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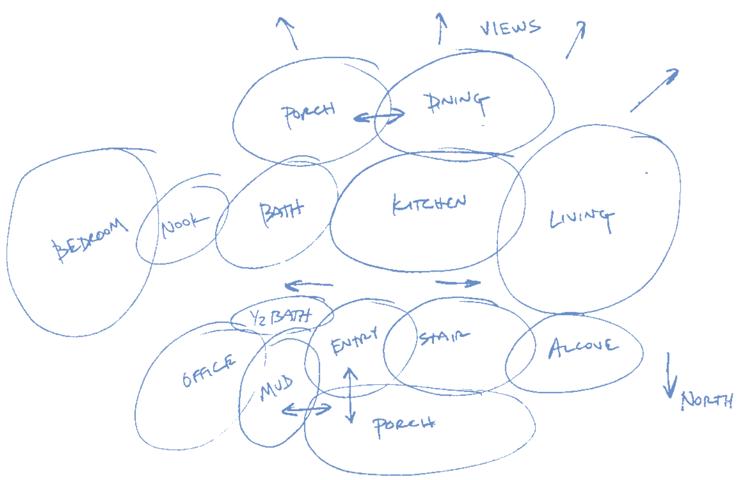

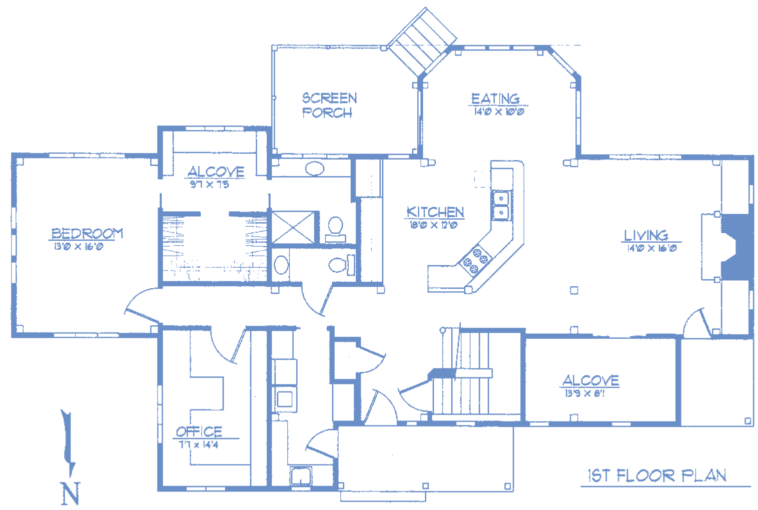

Factors in Timber Frame Design

Kicking Horse Bridge

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CONTENTS

TOPICS: WHY DO WE BUILD TIMBER-FRAMED WALLS? 2
Mark Witter

KICKING HORSE BRIDGE 4
Joel C. McCarty

LATERALLY LOADED TIMBER FRAMES 6
I. One-Story Frame Behavior
Rob Erikson and Dick Schmidt

TIMBER FRAMING FOR BEGINNERS 11
II. Ten Factors in Timber Frame Design
Will Beemer

BELGIAN BARNS III: Ter Doest 16
Kristen Brennan

A VISIT TO FINLAND 19
Ken Hume

On the cover, top, bubble diagram and finished first-floor plan for timber-framed house in Virginia. Drawings by Andrea Warchaizer. Bottom, portrait of Kicking Horse Bridge, Golden, B.C., after placement by cranes across the Kicking Horse River. Photo by Cheryl Chapman.

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TIMBER FRAMING, Journal of the Timber Framers Guild, reports on the work of the Guild and its members, and appears quarterly, 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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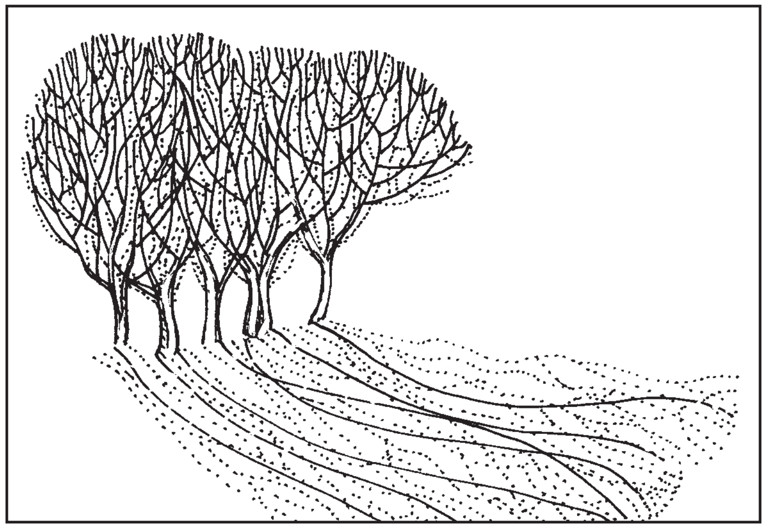


Why Do We Build Timber-Framed Walls?

I WAS first attracted to timber framing because it seemed to me to be about the most efficient way to build a house. Sure, I loved the exposed structure, and the beauty of the wood and the workmanship, but I was after a way to build a house that made sense, that used natural materials as efficiently as could be. Historically proven, highly crafted but low tech, timber-framed buildings made a lot of sense. Wrapped in an unbroken skin of insulation, man, they were perfect.

Now, 20 years later, I'm not so sure, and here's why: panels, and any other enclosure system you choose, besides keeping out the wind, are also perfectly capable of supporting upper floor and roof gravity loads, and in fact can be better than a timber frame at resisting lateral loads in modern buildings. Most of the timbers in a timber frame are redundant. Expensive wallpaper, as Dale Mulfinger said years ago. They don't need to be there.

In 1996 we were asked to build a timber frame house for a client with a tight budget. Sarah was the catcher on our softball team. She loved timber frames and wanted us to build her a house. We designed a compact 1500 sq. ft., tall-posted Cape, four bents with three posts in each bent. The price for the frame with panel enclosure was $50,000, just covering our costs, with no profit. This was more than she could afford, so we looked for cost-cutting alternatives. It's not really cold where we live, so we decided to stick frame the enclosure. This resulted in significant cost savings, but we were still beyond her means, so we decided to pare down the frame.

Know how to make an affordable timber frame house? Take out the timber. Out of 12 posts in the frame, ten were on exterior walls. The entire gable end bents were superfluous, along with the exterior bay girts and plates. We wound up with the two interior bent middle posts, a second-floor beam between them and beams running from them out to the exterior wall. At the roof, a ridge between the two posts, and from each post out to the stick-framed gables. Out of 6000 bd. ft. in the original frame, we were left with 1200. The cost for the erected shell was now $25,000, including R-19 insulation in the walls. Half the original cost.

Chris Alexander *et al*, in *A Timeless Way of Building* and *A Pattern Language*, argue that, in an efficient building, every particle must help to resist loads. They note that building materials that work in tension, such as wood and steel, are increasingly rare and expensive, and typically contain a great deal of embodied energy. It makes no sense to use tensile materials, such as wood, in the construction of a wall, which performs in compression. The Europeans figured this out a long time ago. Few contemporary buildings there use wood in the walls.

Is everybody out there engineering his or her frames? We do, every one, extensively. And we find that when we have to get a timber frame to resist lateral forces, as in a porte-cochère or a pavilion, it takes significant effort and expense on the part of the engineer, the joiner and the crew on site to do so. If there's no wall next to the frame, tenons are longer, braces are bigger and there are often ferrous fasteners—knife plates, bed bolts, lags and the like. If there is a wall next to the frame, we are almost always using it for laterals. Historically, a properly braced timber frame performs well under lateral loading, but it will flex before it loads up and stops moving. That's one of the reasons it does so well. The problem is that modern finish materials, like drywall and windows, can't tolerate that.

Why do we build houses that cost more than they have to? What's the best way to build a wall? Structural insulated panels, stick or masonry. Panel guys might not agree, but we have found SIPs to be the most expensive of the three, especially when you have to carve them up and put in wood for foundation hold-downs and the like. Stick framing is probably the least costly, but not always, and also likely the poorest performer, at least when it's site-built. Stick walls don't have to be site-built—there are companies that factory-build big components and erect them quickly on site with a crane. Masonry can cost a lot or not so much, depending on where you live and what you're doing. Laying up stone or brick is labor intensive. Block walls are tough to insulate. Insulated concrete forms (ICFs) show promise.

One of the owners of the timber frame company I work for recently built his own house. He certainly had access to lots of timber, but he explored a number of building systems before deciding which was right for him. He wound up using Rastra Blocks. They're a mixture of Portland cement and expanded polystyrene, and you stack them up, add some rebar and fill the cores with concrete. You can cut them with a Skilsaw.

One feature of reinforced masonry is its superior resistance to lateral loads. If you can build walls that stand on their own, a tying member at the top of the wall isn't as critical, and you can do sexier stuff in the roof framing. Pushing that tying beam or bottom chord up into the roof framing becomes more of a possibility. A less efficient truss form, like a hammer beam or a scissor, is easier to pull off when you put it on top of a thick masonry wall.

However you do it, if you have to do it on a budget, you probably shouldn't put materials in a house that don't need to be there.

—Mark Witter

Mark Witter (mark@cascadejoinery.com) is a timber framer at The Cascade Joinery in Everson, Washington.

Mark Brandt, a frequent instructor at Guild workshops and an independent craftsman for much of his career, died last month aged 50 at home in Auburn, Alabama, after a long illness. He leaves his wife, Sue, his father and stepmother Paul and Frieda Brandt and brothers John, Chris and Jim Brandt, all of Auburn, and a sister, Marsha, of Mitchell, Georgia. Mark was held in much affection by those who met him, even briefly. Peter Bull, his good friend and colleague, said, "It wasn't time or money he was interested in. Whatever he did, he made sure it got done right. He could be slow as hell." Mark will be remembered in the Guild, which has now renamed its workshop scholarship fund in his honor. Contributions sent on his behalf to the Guild should be designated for the Mark Brandt Memorial Scholarship Fund.

More on Purlin Plates

I WOULD like to address Thomas E. Nehil's letter ("An Exchange," TF61) concerning my statements about purlin plates and roof thrust in my article "Roof Joinery Excluding Trusses" (TF59) in the Historic American Timber Joinery series published in recent issues. It's obvious that my statement "support from the purlin plate reduces the outward thrust of the roof" needs some clarification.

A building with purlin plates supporting the mid-span of the rafters will have substantially less rafter thrust than the same building with rafters clear spanning from plate to peak. If the rafters are supported exactly at mid-span (the most common situation), the thrust measured at the outside walls of the building will be half that of a comparable clear span roof. It follows that my original statement is correct.

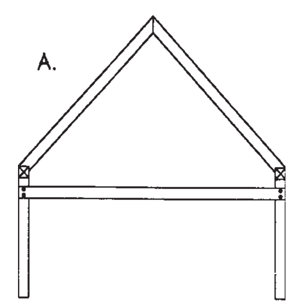
Because the purlin plates reduce the rafter span, Mr. Nehil's point that "the thrust on the purlin is a function of the clear span between purlins" is also correct, at least in theory. However, in real situations roofs supported on purlin plates do not often behave according to theory. I have seen old barns where one side of the roof blows off and the other side, which ought to collapse immediately, remains in place for a couple of winters. I have seen Dutch barns in which an outer wall has subsided because of a decayed sill or a collapsed foundation, thus removing support from the eave, yet the roof does not come down.

