Bent Wood Lamination at Two Scales

AMY FORSYTH
University of North Carolina at Charlotte
The Pennsylvania State University

> Great ideologies are made up out of life's little details, they spiral out of the earth. Our senses convey to us the raw material on which our thinking is based. On the other hand, we have to see to it that we control the world of the senses and not the other way around.
>
> – Alvar Aalto, 1947

One of the most crucial challenges inherent in architectural design is that of accurately representing objects that are larger than ourselves with materials that are appropriately scaled to our bodies. The scale, expense, and effort required in the creation of buildings demand a working technique that represents, rather than replicates, each of the design elements and construction processes that we hope will result in a close approximation of the designs that we know only as a fragmented set of reduced images. The surprises and risks of this extrapolation of the final product are fewer for a seasoned architect, but for students and other aspiring-to-build architects, the distance between the realm of representation and that of the real built artifact is a vast one.

In addition, the craft of building and the creative use of materials are other issues that deserve more attention. As Alvar Aalto, Charles and Ray Eames, and Frank Gehry have demonstrated, the investigation of materials through the design and construction of furniture is an efficient, cost-effective, and inspiring method of representing architectural detail at a more intimate scale. Each of these architects has successfully created a new design vocabulary through the hands-on investigation of materials at both scales. The diversity of their architectural languages as established by the differences in their intentions is a testament to the flexibility and potential of this type of research.

It appears that each generation of architectural "isms" attempts to debunk the previous one. The current impetus towards hands-on building in the design studio is a rediscovery of the strength and instructive beauty of materials by those who were trained within the post-modern era when building construction details were often learned by memorizing drawings of standard details. The rediscovery of some of the values of the modernist era may seem obvious to those who were trained during that time, but is the next step towards the reconciliation of the post-modern focus on representation and plurality with the modernist appreciation and understanding of materials. Recognizing and adapting the strengths of each era, rather than once again vilifying the earlier movement, will result in a richer collection of possibilities.

The intention of this paper is to argue for the value of hands-on design research in focusing on the capabilities of materials and to propose a process by which large scale elements can be adapted to a more manageable small scale. The focus on "an investigation of a particular material and construction method is intended to act as a model for a method of inquiry that exemplifies a means by which an architectural vocabulary might be created by the designer once the properties of a material are understood.

The investigation of bent wood lamination in furniture making is an ideal method of understanding the same principles that are used in large scale laminated wood beams and columns that stand in for heavy timber construction. The process is virtually identical at both scales, although differences in the final product, largely a result of scale disparities, occur in craftsmanship, species and quality of wood, and scope. Bent laminated furniture can be produced by a single person, although extra hands are helpful, while the assembly of laminated structural members requires a team of trained workers and specialized equipment operated within a factory. It is important to note that the process of bent lamination results in the components of furniture or building, not furniture or a building. The means by which these building components are transformed into load-bearing structures or enclosing surfaces requires the exploration of yet another set of issues concerning joinery and fasteners.

This past summer I studied Bent Laminated Wood at the Penland School of Crafts with Michael Puryear, a furniture maker from New York City, and not insignificantly, a brother of the internationally known sculptor Martin Puryear, who was also present as a visiting artist. Michael's work, like Martin's, is rooted in the creative exploration of various materials, especially wood. The success of the work is dependent upon the artist's visceral understanding of the material that has come about after 30 or more years of working in the woodshop and making small, daily observations, while subjecting the material to various tools, machines, and processes.

