

TIMBER FRAMING

JOURNAL OF THE TIMBER FRAMERS GUILD

Number 119, March 2016



Special Effects in Illinois

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On the cover, Will Denton of Trillium Dell Timberworks stands before full-scale engineering test mockup of timber screen assembly destined for installation at new theater north of Chicago. Hydraulic rams stationed on the upper I-beam and fitted under the crossbars of the upper clamps force the slender battens into tension. Photo by Fire Tower Engineered Timber. On the back cover, scaling logs off the truck on a cool day at Garland Mill Timberframes, Lancaster, N.H. Photo by Matthew Hammon.

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Printed on Anthem Plus, an FSC® certified paper

TIMBER FRAMING (ISSN 1061-9860) is published quarterly by the Timber Framers Guild, 1106 Harris Ave., Bellingham, WA 98225. Subscription \$45 annually or by membership in the Guild. Periodicals postage paid at Becket, MA 01223 and additional mailing offices. POSTMASTER: Send address changes to Timber Framers Guild, 1106 Harris Ave., Bellingham, WA 98225.

TIMBER FRAMING, Journal of the Timber Framers Guild, appears in March, June, September and December. The journal is written by its readers and pays for interesting articles by experienced and novice writers alike.



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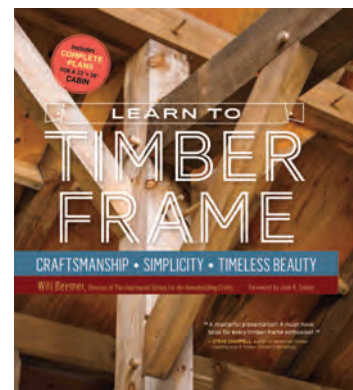


BOOKS

Will Beemer's Book

Learn to Timber Frame, by Will Beemer. North Adams, Mass.: Storey Publishing, May 2016. 8 in. x 9¼ in., 192 pages. Copiously illustrated. ISBN 978-1-61212-668-5. Paper over board, \$24.95.

THIS new book exemplifies the disciplined approach that Will Beemer brings to all tasks, offering a solid background for the new-to-topic learner and then step-by-step direction to complete a small timber frame. Long a workshop offering at the Heartwood School, where the author has taught carpentry and timber framing for 30 years, the small timber frame in all of the iterations shown is a proven platform to learn the basics of square rule layout, cutting and assembly in roughsawn materials. That a simple tool kit and basic skills can be used to achieve a structure empowers the legions of enthusiastic builders who wish to build for self, family and the future.



Early in this book there is a dialogue about stick framing versus timber framing. The familiar invidious comparison of light stick framing with timber framing may unfairly criticize the more modern building system. This comparison may also ignore the transitional, hybrid systems such as the braced frame that developed in the evolution of American wood structures, and our society's constant demand for less skilled labor. Stick framing would appear to allow competency following a short learning curve, but without knowledge of materials both stick framing and timber framing can fail—really any building system will fail.

Consumer-culture memory does not perceive such failures as driven by lack of education. Couple the demand for ever more housing and structures with a profiteer's price point based on leaving out as much as possible, maximize allowable error and set the structure's service life for one generation, and the results are predictable. (The auto industry made some of these choices too.)

In our time, an educated and aware American consumer began to demand quality, craftsmanship, durability and stylish aesthetics. An educated builder can provide each of these as a real value to that consumer. The demand for the well-made objects of skilled trades has seen the resurfacing of skills thought lost, and the aspiring self-builder has been among us for some time now.

Design A discussion of how to configure the function and architectural layout of the book's representative frame, followed by an entry-level discussion of enclosures, wrap the topic of design in a tidy package. There are enough exemplary frame designs to be inspirational, with shots woven in of finished interiors, exteriors and perspectives.

Wood The carpenter's lack of knowledge of wood can degrade both timber framing and modern light framing. The green wood (fresh-sawn, ungraded material) carpenter needs to be aware of the variable quality of materials and how these materials are to be used in a structure. The modern stick-frame carpenter uses materials that have been graded (assigned a structural capacity designation by someone, somewhere and at speed), but designation alone does not define the usefulness of each piece. Many defects and callbacks common to modern stick-framed and timber-framed buildings are the result of poor materials selection by the builder. Learn to look at the wood; know what you are seeing.

The book introduces topics of species and grade at a level that enlightens without overwhelming. (The study of materials is a lifelong journey which is only begun and never finished.) The author's discussion of load types and the source of these loads is also an excellent start. No mention of seismic loads appears, but rather the suggestion that an engineer be consulted when the novice builder moves beyond simple model-building.

Knowing which engineering concerns govern material specification and frame design is key to improving a builder's skills. Load path (an example: gravity loads will find a way to the supporting foundation) is referred to but not discussed in detail, and my experience is that ignoring load path is the major source of defects in all buildings no matter the building system. Harvesting materials is discussed in a cursory fashion, but historical knowledge would remind us all that there are better times of the month and the year to cut trees for structural use. At risk: deformation (shrinkage), durability and performance.

In ordering materials, know what you want and be specific, the author suggests. The new builder may need some guidance and should not be afraid to ask questions. Storage of materials, meanwhile, should be defined by where as well as how. My experience suggests materials are best stored one foot from the ground, dry ground preferred, out of the direct sun, on 1-in. stickers if boards but if timbers on 2-in.-minimum stickers (helps avoid pinching fingers when handling beams). Keeping rain and organic materials out of the pile minimizes staining and allows some seasoning.

Layout The Guild publication *Timber Framing Fundamentals* (to which Will Beemer was a major contributor), published in 2011, offers a more comprehensive discussion of each layout style practiced by timber framers in the past and today. A certain kind of square rule layout is the primary lesson in the new book. This offering should be considered a primer on the topic, again possibly a lifetime study. Subtleties abound. Square rule as practiced today in the US is not a homogeneous set of skills with only one path to success. The common elements of all square rule styles are the use of reference planes (real or posited) and error compensation for material size discrepancy.

Square rule by centerline, snapline and arris (reference planes one face and one edge with arris in common) are three systems in practice (many subsets are scattered about), and the author notes

that these can be mixed in a building. Centerline rule (struck plumb and horizon lines) is an ancient log-building technique (logs preceded timbers). Square rule evolved as a production enhancement technique in the New World with its forests full of tall, straight trees that fit the system well, as relatively short, relatively crooked trees do not.

Most woodworking skills and the systems used to accomplish the task at hand are influenced by personal choice of tools, real or intellectual, and the materials available. Couple that with the fact that the consumer of the finished product has options regarding fit, finish, expense and a host of aesthetics. The author explicates his proven system very clearly, follows with a tool discussion (the reader is reminded that hand tools are enough to get the job done but powered options exist), and then turns to a step-by-step method of laying out the joinery for a small structure.

Cutting If you can read, you can cut it. This sums up Will Beemer's delivery—and nicely done it is. Clear images and multiple drawings marry a two- and three-dimensional presentation. Intuitive awareness of grain direction and tool use comes with experience. You are on the right path when you become aware which end of your timber was toward the top of the living tree. Knowing when to use a chisel bevel up or down is a step along this same path. Sharp: tools cannot be too sharp but the wood species and task define the edge best needed.

An attentive reader following along in this book will gain experience with each joint cut and piece prepared. The topic of joinery shrinkage is not identified as a major informant of technique, but it is implied. In truth, shrinkage offers challenges to aesthetics and engineering concerns, each an important part of the durable and desirable building. Also unemphasized is the effect of out-of-square materials on angular joinery elements such as the braces, collars and rafters of the subject frame. A longer discussion might better prepare the novice for the inevitable. The faces of timbers are either true or not, opposite faces are parallel or not. Knowing in detail how to resolve these anomalies efficiently improves the quality and satisfaction of the work early on.

Assembly Will Beemer's use of the raising script as a means of safely erecting frames is a method known to all professionals. The descriptive text and images may guide a safe raising, but responsibility still falls squarely on the builder. Let caution be your guide. Use 40 lbs. per person as a safe lifting limit for the novice. Test staging planks on the ground before you use them in the air.

A few other key assembly takeaways. Look carefully into the peg hole before you fasten a pegged joint, making sure there is a way through for the peg (daylight is a good sign in a through-hole). Using templates for repeated joints and test-fitting during cutting save embarrassing moments on raising day. There is nothing better than safe completion of a frame raising.

For 30-plus years working with Michele, his wife and partner, Will Beemer has collected a body of work and a stable of spirited instructors at the Heartwood School to accommodate many different learning styles. Successfully. High quality photos and graphics, concise language and clear process will make the new book equally successful with the motivated self-builder who chooses to timber frame.

—CURTIS MILTON
Curtis Milton (curtis@curtismilton.com) operates Monolithic Building Services in Jackson, N.H., and is chair of the Guild's Apprenticeship Training Committee.

The Garland Mill at 160

AS the 9-ft.-long yellow birch lever is pulled down, there's a sound of water surging through the penstock into the wheelpit. Then a few thumps and knocks and the straining of belts. The board saw advances weakly and the edger stutters, then springs to life. As more water drives across the canted fins of the hidden turbine beneath, the mass of iron spins faster, and the floor, in fact the whole building, begins to rumble and shake. Quaint? Well, sort of.

What's the relevance of an old water-powered sawmill in this era of cloud-based data storage, 3D structural printers, and virtual reality? For us, two cousins, it's a pre-Civil War cornerstone of our timber framing business. The Garland Mill, listed on the National Register of Historic Places, has been in continual commercial operation since it was built in 1856 in far-northern New Hampshire, and it produces timbers and boards pretty much the same way it did five years before Abraham Lincoln became president.

In 1986, timber framing came as a natural complement to the mill's customary activities. More than a century earlier, Garland Mill had provided heavy timbers for local builders who routinely used mortise and tenon joinery in their construction. Today the mill saws timbers from native species to meet the needs of its own in-house building company. Pretty straightforward, but let's explore the process as well as the product that has kept the mill going for another generation.

The mill buys winter-skidded logs whenever possible, to keep rocks and mud out of the 50-in.-dia. headsaw that cuts most of the timbers used in the frames. A handful of local loggers and foresters keep their eyes open for good timber and have been supplying the mill for years, in some cases generations. Predominantly white pine (though some spruce, fir and hemlock) arrives at the sawmill from not usually more than 15 to 20 miles away. It's then scaled off the truck (see back cover photo) and piled on the bank or out onto the pond ice.

When the ice goes out, usually by Easter, the mill comes out of hibernation. A frigid torrent flows through the 1938 S. Morgan Smith turbine, the shafts and pulleys creak, and leather and canvas flat belts whip the saws and planers back into action. We use pike poles to maneuver the logs around the pond and into position, and then they get hauled up the front slip and into the sawmill by a heavy bull chain (Fig. 1).