In both cases the roof seems to balance on the purlin plate like a seesaw. Why?

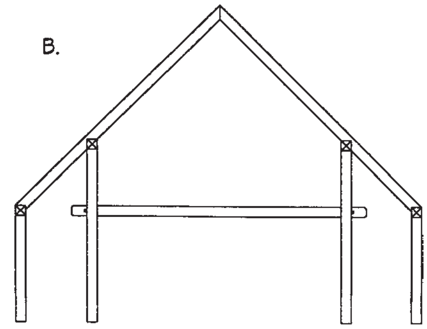
A rafter continuous across a purlin plate must bend before it can exert thrust on the opposite rafter. Many rafters (in Dutch barns often 6x6 or 7x7) are undiminished where they pass over the purlin plate, and so can resist some amount of bending. The comparative stiffness of such a rafter reduces its thrust. If, however, the rafter is deeply notched at the purlin plate, it functions practically as two separate rafters and can resist only minimal bending. I would welcome Mr. Nehil's analysis of this effect.

Jack Sobon — Windsor, Massachusetts, October 15, 2001

In TF61, in "An Exchange," Thomas Nehil wrote: "In the section of the article relating to rafter-to-purlin plate joints, Mr. Sobon indicates, 'Because support from the purlin plate reduces the outward thrust of the roof, the joinery here may be quite simple.' Actually, the thrust on the purlin is a function of the clear span between purlins. In Figure 2 attached, the thrust on the plate shown in the simple gable frame A is the same as the thrust on the purlins in the Dutch barn frame shown in B, since the clear span is the same in both these cases."



Thomas F. Nehil



Kicking Horse Bridge

Cheryl Chapman

The 144-ft. 8-in. clearspan Kicking Horse Bridge, a footbridge for the town of Golden, B.C., framed of Douglas fir and white oak. The check braces, wedges, shear blocks, splice blocks and pegs are white oak, a total of 1,100 pieces and 3,300 bd. ft. The Burr Arch frame contains altogether about 72,000 bd. ft. of timber. Another 12,000 bd. ft. were used in flooring, railing, roof nailers and trim. Design camber is 28 in.

THE Kicking Horse Bridge, which now stands out over its eponymous river a half-mile above the latter's confluence with the Columbia, at Golden, British Columbia, was the result of a four-year effort begun by Guild member Christoph Lösch and driven forward by Golden's able and relentless Economic Development Officer, Lee Malleau. This bridge differs from the famous 1992 Guelph Bridge, over the Speed River at Guelph, Ontario, in several significant ways. The bridge in Golden is longer (clearspan nearly 145 ft. vs. 120), heavier (208,000 lbs. vs. 147,000) and built on a more sophisticated pattern (Burr Arch vs. Town Lattice). The construction project involved many fewer Guild members (40 vs. 400) than Guelph, in part because 60 percent of the new bridge was already cut (quite well, as it turns out, by Sigi Liebmann on Canadian Timber Frame's Hundegger K2 joinery machine) before we arrived. The local design and engineering effort by Reid Costley was leveraged by significant contributions (or interventions) by Ed Levin and others on the peer review team.

We fought (and lost) similar battles with the Fish Police over questions of placing material in the respective rivers. There was no equivalent to Guelph's Albion Hotel (could there ever be?), but we did have transcendent coffee service on site, and belly dancing at dinner. So take your pick. Best of all, the smaller crew (at maximum, 84) made for a much less chaotic job site, and best of the best, more than half of the Golden crew were local volunteers, new to timber framing in general and to bridge building in particular. A poll of experienced Guild fellow travelers at the final evening's celebrations unanimously awarded the town of Golden first prize for hospitality out of *all* the places we've ever been. It was a great place to be a part of, even for only four weeks, and especially during the week of September 11th, and now, for the rest of our lives.

—JOEL C. MCCARTY

Facing page, clockwise from top left: Darryl Weiser provides a steady hand (on the coffee cup) and a clear eye while the bottom chord is jacked for raising clearances. Barry Martin (kneeling) and Colin Stotts tuning the first truss with wedges to pre-stress the post-to-strut joints; empty notches will later be fitted with check braces. "Night Cathedral" lumière achieved by John Palmer and Terry Clark with lamps borrowed from the railroad and the fire department. Kingpost roof trusses hoisted in paired assemblies embracing lateral X-braces. Left to right, Darryl Weiser, Dennis Orr and Barry Martin fit the linking braces down from the roof trusses to the wall posts.

Photos Cheryl Chapman

LATERALLY LOADED TIMBER FRAMES

I. One-Story Frame Behavior

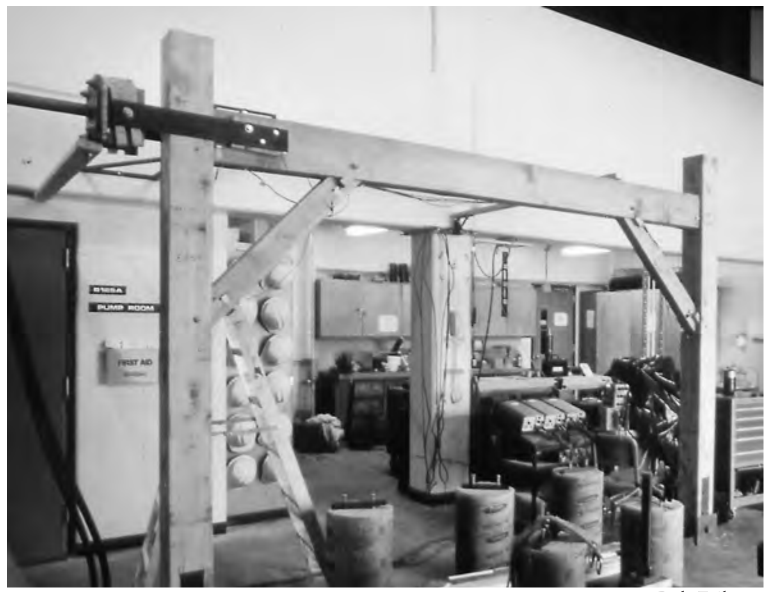
This article is first in a series to discuss the results of research conducted at the University of Wyoming on the behavior of sheathed and unsheathed timber frames subjected to an applied lateral load. Primary funding for this research was provided by the US Department of Agriculture National Research Initiative Competitive Grants Program, with additional support from the Timber Frame Business Council, the Timber Framers Guild and individual timber framing companies who contributed the test frames. Subsequent articles will present behavior of laterally loaded two-story frames and sheathed frames, behavior of laterally loaded structural insulated panel-to-timber connections and modeling of unsheathed and sheathed frames.

DESCRIPTION OF EXPERIMENTAL FRAME. An unsheathed, one-story, one-bay frame (1S1B), 12 ft. wide by 8 ft. high, was subjected to lateral load as shown in Fig. 1. Five such frames were tested, made respectively of Douglas fir, Eastern white pine, Ponderosa pine, Port Orford cedar and white oak.

The frames were shipped unseasoned, and all timbers were planed with the exception of the Ponderosa pine. Nominal dimensions of the timbers were typically 6x10 for beams, 8x8 for posts, and 4x6 for knee braces. The only significant exceptions were 7x10 posts on the white oak frame. Because of the extended period of the testing schedule, significant drying and consequential shrinkage occurred in the timbers. The average moisture content at the time of testing ranged from 9 percent for the Port Orford cedar frame to 18 percent for the white oak frame.

Brace leg dimension, *kb* as shown in Fig. 2, was 36 in. for the Eastern white pine and white oak frames and 30 in. for the Douglas fir, Ponderosa pine and Port Orford Cedar frames. Brace tenon end and edge distances each varied from 1½ in. to 2½ in., and tenon thickness was either 1½ or 2 in. All frames had one peg at each brace joint, except the white oak frame, which had two. The Ponderosa pine and Eastern white pine frames used splined connections between beam and post, while the remaining frames had typical mortise and tenon construction. All frames used 1-in. pegs at all joints, with one exception: the Eastern white pine frame had ¾-in. pegs at the brace joints. The Eastern white pine, Ponderosa pine and white oak frames had white oak pegs, while the Douglas fir and Port Orford cedar frames incorporated red oak pegs.

Load and Displacement. As shown in Fig. 2, a horizontal point load *P* was applied to one side of the frame at the beam elevation using a hydraulic actuator system with a load capacity of 55,000 lbs. and available displacement of 3½ in. in each direction (7 in. total). Load applied in the westerly direction is referred to as the "push" stroke, and in the easterly direction it's labeled the "pull" stroke. A linear potentiometer located at the top of the frame measured global frame displacement Δ_{top}. A computerized data acquisition system recorded the applied load and global displacement.



Rob Erikson

FIGURE 1. EXPERIMENTAL APPARATUS IN THE LAB. 1S1B FRAME SUBJECTED TO LATERAL LOAD (UPPER LEFT).

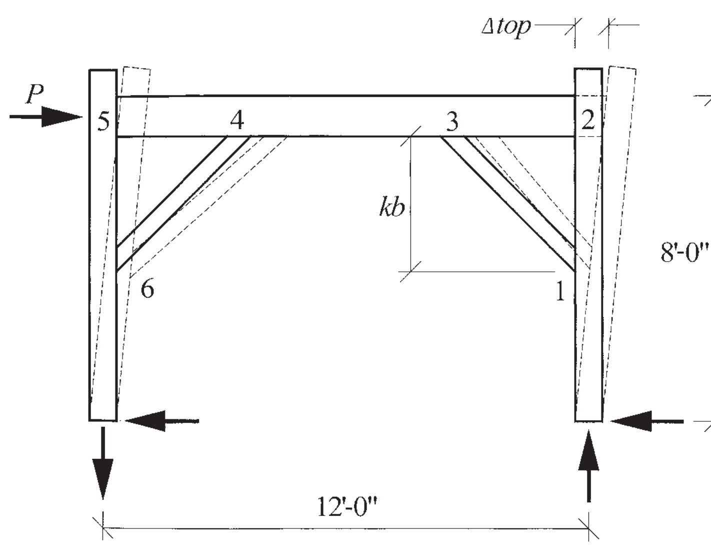


FIGURE 2. DIMENSIONS, LOAD, REACTIONS, DISPLACEMENT AND JOINT NUMBERS. "SOUTH" ELEVATION.

Although the magnitudes of the lateral load applied to the experimental frames were selected somewhat arbitrarily, a comparative value of design lateral load has been determined based on code guidelines (ASCE 7-98, Minimum Design Loads for Buildings and Other Structures). Using a calculated design wind pressure of 15.8 psf and assuming all wind load is carried through a structure with bents spaced 12 ft. on center, the design wind load on the frame is 1510 pounds.

Selected frames were tested with additional gravity load applied. The load was created by suspending several 300-lb. concrete cylinders (shown in Fig. 1, standing on the laboratory floor) from each side of the beam. The gravity load was typically applied as a three-point load on the top of the beam to give a total load of 1800 pounds. Assuming bents spaced 12 ft. on center, a load of 1800 pounds is equivalent to a uniformly distributed load of 12.5 psf.

Overview of Test Results. The following sections provide a brief description of the load cycles and observed joint damage for each of the five frames. The pegs commonly failed in two manners: a single hinged flexure failure as shown in Fig. 3 or a shear failure combined with flexure as shown in Fig. 4. Minor crushing of the peg material was also common in many of the joints. Failure of the tenon relish as shown in Fig. 5 was common in many frames. There were also some instances of a single split from the peg hole to the tenon end. Crushing of the tenon material at the edges of the peg hole was evident in many joints, particularly those of relatively low material specific gravity, such as Eastern white pine. Similar damage occurred at the edges of the mortise peg holes. Joint locations noted in the following paragraphs refer to Fig. 2.