The purpose of the workshop was to design and produce a piece of furniture using a system of resawing wood into thin layers, and dry bending and laminating the layers within a form to create bent wood members that are then assembled into a finished piece of furniture. The class was comprised of woodworkers of varying skill levels; professional woodworkers learning a new method, students of furniture from several different universities, sculptors, artists and craftspeople who were more familiar with other media, and hobbyists. While students prepared their own projects, Michael demonstrated methods, critiqued design, and offered technical advice to assist in the completion of successful projects. Along with other Penland faculty working in other disciplines, Michael showed slides and spoke about his own elegant work, much of which employed bent lamination. Martin was a visiting artist during this session, which meant that, in addition to giving a public lecture, he worked on a project of his own, a fruitwood chair that was similar to one that he had made in 1982 for his large-scale environmental sculpture entitled *Bodark Arc,* located in the Nathan Manilow Sculpture Park, at Governors State University, in University Park, Illinois. He did much of his woodworking in the same shop where our class worked, and many of us had the opportunity to converse with him at length. He was familiar with the bent lamination process his brother was teaching and told me that he had used a larger scale version of this method of lamination to make exposed beams in his house, but later wished he had made use of the specialized equipment that was available at a laminating plant.

A month later, I visited the Unadilla Laminated Products plant, producer of the Unilam system, a company that began as a silo manufacturing plant in New York State. This factory makes laminated wood products that, except for some specialized machinery required by the scale of the products, are manufactured in a nearly identical process to the fine craft production method that I had learned at a crafts school.

The experience of making furniture components, then seeing the same process repeated at an architectural scale, graphically depicted a means of studying the properties of a material and the process of transforming it that is relevant at both scales. The hands-on manipulation of materials results in a greater understanding of their physical properties, enabling the architect to employ these elements in a greater variety of applications, rather than relying solely upon standard detailing. The experience of forming wooden elements in this method provides a vivid teaching tool that would encourage architecture students to contemplate the properties of the material during the initial design stages rather than resolving spatial and conceptual issues in the absence of material influences.

The following text describes the process of creating bent laminated wood members. Text that appears in italics corresponds to the furniture-making process, while the Roman text refers to the manufacturing process at the Unadilla plant.

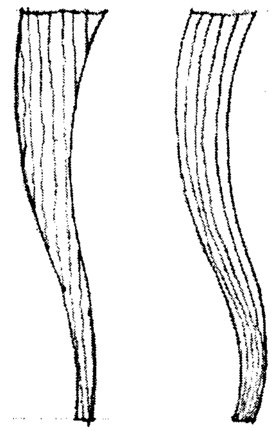

Fig. 1. Undesirable short grain conditions in carved solid wood (left) vs. bent lamination (right).

MATERIAL PROPERTIES AND SELECTION

One of the basic premises of furniture making is that wood is an active material, and so it moves, before, while, and after it is worked. This vitality must be addressed in the design of a piece of furniture. Another fundamental circumstance that has mandated design elements is the fact that wood is strong along the length of its fibers, but once the fibers are cut, the ends have no strength at all. Wood joints in all their variety and ingenuity have evolved to address this fact. Longer fibers have more strength than shorter ones, and the direction of the grain in each piece of wood also impacts the processes that may be applied to it. Although it may be possible to carve a piece of solid wood that looks very much like a piece that was made using bent lamination, economy ofmeans, strength, and integrity of material indicates that the bent laminated wood process is most appropriate for particular shapes of furniture elements to avoid weak short grain conditions. (Figure I) Straight grained hardwoods are the preferred woods in bent lamination, as in most furniture. Hardwoods are defined as trees with covered seeds, such as acorns, nuts, etc. These trees are mostly deciduous. Wood is selected for its surface figure, color, contrasting markings, and other aesthetic properties, in addition to pragmatic issues inherent in particular woods. Most Penland students select local hardwoods, although a few have brought some exotic, tropical hardwoods which are used for their decorative properties. These are somewhat troublesome for several reasons, such as workability, renewability (many are from the South American rainforests) and toxicity. Nevertheless, in skilled hands the final products are lovely.

Softwoods differ from hardwoods in their cellular structure, which affects the flexibility, hardness, and figure of the wood. Uni-lam structural members are made of plentiful, easily obtainable, flexible softwoods, such as Pine and Douglas Fir, with occasional special orders of Red Maple. The lumber is precut, kiln dried, and shipped by truck from the Carolinas. When it arrives at the Unilam plant, the lumber is delivered to the grading shed where best quality boards are set aside to be used in tension members. Other grades have different uses, and there is also a visual grade, which will become the exterior faces of the member, while boards with pitch pockets, knots, and other minor defects become interior laminae. Two thicknesses are used at this plant; 2" nominal pieces are used for straight laminations, while 1" pieces are used for bent laminations.

