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CITA | WORKING FOR AND WITH MATERIAL PERFORMANCE

A B S T R A C T

The understanding of materials as active, whether compressed, under tension or flexed, allows for novel solutions that extend and challenge the space of design. The approaches towards the integration of material behaviour on the conceptual, construction, production as well as on the level of digital design system can serve as a blueprint of how to design with the complexity that characterises the current design space of building practice. This paper focuses on four different approaches to integrate material performance into digital design exemplified in four physical demonstrators by CITA, the Centre for Information Technology and Architecture in Copenhagen.

CITA (The Centre for Information Technology and Architecture) is a research centre at the Royal Danish Academy of Fine Arts, The School of Architecture. Identifying core research questions into how space and technology can be probed, CITA investigates how current forming of a digital culture impacts on architectural thinking and practice. CITA examines how architecture is influenced by new digital design- and production tools as well as the digital practices that are informing our societies culturally, socially and technologically. The centre focuses on IT as a tool for design, production and communication within four key research areas: *Digital Formations*, investigating new parametric design tools and their physical counterpart: rapid prototyping and CAD/CAM (Building Information Modelling, Computer Aided Design / Computer Aided Manufacture) processes. *Behaving Architectures*, investigating new programmable materials including fibre composites, nanotechnologies and interactive textiles, *Interface Ecologies*, investigating real-time modelling, interface design and intelligent programming and *Complex Modelling*, investigating novel ways of designing with digital models through integrated feedback loops between material, simulation and making.

In 2012 the CITA.studio – “Computation in Architecture“ was established, as a two-year international Master course. With a focus on digital design and material fabrication the programme questions how computation changes our spatial, representational and material cultures. The programme gives students the opportunity to develop and explore individual strategies for incorporating digital tools within their architectural practice. With an experimental, hands-on learning-by-doing method CITA.studio explores computation as means to pursue speculative design, experimental fabrication, material actuation and complex modelling. We want to devise our own critical reflections on how digital tools are used in the production of creative and inventive thesis projects. CITA works design led and employs a practice based research method¹ based on the implementation and design of working probes and full scale demonstrators that allow for direct testing and creative troubleshooting. The centre focuses on material and making and how established techniques transform through the integration of digital processes. These create a new closeness between the material and the designer, where his tools now link directly to the process of making. A new sense of crafting² emerges that does not only characterise the setup and making of digital design systems, but allows designers as well to revisit local craft traditions.

CITA | WORKING FOR AND WITH MATERIAL PERFORMANCE

The understanding of materials as active, whether compressed, under tension or flexed, is at the root of all craft traditions. The ability to work a material, to saw and chisel wood, to weld and hammer steel or to weave and knit yarn relies on a profound understanding of its performance. The soft flex of wood, the sprung stiffness of steel and the tensile elasticity of yarn are inherent properties that inform and shape our crafts traditions. It is through material understanding that we come to shape the world of artefacts and structure that surrounds us.

The last 30 years saw an increasing use of computationally steered fabrication technologies³. Computer controlled fabrication now informs most of western manufacture across multiple different scales and materials. This increasing application of digital fabrication technologies has optimised today's industrialised building practice and created the new economic platform for our built environment.

But digital fabrication is more than an optimisation tool. It also allows us, as designers and architects, to reconsider our conceptual and material practices. Digital fabrication has direct consequence on the way that material is thought in design. Digital fabrication shifts material thinking into the core of design intension. If architecture has predominantly been understood as a formalist tradition where formal concerns preceded material thinking, designing for digital fabrication challenges this ideal. Instead, material, craft and performance becomes inherent queries already present at the start of the design phase. Working for digital fabrication emphasises the presence of material and necessitates that the design holds a fundamental understanding of the crafts traditions that are this way included. What is at stake is not only the systematic control of variation or even a return to the richness of ornamentation but equally a fundamental change to a performative understanding of materials. Rather than thinking materials in a categorising manner, as a set of practices that lend themselves to timber, steel, concrete or glass, materials are seen through their capacity to perform: to bend, flex and stretch. In this way digital fabrication allows architects to reconsider the traditions of crafting and to investigate how new processes of folding, twisting or pleating materials can lead to new structural systems.

The ideal of working for and with a performative understanding of materials⁴ also holds a reverse challenge instigating a new set of demands on our design tools. To work well with material performance so as to implement it in structural design necessitates good simulation tools by which these structural

forces can be calculated and anticipated. Current design tools are designed to calculate standardised materials in traditional load bearing structures. As we come to work with more complex structural performances such as self-bracing, flexing and tensioning we need new tools by means of which these calculations can be calibrated. A first, the problem arises in the mere increase in complexity. Material simulation and continual variegation necessitates more complex algorithmic calculation and higher computer power. But the second, perhaps more fundamental problem lies with the division of these design tools into carefully segregated professions each with their own culture of problem definition and solution finding. If we are to work intelligently with material performance and thereby take full advantage of the shared digital platform that lies to ground for digital fabrication, we need to develop new tools by means of which the full partnership of designers, engineers and craftsmen can work together in the early design phases creating material solutions for the design.

Working through the digital towards the material positions architecture and design in a new challenge of material thinking. If we as practitioners can find ways of implementing material performance in the design of our built environment and use traditional materials in new ways, we will create the tools by means of which we can develop a more sustainable and environmentally responsive building culture. To work intently with material performance is to work directly with an understanding of a materials relation to its environment, its production and its use. Working for and with material performance is therefore to work with a situated understanding of design.

