THE SOCIAL WEAVERS

CONSIDERING TOP-DOWN AND BOTTOM-UP DESIGN PROCESSES AS A CONTINUUM

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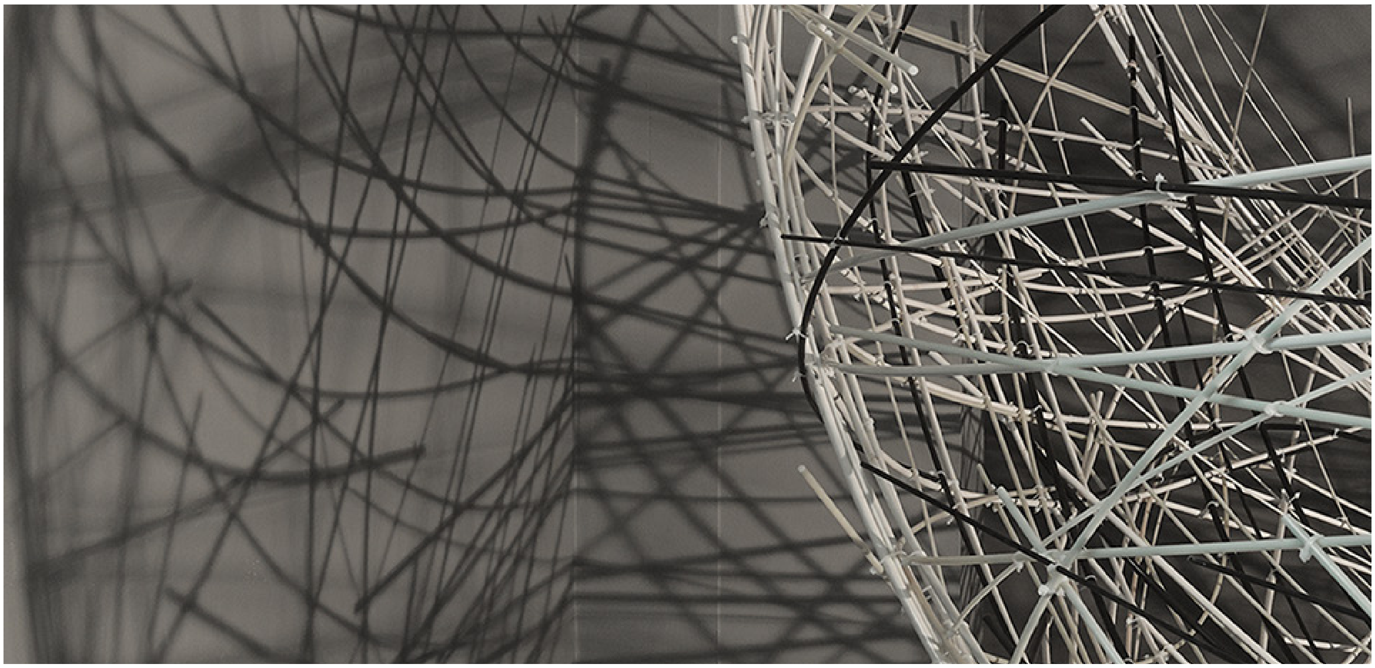


1 Detail View of Demonstrator Assembly (Bennetts 2013)

ABSTRACT

Predictive architectural models have, over recent years, become able to integrate material feedback by incorporating either finite element or physics-based simulation processes. When used to simulate large material and structural deformations, they can be informed by both specific material properties as well as formal mechanical behaviors, for the purpose of calculating and representing material characteristics over time. However, in many commonly used modeling approaches, this increased influence of material is achieved only at the expense or limitation of other agencies: those of the designer, of the design space, and the assembly.

As our design processes increasingly navigate complex, open-ended design spaces, finding effective methods for extending agency becomes a growing architectural preoccupation. The research presented here describes the context of open-ended design spaces, and distinguishes between two characteristic modeling approaches: designer-controlled simulation models that exhibit material agency but are constrained by topologically fixity (top-down), and simulation models that operate with unfixed topology but at the expense of direct agency for the designer (bottom-up). We identify this as a false dichotomy and present a third approach that treats this space as a continuum.

A built case study project demonstrates the underlying modeling concepts and methodology. "The Social Weavers" is a bending active, non-standard grid shell structure made from fiber composite rods of varied diameter and stiffness. The installation develops aggregate self-forming processes that intersect with the behavioral activation and distribution of fiber-composites under design direction for the production of a novel architecture.

MATERIAL AGENCY THROUGH COMPUTATION

Material computation is the activation and exploitation of agency within material. Materials have the capacity to process information, and if these behaviors are incorporated into digital design models, they become materially informed (Deleuran et al 2011). Digital models of this kind extend upon purely representational practices by incorporating iteration, simulation and feedback. They can encode behavior-based relations between scales, materials and structures, and be used to specify material organizations and steer material behavior.

This research focuses on a particular type of material agency: the activation of bending as a self-formation process. Bending-active structures (Lienhard et al 2013) use the capacity of material systems to self-organize under loading to generate three-dimensionally curved geometries from initially straight two-dimensional elements. Although this approach to making structures has a long history in vernacular architecture, few current built examples of bending-active structures exist. Frei Otto's Mannheim gridshell (Happold and Liddell 1975) remains one of the most prominent examples.