Cant dogs (peaveys) and human power take over, at least until the log is wrestled onto the carriage and held fast by the Lane "Sawyer's Favorite," a hand-set, screw-fed steel dog (Fig. 2). No hydraulics at the Garland Mill.

The current log deck configuration and the Lane No. 1 rack-and-pinion drive carriage can saw up to a 35-ft. stick without too much trouble (Figs. 2 and 3). Our immediate predecessors sawed over 40 ft., and the Aldens (the second family to run the mill for two generations) milled all the full-length tie beams for the 50x100-ft. barn they had built a short distance from the mill, a beautiful three-story gambrel-roofed timber frame raised in 1900, completed in 1901 and still in use as storage for our lumber and timber. The ability to saw long, specialty timbers helps the mill justify its existence, particularly in the absence of much power or speed, hindering cost competitiveness with local mills. But local mills don't offer to saw longer than 20-ft. logs!

The sawyer's stand is just in front of the head rig, and a single lever advance runs the log past the saw. Once slabbed, the cant then comes back past the blade, gets ratcheted forward (toward the operator), and another plank or board is pulled off. The log is turned over by hand with peaveys and the process repeated until the takeaway man pulls the finished timber off the carriage and rolls it out the back of the sawmill. A process familiar to all sawmills, though still rather nonmechanized here. The off-cut boards and planks are air dried, then planed and profiled and used as siding or decking, respectively, on the timber-framed houses and barns the company builds. The sawdust is hauled away by





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Photo left Matthew Hammon; photos above and below Heather Burkham

- 1 Bull chain pulling long pine logs from storage pond into mill, with pike pole standing on left.
- 2 Dana Southworth sawing 19th-century style. Lane No. 1 carriage on the move, with “Sawyer’s Favorite” screw-fed dog (by sawyer’s right hand) holding log fast.
- 3 View from other end of mill. Dana Southworth prepares for next roll of pine cant, Matt Hammon, right, sets rear carriage advance.



3



Photos above and below left, Matthew Hammon



Dana Southworth

local farmers as bedding, and folks keep coming back to the mill year after year for pine slab wood kindling. No packaging and no waste.

All the while, across the brook in the office there have been phone calls and client meetings, followed by site visits and design sessions, discussions with the engineer, permit applications—all the initial stages of the design-build process. We like to do the intake meetings together but then one of us takes on architectural and mechanical design and the other takes on timber frame design and production.

Timber production means running the sawmill and planer. For years, all timber ran through the mill's Lane single-side 24-in. planer, situated next to the saw carriage, which required carting the sticks from the outfeed deck (Fig. 4) back into the mill, then multiple hand-fed passes of each piece, then back onto a trailer and around to the joinery shop. A timber sizer finally appeared in 2009—all 17,000 lbs. of it—with flat belt and babbitt bearing technology similar to the sawmill's, but of modestly newer vintage (ca. 1912), and it earned its own little building (Fig. 5).

This innovation was followed shortly by a small forklift and the construction of several drying sheds, which have made timber handling and processing more humane, though a bit less rustic (Fig. 6).

The layout and notching have remained much the same since timber framing operations began at the mill—traditional mortise and tenon joinery cut by hand, and one frame at a time in the shop (Fig. 7). The shop tools have improved over the years, and the shop plans have progressed from pencil and graph paper renderings to SketchUp and DataCAD. The timbers get marked, checked, notched, checked again, stored under cover, then planed and oiled just before delivery to the site. Clients are often enthusiastic participants in the raisings, and in some cases have even been able to round up people attentive enough to pull off a hand-raising. Most raisings are, however, crane assisted (Fig. 8).

Fig. 9 shows part of the interior of a super-insulated house built as a turnkey project in 2000, handily enough just up the road from the mill.

It might be argued that the 1850s water-powered sawmill is actually the tail wagging the dog. Sitting astride the stream that we

4 Freshly sawn timbers ready to be stacked before planing.

5 Dana Southworth using American Boss 12x20-in. timber sizer, built ca. 1912.

6 Timber shed sheltering rafter set and timbers awaiting notching.

7 Tall posts under way in the shop. Crew left to right, Ronan Thompson, Evan Perkins, Scott Cramer, the late Harry Southworth.

8 White pine frame with cherry braces, raised for garage-workshop.

9 Roof framing in house completed in 2000 in Lancaster, N.H.

10 Ben (left) and Dana Southworth pause before stacking afternoon's sawing run.



Photos above and below left, Dana Southworth



Robert Wojciak

also harness to generate electricity to run our laptops and design software, the mill remains the heart and soul of the business. It has helped sell a job or two, supplied numerous hard-to-source big sticks (at least by East Coast standards), and captivated the imaginations of several generations of family owners grateful for and appreciative of their local history. —DANA SOUTHWORTH Dana Southworth (dana@garlandmill.com) and cousin Ben (Fig. 10) are the third set of multigeneration family owners of their mill, after the Garlands (1856–1895) and the Aldens (1895–1974). Brothers Tom and Harry Southworth acquired the mill in 1974. The next generation, who acquired the business from their fathers in 2010, consider themselves historical caretakers at least as much as owners. They say, “Do visit, but beware, if you stay for more than twenty minutes or so, you’ll probably be put to work.”



Matthew Hammon



Studio Gang

Writers Theatre Dovetail Joinery

TO paraphrase the renowned American structural engineer Hardy Cross (1885–1959), structures are merely members held together by connections. Construction too is all about connections, and the Writers Theatre project in suburban Chicago is no exception: the connections that hold the timbers themselves together, as well as the connections among architects, engineers and fabricators.

The Writers Theatre is a new, privately funded community theater in Glencoe, Illinois, on Lake Michigan just north of Chicago, and designed by the celebrated architecture firm Studio Gang (Chicago and New York), founded by MacArthur Fellow Jeanne Gang. Part of their design entailed hanging a second-story wrap-around promenade from the cantilever ends of glulam timber trusses. Rather than use tension rods or something else equally pedestrian, the architects proposed long slender battens terminating in flared dovetails set in undercut dovetail housings, a joint they called the cat's paw (Figs. 1 and 2).

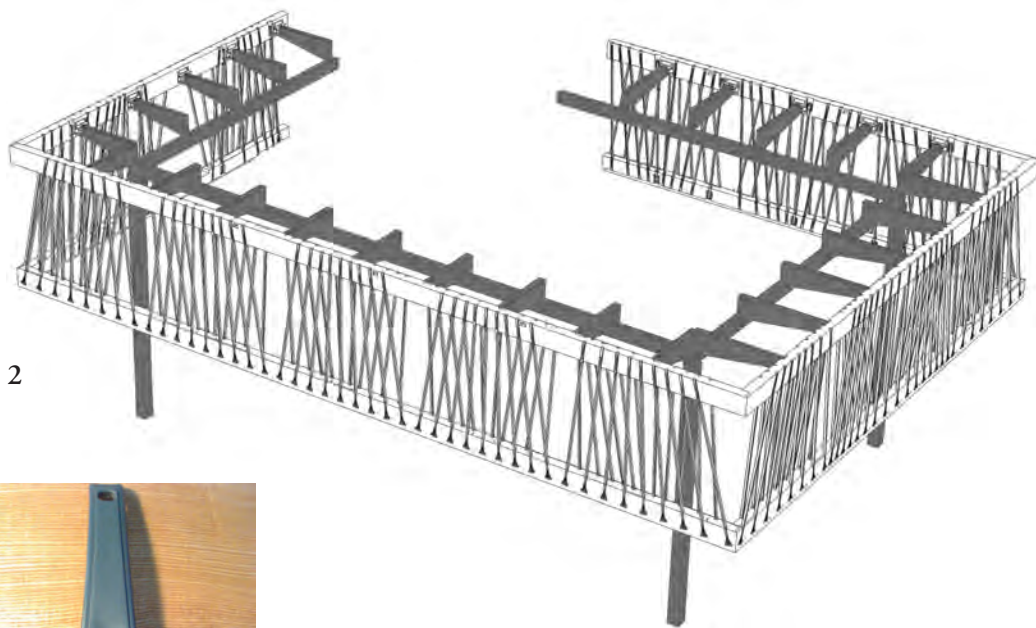
Curved dovetail connections in their own right aren't particularly complicated, but the fact that they support 12x24 glulams up to 90 ft. long, fully exposed to the weather, adds a bit of challenge. Couple that with differential loading on the trusses, whose cantilever ends the battens hang from, such that parts of the promenade could move up while other parts moved down. The battens, ultimately 2x3 Port Orford cedar sticks 16 ft. long, would quickly buckle under any compression (which would be quite unsightly). Thus, the connection had to handle hanging or tensile loads in a very stiff fashion. (Any stress causes strain, a measure of deformation. Strictly speaking, 1 psi of tensile stress on the batten would cause it to stretch—maybe not much, but some. For our 2x3 batten with 3000 lbs. of force applied over 16 ft., using a conservative modulus of elasticity of 1,300,000 psi for Port Orford cedar, we would get 0.074 in. of stretch.) But, if in the

opposite condition the batten were compressed in its length, it would need to immediately release (pop loose) into the space provided. For good measure, each batten was installed at a seemingly random (but specified) angle.

The engineers of record, Halvorson and Partners (Chicago), were more than capable of designing the glulam timber trusses, but the particular joinery was not something they'd done before. Enter Ben Brungraber, Fire Tower Engineered Timber (Providence, Rhode Island), the human connection here being that he and Robert Halvorson had been undergraduates at Cornell (and the two students who made A+ in their structures class). Ben provided his customary excitement, and confidence that the connection was indeed feasible. It quickly became evident that physical testing of the connection was going to be integral to making the detail a success. After soliciting interest and bids, Studio Gang chose Trillium Dell Timberworks in Knoxville, Illinois, to do the testing, fabrication and installation, since they were reasonably close to Glencoe and qualified to send their own crew to the jobsite (the TFG apprentice training program qualifies members to join a union hall and thus to work on projects requiring union workers). Not least, Trillium Dell was one of only a few bidders to say they could figure out a way to do the work as intended.

Halvorson and Partners provided the loading requirements for the various battens and connections, as well as an outline of what testing they wanted conducted, but otherwise left the means and methods to Trillium Dell. Because of Fire Tower's long relationship with Trillium Dell (another human connection) as well as familiarity with the project from the initial concept stage, we were contracted to provide the joint design, testing and shop drawings for the project.

The first order of business was to clarify that no one outside the architect's firm thought the flared dovetail looked like a cat's paw.

