Chapter I
Design and Construction Concepts

Introduction

Low cost, durable, attractive school furniture can be produced in essentially any region of the world from locally available wood, wood residues, or semi-processed woody materials.

Only the simplest machining and joinery processes are required so that production techniques may vary from those best suited to cottage industries to those more appropriate for small conventional factories. Durability is guaranteed by structural design and construction techniques.

Details are given in this manual for the construction of several designs suited for schoolroom use. The construction techniques presented in this manual are not limited to these designs, however. Rather they can be applied to a wide variety of designs so long as the basic principles presented are followed.

Material Sources

Parts needed for the construction of the chair, desk, table, and cabinet frames presented in this paper may be cut from conventional sources of material such as lumber obtained from sawmills. Many parts may be cut from wood waste discarded by sawmills, however, while other parts may be fabricated from low-cost semi-processed wood materials such as pallet deck boards.

When portable thin-kerf sawmills are available, woody plantation thinnings may be processed into slats, boards, and squares that are suitable for converting into furniture parts.

When none of these sources are available, school furniture can be constructed from small round woody stems, obtained either from natural growth or from small tree plantations planted specifically to provide such material.

Equipment

At the simplest, though most labor-intensive, production level only a few common hand tools such as a hatchet, handsaw, draw knife, and auger are required to produce what is today termed “greenwood” furniture. Considerable “smoothing” of the wood usually is required subsequently, however. This operation can be performed with simple “scrapers” and sandpaper, but a hand plane greatly reduces the labor required.

At the cottage industry production level, a simple table saw and a device for cutting round tenons are needed—although a drill press or wood lathe may be substituted for the latter device. A small jointer is extremely useful since, in addition to doing the work of a hand plane, it can also cut rabbets, tapers, bevels, and chamfers. A small thickness planer is also useful, but not essential.

If plantation thinnings are to be used, a small thin-kerf sawmill is very useful in converting round wood stems to squares and lumber. This equipment also can be used to
cut thin material needed for parts such as seat and back slats from larger pieces of lumber.

At the conventional furniture factory production level, no specialized tools are required with the possible exception of a device to cut round tenons with hole saws. Alternatively, this operation can be performed (with jigs) on a drill press or a conventional wood lathe.

**Conversion of Small Tree Stems into Furniture Parts**

A common source of material for construction of school furniture, particularly in remote regions, is small woody stems obtained from plantation thinnings, from natural forest growth, or from saplings grown specifically to provide the materials of construction. These small stems, even when of short length, may be cut with thin-kerf saws into lumber whose thickness is closely related to the desired thickness of the furniture parts to be cut from it. Because the lumber is cut with a thin-kerf saw, only minimum smoothing is required to remove saw marks. When the lumber is cut from short bolts, the overall size of the part may correspond closely to the dimensions of the board.

When suitable equipment is available, small stems may be converted into squares and rectangles that in turn may be converted into furniture parts such as front and rear back posts for chairs and legs for tables and desks. The principle problems anticipated in working with squares cut from small stems—which include the center of the stem—are subsequent splitting of the material as the wood dries along with twisting and warping. Only those woods with good drying and shrinking and swelling characteristics should be selected for use in this type of construction.

Stems also may be processed into large (and small) diameter dowels of standard size by turning them on a lathe or by passing them through doweling machines where this equipment is available. These dowels may then be converted by further turning and drilling operations into rails, legs, back posts, and other furniture parts. Conversion of stems to dowels has an advantage in that relatively small stems may be used. Hence, this process is able to make use of what is otherwise likely to be waste material. In addition, plantings made for the specific purpose of producing school furniture may be harvested and converted to parts after a relatively short growing period.

Stems converted into dowels should have essentially the same growth-related properties as those converted directly into parts. Primary concerns include severe checking and splitting of the dowels as the wood dries. Thus, this conversion process has the disadvantage that it is largely limited to those select species whose stems dry without splitting. It is also important for the stems to have a solid core.

Parts such as table legs and back posts of chairs may be sawn directly from small stems without intermediate conversion. This type of conversion requires that stems be available that are largely free of growth stresses, have low shrinkage coefficients, and exhibit minimum juvenile wood characteristics. Ideally the wood should also have good steam bending characteristics.