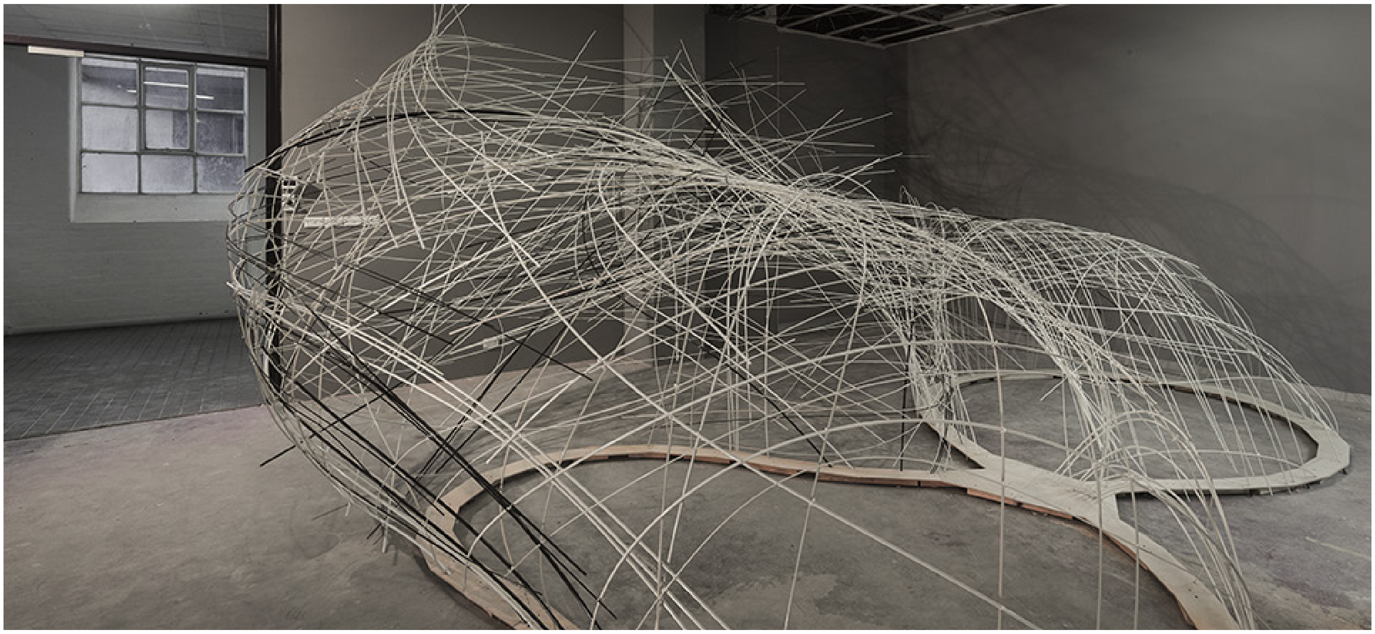
The geometries that are possible for bending active structures are limited by the physical properties of the structural elements. For example, material and cross-sectional properties restrict the allowable curvature in the structure. Materially, bending-active structures must be flexible enough to deform and bend easily, with the capacity to remain elastic. They also need high strength, which makes their high curvature possible. Traditionally, timber has been the most commonly used material, however fiber-reinforced composites have a lower relation of stiffness to strength and are thus able to achieve higher curvatures.

Because of these considerations, the incorporation of material information, the prediction of transformation, and the steering of bending behavior become central to the design process (Lienhard et al 2013). Here, composites represent an opportunity to extend the specification and design of bending-active grid shell structures. They allow the development of high curvatures but also, because they are precisely specified and standardized in their mechanical performance, provide an opportunity for grading (Nicholas and Tamke 2012). Composite grid shells made from elements of varied stiffness introduce the possibility of customized structural rigidity, for the purpose of optimizing the calibration of loading, resistance and reaction in each element. An allowance for dynamic variation of material through agent-based decision processes is not normally part of the design process. Its consideration during this phase may expand the possibilities for desirable flexibility in the design as a whole.

2 Inhabiting the Structure of the Demonstrator (Nicholas 2013)

BOTTOM-UP AND TOP-DOWN

In the context of computational design modeling, the terms top-down and bottom-up are often understood in relation to one another as poles in a methodological dichotomy, with the former describing an explicitly-directed, fully-bound and centralized approach, and the latter an implicitly-directed, unbound and decentralized one. In this context, top-down design models exhibit deterministic tendencies, with global configuration criteria operating across the system and individual components responding to and embodying these directives. Bottom-up design models instead exhibit tendencies for step-wise dynamic morphogenesis, with the configuration of components functioning through agencies afforded by local intelligences and stochastic interdependencies between elements (Crespi et al 2008). The development of computational design models typically entails identifying and prioritizing one of these methods for implementation, based on some mix of suitability and conceptual orientation.



4 The Social Weavers Demonstrator (Bennetts 2013)

An alternative description of this dichotomy is provided in M.P. Schützenberger's classification of goal-seeking behaviors (Schützenberger 1954), in which he characterizes two similarly polar approaches to addressing a problem space as being strategic and tactical. In this context, strategic refers to the top-down, in that global algorithmic direction is produced through an exhaustive–and often complicated–examination of all possible solutions in search of the optimal. Effectively identifying an "ideal" instruction set for all component elements, it defines a final state according to a centralized intelligence. A tactical approach, then, reflects the bottom-up such that a series of localized algorithmic decisions are deployed in smaller spatial and temporal steps. This process discretizes–and seeks to simplify–the problem space into sets of localized conditions, which then may incrementally accumulate to produce movement toward the desired goal.