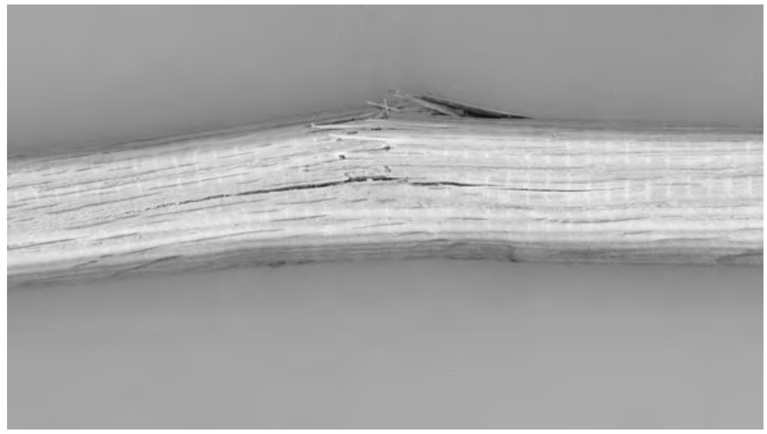


FIGURE 3. PEG FLEXURE FAILURE.

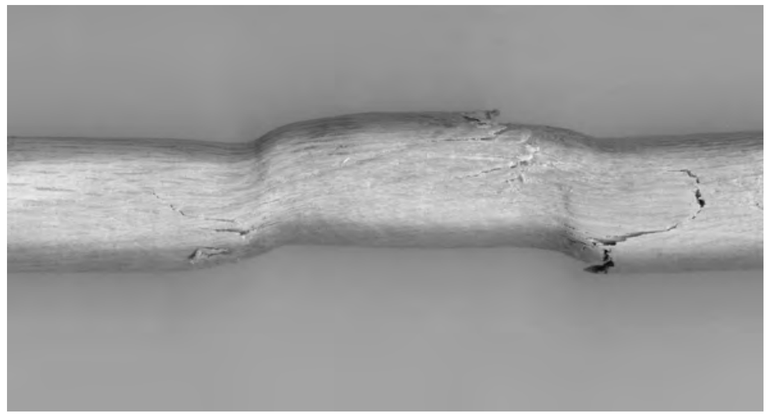


FIGURE 4. PEG COMBINED SHEAR AND FLEXURE FAILURE.

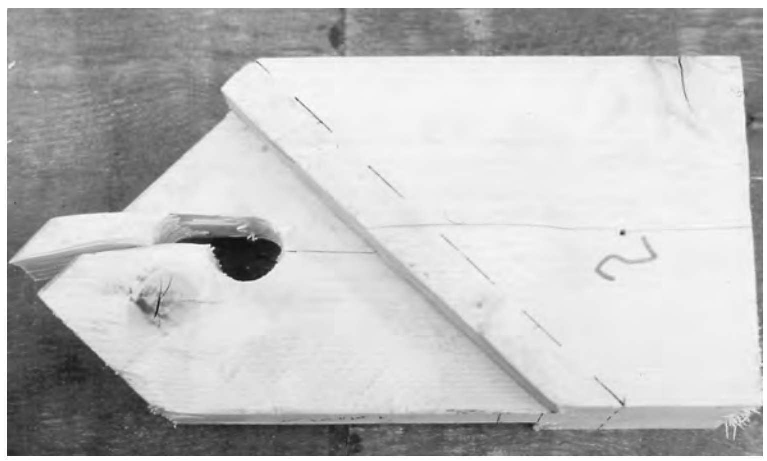


FIGURE 5. TENON RELISH FAILURE (PORT ORFORD CEDAR).

Douglas Fir. The Douglas fir frame was load cycled three times. The first cycle included no gravity load other than the frame's self-weight, but the second and third cycles included 1800 pounds of additional gravity load. Disassembly after testing revealed that the pegs located at the beam-to-post joints had minimal damage. However, three of the four brace pegs failed in flexure. The peg at joint 1 had some crushing but otherwise did not fail. There was minimal damage to the members.

Eastern White Pine. The Eastern white pine frame was subjected to 10 load cycles. The frame was initially cycled with no additional gravity load. Prior to the second cycle, 1800 pounds of additional gravity load were applied and remained in place for the duration of testing. Disassembly of the frame revealed crushing of the peg located at brace joint 1. All of the brace tenons (joints 1, 3, 4, and 6) had slight damage near the peg hole. The holes were slightly elongated and a minimal amount of spalling was present at the surface of the tenon. No damage was visible at the post-to-beam joints.

Ponderosa Pine. The Ponderosa pine frame was cycled 18 times. Gravity load of 3000 pounds was added for cycle 11 and reduced to 1200 pounds for cycle 12. The gravity load of 1200 pounds remained for the duration of testing. Initial joint failure, during cycle 17, was exhibited by a loud "pop" from joint 4 as the frame reached an applied load of 2200 pounds in the push direction. Joint 4 was in tension during the push stroke. Although there was a tensile failure in the brace joint, the frame was able to resist additional load because of the compressive capacity of the opposing brace. Disassembly of the frame revealed no significant damage to the pegs, but the tenon relish failed in brace joints 1 and 4.

Port Orford Cedar. The Port Orford cedar frame was subjected to 912 load cycles. Of these, data was collected for only 11 cycles. The remaining cycles were conducted at a relatively rapid frequency of 12 cycles per minute with an imposed deflection of 1 in. in each direction. Repair of joint 1, a brace-to-post joint, was performed after 376 cycles. The brace mortise was originally mislocated and a "Dutchman" had been installed with polyurethane glue (the joints were cut at a training workshop). Although there is evidence to suggest that polyurethane glue is an acceptable structural adhesive, it may not be appropriate for repairing timber frame joints. The original patch suffered significant delamination and was subsequently repaired with a Resorcinol adhesive. Testing immediately after repair indicated that failure of the Dutchman had minimal effect on overall frame performance. The joint subsequently performed as expected, and no further repair was required.

In addition, after 376 cycles, all pegs and both braces were replaced. Inspection of the original pegs revealed flexural failures in brace joints 1 and 4. A tenon relish failure also occurred at brace joint 4. The remaining pegs and tenons had minimal damage. The pegs that were installed during cycles 377 through 912 had significant failures. All of the pegs had flexural failures except the peg from joint 3, which incurred only minor crushing. There was no damage to any frame tenon.

Frame	Push Stroke Max Load (lb)	Push Stroke Max Disp. (in)	Push Stroke Stiffness at Max Load (lb/in)	Pull Stroke Max Load (lb)	Pull Stroke Max Disp. (in)	Pull Stroke Stiffness at Max Load (lb/in)	Average Stiffness at Max Load (lb/in)	Total Free Disp. (in)
Douglas Fir	1010	1.13	980	1010	1.14	990	980	0.20
Eastern White Pine	1000	0.94	1340	1000	1.10	1130	1240	0.40
Ponderosa Pine	1200	1.15	1260	1200	1.18	1110	1190	0.30
Port Orford Cedar	990	0.85	1180	1000	0.83	1640	1410	0.25
White Oak	1520	0.50	3170	1530	0.56	2820	3000	0.05

TABLE 1. SERVICE LEVEL PERFORMANCE WITH NO ADDED GRAVITY LOAD.

Frame	Gravity Load (lb)	Push Stroke Max Load (lb)	Push Stroke Max Disp. (in)	Push Stroke Stiffness at Max Load (lb/in)	Pull Stroke Max Load (lb)	Pull Stroke Max Disp. (in)	Pull Stroke Stiffness at Max Load (lb/in)	Average Stiffness at Max Load (lb/in)	Total Free Disp. (in)
Douglas Fir	1800	1000	1.07	1150	1030	1.10	1160	1150	0.40
Eastern White Pine	1800	1010	0.68	1490	1010	0.71	1430	1460	0
Ponderosa Pine	1200	1200	1.08	1440	1200	1.08	1120	1280	0.25
Ponderosa Pine	3000	1200	0.95	950	1200	0.95	1060	1010	0
White Oak	1800	1500	0.35	3750	1580	0.42	3770	3760	0

TABLE 2. SERVICE LEVEL PERFORMANCE WITH ADDED GRAVITY LOAD.

White Oak. The white oak frame was cycled three times. The frame was initially cycled without gravity load and then 1800 pounds of dead weight were added for load cycles 2 and 3. This frame had the only significant member failure observed throughout all of the testing. As the load approached the maximum of 2600 pounds on the push stroke, the west post began to split at the top due to cross-grain tension applied by the beam as it withdrew from the post.

The white oak frame had significantly more peg damage compared to the other frames. All of the pegs installed on this frame exhibited some crushing damage and all but one of the brace joint pegs failed in flexure or the combined flexure and shear mode. One of the pegs at brace joint 4 showed only bearing damage. Relish failures were limited to the east knee brace. Joints 4 and 6 each had one relish failure.

Service Level Results. Table 1 provides global stiffness results for each frame subjected to lateral load and self-weight only (no additional gravity load applied). With an average stiffness of 3000 lb/in., the white oak frame had more than twice the stiffness of the other frames. The higher stiffness of the white oak frame was due to the additional brace peg and the higher stiffness of oak joints.

Previous joint testing by others has shown a reduced stiffness at low load. Such reduced low-load stiffness causes an interval of relatively low stiffness in the load-displacement curve of the full-scale frames. This deflection, termed *free displacement*, Δ_{free} is shown in the chart of Fig. 6. The chart demonstrates the method of determining maximum global stiffness k_G and free displacement. Free displacement for all frames is included in Table 1. The value ranges from a high of 0.40 in. for the Eastern white pine frame to a low of 0.05 in. for the white oak frame. Again, the favorable value for the white oak frame was primarily a function of material properties and the added brace peg.

Effect of Gravity Load. Four of the frames were tested with additional gravity load applied to the beam, and the results are shown in Table 2. Three of the frames were tested with 1800 pounds of additional gravity load, while the Ponderosa pine frame was tested first with 3000 pounds of additional gravity load and then with a reduced load of 1200 pounds. Three of the four frames exhibited zero free displacement with the additional gravity load (the Ponderosa pine frame required the full 3000 pounds to eliminate free displacement). Fig. 7 demonstrates the reduction in free displacement. The results for the Douglas fir frame are anomalous in that the frame exhibited increased free displacement when gravity load was added.

Removal of Brace Pegs. An investigation of the effectiveness of brace pegs was performed by removing them from the Eastern white pine frame and comparing results to a previous test. A gravity load of 1800 pounds was in place for both tests. As shown in Fig. 8, removal of the brace pegs resulted in increased free displacement; however, the average frame stiffness of 1270 lb/in is not significantly less than the fully pegged frame stiffness of 1470 lb/in. This is due to the compressive brace resisting the full load once the brace shoulder was in full bearing contact with the beam and post.

Direct Measurement of Brace Force. As shown in Fig. 9, a load cell was installed in one of the braces of the Port Orford cedar frame. Fig. 10 shows applied load P and brace F force plotted versus global frame displacement. This chart demonstrates the relatively higher proportion of lateral resistance provided by the brace in compression compared to the same brace subjected to tensile loading. The brace carried a compressive force that was 75 percent greater than the tensile force, 2419 pounds versus 1386 pounds.

