DIGITAL STEAM BENDING:
RECASTING THONET THROUGH DIGITAL TECHNIQUES

ABSTRACT

Digital Steam Bending is a design and fabrication research project that investigates the historically relevant, regionally significant technique of steam bending using advanced parametric software modeling, STAAD structural analysis, and computer numerical control (CNC) fabrication methods to reenvision the nearly forgotten technique of wood steam bending developed by Michael Thonet in the 19th century. In doing so, Digital Steam Bending performs several operations: it reclaims a forgotten technique of fabrication and reframes it through the lens of contemporary digital craft, it claims new ground in the traditional periphery of architectural practice through shifting scales, and it confronts the difficulties of digital design and digital form generation through applied material practices. It also gestures toward the possibilities that regional resources and craft may leverage against high-carbon globalized manufacturing.

Digital Steam Bending was conducted as a series of interconnected feedback loops in which material resistance, formal manipulation, and digital tools were each allowed to influence the others. Material testing on various wood species began simultaneously with the development of formal digital models, where built-up aggregations of unique but similar individual parts were parametrically modified to derive possible means of tectonic connection and overall form in search of spatial, architecturally scaled assemblies and structures. Locally harvested, FSC-certified, air-dried white oak evolved as the optimal material due to its high density, consistency of grain, natural durability, and local abundance. Several base components were designed, tested, and refined before ultimately arriving at full-scale fabrication. The assemblies were then installed and documented as an exhibition at the University of Michigan's Taubman Gallery and a full-scale gateway structure at Frederik Meijer Gardens in Grand Rapids, MI, during Art Prize 2010.

Steven Mankouche
Taubman College,
University of Michigan

Matthew Schulte
Taubman College,
University of Michigan

Joshua Bard
Carnegie Mellon University

1 INTRODUCTION

Digital Steam Bending posits a number of open-ended questions that confront current trends in architectural practice and academia. Specifically, Digital Steam Bending challenges the discipline's tendency to ignore historical methods of craft and fabrication and suggests a shift away from formally based, parametric design toward a more critical, integrated model of digital and material practice.

The emergence of powerful software platforms as design tools, along with increased access to CNC fabrication tools, has extended the dexterity and physical command of architects and designers. Given this, the authors propose an expanded research model that integrates tacit material knowledge with digital workflows where material resistance and fabrication processes provide feedback into digital realms and vice versa. Digital Steam Bending emerges from the confluence of a unique, historical, skill-based craft and a natural, if unpredictable material, recast through the application of parametric digital tools and advanced CNC fabrication techniques. It sets up a continuous negotiation between intelligent digital models, spatial consequences, and physical artifacts in the evolution of design strategies that move across traditional boundaries of scale and design practice.

Inspired by the elegance and the unique history of the Thonet No. 14 café chair (Figure 1), we began asking ourselves: can we, as architects and designers, find fertile ground in revisiting methods of fabrication that were once successful, but were ultimately abandoned in the drive toward modernity? It seemed to us that strategies for fabrication that predated electrification and the development of the global industrial complex provided opportunities to engage architectural modes of thinking and making that are rich with historical significance, that connect us to the local environment, and that provide avenues for design thinking in truly sustainable ways. The availability of digital computational resources and tooling, with their ensuing biases and sometimes problematic tendencies within the discipline and practice of architecture, could then be set at both collaborative and cross-purposes to applied material research.

figure 1

figure 2

figure 1
Steam-bent snowshoe, a No. 14 café chair, and the Thonet label.

figure 2
Barefoot workers at a Thonet factory. (Source: Vegesack 1997.)