Interestingly, Schützenberger uses this general distinction between the strategic and the tactical as a framework to reconsider their perceived dichotomy not as isolated states, but instead as conceptual end-points along a continuous spectrum. To achieve this, he demonstrates each to be a derivative of a single mechanism, related to interpreting a solution for a problem space, with the distinguishing variable being the "span of foresight"–or the scope–used to discretize the deployment of the decision-making algorithm. This span of foresight becomes a measure to understand the tendencies of a model not in absolute terms, but rather as a gradient: larger scopes of decision result in more top-down decision systems, and smaller scopes of decision result in more bottom-up decision systems.

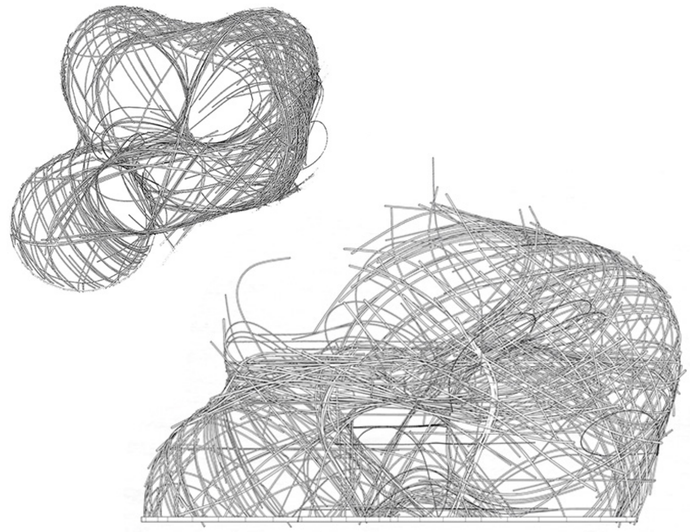
A general trend in computational design thinking has been to privilege bottom-up generative systems as being ideally suited for dealing with complex design concerns. These are also typically seen to exhibit emergent properties favorable for addressing dynamic or differentiated intrinsic and extrinsic conditions (Hensel et al 2010). Such systems might also be recognized as the "open-ended" design models that Peter Cariani considers necessary for addressing "ill-defined problems that defy direct solution" (Cariani 2008). In the context of this trend toward the bottom-up, however, the role of the designer in developing or managing a set of controls is less clearly defined, or is perhaps minimized in description in service of the epistemological framing of the emergent. And though it may be possible in theory for a model to be wholly bottom-up, in practice nearly all computational design models rely on some capacity of top-down approaches, even if only acknowledged as being involved in setting boundary conditions associated with generative algorithms, material specifications, or the array of assembly systems. Conversely, if a computational design model should be understood as producing new information about a design system–in contrast with a computerized model, which operates as a translational procedural representation (Terzidis 2006)–then in some capacity, a computational model must necessarily exhibit some type of bottom-up behavior through interdependencies between component elements. Real-world design models are then operationally neither entirely top-down nor bottom-up, but instead are located along a continuum similar to that described by Schützenberger, with their constituent components executing instructions at different levels of spatial, temporal and informational discretization.

Through the lens of agency, this project recognizes simultaneous advantages in both approaches, and actively synthesizes the designer-control idealized in a top-down approach with the collective and emergent intelligence idealized in a bottom-up approach. Rather than privilege one over the other, it presents a design system that productively takes advantage of agencies associated across orientations: for the designer, the design space, the material, and the assembly. That is to say, at any particular level, a component of the model is informed in a top-down manner by other components, and produces new information via bottom-up processes that in turn become top-down specifications for lower levels of hierarchy.

TWO OPPOSED MODES FOR AGENCY-BASED MODELING

Projects such the Faraday Pavilion (Nicholas et al. 2011) and Dermoid (Tamke et al. 2012) are characterized by the emergence of incremental intelligence through material agency, but also in the incorporation of an explicit design intent that is characterized by topological fixity.

The Faraday Pavilion gridshell uses bottom-up methods to approximate a pre-given geometry within the constraints of a specific material system: GFRP tubes. The project uses a lightweight physics-based design tool that incorporates the simulation of bending behavior and the calculation of bending stress and material utilization. There are two stages of simulation: in the first, radial elements try to closely match a target geometry while remaining within their capacity for bending. As this first stage of simulation

