Digital Steam Bending:
Re-Casting Historical Craft Through Digital Techniques

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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 modelling, structural analysis and CNC (Computer Numerical Control) fabrication methods to reinvision 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 digitally assembled, modified and reassembled 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 as full-scale gateway structure at Fredrik Meijer Gardens in Grand Rapids, Michigan during Art Prize 2010.

ON APPROACHES: digital approaches and the 'real world', sustainability, alternative research methods
KEY WORDS: Thonet, steam bending, parametric, biodegradable, fabrication, testing.

Figure 1: Steam bent snowshoe, a No. 14 Café Chair and the Thonet label

INTRODUCTION

The thrust of this paper is to use Digital Steam Bending to posit a number of open-ended questions and claims that call into question current trends in architectural practice and academia. Specifically, this paper challenges the discipline's tendency to ignore historical methods of craft and fabrication and to assert digital design without context or material considerations. These questions emerged as a result of work conducted under a grant through the University of Michigan, aptly named Research Through Making. 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 which were once successful, but were ultimately abandoned in the drive toward modernity? It seemed to us that strategies for fabrication which 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.

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 techniques for forming solid wood members using steam heat, rigid formworks, and steel tension straps to shape wood members, i.e. "steam bending". Steam bending is a pre-industrial fabrication process which was used extensively in the Great Lakes Region of the United States as a traditional method for fabricating canoes, snowshoes, 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 such a degree as would be prohibited by cool, dry timber. Steam bending allowed the over-shaping of the material thus producing "a secondary natural aesthetic" (Gleiniger 1998, 40), but early uses, dating back to the late 1700's were technologically underdeveloped and aimed almost exclusively at functional uses. The shipbuilding industry was an early adopter of this technique for forming the complex, curving members used to build ship's hulls. However, the technique was most often deployed for one-off form fitting applications during the framing and "planking up" processes for the hulls of wooden boats. The necessity of use was less an intentional design choice so much as a stop gap measure driven by the high cost and scarcity of durable metal fasteners which were required to force compliance in the ship's timbers. In the United States, during the 1840's and 1850's inventor Thomas Blanchard and shipbuilder John W. Griffiths both promoted the use of adaptable steam bending machines but met with only mild success due to high cost and economic trends pushing the shipbuilding industry toward steel manufacturing (Thiesen 2006).

In Europe, Michael Thonet significantly developed the steam bending process for furniture making, effectively taking it from a custom technique used only by highly skilled craftsmen to a mechanized and refined industrial process. On July 10th, 1856 Michael Thonet received a patent from the emperor of the Austro-Hungarian Empire to produce chair and table legs from steam-bent wood (Wilk 1980).

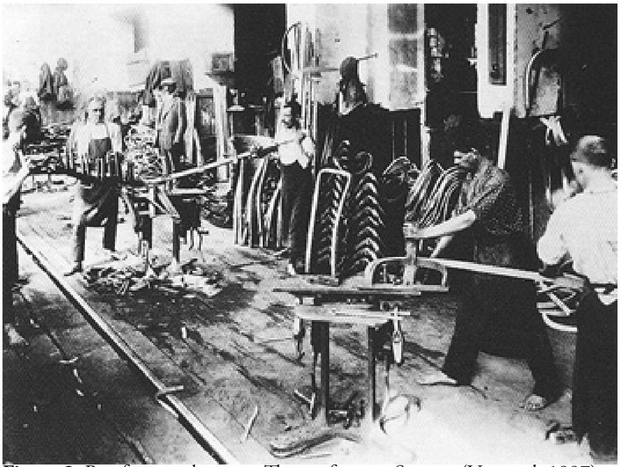

Figure 2: Barefoot workers at a Thonet factory. Source: (Vogesack 1997)

Thonet's patent was the culmination of more than a quarter century of material and process research in the fabrication of steam-bent solid wood members. Prior to that Thonet worked extensively with layered wood veneers and glued wood composites. Early techniques were extremely labor and material intensive. Due to the lack of sufficiently durable adhesives, previous techniques failed to move beyond the realm of super-custom, one-off furniture.