DESIGN

Once the design is established, through sketches, critiques with the instructor, and reality checks, full-scale drawings are made of the piece. One of the tools found at Penland is an enormous French curve made of Masonite that I used to make a drawing of a beautiful "s" curved, tapered table leg. The number of laminae are determined by the flexibility of the material, how well each thin layer conforms to the curve. Material is resawn, along the length of the grain, to 1/4", then tested for conformation with the curve. If the wood was too stiff, another test strip was cut, to a thinner measurement. The minimum thickness possible with the tools and the somewhat limited skills of their operators was determined to be 1/8". When it became apparent that the extreme curve traced by the French curve was incompatible with the natural bending tendencies of the wood strips, I redesigned the leg according to the demands of the material and was more pleased with the final result. (Figure 2)

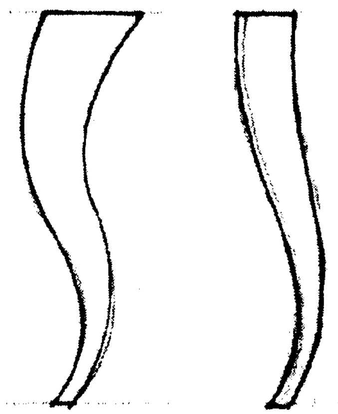

Fig. 2. Curve of leg made with French curve (left) vs. leg made with wood strip (right).

Unadilla Laminated Products receives construction drawings of each structural member from the architect or builder. In-house engineers make the necessary structural calculations to determine the umbers of plys and their locations to create the appropriate profile, then shop drawings are made of each structural member, which are then approved by the architect or builder. A gymnasium-scale room with an open plan provides the space where full-scale plywood templates are laid out with compasses also made of plywood or string. (Figure 3) The templates are then cut out using a jigsaw.

Fig. 3. Full-scale templates in lay-out space at Uni-Lam.

FORM MAKING

Forms, also called jigs or molds, are made of plywood, particle board, or medium density fiberboard and Masonite, cut on the table saw and band saw, smoothed on the router table, screwed together, and the working surfaces are then covered with plastic packing tape to keep the pieces from sticking to the form work. Form worksides are waxed to keep glue from building up over successive glue-ups. There are several types of molds to choose from, depending on the kind of curve the final piece is to maintain. (Figure 4) One-part molds are used for simple curves. The laminae are sandwiched between the mold and pieces of Masonite so that the smoothness of the radius isn't distorted by the pressure of the clamps. Two-part molds, which are used for complex curves and tapers, must follow each side of the curved piece precisely. Guide pieces hold the two halves of the form together, so they don't slide during glue up. Another method involves the making of movable clamping "stations," pieces of carved solid wood or plywood right angles screwed into a backing sheet of plywood. This system allows the maker to relocate

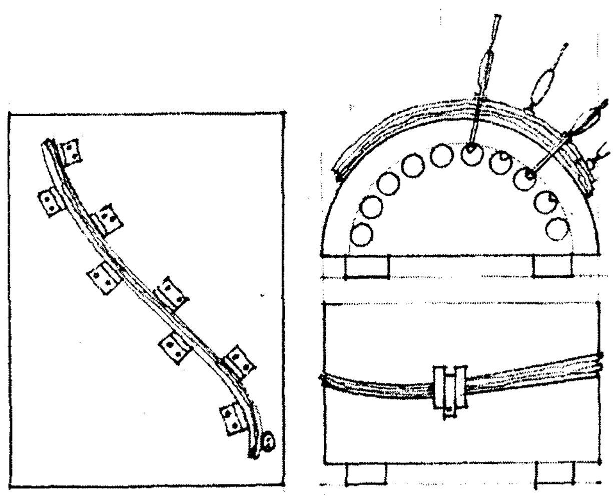

Fig. 4. 3 types of molds: Stations (left), one-part (top right), and two-part (bottom right).