figure 3

figure 4

The success of the Thonet No. 14 café chair is difficult to overestimate. But at the heart of Michael Thonet's success were significant advancements in steam bending techniques for forming solid wood members using steam heat, rigid formworks, and steel tension straps in the shaping of wood members. Steam bending is a pre-industrial fabrication process that was used extensively in the Great Lakes region of the United States as a traditional method for fabricating canoes, snowshoes, storage barrels, and even early automotive components. Steam bending subjects a piece of air-dried lumber to steam heat and moisture, thus momentarily softening its fibers and enabling it to be bent in multiple directions and to a degree that would be prohibited by cool, dry timber. Steam bending allowed the overshaping of wood material, thus producing "a secondary natural aesthetic" (Gleiniger 1998), but early uses dating back to the late 1700s were technologically underdeveloped and almost exclusively functional. The shipbuilding industry was an early adopter of this technique for forming the curved members used to build ship's hulls. However, the technique was most often deployed in one-off form-fitting applications for framing and "planking up." The necessity of use was less an intentional design choice, more a stopgap measure driven by the high cost and scarcity of durable metal fasteners, which were required to force compliance in the ship's timbers.

In Europe, Michael Thonet significantly developed the steam bending process for furniture making, effectively transforming it from a custom technique used only by highly skilled craftsmen to a mechanized and refined industrial process. Developments in wood steam bending ultimately gave rise to an entire line of bentwood furniture, the most iconic of which is the café chair No. 14, often referred to simply as the "Thonet chair."

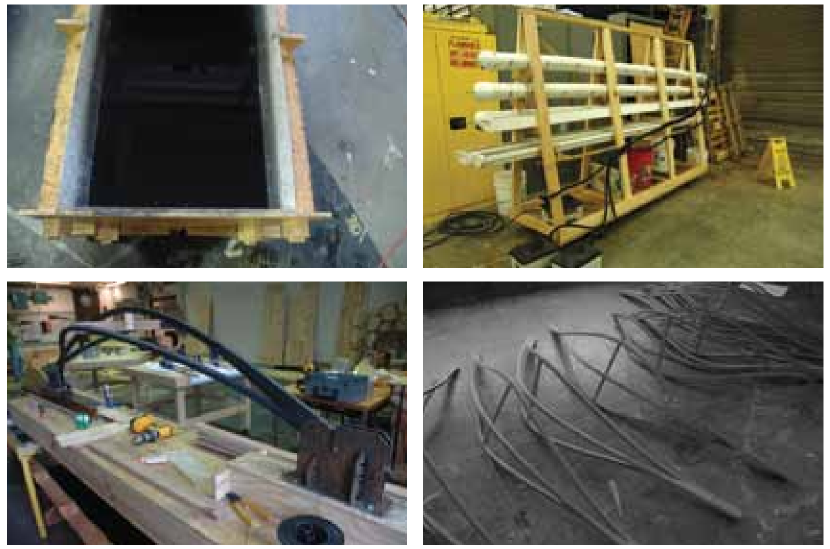
By 1930, global sales of the No. 14 chair had reached 50 million units (Gleiniger 1998). While the No. 14 chair is eminently recognizable for its design, it is also one of the most iconic symbols of mechanized industrialization and is considered by many to be the first global industrial product. In its success, the No. 14 chair made great strides in separating skilled craft and material knowledge from industrial production and subsumed a material ethic of efficiency in a culture of industrial consumption.

In the American Great Lakes region, steam bending was often used in the fabrication of shipping vessels, but the technique was also employed in other industries such as carriage and automobile manufacturing. But since the peak of production in the early 1900s, steam bending has become virtually obsolete, due in part to global demand for timber, poor resource management, and increasing labor costs. These facts, coupled with new material developments, caused the furniture industry to jettison steam bending for newer, more modern materials and processes. Steel quickly replaced wood as a more expedient (and modern) material for construction and fabrication. Steel was readily available; it was also durable, and most importantly, the techniques for fabricating with steel yielded highly predictable, consistent results. Steel virtually eliminated material resistance

figure 3
1931 Thonet catalog advertisement.

figure 4
1944 Fortune magazine advertisement. (Source: Ngo 2003.)