Thonet's developments in wood steam bending ultimately gave rise to an entire line of bent wood furniture, the most iconic of which is the Café Chair No. 14, often referred to simply as the "Thonet Chair". In 1857, Thonet opened his factory in Koritschan; the factory works there were dedicated almost entirely to the production of No. 14 Chairs. Within three years of commencing production, the factory produced more than 50,000 pieces of furniture (Wilk 1980). By 1930, global sales of the No. 14 Chair had reached 50 million units (Gleiniger 1998). While the No. 14 Chair is recognizable in its design and elegant fabrication, it is also one of the most recognizable symbols of mechanized industrialization.

> The Koritshcan factory opened in 1857, and with it Thonet's production of furniture moved completely out of the realm of craft into industrial production. For the first time no craftsmen or cabinetmakers were employed. The local workers were trained in the completely new methods of industrial production, which stressed the importance of timing and the necessity of teamwork (Wilk 1980, 23).

Figure 2, depicts conditions in one of Thonet's factories during the turn of the century. Large numbers of low-wage workers (shown in bare feet) were responsible for the production of most of Thonet's furniture. Regionally, steam bending was often used in the fabrication of shipping vessels, but the technique was also employed in other capacities. The mid-west region of the United States was uniquely rich in raw materials and at the cross roads of the modern industrial movement. In Michigan, carriage manufacturers were the predecessors to the automobile industry. The production of horse drawn carriages frequently involved the use of steam bending to produce laminated wheels and portions of the carriage frames. Moreover, during the 1890's the Midwest region proliferated with small automobile start-ups, and later, the Detroit area became the seat of the United States automobile production.

Since the peak of production in the early 1900's, steam bending has become virtually obsolete and, the demand for steam bent furniture products and wooden ships dropped precipitously during the 1920's and 1930's. The availability of a sufficient quantity and quality of old-growth timber declined drastically due in large part to poor resource management and global demand for timber. Additionally, increasing labor costs 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 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 1920's even Thonet manufactured chairs out of chromed tubular steel.

Further advancements in chemistry also played a role with steel to seal the fate of steam bending. Prior to the early 1900's, adhesives for wood lacked sufficient quality and durability, keeping the plywood industry at bay. Animal based glues were expensive, difficult to manufacture and could not withstand exposure to humid environments. Subsequent casein and blood-albumin glues were equally expensive and energy intensive, but once cured yielded water insoluble bonds (Pizzi 1989). 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. It could be easily formed into sheets or applied as a liquid between veneers of wood (Ngo 2003). The demand for veneer-ply boats hulls and aircraft parts during the war years propelled plywood to domination in the wood industry and drove the final coffin nail into the steam bending industry (Figure 3). Most notably, Charles and Ray Eames' developed many of the benchmark articles of wood veneer products which epitomized the modern lifestyle of the 20th Century. Although plywood products use many of the same techniques that steam bending uses, including bending jigs, fixtures and heat, they also by necessity, use adhesives in relatively large quantities which often have pernicious chemical byproducts and can be unfit for human contact.

Figure 3: 1944 Fortune magazine advertisement Source: (Ngo 2003)

1.1. MATERIAL(S) OF CHOICE

Presently, locally produced, locally harvested and renewable materials represent one way in which we can reduce demand for energy intensive, non-renewable resources. In the 21st Century, research and discourse with design fields is increasingly focused on dealing with the environmental impact from many years of expedient production. The energy cost and carbon footprint of products made from plastics and metals—especially those whose origins or ingredients travel thousands of miles before reaching the point of consumption—are extremely high. Further environmental costs are incurred when non-biodegradable 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 plastic or metal fasteners. Steam bending can be accomplished with a minimum of energy input and it requires no toxic chemicals or adhesives. Choosing locally produced, locally harvested materials as the basis for focusing research allows design thinking and architectural discourse to encompass vernacular material roots and historical precedent while leaving open the possibility for engagement with contemporary architectural practices.

The most conducive materials for steam bending are those which are the least refined by industrial processing. Since steam bending requires lumber with high moisture content, less processed, air dried material is superior in performance to its kiln dried relative. The water naturally contained in the cells of the wood works to keep the fibers supple during bending and also acts as a flux, aiding the transfer of heat from the steam chamber to the section's center. Rough sawn, air dried lumber has a typical moisture content ranging from about 8-19 percent while kiln dried hardwood lumber is typically brought down to about 4-5 percent moisture content by weight before ultimately being rehydrated to around 8 percent (Allen, 2009).