FOUR DIFFERENT APPROACHES TOWARDS THE INTEGRATION OF MATERIAL BEHAVIOUR AND SIMULATION BASED DIGITAL DESIGN

Within the research practice of CITA the merge of computational and material thinking is explored. In a series of research demonstrators, Thaw, Dermoid, Faraday Pavilion and The Rise, we explore how performative and crafts based thinking of design can lead to new ways of thinking structural design. These demonstrators all focus on pliable material and how to employ these in an effort to create lighter and less material consuming structures that might show a path towards the conceptualization of a more resilient architecture. Though the four demonstrators have their own material context and research question they show the development in knowledge, where one project learns from the other. Furthermore, they present four principally different approaches towards the integration of material behaviour into digital design systems:

- 1 Animation of Material behaviour – These approaches use computation to replicate real world phenomena without being based on real world physics. Examples are animation systems from the movie industry that are able to animate oceans based on vector calculation, rather than an understanding of water molecules.
- 2 Hybrid of Lightweight simulation and Analytical tool – Analytical Tools as Finite Element Analysis (FEA) for structural systems validate and eventually correct the findings of animation systems or other lightweight simulations that are based on high degree of abstractions or animations.
- 3 Simulation based on mathematical function in combination with Analytical tool – some parts of material behaviour can be understood through formulas, as for instance the buckling of linear elements through the Elastica Theory by Euler and Bernoulli. Material systems that are based on this behaviour can be integrated into a design process that eventually validates more complex interaction of elements through analytical tools as FEA.
- 4 Integrated Simulation – The relative complete understanding of a material system allows for the integration of design and simulation and the establishment of a continuous feedback loop in the design genesis. The underlying simulation engine is typically lightweight, but calibrated to the behaviour of the specific material systems.

The research demonstrators are speculative in that they explore principles of making and design. Rather than solving a direct architectural problem they query the underlying logics of specific material systems and investigate methods how a confluence of computational thinking, simulation, material behaviour and digital fabrication can take place.

THAW - ANIMATION OF MATERIAL BEHAVIOR

A central consideration in Thaw (Ramsgard) is the representation of material performance as an instrumental component of the digital design. Thaw is a five meter tall woven wall membrane constructed of ash slats braced by steel joints for the “Digital Material” exhibition at the ROM gallery in Oslo. The principal question of the project was: how can parametric tools integrate material performance at the outset of design?

Encoding measured behaviour into a parametric model

As a material structure Thaw explores active deformation through the elastic bending and twisting of its wooden members as well as the friction

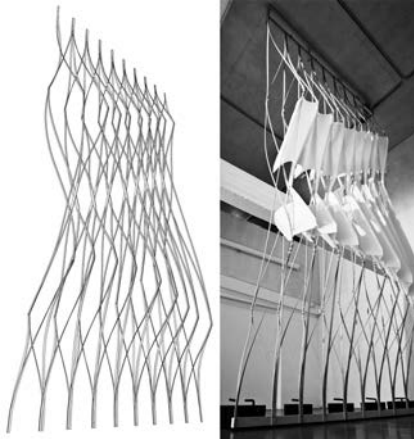


Figure 01. Thaw – Parametric model and final Installation

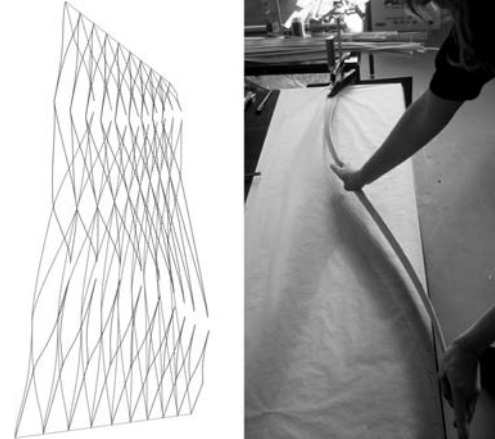


Figure 02. Measuring Material behaviour and parametric model

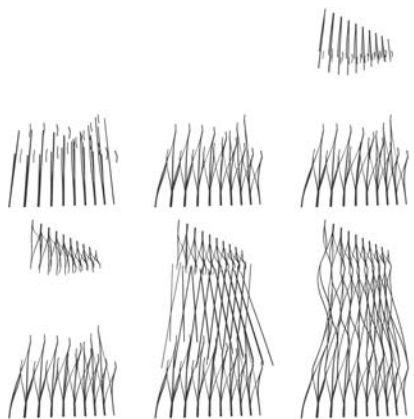


Figure 04. Assembly of Thaw with Lightweight Dynamics Simulation

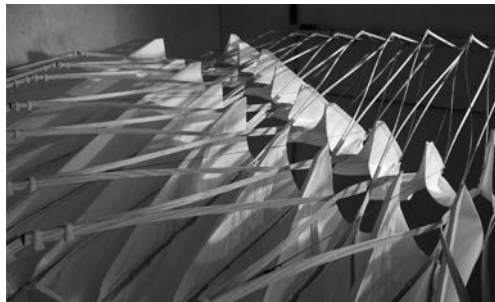


Figure 03. Thaw in Oslo, straight ash slats connected with bespoke steel joints and non-woven textile as skin.

based interlocking of the weave. For the design and construction of Thaw a geometrically relational parametric model was built (Fig. 01). Following this the bending deformation of varying member lengths were analysed under a range of load conditions (Fig. 02). Subsequently the produced data set was abstracted into formulas which could simulate the “bend” of members using a law curve in the parametric model (Fig 02. right). This gave a general idea of how the wood would deform in the structure. From this experimentation we have learned that this analytical and empirical approach provides highly valuable data in understanding the material behaviour. It is yet purely relational – like a weaving pattern it is not providing a visual representation of the final structure but serves as a material description detailing successfully the lengths of material and their intersections allowing for direct fabrication. It is furthermore also a geometric description, which was essential in order to design the cladding skins and develop their cutting patterns (Fig 03).

