

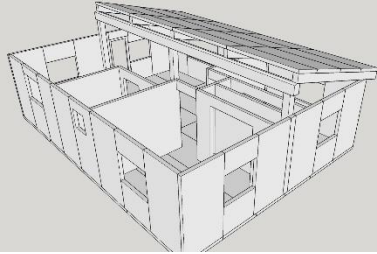
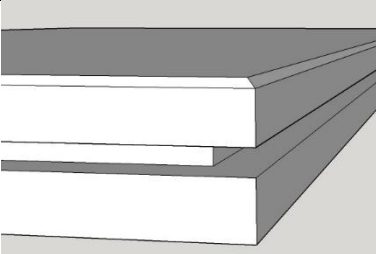




# User's Guide for Residential Cross Laminated Timber Panels

By

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US Forest Service Wood Innovations Grant #18-DG-1108150-003  
 NCSU Project #572460

December 14, 2022

		
<p>Example residential CLT home with one side of roof removed</p>	<p>Side profile of a residential CLT, showing a vee on face</p>	<p>CLT Team Columbia Forest Products Chatham, VA</p>
		
<p>Trail 2019-Furniture Industry Cold Press</p>	<p>Trail 2022-NCSU Press</p>	<p>Frederik Laleicke with lumber donated by Jordan Lumber</p>

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## Concept of Residential CLTs

In 2016 Harry Watt of NCSU Wood Products Extension developed the concept of using idle casegoods furniture equipment to make small sized CLT panels using a stacking principle that was used to make plywood parts for furniture in the US. The cold presses that made by companies like Newman, Press Systems, L & L and Dependable are capable of pressing a stack of 40" of material at 150 psi using hydraulic pumps and cylinders. These presses have largely been idle when in the 1990's the US casegoods furniture industry left for Asian countries, resulting in many these presses being stored in warehouses or sold for their scrap metal content.

Other machinery needed to make residential CLTs also went idle that included double end tenoners, planers and material handling equipment. Some of this equipment has been repurposed into other non-furniture segments of the US wood products industry. Harry Watt wanted to find a working concept to utilize this equipment to make affordable small houses understanding that when \$100 million CLT factories focused on high-rise buildings would not be able to produce CLT panels that could compete in the residential construction markets.

In January 2017 NCSU Wood Products Extension applied for a USFS Wood Innovations grant for this project and was not funded. In January 2018 we reapplied and was granted the project to prove that the concept was viable. The work on this project was greatly impacted and delayed by the management of the Covid 19 pandemic but has been completed with a successful develop of the residential CLT concept.

## Wood Species and Lumber Grades

Southern yellow pine is an acceptable wood species to make CLT panels and the one used in the NCSU residential CLT project. The #2 grade is specified for faces and backs and the #3 grade is specified for cores. In a practical note, a factory should only use the #2 grade due to the low price difference between #2 and #3 as well as the need to simplify purchasing and manufacturing the panels.

## CLT Standards

The American Panel Association is the trade association that manages the manufacturing industry of making CLT panels and they require any manufacturer producing CLT panels to be certified according to the ASTM standard PRG-320. This standard details the requirements of manufacturing, moisture content requirements, adhesives, layup details, dimensional variance allowances, strength testing requirements and other details of producing CLT panels.

Generally the requirements require species of wanted properties suitable for CLT panels, a moisture content of 12% +/- 3% and of odd numbers of layers of lumber offset by 90 degrees between layers. Strength testing for residential CLTs involves bending tests, shear and delamination tests according to ASTM Standard D198. Given that residential CLTs do not use fingerjointed materials in the core, no tensile strength testing is required.

### Economic Scale for Residential Cross Laminated Timber Manufacturing

When a residential CLT factory is designed, the balance between planning, laying up, pressing and trimming has a configuration of using an industrial double headed planer, automated layup line, automated adhesive spreading, three cold presses that open up 42" or more, and two double end tenoners. The planer, cold presses and double end tenoners can be found in older furniture era equipment.

If the factory were paced by the three presses with sixty-minute cycles, then approximately 160 panels per day could be made, with a value of \$8 a square foot, the factory would approach \$10 million annual sales.

### Facility requirements

The three-press factory configuration would likely require about 30,000 square feet of factory space to adequately support the storage of incoming lumber, processing into basic 4x8' panels, remanufacturing panels for angles and smaller sizes, plus staging and storage. Given the high output level and delays common to delivery to job sites, storage space is important to operating the factory in a smooth manner.

The facility requires heat and humidity spray in the winter and has to have a management plan of keeping large doors closed in the winter months. The facility has to have a quality control department with testing equipment as required by ASTM PRG-320.

### Manufacturing Processes

The residential CLT business purchases lumber in full truckloads of about 15,000 board feet of 2x6" and 2x8" lumber in lengths of eight and sixteen feet long. The sixteen footers are recut into 4 and 8' sections as needed for faces and cores. If the lumber has not been kiln dried to 12% emc, then the lumber has additional kiln drying to meet the desired 12% mc level. While most large Southern pine sawmills dry to 19%, most do not dry to 12% and the residential CLT manufacturer has to redry or buy from a mill that can reduce the moisture content to 12% or select it from the stream of lumber.