In Fig. 11, brace force F is plotted against the sum of the corresponding brace displacements Δ_{kb}. The results can be interpreted two different ways for characterizing brace behavior. One method of interpretation assumes constant stiffness across the full range of displacement, although allowing a distinction between compressive and tensile actions. This interpretation yields

tensile brace stiffness k_{tens} = 14,200 lb/in,
compressive brace stiffness k'_{ccmp}= 24,800 lb/in
and a joint free displacement Δ_{kbfree} = 0.035 in.

However, Fig. 11 obviously indicates two distinct parts of compressive behavior:

an initial stiffness k_{comp}
and a secondary stiffness k'_{comp}.

The initial compressive stiffness k_{comp} = 16,000 lb/in is comparable to the tensile stiffness, and this behavior is assumed to be due to load transfer exclusively through the pegs. The significantly higher secondary stiffness k'_{comp} is assumed to be due primarily to bearing action of the brace shoulder onto the beam and post surfaces in addition to the action of the joint components.

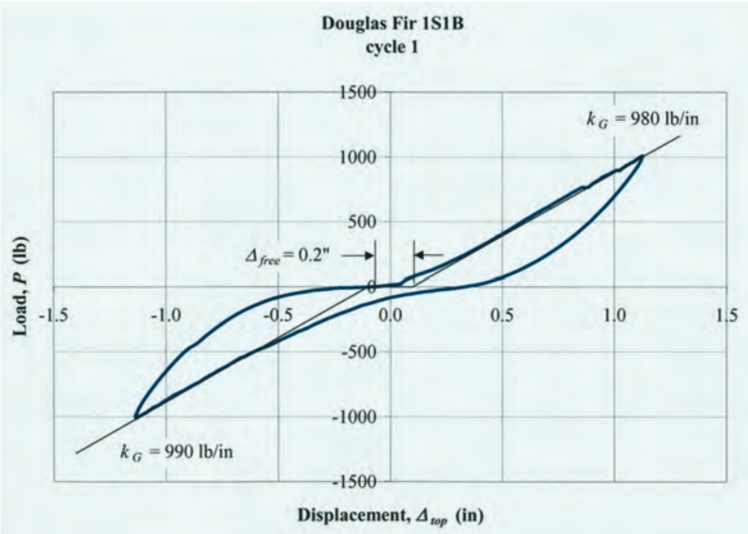


FIGURE 6. TYPICAL SERVICE LEVEL LOAD VS. DISPLACEMENT CURVE.

FIGURE 9. PORT ORFORD CEDAR KNEE BRACE LOAD CELL.

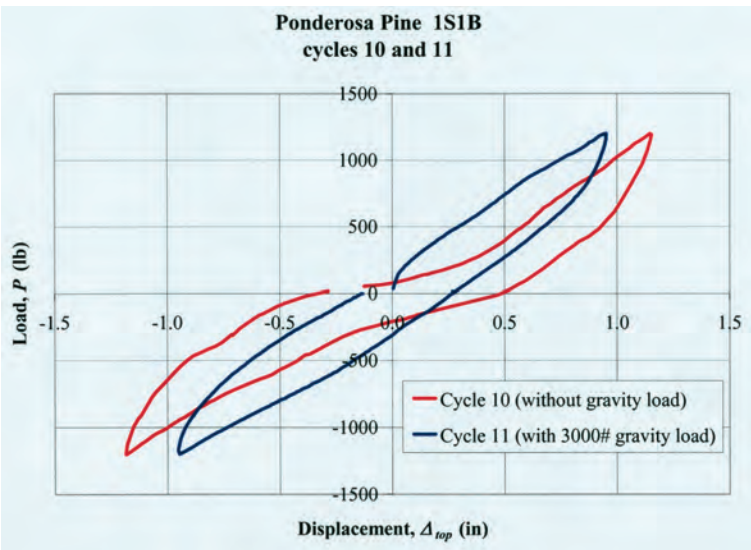


FIGURE 7. REDUCTION IN FREE DISPLACEMENT DUE TO GRAVITY LOAD.

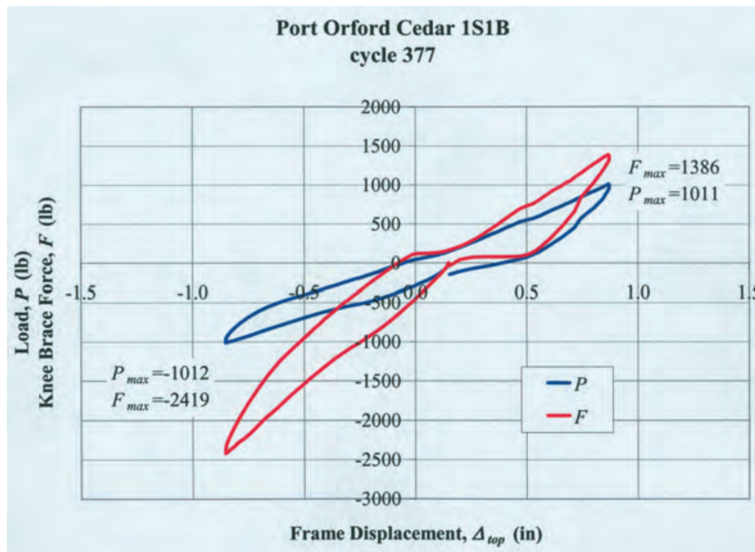


FIGURE 10. KNEE BRACE FORCE VS. APPLIED LOAD.

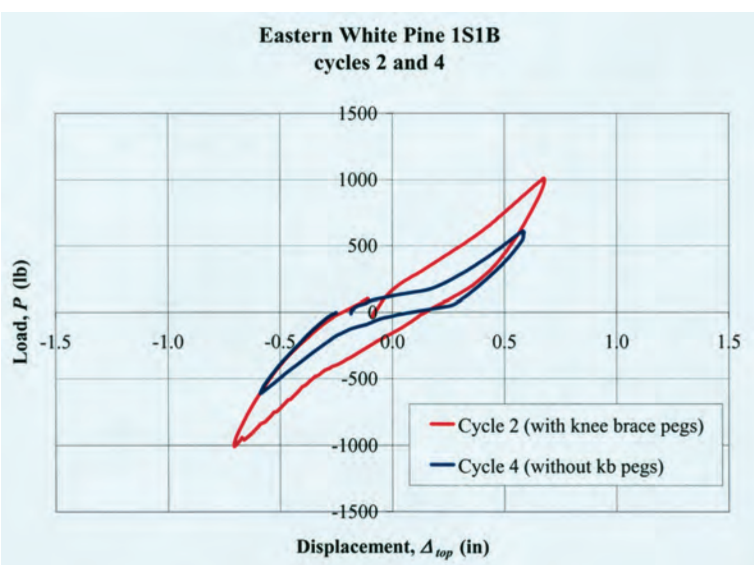


FIGURE 8. EFFECT OF REMOVING KNEE BRACE PEGS.

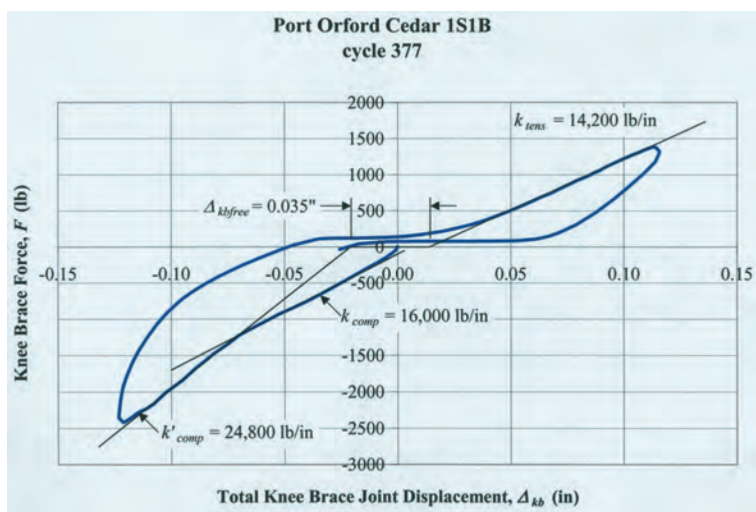


FIGURE 11. KNEE BRACE JOINT STIFFNESS.

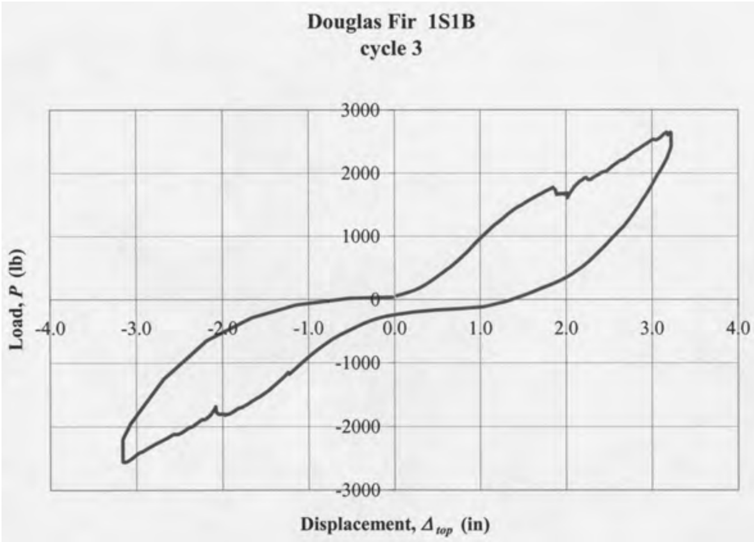


FIGURE 12. TYPICAL MAXIMUM LOAD CYCLE.

Frame	Push Stroke		Pull Stroke	
	Max Load (lb)	Max Disp. (in)	Max Load (lb)	Max Disp. (in)
Douglas Fir	2646	3.22	2555	3.16
Eastern White Pine	3134	2.56	3004	2.45
Ponderosa Pine	2662	2.46	2190	2.25
Port Orford Cedar	3456	3.22	2513	3.17
White Oak	6295	3.71	-	-

TABLE 3. MAXIMUM LOAD CYCLES.

Maximum Load. Table 3 lists the maximum load and corresponding displacements for each frame. A typical chart of the maximum displacement cycle is shown in Fig. 12. Although there is discontinuity in the curve due to local failures, the frame continued to carry increasing load up to the maximum available displacement of approximately 3 in. At such a high level of displacement, the frame is assumed to be well beyond any serviceablity limit. Therefore, since this curve is typical of all frames examined, it can be concluded that stiffness, not strength, is likely to be the controlling design factor for unsheathed frames under lateral load.

Summary. All frames were able to resist load greater than the calculated design load of 1510 pounds. In addition, at displacements far beyond serviceablity limits, all frames continued to carry increasing load. Therefore, traditional timber frames will typically have sufficient strength to resist lateral load due to wind.

Using an allowable deflection of 1/400 of the height, the allowable drift due to wind load on an 8-ft.-high frame would be approximately ¼ in. Given the design wind load of 1510 pounds, the minimum required frame stiffness would be 6,040 pounds per inch. The stiffness of all frames was significantly lower than this value, indicating that traditional timber frames may not have adequate stiffness to resist typical wind loads. Of course, this conclusion must be considered relative to each individual building. If a building were fully enclosed, the wind load would be similar to the calculation results previously described. In this situation, any wall that lacked structural sheathing (such as one with a large proportion of glazing) would not have sufficient lateral load resistance from brace action alone, and alternative stiffening methods would be warranted. However, if we considered an open structure such as a pavilion, the wind loads would obviously be reduced and the braces might provide adequate stiffness.