Prior to entering the steam chamber, the wood is soaked in a bath of plain water for a period of approximately 36 hours to bring the timber sections up to about 25-30 percent moisture content by weight, or, as near as possible to the fiber saturation point. Once the timbers are sufficiently hydrated, they may be removed from the soaking bath and placed in a steam tube. The amount of time spent in the tube is determined by species, initial moisture content, and thickness of section. Once the material is fully heated, it is removed from the steam chamber and quickly transitioned into one of several adjustable fixtures (Figure 4) to be manipulated into the desired form. The use of pre-fabricated chords and spreaders (Figure 5) together act as a mobile drying fixture while the formed pieces cool and subsequently air dry.

Figure 4: Variable jig with a steam bent wishbone

Figure 5: Formed, braced ribs drying

1.2 FROM THE PERIPHERY

Traditionally, steam bent wood work was an afterthought to the primary production of architectural space. Bent wood trim and furnishings when used, were often chosen as an analogy to other malleable materials like iron or plaster. Architectural case studies of steam bent wood are difficult to find. Thonet's contemporaries Henry Van De Velde, Victor Horta and Hans Wagner occasionally used steam bent wood trim in their interiors, but the applications only aspired to a supportive role as small scale accoutrements to the essential tectonics of construction and the execution of architectural space. Even today, material and tooling limitations primarily dictate the scale of individual pieces of steam bent wood, but the use of digital parametric tools aid in shifting from the scale of furniture up to an integrated architecturally-scaled construct with a coherent structural system. In our research, we have endeavored to understand our design process as one in which the overall fluid expression of a malleable whole is the aggregation of large numbers of unique small-scale components. This is not a new idea, but it is particularly the skilled deployment of digital parametric models which allow a complex assembly of parts and an historical fabrication method together to produce an integrated whole with unique dimensions and geometries under the control of the designer. In these assemblies, each individual component is linked to the next through a set of logic and geometric relationships. Through refinement and evolution of our work we are able to position the whole as an integrated system of structural sub-assemblies the result of which is a significant shift up in scale that gives steam bending currency at the level of architectural structure.

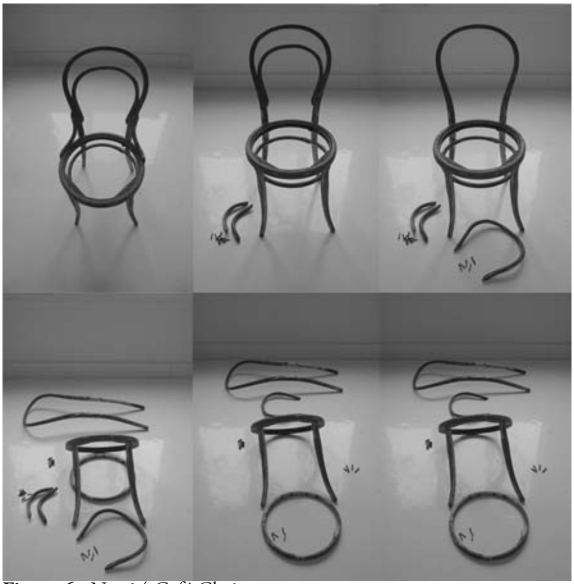

Figure 6: No. 14 Café Chair

1.3 THE DNA

Much of the Thonet furniture line was available as "knock-down" pieces, 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 (Figure 6). 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 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 it also meant that the spectrum of individual choices was discretized and therefore many formal outcomes which could be rendered through steam bending were precluded.

1.4 STEINER ELLIPSES

Inspired by the graceful, high-arching seatback 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 (Figure 7).

This was a simpler, first model in which we explored the range of material capabilities and refined the parameters for material processing. It provided a basis for bringing the material failures (Figure 8) into communication with a set of digital parameters which could then be modified to predict the feasibility of other constructs. Each module of a larger framework is based on dynamic clusters of four Steiner ellipses.

The framework's structure is highly adaptable to different symmetrical and asymmetrical conditions and applications. Although it's fluid and adaptable nature holds promise for formal operations, it's intensive requirements for 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 (Figure 9).