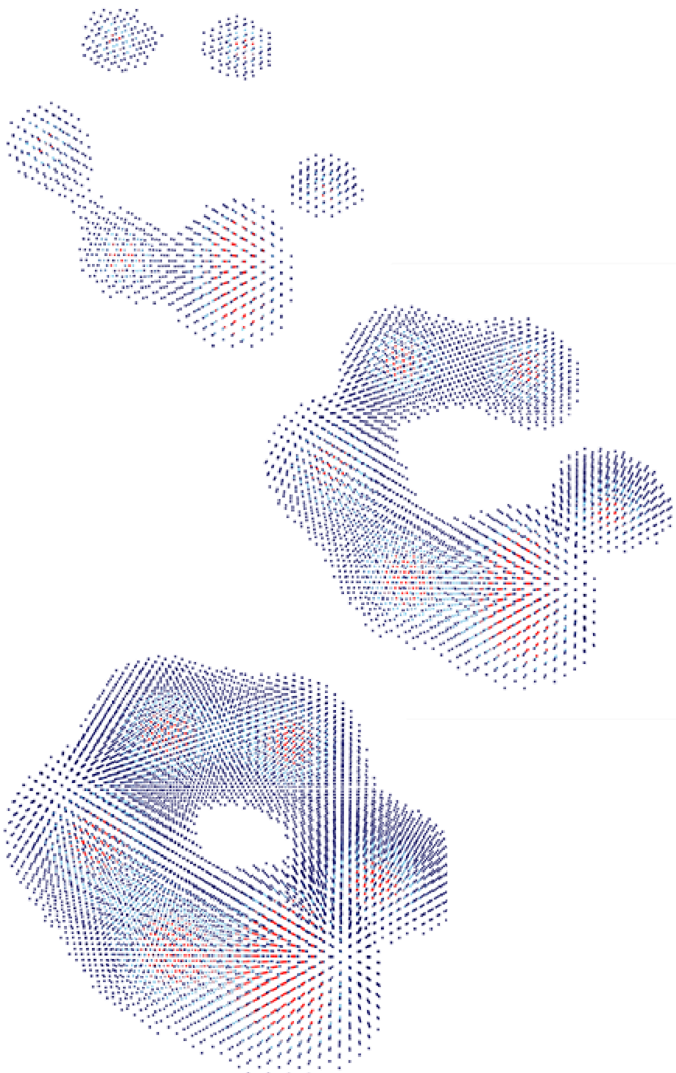


3 Plan and Elevation Drawings of the Demonstrator (Nicholas 2013)

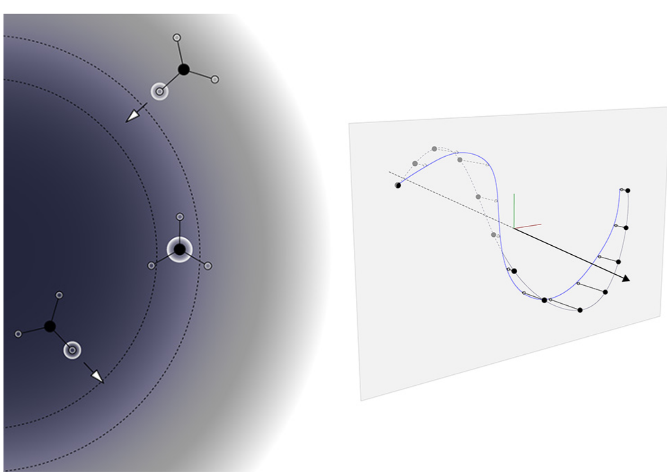
progresses, the geometric definition of each radial element emerges from the negotiation of the element's local utilization, its natural minimum energy bending behavior, and the architectural design intention as captured by the target geometry. The second stage, in which transverse elements are introduced, is less directed. Transverse elements are constrained to the radical elements, but are free to change their start and end points as well as their path across the structure, which is influenced by material bending and length parameters. Lastly, the combined structural interaction of radial and transverse elements is simulated.

In the Dermoid, a base topology is developed from interconnected hexagonal polygons, and then affected by an interplay of forces, constraints and boundary conditions. A geometric understanding of the constraints, which are related to design topology, structure, material, and production and assembly, and their interdependency and relation to the overall system is established, and then resolved within a physics-based system. While the arch and dome-like shapes that emerge are not constrained in their number of edges or overlaps, the definition of polygons and their connectivity to one another can only be defined in advance of simulation.

The companion projects The Rise and the ACADIA Rise from 2013 reflect efforts to develop models that fully privilege open topologies, but do so at the expense of designer agency. The Rise was an installation piece shown at the Foundation EDF in Paris exhibit titled ALIVE–Designing with Living Systems. The ACADIA Rise was a second piece constructed as part of a workshop at the ACADIA 2013 conference, which extended certain key features of the generative system used in the Rise and explored alternative means of activating structural performance.



7 Metaballs provide a dynamic design interface that can be adapted throughout the design process. Altering the threshold leads to significant changes in topology (Nicholas 2013).



8 Non-standard particle simulation forces used to exert designer agency during morphogenesis: Scalar-field sample gradient force, and Planar-orienting force (Stasiuk 2013).