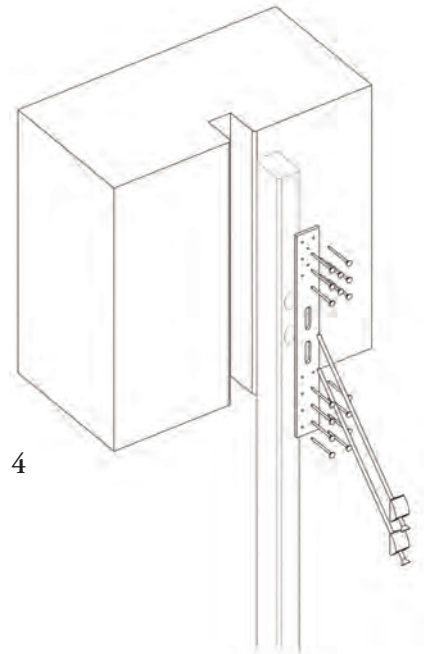


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Photo and drawings Fire Tower Engineered Timber unless otherwise credited



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1 Writers Theatre, Glencoe, Ill., with screened timber walkway.

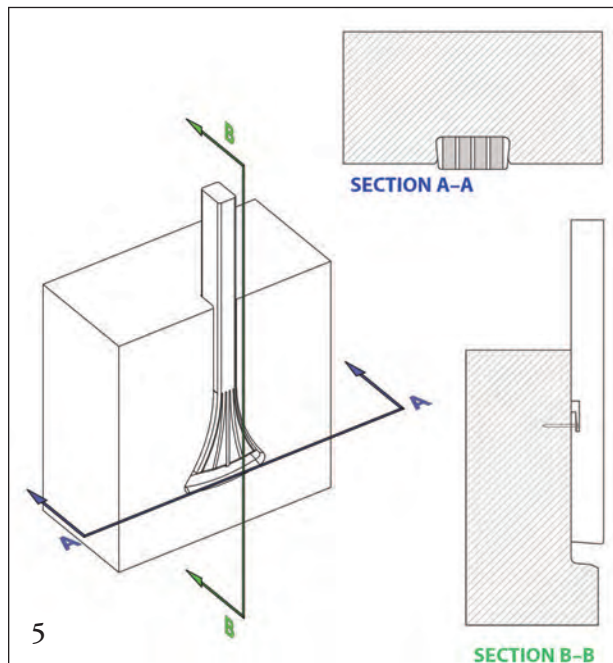
2 Walkway framing. Shaded elements represent cantilevered rafters provided as support.

3 Ice-scraper temporarily offered nickname for flared dovetail.

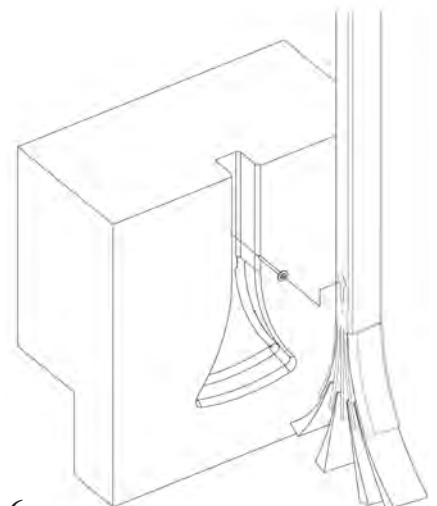
4 Exploded view of sliding joint at batten top.

5 Sections at bottom joint revealing beveled surfaces and clearances.

6 Exploded view of wedged and undercut dovetail joint.



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For us, the best visual corollary was a windshield ice-scraper (Fig. 3). Out of professional courtesy, however, or because of the excessive catalytic energy required to make a name change stick, after a short while we submitted to calling it a cat's paw.

That out of the way, the next step was to work out all the connections. The design called for a row of battens let into the interior surface of the hanging beam and another row into the exterior surface. One end of the interior and exterior battens could be simply and rigidly attached with a series of sloped, fully threaded screws. The other ends required a connection that could consistently handle tension loads, but release if loaded in compression.

For the interior battens, both ends of which would be hidden in either the roof or floor build-up, we used mechanical fasteners. A metal plate, secured to the face of one end of the batten with short screws, offered two slots for the installation of long screws entering on a slope, with mating sloped-head washers. The long screws passed through the plate and an oversized hole in the batten

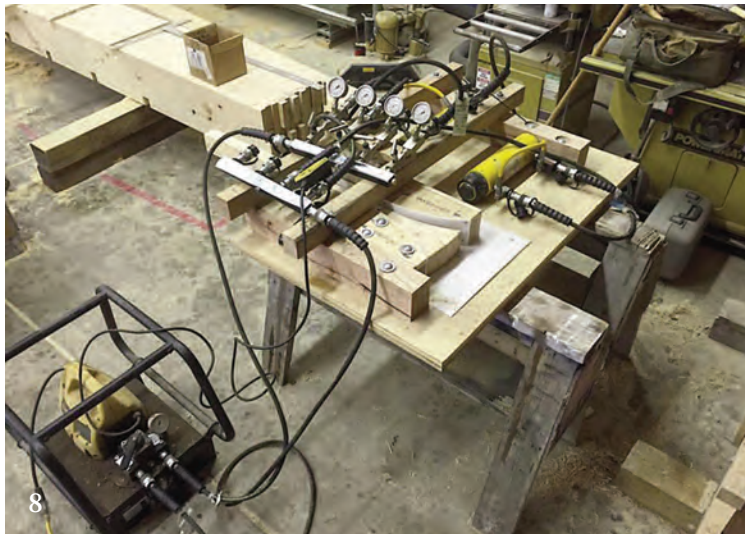
to attach firmly to the glulam beam. The sloped washers bore on the screwhead when the batten was loaded in tension, but were able to slide back when the batten was loaded in compression (Fig. 4).

Given the proposed finishes at roof and floor, putting the steel plates at the top was most practical. Thus the battens could slip in compression on the inside top (metal plate connector) and on the outside bottom (at the dovetails).

The connection posing the real challenge to design was the last, the modified dovetail at the lower end of the exterior battens. Not only did it have to readily carry tension load yet release under compression, it also needed to look good since it was a very visible connection, and to do so while fully exposed to Chicago's worst weather. Because there were upwards of 120 such connections to make, it was also critical to ensure consistent and predictable fabrication. After investigating options via a large and disparate committee, we arrived at the final design: to kerf the ends of the batten and pound in wedges to produce the desired radiused connection (Figs. 5 and 6).



Above and below, Trillium Dell Timberworks



7 Sawn cedar wedges, one side curved, to insert into kerfed tenon.

8 Hydraulic powered pistons applied pressure to shaped jaws of clamp, gluing up newly steamed kerfed and wedged batten end.

9 Completed flared dovetail, wedges polyurethane glued.

10 Direct tension test of thin material on curve representing "finger" of dovetail produced by kerfing batten. Straight pieces of equal thickness were tested comparatively.

11 Samples of material on curve tested to failure.

Batten ends and sawn wedges (Fig. 7) were steamed together in a purpose-built steam box and then inserted with polyurethane glue into a hydraulically powered mold (Fig. 8). The result was a solid flared dovetail with beveled edges, of consistent size (Fig. 9).

Because the spread "fingers" are the only continuous fiber in the dovetail tenon once it's kerfed and wedged, and they have a fairly tight curve, we investigated their capacity compared to wood fiber that hadn't been curved. We conducted a direct tension test on six samples of wood over the tightest radius the fingers would see in the final connection, and compared these to six equal-sized straight samples (Figs. 10 and 11). While the straight samples appeared stronger (averaging 7500 psi ultimate tensile strength compared to 5800 psi for the curved samples), the failure stress varied from test to test substantially enough that we couldn't claim they were statistically different. After getting signoffs from the various powers (architects, engineers of record, third-party reviewing engineers) that the thickness of the fingers was

appropriate for the radius (we would otherwise have needed to add more kerfs and wedges to get thinner fingers), we proceeded to mock up full-scale connection samples to test.

TO test full-scale connections, Trillium Dell fabricated seven flared battens and cut corresponding mortises in a length of glulam. The battens were set into the mortises loosely and then loaded in direct tension (Fig. 12). We loaded the connection cyclically five times, from zero load to design load (3500 lbs), and then released. The connection was then loaded to twice design load (7000 lbs) and held at that load overnight (at least 12 hours) before loading the connection to failure. In all but one case, failure occurred in the batten at a point of substantial slope of grain (Fig. 13). Other test pieces failed in the grips where the load ram connected to the batten. None failed in the dovetail tenon itself. To test the effect of moisture, we soaked four flared battens in a rain barrel for 24 hours, two with end-grain sealer, two with none (Fig. 14).



12 Full-scale mockup to test dovetail joint alone.

13 Failure in batten at short grain.

14 Dovetails soaked in rain barrel for 24 hours, results for sealed and unsealed ends. Sealed ends performed better.

15 Fixed connections tested in short length of glulam.

16 Tension-only connections similarly tested.



Although screwed connections are easily designed within the parameters of the *National Design Specification for Wood Construction*, many of the parties involved weren't familiar with fully threaded screws and their performance. We conducted three tests of the screwed-together connections at the fixed end of the batten (Fig. 15) as well as three tests of the tension-only screwed connections (Fig. 16). They proved to be not only stiff, but also strong. (Compare a bungee cord and a piece of rope that break at the same load. One stretches substantially more than the other and thus is less stiff, despite their having the same strength.) Their ultimate capacity was never reached, however, because the test samples failed at the grips, as they did in the dovetailed connections.

After testing the short specimens, we built a 12-ft.-long, 16-ft.-tall, full-scale mockup (Figs. 17, 18 and cover photo) with five interior and five exterior battens. The mockup was securely mounted to a base frame with 10 sets of bearing plates and threaded rods, and then loaded in tension by two hydraulic rams,

corresponding in position with where the upper glulam would hang from the cantilever truss ends. We reviewed the load data developed from the short samples and chose an initial preloading of approximately 1750 lbs. to minimize the initial take-up deformation in the dovetails (Fig. 18).

The bottom chord design load was 800 lbs. per lineal ft., uniformly loaded, giving a total design load of 9600 lbs. for the 12-ft. mockup. However, because of the possibility of differential local loading (pattern loading), each batten needed to be designed for 3500 lbs. Pattern loading may have different effects from uniform loading. For example, a simple cantilever beam loaded only at one end may need to be held down at the other, whereas if uniformly loaded along its entire length it may be dynamically stable. In addition to the eight "regular" battens (with a combined design load capacity of 28,000 lbs.), two of the battens concealed buried full-length ½-in. high-strength steel rods as additional backup, each capable of carrying the entire design load (9600 lbs.



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per 12 ft.), giving a total allowable design capacity of 47,200 lbs. for an original design load of 9600 lbs. In other words, it was stout. And in the finished structure, one could take a chainsaw and cut out every batten except the ones with the steel rods, and the structure would not only remain standing but remain safe for a full occupant load. (Composite battens, visible in the cover photo, are indicated by special housed steel fittings top and bottom.)

The testing program called for monotonically loading (single steady pull) the connections to at least two times the design load (19,200 lbs). Instead, we conducted a cyclic loading akin to the testing of the short specimens (zero to full design load, five times), and then took it to four times the design load, which wasn't even the full design capacity of the connections.