The direct translation of this data into a function-based simulation has however exposed several drawbacks in representing material structures beyond that of the singular member. A model based on the isolated deformation of a single member does not account for the collective physical interdependency in the overall structure. The load-conditions applied in the process of analysing the singular component will furthermore not correspond to the actual distributed load condition for any given member in the structure.

Light Weight Dynamics Simulation

In order to predict digitally the material performance of the aggregate structure a digital-material prototype was developed where the elements were informed about material properties and physics based constraints and the environment which they inhabit (Deleuran). The light weight dynamics solvers used is capable of computing multiple physical phenomena interacting simultaneously, thereby supporting the identified requirements for a digital-material prototype. To inform this model a calibration rig was set up. By measuring and correlating this deformation with corresponding nMeshes (a polygon mesh with embedded material properties in the digital model) the parameters of the system and mesh resolution were tuned to a level where a relatively approximate behaviour was simulated. Where each element was now informed about its material behaviour the following was the setup of the structural system. It was learned here that the digital model could only be assembled in the same sequence as the physical model would. The process was therefore remarkably similar to the tedious task of manually doing it by hand in real life. Hence the specific order of physical

events in time is a highly important factor when simulating a complex structure such as Thaw (Fig 04).

Beyond the problematic nature of setting up the constraints the issues were also encountered with making the slats stiff enough without having to use settings that seriously affected the frame rate. The behaviour of the digital model is therefore less rigid than the real installation and although visually remarkably similar it shows too big deviations from the physical counterpart to be used for the generation of, for example, fabrication data for a potential skin.

DERMOID - A HYBRID OF LIGHTWEIGHT SIMULATION AND ANALYTICAL TOOL

Thaw and especially the Dermoid project investigate aggregate material performance within structures made of many smaller elements (Tamke). The Dermoid demonstrators (Fig 05) are the result of research into the integration of material performance into architectural design that was conducted in the frame of the VELUX guest professorship of Prof. Mark Burry (SIAL). Using timber as a case the research focused on the introduction of the materials pliability into structures and development of computational design environments that allow for an intuitive material led design practice. Within a set of workshops over a two year period a reciprocal frame system made of individually shaped and flexed plywood members was developed.

Physical and digital modelling approaches

Speculative probes and prototypes in digital and physical models were driving the investigation and helped to develop large spanning aggregates of short members. The prototypes showed yet the high degree of interrelation between the elements, material and production. This necessitates a generative modelling approach that is holistic in nature and can simultaneously deal with the level of design, production, tectonics and assembly. The development was therefore conducted in a modular digital environment that consisted of exchangeable custom-made tools. The modelling process differentiated between parts that operate on parameters that are directly dependent on others and those that are highly interdependent and need to interact mutually. Where the first are mainly positioned on the level of detail and construction and were managed in the parametric modeller of the Rhino CAD that generated finally the production files for the laser cutting of the plywood we used the nucleus physics engine of Maya™ (Fig 06). It was here a time-based process established where the



Figure 05. Dermoid II in the Danish Design Museum during the 2011 Copenhagen Design Week



Figure 06. Dermoid I at 2011 Medhals Smedie in Copenhagen

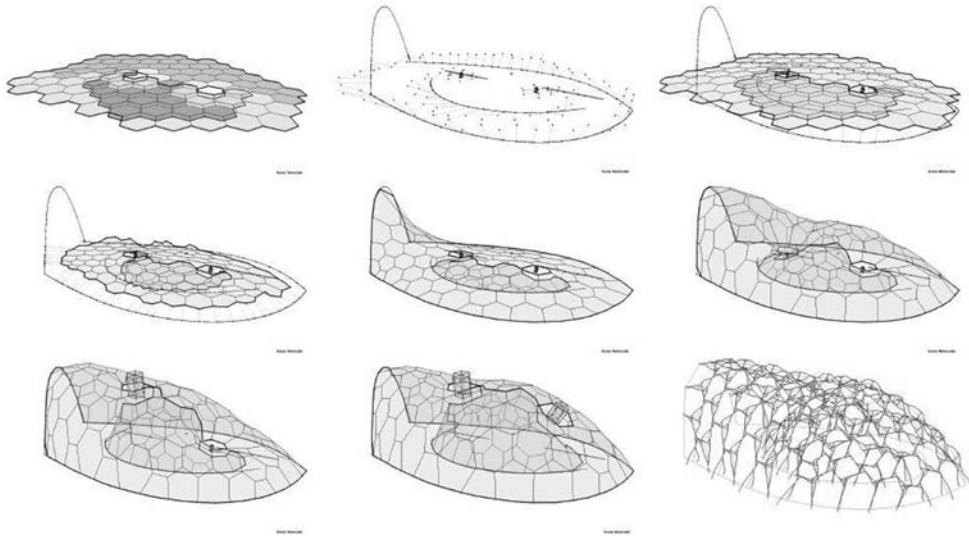


Figure 07. Formulation Process of Dermoid I with the Nucleus Engine in Maya

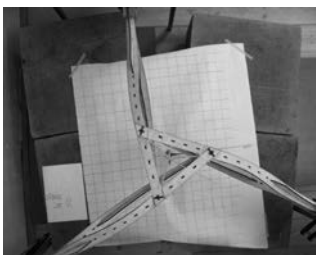


Figure 08 a,b. Measuring of one Module of Dermoid

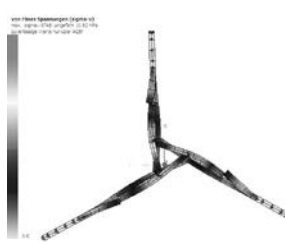


Figure 09. Detailed FE Simulation of a Single Dermoid Module Figure X: FEA of Overall Structure

concurrent parameters on the level of design, structure, material, production and assembly could be solved. The process allows an intuitive near to real time design process of complex structures with manifold topologies.