figure 5



left to right, top to bottom: figures 7, 8, 9 and 10

figure 6

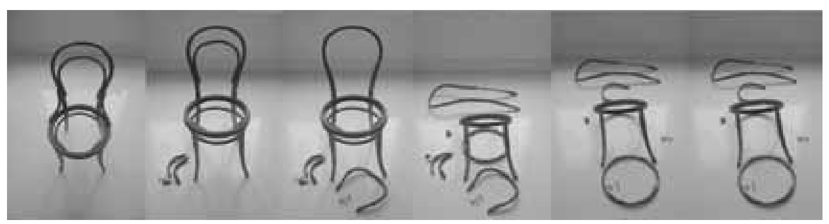


figure 11

figure 5
Eames splint. (Source: Ngo 2003.)

figure 6
Eames lounge chair.

figure 7
Water bath.

figure 8
Mobile steam chambers.

figure 9
Variable jig.

figure 10
Formed ribs drying.

figure 11
No. 14 café chair, disassembled.

from the process of fabrication, thus allowing an even greater step away from the necessity of craft and skill in making. As the demand for steam-bent wood products declined, the skill to produce such items was all but lost. By the late 1920s even Thonet manufactured chairs out of chromed tubular steel (Figure 3).

Further advancements in chemistry also played a role with steel to seal the fate of steam bending. Prior to the early 1900s, adhesives lacked sufficient quality and durability, keeping the plywood industry at bay. In 1912 Leo Baekeland, chemist and inventor of the phenolic resin Bakelite, suggested the use of his synthetic resin in forming plywood. Baekeland's adhesive resin yielded an extremely strong, durable, and virtually impervious bond (Ngo 2003). The plywood industry evolved around this technological development until the demand for veneer-ply boat hulls and aircraft parts during the war years propelled it to domination in the wood industry (Figure 4).

Most notably, Charles and Ray Eames developed many of the benchmark articles of wood veneer products that epitomized the modern lifestyle of the 20th century (Figures 5 and 6).

Although plywood products use many of the same techniques as steam bending, including bending jigs, fixtures, and heat, they also, by necessity, use adhesives in relatively large quantities, which often have pernicious chemical by-products and can be unfit for human contact.

figure 12

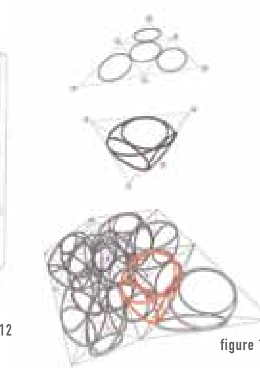


figure 13

figure 14

figure 15

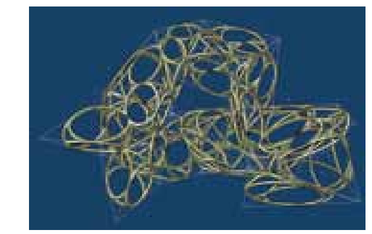


figure 16

2 MATERIAL(S) OF CHOICE

Contemporary research and discourse within design fields (and many others) is increasingly focused on dealing with the environmental impact of many years of expedient production. The energy cost and carbon footprint of products made from plastics and metals—especially those products (or raw materials) that travel thousands of miles before reaching the point of consumption—are extremely high. Further environmental costs are incurred when nonbiodegradable materials enter the waste stream. Steam bent, all-wood structures are completely biodegradable, and steam bending allows complex formal geometry to be achieved without the use of adhesives or metal fasteners. Steam bending can be accomplished with a minimum of energy input and requires no toxic chemicals or adhesives. Choosing locally produced, locally harvested materials as the focus for research also allows design thinking and architectural discourse to encompass vernacular material roots and historical precedent, while leaving open the possibility for engagement with contemporary digital practices.