With the assembled and loaded mockup at hand, we conducted dynamic testing of battens, repeatedly impacting them near midspan, creating increasing amounts of deformation and measuring the amount of time a batten oscillated.

The architects were concerned that the battens might rattle when occupants walked by and knocked against them, or during high winds. Despite part of the design team's earlier lecture about proper tolerances ("you shouldn't be able to fit a business card between the neck of the batten and the mortise"), they then

17 Full-scale 12-ft. mockup of screen, five battens each side, in steel test jig. Hydraulic rams push off I-beam at top, pulling upper glulam. Lower glulam is clamped firmly to I-beam at bottom.

18 Detail of dovetailed connections and lower glulam clamped to I-beam at bottom of jig. No. 2 Port Orford cedar allows knots. Inset shows lapped miter joint under way in actual wall plate.



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Trillium Dell Timberworks

wanted that gap packed with a thick piece of rubberized sorbothane sheet (think really expensive ice and water shield, but with lame adhesive) to dampen vibrations on the battens. Dynamic testing of the battens with and without the sorbothane showed markedly better performance without the sorbothane, as it fit so tightly that it altered the end fixity of the batten. Installing the sorbothane even during our few tests, conducted on a dry fall afternoon, proved onerous, so omitting it from the final install was well received by the crew. At this point, with four times the design load on the mockup, the project architects and engineers wanted to halt further testing and ride up the man-lift to get a picture from atop. Unfortunately, in so doing, they became quite fond of the mockup and wanted to take it back to their office with them. (At the time of this writing, it's still stored in a shed at Trillium Dell's shop.) Unfortunately, their decision aborted my crowning glory, as I had designed the test frame to make sure we could finally break something after all the prying eyes went home for the day.

—JOE MILLER

Will Denton of Trillium Dell Timberworks oversaw the fabrication of the joinery and the installation of the screen framing.

Fabrication This build had several challenges, including tooling up efficiently for a one-off job, fabricating the compound dovetail joint (10 or so for testing and 120 for final product), and fitting and handling a 12x24 90-ft. glulam in an 80-ft. workshop. We had to develop an efficient way of necking down a 2 $\frac{5}{8}$ x 3-in. stick of No. 2 Port Orford cedar (knots permitted) 16 ft. long to a 2x3 terminating in a bevel-edged flared dovetail, and do it many more than 100 times. Our first dovetails were disastrous. We had to develop processes for cutting, steaming, bending, clamping and shaping. The kerfs for the dovetail end required a custom jig, and the wedges to fit and spread the kerfs were cut on a sled, both for the bandsaw. From here the wedges and dovetail blanks made their way to steam boxes made for this one job.

How do you steam just 1 ft. of a 16-ft. batten? We used chimney flue tile with rubber gaskets and high density plastic ends with a 2 $\frac{3}{4}$ x 3 $\frac{1}{8}$ -in. hole cut in the center. Through trial and error we developed a steam time of about two hours. After the batten and wedges came out of the steam box, they had to go rapidly into a clamp. The outside shape of the flared dovetail was the form for the clamp work. We started off with a couple of F-clamps, but graduated to two 30-ton Enerpac rams. Polyurethane glue worked well for us because of its one-hour clamp time and its positive relationship with water. Most glues do not like water, and the rest have long clamp or cure times. With 120-plus of these assemblies to crank out, every minute counted.

After the clamp-up of the battens, further shaping of the bevel-edged dovetail was completed only after the development of many jigs (and each jig had to be a perfect match to the opposite jig required for the housings in the glulams). While we were cutting the battens, all of different lengths, we laid out and cut the housings in the glulam plates for the top and bottom of the four walls of the walkway. All told we cut 260 battens: 120 with dovetails for the exterior sides, 116 with straight ends for the interior sides where top and bottom would be concealed, and 24 split, grooved and glued up to conceal high-strength $\frac{1}{2}$ -in. steel rods. Given the varying off-plumb pitches of the battens, any standard grid layout went out the door. Each batten was assigned a numeric designation and, with the help of Joe Miller's excellent shop drawings, given a location. To rout appropriate housings for

the dovetailed battens, we used three jigs and five router bits—an end mill bit to rough out the shape, a 3-in. straight bit with radiused tip for the neck of the batten, a third with an undercut, a fourth with an overcut to allow for drainage and, finally, a roundover bit to give a shadow line for the architects.

As we have seen, layout and cutting the first face were no problem at all! Now, how to roll a 6000-lb., 90-ft. glulam in an 80-ft. shop in February in the Midwest? Enter a chainfall hoist and a 10,000-lb. telehandler. We rolled the glulam behemoths as few times as possible, laying out three faces before the first turn and cutting as much as possible on each face before rolling. To keep the wind out, we built a false wall in the shop doorway, leaving 12 ft. of glulam to poke out the end.

After reviewing some 50-odd stain samples (Heritage Natural Finishes), the architects picked one that fit, and we had to come up with a way to send the beams through the streets of Chicago to a one-lane, one-way street in Glencoe that we weren't allowed to block off. We blocked it off anyway for four hours while we unloaded the glulams with a telehandler. This was a tight site—we had to borrow 12 parking spots to store the timbers.

After getting eight glulams averaging 62 ft. in length through Chicago, along with tooling, equipment and 260 battens, we still had to put this structure up.

Site installation As a start to the project, I was thrown off the site for unauthorized use of a tape measure (this was a 110 percent union job), but by the end of the week I was a card-carrying member of Local 58 of the United Brotherhood of Carpenters and Joiners of America. (Since this moment Trillium Dell has thrived on being the only union timber framing shop in the United States, allowed to join by virtue of its broad involvement with the Guild's Apprentice Training Program.)

After joining the union I was allowed to do field measurements. Because of a small camber oversight by the glulam subcontractor, the rafter tails were out of plane by plus or minus 5 in.! (We had built to a sixteenth in elevation and plan.) Before we could proceed, the subcontractors had to shore the trussed walls and jack them to level, as well as remake all the steel webbing members. They managed to get within half-inch of square in plan, and we were then able to attach our promenade screen to the perimeter. We started by hanging all the upper chords, followed shortly by the lower chords, the latter held in place by steel spacer studs and Lugall hoists to hold everything tight.

We stitched together the lower and upper chords with the 260 battens, each in its designated spot, 120 of them with the flared dovetail connection to be assembled pretensioned. At the corners of the glulams, thanks to the newly leveled supports, we achieved the best lapped miter joints I have seen, fastened by hidden bolts (Fig. 18 inset). The promenade screen ended up being within plus or minus an eighth over the 200 linear feet of screen. It has to be one of the most elaborate covered porches in America, perhaps rivaling that of the Grand Hotel on Michigan's Mackinac Island.

—WILL DENTON

Joe Miller (joe@fjet.com) PhD, PE, is a principal at Fire Tower Engineered Timber and symposium chair of the Timber Frame Engineering Council. He engineered and oversaw the testing of the special joinery for the Writers Theatre. Will Denton (will@trilliumdell.com) is a project manager at Trillium Dell Timberworks in Knoxville, Illinois, a journeyworker in the Timber Framers Guild and a graduate of the American College of the Building Arts.

Safe Cribbing and Jacking

MANY timber framers have done some amount of jacking in their work, especially those of us in the restoration field. Sometimes the methods we use are learned by working with professional house movers and jackers. Sometimes we learn them by studying what peers in timber frame restoration are doing. It benefits all of us who replace sills or posts, or do other repairs requiring jacking, to look at what people do who make a living lifting and moving buildings. Their methods allow them to lift very large buildings high in the air, safely, and even transport them on their setup if need be. This article compiles guidelines and protocols, by no means exhaustive, that we might learn from. Remember, this is a dangerous field: personal safety should always be at the forefront.

While it's certainly possible to lift specific locations in a building, or even entire buildings, using adjustable jack posts, conventional scaffolding or improvised towers of wood cribbing, it's unsafe and unwise to do so. Insufficient and precarious setups often require the timber framer to reset or reinforce in the middle of the job, or to sacrifice safety entirely to complete the work at hand—or to leave the work uncompleted. Too often I hear people say that they weren't able to straighten or level buildings they were working on because their setup did not allow them to. With a proper setup of cribbing, steel I-beams and reinforcing brackets to supplement the timber connections for jacking, it's practical and safe to lift, straighten or rack a building to bring it back to its original shape (Fig. 1). Posts can be fully suspended and repaired at their feet as needed. If they need to be aligned as they are set down into a sill, they can be pushed or pulled around without fear of disrupting a precarious jacking setup.

The base Before building a cribbing tower, it's important to think about the different components that will affect the tower's ability safely to lift and then support the load desired. How will jacking pressure transfer from the cribbing tower upward into the building? How will the load be handled that in most cases will be cantilevered out from the cribbing towers on steel I-beams?

Obviously, a tower should be built as close as possible to the wall(s) it's lifting. Many cribbing towers, however, are built to permit foundation replacement, and the towers need to be set off far enough to allow safe removal of the existing foundation without shifting or undermining of the cribbing tower. This means that the steel I-beams need to be sized according to the cantilevered weight of the building beyond the cribbing towers, without deflecting beyond an acceptable amount.

A suitable base for the cribbing tower is essential as well. If jacking for a foundation replacement, the safest approach for the base of the crib towers is to dig down to the same depth as the foundation footing. Often this means supporting the building with an initial setup of steel and cribbing that allows a machine to dig within the building footprint safely.

We have also dug down by hand to obtain a solid level surface shy of the footing depth by several feet. Building towers that will be surrounded by a "moat" of exposed material below their base when the foundation itself is excavated, while possible and safe enough in the right soils, does add an element of risk (Fig. 2).

Depending on soil type, large stones may be found that extend

underneath the cribbing tower, disrupting the soil. Equally challenging, sandy soils will tend to slough off once exposed and can undermine the base below the cribbing towers, especially in heavy rains.

When using this method, as the foundation is excavated, it's a good idea to connect the trenches around the building with each other and to a common drain in case the trenches fill with water before footings are placed. It's also wise to run the base layer of cribbing perpendicular to the nearest trench to prevent undermining of one or more pieces of cribbing. At least two pieces of cribbing on each side at the base, if not a full layer, are always advisable.

If you are considering building on top of an existing slab, remember that the materials below that slab have probably settled somewhat over time and that the slab itself may not be uniformly supported. We have made the mistake of attempting to preserve an existing concrete slab and thus jacking on top of it while replacing the foundation. As the last existing wall was removed, we discovered that the slab had been placed over loosely filled sand and on that side was hanging in space. Quick (and less than ideal) reinforcement was required in order to keep the slab from cracking and to avoid a potentially disastrous failure. Since then, if we plan to lift from an existing slab, we jackhammer and remove the concrete at our tower locations. Do not jeopardize your safety in the effort to preserve a slab intact.

Cribbing Most often, the base support for jacking and lifting is wood cribbing. An assortment of sizes and species is in use, but generally in the 6x6 range and, unless crushing is a specific issue, typically softwood. Jacking companies in the Northeast use spruce, pressure-treated Southern yellow pine and hemlock predominantly.