A first Dermoid structure was built for an exhibition in spring 2011 (Fig 07). The invitation to build a similar structure for the 2011 Copenhagen Design Week provided the possibility for a new site specific design of the structure and to integrate simulation based knowledge on the structures behaviour into the digital design process? This feedback allowed us to improve the structure through the grading of material thickness, beam and element dimensions (Lafuente).

Linking Dynamic based design and FE

As the main goal of the design with the physics engine is to enable fast iterations of the design the constraints of the time expensive calculation of structural performance is not integrated. However, structural aspects have a relevant influence on the grid shell's performance. Structural analyses afford the required information for a higher optimisation in terms of deformations and material utilisation. By means of FE-Modelling, the resulting sectional-forces and nodal displacements can be calculated and the influence of diverse geometric parameters can be analysed. This information provided feedback to the design environment where the beam arrangement and cross-section designations can be redefined. The optimisation and redefinition of the Dermoid gridshell was possible thanks to an iterative exchange of information between the parametrically-defined design and the FEM-based structural models.

A hybrid approach for Analysis

The Dermoid structure consists of a lattice shell composed of curved T-profiles made of bended plywood. Three beams are connected to each other into three legged modules in a hexagonal grid through reversible pinned tenon joints. On the one hand, the complexity of the FE-simulation resides in the innovative assembling process of the structure, making use of partially-bent members with composite sections and reversible joints, and on the other hand, in the irregularity of its geometry, which does not present any symmetry or repetition. This complexity prohibited a straightforward import of the structure into FE. It was rather rebuild within the analysis as an abstracted model made of line based curves. In order to do so, a hybrid approach towards the modelling within FE was chosen. Intensive measurements on a single physical module allowed us to deduct specific stiffness reduction factors (Fig. 08 a,b & 09).

These could be applied on the simplified overall structural FEA model. Within this the overall structural behaviour could be analysed and the results feedback into the design model. Several iterations and a link of the elements dimensioning allowed finally to build a 10 meter spanning and 13m long construction with a height of 4m out of 4mm plywood. The hybrid approach was possible as the bending of the material was constraint to the single modules. As these depended on the material performance the overall structure can be seen as a regular shell structure.

FARADAY PAVILLION

The Faraday Pavilion, a GFRP elastic gridshell for the 2012 Roskilde Music Festival with an irregular grid topology cannot follow this divide. Here the interaction on the level of elements and on the overall structure has to be included into the digital design. The geometry of the gridshell is form-found through the simulation of bending, where the calculation and steering of this aspect becomes a central part of the architectural and engineering design process. The process of design and analysis investigates how designers might incorporate models of behaviour at multiple scales and an incremental approach to simulation and construction allows for both the shell form and grid topology to emerge during the form-finding process as a negotiation between design intent and material tendency, instead of being determined in advance.

Design Concept

The Faraday Pavilion provides a place for people to rest, to meet, to eat and to socialize between concerts. From three circular seating elements emerge a series of gridshells, each with a span of about 10m, a maximum height of 4m and a total extents of approximately 30x40m, under which people can sit, lie and picnic (Fig 10, 11)

An Incremental Force-based Modelling Approach

The modelling of the structure begins with design intent, expressed through geometry, and then seeks to closely match that intent through a materially informed form-finding process that reflects the incremental method later used in the physical construction of the pavilion on site.

The sequence of design and simulation is firstly a generative architectural modelling process, using force-based simulation, which forms the input to a non-linear FEA simulation. Within the force-based simulation, the geometric



Figure 10. Faraday Pavilion at 2012 Roskilde Musical Festival at Day



Figure 11. MFaraday Pavilion at 2012 Roskilde Musical Festival at Night



Figure 12. Subsequent Solving of the Different Layers within the Structure and the Network Effect.

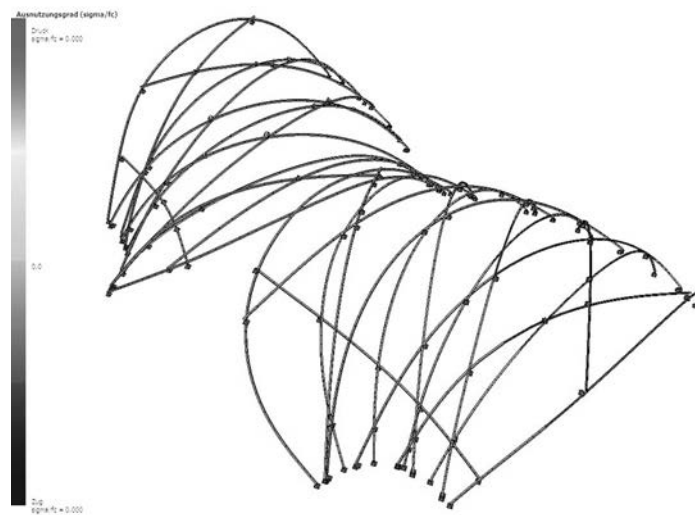


Figure 13. Result of the FEA of a Section of the Faraday Pavilion

definition of each element emerges from the negotiation between top-down and bottom-up parameters. Radial and then transverse elements are simulated sequentially, as individual elements whose path across the structure is influenced by material bending and length parameters, and the whole structure is subsequently simulated again to determine overall network behaviour, free from any artificial shaping forces; this qualitative simulation provides the input data for a quantitative simulation using the FEA software Sofistik AG.