The process of steam bending involves the coordination of a number of competing variables—time, moisture, temperature, etc.—but is conceptually rather simple. Dense, consistent, straight-grained woods are preferred. The material is sawn into sections or blanks, which are then soaked in a bath of plain water (Figure 7) to bring the moisture content as close to the fiber saturation point as possible. Soaked timbers are placed in a steam chamber (Figure 8) where heat from the steam penetrates to the thickness of the sections, temporarily allowing the cell walls of the material to become pliable and thus allowing the sections to be grossly reshaped. The formed components are allowed to cool and dry, at which point they will remain permanently in their new shape (Figures 9 and 10).

3 FROM THE PERIPHERY

Traditionally, steam-bent woodwork was an afterthought to the primary production of architectural space. Bentwood trim and furnishings, when used, were often chosen as an analogy to other malleable materials like iron or plaster. Thonet's contemporaries Henry van de Velde, Victor Horta, and Hans Wegner occasionally used decorative steam-bent wood, but architectural applications only aspired to become small-scale accoutrements to the essential tectonics of construction and the execution of architectural space. Even today, material and tooling limitations dictate the scale of individual pieces of steam-bent wood, but the use of digital parametric tools aids in shifting the application from the scale of furniture up to an integrated, architecturally scaled aggregation.

4 THE DNA

Much of the Thonet furniture line was available as "knock-down" pieces, prefiguring flat pack and modular product strategies more than a century before IKEA. The No. 14 chair required only a handful of individual parts, which could be densely packaged for shipping and then assembled after reaching their final destination (Figures 11 and 12). By resolving the chair into a small number of rational, standardized components, an entire line of furniture was able to share many parts and tooling. This

figure 12
No. 14 chairs packed for shipping.

figure 13
Steiner ellipse building blocks.

figure 14
Space frame elliptical model (bottom) and full-scale construct (top).

figure 15
Material failures.

figure 16
Digital parametric model.

figure 17

figure 18

simple idea promoted the refinement of the process and the standardization of parts to a degree that had previously only been imagined. Streamlining the operation enabled consumers to access a wider variety of affordable choices. But each separate component required its own dedicated jig, which meant that the spectrum of individual choices was discretized, and therefore many formal outcomes that could be rendered through steam bending were precluded.

5 STEINER ELLIPSES

Inspired by the graceful, high-arching seat back of Thonet's No. 14 café chair, we began our research by exploring aggregations of wooden loops—bent first in one direction, then in two. We developed digital and physical models as well as a series of adaptable formworks for producing ellipses, which were then grouped and aggregated to compose tetrahedral space frames based on Steiner ellipses (Figures 13 and 14).

material capabilities and refined the digital parameters for material processing. It provided a basis for bringing the material failures (Figure 15) into communication with a set of digital parameters that could then be modified to predict the feasibility of other constructs (Figure 16). Each module of a larger framework is based on dynamic clusters of four Steiner ellipses. This development led to a highly adaptable structure that flowed from symmetrical and asymmetrical conditions and applications. Although its fluid and adaptable nature showed promise for formal operations, its intensive requirements for formwork, tectonic fastening, and material limitations sidelined it as a primary strategy for rendering robust structure at an architectural scale. Because the circumferential distance of a modestly sized ellipse began to exceed the reasonable availability of material and tooling strategies, the development of large-scale constructs was at odds with our desire to explore structurally and materially efficient models for engagement at scales larger than that of typical furniture.

6 THE WISHBONE

In further research, we developed a second structural component, a rib or "wishbone" (Figure 17). This development came as we were processing the results from several space frame prototypes. While we had developed a means of manipulating material and modeling behavior, we were limited in scale by the ellipse's geometry and structural tendency to deform unpredictably as the scale of assembly increased. The early process of milling the raw material into square blanks for bending ellipses, we realized, could be manipulated through digital tooling (in this case a CNC water jet cutter) to open up another range of forms and processes, which ultimately yielded greater success. Similar to the ellipse construct, formal strategies and material assemblies were explored through digital modeling and physical testing.