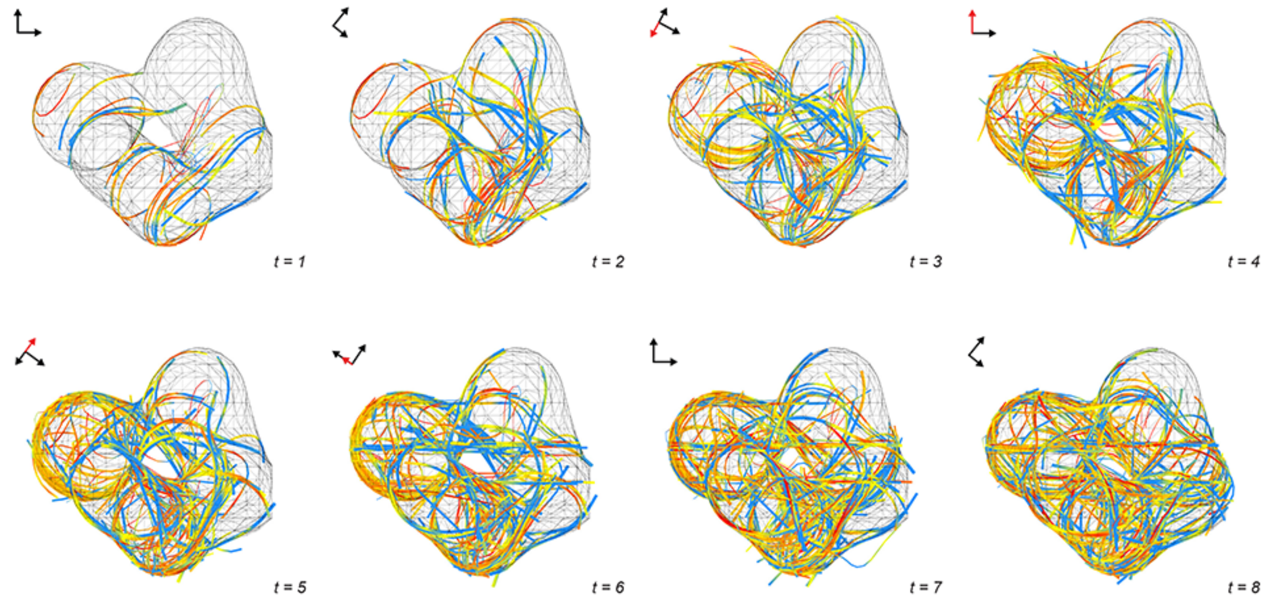
The primary generative algorithms used for these projects imitate vegetative growth, considering exposure to virtual sources of "light" as modes for catalyzing material accumulation through the step-wise passing of energy thresholds, with morphogenesis driven according to an algorithm notionally based on phototropism, the mechanism of growth towards light. Similarly, branching logics and material organizations respond to the model's "sensing" of local structural requirements. In order to fully activate the resulting material behaviors of the growth process, continuous particle-based simulations are executed as a critical component within the algorithm. In doing so, they collapse the cycle of generation, simulation and analysis into a series of continuously discretized and interdependent stages (Tamke et al 2013).

For each of these projects, the agencies produced through material simulation systems are essential for morphogenesis. The critical threshold that separates such modeling approaches–one tending towards the top-down, the other towards the bottom-up lies in the notion of topological fixity. For both the Faraday Pavilion and Dermoid, though they implement material agency through simulation, they nonetheless rely on complete designer control for the setup of each individual element, and all of the relationships between force elements. Conversely, the Rise and the ACADIA Rise–while also simulation material behaviors–implement a wholly generative system whose lack of fixed relationships privileges emergent agencies at the expense of ongoing designer control. These projects thus define the problem space for an approach that may deliberately synthesize agencies that have typically operated at odds with one another in computational design systems.

CASE STUDY: THE SOCIAL WEAVERS

The design possibilities of this new approach were investigated and tested in a five-day experimental design and build workshop, entitled "The Social Weavers". The workshop aimed to introduce students to methods through which digital-material practices are able to introduce simulation and design data into the process of materialization. It used the design of pre-calibrated, bending active composite material assemblages as a mode of operation.

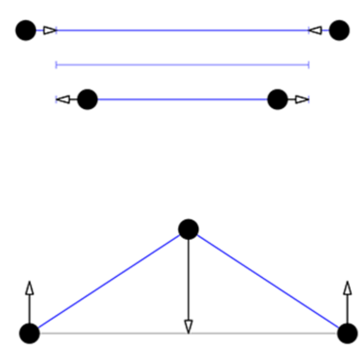
The workshop commenced with an introduction to materially informed design strategies and the concept of active-bending. Students were introduced to the computational design tool and undertook initial investigations to develop design schemes for the project site. In tandem, they conducted a series of experimental and empirical material tests to determine the minimum bending radius of each diameter composite rod, as well as young's modulus and bending strength, to calibrate the design tool. All schemes were presented to the teaching team and entire student cohort



5 Elements are gradually introduced into the simulation, with differing orientations. The bending stresses experienced by each element are visualized throughout the simulation, and impact upon the material specification of each element (Nicholas 2013).

so as to identify and select advantageous aspects to be taken forward into a new design iteration. This process repeated until a final design was agreed. The students were then divided into small teams, which had responsibility for specific tasks, such as site preparation, production of the fabrication information for the guide work, labeling all member groups variously to prepare for the assembly of the nest.

The Social Weavers structure (Figure 7) and (Figure 8) is made from actively bent fiber composite rods of varying diameters. The non-standard grid shell structure is approximately four meters by four meters by three meters, and comprises 412 three-meter long rods. The initial design inspiration is found in nature, where birds such as the weaverbird weave structures from continuous grasses, one element at a time. The incremental addition of elements to build the nest allows for more complex topologies and forms to emerge. This incremental process also allows for a distinctly 'designedly' approach, in which material can be added, then considered, adjusted, and added to again. An extreme example is found in Southern Africa, where the Social Weaver (philetairus socius) builds large compound community nests. These are some of the most spectacular structures built by any bird.