Three Nested Models of Behaviour

Each FRP element is defined within the simulation by nodes connected by springs and bending constraints, whose transformation is linked to the consideration and iterative calculation of minimum bending radius and utilisation, its natural minimum energy bending behaviour, the attraction to a nonstandard target geometry, its connection to other elements within a structure and a consideration of the relationship between element length, the amount of bending energy stored within each element and the corresponding ability of the construction team to bend by hand on site. These different numeric and calculative models, which are applied to the material, element and structural scales, are solved together within a force-based simulation (Fig. 12).

FEA Simulation

A three-dimensional, geometric, non-linear finite element model defined with the FEA software Sofistik AG was used to analyse the resulting geometry and bending stresses after the shaping of the gridshell. The tubes and the connections between the radial and transversal layers were modelled as beam and coupling elements, respectively. The corresponding material and section properties were considered (Fig. 13).

THE RISE - INTEGRATED SIMULATION

The research-based installation “The Rise” (Fig. 14)⁵ – commissioned for the spring exhibition “ALIVE: Designing with Living Systems” at the EDF Foundation Espace in Paris – investigates to which extent the simulation of a material system can be integrated into the genesis of design. Real-time material and structural behaviour is examined in order to use the bending capacity of rattan bundles for structural purposes. Like a bush the 5m high installation has its own internal growth patterns that branch the material into a highly distributed aggregation from two growth sources. Similar to such plants as the strangler fig and other types of ficus, shoots can fuse in new circular

relationships, creating both structural strength and additional infrastructural network pathways that enable the networked system to reach its goal with a minimum of material.

Similar to the tropism that steer the growth of vegetative systems⁶ the biomimetic model of The Rise interrogates and collapses the usually discretized design cycle, iterating between modes of design action and analysis, such that both material intelligence and environmental sensing are embedded in a continuous particle-based physics simulation, calibrated through observed and measured real-world material behaviour. The simulation is interdependent with incremental topological reactions in the model geometry. Performance and behavioural analyses are fully integral to this time-based sensing / growth / material simulation algorithm. This approach opens the possibility of developing a modelling system that can become aware not only of the environment, but of its own reactions to external stimuli.

The generative design and fabrication systems developed for the 1:1 demonstrator of “The Rise” reflect a synthesis of multiple research questions related to:

- 1 The on-going investigation of material performances and structural behaviours in differentiated active bending assemblies (Lienhard).
- 2 The deployment of novel digital physics-based simulation processes for accretive morphogenesis and the interrogation of dynamic parameter spaces.
- 3 The development and application of biomimetic systems.

The adaptive growth algorithm and continuous physics-based material simulation deployed through the generative model work in concert to activate the characteristics of the rattan core as primary contributors to morphogenesis and enable an algorithmic procedure that is informed by both self- and environmental awareness. “The Rise” has been developed to behave like a climbing growth organism. It utilizes structural shoots and gripping feet that identify and cling to their physical surroundings as vine-like plants do. Additionally, it achieves structural triangulation through a process of self-grafting.

Material Systems

As a material assembly, “The Rise” is comprised primarily of rattan and high-density polyethylene (HDPE), and secondarily of steel and aluminum. Rattan is soft and is comprised almost entirely of a collection of continuous, tightly

packed hollow fibres which enable efficient transfer of water and nutrients, rapid growth and extreme bending⁷. Rattan is identified as the material of choice for several reasons. Most crucially, at the scale of the installation, its extreme pliability makes it highly suitable for our investigation into continuous material simulation during the modelling phase. The woody, fibrous rattan members perform multiple roles. They provide the installation's primary structure as bundled struts which then strategically split apart to engage in a geometrically varied branching moment-connection detail (Fig. 15) that operates in oppositional bending. The HDPE is deployed as a series of bespoke CNC-milled circular plates – referred to as “packing nodes” and “stars” – that respectively bundle and split and orient the rattan fibres (Fig. 16).

Integrating Morphogenesis, Calibration and Fabrication

Material properties in “The Rise” are embedded as part of the digital modelling process. The use of a centralised geometry system for the navigation of multiple design priorities proves crucial in this regard as careful management of model topology enables the integration of the continuous physical simulation with all aspects of the recursive morphogenetic growth algorithm (Fig. 17). But this careful topological strategy is simultaneously essential for its provision of a clear platform to calibrate the digital processes according to observations of physical experiments, and ultimately for managing the production process, sizing of members, and detailing of all aspects of the structural fabrication systems.