All frames exhibited free displacement at low loads. While this free displacement may be an important consideration, in all but one instance it was significantly reduced with the application of additional gravity load. It is expected that most frames would be subject to additional gravity load, in the form of dead loads such as floors, partition walls and finish materials, and live loads such as furnishings, thereby negating free displacement.

Direct measurement of brace force in the Port Orford cedar frame indicates that the compressive force is much greater than the tensile force. Analysis of brace joint displacement versus force in the Port Orford cedar frame indicates that the compression component consists of two parts. The joint stiffness is initially low at small displacement but increases as displacement increases. The stepped increase in compression-side stiffness is assumed to be due to the additional stiffness as the joint surfaces bear against one another. This conclusion is also supported by the test where the brace pegs were removed from the Eastern white pine frame. In the latter situation, the compression brace resisted all lateral load. Although the frame exhibited increased free displacement, the maximum magnitude of frame stiffness was nearly as large as the stiffness of the fully pegged frame. From these tests, we conclude that braces will carry most of the lateral load on the compression side of a given frame upon full member bearing. But for this to develop, some initial joint displacement must occur, and the tensile-side brace will carry a relatively higher percentage of force up to the point of brace shoulder bearing contact on the compression side.

—ROB ERIKSON AND DICK SCHMIDT

Rob Erikson is a graduate student and instructor at the University of Wyoming, Laramie, and a part-time builder. Dick Schmidt is professor in the Department of Civil and Architectural Engineering at the university. *Experimental frame materials were provided by The Cascade Joinery, Everson, Washington (Douglas fir frame); Benson Woodworking, Walpole, New Hampshire (Eastern white pine frame); 2 Dog Construction, Laramie, Wyoming (Ponderosa pine timbers); Earthwood Homes, Sisters, Oregon (Port Orford cedar frame); and Riverbend Timber Framing, Blissfield, Michigan (white oak frame).*

TIMBER FRAMING FOR BEGINNERS

II. Ten Factors in Timber Frame Design

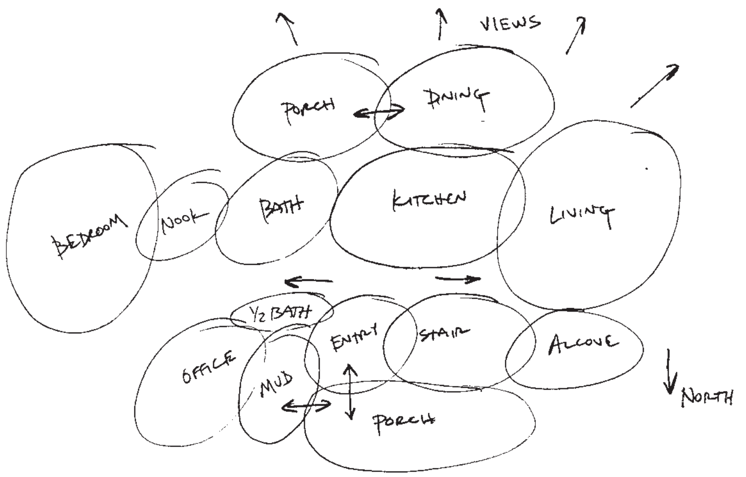
ONE of the appeals of light framing is its adaptability. Almost any house could be stick framed. Frequently enough, framing plans aren't even included with architectural drawings, since the framing skills required are so ubiquitous and standardized. But once you have decided that you want a timber frame, you must consider some extra parameters as early as possible in the design.

A frame for a small, simple house or barn is relatively easy to design. I break down the process into *architectural* design, which determines where posts, beams and braces go according to space planning concepts and aesthetics, and *engineering* design, which determines the joinery and sizes of timber required to carry the loads involved. It's always a good idea to get the advice of professional designers, especially if you have any doubts about your project, but by doing some of the preliminary work yourself you can save yourself some consultation time and money. Here are ten factors that should help you through to an initial design.

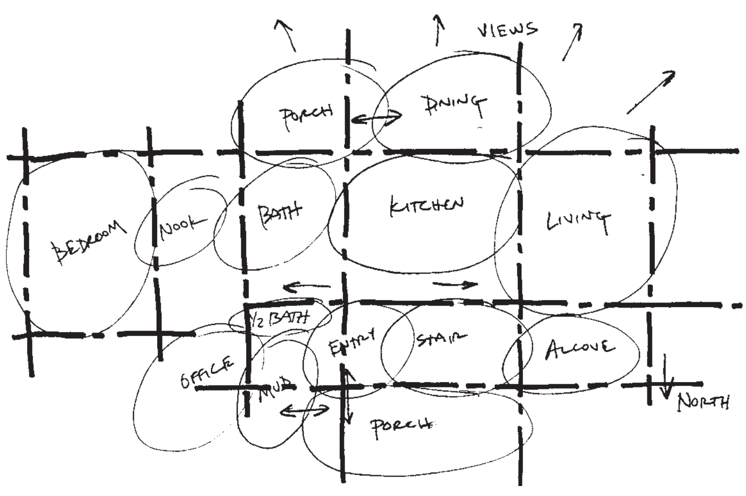
1. The Floor Plan. Most drawing starts with the floor plan, derived by applying a *structural grid* to the bubble diagrams (example at right) of spaces and the program the designer or client has probably wrestled with for a time. Because the timber frame is such a grid, it's important not to wait too long to consider where the frame components will go. It's also difficult, though sometimes possible with simple plans, to take a finished set of drawings for a stick-framed house and fit a timber frame in.

The most economical house to build has only four corners—a rectangle. Every time you add corners you add significant complexity and therefore cost. When first designing a timber frame for a house, I'm usually faced with an arrangement of amorphous shapes (the bubble diagram) showing the activities in the house and their relationships to one other. I also have a rough idea of the space required for each activity. The *plan,* apparently an overhead (birds-eye) view, is properly a horizontal section or slice through the building at a 5-ft. height above the floor level. In drafting, most changes and decisions are based on the activities served by the first-floor plan; the foundation, other floor plans and even the elevations are derived from this first drawing. Try to get most of the things right on the first floor (which I assume will contain the principal living areas) before moving on to the other floors. Don't forget storage areas. And give sufficient attention to the stairs, which I think are the hardest thing to design well in a house.

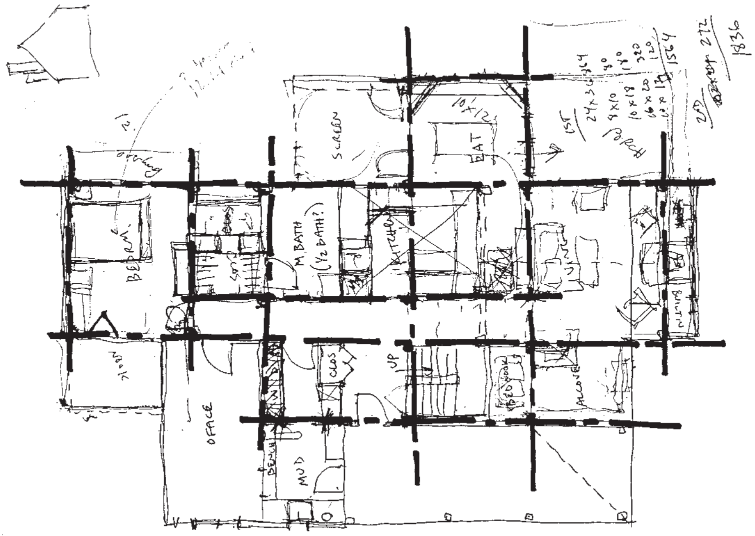
I start by assuming a 12-ft. grid of posts in the first-floor plan. Girders (beams that carry joists) rest on the posts, and 12 ft. is an easy span for most joists and girders without getting into excessively large sizes and special joinery. Shorter spans are okay, but for longer ones, once they get up around 16 ft., the necessary beams get really big, and floors get bouncy. If your posts can line up in rows across both the length and width of the building, that's a good sign that you'll be able to use simple joinery and a straightforward arrangement of joists and beams above. Posts that run continuously all the way up to the roof framing (plates, purlins and sometimes a ridge) avoid unequal shrinkage in the floors that must arise if you frame the building with some posts interrupted by beams. With continuous posts (photo overleaf), their locations on the second floor are of course already determined, as are the supports in the foundation system. This is not a hard-and-fast rule; posts don't have to be supported directly underneath. They can land out on the unsupported span of a beam (*point loading),* but this should be done only with good reason and proper structural analysis.

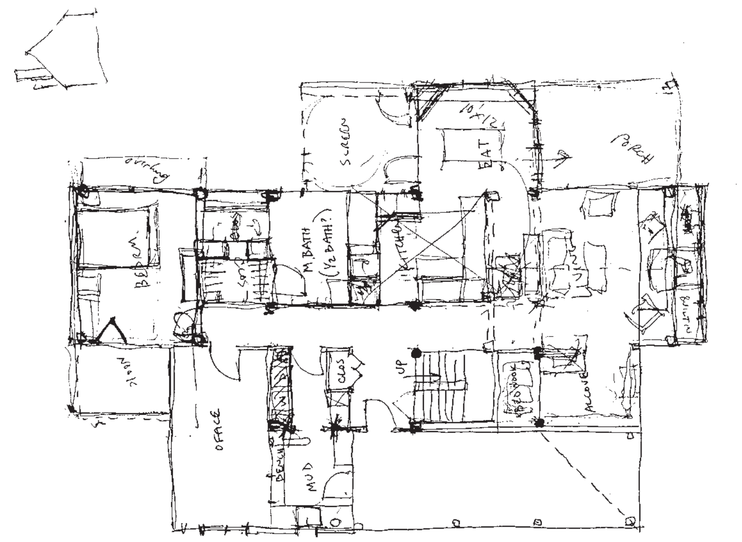


Andrea Warchaizer

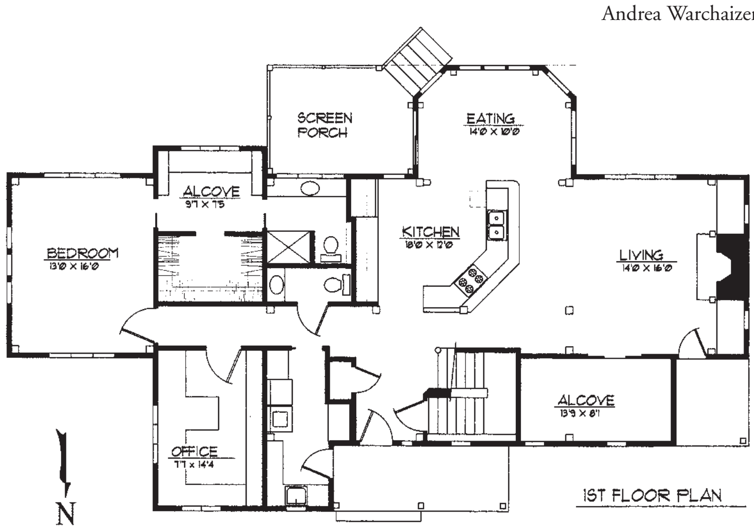


Bubble diagram of program for house for family of four, with initial structural grid applied. Drawing sequence continues overleaf.





Andrea Warchaizer



Sequence of designer Andrea Warchaizer's drawings for a timber-framed residence in Lexington, Virginia, completed earlier this year.

Timbercraft Homes

Continuous, full-height posts avoid differential shrinkage at floors.