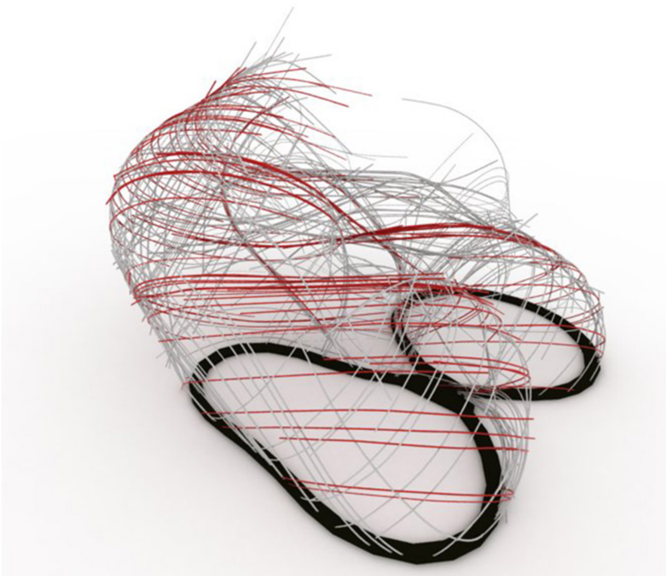


6 Standard particle-simulation forces used to model material behavior during morphogenesis: Hooke's Law spring force diagram, and Vector-normal bending force diagram (Stasiuk 2013).

The installation structure is based on the placement of more flexible material in areas of greater curvature, and stiffer material in flatter areas. This has the effect of minimizing reaction forces, and maximizing shape approximation. The structure uses five different diameter, glass reinforced rods: 55 are 10mm diameter, 116 are 8mm, 156 are 6mm, 70 are 4mm and 22 are 2mm. These diameters are the outcomes of the computational process.

SHAPING THE NEST

The Social Weavers installation is conceptualized as a nest. It is comprised of multiple, actively bent splines that are articulated through a network of collected, interwoven elements, whose local behaviors aggregate into a globally non-linear structural assembly. The central component of the design model for the Social Weavers is the custom-written, verlet-integrated spring-based simulation library that is set up specifically to allow for collections of particles to be organized through



9 Highlighting a Single Orientation Plane within the Multidirectional, Layered Structure (Nicholas 2013)

10 Material Differentiation as a Result of Simulation (Nicholas 2013)

unfixed and transitional topologies. It allows for the incremental addition of new elements over time, and for existing elements to continuously undergo reassessment of the force relationships in which they participate (Figure 5).

For the simulation of the individual elements, forces that have been demonstrated to effectively describe the elastica-driven behavior of elements operating in active bending are deployed (Ahlquist et al 2013). Each spline is subdivided into an appropriately-dimensioned subset of particles for defining both the springs which use Hooke's law for resolving elasticity in the long axis and the vector-normal method for resolving the forces applied for the description of elastic bending behaviors (Figure 6).

In addition to these "natural" forces which effectively describe environmental and material behaviors in the design model, the Social Weavers also relies on a series of "artificial" forces that empower the designer to more directly assert agency in a design process that relies on unfixed topologies that undergo continuous transformation during simulation (Figures 7) and (Figure 8). These forces create influence on the organization of the splines in multiple capacities:

1) for movement along the gradient of a scalar field;

2) according to a series of planar orientations; and

3) as instruments for creating separation between splines that share these orientations.

Operation of the design model for the Social Weavers consists of establishing the parameters of the scalar field that will be used to shape the morphology of the assembly, determining a set of different weave orientations for arraying the actively bent splines in space, and finally, during the execution of the simulation, incrementally releasing splines elements into the design space and allowing them to self-organize within the designer-set parameters. At any time during this modeling phase, the designer is capable of making adjustments to any of these forces, effectively reorienting elements or adjusting the underlying scalar field that drives the general organization of individual elements.

Unlike many nests that are designed for smaller units of birds, the geometric variation of the Social Weavers is an expression of the multiple distinct spatial conditions required of the complex social organizations emblematic of the nests of the birds after which the installation takes its name. For the design model, this diagram for growth is interpreted by considering morphogenesis as a response to a scalar field condition. In order to achieve local differentiation, this field is defined using a metaball falloff function with multiple centroids, and any number of points and associated radii, together with a threshold value, can be used as inputs for the centroids. Their number can be increased or decreased at any time during the simulation, and the threshold can also be adjusted, making significant topological change possible.