Creating digital correlations between the geometric behavior of the construct and the material properties was necessary to gain control over the design at the level of the parameter and in the expression of design intent. In the early wishbone prototypes and the gateway structure (described below in greater detail), we implemented an iterative process of digital manipulation and computational optimization, to produce a schedule of parts providing the precise dimensions and features of each unique component. The digital model is constructed such that a two-dimensional cut sheet is generated directly from geometry present in the model. This enables a fluid translation between model, material, and tool as the design evolves. Wood blanks are tagged with a serial number indicating the part's identity as well as its position relative to the whole, then drilled and sliced in preparation prior to soaking. Our method for forming the pieces is similar to methods used in the shipbuilding industry in that it does not require a tension strap, but it makes a significant departure from previous methods in its use of a variable jig. As the blank is compressed, the sides of the wood member spread outward and bow upward. By modulating the physical tool and balancing between variables of time, temperature, and physical movement, the individual pieces may be coaxed into the form designed through digital means. The resulting components may then be assembled into a thickened sheetlike lattice. The ribs yield a variety of inherent construction logics based on nodal connection points, which form a robust,

figure 17

Split blank, formed rib, and prototype aggregated arch structure.

figure 18

Early Thonet cast iron mold. (Source: Vegesack 1997.)

flexible structure. In this case, the expression of form is directly related to the process of fabrication and the underlying geometry of the part. The degree of curvature ultimately achievable through this process of fabrication is limited by a threshold for material failure; most of the components within the structure are formed near the limit. Some components are imparted with lesser degrees of camber and spread to increase variation and sculpt the natural tendency toward arch structures.

7 NATURAL SELECTION: MATERIAL RESISTANCE AS DESIGN GENERATOR

It is important to emphasize that the traditional uses of steam bending do not embrace the notion of variability. The specificity of Thonet's cast iron jigs prescribes a process aimed at forcing an unpredictable material such as wood to submit to a standardized form (Figure 17). The history of Thonet's success is illustrative of the historical trend for craft to be focused either on the production of one-off, labor-intensive constructs, or for the refinement of tooling used to achieve consistently reproducible copies. For Thonet, consistent parts were vital to production. The forms themselves were complex, but the parts could be produced by unskilled laborers. Thonet's advancements in industrial processing did indeed yield many long-lasting and remarkably consistent pieces, but his process also involved enormous quantities of waste and failure. Requiring an unstable and often low-precision material to conform to tight standards meant that adaptability through open systems of feedback was not an option.

Our method of research through making, on the other hand, describes an open process of evolution in which systems for thinking, seeing, and making all remain in dialogue with each other, connected by digital environments, material constraints, and tooling biases. By not positioning the endgame as the achievement of a fully developed construct in compliance with independent representational modes, unexpected consequences of making are allowed to influence and ultimately richen the design. It was well known to us that wood, especially white oak, will ebonize when placed in contact with chemicals (including plain water) that accelerate the process of oxidation. Our choice of tooling, in this case a CNC water jet cutter, used to administer the custom slices to the wood blanks caused a drastic, localized blackening of the wood fibers due to iron oxide in the water jet's supply tank from many previous hours of steel processing. Rather than abandon the CNC slicing for another analogous process, we made the choice to fully ebonize the material prior to bending by soaking the

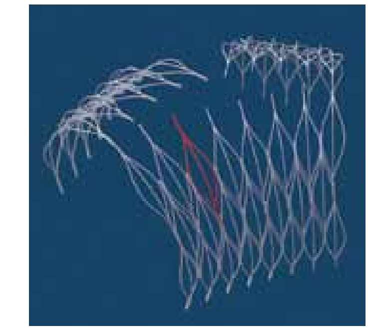


figure 19

figure 20

figure 19

The gateway parametric model—a digital jig.