Through thin-kerf sawing, small stems also may be converted directly into slats that may be used in chair seats and backs. Often, slats may be bent to shape while green in order to obtain a final desired curvature. The need for steam bending is thereby eliminated, thus increasing the variety of species that can be used.

**Frames Constructed of Squares or Rectangles**
Presumably, most of the furniture constructed of squares would be of stretcher and post construction in which stretchers with turned pin ends are used to join the posts together to form three-dimensional frames. This construction has several advantages. Individual parts are easy to machine from stems. Construction of joints is relatively simple—holes must be drilled in the posts at the appropriate locations and pins must be turned or cut on the ends of the stretchers. The walls of the holes are coated with adhesive, and finally, the frame is assembled with a “swell” fit between the tenons and the posts. A tight fit between these parts is useful in that it eliminates the need to clamp the assembly while the adhesive dries.

Frames constructed in this manner are both strong and durable. The forces acting on the stretchers in a side frame are distributed relatively uniformly among the joints so that none of the joints is heavily loaded and a robust construction results.

Essentially identical frames can be constructed with rectangular-shaped as opposed to square-shaped posts. Use of such sections usually reduces the weight of the chair. Furthermore, if the stock is sufficiently wide, the back posts may be sawn to give a backward tilt to the top rail as shown in Figure 1-1.

Frames Constructed of Round Wood

Round wood frames may be fabricated from stems that first have been processed into dowels, or they may be fabricated from stems and limbs that have been converted directly into parts. Construction of furniture from processed dowels is essentially analogous to the construction of furniture from squares as is construction of furniture from stems or limbs that have been processed directly into parts. This latter type of direct conversion of tree stems and limbs into furniture parts and complete furniture frames is not new—“mountain” chairs have been produced from round stems for many years. When properly constructed, such chairs are quite durable and frequently outlast chairs of “modern” construction. The validity of these historical designs, arrived at by trial and error methods, has been proven through present day mechanics and performance tests.

It is anticipated that most furniture frames constructed with round wood, i.e., large dowels, would be of post and stretcher construction such as the chair shown in Figure 1-2. An example of a desk side frame is given in Figure 1-3. Such frames are relatively easy to make with simple tools and are of robust construction. Steam bending of dowels, is of course possible for those designs that require it. Smaller diameter dowels in particular may be bent to various shapes and used in the construction of furniture somewhat reminiscent of that produced by Thonet. The back posts for chairs also can be bent to form using green bending or steam bending techniques.

Round Mortise and Tenon Joints

Round mortise and tenon joints provide a simple yet strong and durable method of fabricating furniture frames. This method of construction is effective both in constructing very strong side frames and in joining side frames together to form complete
chair or table frames. The use of round mortise and tenon construction is not new. It has been used for years in the construction of Shaker and mountain furniture such as that shown in Figure 1-2.

A major advantage of round tenons is that it is relatively easy to obtain a close fit between the round tenon and the hole into which it fits. Holes (round mortises) can be drilled to size with relatively simple equipment - a brace and bit will suffice. Ends may be turned on the ends of the stretchers with equipment specifically made for the purpose, but they can also be turned on a simple wood lathe.

By matching the size of the drill bit used to machine the holes for the pins with the diameters of the pins, a close fit between pin and hole can be obtained. The ability to match the diameter of the tenon to the diameter of the hole without the need for strict quality control procedures provides the key to the construction of uniformly durable furniture.

Cutting Round Tenons

The ability to cut round, dimensionally accurate, tenons on the ends of stretchers and rails is critical to the construction of strong durable school furniture. Traditionally, round tenons have been cut on a lathe, or, in the case of rustic furniture, with a drawknife. Various types of rotating cutter heads are also available today that are often used by home craftsmen.

Hole saws provide a simple and relatively inexpensive means of producing uniformly round tenons that are dimensionally accurate from one piece to the next. In cutting tenons with a hole saw, the end of a stretcher or rail is “fed” into the hole saw. A jig is needed both to align the stretcher and to prevent it from turning.