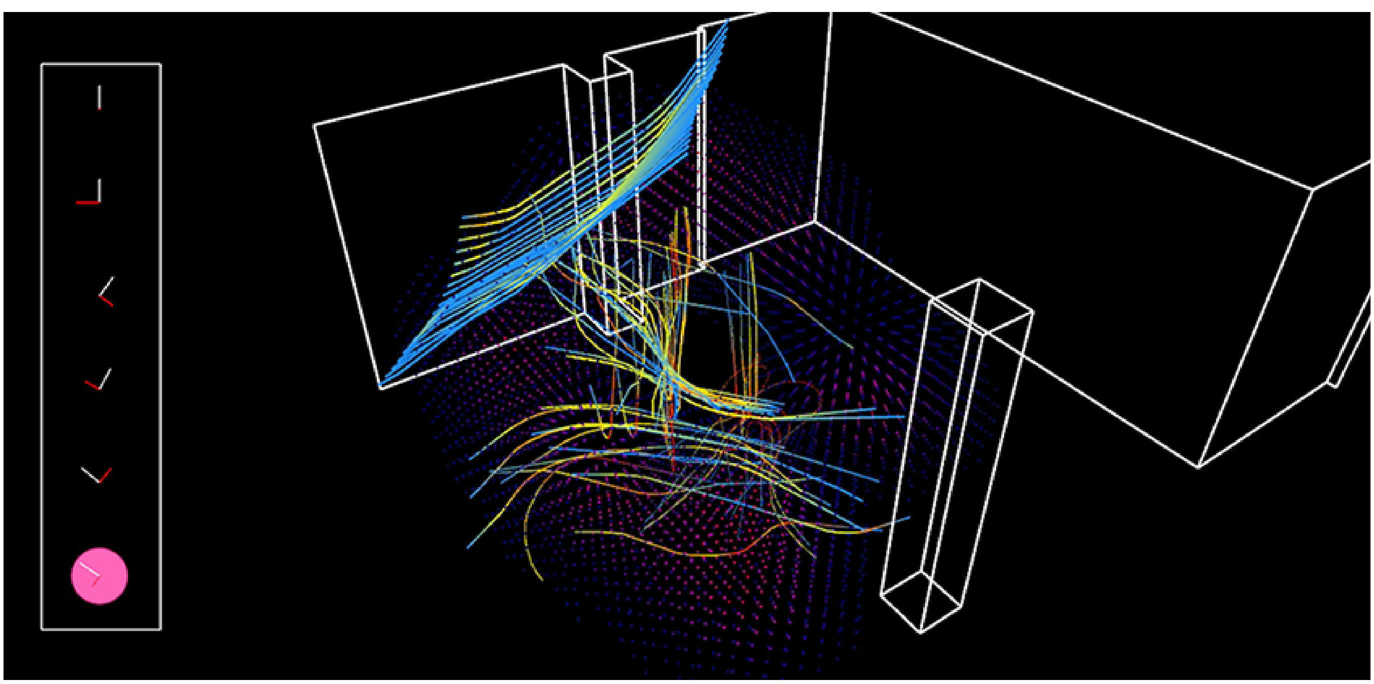
The scalar field force applied for the Social Weavers contrasts with forces in many simulation engines that rely on target geometries for either pulling or repelling particles. In these latter instances, forces typically rely on closest point calculations to determine the vector of influence on a given particle, movement that is purely normal to the target geometry. For the scalar field sample gradient force, however, each particle continuously samples itself within the field being evaluated. Each particle then senses the space around itself and determines the vector that indicates the optimal direction for movement towards the designer-defined ideal field threshold. With metaball fields, this then does not necessarily result in movement toward the normal of the surface condition, but can in fact reflect movement along the isosurface interior, or between apparent ideals. The process of sampling this field for each particle rather than pulling it to a design mesh–fixed or unfixed–then allows for the actively-bent splines to engage in a more nuanced force-based relationship with the design environment as it reflects a direct dialogue between design and material agencies.

The second, related control for this designer-driven approach is an orienting force. In order to ensure the proper densities of fibers across different directions, this orienting force is devised to allow for the designer to specify a collection of ideal, cross-laminating orienting planar coordinate systems that are assigned to different groups of fibers such that each first establishes an origin for itself in Euclidean space–at a point that averages its particle locations–and the target coordinate system is copied to this origin. Then, relative to their own locations in space, the constituent particles are drawn into this alignment. This keeps multiple fibers assigned to the same orienting planes parallel to each other, but free otherwise to move throughout the design space (Figure 9). This force is closely coupled with a simple separating force, such that fibers that share the same orienting plane are repelled from one another up to a cutoff length. This prevents the fibers from overly bunching in areas along the scalar field that reflect the highest degrees of relaxation.

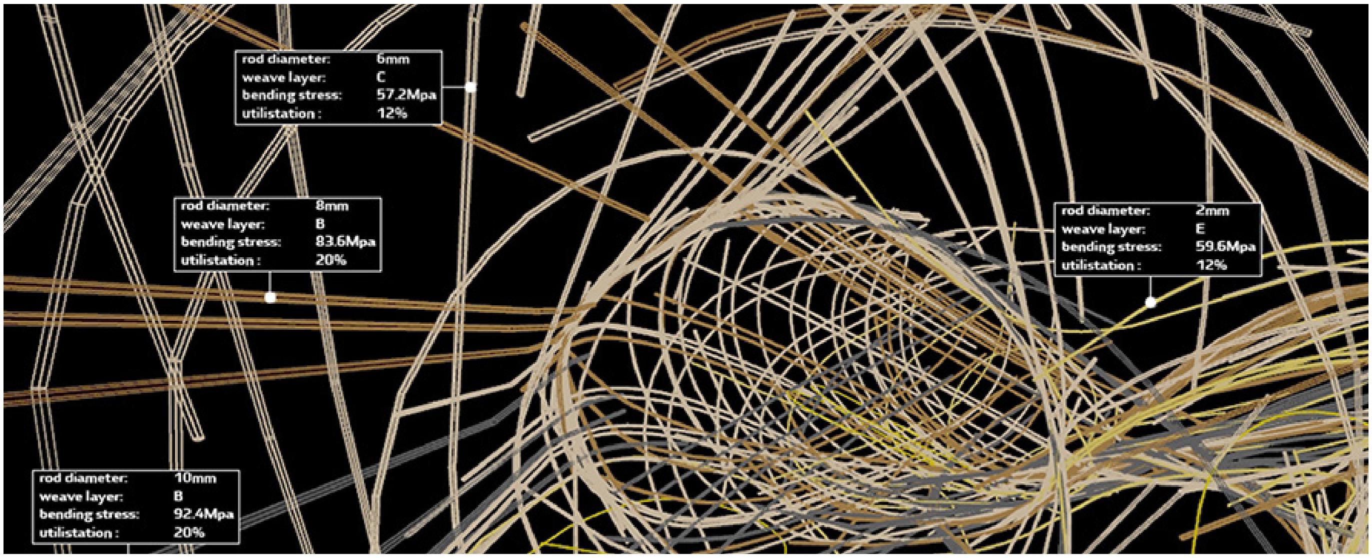
Finally, the simulation supplies the parameters for a dynamic system for material specification. The relaxation of the elements is affected by multiple forces as described above, which require the element to be either straighter or more curved. Each element begins with a 10mm diameter specification, which changes as the element encounters differing conditions. Change in diameter is driven by utilization, as a function of bending stress, which is recalculated during each iteration. If an element of a particular diameter is utilized by greater than 70 per cent, meaning that it needs to negotiate higher curvature, it reduces its diameter by one step. If an element is utilized by less than 30 per cent, meaning that it is straighter, that element increases its diameter by one step. The diameter steps are 2, 4, 6.25, 8 and 10mm (Figure 10).