In our own restoration work, we prefer hemlock because of its strength and rot resistance compared to other locally available softwood timber. Thomas Barczak and Carol Tasillo, in *Evaluation of Multitimbered Wood Crib Supports* (published by the Bureau of Mines in 1991), suggest that "cribs should be constructed from the same wood type, seasoned to a similar moisture content to minimize the differential compression of individual timbers that promotes buckling of the crib structure." We try to use cribbing of the same milling batch across each level, not only to ensure that the sizing is similar but also to keep the timber characteristics the same on either side of the crib tower at each level. Our cribbing is a mix of 6x6 and 5½x7, the latter size so that pieces may be inserted into standing cribbing towers if necessary, or used on edge to shore up to the beam when there isn't yet enough height for another layer.

1 Cribbing and steel I-beams still in place from foundation replacement, now in use to lift top plate in order to replace two wall posts and associated girts. Because of their height (aspect ratio), towers are braced with 2x6s screwed into every cribbing level and counterbraced to platforms on steel needles.

2 Steel and cribbing support barn in preparation for foundation replacement. Lifting at ties allows placing straight wall and manipulating posts back to plane. Slab jackhammered and removed at cribbing tower locations, "moat" not yet fully dug.



Photos Eliot Lothrop unless otherwise credited





3 Paired, braced 26-ft. towers sheathed on two faces support failing gable end of barn at purlins, first 7 ft. built twice as long for stability. Slates first removed from lower half of roof.



4 Nearly 30 ft. of top plate, all wall framing on one side and entire gable end have been removed. Towers allowed purlin lift to install new timbers while keeping roof on barn.

We have found that carefully squaring the ends of the cribbing to a uniform length and building towers with flush corners assist greatly in keeping towers plumb and square as they ascend and in service (Figs. 3 and 4). Some folks inset cribbing 6 in. or so at corners, their theory being that adjacent layers then lock together slightly when compression occurs.

When building with rectangular sections of cribbing, it may be tempting to put the sections on edge to gain height more quickly, but if the building is subject to any movement at the top of the cribbing the tower will be unstable. Strength and stability in a tower come from overlapping surface area from one level to another. The more shared surface area, the more stable the tower.

Building a tower A proper tower of cribbing is built in layers of blocks alternating direction with each layer. You must start out with a carefully leveled base for the first blocks, then check for level at every layer as you build the tower. Measuring and swapping out cribbing as necessary is always preferable to inserting shims to adjust for level. As you stack, check for insect damage, dry rot, cracks, knot clusters and shake, and discard faulty blocks. We like to keep handy a can of orange spray-paint for discarded cribbing that we can use instead as stickers around the jobsite. Coating the end grain of good cribbing with Anchorseal or another wax, and taking care to cover it when not in use, greatly aids in its longevity.

There are many different ways to build cribbing towers, but the most common setups are called *four-point* (two pieces of cribbing per level with four points of contact), *nine-point* (three pieces of cribbing), or *full crib* (solid). The strength of a cribbing tower comes from the contact area between the layers of cribbing. The more blocks per level (short of solid cribbing), the more contact area and the stronger the tower. Barczak and Tasillo note that contact area varies with the square of the number of pieces per level, and thus crib performance “improves dramatically” with added pieces.

The load should be located as close to the center of the tower as possible and carried on several blocks, all transferring their load to the outside of the tower. When using a four-point crib, it’s wise to add a third piece of cribbing for at least the top two or three levels. This cuts in half the span of any possible load-bearing blocks and reduces the possibility of a piece breaking.

If you are building a nine-point crib, it’s important that the middle pieces of cribbing in any layer not be in the least higher than outside pieces. Even a fraction of an inch difference will make a tower unsteady. Blocking of various or fractional dimensions can be handy. If your tower is built out of 6x6, you can easily insert a 5½x7 flatwise after the fact and shim the contact points with ½-in. plywood. Just remember that without the shim, the additional piece is useless as it is not in contact with the next level.

There is no set criterion as to aspect ratio (height to width) for a tower, but the lower the ratio, the more stable and less prone to



5 Lifting eaves side of barn from beneath transverse sills with steel brackets to bring load to outside wall. Notice pyramid arrangement of cribbing at top of tower in foreground.



6 Hydraulic jack set on block in previous level, 2x shim placed. Jack's threaded post allows placement before jacking.

buckling the tower will be. If you do need to build a tall tower, consider increasing the number of blocks per level in order to increase the shared surface area. It's also wise to brace the tower back to something that will not be lifted. Temporarily wrapping some or all of the tower in plywood or diagonal 2x6s also adds to stiffness and will help prevent tipping.

Picking up the load (Figs. 5 and 6) As timber framers, we should have as much knowledge about load paths and bearing points as a professional house jacker. At our company, we are preservationists first and foremost and we prefer not to cut holes in sheathing to thread our needle beams through a building. Instead, we use existing door and window openings whenever possible (Fig. 7). Professional house jackers might bolt inverted brackets to the posts of a building and then jack with steel beams placed under the brackets. We often use existing horizontal timbers such as tie beams as jack points, thereby lifting posts without being entangled with them. We supplement joinery from tie or girt to post with 2x material or steel brackets that direct any sort of cantilevered load back to the post. Care needs to be taken in cantilevering load at any distance from the support, especially if the timber is small or its condition is inferior.

An assortment of brackets is helpful, as each frame or jacking scenario may have different conditions or requirements. If the load and support are relatively close to each other, a smaller bracket with lag bolts may be used. A further cantilever or taller knee wall may require large brackets with through-bolts, or clamping around the post with allthread to secure it tightly. When jacking directly on a steel bracket, the jack can actually lever off the bracket if it's only fastened by lag bolts (Fig. 8).

We use steel I-beams for lifting, almost exclusively. While they may present a weight problem for smaller crews with no machinery available to set them, they are by far the safest materials for jacking. Professional jackers start by installing deep-sectioned main beams, typically running the full length of the building (up to 60 ft.). The transverse beams, or needles, which (ideally) cross the full width of the building, are then rolled in on top of the

7 Telescoping jib forklift attachment sets needle beam to lift post via through-bolted bracket, allowing sill repair.

8 Array of brackets and other appliances used in jacking. From left, adjustable shoring post, beam roller, 6x6 shoring post foot, angle bracket and bracket for tall knee walls or long cantilevers.





Marcie Bolton Photography



Trillium Dell Timberworks

9 Central control for unified jacking system uses self-powered hydraulic pump and hoses to send fluid to multiple remote jacks for simultaneous lift at many points.

10 Crib jack, here disconnected from source, rests on pairs of blocks or rails supported by blocks.

11 From left, 12-ton hydraulic jacks (two profiles), 15-ton, 25-ton and 50-ton journal jacks, 16-ton screw jack with 20 in. of lift.

main beams. This work can be done by hand, even with the heaviest beams, by using a beam roller. (Rollers can be purchased through companies like Holland Moving and Rigging or manufactured by an experienced professional.) If jacking underneath reinforced ties or girts, you may be able to accomplish all lifting with only the main beams, but this plan offers no backup if there is an issue with the jacking or the structure that it relies on. Needles set on top of the main beams can be posted directly up to wall top plates and give a greater factor of safety.

When lifting a building from the tie beams or girts and thus taking the weight off the posts, any sort of inflection in the tie may change the angle of the posts, and adversely affect the roof system. To prevent spreading in the roof system, or uncalculated sudden failure, temporary comealongs should be installed across every bent, or wherever spreading seems likely.

The lift With the base set, and the pick located and reinforced as needed, it's time to do some lifting. Most professionals use a unified jacking system with central hydraulic power source and multiple individually controlled lines running to crib jacks (Figs. 9 and 10). Crib jacks sit down in the top of a tower, hung on the cribbing or tube steel on either side by wings that are part of the jack. This low and stable position allows the jack to have a tremendous amount of throw, typically around 18 in. Those of us who don't make our living jacking buildings, however, probably can't afford a unified jacking system and will look to individual jacks.

A wide assortment of jacks may be used to lift buildings (Fig. 11). The most basic and foolproof, but also the slowest, heaviest and sometimes the most cumbersome, is the screw jack. Many timber framers like using screw jacks because they can "feel" the weight or resistance of the building at each location as they are jacking, and respond accordingly. The disadvantage is that when the jack is on top of a cribbing tower, with blocking and other items in the way,

it's often physically very difficult to manipulate the bar to turn the jackscrew to lift the building. Much friction must be overcome, even if the screw is well greased.

The faster, lighter and easier option is the hydraulic jack. Probably you can afford to own a set of hydraulic jacks that will lift up an entire building, but hydraulics don't offer feedback through the pump lever. Without being able to sense the resistance, you may find it easy to get carried away at a single location, possibly breaking a framing member. In addition, hydraulic jacks do settle over time and should never be left in place for long without the load being solidly shored up. We make it a point at the end of the day to block up at any hydraulic jack station and remove the jack for the evening.

A good medium between the hydraulic jack and the screw jack is the journal jack, which has a ratcheting mechanism such that a vertical throw with the handle operates a screw jack within, via a hidden bevel gear on the journal rotated by the handle that meshes with another at the base of the screw. Here you have the best of both worlds: easy lifting without the worry of settling, and the ability to feel the weight of the building as you crank the jack—and with a much more rugged base than a hydraulic jack.

As you get ready to jack on top of a cribbing tower, it's a good idea to put a piece of hardwood or plywood beneath the jack. Without this pad to spread the concentrated load, and even with it in some cases, the jack is prone to dig into the cribbing, which may cause the jack to lean and overturn. Carefully aligning the jack with the web of the I-beam is also essential to prevent roll. As you begin lifting a steel I-beam with the jack, you should have an assortment of wood in different thicknesses and widths at the ready for blocking the rising load.

We use an assortment of roughly 6-in.-wide by 1-ft.-long pieces of ½-in. and ¾-in. plywood as well as dimensional (1½-in.) and roughsawn 2x6, with a pile placed at each tower. As the I-beam



12 Bank barn lifted high with arrangement of main beams and needle beams, to place new foundation. Formwork for footing under way. Crib tower construction needed great care as one end of barn sat directly on road and the other over steep drop.

13, 14 Severely distorted 1830s barn frame jacked up level and straight, ready for post repairs. Near corner had sunk into ground nearly 3 ft. Jacking permitted foundation replacement as well as major timber frame repairs.

lifts off of the cribbing, shim underneath the beam repeatedly as you go, so that there is always a nearby fall-back support should something go wrong.

The stacks of shims should not exceed the height of your cribbing layer, and you should install a full-dimension block of cribbing as soon as you can. It's also good to be wary as the throat of the jack comes close to full extension. If there is any potential for the jack to kick out or move, or if the pick seems heavy, it's best to reset at a new height and continue to lift with a mostly retracted jack. For this reason, the shorter the better for jack selection, as long as the capacity meets your needs.