The manufacturing process begins with a double face planer that reduces the incoming thickness of 1-1/2" to 1-3/8" by removing 1/16" off each face with a knife planer. The boards then receive a coat of water-based primer if using an isocyanate adhesive before being staged ahead of the layup line. The faces, cores and backs have their own sorting locations as the layup system draws a layer from each type to make the panels.

The layup line uses a suction lift to pick up a layer of lumber and places in in the layup center where the stack is built. Each CLT in the stack is separated by a layer of plastic that can be a plastic sheet or a sheet of high pressure laminate, like Formica. After the backs and cores are laid down, the adhesive system extrudes a layer of adhesive in ribbons the full 8' length of the stack. When a stack is complete in about twenty minutes the stack is exited by a material handling roller system to the three presses.

The presses stack press the residential CLT panels for about an hour at 150 psi. This is adequate pressure to close gaps as the lumber complies with thickness variations of 0.008 across each board and 0.012 down a board.

Following the press is a set of furniture era double end tenoners that trim the CLT panels to size using large sawblades and cut a groove in the center of each edge of the panel for the assembly plywood splines. At the end of the two trim saws the panels are precisely trimmed to the 48x96" size and has a groove in the middle of all four sides that is 3/4" high x 2" deep made with the coping heads of the DET.

All panels that are not used full size have to be trimmed on a sliding table saw. The sliding table saw requires a 14" sawblade to make the bevel cuts at the required 4/12 roof pitch. Panels are cut back for needed sizing for doors and windows, as well as any sizes needed for meeting the needs of the home design.

### Equipment Requirements

Note these requirements for basic equipment to make residential CLTs:

1. Dry kiln-ability to dry at 12% moisture content +/- 3%.
2. Planer-double side planer with either a helical head or staggered insert head
3. Primer sprayer-required with isocyanate adhesives
4. Automate layup and adhesive line
5. Presses-three furniture era cold presses that open to a minimum of 42"
6. Double end tenoners-two DETs set at a 90 degree angle
7. Sliding table saw

### Design methods

Our concept is based on the modular panel dimensions of 4' and 8' with a good home design of all panels when resawn on the increments of height of 1 to 7' and widths from 1 to 3'. The design concept insures the economy of scale in the use of materials and factory time plus reduced errors in design. Using this modular concept with 3-D design software makes formatting houses simple and fast.

The floor design should always be on a 4 and 8' module but does not always have to be a simple rectangular design. For example, a home design can slide the sides of a 12' wide home on opposite ends for increased style that offers a deck on each end of a home.

### Connecting with splines and fasteners

Panels connect on the edges with  $\frac{3}{4}$ " plywood splines that are  $\frac{3}{4}$ " in thickness and just under 4" wide, with equal inserting into two adjoining panels. Wood screws are used to pin the splines to the panels on all edges where there are splines. Connecting wall panels to the foundation can use a center cleat on the bottom edge of a wall panel or using exterior metal straps. Long construction screws are used to attach roof panels to walls, roof panels to rafters, floor panels to joists and wall panels at corner. The Physical Engineer specifies the fasteners used on a home, as well as the size of rafters and joists. Rafters are set in panels 1-1/2" deep in pockets with construction screws that penetrate the walls from outside.

### Construction Assembly on Site

The factory prepares a job with panels arranged on skids in the order needed for assembly on site. At the home site, a lift is needed when moving and placing the 400 pound full sized panels as well as panels that are smaller. The assembly starts on the foundation by first setting sill plates and floor joists before floors and walls are erected. Each panel is fully attached with construction screws and screws for splines. No cutting of panels is needed to be cut at the home site.

The design should include an overhang on the roof from one to two feet to cover problems with out of square foundations. The foundation has to be perfectly level and leveling compound is needed under the floor sill to overcome variations in the height of the foundation.

### Business economics

A three press residential CLT factory that is in balance and reaches its potential at 160 panels per shift should reach about \$10 million in annual sales and a 15% profit on sales. Good management and increase the bottom line figure to 20% profit. Leasing a building instead of constructing a building would reduce the capital requirement to about \$2 million (needed using the furniture era equipment). Approximately fifteen employees are needed to operate the business and the employees would need to be trained to operate all the equipment as well as other employees manage the kilns, quality control and sales of the business.

### Summary

This concept of modular CLT construction is a viable construction method and affordable for US residential homes where large panel manufactured CLTs are not due to much higher panel prices per square foot. The design concept of being modular on full foot increments results in design simplicity and high yields on panels. No cutting of panels for doors and windows is needed. At typical 1,000 square foot home should be able to be assembled in two days. This concept works well for affordable housing projects where many homes are constructed with limited design options.