Morphogenesis

Some of the primary features of the model's growth process are its capacity to *branch* and *graft*. These model transformations are defined structurally by geometrically bespoke moment connections that allow for the model to actively seek goals defined by the design algorithm's response to its environment, which include reaching toward the light or back to its surroundings for structural support. The aforementioned demand that the material characteristics be reflected *during* the growth process combined with the on-going need to utilize output for both calibration and fabrication leads to the testing and application of a minimally triangulated truss-like model assembly expressed in a mesh. The springs are managed using the mesh vertices as individual particles to which mass and gravity forces are applied, and the mesh edges are characterized as a system of springs. The triangulated modules are allowed to accrete and branch according to virtual energy accumulated during the simulation. Each stage of accretion is defined as an incremental module. Each stage of branching is



Figure 14. The Rise – Installed in the Atrium Space of the 2013 Fondation EDF Espace in Paris

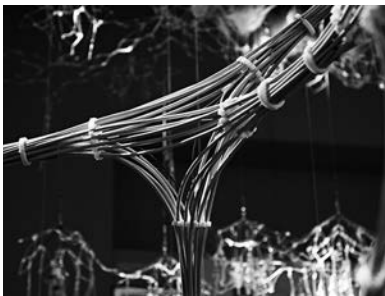


Figure 15. Detail of Demonstrator “The Rise” in Paris, showing rattan bundles managed by HDPE “Packing nodes” and the rattan deployed in oppositional active-bending branching moment connections as organized by HDPE “Stars”

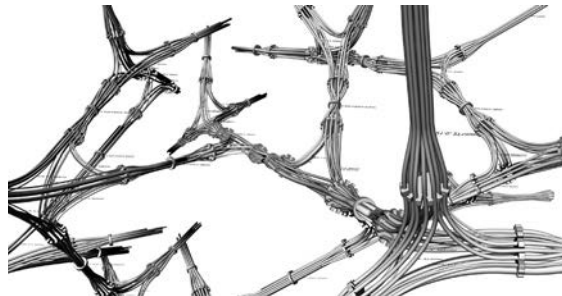


Figure 16. Computationally Generated Digital Model of Rattan Struts and Connection Nodes as Organized by HDPE “Packing nodes” and “Stars”.

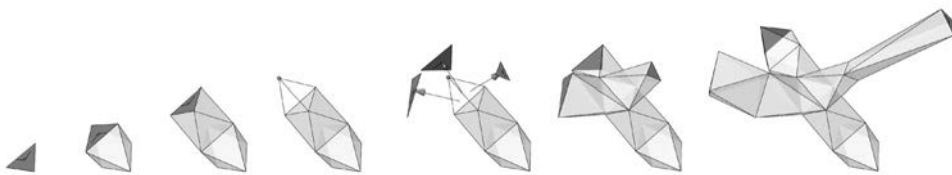


Figure 17. Minimally triangulated modular accretion and branching processes for simultaneous management of spring-based system and model topologies that register bespoke geometric relationships developed from the growth algorithm

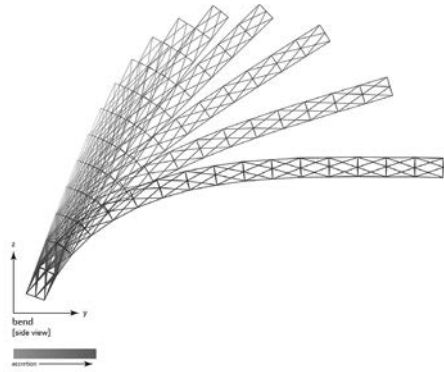


Figure 18. Spring model as it accretes additional modules and demonstrates incremental bending under increasing self-weight and length

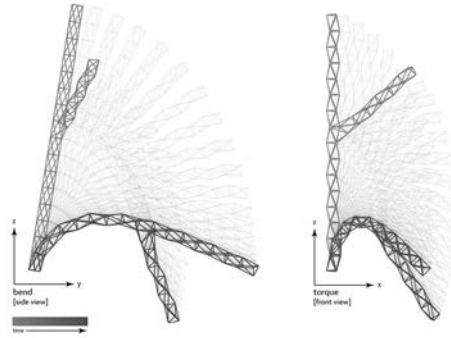


Figure 19. Spring model exhibiting torque/rotation due to asymmetrical loading/orientation of branches combined with bending

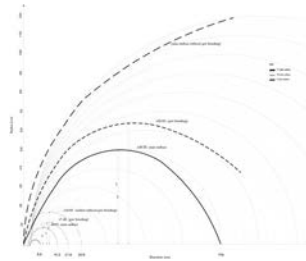


Figure 20,21. Bending radius and member failure as a function of section and pre-stress duration



Figure 22. Measuring multiple rattan thicknesses and bundling configurations bending under variable loads



Figure 23a. Localized spring deformation of morphogenetic model due to bending under self-weight during growth

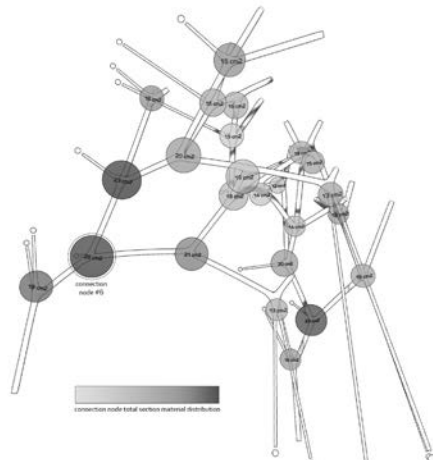


Figure 23b. Translation of local deformations to assigned material thicknesses along each connection node

defined by the growth tip being raised into a tetrahedron whose new faces define the tips for three new faces.

Calibration

The abstraction of individual bending members in the design and simulation model by means of an axis line seems to be generally appropriate and robust for even more complex active-bending assemblies⁸. However, in the case of “The Rise”, due to the dominant asymmetrical loading and cantilevering conditions during the morphogenesis, output of axis forces have a significant impact on the deformation figure of the elements and have hence to be considered. As a simple line based model cannot compute the emerging torque and rotation of the assembly the members in “The Rise” were modelled in a truss-like configuration. This allowed the model to adjust to both the open-ended nature of the algorithm and the accretion during the generative phase (Figs. 18 and 19).