With every other layer of cribbing, it will be necessary to initially "pyramid" the level by installing two pairs of cribbing pieces at the outside edges of the tower, with a third piece of cribbing on top to support the I-beam (Fig. 5 on page 17). The pyramids run perpendicular to the steel beam.

To return the tower to the standard "log cabin" crib style, the jacking will need to go up another level. When rearranging, take care to maintain stability in the tower, keeping the throw of the jack as low as possible, and coordinating with others who may be jacking on the same beam from another tower. Using this method and constantly checking for level all the way around a building, you can lift and straighten just about anything (Figs. 12–14). When we set up to begin jacking, we position a 360-degree laser level and measure from a given point (top of posts, plates or ties) at every visible node in the building to understand where we need to lift the most. Many laser levels have a magnetic base or a stand and can remain set up to project a laser line visible around most or all of the building. Even a rough reference of the laser on the steel I-beams while lifting is a good indicator of how close to level things are staying or getting.

—ELIOT LOTHROP

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Medieval Germanic Roof Structures 4



Photos and drawings Philip Caston

IN the previous article in this series (TF 118), I discussed framers' innovations in the design and assembly of late-medieval roof structures, specifically in how they alternated differently configured primary frames to obtain different static cases for different circumstances, and how they incorporated iron fasteners.

During my 1996 inventory of the largest roof structures in the Mur-Mürz Valley in the Austrian province of Styria, I came across another late-medieval roof that embodied these innovations and proved as well to be a remarkable piece of framing (Fig. 1). This structure, some 60 ft. wide, 110 ft. long and 52 ft. high, covers the nave and both aisles of the former abbey and parish church dedicated to Saint Andreas (Saint Andrew) in Leoben-Göss (N47° 21.790' E015° 05.735'). The nave vaulting extends into the lowest tier of framing, breaking into the space that could otherwise be occupied by the tie beam of a statically stable tie beam-rafter-pair triangle, a significant problem that the framer or designer had to contend with. The timber for the roof was felled in the winter of 1509–10, according to dendro-dating, then converted to framing members and erected the following summer before the vaulting was completed.

The roof structure is not only completely original but in excellent condition. A prospective retiling of the roof (executed in 2002) initiated an advance investigation of the structure, producing two highly detailed measured drawings. These revealed absolutely no significant deformation of the structure, built from spruce (*Picea abies*) over 500 years ago. They showed also that the last bay at the end with the two towers is smaller and contains twice as much crossed bracing along the central axis, a spinelike wall of posts, presumably to stiffen the structure against wind forces, snowload and the long-term weight of roof tiles.

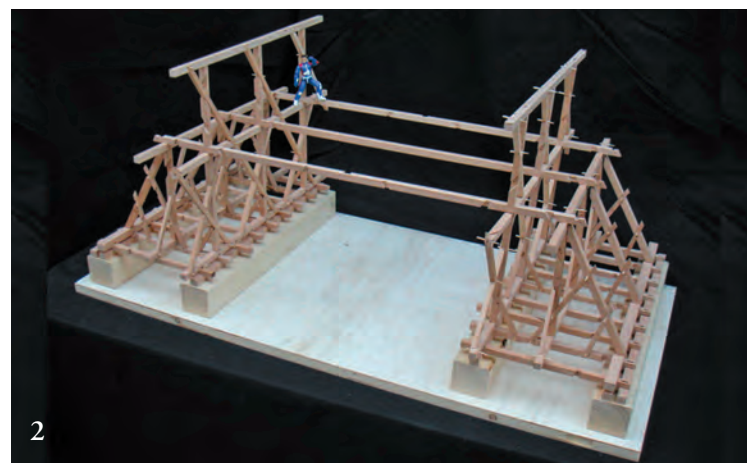
The measured drawing gave my civil engineering students at Neubrandenburg University of Applied Sciences the chance to

make two models of the center section of the structure. The first model was made of wood at a scale of 1:20 (Figs. 2 and 4), the second constructed in virtual 3D space. Both were used to analyze the design and to reconstruct the erection sequence. The virtual model generated the perspective renderings in this article.

At first glance, the structure seems to have a fairly typical, if large, late-medieval design. A steeply angled roof surface, in section almost forming an equilateral triangle, encloses 36 rafter pairs, each held together by five tiers of collar beams and a tier of interrupted tie beams and lower bracings. Every third frame is a primary frame, alternating A–C–C–B–C–C–A, as previously described in the two cathedral roofs in Regensburg. Both primary frames contain four rows of posts (two on each side of the central vaulting) in the lowest tier and two rows in each of the consecutive two tiers. The posts are part of a *stehender Stuhl*, in a roof structure a supporting framework or truss with upright posts (as distinct from a *liegender Stuhl* with its leaning struts).

As seen in Fig. 3, frame type B has the posts linked together transversely by a passing brace that connects through the lowest three tiers. Frame type A is more complex. The passing braces are much longer and extend over five tiers to a central post. This post, along with the others in the other type-A frames, forms an axial spine over the complete length of the roof structure. Large crossed braces and shorter upper braces connect the posts transversely with the collar beams, passing braces and rafters in the frame, while long and short intersecting crossed braces connect the posts longitudinally with the purlins in the spine. From a statics point of view—how the frame finally transmits its forces to the walls—there is no apparent reason for two types of primary frame.

The outermost pair in the lowest tier of posts in both primary frames are not just braced in both the longitudinal and the lateral directions, and again by the passing brace, but are additionally secured by large struts that emanate from two longitudinal sills, one on either side of the structure (Fig. 2). These struts are not afterthoughts, in fact they are just the opposite, and they are deliberately lapped by the lowest braces. They appear to be superfluous to the design, not involved in aiding the purlin by transmitting vertical or diagonal forces from the main frame members. So why are they there? Perhaps they are linked to the challenging problem of the vaulting that extends into the roof space and prevents the use of the most statically important roof member, a tie beam at the bottom of the rafter triangle.





5 St. Andrew in Leoben-Göss, junction of second lowest collar beam with post and crossed braces in frame type A. Lap joints allow assembly only in a certain sequence.

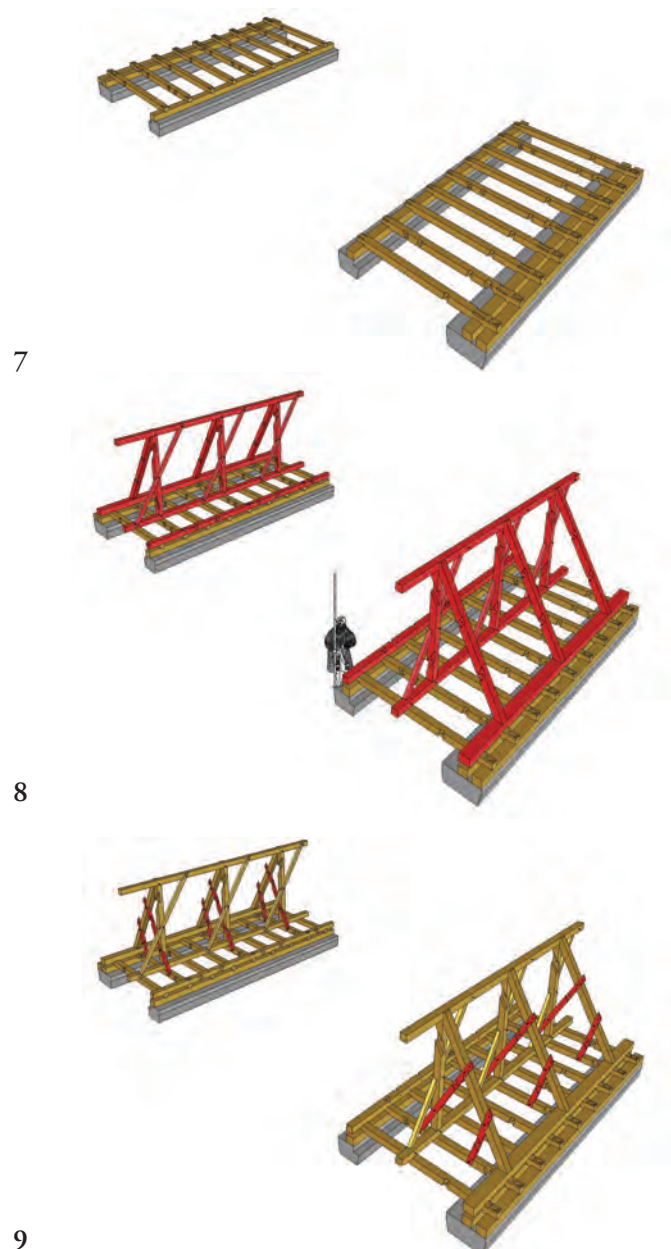


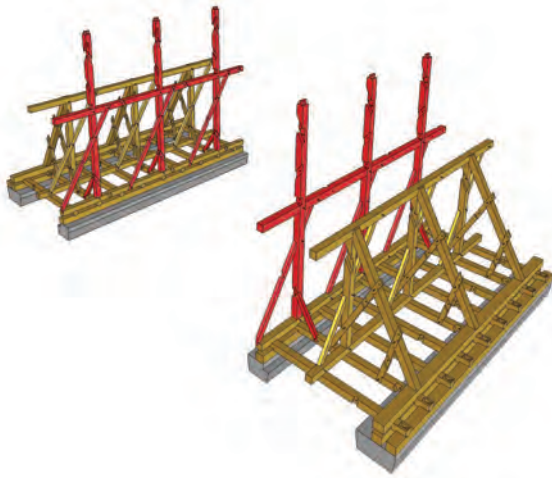
6 View of central spine taken at lowest level of collar beams. During construction collar beams would have provided ideal work platform for framers to use to erect next tier.

As we saw at St Mary's at Pöls in the last article, iron spikes or nails occasionally appear in Leoben-Göss, here simply as fasteners in place of wooden pegs. All the rafter and stehender Stuhl joints, and all of those in the lower tier of the whole structure, are secured together by pegs, but the upper ends of the transverse passing braces are predominantly spiked (Figs. 5 and 6), as are the long crossed braces. Some of the laps are not spiked or pegged together at all, which is just as unusual as using iron spikes. This roof is not far from the iron ore mining area mentioned in the previous article, and perhaps the region was flooded with cheap iron products, which the framer used to save time in the construction. Other iron in this frame includes straps to bind the bottoms of the tall posts in the central spine, so as to secure short relish at mortises for the underslung purlins (Figs. 6 and 14a).