Christopher Alexander (in *A Pattern Language*) names one pattern Varying Ceiling Heights, which distinguishes different areas on the same floor level. Timber framing does this not only through various depths of joists and beams, but also the direction in which they run. It's usually most economical to run joists across the shortest span between beams, but it's not taboo to change joist direction for a desired visual effect. Designing floors and ceilings at different levels also avoids joinery concentrated at the same elevation on posts, which can weaken them.

Braces should also be considered when laying out the floor plan, since windows, stairs, passageways and traffic patterns will be decided at this step as well. Consider where people might collide with a brace while walking underneath, or where braces would interfere with windows or doors or their casings. The more braces, the stiffer the frame; at a minimum there should be at least one going in each direction in each bent and bay line of posts. Braces work mainly in compression, so one of the two would always be working under a wind or other side load on the structure. The longer the brace, the better as well, with a 30-in. leg (in the right triangle of which the brace forms the hypotenuse) as a minimum, in my opinion. Shorter braces can actually be destructive by acting as fulcrums to drive apart the corner joints they are meant to stabilize.

Last, don't forget to check your local building code and with the

Charles Landau

Four posts define the borders of a sitting area focused on the fireplace. Braces are omitted on the sides where people are likely to pass.

Post locations are also used to delineate separate activities and areas in the building. Since there are no bearing walls, partitions can be put anywhere, but one of the advantages of a timber frame is that it provides an open floor plan. You can use the posts to break up this open space by framing architectural features such as fireplaces, sitting and dining areas or staircases, as in the photo at right. Traffic flow patterns generally should not be interrupted by posts and braces, but, conversely, the latter can be used to create alcoves.

inspector about requirements such as minimum room sizes, stair header height, window sizes and heights off the floor. and the distance beams can project below minimum ceiling height.

2. Architectural Style. Design is not a linear process. You should consider all of the factors simultaneously for best results. The *elevations*, or views of the upright walls, will be determined by spatial requirements (room sizes, need for a second floor and the like) but also by the *style* of building you want. Don't get hooked on one style too soon, but be aware that one tends to build like the neighbors. For good neighborly relations you may not want to put a geodesic dome in with a bunch of Colonials. Historical precedents can be good models; here in New England we have some traditional forms such as Capes and saltboxes that suit well to timber framing. On the West Coast, the Arts and Crafts Movement might influence you. For a given square footage, multi-story houses are easier to heat in cold climates and require less foundation length; on the other hand, most houses in the south are one story and easier to maintain.

The roof is usually the dominant visual element on the exterior and does the most to state the architectural style. To help you decide roof pitch, consider your snow load and roofing labor and costs, as well as usable space you may need underneath the rafters. Valleys and hips add visual interest to the roof, and dormers may help the interior layout as well, but all increase the complexity of the framing and the potential for leaks. "Overframing" such interruptions with dimension lumber or structural insulated panels (SIPs) can simplify the work here.

Check your building code again and local ordinances for things such as maximum building height, minimum and maximum roof pitch and, in some places, architectural style controls. Again, before tackling the more complex roof systems, keep it simple until you have some experience. Consult books such as the *Field Guide to American Houses* to find guidance on your favorite style.

Photos Spike Baker

Above, superior mortise and tenon joinery can be used without difficulty in floor systems if a crane does the lifting of the assembly. At right, a ladder of drop-in purlins flying in to a principal rafter-common purlin roof. Here the crane has already lifted into place the extremely heavy bents complete with rafter framing.

Jim Buck

The modern mobile crane offers the possibility of raising very large assemblies that are difficult or impossible to put together in the air.

Will Beemer

Many hands make light work and gather people together in satisfying common effort. Hand raisings are generally quieter, too.

3. Raising Method. I distinctly remember watching the design of roof frames change in the course of just a year or two, as evidenced by successive slide presentations at the Guild's annual conferences. All of a sudden we were seeing flying purlin systems (as well as floor framing), pre-assembled on the ground with soffit or tusk tenons, replacing with more load-efficient connections the drop-in joinery so common before. We were seeing an improvement in timber frame design resulting not only from a better understanding of the structure but also from an increased awareness of the capabilities of cranes at the raising.

Crane raisings are safer and often quicker than hand raisings, and require fewer people. There are times when a hand raising is a good alternative, such as when you can't get a crane in to the site or when you want the community involved. Principal rafter systems with common purlins lend themselves to crane use, indeed almost require it, since the bents are assembled horizontally, all the way to the rafter peak, and stacked on top of one another ready for hoisting on raising day. The common purlins are then flown in individually or in strings. Hand raisings require smaller bents with lower centers of gravity, and smaller pieces to be handed up from below. Common rafters work well here as they can be installed vertically, using gravity to secure the seat and keep the rafter from slipping down. Large-section common purlins would have to be muscled up the roof, fighting gravity all the way.

There may be times you have to design the frame to go up one story at a time, either when you don't have a crane or other means to lift bents or large pieces high enough, or because your post material will not be long enough to reach the roof beams. This would be analogous to *platform framing* in light construction. In this case you should design the frame to account for the various shrinkage rates of beams and make it uniform throughout the structure. If your posts don't line up in rows across the short dimension of the building (the way bents usually run), or if your frame design is based on the English tying joint, it may make more sense to raise assemblies that run the long direction (walls).

Before you get too far along in the design I recommend you write out, or at least imagine, a raising script, and certainly you should write out the script before the raising and distribute it to the crew. I've seen more than a few frames that were impossible to assemble without some joinery "modifications" at the site, often resulting in sawn-off tenons. Visualize how you're going to peg joints together before and during the raising; often pegs will interfere with other joinery and timbers. The more complex the frame, the more likely most of it will have to be pre-assembled on the deck and raised with a crane.

4. Structural Engineering. One of the main things building inspectors look for is the proper sizing of joists, beams and rafters. To size members, the designer must match the *loads* involved with the strength characteristics of the *species* of wood and the *width, depth, span,* and *on-center spacing* of the timber. All of these are variables the designer can play with until the requirements are met. In conventional construction, the standardization of the available sizes and grades of lumber limit these variables. In timber framing, the possibilities are much more open. And when thinking about loads, don't forget to consider the posts, whose net section—and thus load-bearing capacity—can be much reduced by joinery.

In some locales, especially those with stringent earthquake codes such as the West Coast, building inspectors may ignore the contribution of diagonal bracing to the frame's rigidity. You may be required to use SIPs, plywood or some other shear diaphragm to add to the rigidity of the frame. Inspectors may also restrict the notching of beams, sometimes allowing no cutting into the top surface. It's best to find out early if you'll be required to have your frame engineered, and then find a timber engineer who is licensed to work in your area.

5. The Wood. Strength isn't the only thing that determines the species of wood you are able to use for your frame. I'm an advocate of using local materials wherever possible, but I'll import a few pieces of Douglas fir if it saves me from using a much bigger dimension of our local Eastern white pine, or from using scarf joinery. Long continuous pieces will usually be stronger than scarfed ones, especially for plates and tie beams. If long pieces are available and affordable, deliverable and raiseable, design the frame around them. One problem with the popular principal rafter-common purlin system is the lack of continuous pieces in the longitudinal direction of the frame. Whatever the roof framing above them, continuous plates offer inherent stability, especially during the raising.

Mixing species in a frame is also okay in my book, matching the strength characteristics with the job to be performed. This is important if your woodlot has mixed species, with no one species plentiful enough for a whole frame. Species weaker in bending might serve as posts or braces, while stronger ones can be used for joists, beams and rafters. It's always nice to incorporate at least one piece of wood from the site into the frame, and, if the entire timber supply is milled or hewn onsite, it may never even have to move into a shop. Such a scenario might lend itself to a scribed frame, much as the English do, with layout occurring *in situ.* The girth and height of the trees simply determine the milled sizes of timbers available.

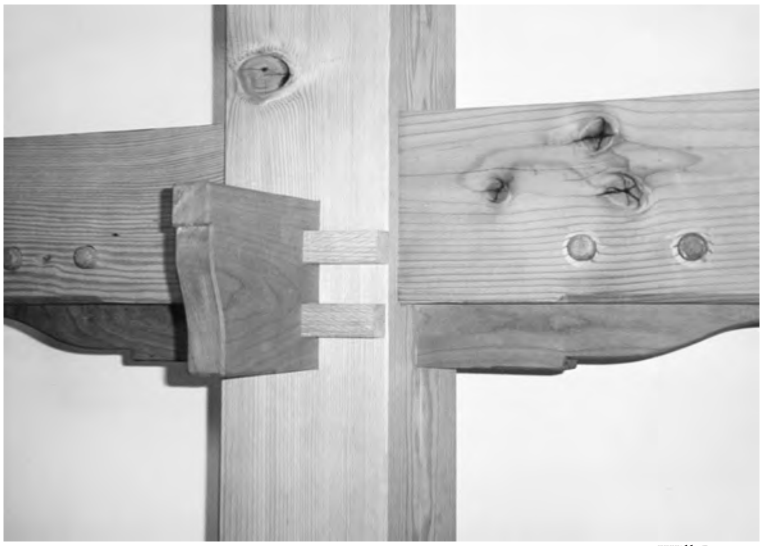
Other characteristics, such as rate of shrinkage and strength in shear, determine the location and dimensions of joinery and the allocation and orientation of the timber in the frame.

6. Interior aesthetics. We're attracted to timber frames because we like the look of wood on the interior. It can be overdone, however. Wood absorbs light, and wood planking on the ceiling can make an interior darker than if plaster or another light-colored surface is applied between the joists and rafters. The colors of wood can influence the choice of everything from flooring to cabinets. Species like red oak and fir have a rich reddish color, while pine has a much lighter yellowish hue (although it must be said that time softens all contrasts), and some thought should be given to how the colors of other woodwork in a house fit with the colors of the frame.

The joinery represents the craftsmanship we want to show, and should be chosen and cut to minimize unsightly gaps that could result from shrinkage. Because of differential shrinkage and distortion, and even seasonal changes once a frame is older, flush surfaces and edges are almost impossible to maintain. Joists are often shallower than the beams they go into (and occasionally even laid flatwise), not only for structural reasons but also to provide contrast and scale in the frame members. Splines and pegs are often left proud of the surface of a beam (overleaf). A contrasting color of pegs can be used to accentuate the joinery.

7. Enclosure Systems. Structural insulated panels, made of sheet goods on a 4-ft. module, have contributed much to the viability of timber framing, and also influence frame design. Since they can be put on the roof either way, a purlin or common rafter system on 4-ft. centers can be designed to conceal the panel joints. Similarly, exterior wall girts and posts can be laid out to align with seams. Wall panels usually rest either on the sill plate or the floor deck, and if the frame is moved in from the perimeter to account for the panel thickness, you should be sure that there's still adequate bearing for the posts on the foundation. A good resource for foundation details is Tedd Benson's *The Timber Frame Home.* For panel details, get an installation guide from one of the manufacturers; Winter Panel publishes a great one. No matter which supplier you use, ask early for frame-design guidelines to efficient use of their panels. Avoiding waste is a primary concern, and pre-cutting panels at the factory is worth the extra cost. Alternative enclosure systems (exterior stud walls, straw bale, straw-clay) may cost less in materials but more in labor. The requirement they have in common with SIPs is that the frame should be moved inside the enclosure system so it's completely protected from the elements. Placing the frame inside the heated space leads to the extended life span of the structure.