Figure 8: Material failures

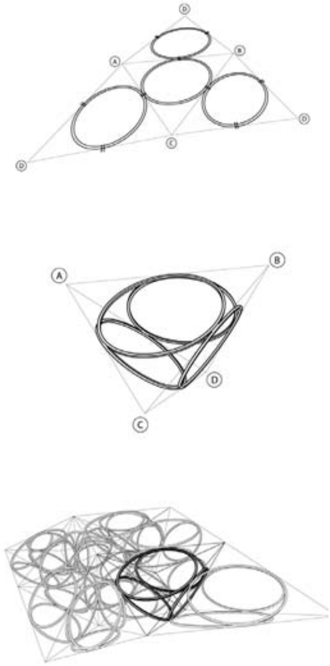

Figure 7: Steiner Ellipse building blocks

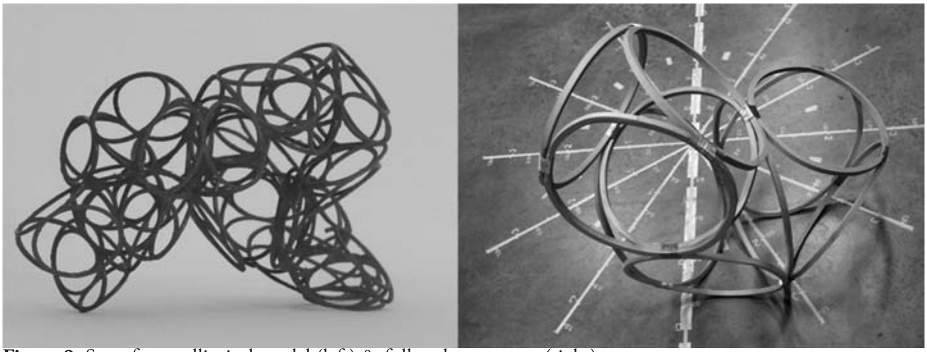

Figure 9: Spaceframe elliptical model (left) & full-scale construct (right)

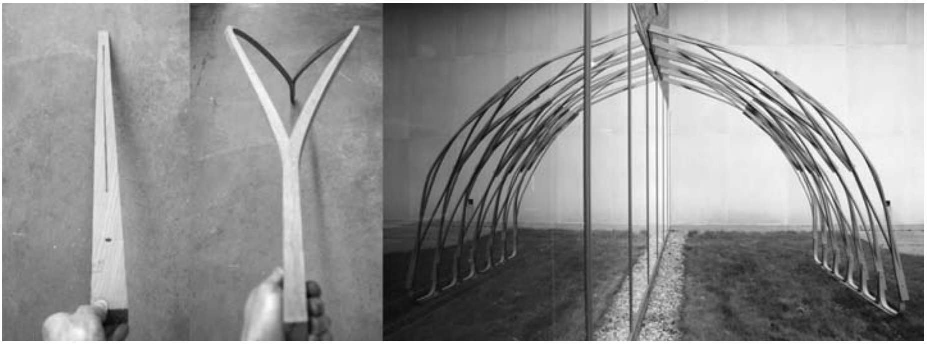

Figure 10: Split blank, formed rib and aggregated arch structure.

1.4 THE BONES

In further research, we developed a second structural component, a rib or "wishbone" (Figure 10). This development came as we were processing the results from several space frame prototypes. While we had developed a means for 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 waterjet 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. Through a series of parametric manipulations and computational optimization, we produced a schedule of parts which specifies the precise dimensions and orientation of each unique part. A digital cutsheet then enables the translation between model, material and tool. The prepared blanks are tagged with a serial number indicating the part's position relative to the whole. Our method for forming the pieces is similar to those used in the shipbuilding industry in that it does not require a tension strap, but it makes a significant departure from previous methods with the use of a variable jig. As the blank is compressed, the sides of the wood member spread outward and bow upward. The resulting components may then be assembled into a thickened sheet-like lattice. The ribs yield a variety of inherent construction logics based on nodal connection points which form a robust, flexible structure. The expression of form is directly related to the process of fabrication and the underlying geometry of the part. The degree of bend 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.

1.5 NATURAL SELECTION: MATERIAL RESISTANCE AS DESIGN GENERATOR

The specificity of Thonet's cast iron jigs prescribe a process aimed at forcing an unpredictable material such as wood to submit to a standardized form (Figure 11). 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 consistently reproducible copies. For Thonet consistent parts were vital to production. The forms themselves were complex but could be produced by unskilled labor. Thonet's advancements in industrial processing did indeed yield many long lasting and remarkably consistent pieces but, the 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 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

Figure 11: Early Thonet cast iron mold. Source: (Vongesack, 1997)

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 waterjet cutter, that was 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 waterjet'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 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 to the bold colors of a garden in bloom (Figure 13). In hindsight, the acceptance of the biases of tooling and materials led to the understanding and exploitation of a completely natural, non-toxic realization of one of the most important features of the project.