A series of physical tests are performed and used for calibration of the computational modelling development. These examine the behaviour of rattan members in bending, both in the practical determination of minimum radius according to each section used in the assembly process (5mm, 10mm and 19mm) (Fig 20), as well as for the empirical observation of deformation in bending with variable loads and individual and bundled configurations (Fig. 21, 22).

Equipped with these observations, the growth algorithm is executed. As each growth iteration and simulation cycle is processed, the digital generative model generates a body of output data to be used for on-going analysis and as direct input to the fabrication model. These data supply information regarding local spring deformation associated with the topology of each branching, grafting and climbing moment. The topology of each branching event is captured through carefully managed data structure that houses the final fabrication model geometric bases as a series of aligned planes, individually arrayed according to each of these critical moments. It is through the data structure that multiple, interdependent fabrication drivers are specified and coded, including: information designating variable connection types (including regular branching, grafting, and structural tie-back), strut connectivity assignments, assembly sequencing, and member sizing.

The spring deformation data are registered specifically for the purpose of assigning material thickness to each connection node such that it is capable of managing local compressive and tensile stresses (Fig. 23 a,b).

These local forces must be managed in concert with a branching moment connection that achieves its architectural expression, geometric configuration and structural performance as a collection of rattan members operating against one another in oppositional active bending. Through a series of analyses and prototypes both digital and physical, a system for synthesizing these performance characteristics in fabrication emerges (Figs. 24 -27).

Prior to the design and detailing execution for the final installation in Paris, a series of 1:1 prototypes is built at CITA. The final calibration of the sectional thickness assignment strategy that is deployed for detailing the installation is executed through both direct observation and measurement of the material behaviours and comparisons of a 3D scan to the digital prototype model.

A PRELIMINARY RESUME: PERSPECTIVES FOR A NEW MATERIAL PRACTICE

These projects approach the same concern, the integration of material performance as an active design parameter employing four distinct trajectories towards the necessary integration of material behaviour into digital design systems. They share aspects of their methodologies, while also demonstrating differences and idiosyncrasies particular to their individual investigations. As a collection, the four projects evidence the partial mapping of a rich territory of investigation for digital representation and material practice.

In seeking to connect material behaviour to digital representation, all four projects take a pragmatic approach to measurement, inventing systems of measurement when pre-existing measures do not exist as a means to build up behavioural knowledge. This building up of knowledge can take place on the level of the element as in Thaw or on the scale of an element as within the Dermoid project. The need for such bespoke measures demonstrate that simulation techniques can only develop non-generic descriptions of behaviour to the extent that they are informed by an empiric knowledgebase, gained in these projects through direct physical testing and measurement.

Designing with material performance means designing with time based processes. Where this definitely relates to the behaviour of material under changing constraints within assembly and use of a structure it is especially true within the setup of the digital models. It seems, that in order to capture the emerging forces, a digital model needs a neutral start point from which it is charged and assembled. This modelling approach was successfully applied

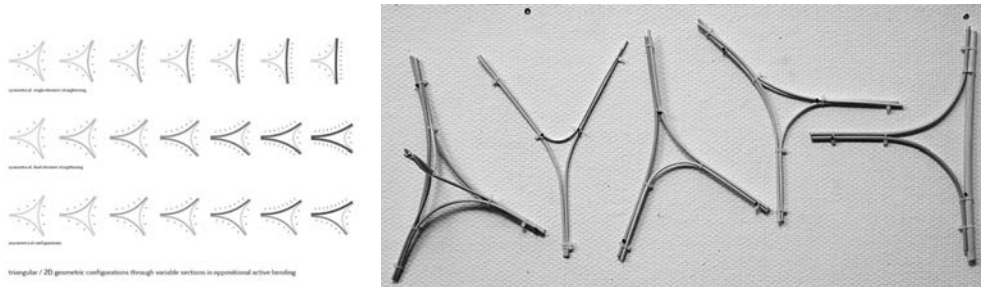


Figure 24a, b. Digital and physical examples of oppositional active bending and connection node geometric responses resulting from variable thickness/bending stiffness of specific elements

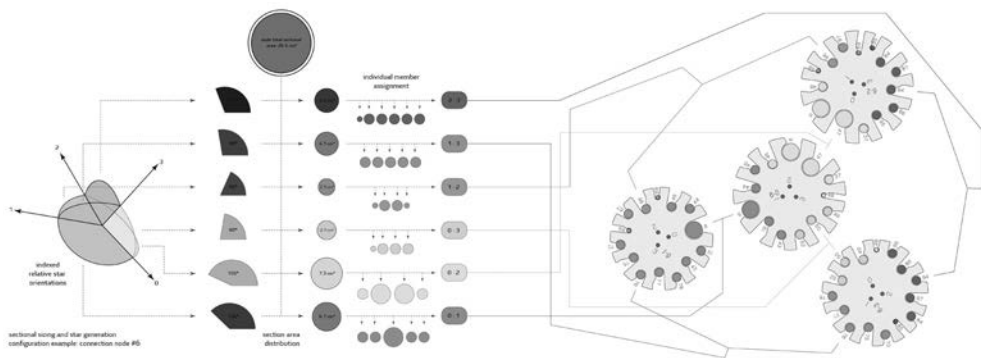


Figure 25. Connection node development: connectivity/topological assignments, geometry analysis, total sectional material allocation, and individual member assignments, and final star configuration for connection node #6

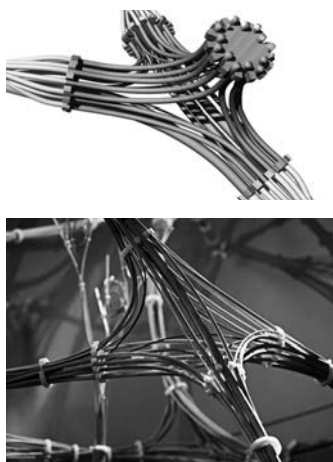


Figure 26a, b. Digital representation of connection node #6 and the physical manifestation of connection node #17, demonstrating two different, bespoke branching geometries achieved through variably-sized and numbered oppositional active-bending rattan members, managed through the HDPE “star” configurations.