A simple horizontal drilling device that simplifies and improves the quality of the cutting is shown in Figure 1-4. The principal components of the device are a one-fourth-horsepower electric motor, a wooden framework, and an inexpensive arbor, chuck, and hole saw. Total cost of the equipment should not exceed $50 US. Presumably, this simple piece of equipment could be constructed and used in many remote regions of the world—provided electricity is available. Where electricity is not available, the electric motor can be replaced with two bearings and a shaft so that it can be powered by other means such as a gasoline engine. This system may also be used as before with an electric motor to reduce the speed of the hole saw,

Figure 1-2. “Mountain” furniture constructed with round mortise and tenon joints.

Figure 1-3. Sample desk side frame constructed of “rounds.”
After a tenon has been cut with the hole saw, the excess material around the pin must be removed by hand. This material may be removed with a small handsaw, or it may be cut on a table saw. If a table saw is used, the fence is adjusted so that the saw will cut the shoulder on the stretcher at the desired point. The height of the saw is then adjusted to cut through the material adjacent to the tenon on the flat side of the stock—without cutting into the tenon. After this material has been removed, the material on the corners is removed. It is helpful to use a block of wood with a V-shaped groove cut into the face of it in order to hold the stretcher or rail while cutting material from the corners.

Plug cutters may also be used to cut tenons using essentially the same equipment described above. The “kerf” of these cutters is greater than that of hole saws, and hence, they may remove the excess material and create the “shoulder” for the tenon. They may, however, splinter the material as they cut the shoulder. Usually, plug cutters must be run at a much slower speed than hole saws; therefore, they should be used with the equipment shown in Figure 1-5.

Round tenons also may be turned on a conventional Figure 1-5. Modified horizontal drilling device for cutting round tenons with hole saws. Use of an arbor and “step down” pulleys allows hole saws to be run at reduced speed.
wood lathe. The major disadvantage of this process is that considerable care must be exercised to ensure that the tenons are cut uniformly to the desired diameter. Thus, a high degree of quality control is required with this process that is not necessary with hole saws. However, very simple lathes such as the “whip” lathe can be used to turn tenons in remote regions.

Tenons may also be cut with a common drawknife although they cannot be expected to be as dimensionally accurate as those cut with the tools described above. Tenons cut in this manner are often used in the construction of “green wood” chairs. Many early American colonial chairs were constructed with tenons cut in this manner. Much of the furniture used by trappers and hunters in remote cabins was also constructed with tenons cut with drawknife and mortises drilled with an auger.

**Shrink and Swell Fit, Round Mortise and Tenon Joints**

In the shrink and swell method of round mortise and tenon joint construction, tenons and mortises are machined while their corresponding parts are maintained at an elevated moisture content such as 16 percent. The tenon is cut slightly larger in diameter than the mortise. The part containing the mortise is then held at its current moisture content while the part containing the tenon is dried to a lower moisture content such as five percent. As the tenon dries, it shrinks to a size where it may be inserted in the mortise. The two parts are then allowed to come to the equilibrium moisture content. During this process, the tenon swells while the mortise shrinks, and a “grip” fit is obtained.

The designer’s problem is to specify these fits in such a way that they can be reproduced in practice. This entails specification of the maximum and minimum diameters of the tenon and the mortise at the time they are cut. For purposes of discussion, however, specification of average tenon and mortise diameters will suffice.

Two factors are of primary importance when considering the diameters of the tenon and mortise. First, what amount of relief is needed to allow the easy insertion of the dry tenon in the green mortise. Secondly, what amount of relief between the dry tenon and green mortise will ultimately result in the strongest “grip fit.”

An important point to consider when determining shrinkage fits is the stress developed in the walls of the mortise, which depends largely upon the shrinkage allowance. If the shrink fit is too tight, the ultimate strength of the wood may be exceeded, and the mortise will split - a particularly important consideration in the case of L-shaped joints. Likewise, the elastic limit of the tenon may be exceeded so that the tenon takes on a permanent set. On the other hand, if the shrink fit is too loose, the intensity of the grip is diminished so that a weak joint results.

In determining shrink and swell fit allowances, both the change in moisture content of the tenon during drying and the inherent shrinkage coefficient of the wood used must be taken into account.

**Production of Curved Parts**

Although curved parts may be produced both by sawing solid wood blanks to shape and by glue-laminating parts from veneer, other processes can also be used to produce sculptured or shaped parts.

**Steam bending**

Steam bending may be used to produce a wide variety of curved shapes from either doweled or flat sawn parts. Tropical woods are notorious, however, for being difficult to
bend (as opposed to many temperate species). High temperature steam bending may allow some intractable woods to be bent, but the cost of equipment and safety considerations may negate the advantages.