8. Other Systems. Mechanical systems, especially plumbing and heating, need to be considered early in the design so as not to interfere with the timber frame. Make sure you include your plumbing, electrical and HVAC contractors as soon as you can. Light-frame studs and joists can be notched for pipes, ducts and wires following code guidelines, but also rely on their close repetitive spacing to compensate. Heavy timbers are much more sensitive to notching and can be challenging to a laborer who may not realize that the timbers will remain exposed. Plumbing traps and waste and vent lines often run in walls and between floor joists, and long horizontal runs cause more problems than vertical ones. Hence, as in any house, it makes sense to stack your second-floor bathrooms over



Will Beemer

Spline joinery is popular, especially for connections in Douglas fir (as shown here), a species famously weak in tension perpendicular to the grain, the mode in which a mortise is stressed during withdrawal of a pegged tenon. Here splines are used decoratively and pegs are left proud.

Timber framing is more expensive than light framing largely because of the more highly skilled labor required. Once a client opts for the timber frame, it's not long before the entire project cost escalates as an attempt is made to match the quality of the other systems to the framing. Some people save money by building a *hybrid* frame, where the private, enclosed areas of the house are light framed while the open, public areas are timber framed. While lacking the integrity of a full timber frame, hybrids can also be built using a timber-framed first floor only, or by connecting a timber-framed interior to a conventionally framed exterior.

Because of their special characteristics, most timber-framed structures are custom designed. It's very difficult to find a stock set of timber frame plans to buy because so much depends on variable materials and methods. The final product will reflect not only your skill as a carpenter but also as a designer. —Will Beemer

Will Beemer (will@tfguild.org) has charge of the Guild's workshop program and has directed The Heartwood School for many years. This article is second in a series.

those on the first floor, and if possible the kitchen, so the large pipes can run up a plumbing (wet) wall between rooms. To avoid seeing traps and runs between ceiling joists, you must have either a dropped ceiling in that area or the fixtures raised onto platforms in the room above. It's also possible to build a light-framed floor using shallow joists *over* the timber frame to provide chases for mechanical runs, or to avoid timbers entirely in the bathroom floor, in favor of light joists. We use a lot of hot water baseboard heat in our neck of the woods, and I've learned to provide a notch at the back of exterior posts at floor level for the pipes to run.

While electrical wires can be run in SIPs without problems, you should anticipate where wires on the interior might have to run over timbers, and prepare channels to hide them. The lack of interior stud walls is a disadvantage here, as there's no place to run wires vertically or to mount receptacles and switches. Consider carefully the layout of posts and beams as they relate to likely activities and furniture arrangements. Lighting can be especially problematic in large open spaces.

9. Joinery and Cutting Methods. The design of your joinery and the frame itself will reflect the tools you have to cut it. Spline joinery increased in popularity once efficient power tools became available to cut long mortises. Splines also allow you to use shorter timbers, tension joinery and three-way (photo above) or four-way connections of beams at the same level on a post.

If you're hewing timbers on the site, you'll probably want to minimize the work by leaving the timbers close to the size of the original tree, even tapered. Perhaps only one side of a log would be flattened in the case of a first-floor joist, though don't forget to strip the bark and so deprive insects of comfortable long-term shelter.

Budget. One factor that obviously affects the frame design is your budget, and cheaper almost always means simpler. Besides the complexity of floor plan and joinery, other things that may be limited or made impossible by their cost are the finishing details such as chamfering of edges and surface planing and coating.

The cost of materials is easy to estimate; labor is the hard thing to guess at. If you're new to the trade, I advise following the KISS principle: Keep It Simple and Small. Learn your capabilities and that of your crew and how big a job you can handle with the tools that you have. Study the problems and opportunities in timber framing that make it different from other systems.

Some works on design, available from timber frame book specialists Summer Beam Books, 877-272-1987 or www.summerbeam.com:

Tedd Benson, *The Timber Frame Home*, Taunton Press, Newtown, Ct., 1988. Best overall book on architectural design for timber frames.

Jack Sobon, *Build a Classic Timber Framed House*, Garden Way, Pownal, Vt., 1993. Great book on traditional design and timber layout and cutting; good structural design section.

Christopher Alexander, Sara Ishikawa and Murray Silverstein, with Max Jacobson, Ingrid Fiksdahl-King and Shlomo Angel, *A Pattern Language*, Oxford University Press, New York, 1977. A very useful design tool for the preliminary stages.

Virginia and Lee McAllester, *A Field Guide to American Houses*, Alfred A. Knopf, New York, 1988. An encyclopedia of design patterns that give the house its distinct style.

Steve Chappell, *A Timber Framer's Workshop*, Fox Maple Press, Brownfield, Me., 1995. Good structural section and joinery details.

Fine Homebuilding Magazine, *Timber Frame Houses*, Taunton Press, Newtown, Ct., 1992. Collection of articles on a wide variety of timber frame designs and techniques.

Timber Framers Guild, *Timber Frame Joinery and Design Workbook*, Timber Framers Guild, Becket, Mass., 1996. Collection of articles on joinery, design and engineering.

Richard Harris, *Discovering Timber Frame Buildings*, Shire Publications, Aylesbury, Bucks, UK, 1978. Great little book from Britain defining terminology and traditional frame typologies.

Les Walker and Jeff Milstein, *Designing Houses*, Overlook Press, Woodstock, N.Y., 1979. Good introduction to the process of going from bubble diagrams to working drawings.

Scott T. Ballard, *How to Be Your Own Architect*, Betterway Publications, White Hall, Va., 1987. Good introduction to developing the design program and drafting techniques.

Winter Panel Corp., "Installation Guide for Timber Framers," free from Winter Panel, 74 Glen Orne Dr., Brattleboro, VT 05301, 802-254-3435, or downloadable from www.winterpanel.com.

Belgian Barns III: Ter Doest

Kristen Brennan

Ter Doest barn, ca. 1230, at Lissewege, West Flanders, Belgium.

IN Flanders, where building codes have required the use of brick or stone in exterior construction since the early 17th century, the most astonishing timber framing is found indoors, particularly inside the one remaining Gothic tithe barn of Ter Doest Abbey in West Flanders.

The Ter Doest barn, today in the village of Lissewege, ten miles northwest of Bruges, was erected at the peak of the Gothic era, *ca.* 1230. For its timber framing it rivals the immense Gothic churches of Amiens, Beauvais and Rouen constructed at the same time. The barn was built by the Cistercian order of monks, who controlled a large portion of Belgium's coastal land beginning in the early 12th century. Founded by the Benedictine Order in 1106 at the current site of the barn, where the abbey's first abbot claims to have seen a vision of the Virgin Mary, Ter Doest's history is intricately intertwined with that of another monastery, founded by the Cistercians one year later, the Abbey of the Virgin of the Dunes in Lez-Coxyde a few miles away.

The Benedictines lived on and worked the land at Ter Doest as an independent abbey until 1174, when it was annexed by the richer abbey of the Virgin of the Dunes. The latter was one of the first abbeys of the Cistercian order, founded a mere nine years after the inception of the order in Cîteaux, France, in 1098. The Cistercian order in Belgium grew eventually to control lands from Zeeland (in present-day Holland) to the Hulst and East Hoek regions in the south (now southern Belgium). The Cistercians were an agricultural order, and they constructed at least five additional abbeys to supplement the main complex at the Dunes. Beginning in the early 1100s, both Benedictine and Cistercian monks began reclaiming coastal areas that had turned to rich agricultural fields because of frequent flooding. Despite the large number of young men joining the monastery each year, the church decided to distribute free land to attract people to the area in order to utilize all of the land it owned, and, more important, to collect the tithe from the tenants. The Ter Doest barn, like its sister barns at the other abbeys, was built as a collection and storage point for the tithe crops that would be used to support the monks, and that could be sold if needed for income.

Generously proportioned at 180 x 72 ft. in plan and 59 ft. high at the gable peak, Ter Doest rivals many churches in size and splendor. Its nine-bay, three-aisle oak frame is surrounded by *mouffe,* a local soft red brick. Only the two longitudinal brick walls are load bearing. The gable-end brick sheathing protects the large frame from the constant inclement weather blowing in from the North Sea. In Flemish, the framing style is referred to as *stapelgebinte*, in which the tie beams across the central aisle are simply mortised over the tops of the principal posts. In later barns of this region, other

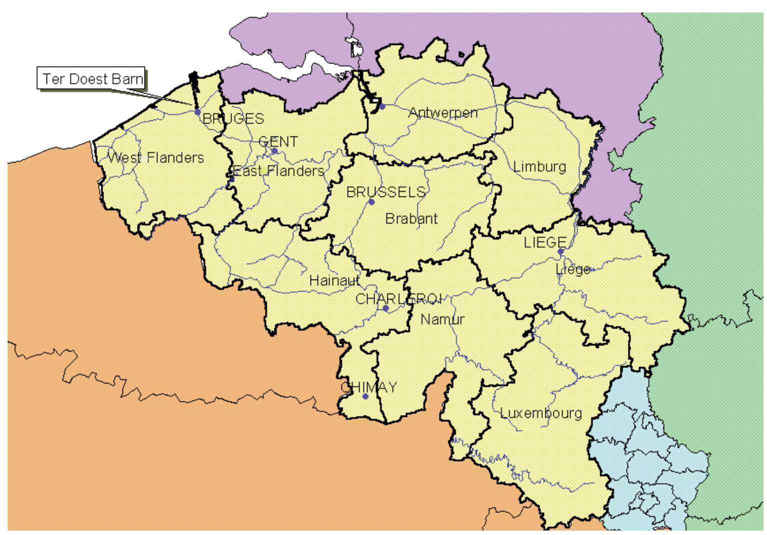


Photo by Malcolm Kirk, used by permission

Above, gable end of Ter Doest barn, 72 ft. wide by 59 ft. high. Major central buttress supports masonry wall over broad span of central aisle inside. At right, view from interior looking down side aisle and out through open doorway. The portal at the other end of the barn, which allowed wagons to drive right through after unloading, has been bricked up. The stone and brick footing under the post at far right is about 24 in. square.

Kristen Brennan

Photos Malcolm Kirk, used by permission

Interior of the nine-bay oak-framed Ter Doest barn, 180 ft. long by 72 ft. wide. Substantial timberwork supporting the purlins allows exceptional bay width. At right, detail of aisle post top showing simple stapelgebinte connnection between tie beam and post.

forms of tie beam anchorage were used, including bridle joints and outside-wedged through tenons, the latter seen in Klemskerke Abbey barn, dating from 1319. Belgian and Dutch researchers have long disputed the origin of the anchor beam joint. Belgian scholar C. Tréfois has documented a convincing evolution from the *stapelgebinte* form of Ter Doest to a bridle joint and then to the outside-wedged, through-tenoned anchor beam connection that found its way to colonial Dutch-America.

Ter Doest functioned as an abbey until 1569, when the Bishop of Bruges took possession of its assets and revenue after the death of the last abbot. In 1571, the unused abbey, like much other church property, was pillaged and burned by Protestant iconoclasts. In need of building materials for his new seminary in Bruges, the Bishop dismantled all of the Ter Doest abbey buildings with the exception of the barn, and reused the bricks in Bruges. The remains of Ter Doest were ceded back to the Abbey of the Virgin of the Dunes in 1594, and, after a more modest monastery was constructed, Ter Doest recommenced its life as a Cistercian abbey in 1624. The last Cistercian monk left Ter Doest in 1833. The barn was sold to a farmer, and it has been used as a private barn ever since. With the possible exception of the 30-year period during the religious wars at the turn of the 17th century, the Ter Doest barn has been in continual service for 750 years!