Fig. 5. Uni-Lam clamping station.

the stations to create new curves and so to reuse the form for many other projects.

The clamping stations located on the main floor of the Unadilla plant have parallel metal tracks embedded in the concrete every foot on center. Vertical metal rods slide along the tracks to locate points on the curve and establish clamping stations. Like the station method in furniture molds, the stations may be relocated for each new set-up. (Figure 5)

MATERIAL PREPARATION

After planing, jointing and table sawing to square each board, the material is resawn in thin layers along the grain. Great care is taken to assure that the layers remain in the same order as they occupied within the tree to maintain the continuity of the grain. More layers are cut than are required for the piece, so that there will be test pieces and allowance for mistakes and warpage. If the laminae are to be tapered, the edge of the remaining wood should be surfaced on the jointer between each pass on the band saw so that each side will fit together smoothly. Band saw marks can remain on the faces of each laminae as long as each layer is to be joined to the next sequential layer which bears the corresponding marks. Tapered laminae are run through the planer on a thickness-planer jig that has been made to taper the material at the appropriate angle, paying close attention to the direction of the grain to avoid tear-out.

Since the lumber is already pre-sized for thickness at Unadilla, length is the crucial dimension that must be addressed. This is accomplished by a specialized machine, that finger-joints (Figure 6) the ends of each member, applies glue, and, with the help of an operator, joins two or more segments into a single long member. Fingerjoints are efficient because the frequent diagonal cuts create many surfaces of face grain for gluing. The joint is cured by being placed into a high-frequency tunnel that hardens the glue. For structural integrity, care is taken to make sure that the finger joints don't

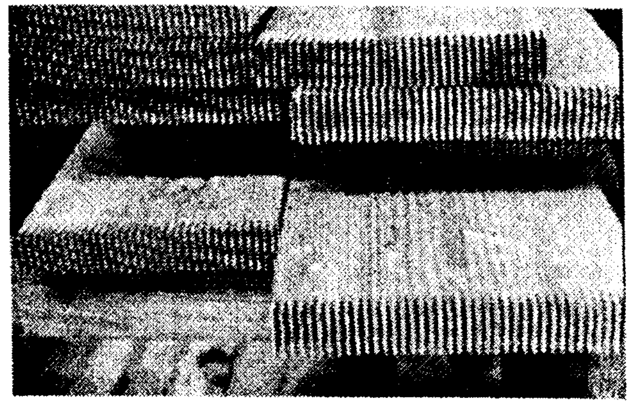

Fig. 6. Finger joints.

Fig. 7. Glue-up at the Uni-Lam plant.

coincide with adjacent pieces within the larger member.

GLUE-UP

To assure a successful glue-up, the laminae are assembled and clamped within the form without glue at first to make sure that all necessary implements are in place, all clamps are ready, and the molds fit together perfectly with the laminae assembled inside, in order, without slippage. Students assist one another with this task, as well as with the final gluing, a choreographed exercise in cooperation, precision, and timing. Once the dry-run is completed, the glue-up begins. Disposable paint rollers are used to apply glue to each side of each layer, except for the top and bottom layers. Regular yellow wood glue is used by most students, although there are other choices, such as "Gorilla Glue," as well. Glue must be applied quickly and each piece must be stacked carefully in order on the form work. When the last layer is glued and placed, the assembly is clamped, beginning at the middle of the form, and gradually tightening each clamp. Clamps occur every few inches, and their orientations on the form are alternated for even pressure on both sides of the form. (figure 8) If enough glue has been applied, the excess will run down the sides of the mold, but aside from making sure that it doesn't drip on anything valuable, it is left until it dries. Each assembly is placed out of the way to dry overnight.

Waterproof phenol-resorcinol glue is applied evenly over both surfaces of each lamina by meansof a glue-spreading machine, which looks very much like a planer, but has glue-spreaders instead of knives. Operators pull each piece out of the machine and stack them in the form work. The forms can handle two finished members per form, and the workers have an hour to assemble each member before the glue begins to cure. Once all laminae are in place, the workers begin to tighten the clamps, starting at the middle and working outwards in both directions, using pneumatic wrenches to tighten down the screws. (Figure 7) The assembly is then left to dry for 24 hours.