**Growth Induced Bending**

In the case of direct conversion of stems into parts such as chair back posts where only moderate bending of rather large members is required, live stems can be gradually bent to the desired shape as they grow.

**Green/Wet Bending**

Bending thin-sawn wood to shape and allowing it to dry while restrained provides a practical process for producing curved seat slats and parts for chair backs as well as other parts. This process is well suited for use by cottage industries in remote areas. In this process, the parts are bent to shape on a suitable jig and allowed to dry. In general, only simple equipment is required.

The sharp curve on the front edge of seat slats can be formed with the apparatus shown in **Figure 1-6**. The length of the jig shown is not critical, but it is advantageous if it is of sufficient length to allow several sets of strips to be formed at the same time. In practice the laminations are bent between two lengths of pipe by a third pipe located midway between the first two. A length of threaded rod located at each end of the center pipe with an attached nut is used to provide the force required to shape the laminations. Forces are applied perpendicular to the laminations by the walls of the two outer pipes only at the point of contact of the strips with the pipes. Since no forces are applied to the strips beyond these points, the “wings” remain straight. Since metal pipes may stain the wood, it is necessary to cover them with a protective material such as plastic. In practice, a short piece of plastic pipe can be slipped over the metal pipe to provide this protection. Provided it has the necessary strength, heavy-walled plastic pipe may be used alone and the metal pipe eliminated.

In practice, green strips of wood are inserted in the press and the nuts tightened on the center pipe until the strips are slightly bent. The strips are moistened periodically, and the nuts again tightened at a later time - usually the next day. This process is repeated until the desired degree of curvature is obtained. Although the procedure may take several days to complete, several sets of laminations may be bent at the same time. Furthermore, the jigs are inexpensive so that a user might reasonably be expected to be able to afford a number of jigs consistent with desired output.

After the desired shape is obtained, the slats are allowed to dry and removed from the jig. Each strip is then sawn through the corner to form two strips with a front “lip.” The straight ends of the slats subsequently may be re-wetted and green bent to a desired seat contour.

**Creep-Bending of Wet Wood**
When sharper bends are required than can be obtained with simple wet bending, it may be necessary to allow the wood to “creep.” In this process, the wood part is first bent to the smallest radius possible without fracturing. It is allowed to remain in this condition for some time - usually overnight - and then bent to a sharper radius. This process is continued until the desired radius is obtained.

The bending jig shown in Figure 1-7 may be used to bend green (i.e., wet) back posts to shape. In this process, the back post, while green, is supported at each end and subjected to a load perpendicular to its longitudinal axis at mid span as shown in Figure 1-7. The backpost then is bent as much as possible without fracturing and allowed to remain in this deflected condition for some length of time—usually overnight. The clamping nut is periodically tightened and the back post allowed to creep until the desired degree of curvature in the back post is obtained—note that an allowance should be included for “springback.” The post is then allowed to dry. In some cases, the wood may be bent to the desired shape in one stage; in other cases, it may be necessary to allow the wood to creep so that the bending process must be carried out in stages.

It should be noted that in this process, as the wood creeps, most of the creep occurs in areas of high stress. Thus, a load head of small radius will produce relatively sharp bends. Conversely, a large shaped load head with a gentle curvature may be used to produce sweeping curves.

More complex curves may also be formed by this process as shown in Figure 1-8. In this case, a modified form of the bending jig is used to produce top rails for chairs by green-creep bending in which the ends of the rail remain parallel to its original longitudinal axis. If desired, one end of the center load pipe may be pulled further down than the other end in order to provide a taper across the width of the back rails or back cross slats.

Chemical Bending of Seat and Back Slats

Wood treated with ammonia may be bent into shapes with much smaller radii than is possible with wood treated by means of conventional processes such as steam bending. Although there are several difficulties associated with the use of typical ammonia based processes, an adequate treatment of seat and back slats can be obtained by soaking the ends of the slats in a solution of household ammonia for 24 hours. After this treatment, the ends of the slats can readily be bent to quite small radii.