In 1905 the historian Armand Heins sketched the ruins of other period barns built at the farms of Allaerthuizen, Boegarde and Hemme. All three were constructed under the leadership of Abbot Nicolas de Bailleul of the Virgin of the Dunes about 25 years before Ter Doest. Heins's sketches show that the monks worked in a period of transition between Roman and Gothic styles. While the pointed false windows in the gables of Ter Doest are uniformly Gothic, with tri-lobe decorations, the three earlier barns still retain a large number of Roman arched openings. All are of massive scale and use brick curtain-wall gables and similar side-aisle and gable entrances. —Kristen Brennan

Kristen Brennan studied at the Free University of Brussels and now pursues a master's degree in historic preservation at Cornell. This article is last in a series on Belgian barns. Research funding was provided by a US Department of State Fulbright Graduate Student Fellowship.

A Visit to Finland

FINLAND is a country of some 5.2 million people, covering an area 25 percent greater than the UK, population 58 million, where I live. It has a tree cover of 68 percent compared with only 10 percent in the UK. It has been under Swedish and Russian (and briefly German) control and emerged only fairly recently this past century as a truly independent nation. Outward looking as a member of the European Community, Finland is about to trade its own currency, the Finn Mark, for the Euro. Almost everyone under 50 years old speaks English.

The population tends to gravitate toward Helsinki on the south coast, leaving the north relatively free of development. The country stretches beyond the Arctic Circle, where the the northeners enjoy long summer days but also endure endless darkness in winter.

My point of arrival in Finland was Oulu, a neat little seaside town (www.ouka.fi—*ouka* is correct) a couple of hundred miles from the Arctic circle and home to the Nokia cell phone company. The Finns have more cell phones per capita than any other people in the world. I found it interesting to travel in an automobile where the other three occupants of the vehicle (including the driver) were all talking on their cell phones at the same time.

The traditional style of urban building resembles very closely its North American counterpart, but there are more log and pole buildings in the rural areas. However, upon close inspection, many of the older town buildings prove to be log buildings that have been covered with spruce clapboards and fitted with door and window moldings. Long solid timber sills sitting on top of granite foundation blocks have been skillfully scarfed together such that it would not be possible to insert a piece of paper anywhere along the joint line. Only faint cracking in the paint reveals joint lines.

I BEGAN my study of Finnish building tradition by visiting the Turkansaari Outdoor Museum in Oulu, a small collection of log houses, churches and farm buildings. I saw some timber frame roof construction in a cattle byre, where the tying joints were fitted with spruce root knees rather like the tamarack root knees seen in the US. The museum also has a boat shed with small shallow-draft rowboats used to ferry barrels of pine pitch to the nearby port of Oulu. The museum still makes its own pitch in an open-air setup that somewhat resembles a charcoal kiln, except that the pine logs are stacked up on a bed of sand, and the dripping pitch percolates down through the sand to be collected in a pipe at the bottom of the pit invert. The pipe drains into a small barrel beside the main burn pit. The pitch is evil-smelling stuff, and the smell hangs around for weeks afterward on clothing exposed to it.

The museum also makes good use of small-diameter spruce poles for ventilated hay storage sheds with inward-sloping sidewalls, pole floors and intricately arranged fencing. We made a whistle stop tour of my tour host's shop in Oulu, Iin Fasadii Oy Panel Homes (www.iinfasadi.fi). The panels are made on large metal jigs occupying a major part of the factory floor. A standard panel is made from beautiful quality 8-in.-deep spruce studs accurately machined to an incredibly high standard. The panels are filled with 8 in. of dense mineral wool sandwiched between layers of vapor barrier and gypsum wall board, even the outside face. This face is then battened and covered with a layer of shiplap spruce siding, prepainted with a breathable paint. I thought it a shame to cover up this beautiful timber.

A short car ride south took me to Pyhäntä, where Pyhännän Rakennustuote Oy (www.juka-talo.fi) make glulams and panel-wall buildings. Managing director Vesa Heinonen showed us around, starting with the logs arriving at their sawmill, and then all the way through to a finished building. The Finns just love machinery and, regardless of the beautiful quality of their timber, they set about cutting it apart, drying it, planing it and then jointing and gluing it together again into continuous lengths of 60 to 80 ft., 8 in. deep and 5.5 in. (2-ply) or 8 in. (3-ply) wide. They make these laminated beams with the sapwood facing in, and consequently each beam shows two heartwood faces. Clear adhesive is used in the glulam process, and it is almost impossible to discern the joint lines because of the clear, close-grained wood. The spruce beams *(Picea abies,* Norway Spruce) I saw being laminated were converted from closely grown trees showing from 15 to 28 growth rings per inch.

Ken Hume

Street scene in Oulu, Finland. Urban houses, despite elaborate trim and siding, are logbuilt under the skin .

With the marvel of the wood processing still buzzing in my ears, I plucked up the courage to ask whether such immense log consumption was sustainable. A visit was quickly arranged to the Forest and Park Service (www.metsa.fi) in Pyhäntä. The local state forester gave me an overview of their sophisticated growth measurement and felling control procedures (which are rigorously enforced). I was assured by the Forest Service that, despite the large volume of cutting I witnessed, the volume of standing timber was on the increase and, what's more, increasing in average diameter size. Thus final crop quality is improving with controlled cutting.

The Finnish forest is part of the great boreal forest belt that stretches around the world through Scotland, Norway, Swe-den, Finland, Russia, Canada and the US. According to the Forest Service, the natural management of boreal forest is based on a process of continuous succession following natural disturbances, mainly fire and windfall.

In Finland, the first tree to colonize a bare area is willow, especially if the ground is wet, closely followed by aspen (poplar) and birch, which grow taller and provide some light cover, and then are intercolonized by Scots pine, which in turn provides the shade needed by young spruce to become established. The spruce eventually pushes through the pine and kills it off by shading. Thus the tallest and straightest trees tend to be spruce. The dead standing pine left behind, from which the bark has fallen away, is not wasted. In fact, this material, called *kelo*, is extremely valuable, with tight grain and a high resin content, making it prized for log building.

The key to the fantastic timber quality I saw in both pine and spruce is slow succession growth, and this is now helped along by careful, judicious mechanized thinning. (The downside to the thinning is that growth rings are likely to be less tight in the future.) The forests are not overly dark places, and there is good ground cover with masses of berries for animals and people to eat.

Reassured by the description of forest management practices the Finns have adopted, we then visited the site of the new Shingle Church being built at Kärsämäki (www.evl.fi/srk/karsamaki), a joint venture between the local inhabitants and the university, with EC grant funding. The building is a hybrid design with log walls on which a timber-framed roof structure and external curtain wall are being built by local craftsmen and visiting architectural students. These craftsmen had hewed out most of the squared logs used in the walls and had also set up an elevated pit saw ramp and trestle. Their Finnish-made pit saws are only about 4 ft. long, with quite thick blades and steeply raked teeth. Their hewing axes are forged and sharpened to a bowed knife edge, and so can be used both left- and right-handed. They also leave quite deep scallops on the finished log faces. I examined some older farm buildings close by and found similar but less obvious hewing marks, indicating a flatter blade profile.

The close-boarded timber frame roof structure perched on top of the log walls and the outer curtain wall of tall posts joined to the edge of the roof make a rather precarious-looking structure. Inside, at the center of the building, eight 5x5 lap-jointed timbers come together to form a "Devil's Fist" joint. Though I found this arrangement incredibly clever, I also found myself becoming quite unsettled when up in the roof framing. I became concerned about the rather slender timber sizes in relation to the immense load applied by the weight of roof.

Ken Hume

Carpenter at Kärsämäki church. Hewing axe is beveled on both sides, and its bowed edge leaves a deep scallop in the squared logs.

While southern Finland has a small amount of oak, of hardwoods the north has only birch, rowan (mountain ash), aspen and willow. Consequently, local pegs are made from rowan, and sometimes Juniper, found as a slow-growing bush. Some pegs I saw were cut directly from small branch sections. Roof shingles are cleft from aspen and then dipped and coated with pine pitch. They are nailed to the roof using hand-forged nails made on site. The pitch drips and coats everything in its path, including all the handrails on the scaffolding.

IN southern Lapland, where most of the *kelo* is found, we arrived at our rented cabin, made appropriately of this material, in late afternoon, just as the New York bombing took place. We sat glued to the TV and watched in total disbelief and dismay. It was hard to reconcile these events with the endless beauty and tranquillity that surrounded us. Later that evening we adjourned to the local hotel to dine and, unbeknown to us, to dance. We were in luck—it was ladies' choice night. It's considered impolite to refuse, so after being pinned down by a granny from Vasa I discovered that a request to dance in Finland means two dances! When we left the following morning there had been a light frost, and the leaves were already turning yellow.

While log and panel building are currently the dominant forces in the Finnish building marketplace, the country may be ready to dip its toe into timber framing. Building codes do not really reflect any special requirements or guidelines. I made a presentation to the VTT (*Valtion Teknillinen Tutkimuskeskus*, in English the National Research Center of Finland, www.vtt.fi), to assist recognition of this apparently new building form. The Finns seem to place a high emphasis on computer methods used in the UK and the US to analyse structures and calculate joint loadings.

My hosts explained to me that their national linear measurement system was originally based on the *poronkusema*, the distance a male reindeer can travel between natural relief stops. Since this distance is somewhat variable depending on terrain (and conceivably other factors), it has resulted in some difficulties of standardization. Perhaps it might be more appropriate for the VTT to incorporate scribe rather than square rule into any new building standards.

During this visit to Finland (my first), I think that I managed simply to scratch the surface of Finnish building practices. To get closer, I contacted Mike Hanyi, the only Finnish member of the Timber Framers Guild, in Loviisa, about an hour's drive from Helsinki. When I talked with Mike, I was surprised to discover that he is an American recently arrived from upstate New York (though married to a Finnish girl). Mike is keen to establish timber framing in Finland and especially to introduce the Finns to timber framing through a local community project, on the model of the several Guild pavilions. Such a project is planned for Kotka, where an international home exhibition will be held in 2002.

Mike is not alone in seeking to establish timber framing in Finland. Several Finnish companies are in possession of books by Tedd Benson and Jack Sobon, and are now eager to take their first steps into production of timber-framed buildings. Their first word in Finnish that I clearly understood was "Hundegger."

—KEN HUME

Ken Hume (ken@kfhume.freeserve.co.uk) is a Registered Professional Engineer in North America and a Chartered Engineer in the UK . This article appears in different form at www.clik.to/worldofwood. The Museum of Finnish Architecture in Helsinki (www.mafa.fi) can supply books by mail, in particular Rakennettu puusta *(Timber construction in Finland), 1996, 192 pages, ISBN 951-9229-91-4, and* Suomalainen puukirkko *(Finnish Wooden Churches), 1992, 160*

Photos Ken Hume

Above left, one style of Finnish full-scribe squared logwork, here with cogged corners, elsewhere with dovetails. Other Finnish logwork is in the round with extended, variously notched corners. Above, hybrid squared log and timber frame church under construction at Kärsämäki. Below, framed Devil's Fist joint inside the church, where eight timbers meet in lapped connections. At left below, model of the church showing roof and curtain wall framing around a log core. There is some resemblance here to a Greek temple with a solid core and a surrounding colonnaded porch. At left, mockup of the Devil's Fist joint (missing one post), built as a trial of the joinery.

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Apt use of posts to define an axis combined with good use of minor shaping and changing joist direction to define areas, as well as harmonious colors and a well-lighted wooden ceiling. Quarter-round shoes fitted to posts at floor and ceiling to cover post shrinkage can be avoided, but only by dadoes carefully cut to receive floor and ceiling materials. See "Ten Factors in Timber Frame Design," page 11.

Northern Timber Framing