1.6 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 (Figure 12). Thus, material limitations and failures become significant form generators and informants to our digital models. The build-up 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. In that sense, digital development runs 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. Movement forward is a balancing act of reciprocity and speculation between the digital and the physical.

In contemporary architectural practice, 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, structural wonder materials. Typical materials which are exploited for similar characteristics, such as concrete and steel have large environmental footprints. Problematically, the discipline produces a large number of theoretical projects which are relegated to "paper" or else, the essential moments of the design are drastically watered down to accommodate structure and cost.

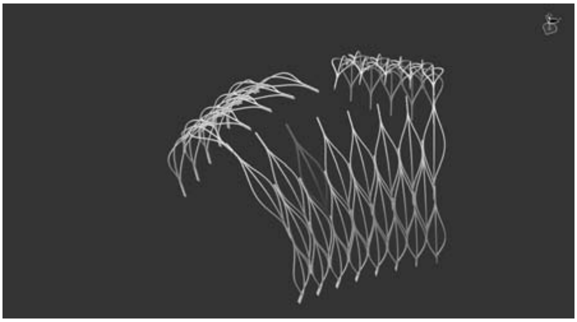

Figure 13: Full-scale gateway installed at Fredrik Meijer Gardens, Grand Rapids, MI. Source: (Beth Singer, 2010)

Our research gets traction by engaging alternative methods of design thinking through open dialogue between material, process and structure where each are balanced acts of architecture. It does so in two ways. First, by embedding material and construction logics within digital models, the outcome(s) of successive evolutions in digital environments converge along sometimes widely disparate trajectories that nevertheless remain (mostly) within the realm of possibility. In fact, we may more easily occupy and thicken the threshold between possibility and impossibility and navigate this created boundary with alacrity. Secondly, by embedding material characteristics and tectonic logics into the parametric model, the model becomes both fuzzy and precise. That is, the model becomes capable of dealing with traditionally difficult characteristics such as elasticity and material spring back, while keeping precise track of a detailed set of instructions that can be communicated to CNC machinery, or translated into unique form. We allow ourselves through play with and within digital spaces to release a degree of control in order to uncover or invent unique configurations of material, light and form. The feedback loops which drive the development of the model are ones in which material is tested, formed and often taken through the point of failure. We are able to translate knowledge and measurement of the empirical world into increasingly sophisticated and robust digital parametrics, or rules of engagement which 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 finding what we refer to as 'beautiful monsters'.

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.

1.7 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 ways of seeing and envisioning 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 (Figure 14).

The nature of the process is one of coordination and constant recognition of the structural tendencies and resilience of the incomplete structure and sub-assemblies. 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 (Figure 15) in order to move between the gravity free virtual world, real materials and space.

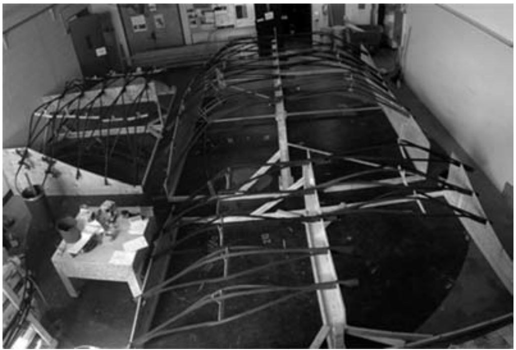

Figure 14: CNC cut fabrication forms

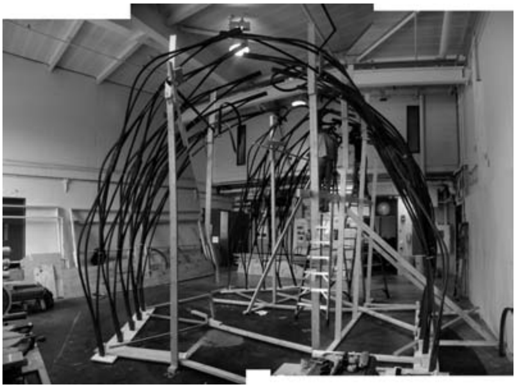

Figure 15: Full-scale construct under fabrication

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