Production of Chair Seats
Flat chair seats may be constructed of plywood, but medium density fiberboard provides a better seat material because it does not splinter. Seat edges should be rounded. Seats are commonly attached to the rails by means of screws that are driven through the rails and into the underside of the seats. These tend to loosen with time since the screws can penetrate only a short distance into the seat. For maximum durability the seat should be attached to the rails with \( \frac{1}{4} \)-inch diameter flat-head carriage bolts. These bolts should pass through the top of the seat and be secured by a nut in a "countersink" hole located on the bottom side of the rails, Figure 1-9. Ordinarily, seats should be attached to the front and back rails with two bolts each. Location of the bolts varies with design, but in general they should be located outside of the primary seating surface. When the seats are supported by the side rails in addition to the front and back rails, thinner seat material such as 3/8-inch thick medium density fiberboard may be used.

When soft seats such as those constructed of cane, splints, bark or fabric tape, or braided fabric seats are used, the side seat stretchers are positioned above the front and back rails. The intent of this construction is to decrease the pressure exerted by the front rail on the underside of the user’s legs. The chair frames should also be made wider to allow the tops of the front posts to pass comfortably on either side of the user’s legs.

When seats are constructed of thin wood slats, each slat is ordinarily fastened to the front and back rails with a mechanical fastener—often a brad, but screws and staples are also used. The rear fasteners may be eliminated through the use of a second back seat stretcher superposed above the normal seat stretcher as shown in Figure 1-1.

The ends of very thin slats may be bent sufficiently to “hook” over the front and back seat stretchers so that no fasteners are needed. These slats must be reinforced with cross slats, however, to provide sufficient strength. A second side seat stretcher is used on each side of the chair to hold the ends of the cross slats in place.

Alternatively, the ends of thicker slats may be bent to the desired curvature after they have been treated with ammonia. A typical use of slats bent in this manner is given in Figure 1-10. In the chair shown, the slats are first bent to the desired seat or back contour, either by a green bending process or by steam bending. The ends of the slats are then soaked in ammonia and bent to the desired radius at each end. The slats are slipped over the free ends of the cross stretchers as the chairs are assembled and cannot be removed without disassembling the chair. This construction effectively locks the slats in place and helps to hold the chair frame together.

Production of Desk Tops

Desk tops are often constructed of plywood since it is relatively low in cost (in the grades used), has good structural strength, and has good resistance to “creep.” Although plywood tops are at first satisfactory, they usually develop checks and splits on their
surface that make them unsatisfactory as a writing surface. When available, a 1/8-inch thick piece of hardboard laminated to the top of the plywood provides an excellent durable writing surface. The hardboard should be attached to the plywood top with slotted connections that will allow the hardboard to expand and contract with changes in moisture content.

Medium density fiberboard makes excellent desktops—it is smooth, hard, and durable. In general, tops should be constructed of ¾-inch thick material, and the sharp edges should be rounded.

Laminated (Formica, e.g) materials also may be used for tops although "chipping" of the edges may occur with time. Where available, material cut out of counter tops for kitchen sinks may be obtained at low cost and used for tops.

To prevent tops from "creeping," they should be supported on the edges whenever possible and long unsupported spans should be avoided. In some designs, the tops can be supported on only the front and sides while the rear edge is left unsupported. Heavy loads should not be stored on desktops supported in this manner. Whenever possible, the tops should be constructed so that they are reversible; in particular, holes drilled for attachment of the top to the support frame should be symmetrically located.

**Dimensions**

It is important that the furniture properly fit the children. A typical combination seat and desk commonly used in the past is shown in Figure 1-11. This particular unit was used in grades 4 to 8, but obviously did not fit all the children in those grades.

**Finish**

The wood should be sanded to the desired smoothness before the finish is applied. In general, furniture finished with high gloss finishes requires a smoother surface than those finished with oils.

Boiled linseed oil provides an excellent low gloss finish that can be easily applied and readily maintained. Minimum surface preparation of the wood is required. It is applied by hand with a cloth and then hand rubbed and allowed to dry. When dry, the finished surface can be gently rubbed with steel wool to further smooth the surface.

Several coats should be applied over a period of a few days when the furniture is first finished. The surface can then be maintained by reapplying a coat of oil once a year.
Any rags or cloths used in applying or rubbing a linseed oil finish subsequently may combust spontaneously. If stored, they should be kept in metal containers with tight fitting lids.

Selected References