figure 20

Full-scale gateway installed at Frederik Meijer Gardens, Grand Rapids, MI. (Source: Beth Singer 2010.)

figure 21

STAAD analysis, graphical representation of failure loading conditions.

figure 22

CNC cut fabrication forms.

figure 21

pieces in excess water from the tank. The result was a full, even blackening of the wood fibers which, when taken in the context of site and composition, yielded a strikingly serene and quiet formality in contrast to the bold colors of a garden in bloom (Figure 20). In hindsight, the acceptance of the biases of tooling and materials led to the understanding and exploitation of a completely natural, nontoxic realization of one of the most important features of the project.

8 EVOLUTION: QUESTIONING THE JIG

Much of our research and continued methodology is focused on situating "physical" knowledge in digital environments. Embedding material behavior and tacit knowledge acquired through direct physical contact with material and process allows us to bring digital spaces into closer analogy with the physical ones they represent. Thus, material limitations and failures become significant form generators and informants to our digital models. The buildup of physical knowledge enables a flexible and often accurate way of extrapolating digital output to the physical world. However, it is by no means an absolute connection, and thus the feedback moves both ways. Digital development runs along a parallel track with physical making. It allows us to accept the deviations and the inherent imprecision of natural, idiosyncratic materials.

It is often the case that physical making is one step ahead of the capability of the digital model to reflect the ability of materials to assume new form or provide certain structural characteristics. The process of design is a balancing act of reciprocity and speculation between the digital and the physical.

In contemporary architectural practice and academia, and within the discourse surrounding each of these connected aspects of the discipline, it often becomes problematic to strike a balance between the allure of digitally crafted space and form and the ability of materials and structural systems to be resolved into a functioning architecture. Digital spaces tend toward designs that are conceived without substantial influence from material capabilities—they are the confluence of infinitely adaptable, malleable, compliant, homogenous materials such as plastic, steel, and concrete, all of which have large environmental footprints. Furthermore, many approaches to digital design and fabrication rely heavily on the extensive use of CNC tools to produce a vast array of small parts, each of which only requires the translation of geometry from a digital model into material; they do not require the designer or fabricator to develop or possess a tacit understanding of the material. Problematically, the discipline produces a large number of projects that fail to surpass the novelty stage of parametric design or to position the work as a means of critical engagement or enquiry.

Our research gains traction by engaging alternative methods of design thinking and making through open dialogue between digital environments, materials, processes, and structure. By embedding material properties and construction logics within digital environments, the outcome(s) of successive evolutions of both physical making and digital projection converge in the thickened threshold between digital fragments and material consequences. Through this exchange between the digital and physical, constructed digital environments are made to grapple with traditionally difficult material characteristics such as elasticity and, in this case, material springback, while also keeping precise track of a mutating, detailed set of instructions required to process material into unique form. The feedback loops that drive the development of the model are ones in which material

figure 22

is tested, formed, and often taken through the point of failure. We translate tacit knowledge and measurement of the empirical world into increasingly sophisticated and robust digital parametrics that liberate us to explore beyond the scope of limited human piece-wise design strategies. It cannot often be fully determined what range of outcomes will result from the simultaneous interactions between complex parameters. Thus, the model is itself a digital jig of sorts, which can be placed in the service of the designer as a collaborator for exploring a range of material expression.

Thonet's jigs were templates of the parts. However, in our research, as in our digital models, each piece is unique, and thus the armatures for production must allow for the complete range of flexibility built into the digital model. In this sense our jigs are more an instrument to be played, than an exact and fixed formwork.

9 STRUCTURAL TESTING

As an integral component in the development of this research, structural analysis (STAAD) became useful in understanding the complex physical relationships at the level of the part and the whole that stem from the digital models. At the outset we hoped to illuminate weaknesses in the structure and gain insight into its feasibility at full scale, while introducing an additional feedback loop to our design process.