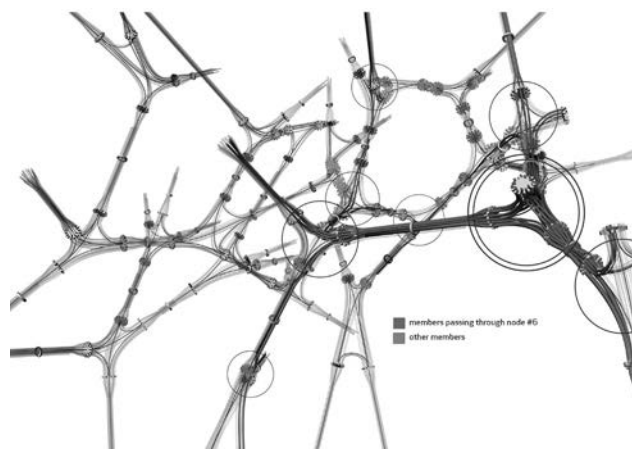


Figure 27. Tracking member continuity for all rattan members that pass through connection node #6

within the Faraday pavilion. More complex assemblies as in Thaw show yet the limit of this approach and further research is needed in order to better understand how lightweight digital design systems can be informed about existing forces, while staying in reach of design considerations.

However, through time based processes the ability of computation is demonstrated to negotiate and synthesize multiple constraints and parameters. The projects Dermoid, The Rise (Fig. 28) and Faraday Pavilion projects show how requirements and limits from material, machining, assembly and use can be incorporated into constraints. Where these have to be numerical due to the computational basis of our approaches the parameters can yet be of very different kind, ranging from simple limits, over defined numerical domains and gradients to the description of the behaviour through non-linear formulas or integrated simulation. The toolset for a new material practice has to be adaptable and bespoke and able to incorporate all of these.

Where all four projects are equally determined by the geometrical boundary conditions of the environment the role of geometry in steering material towards a desired state or design intent is approached differently in the Faraday Pavilion, Dermoid and The Rise. The Rise defines solely a set of starting vectors, from which a structure emerges based on a material system following the logic of branching and joining. By collapsing the space between generation, simulation, analysis and feedback and reducing the distinction between each to a brief moment of internalized computation The Rise eliminates the expression of design intent through geometry and limits design interaction to the level of code. In contrast, the Faraday Pavilion defines a desired geometry, the target trajectory of radial elements, towards which material is attracted subject to



Figure 28. "The Rise"

its limits. Where *The Rise* ventures into the unknown, the *Faraday Pavilion* moves towards a known geometric state but stops short. In contrast, the *Dermoid* design process pursues a different strategy, developing a space in which many configurations can be found based on the adjustment of boundary conditions. We argue that this variety of approaches reflects the role of the simulation process as a tool for design, rather than analysis, and is the result of the associated need to integrate the simulation within a larger design workflow, within which geometric intention can reside in different places.

The cross examination of the projects identifies communalities in approaches for a new material practice. Here it is especially the ability of computation to integrate processes: The Measurement of material performance - as the behaviour of physical models on the level of material, element and structure can be encoded and informs Simulation of material performance. Rather being an analytical tool simulation is here understood as a tool for design and hence directly integrated in the workflow. Simulation allows for implanting the physical behaviour and interaction of materials into the digital design model. It becomes a central part of a project's overall solution and allows and necessitates a particular detailing for material behaviour and specification of material performance and the reiteration and evaluation of the outcome through digital fabrication considering material properties.

NOTES

N.B.

Thaw was developed by CITA (Mette Ramsgard Thomsen and Karin Bech) in cooperation with Behnam Pourdeyhimi, NC State University, College of Textiles and supported through The Nordic Culture Fund, Realdania, Lisbon Architectural Triennale, Royal Danish Academy of Fine Arts, School of Architecture

Dermoid is an outcome of the collaboration of CITA and SIAL on the base of the VELUX Visiting Professor Programme 2009–2010 of the Villum Foundation and the 2011 Danish design Week. The *Dermoid* demonstrators 1-3 had a core team from CITA (Martin Tamke, Anders Holden Deleuran, Aron Fidjeland) and SIAL (Mark Burry) which was collaborating with a wide set of members from CITA and SIAL, as well as the Structural Morphology Group around Christoph Gengnagel at UDK in Berlin and the students from Copenhagen and Melbourne.

The *Faraday Pavilion* is a cooperation of CITA (Paul Nicholas) with Ali Tabatabai, and the Structural Morphology Group, UDK, Fiberline Composites and Hempel and was supported through The Danish Council for Independent Research, Humanities as part of the 'Designing Material Materialising Design' PostDoc.

The Rise would not have been possible without the enduring efforts from the CITA team of David Stasiuk, Martin Tamke, Hollie Gibbons and Shirin Zhagi on design and development, Hasti Valipour for the Parisian support, Carole Collet for the invitation to the exhibition and excellent curatorship and Mette Ramsgaard Thomsen for the guidance and support.

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