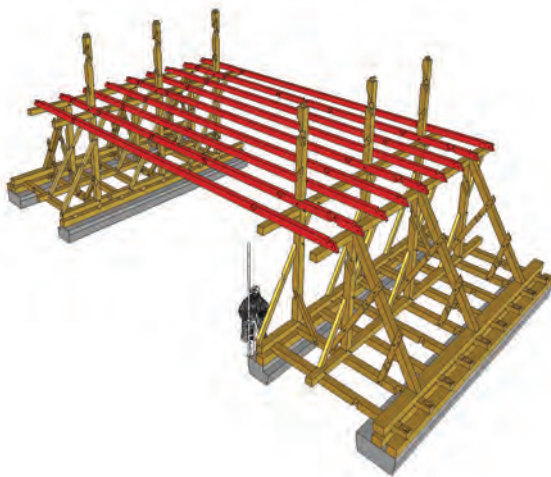
TO consider how the structure grew with the various stages of assembly, we constructed the two study models. Luckily, frames with lap joints lend themselves to working out a plausible assembly sequence, as the overlapped member must always precede the overlapping. When making the models, no consideration was given at first to the final assembly. Pieces were added, removed, then added again, some quite often, until all the pieces were somehow in place. The deconstruction process is better for establishing sequence, as you have to consider only what can be removed, not all the possible pieces that could be added. In this way we could follow the general sequence and reverse it to chart a plausible assembly. Of course, no real site operation is likely to have followed that exact path, especially in a large, long roof. We don't know much about the details: what kind of temporary supports were used, what sort of scaffolding, what type of crane or derrick, the repertory of early 16th-century tools. The following steps are based on the physical limitations of the framing itself.

Wall plates and tie beams (Fig. 7) The longitudinal wall plates are laid on the outer and arcade walls in preparation for the interrupted tie beams. The aisle vaulting could have been finished





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earlier, as it sits lower than the wall crowns. The large nave vaulting was added later, penetrating the roof space and partially burying the wooden structure. There are no clues as to how the assemblies flanking the nave were aligned, of utmost importance as later the two parts would grow together and have to fit perfectly. Perhaps a chord spanned from one side to the other as a reference; perhaps sighting rods were employed.

First trestle parts (Fig. 8) Useful working platforms now bridging the aisles, three longitudinal sills are laid on which to build a stehender Stuhl, on each side. It's apparent that both aisle assemblies could have been built simultaneously and possibly linked to each other temporarily for stabilization. Since the inner posts over the arcade walls are much taller than the outer ones, however, it seems likely that the outer more manageable ones would have been built first. Fig. 9 shows them complete with struts. They form a series of simple, stiff, large triangles, conceived to counteract real or perceived large horizontal forces, in the form of a trestle.

Bracing the trestle (Fig. 9) At this point the lower passing braces could have been inserted. One might suppose from the half-lapped upper ends that they were applied to rafters already in place. This is not the case. At least in the primary frames, they definitely were not put on last, as they are themselves overlapped by the passing braces and must have been fixed in place at some time beforehand.

Erecting the inner stehender Stuhl (Fig. 10) The inner Stuhl on both sides of the nave extends up into the second tier, with long posts vulnerable to damage as their section is considerably weakened where the collar beam and purlin intersect them. Once stood up, each post can be secured by a foot brace in the transverse plane and a passing brace linking it to the sill and purlin in the Stuhl plane. As for safe maneuvering over the abyss of the nave during these operations, the carpenters might have installed periodic cantilevered supports for plank runways the length of each arcade, or perhaps mason's falsework for the future nave vaulting might have been partly in place.

First collars (Fig. 11) This would have been a make-or-break step in the erection. Installing the first layer of collar beams would reveal how well the two sides were aligned. This new layer of beams can act as a work platform for the next tier of elements. The collar beams, however, have a small section for this free span of about 31 ft. and might have been temporarily supported from below to counteract deflection during the raising.

Bracing posts and collar beams (Fig. 12) As with the lower passing braces in the trestles, this is the first possible opportunity to fix passing foot braces between the tall posts and collar beams. Again, these were definitely attached before the long passing braces were erected.

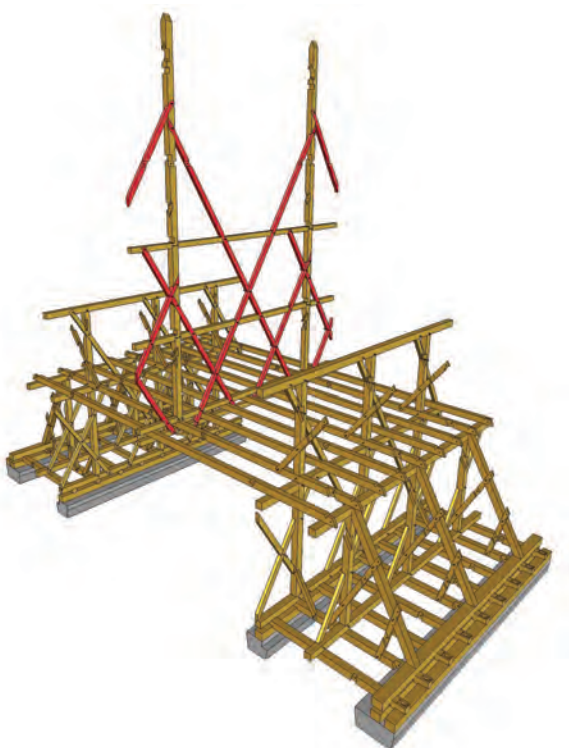
Purlins and struts (Fig. 13) Similarly, the inner assemblies can now be finished, the purlins capping the tall posts followed by long passing braces that tie them back to the sill in the lowest tier. Vertical forces (and, later, roof loads) can now be transmitted directly to the arcade wall and all posts are multiply braced transversely and longitudinally.



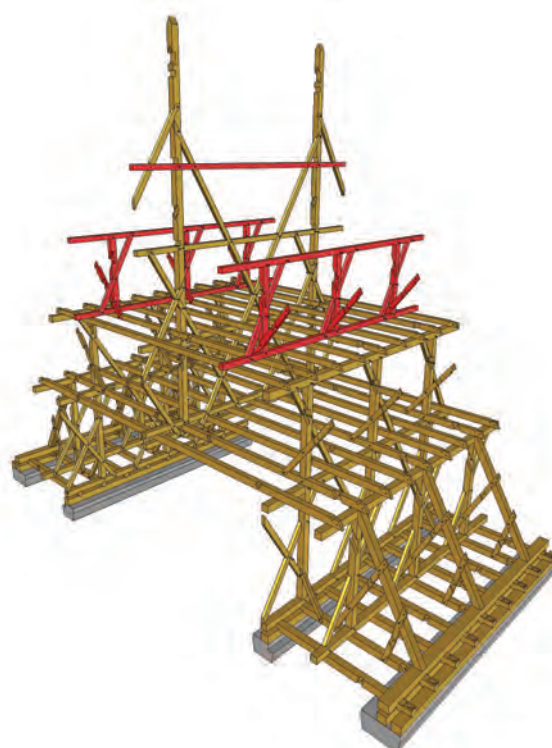
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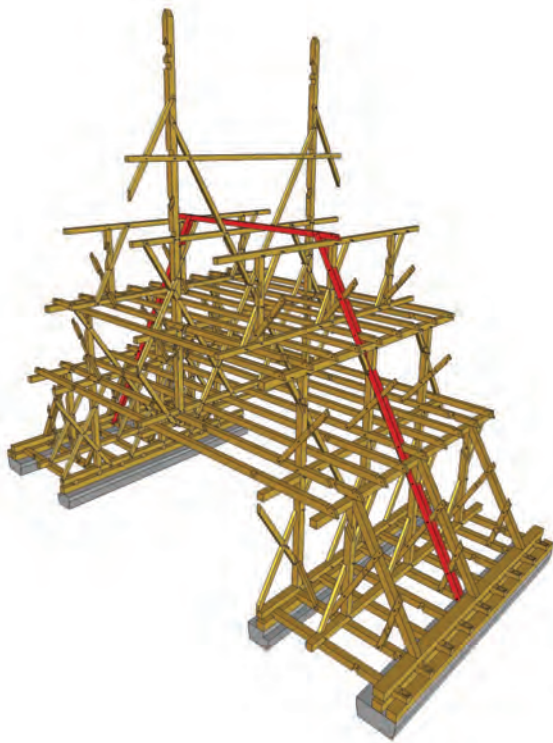
Axial Stuhl (Fig. 14) The axial Stuhl, the spine of the roof frame, can now be started. A central purlin placed under the collar beams and a corresponding sill above them, ultimately to be linked by long passing braces, form a deep footing for the huge posts, which ascend some 39 ft. over four tiers to the peak. The sill and underslung purlin (Fig. 14a) and two purlins above all tenon into the posts, which presents an interesting assembly puzzle. The highest purlin, which is lap-jointed, can only be attached later, from the side. Note iron strap at post bottom.



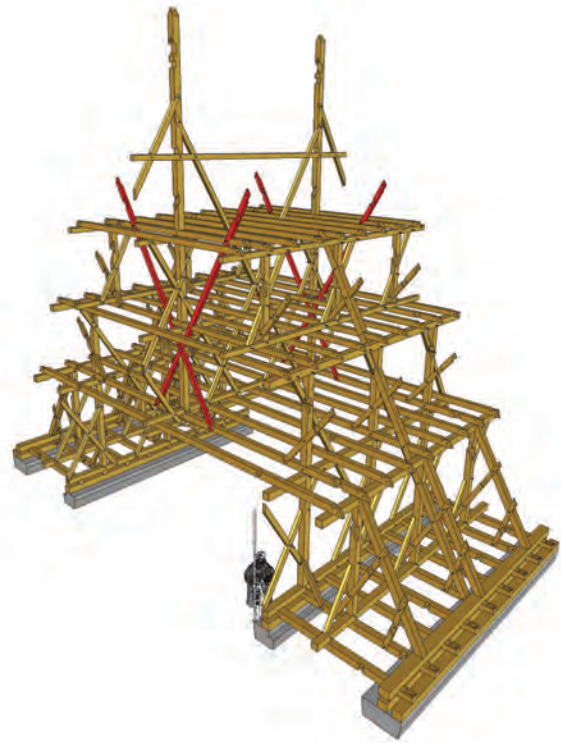
Bracing the spine (Fig. 15) The long passing braces in the spine must have been the next pieces added since they are overlapped at the top by the fourth purlin added later. The braces come in two lengths, the shorter spanning two tiers and sufficient for initial stiffening of the assembly. The longer struts that extend up into a fourth tier could have been added later when the next higher platform was ready, but the lap joints at the junctions of the two types show this was not the case. Some of the shorter struts must have been added after the longer ones.

Next work platform (Fig. 16) Adding a new tier of collar beams is a repeat performance of Fig. 11. They produce a working platform to aid the framers with the erection of the next tier.