SHAPING AND FINISHING

Once the glued pieces are removed from the molds, the dried glue is removed with a scraper and the flush surfaces are planed flat on the jointer, planer, or the table saw. Ends are cut to size on the chop saw. The pieces are now ready for assembly into a piece of furniture. In the finished furniture piece, great care will be taken to avoid revealing the end grain, according to the traditions of furniture making, both for aesthetic reasons and because the end grain is especially vulnerable to moisture.

After the glue has dried and the members are removed from the forms, they are run through an enormous planer that has feed rollers the size of automobile tires. This surfaces both flat sides of each member simultaneously. If there are pitch pockets, loose knots, or other imperfections, these are patched. Final shaping takes place with the assistance of mobile saws; wheeled band saws and two-person operated circular saws. End grain is treated with sealant to protect the member from moisture, and a water-resistant sealant or finish is applied, depending on the future use of the members, which are then individually wrapped in brown paper for shipping.

ASSEMBLY

At this point in the process, the production of bent laminated components is complete and construction methodology is replaced by more specific individual design requirements. Here I would like to depict the finished table (Figure 8) that inspired this paper. In designing and building this piece of furniture, I recognized that many aspects of architectural design were incorporated in its making. The importance of joinery, the integration of systems, the creation of a related vocabulary of forms that address its use and appearance, the demands of the materials and the necessary order of its production invite a comparison with the more complex architectural design and construction process. The reduced scale and complexity of the design and construction of a piece of furniture provides a pedagogical tool for beginning architecture students to examine some of these processes at a manage-

Fig. 8 Table with bent laminated legs and aprons

able scale. I intend to test these ideas in a first-year design studio this Spring semester, by assigning a construction project that synthesizes furniture and small architectural scale components and uses bent lamination in conjunction with other architectural elements. Organized around the idea of "sanctuary," the students will create a retreat for themselves. using both representational techniques (computer and hand drawings and models) and full-scale constructions. The small scale of the project will allow an investigation of the relationship between representation and actual construction, illuminating the differences between a design as represented and a design that is realized, using the materials of its realization as inspiration for its representation and incarnation. Student projects will incorporate spatial relationships in addition to object properties to further develop architectural sensibilities.

CONCLUSION

The first-hand comparison of two scales of one wood-working process allow an understanding of material issues that are relevant to both disciplines of furniture and architecture. Like the Eames' experiments with plywood or Aalto's investigations of kerf-bending wood in test panels, furniture, and finally architecture, creative experimentation with a material can lead to new ways of building in either scale. It is important, however, to recognize the discrepancies that scale introduces in these processes. In the process of bent lamination in wood, disparities arise not only from the scale of the components, but from the corollary issues of cost and availability of material, which in turn affects the craftsmanship, which is also affected by the mechanization of some processes. Once a process gets beyond the capacity and culpability of an individual, the issue of craftsmanship becomes increasingly precarious. In the interest of disclosing the undiscovered potential of materials, the craftsman's approach can enlighten the architect.

REFERENCES

Aalto, Alvar. *Sketches.* Schildt, Goran, Editor. Cambridge, MA and London, England: The MIT Press, 1985.

Benezra, Neal. Martin *Puryear.* Chicago, IL: The Art Institute of Chicago, and New York, NY: Thames and Hudson, 1991.

Chiavelli, Jim, Publisher. *Fine Woodworking Design Book Seven.* Newtown, CT: The Taunton Press, Inc., 1996, pp. 39 and 76.

Hoadley, R. Bruce. *Understanding Wood.* Newtown, CT: The Taunton Press, Inc., 1980.

Kelsey, John, Editor. *Fine Woodworking on Bending Wood.* Newtown, CT: The Taunton Press, Inc., 1985.

Stevens, W.C. & Turner, N. *Wood Bending Handbook.* Parkersburg, WV: Woodcraft Supply Corp.. 1970.