Our structural model was developed first in Digital Project, where we created a framework of driving geometries. STAAD software was then used to test the model, assuming a broad range of conditions that simulated the effects of structure self-weight, wind, and snow loading up to regional code requirements.

The results of the testing show that the structure is remarkably stiff and efficient given its minimal weight. The lateral spreading of members yields an approximate triangulation of structure providing integral resistance to lateral forces similar to a space frame. In combination, material properties and part geometry allow the system to undergo remarkably large deflections without part failure. In wind load simulations between approximately 75 and 85 mph, member stresses move into the upper one-third of the acceptable range, and deflections increase to the limit of serviceability. Our testing continued up to 90 mph, a benchmark standard for wind-loading requirements in our region of the country. At this level of load, data indicates that members within the system develop theoretical stresses in excess of the allowable limits; therefore, we consider our structure to have failed.

figure 23

figure 24

figure 23

Temporary centering used during assembly.

figure 24

Structure nearing completion during pre-assembly.

10 NOTES ON ASSEMBLY

When the means and action of fabrication are divorced from the process of design (a particular risk of closed digital systems), aspects of the actual construction and assembly processes are placed at risk of terminating or at least compromising the integrity or intent of the design. Digital tools offer powerful ways of envisioning and directing design strategies, but they can also promote inattention to the processes required to realize full-scale work.

In our case, the entirety of the arch structure was developed alongside an additional but invisible set of construction formworks that enabled the mutable and complex aggregation of components to be physically joined (Figures 21–23).

The nature of the process is one of coordination and constant recognition of the structural tendencies and resilience of the incomplete structure and subassemblies. Within our research and fabrication, it is only at this point of the process when it becomes necessary to establish a rigid formwork or scaffolding in order to move between the gravity-free virtual world, real materials, and space.

11 CONCLUSION

Digital Steam Bending points to an expanded model of digital and material practice in which powerful computational tools extend one's capability to explore the reciprocity between digital and physical realms across a range of scales. Through this research, the authors have sought material resistance as an active collaborator in the generation of design, providing insight into the potential of materials and data to be transformed by physical processes and vice versa through a series of interconnected feedback loops. Digital Steam Bending has recovered a nearly lost art and craft and forged new ground for steam bending at an architectural scale.

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PROCESS THROUGH PRACTICE:
SYNTHESIZING A NOVEL DESIGN AND PRODUCTION ECOLOGY THROUGH DERMOID

ABSTRACT

This paper describes the development of a design and prototype production system for novel structural use of networked small components of wood, deploying elastic and plastic bending. The design process engaged with a significant number of different overlapping and interrelated design criteria and parameters, a high level of complexity, custom component geometry, and the development of digital tools and procedures for real-time feedback and productivity. The aims were to maximize learning in the second-order cybernetic sense through empirical experience from analog modeling, measurement, and digital visual feedback and to capture new knowledge specifically regarding intrinsic material behavior applied and tested in a heterogeneous networked context. The outcome was a prototype system of design ideation, conceptualization, development, and production that integrated real-time material performance simulation and feedback. The outcome was amplified through carrying out the research over a series of workshops with distinct foci and participation. Two full-scale demonstrators have so far been constructed and exhibited as outputs of the systems and processes developed.

Jane Burry
SIAL, RMIT University

Mark Burry
SIAL, RMIT University

Martin Tamke
CITA Royal Danish Academy of Fine Arts

Mette Ramsgard Thomsen
CITA Royal Danish Academy of Fine Arts

Phil Ayres
CITA Royal Danish Academy of Fine Arts

Alex Pena de Leon
SIAL, RMIT University

Daniel Davis
SIAL RMIT University

Anders Deleuran
CITA Royal Danish Academy of Fine Arts

Stig Nielson
CITA Royal Danish Academy of Fine Arts

Jacob Riiber
CITA Royal Danish Academy of Fine Arts