a similar process explored though a wide milieu of alternate mechanisms to achieve an analogous behavior. This research extrapolates the parametric system developed within smaller scale prototypes (Figure 19). Areas of consideration include:

(a) custom laminates of thicker material
- custom plied sheets of thicker wood laminated in accordance with expansion rate to generate an expanding front face and constraining backface

(b) mechanical constraints of expansion process
- implementing mechanical fasteners to asymmetrically control expansion rate of materials

(c) modular hinging through inflation
- utilizing pneumatic expansion

(d) hydro-contractive properties of certain ropes and filaments
- exploring the contractions rates and forces of ropes to mechanize hinge forces
- contraction on one side to induce a complimentary expansion on the opposing side of a mechanical system

Collectively these future trajectories entail a similar process of cooperating transformations of geometry through innate material behaviors to induce global morphological changes in response to climactic hydrothermal factors.

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