Final stehender Stuhl (Fig. 17) The next pair of trestles will provide the support for the final work platform. Not all the lower



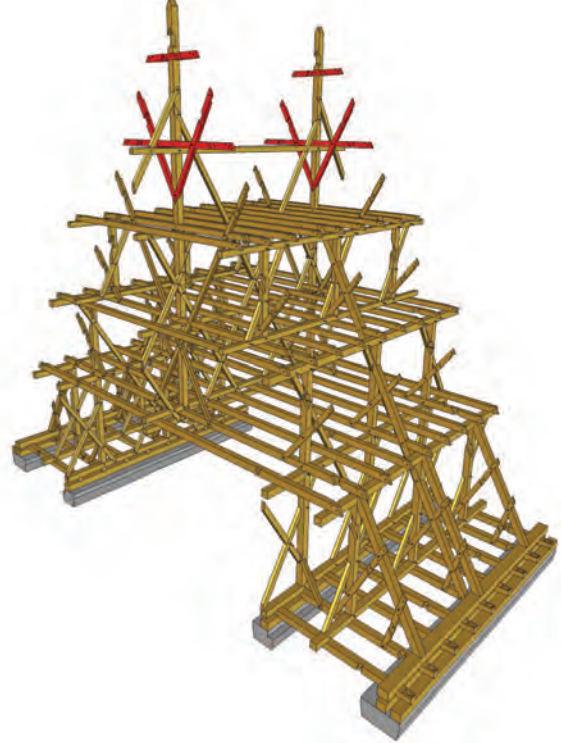
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transverse braces may have been added at this stage, as they protrude quite a long way out beyond the posts, but those in frame type B must have been set in final position as they are about to be overlapped by the passing braces. This is the next opportunity to attach the uppermost purlin to the spine (but not the last).

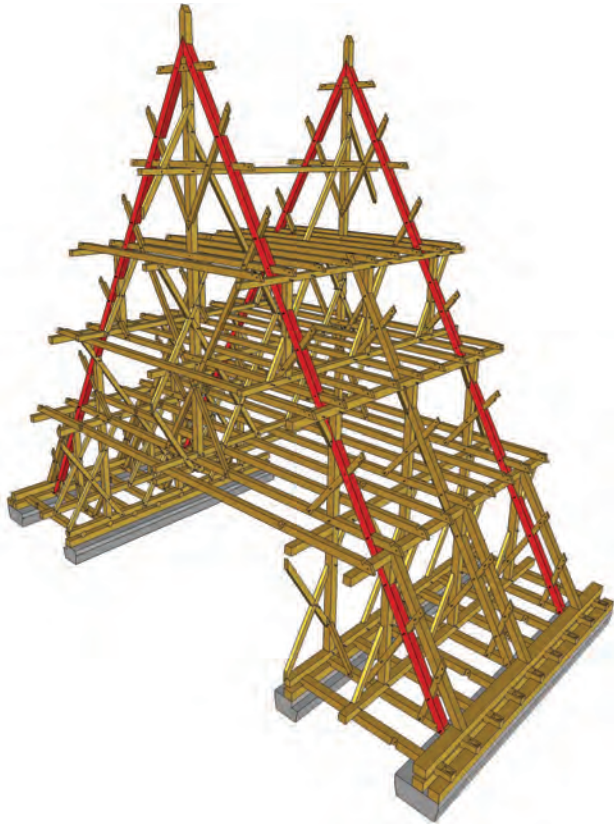
Tying three tiers together (Fig. 18) One reason for the choice of alternate primary frames may be apparent here. The passing braces in frame type B, the next pieces that could be fitted, pass over three tiers of posts, collar beams and lower braces, and connect the interrupted tie beams on both sides of the nave to a third-tier collar beam, thus forming a kind of stabilizing strap at this possibly unstable point of the raising. (The long passing braces of Frame type A, which would perform the same function even more thoroughly, cannot be fitted yet.) While this element may stiffen the transverse structure, however, it is flawed by the extremely

deep notches required to keep it in plane with the small-section lower braces, which cannot be notched deeply.

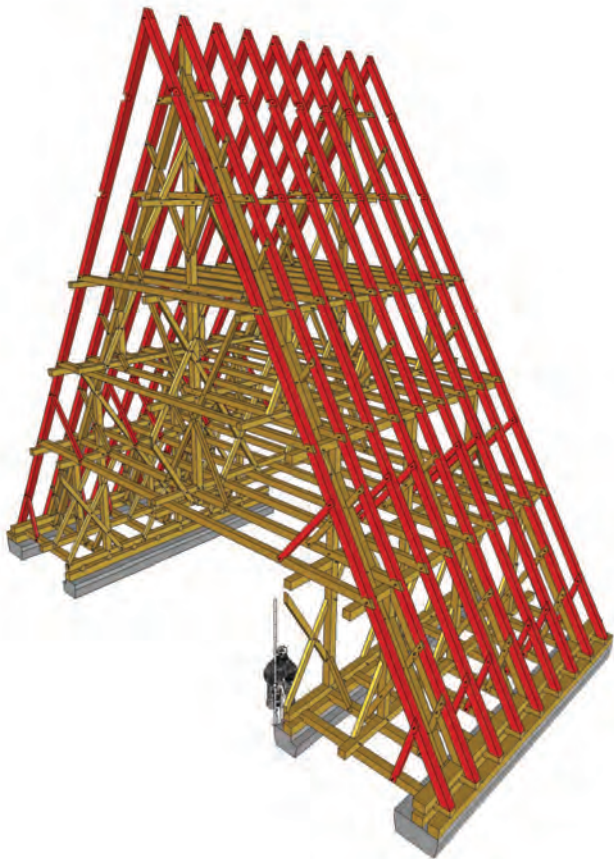
Final work platform (Fig. 19) Having stiffened the whole structure, a new work platform can be added, the final horizontal surface that the framers can use for assembly.

Preparing to attach long passing braces (Fig. 20) Before the long transverse passing braces in frame type A are fitted, a pair of shorter, but still fairly long, crossed braces are lapped over the posts and collar beams.

More collars and braces (Fig. 21) Strangely, these fairly short pieces are attached to the post before the passing braces. They could have been attached easily afterwards, but the laps show that not to be the case.

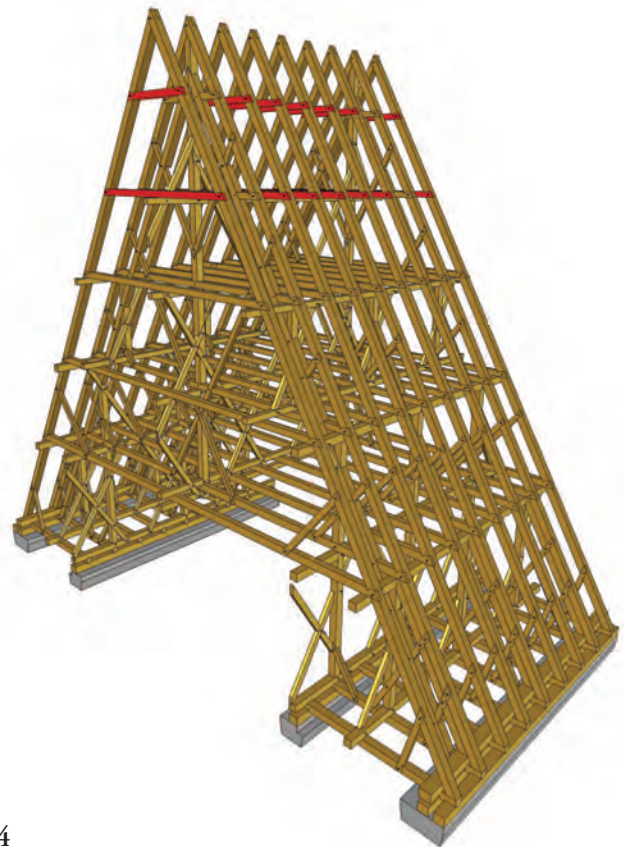


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Finishing the subassembly (Fig. 22) The long passing braces in frame type A overlap 14 other members, ultimately to connect the upper ends of the posts with the interrupted tie beams at the base of the roof, in effect to act as inner rafters. Sixteen lap joints have to fit perfectly to install each brace. Assembling these braces in our wooden model proved difficult. It showed us that the framers of Leoben-Göss not only worked with the highest precision possible with scribed joinery but also trusted that the structure would not deform significantly during the erection.



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Erecting rafters (Fig. 23) The rafters, probably the first pieces of each scribed frame to be laid out and cut, with everything else added layer for layer on top, are almost the last members to be hauled up to the roof and attached to the elaborate, structurally stabilized subassembly. The rafters initially overlap just a few collars and braces and are easier to connect than the 14-lap passing braces of frame type A.

Finishing the frame (Fig. 24) With the rafters in place, the final small pieces such as upper collar beams and various lower braces are fitted to complete the structure.

ELEMENTS of this unique roof design at Leoben-Göss can be found in a smaller roof over the nave of the church of St. Ruprecht in Bruck an der Mur (N47° 24.234' E015° 15.352'), Styria, just 12 miles away, a frame unfortunately not yet successfully dendro-dated. This roof frame is not interrupted by nave vaulting and measures about 44 ft. wide and 47 ft. high without the interrupted lower tier, in almost the same design as the roof in Leoben-Göss (more than 60 ft. wide and 52 ft. high). The important common element is the use of types A and B primary frames, which differentiate between a long and a short passing brace. Probably we have here the work of the same experienced designer. It would be interesting to know if St. Ruprecht is older or younger than Leoben-Göss. Was the former an experiment to test the design and erection or was it the result of the design and erection in Leoben-Göss?

—PHILIP S. C. CASTON

This article is fourth in a series charting the development of roof framing in Central Europe, based on examples investigated. Philip Caston (caston@hs-nb.de) will continue the series later in the year.

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This spring, the Algonquin College, Perth Campus - Heritage Institute in Perth, Ontario, will offer two five-day courses in Stereotomy - *Art du Trait* - with Patrick Moore.

An accomplished carpenter who has studied in France, Patrick brings a rare skill to North America. Through hands-on learning, students will learn the basics of building roof and timber-roof structures.

Week 1: May 30-June 3, 2016 - Stereotomy - "Art Du Trait": Introduction - Limit 15 spaces - Price TBD

This introductory course is a five-day Applicable Stereotomy - *Art du Trait* - course in which students will learn the basics of roof and timber-roof structures. Students will learn the basics of hips, valleys and other roof-framing methods, including the intersections of roofs. Using le trait, students will build a series of models, maquettes and raccords of timber-roof systems.



Each student will build a scaled-down model of a roof, using actual joints, and will apply le trait to the task at hand. At the end of the course, students will have the knowledge and understanding to tackle any usual roof intersections that they may encounter.

Week 2: June 6-10, 2016 - Stereotomy - "Art Du Trait": Basic - Limit 15 spaces - Price TBD

This is the second week of the *Art du Trait* course. Patrick will explore the topic in greater depth, and students will work together as a class to gain hands-on experience building an outdoor structure, using the stereotomy method.

Students who complete both Week 1 and 2 of the *Art du Trait* courses will receive a certificate of completion.

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