DESIGNER AGENCY

The Social Weavers relies first on the designer definition of the metaball centers and charge values, and secondly on the incremental introduction of sets of splines into the modeling environment. The design space enables the designer to visually rotate collections of splines around the target metaball field and release collections of splines toward it–to do so, the designer defines an orientating plane, the number of elements and their length, and the position from which those elements will be initialized in the simulation (Figure 11). Because each collection of fibers introduced into the modeling environment is assigned a particular orienting plane, through the layering up of multiple elements over multiple orienting



11 Introduction of New Elements into the Design Environment (Nicholas 2013)



12 Differentiation of Material Specification as an Outcome of the Simulation (Nicholas 2013)

planes, the designer is able to ensure that the fibrous coverage of the metaball field condition is evenly distributed in cross-laminated patterns. A multi-directional structure then is gradually established over the target field, the time-dependent nature of which allows for the designer to get immediate feedback regarding both performance and organization. The final path, position and material specification (Figure 12) of each element then is influenced by a collection of tactical forces that describe movement along the scalar field gradient, attraction to locally-originated orienting planes, a desired minimum spacing from elements with the same orientation, and by the element's underlying elastic behavior. Most significantly, however, all of these bottom-up force calculations and unfixed topologies are directly supervised strategically by the designer. The assertion of designer agency is embedded such that the advantages of an emergent, locally responding design system can be deployed with a high degree of intentionality and control.

DISCUSSION AND CONCLUSION

The Social Weavers demonstrates the application of such an approach to encoding and deploying material behavior, specifically the bending and directionality of GFRP rods. The project seeks to capitalize on the simultaneous deployment of multiple agencies in the design environment, specifically the agency of the designer, the agency of the design space, and the agency of the assembly. While it has supported a more designedly approach to defining materially informed and emergent, non-standard gridshells, the modeling that underlies the project is currently limited, in that its structural simulation fails to take some key considerations into place, such as the effect of connections between splines and global performances. The reason for this exclusion is computational cost. While the scale of the physical demonstrator allows this freedom, in order for this approach to be scaled up, it is important that this aspect be addressed. This paper argues that top-down and bottom-up processes should be thought of as a continuum, rather than as two opposed poles. That is to say, at any particular level, components of a model might be informed in a top-down manner by other components, and produce new information via bottom-up processes that in turn becomes top-down specifications for lower levels of hierarchy. Such a view affords new approaches to the inclusion of agency within design, and the opportunity to extend upon existing design models by incorporating and synthesizing explicit design intent, the emergence of intelligence through material agency, and open topologies. The need for synthesis between bottom-up and top-down approaches is driven by architecture's increasing involvement in the design of programmed relationships between matter and energy, and the designed orchestration of material formations such as The Social Weavers installation. This material practice requires more than solely top-down or bottom-up approaches in which agency too often appears a zero sum game, where its granting in one aspect must reduce its deployment in others.

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IMAGE CREDITS

Figure 1.Bennetts, Peter (2013).

Figure 2. Nicholas, Paul (2013).

Figure 3. Nicholas, Paul (2013).

Figure 4. Bennetts, Peter (2013).

Figure 5. Nicholas, Paul (2013).

Figure 6. Stasiuk, David (2013).

Figure 7. Nicholas, Paul (2013).

Figure 8. Stasiuk, David (2013).

Figure 9. Nicholas, Paul (2013).

Figure 10. Nicholas, Paul (2013).

Figure 11. Nicholas, Paul (2013).

Figure 12. Nicholas, Paul (2013).

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DAVID STASIUK is an architect and researcher, currently a PhD Fellow at the Centre for Information Technology and Architecture in Copenhagen (CITA). His research investigates development strategies for adaptive computational modeling. This work examines the possibility for developing emergent parameter spaces through the integration of simulation systems with topological transformation both as a part of model setup and in the design environment. He is currently engaged in the application of machine learning techniques for model generation, and as a dynamic means to search design space. His professional work has focused on bespoke detailing for advanced architectural geometries, computational design implementation, and the development and deployment of digital fabrication and documentation techniques.

PAUL NICHOLAS holds a PhD in Architecture from RMIT University, Melbourne Australia, and joined the Centre for Information Technology and Architecture (CITA) as an adjunct professor in 2011. Paul's particular interest is in computational approaches that support new and interdependent links between architecture, engineering and materiality. Having previously worked at Arup Melbourne from 2005 and AECOM/Edaw London from 2009, his current research explores the idea that designed materials such as composites necessitate new relationships between material behavior and design representation. Paul co-founded the design practice mesne in 2005, and has exhibited in recent Venice and Beijing Biennales.